Advances in Characterization and Modeling of a Lower Cretaceous Heterogeneous Carbonate Reservoir Onshore Abu Dhabi, UAE*

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Abstract

A Lower Cretaceous carbonate reservoir onshore Abu Dhabi is characterized by high heterogeneities, whose nature and distribution is controlled by the interplay of depositional facies and diagenetic overprints within the sequence stratigraphic reservoir architecture. These heterogeneities are believed to have a great impact on the reservoir fluid flow behavior; the understanding and prediction of these heterogeneities are crucial to mitigate the uncertainties associated with 3D reservoir modeling. In this work a comprehensive reservoir characterization and modeling study have been conducted to capture the nature of the geological heterogeneities controlling the reservoir properties.

The impact of diagenesis on the rock types is driven by the characteristics of the depositional facies and is captured in a refined geological facies scheme. Through core and petrographic observations and analysis, four classes of geological facies are defined: 1) rudist-bearing rudstones and floatstones, 2) *Bacinella/Lithocodium*-coral floatstones, rudstones and breccia, 3) Orbitolinid- and skeletal-rich facies, and 4) fine-grained, matrix-supported facies. The link between geological facies and depositional settings and how they control the reservoir quality is established.

The nature, areal distribution, and vertical stacking pattern of the geological facies has been used to refine the sequence stratigraphic architecture and geological concept of the reservoir.

The geological facies have been integrated during the petrophysical synthesis and an excellent correlation with the petrophysical groups have been reached, allowing the generation of seven Static Rock Types; these are divided in two classes, based on their stratigraphic occurrence and petrophysical evidences. The best Static Rock Types are represented by the rudist-rich floatstones/rudstones and the *Bacinella/Lithocodium*-coral facies; both are characterized by a multiple porosity system because of the diagenetic imprint. Based on the revisited geological concept and sequence stratigraphic architecture, the Static Rock Types are distributed within the reservoir, and permeability modelled accordingly.

A fit-for-purpose 3D static model has been developed. Significant sequence stratigraphic surfaces tied to interpreted seismic horizons are the main input to model the reservoir structural framework. Static Rock Types have been used to condition the reservoir properties model; the latter have been distributed by using a novel approach to ensure accurate lateral and stratigraphic distribution and, therefore, to improve the quality of the prediction of the reservoir properties.

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ADNOC Onshore

Our challenges and actions

Maturing fields leads to different challenges – old vs. refined concepts.

To build predictive and reliable models that capture geological heterogeneities controlling the reservoir behavior.

To capture the impact of sedimentological and diagenetic processes on the reservoir properties and their distribution

- To create a reliable geological concept for modelling strategies
- To generate a robust static rock type scheme

Geological introduction

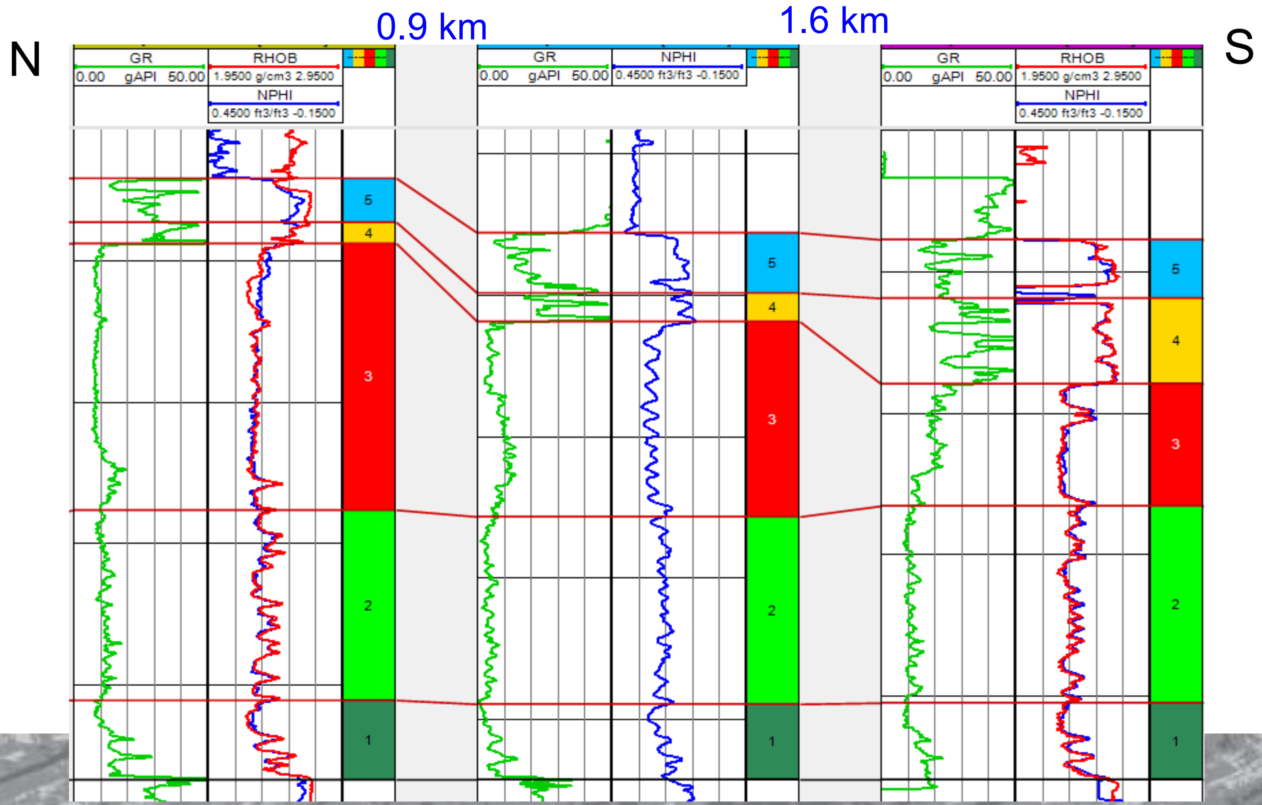
Lower Cretaceous, 450 ft-thick

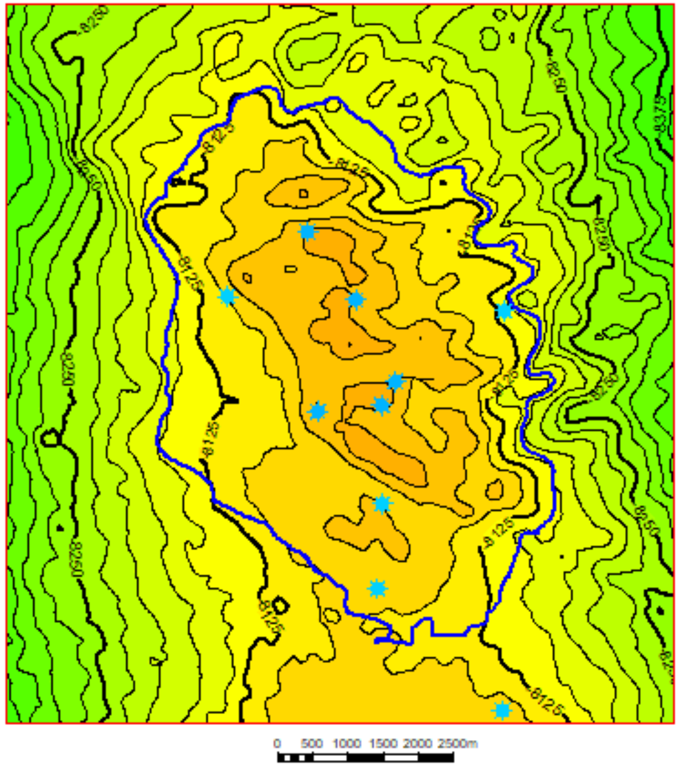
Shallow-marine platform limestone

Five 3rd-order stratigraphic sequences

Lateral thickness change of some sequences

Lateral and vertical facies changes





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Workflow

- Describe and understand sedimentological and diagenetic features – paragenetic sequence
- Generate a new geological facies scheme – sedimentological concept
- Use the new scheme to refine the stratigraphic architecture (from litho- to sequence stratigraphy)
- Petrophysical synthesis – Petrophysical Groups
- Integrating geology and petrophysics to generate Static Rock Types
- Defining modelling strategies
- Input of dynamic data and lesson learnt from previous models and neighboring analogs

