EGYPTIAN CARBONATE RESERVOIRS CHALLENGES

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Carbonate Reservoirs
GPC ٢٠٢١ Workshop

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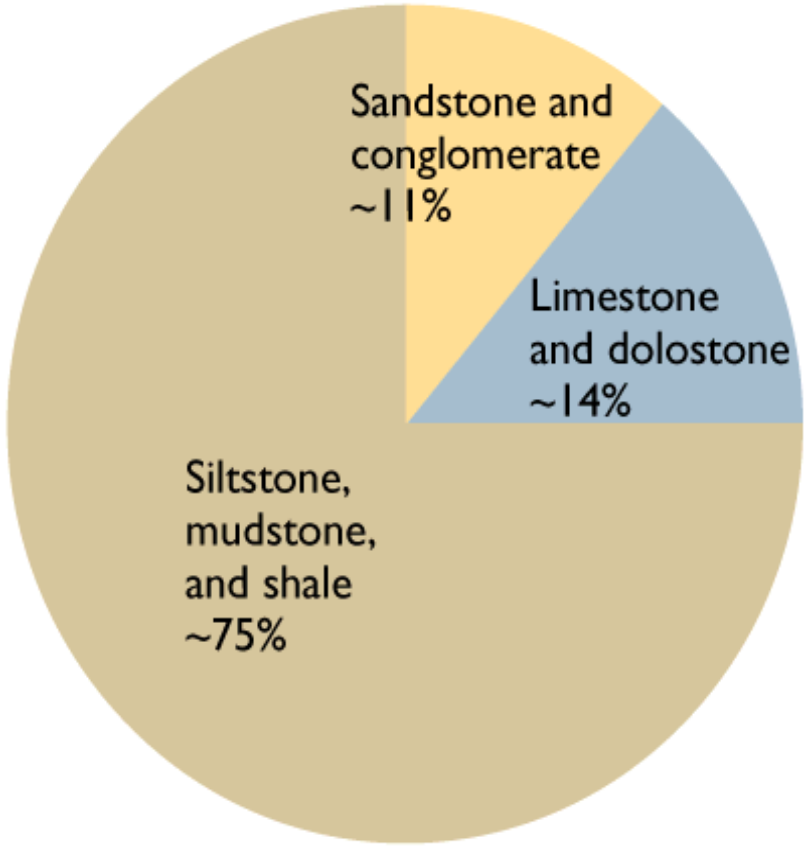
Egypt

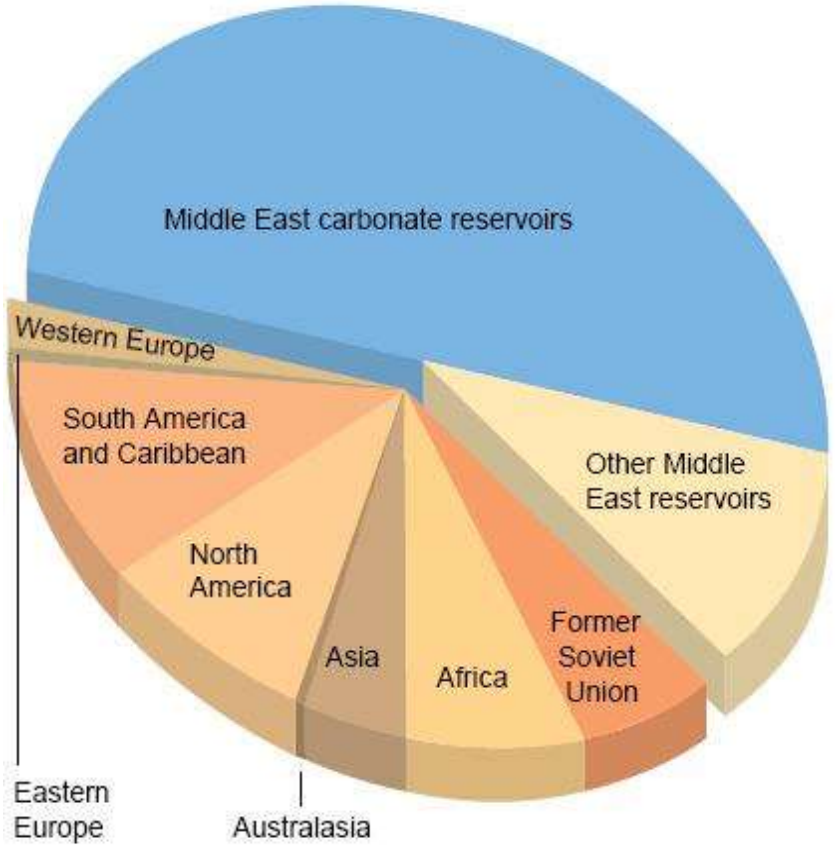
General

Carbonates fight above their weight where:

- They (as a reservoir) contain about ٦٠ % of the world's hydrocarbon reserves although being about ١٤% of all sedimentary rocks.

- They (as source rocks) contribute ٣٠-٤٠% of all hydrocarbons.





CARBONATE RESERVOIRS

❖ Complexities and Difficulties:

- Carbonate reservoir rocks have almost complex spatial and vertical stratigraphic and facies relationships as well as heterogeneous distribution of diagenetic facies. This inconsistent nature results elusive geometries and extensions of carbonate pays.

- Predicting these heterogeneities is strategic to field development and optimum production.

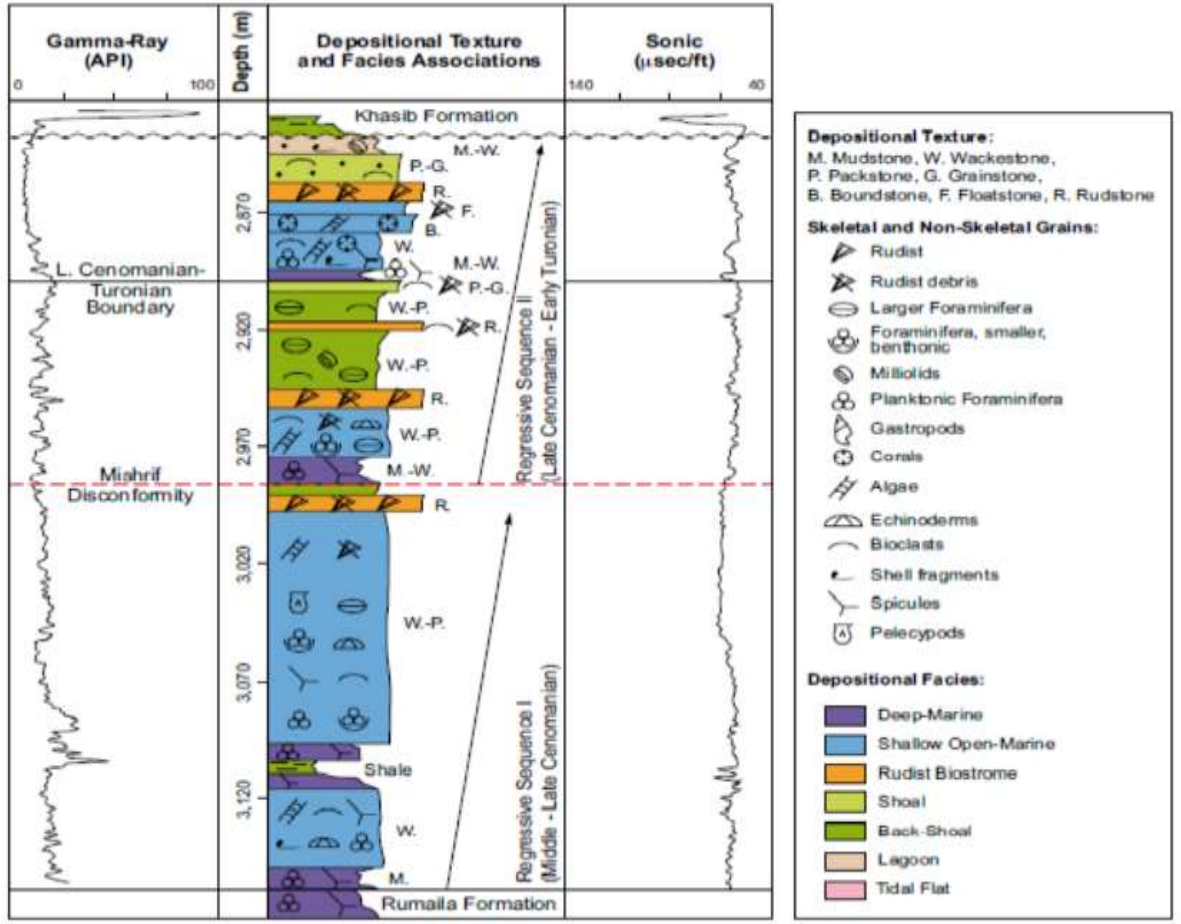
- To Solve these difficulties and predict geometries, detailed cores description, microfacies analysis integrated with E. logs, resistivity and acoustic images and seismic sections/attributes are essential, but being in most cases not available and expensive.

CARBONATE RESERVOIRS

❖ Complexities and Difficulties:

- Almost all carbonates of different depositional setting and characteristics give a rather similar responses by the different borehole logs due to their simple mono-/ dimineralogic and chemical composition. This hinders:

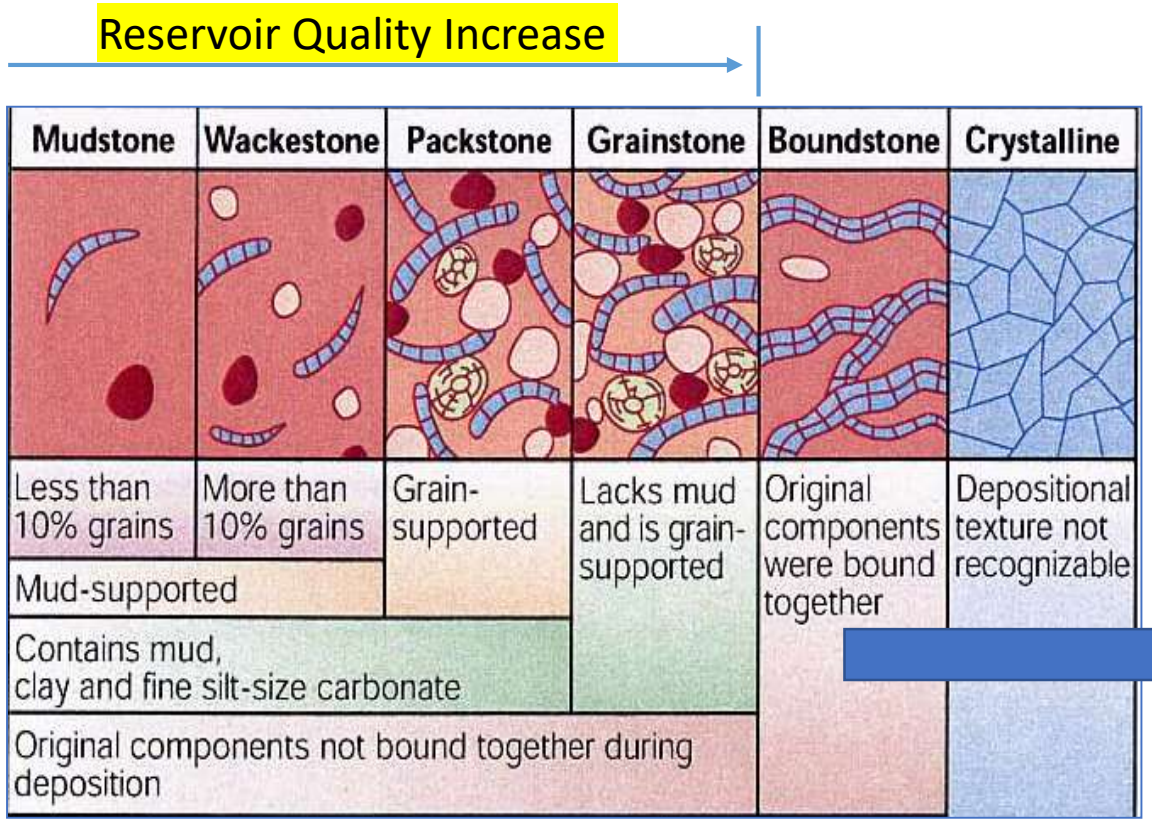
  - Identification of both primary and secondary structures of the drilled carbonate section.
  - Stratigraphic subdivisions and correlation
  - Identification of different carbonate facies and their stacking pattern
  - Assigning depositional setting.



*Background

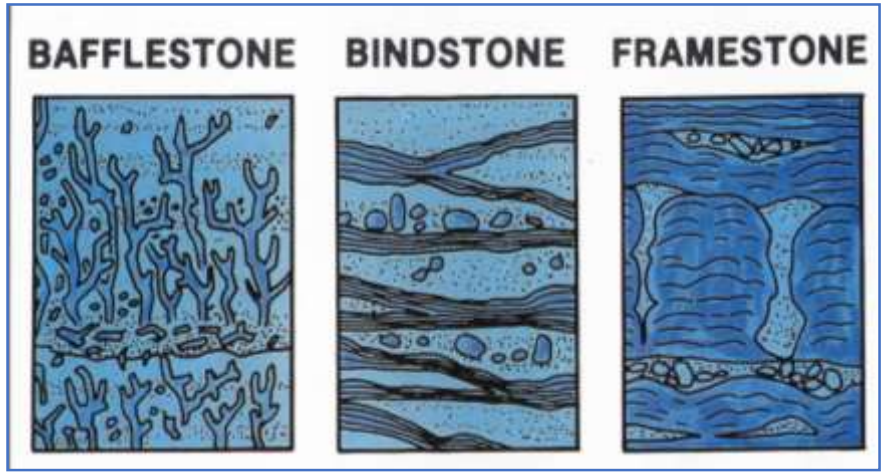
As known to identify carbonate facies as indicators for depositional processes, conditions & paleoecology requires two crucial parameters:

١- Rock fabric/texture to interpret process/condition



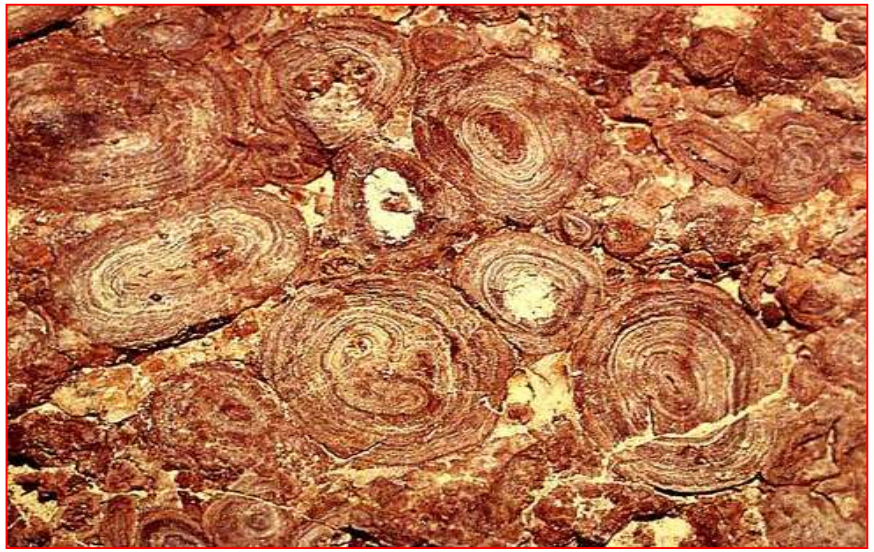
Dunham's (١٩٦٢) classification of limestone rocks

Embry and Klovan (١٩٧١) classification of reefal limestone rocks



* Background

٢- Rock allochems & faunal type/diversity to interpret the paleoecology, water bathymetry & circulation

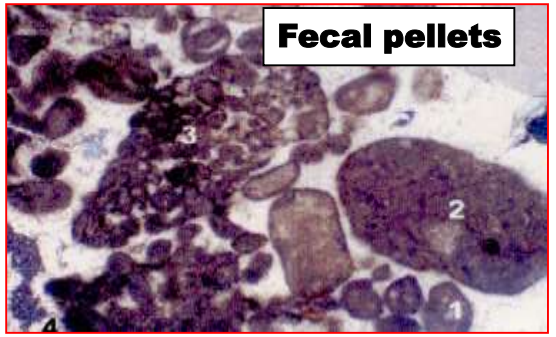


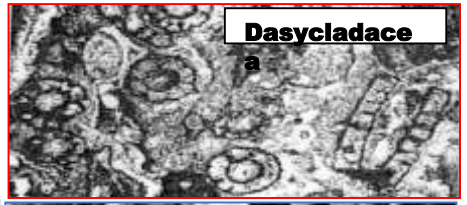
These two essential keys of depositional criteria can not be identified from openhole and image logs but require a calibration with <u>cores and petrographic thin sections</u>