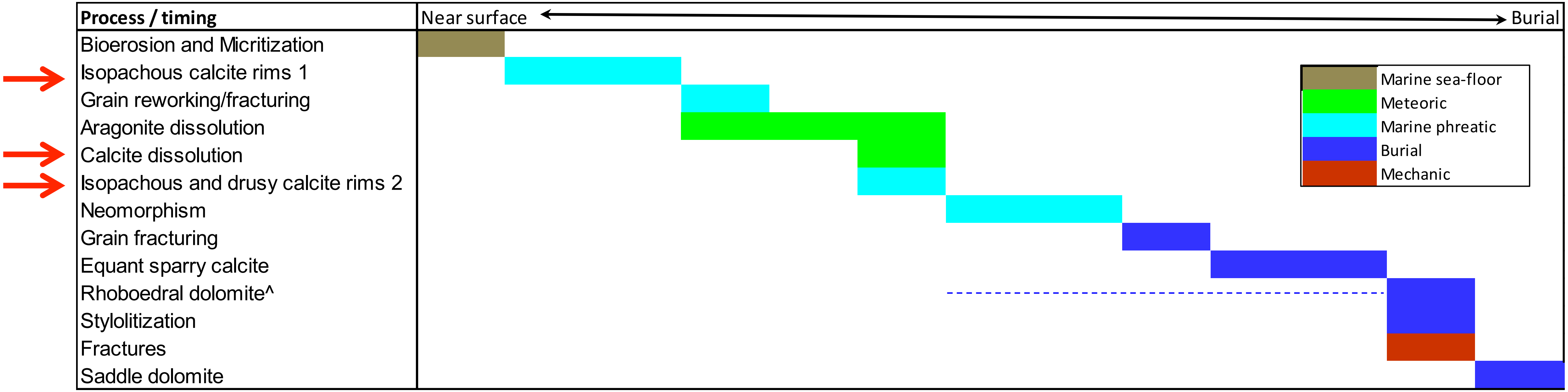
Paragenesis

Impact of diagenesis strongly controlled by the depositional facies, especially their texture and grain types (mineralogy).

Early diagenesis has the main control on reservoir quality:

marine cementation → isopachous calcite rims stabilize the depositional open frame of grain-supported facies

aragonite dissolution (maybe meteoric) → extensive vuggy porosity network in aragonite-rich sediments (rudist and corals)



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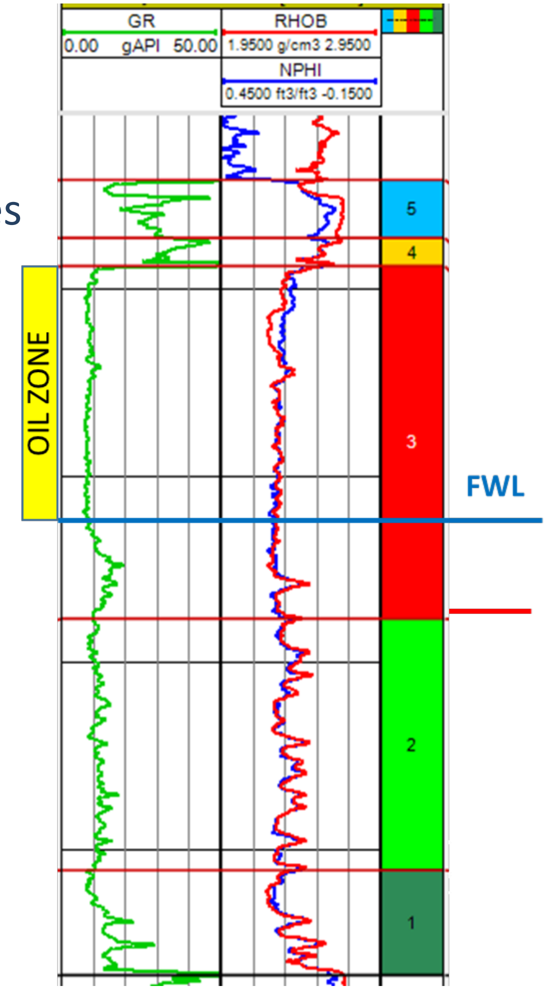
Stratigraphic occurrence of geological facies

Seven geological facies recognized in the reservoir.

Occurrence and distribution of geological facies are linked to the reservoir sequence stratigraphic architecture.



Main reservoir

Geological Facies	A & A1	B & B1	C	D	E
Av. Por	21	23	24	20	15
Av. K	164	18	2	2	0.3
Main grain type	Caprinid	Rudist calcite	Orbitolinid	Peloids, bioclasts	Mudstones

Sequence 2 Sequence Boundary

Geological Facies	F	G
Av. Por	21	23
Av. K	164	18
Main grain type	Coral+algal grains	Algal & matrix

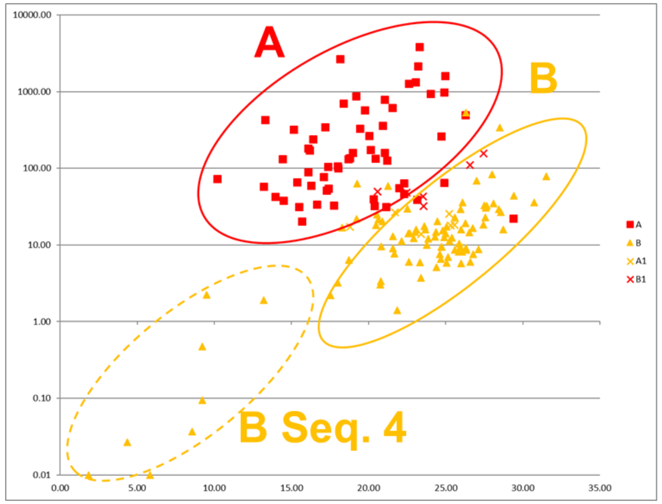
+ secondarily

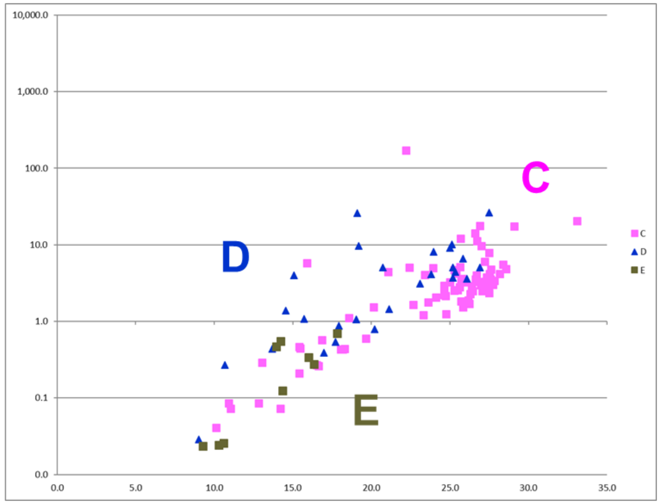
C	D
24	20
2	2
Orbitolinid	Peloids, bioclasts

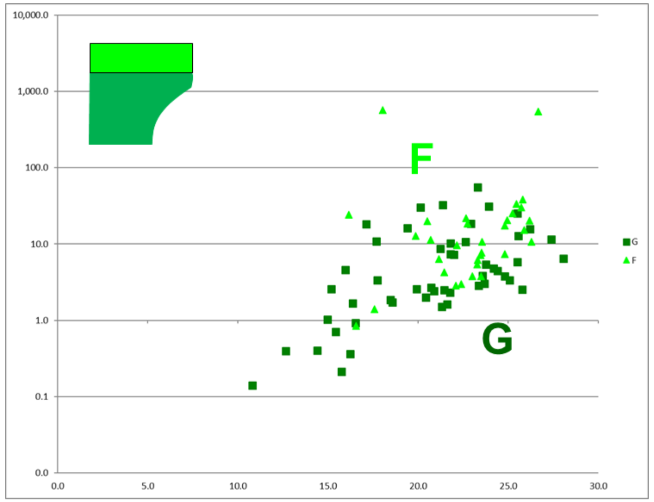
Geological Facies

The geological facies capture the sedimentological and diagenetic processes and features.

Main defining criteria: grain types and mineralogy, porosity system, textures, stratigraphic position







RESERVOIR FACIES

A	Caprinid rudstone-grainstone, vuggy porosity, aragonite dissolution & replacement.
B	Caprotinid/Myophorid/Requienid floatstone-packstone, intergranular porosity
B (Seq.4)	Caprotinid floatstone. Tight grain packing and mechanical compaction.