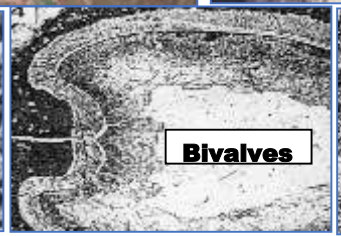
Allochemical Group

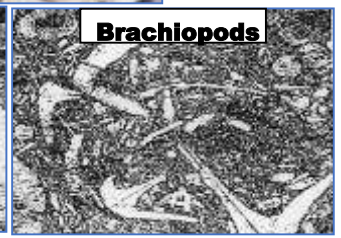
A- Non-skeletal grains

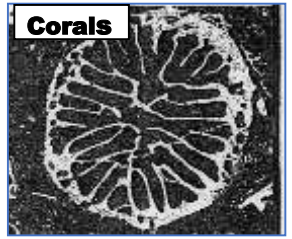
B- Skeletal Grains

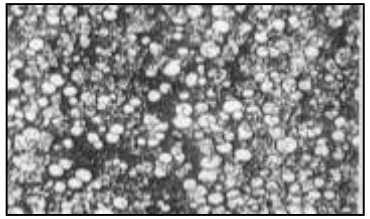


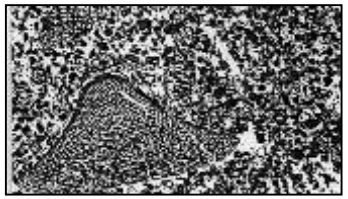


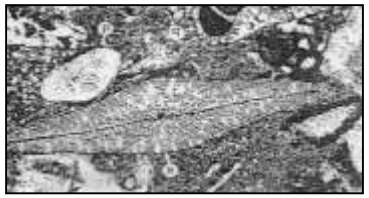


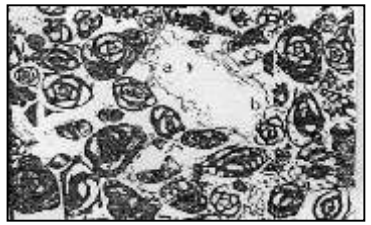






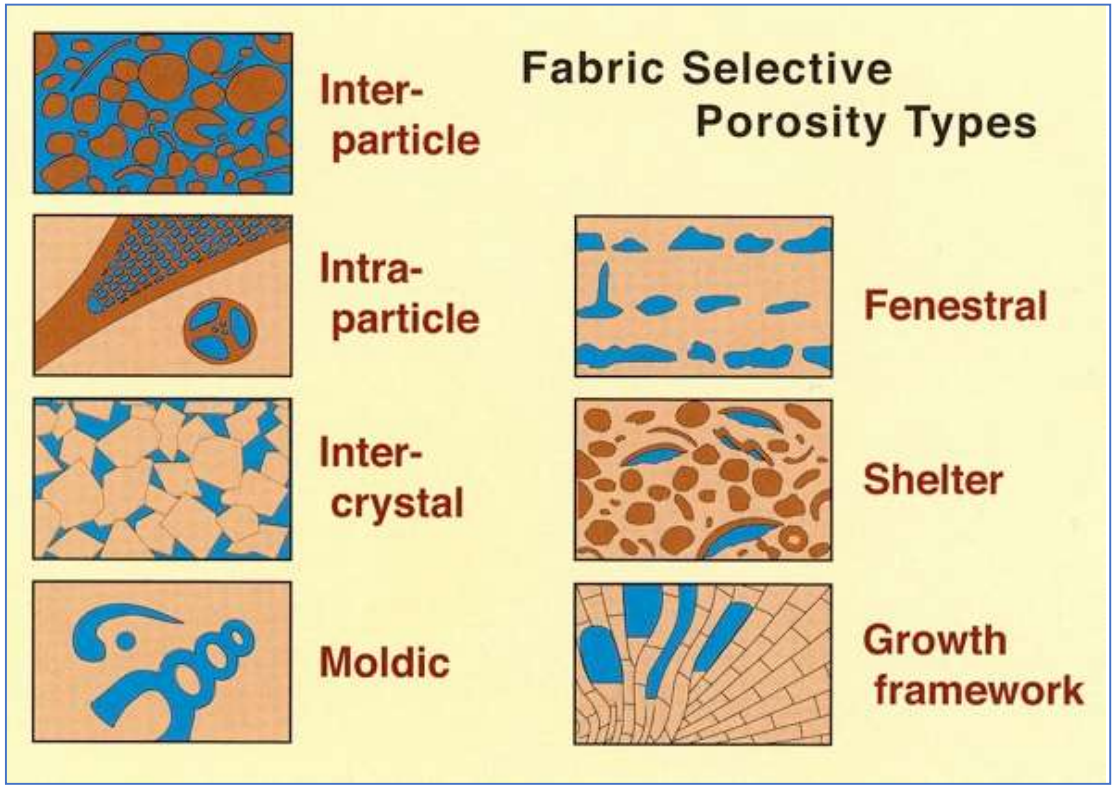


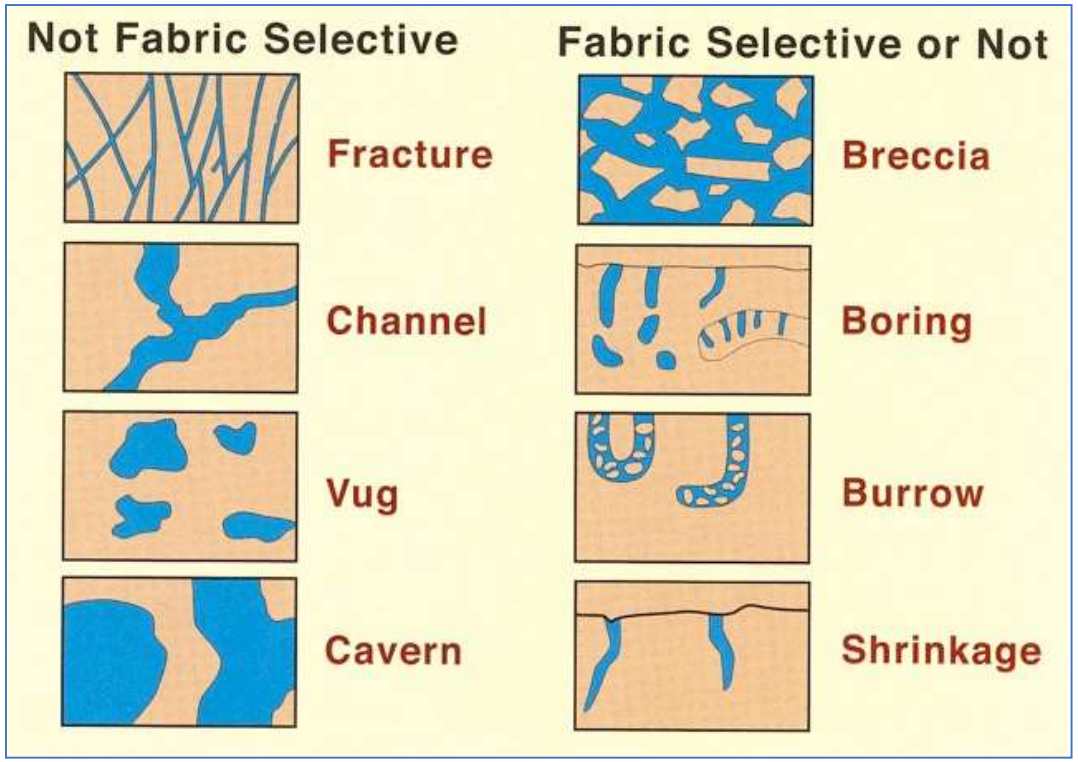




Carbonate Porosity Types

Classification of carbonate pore types according to relation to original depositional fabric (Choquette & Pray, ١٩٧٠)



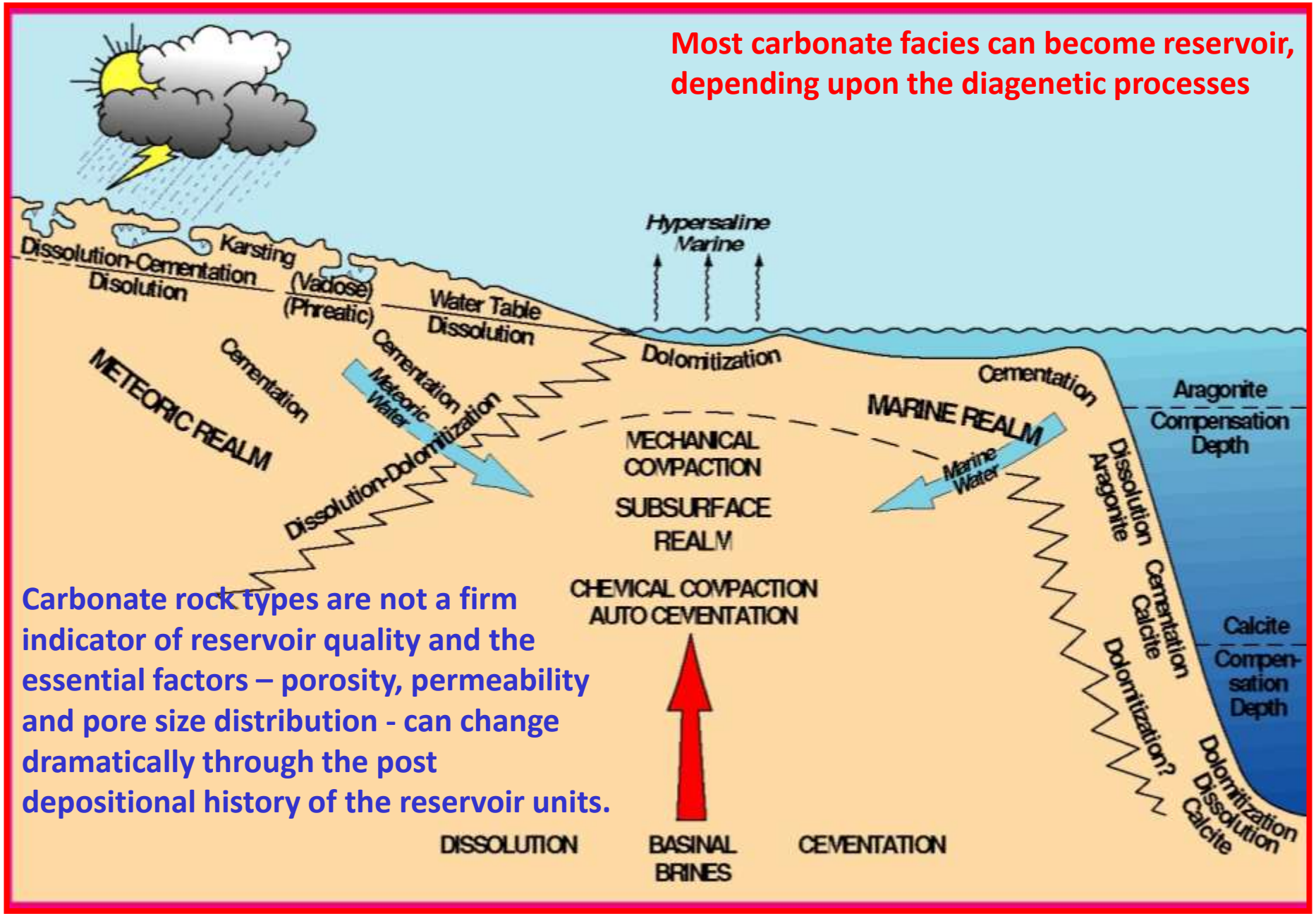


- **The porosity is unevenly distributed (localized)**
- **High porosities of different origins could be detected in various carbonate facies**
- **Porosities associated with high permeability are usually occurred in Grainstones, Boundstones and Packstones deposited from shaols, reefs and tidal flats, respectively**