C	Orbitolind-rich wackestone-packstone. Intragranular porosity.
D	Foraminifera, skeletal, peloida, wackestone-packstone. Intergranular porosity.
E	Mudstone-wackestone. Moldic and intragranular porosity

SHALLOWING-UP PERITIDAL CYCLE

F	*Lithocodium/Bacinella* and coral rudstone and floatstone. Locally breccia. Intertidal-subtidal to near-exposure.
G	*Lithocodium/Bacinella* floatstone-packstone. Framework and intragranular porosity. Subtidal

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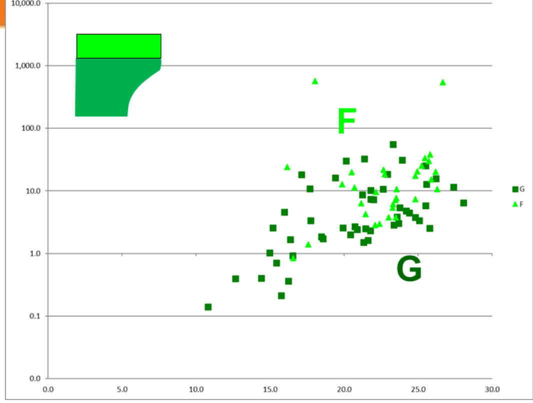
Sequences 1 and 2

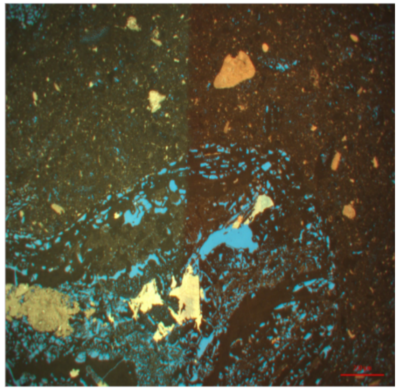


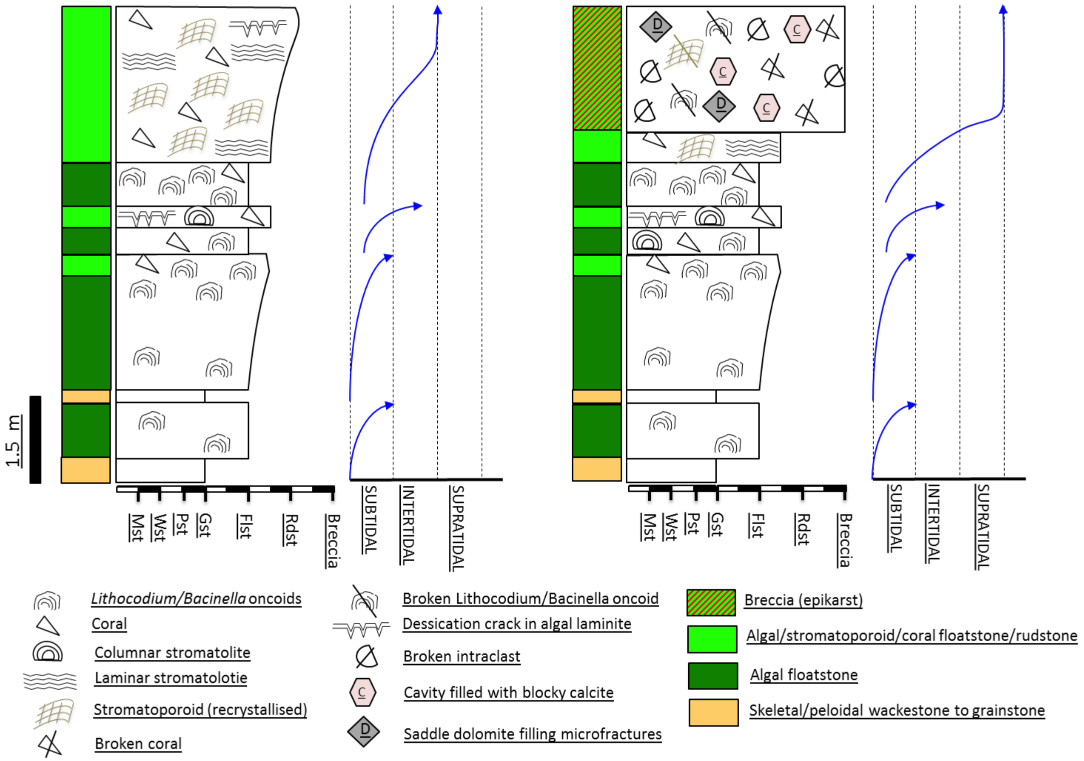
Geological facies F and G form algal-coral shallowing-up cycles on shallow algal platform

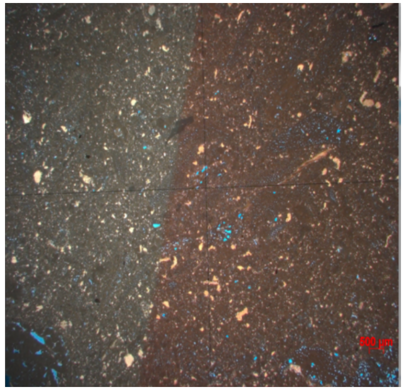
F: *Lithocodium/Bacinella* and coral rudstone: cycle top and near-exposure

G: *Lithocodium/Bacinella* floatstone, cycle base

Neighbor field also used as analogue





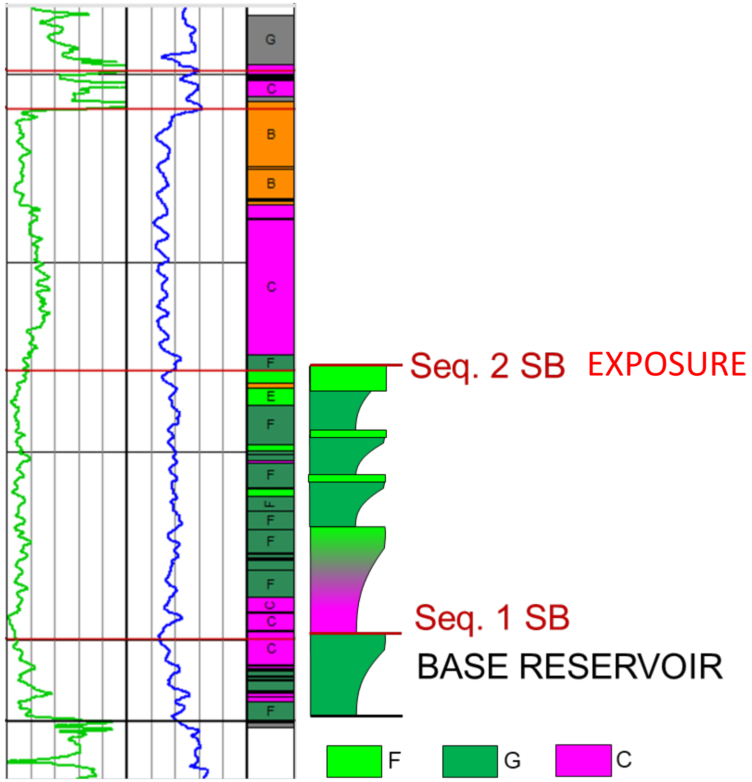


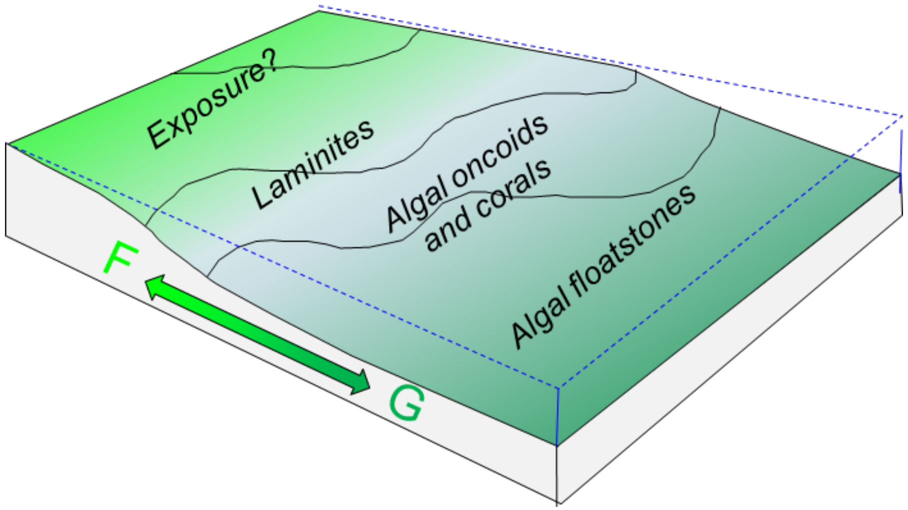
Sequence 1 and 2 – geological concept

Algal-coral shallowing-up cycles represent reservoir genetic units forming Sequences 1 and 2

Reservoir properties distribution following genetic units architecture and depositional trend