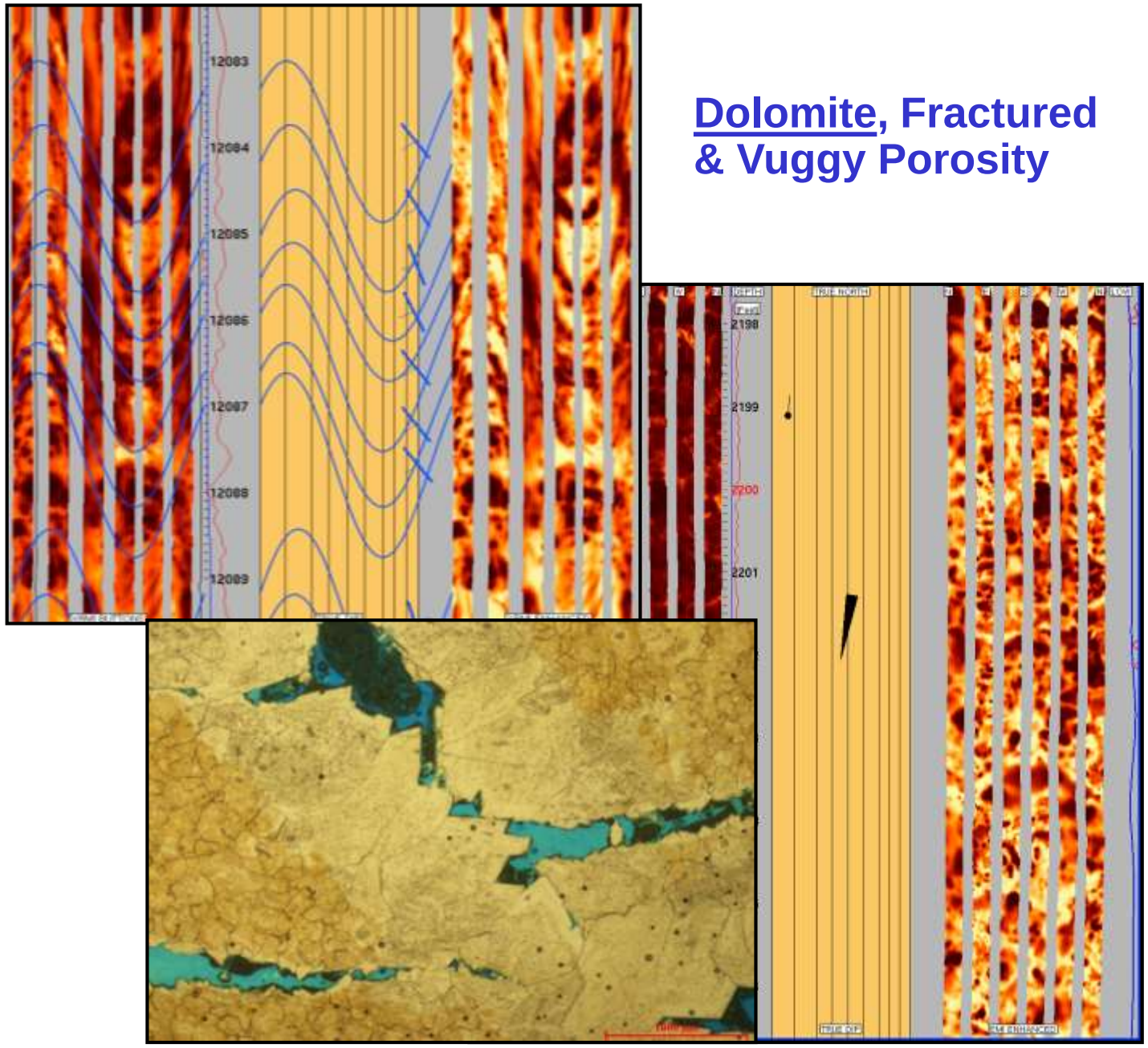
Carbonate reservoirs

- Reservoirs
  - reefal limestones and associated talus (material broken from the reef)
  - carbonate shoals and sandbanks
    - best reservoir quality in upper, coarser parts
  - chalks
  - leached zones below unconformities
- Other factors which influence carbonate fields
  - dolomitisation - volume change produces intercrystalline porosity
  - fractures - many carbonate reservoirs have high porosity but low matrix permeability