Major Sequence 2 boundary from exposure features





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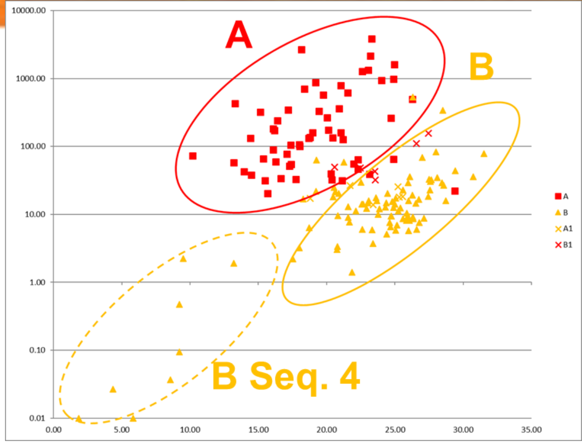
Sequences 3, 4 and 5



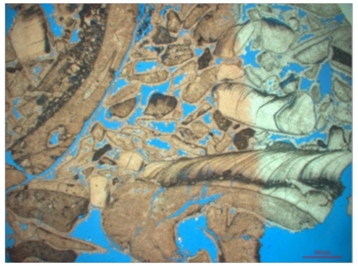
Rudist-dominated platform top facies

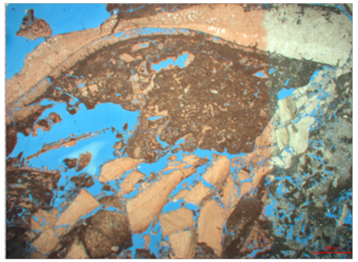
A: rudstone-grainstone and breccia, vuggy, Caprinids (aragonitic shell parts) – HIGH ENERGY

B: floatstone-wackestone, intergranular+vuggy, Caprotinids, Myophorids, Requienids (calcitic shells) – LOW ENERGY

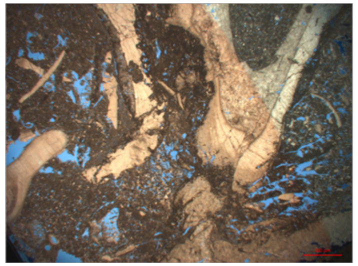
B (Seq. 4): floatstone-wackestone, matrix-supported, intergranular, Caprotinids, Requienids, compaction - COMPACTION

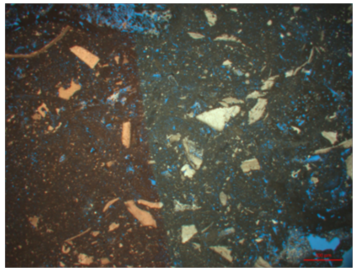
A



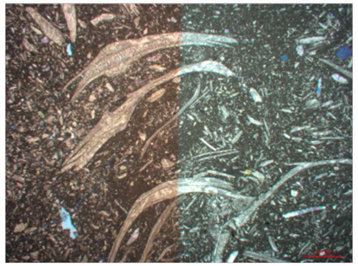


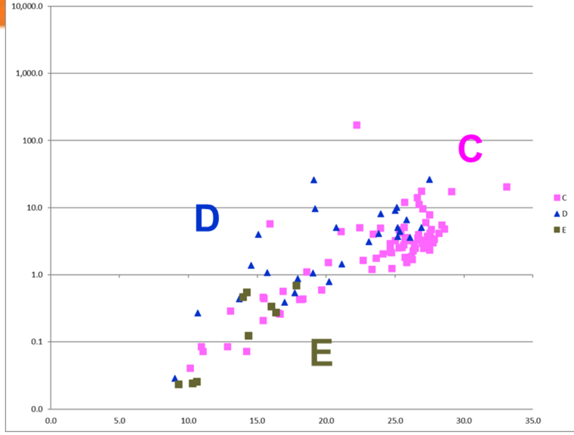
B





B (Sequence 4)





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Low energy, protected platform facies.

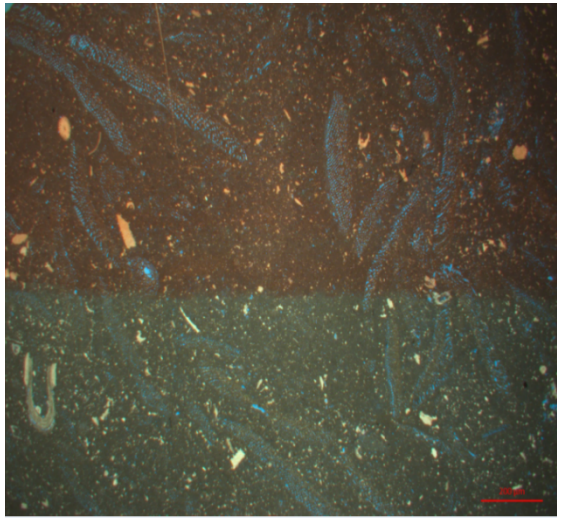
C: Orbitolinid-rich grainstone to wackestone, also indicative of transgressive sequences

D: Bioclastic (peloidal-skeletal) packstone-wackestone

E: non-reservoir mudstone

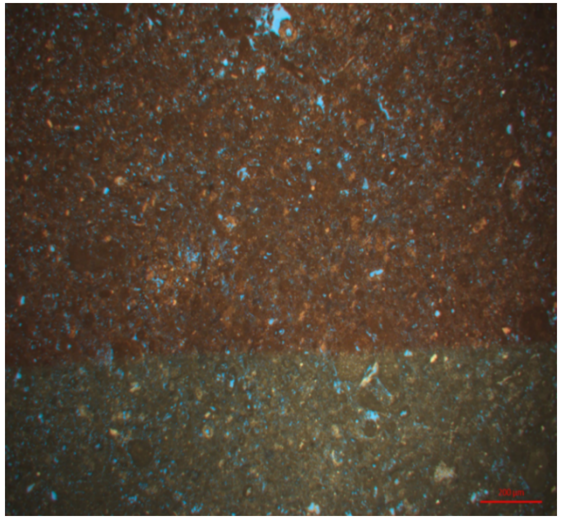
C

Dominant intra-Orbitolinid porosity (intra-granular)
Low pore connectivity



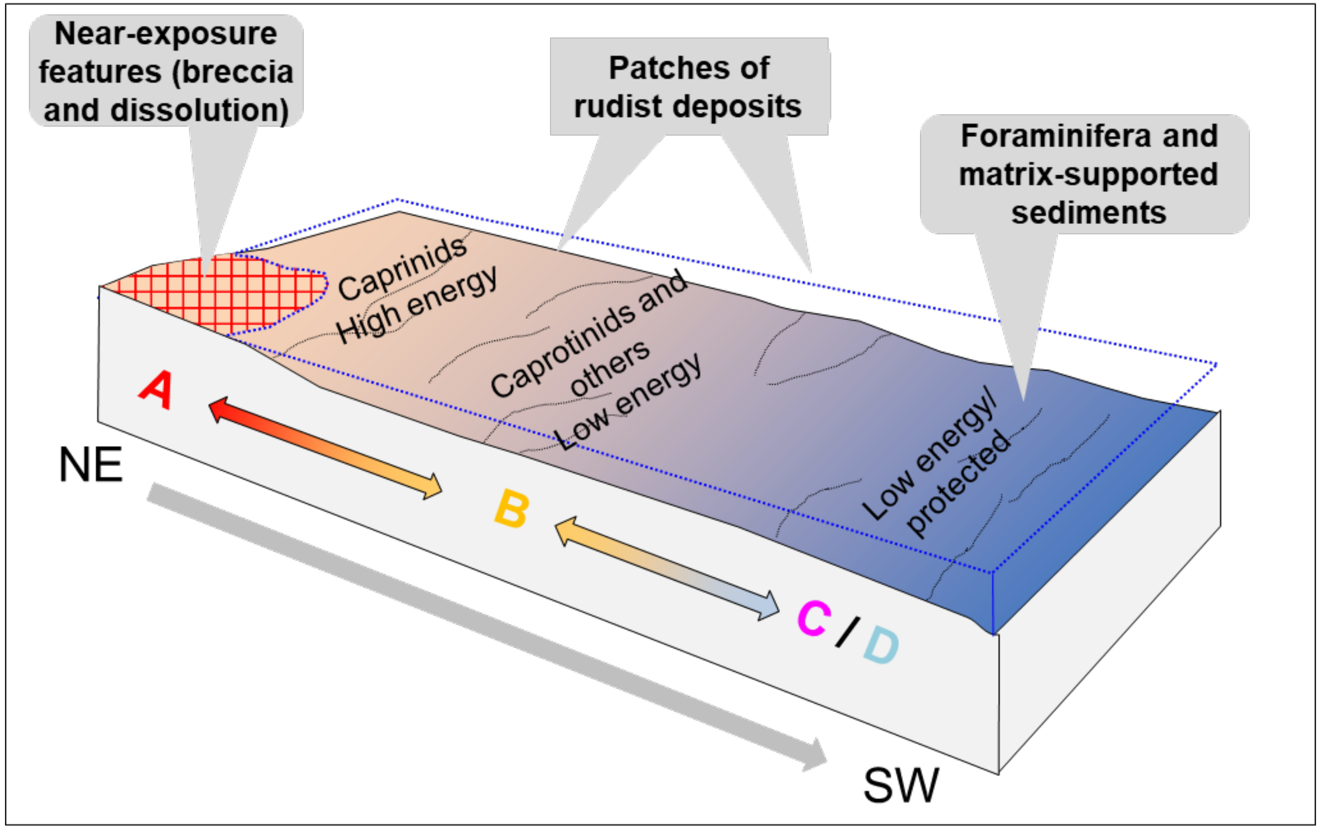
D

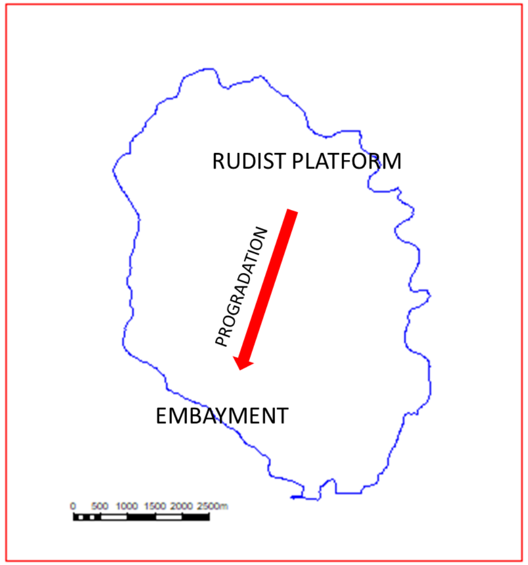
Low inter-granular porosity
Matrix supported



Sequence 3, 4 and 5 – geological concept

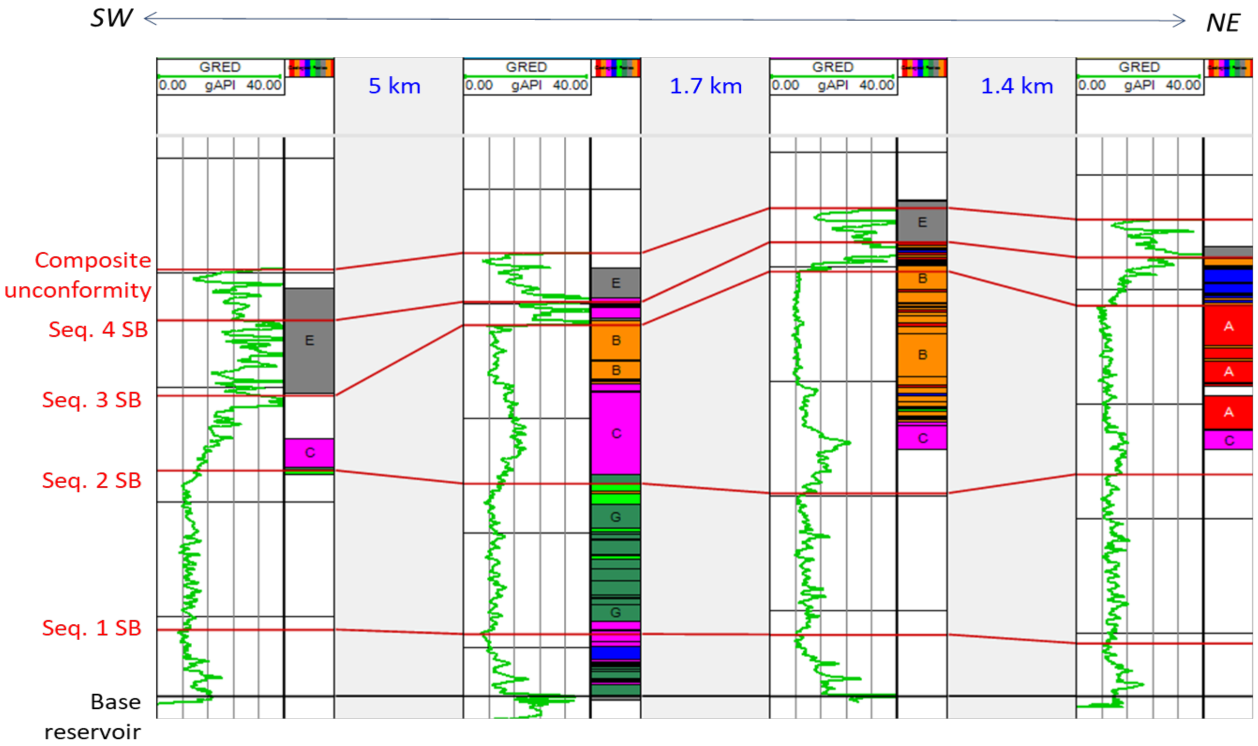
- Geological facies properties and their distribution controlled by the interplay of depositional energy, sediment texture and rudist type/shell mineralogy.
- Energy trends and rudist distribution follow the platform progradation.



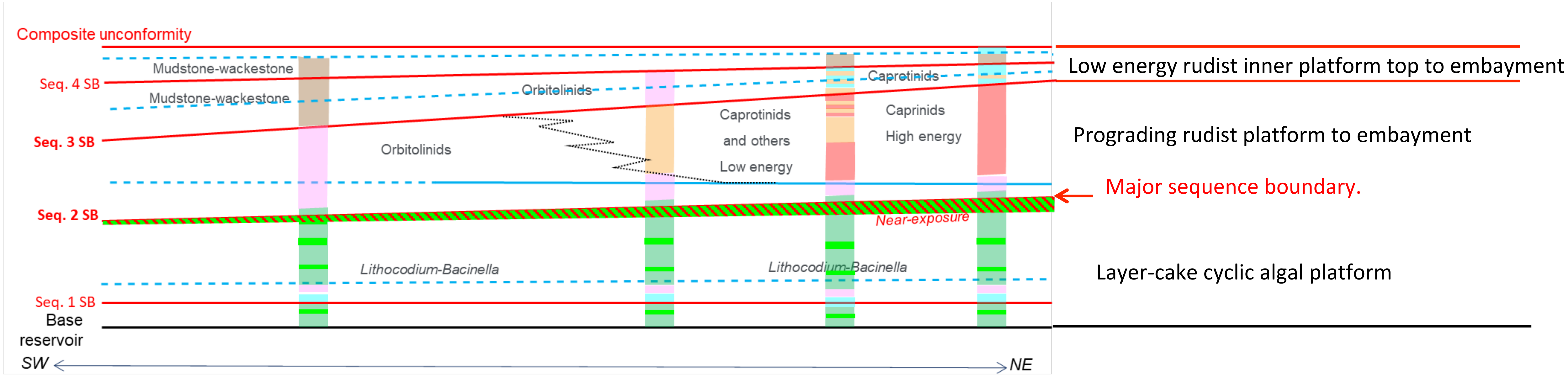


Geological Facies	Description
A	Caprinid rudstone
B	Caprotinid/Myophorid floatstone
C	Orbitolinid wackestone-grainstone
D	Foraminiferal/skeletal/peloidal wackestone-packstone

Architectural reservoir framework and concept



Major sequence boundary marked by an exposure surface.
Carbonate factory changes, due to changes in oxygen levels.
Correlatable to neighbor fields.



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Petrophysical synthesis and Static Rock Typing workflow

Data QC and preparation: time is what you pay, value is what you get!

Core Data QC

- Data availability QC
- Depth shifting
- Stress Correction
- Removing anomalies (fractures/ stylolites)
- Comparison between the trim and plug data
- Resampling and Closure Correction

Extracting Parameters for PG

- Hyperbolic Tangent
- 2D Array extraction Tangent
- Principle Component Analysis

IPSOM model

- Generate PG
- PG QC
- PG link to geology

Static Rock Typing

A two-fold static rock type scheme was created by integrating the geological concept and the petrophysical synthesis (Petrophysical Groups)

- 2 SRTs in Sequences 1 and 2- algal platform
- 5 SRTs in Sequence 3, 4 and 5 – rudist platform and embayment/protected

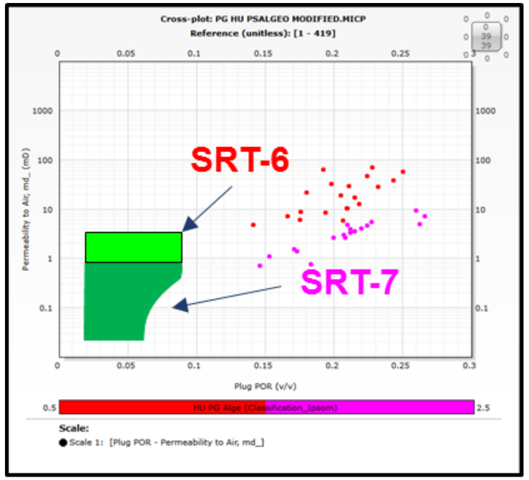
From Petrophysical Groups to Static Rock Types Sequences 1 and 2

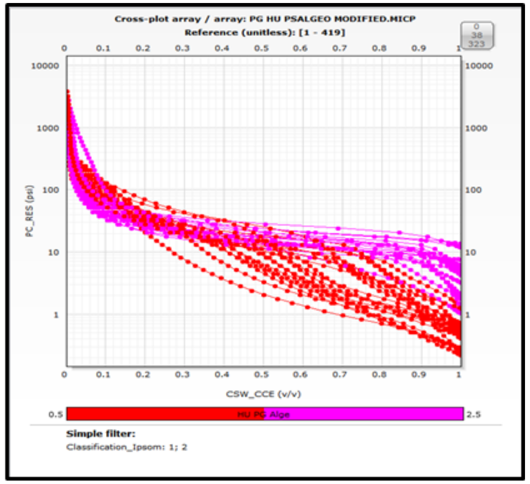
Two static rock types in the algal platform of Sequence 1 and 2.