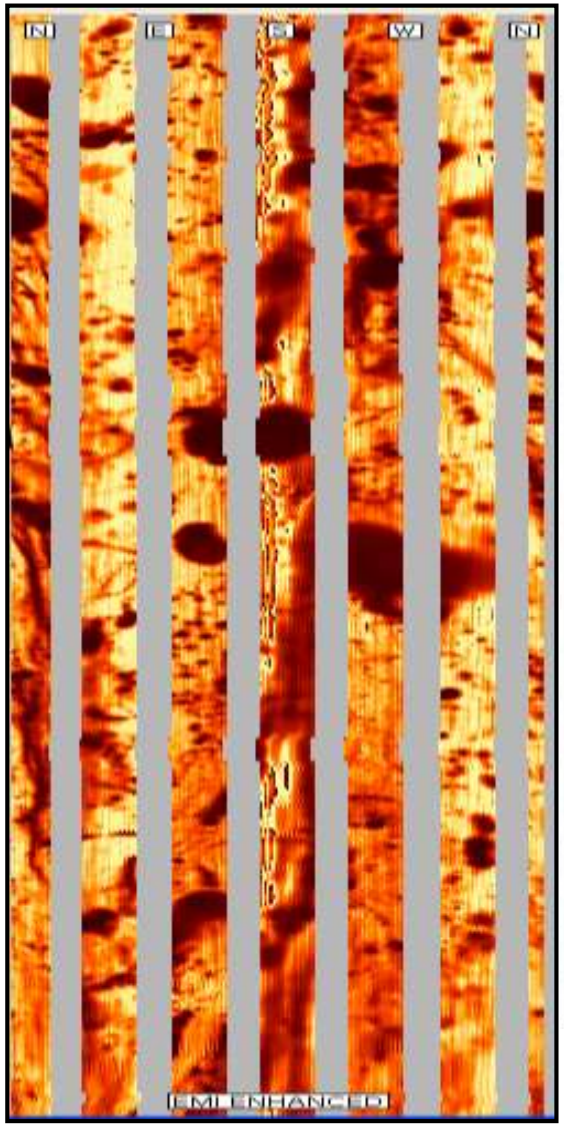
DIAGENETIC ENVIRONMENTS



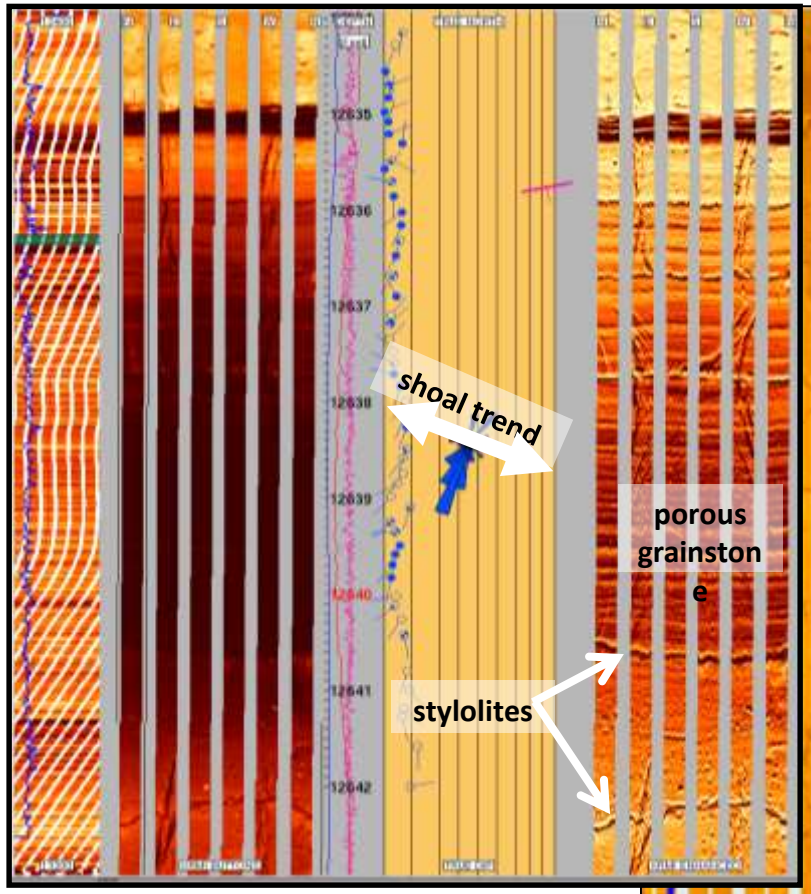
Carbonate Diagenesis

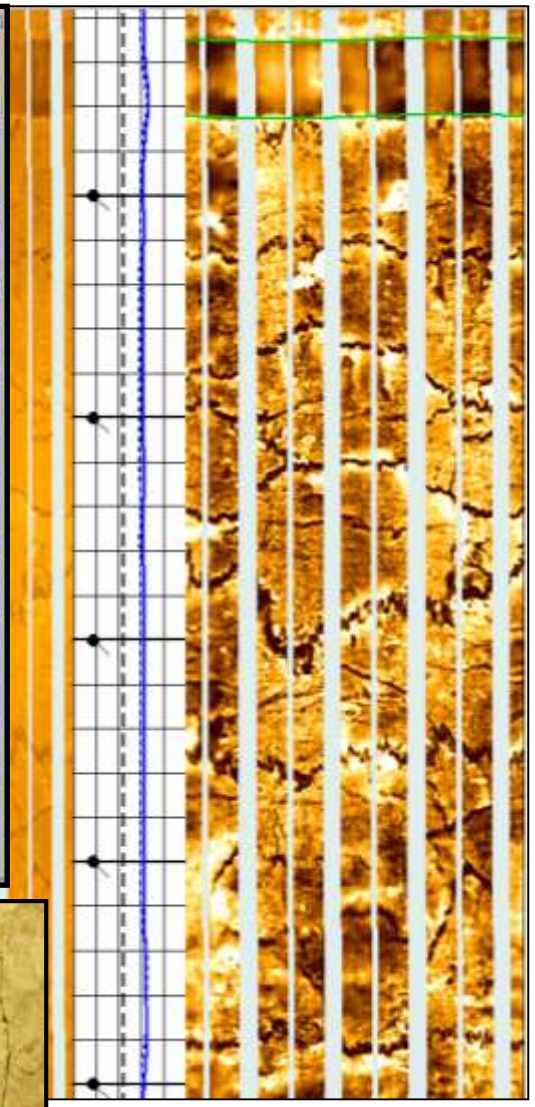


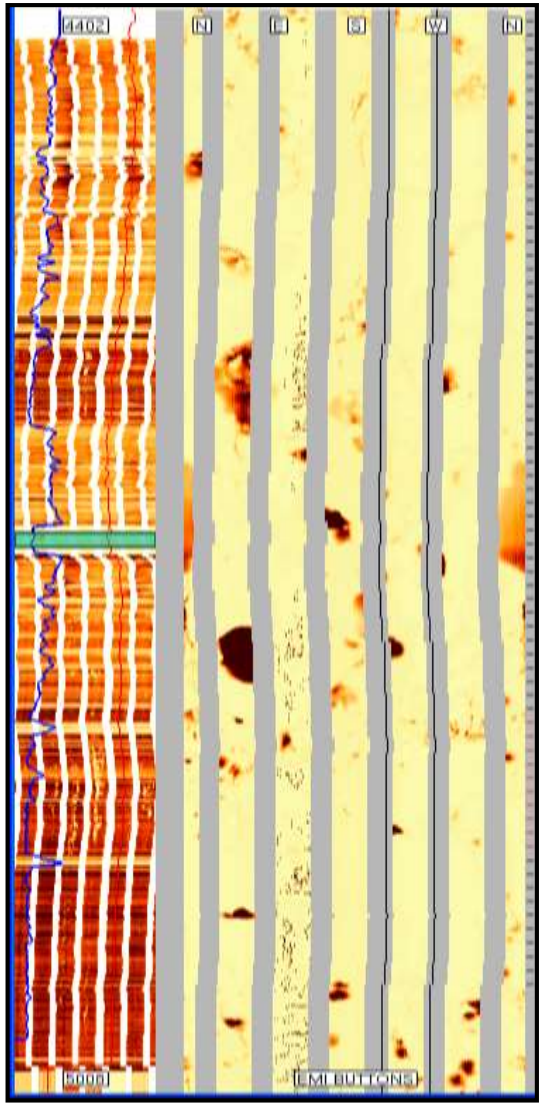
Dolomite, Fractured & Vuggy Porosity



Vuggy Carbonates due to Dissolution, enhances the reservoir quality



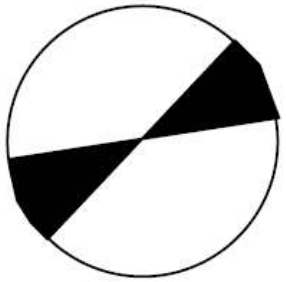




Stylolites due to Compaction & Cementation reduces the reservoir effieciency

Challenges in Fractured Reservoirs

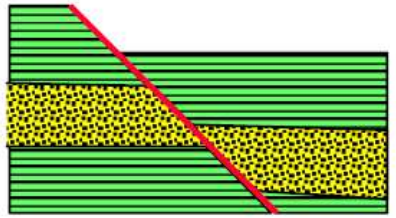
Fracture types & Distribution



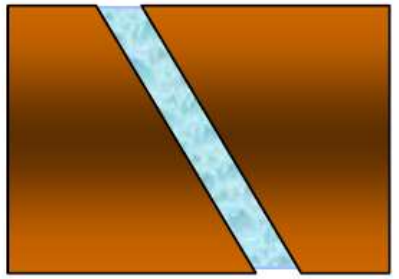
Orientation

Density & clustering relationship to bedding

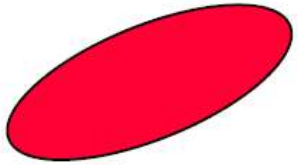
Flow properties



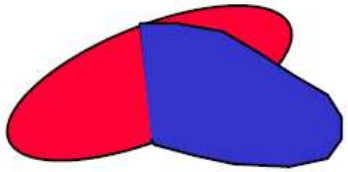
Sealing or open?



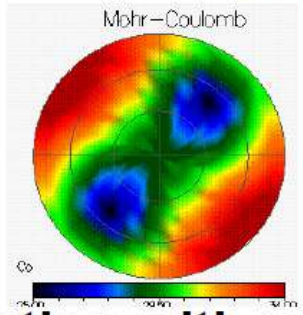
Aperture



Fracture size (length)



Abutting relationships

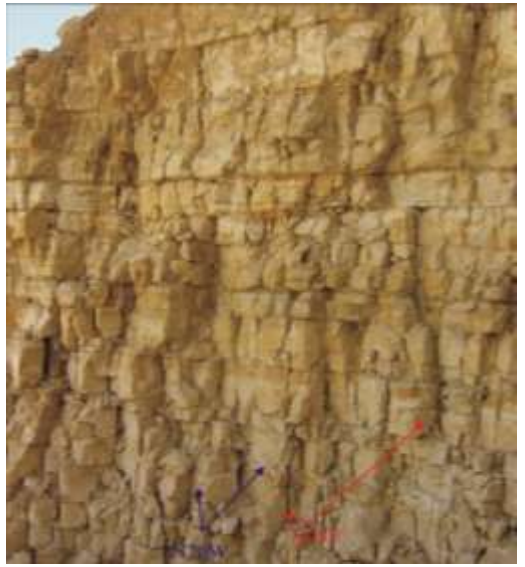


Orientation with respect to in-situ stress

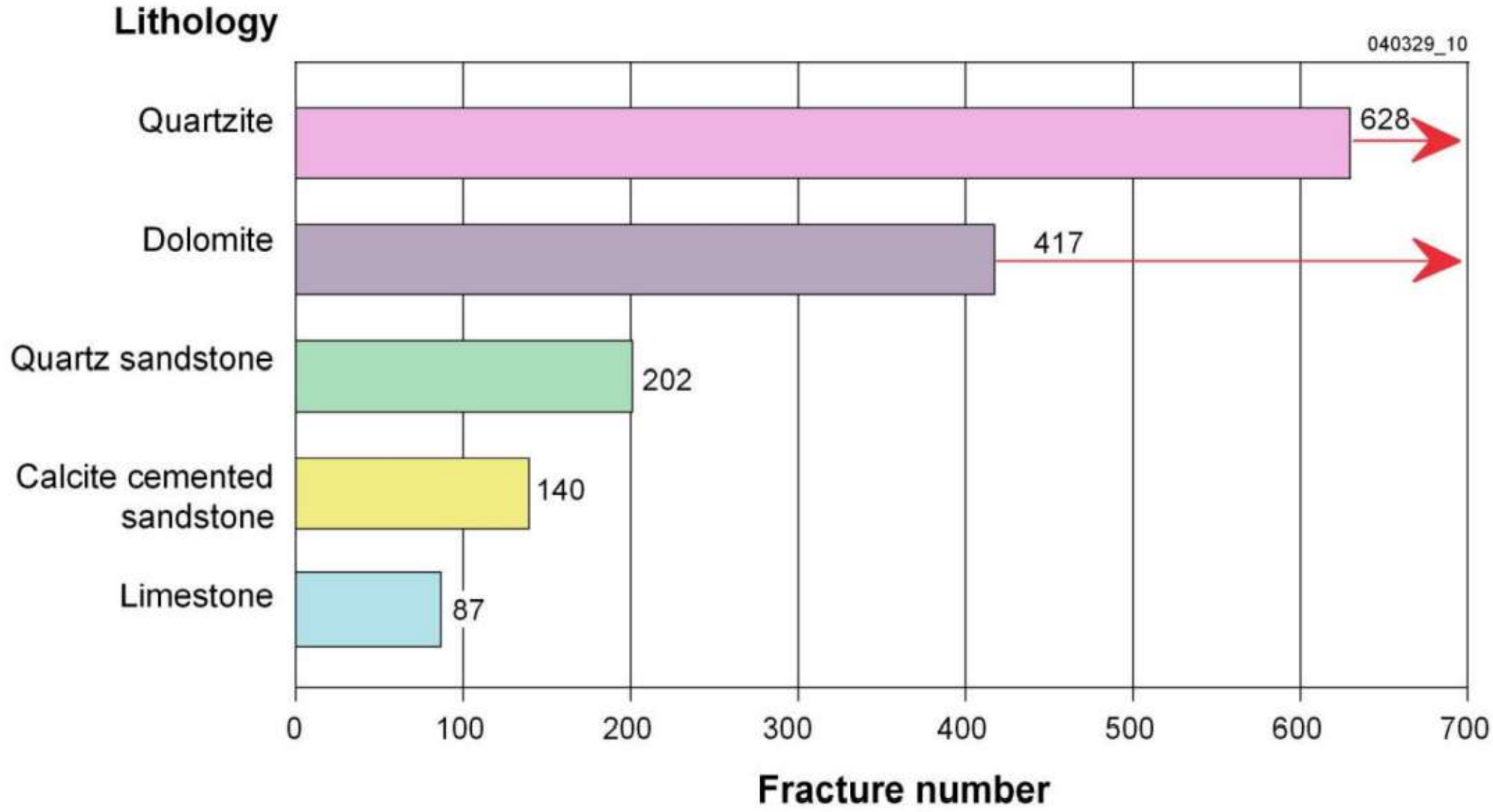
FRACTURE MODEL

After j. Prosser, ٢٠٠٤

Borehole images can help!



Fracture density (fracture number per 100 feet) of common lithologies under same burial environment (Stearns & Freidman, 1972)

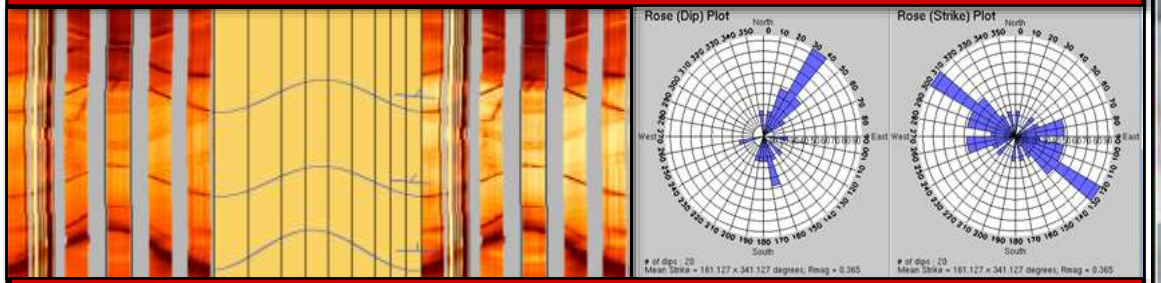


Fractured Carbonate Reservoir Characterization

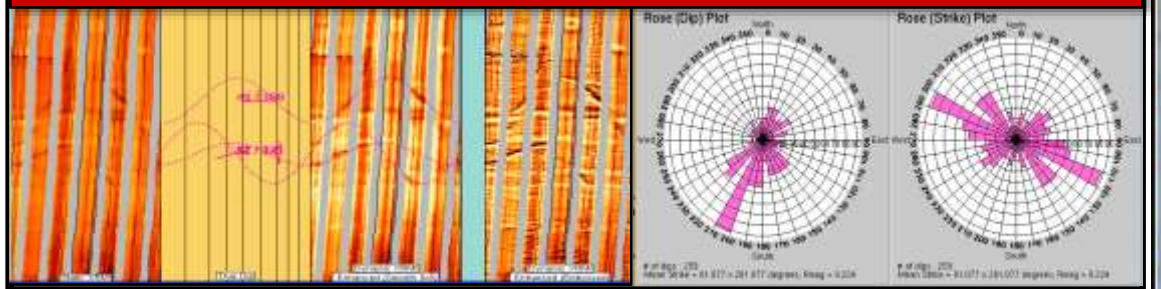
Fracture Identification and Characterization

Fracture Analysis (Natural Versus Induced)

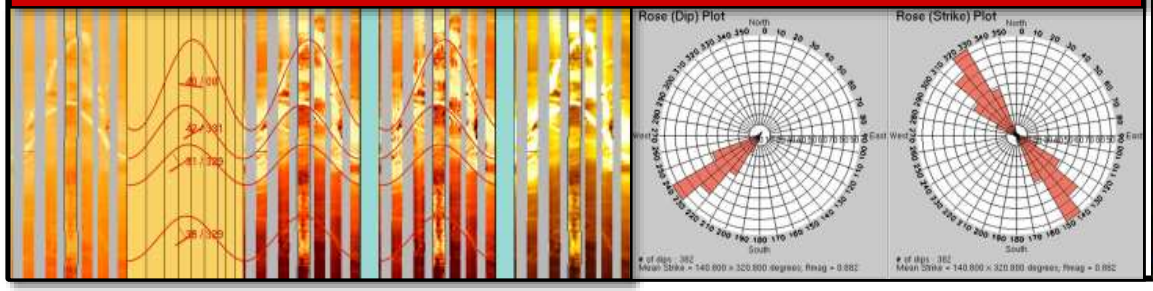
Conductive Fractures



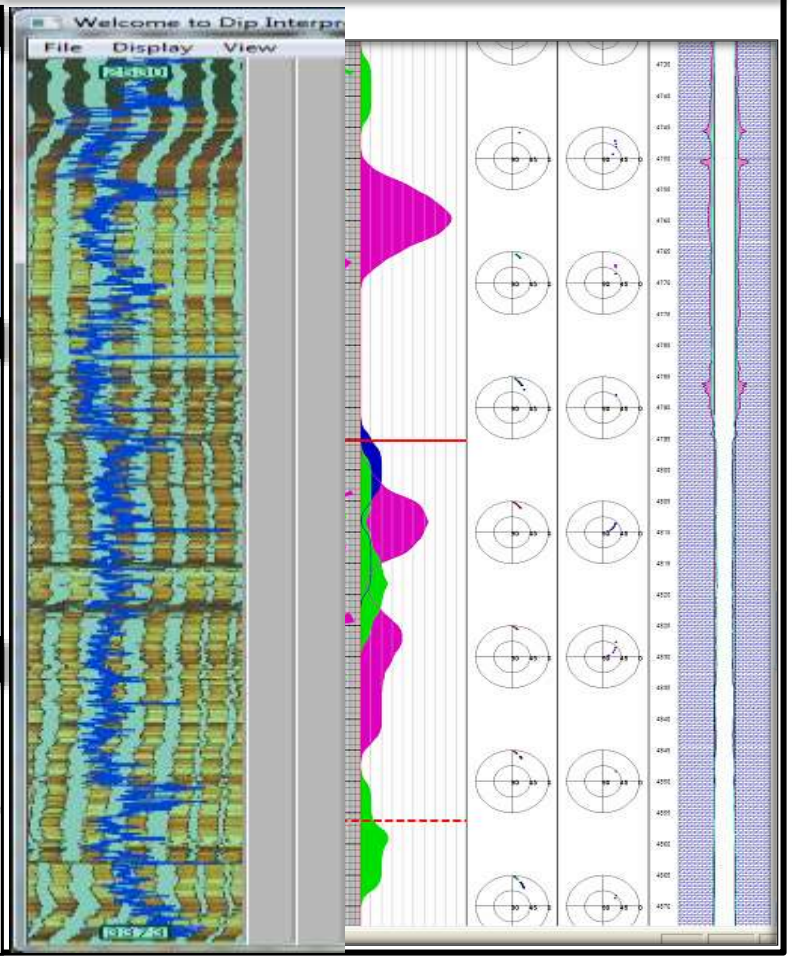
Semi-conductive Fractures



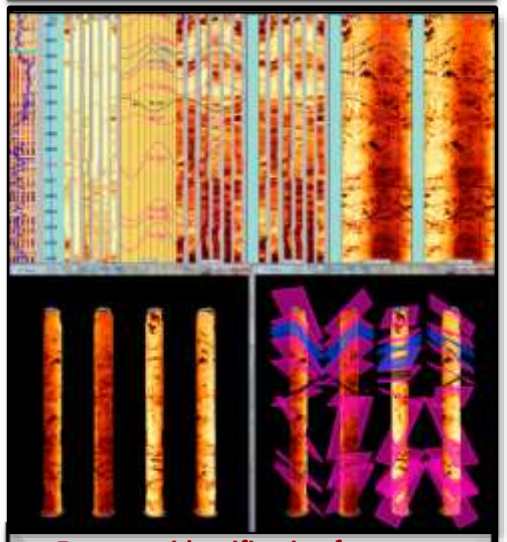
Resistive Fractures



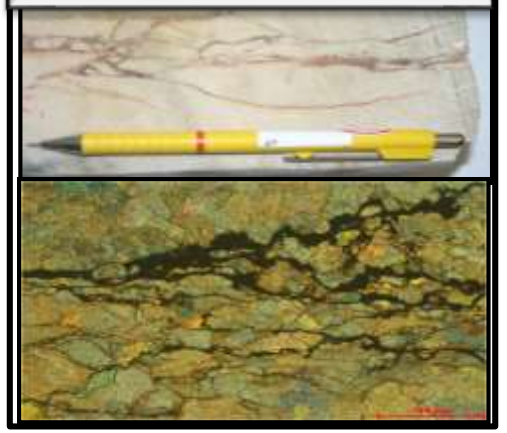
Fracture Distribution and Fracture Density



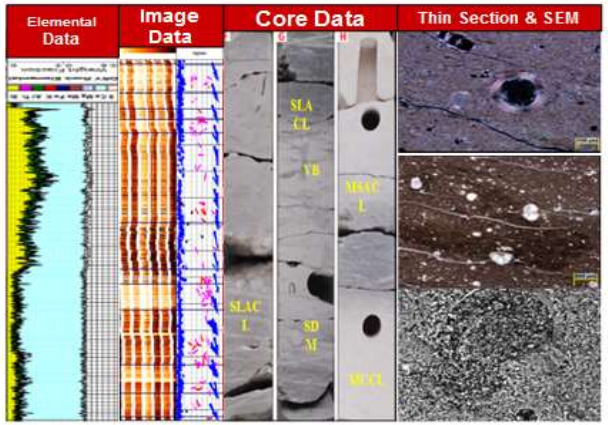
۳-D Fracture Visualization using Acoustic/Micro Resistivity Images

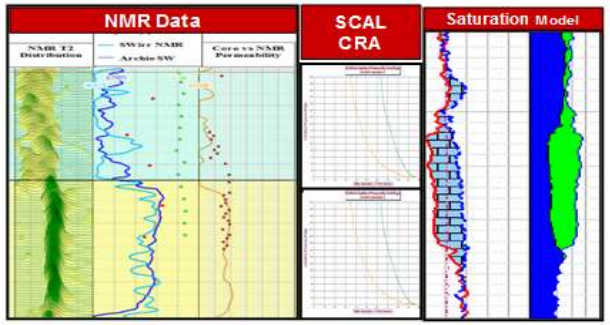


Fractures identification from core and thin section



Carbonate Reservoir Characterization

Evaluation	Data Preparation and Methodology	Results and KPI
Geological Interpretation		▪ Image data analysis versus core calibration ▪ Elemental data analysis versus core & XRD calibration. ▪ Thin section & petrography analysis.	▪ Depositional Fabric, fracture analysis and Diagenetic processes ▪ Mineralogical Analysis, and Quantified Clay typing. ▪ Pore system Identification & Classification

Petrophysical Evaluation		▪ Nuclear magnetic Resonance Analysis and core calibration
		▪ Hydrocarbon Saturation:
		  ▪ Archie parameter –Core
		  ▪ Capillary pressure Interpretation
			▪ Porosity and Permeability Relationship
			▪ Fluid Typing and distinguish moveable from immovable water
			▪ Hydrocarbon saturation