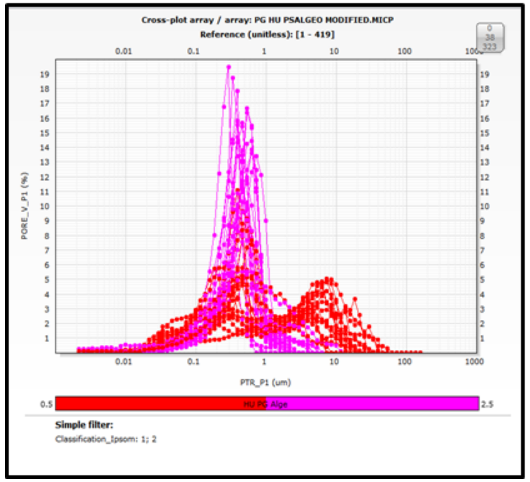
SRT 6 = cycle cap (Geological Facies F)

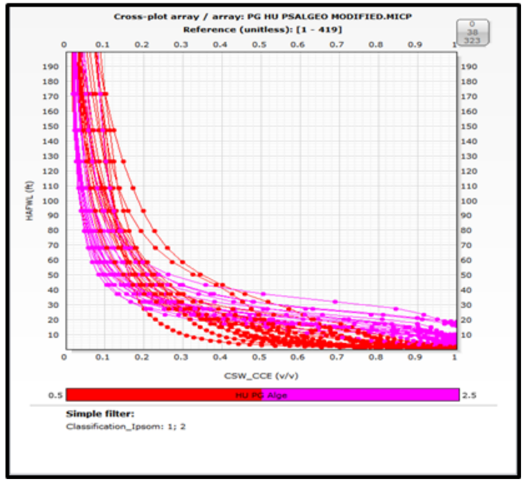
SRT 7 = cycle base (Geological Facies G)

Neighbor field with more abundant data set also used to define algal-coral SRTs









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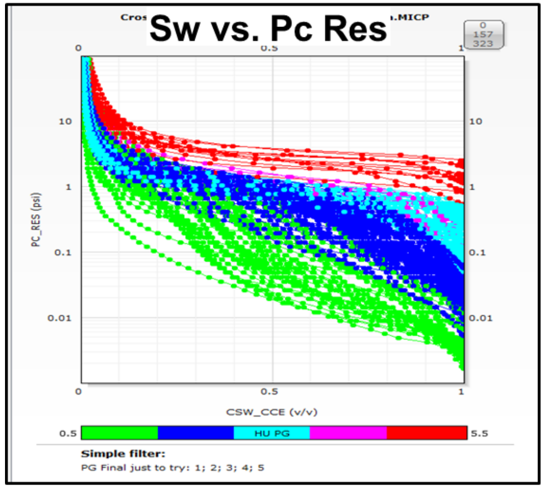
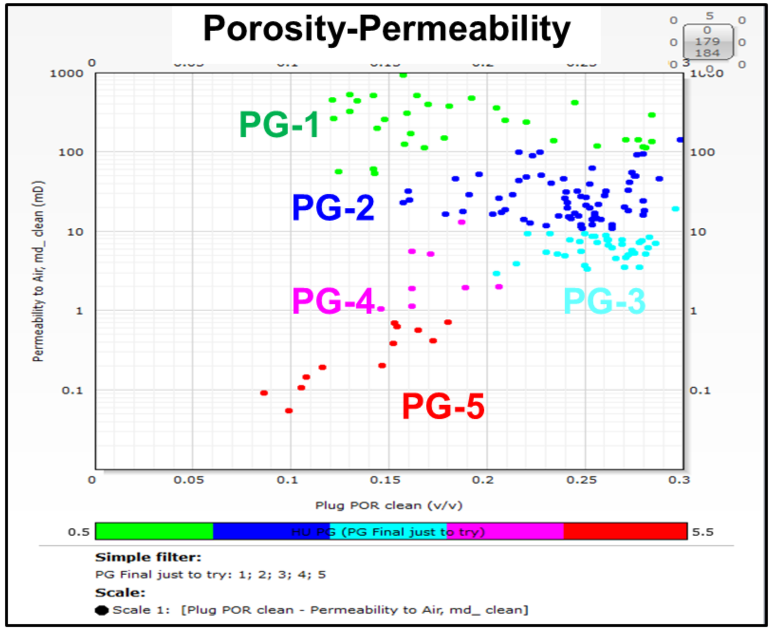
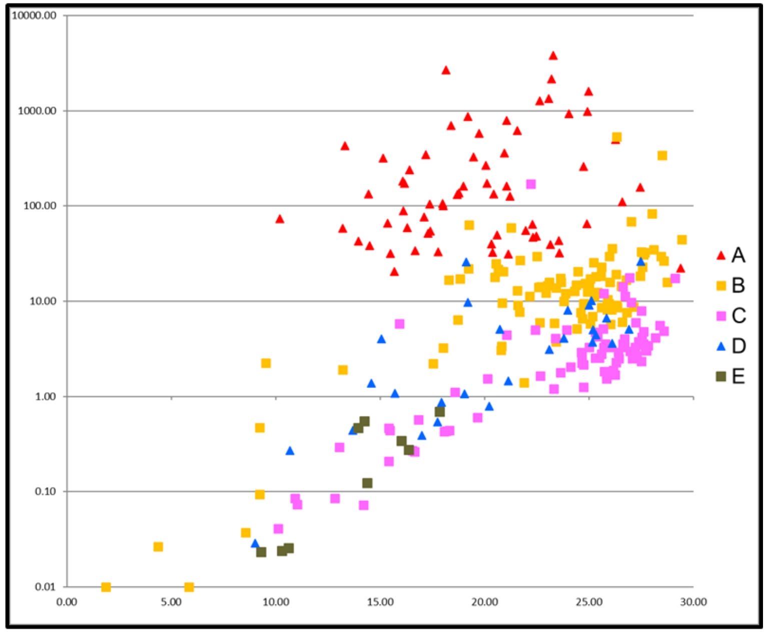
From Petrophysical Groups to Static Rock Types
Sequences 3, 4 and 5