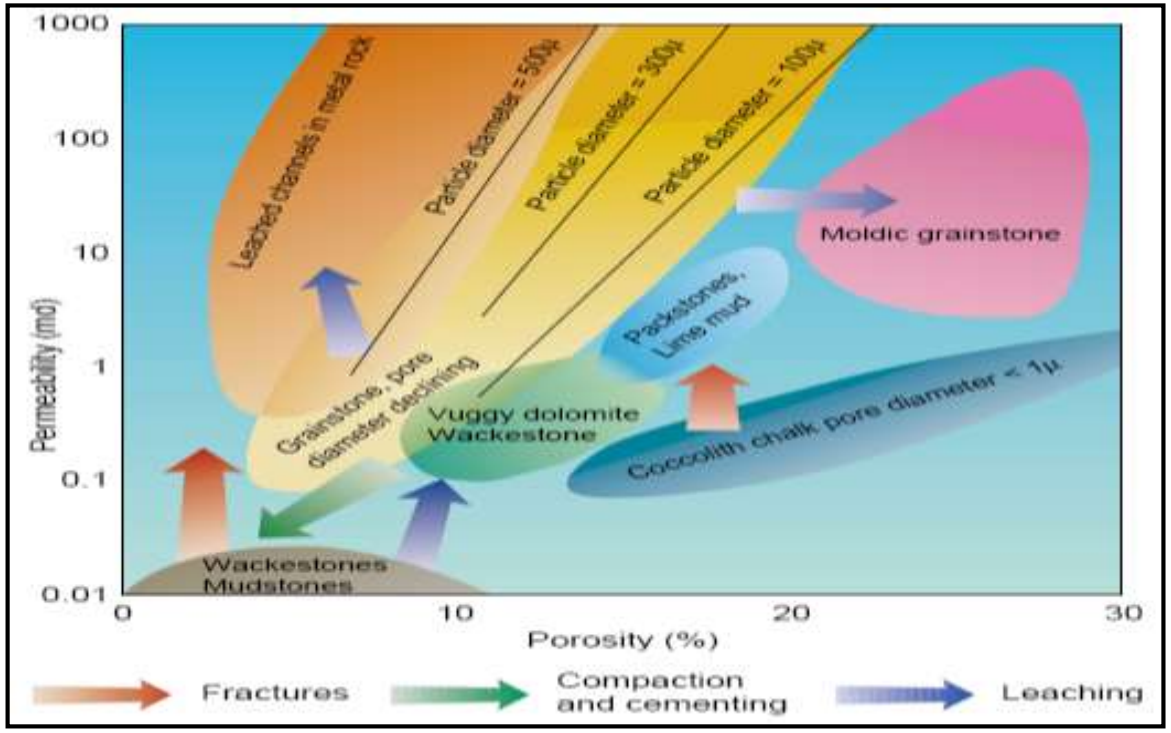
Production Assessment		▪ Perforation production Data. ▪ Hydraulic fracturing Job Design (Stationary points, spacing, etc.)	▪ Optimum Production performance

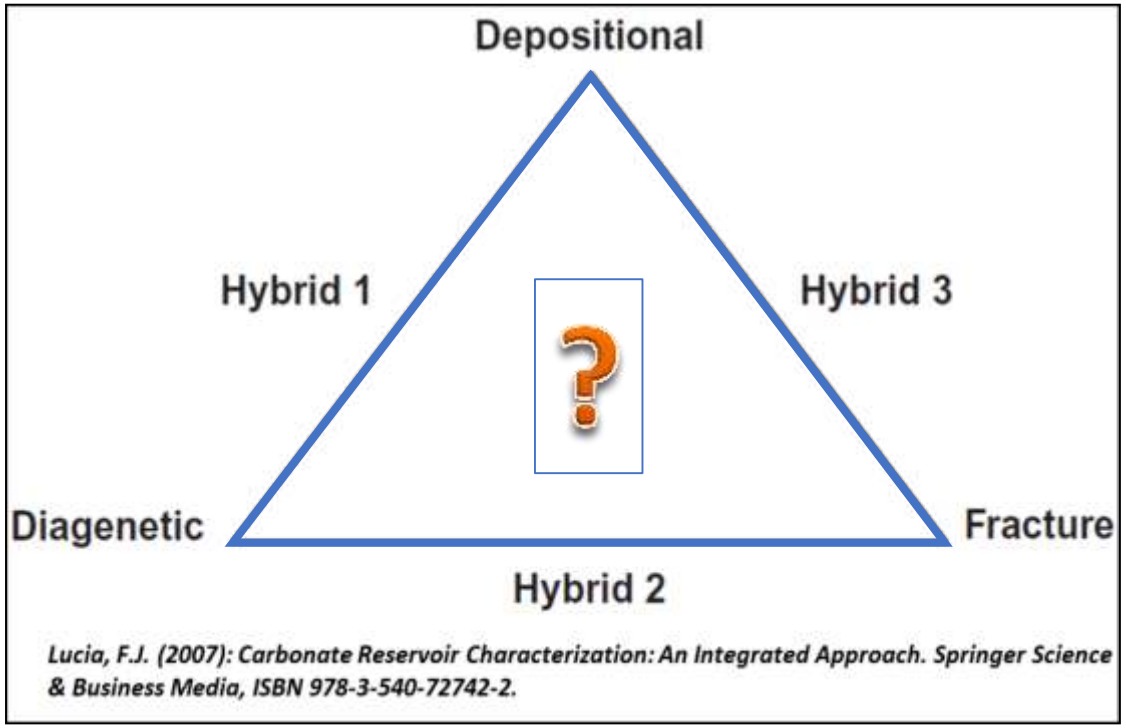
Workflow and Results to Identify the Critical Success Factors Controlling the Development of Carbonates Reservoirs

Carbonate Reservoir Challenges

Carbonate Reservoir Classification (Reservoir Property Controlling factors)

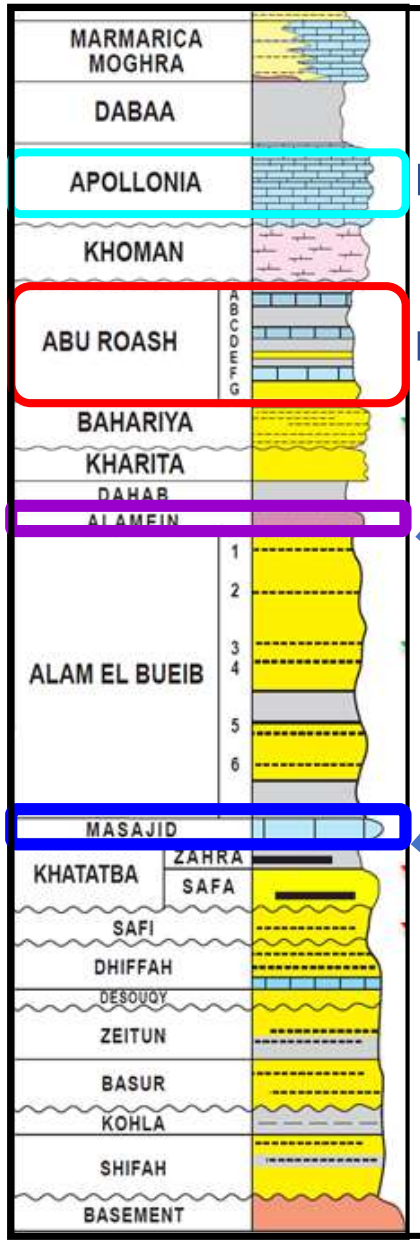
- **Identification of the main influencing process (*depositional*, *fracturing* and/or *diagenetic*) is essentially controlling the reservoir properties.**
- **Carbonate Porosity & Permeability are defined upon the contribution degree of the *depositional* versus *post depositional processes*.**





Lucia, F.J. (2007): Carbonate Reservoir Characterization: An Integrated Approach. Springer Science & Business Media, ISBN 978-3-540-72742-2.

Main Carbonate Reservoirs, North Western Desert

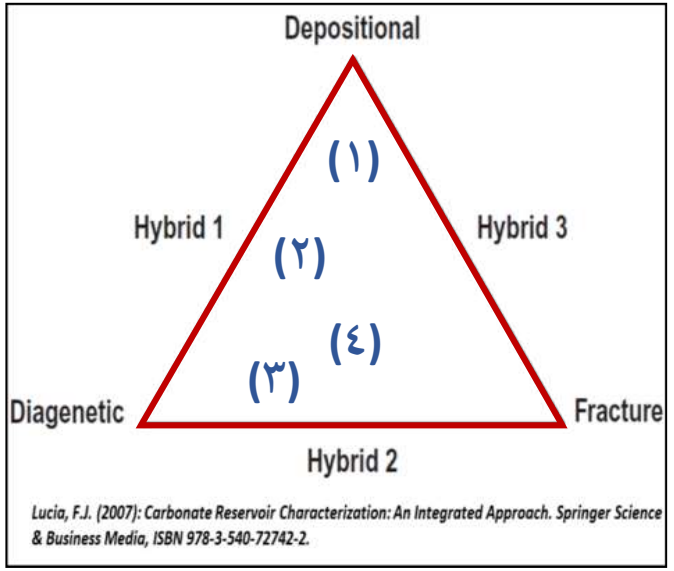


"Apollonia" **(١)**

- *Shallow seated relatively homogeneous reservoir*
- *It is mainly depositional reservoir*
- *There is a minor diagenetic imprint on the depositional fabric and some fractures*

"A/R B, D, F & G" **(٢)**

- *Relatively shallow seated heterogeneous reservoir.*
- *Depositional/diagenetic reservoir with slight influence of fracturing*
- *Preserves its depositional rock fabric with extended diagenetic processes i.e. dolomitization*



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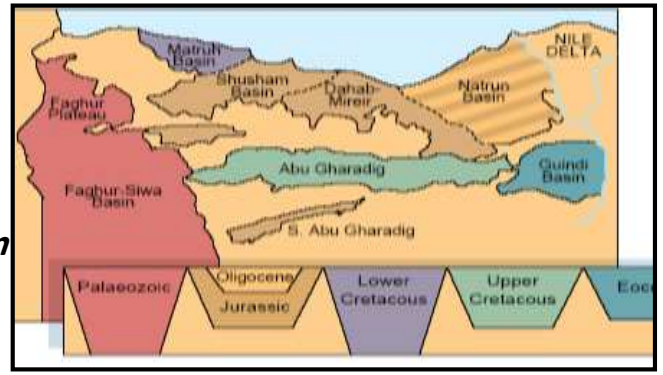
"Alamein Dolomite" **(٣)**

- *Deep seated highly heterogeneous reservoir.*
- *Diagenetic/fractured that still preserves original depositional rock fabric in some parts.*
- *Highly influenced by post-depositional processes especially; dolomitization, dissolution, cementation and fracturing*