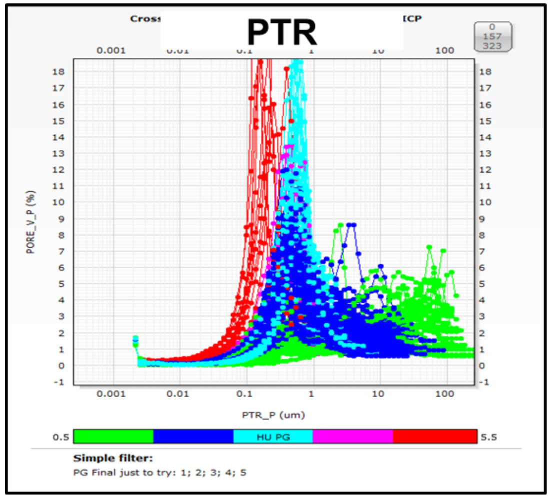
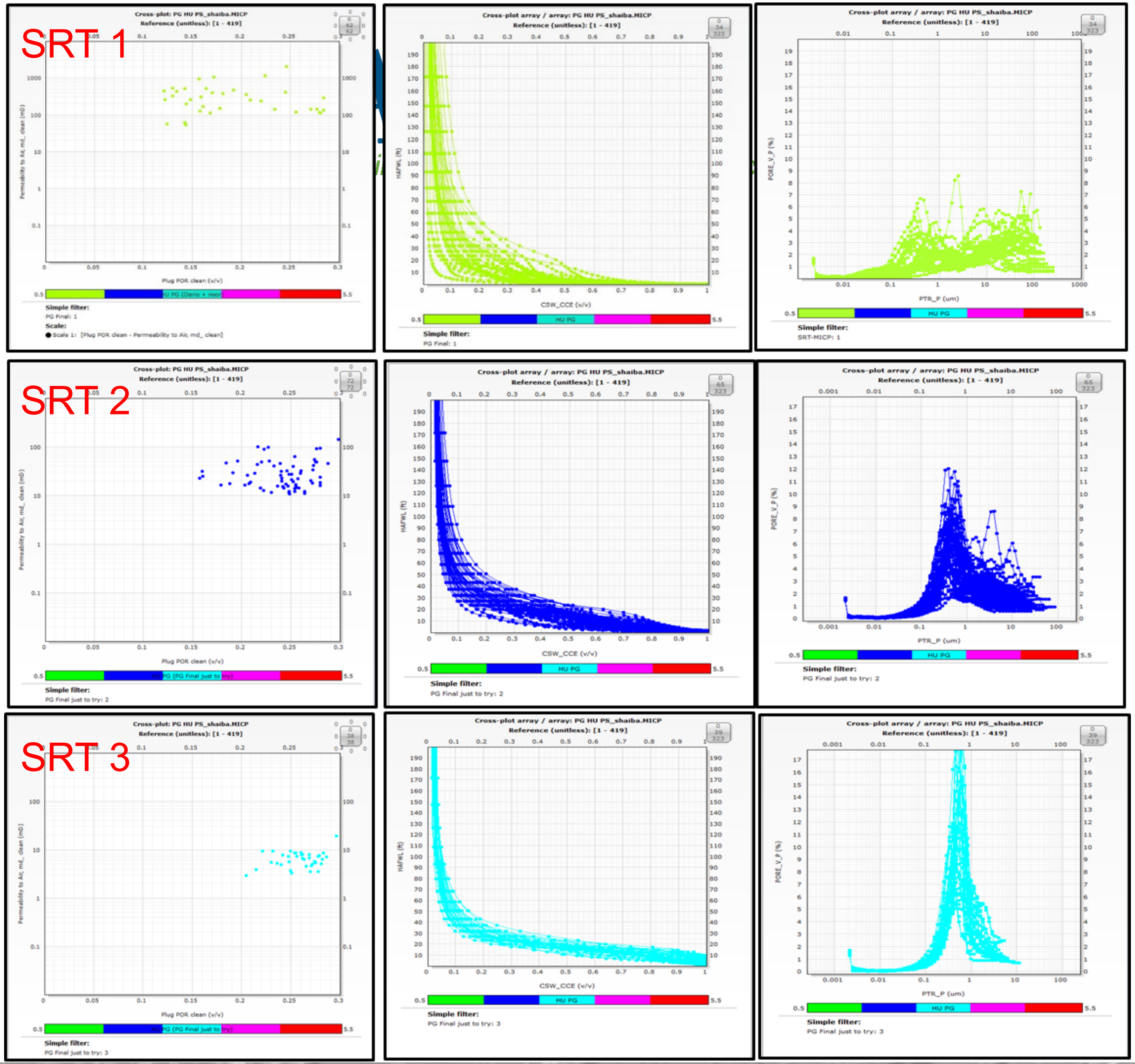
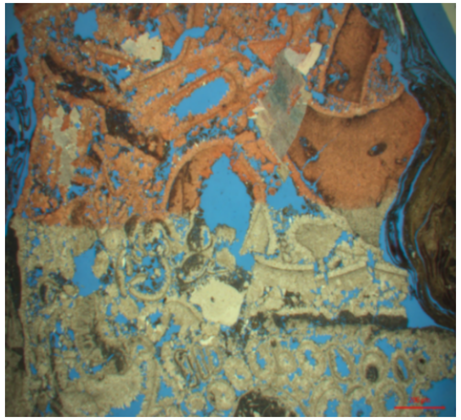


Table of the row frequencies (%)
(Reference: SRT, Test: GF)

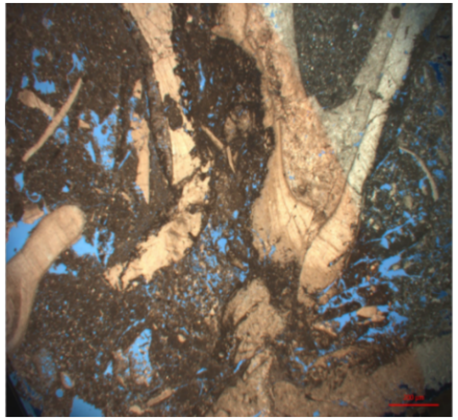
Test — Cramer's V = 0.62 C = 72.41 %

Reference	GF A	GF B	GF C	GF D	GF E	Total:
1	100.00					100.00
2	20.00	76.67		3.33		100.00
3		28.57	42.86	28.57		100.00
4		20.00		80.00		100.00
5		8.33	50.00	16.67	25.00	100.00
	-	-	-	-	-	-

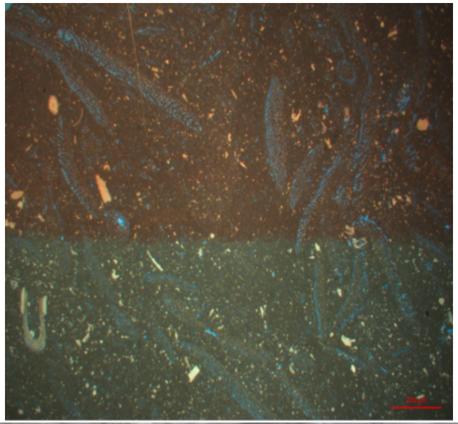




Caprinid rudists dominated (Facies A)
Grain-supported
Multiple pore system
Highest K (100-1000 mD)
Phi: 14-30%
Lowest Pd and Swi



Caprotinid/Myophorid rudists dominated (Facies B)
Matrix supported
Dual pore system
K: 10-100 mD
Phi 16-30%
Low Pd and Swi



Orbitolinid grainstone to wackestone (Facies C)
Matrix supported
Single pore system (intragranular)
K: 1-10 mD
Phi > 20%

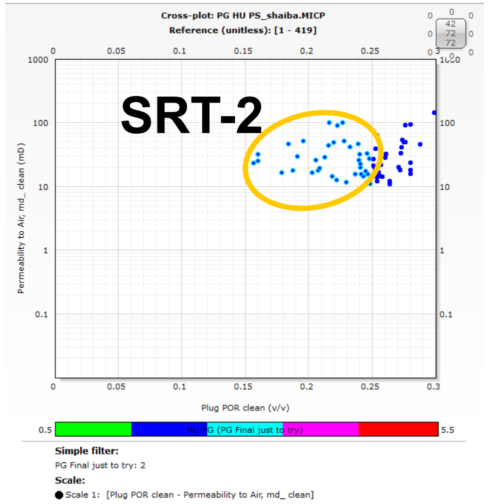
Petrophysical differences between stratigraphic sequences

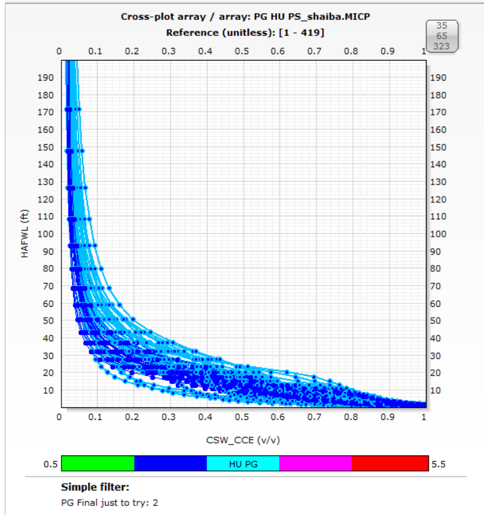
Overlap of some Phi/K values in SRT2 and 6.

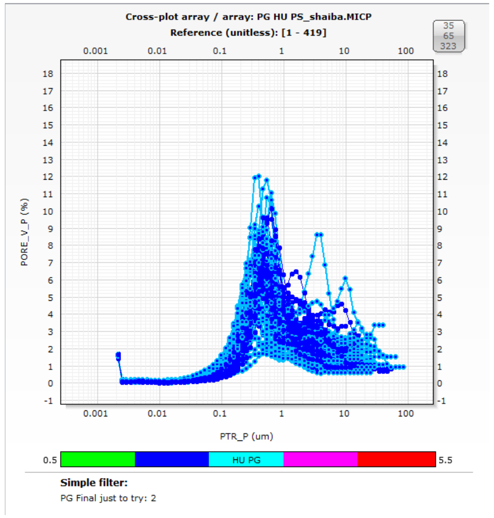
SRT-2 is less heterogeneous than SRT-6 – different porosity systems:

Calcitic Caprotinids *vs.* aragonitic corals

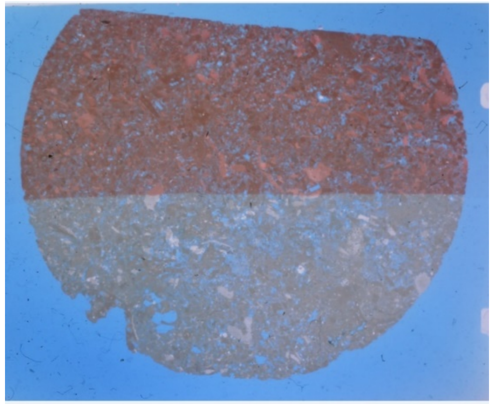
Moreover, SRT-2 and SRT-6 occur in two distinct stratigraphic intervals

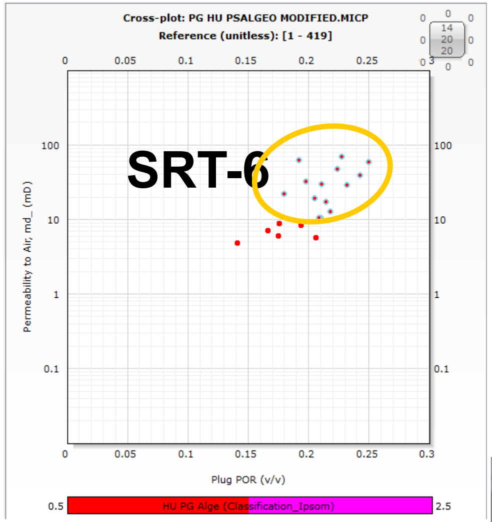


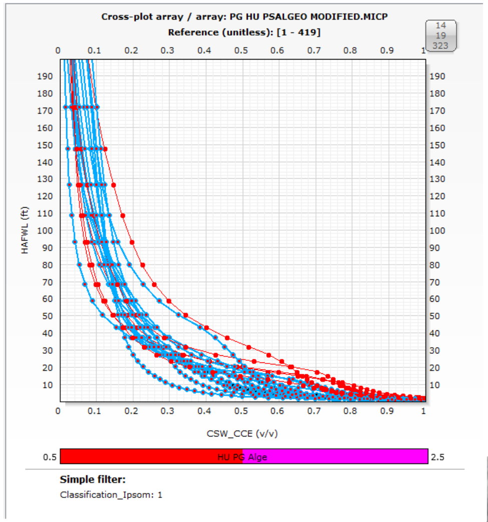


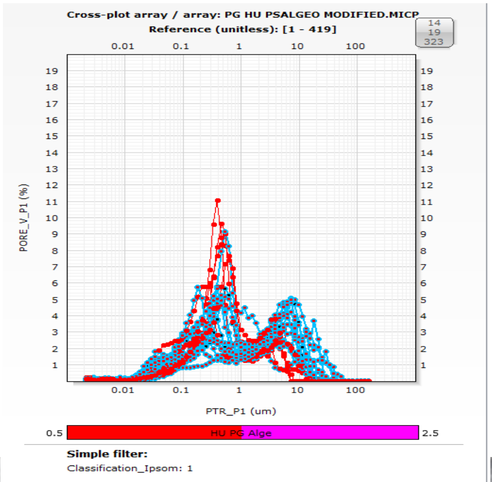


Dominant intergranular porosity

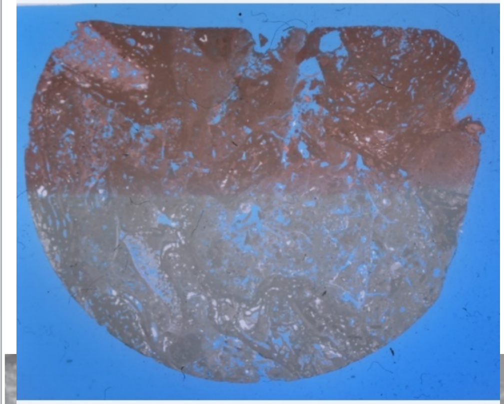








Vuggy, intra- and intergranular porosity – aragonitic corals

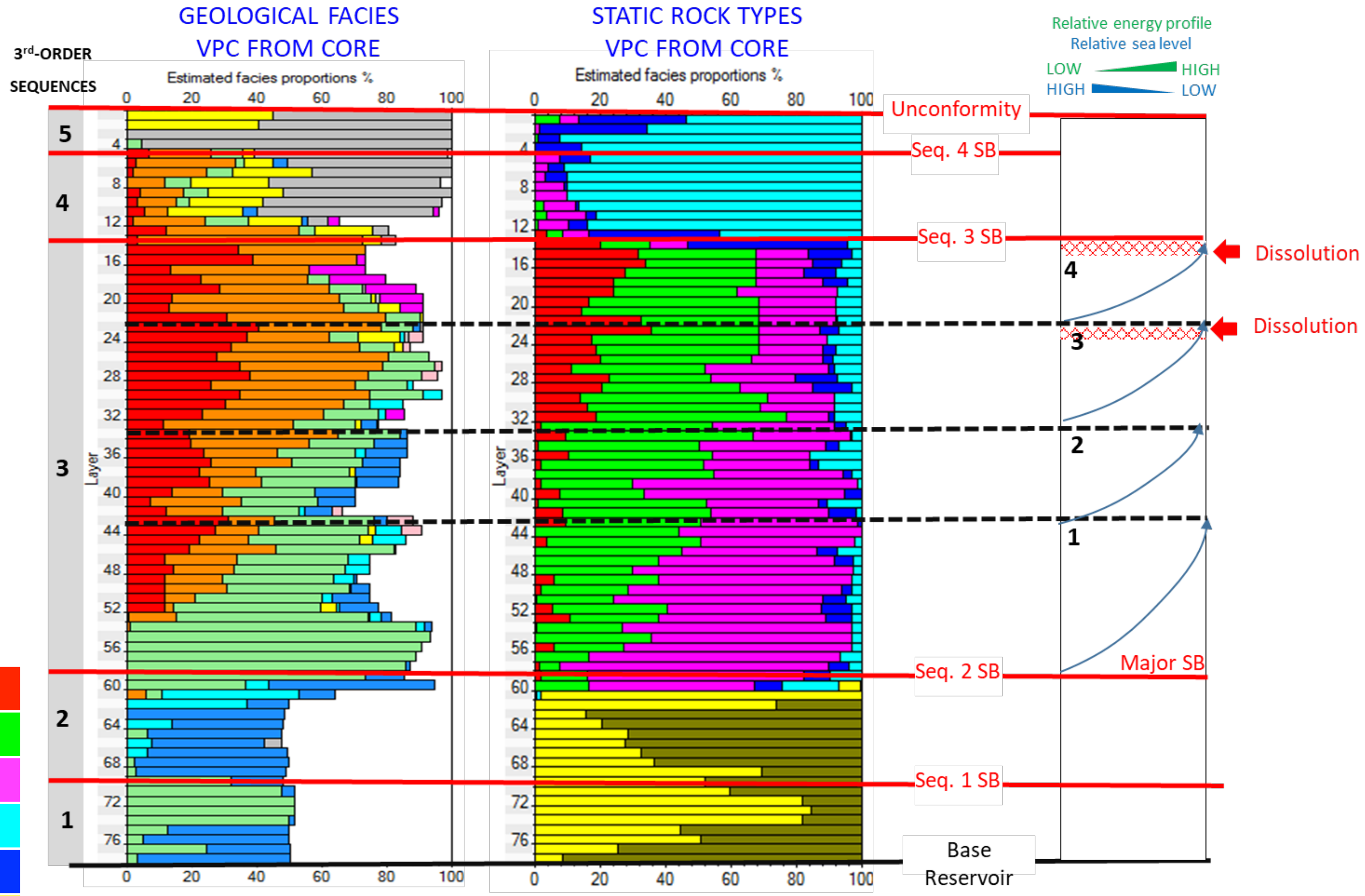


Vertical Geological facies and SRT distribution - refining the sequence stratigraphic architecture

VPCs built based on core data

Refined sequence stratigraphic architecture – updates to model zonation of the reservoir section (Sequence 3)

Robust link between geological facies and SRTs



GF	SRTs
A	SRT1
B	SRT2
C	SRT3
D	SRT4
E	SRT5
F	SRT6
G	SRT7

From the geological concept to the model

2D maps are built from the proportion of the SRTs for all the wells per each zone.

The 2D maps are combined with VPCs and used like trend to generate 3D SRT grid.