"Masajid" **(٤)**

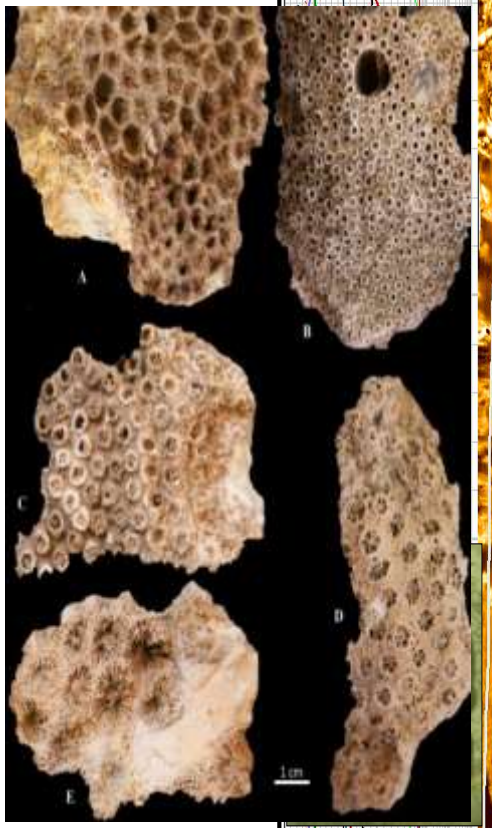
- *Deep seated highly heterogeneous reservoir*
- *Fractured/diagenetic reservoir with some of the original rock fabric*
- *Highly influenced by post-depositional processes especially; multi phases of dolomitization, dissolution, cementation, compaction & fracturing*

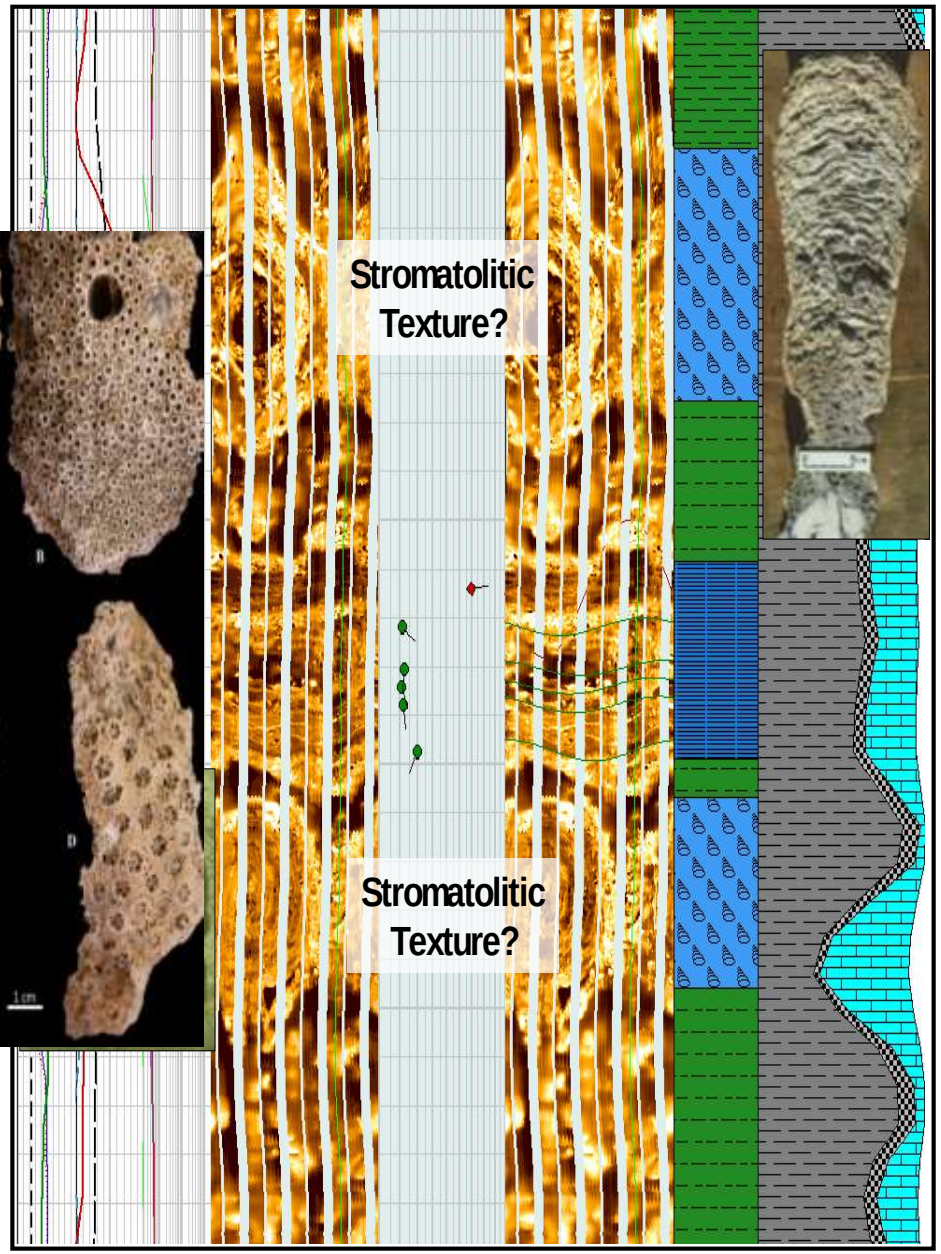


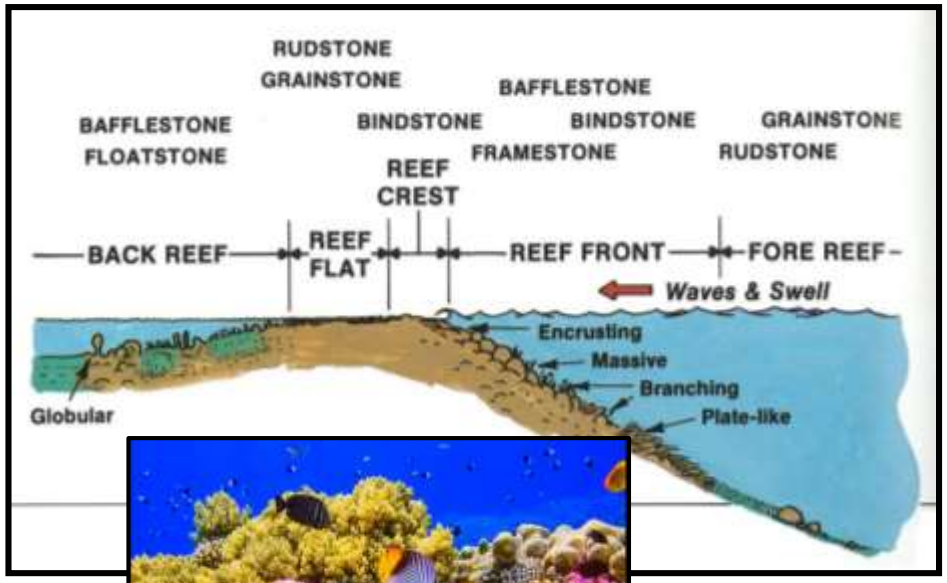
The Different Stratigraphic units in the Gulf of Suez Oil Province & their Depositional Environments

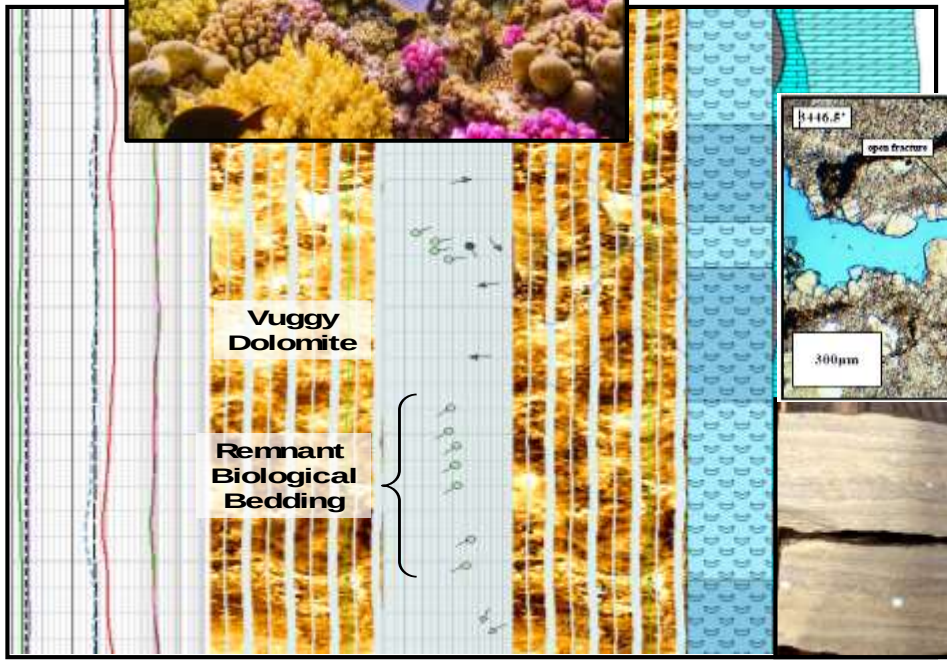
AGE		LITHOLOGY	ROCK UNITS		DEPOSITIONAL ENVIRONMENT
PLEISTOCENE			ZAFARANA FM		Lagoonal-Continental
			WARDAN FM		
MIOCENE	MIDDLE - LATE		RAS MALAAB GROUB	ZEIT FM	Lagoonal
				SOUTH GHARIB FM	Lagoonal-Shallow Marine
				BELAYIM FM: H.FARAUN Mbr	Lagoonal-Shallow Marine
				BELAYIM FM: FEIRAN Mbr	
				BELAYIM FM: SIDRI Mbr	
				BELAYIM FM: BABA Mbr	
				AYUN MOUSA FM: RAS BADRAH Mbr	Open Marine
				AYUN MOUSA FM: LAGIA Mbr	Shallow Marine Lagoonal
	EARLY - MIDDLE		GHARANDAL GROUB	RUDEIS FM: ASL FM	Open-Shallow Marine
				RUDEIS FM: HAWARA FM	Open Marine
				RUDEIS FM: MHEIHERRAT FM	Open Marine
				NUKHUL FM	Shallow Marine Lagoonal
OLIGOCENE			ABU ZENIMA FM		
EOCENE	LATE		TANKA FM		
	MIDDLE		MOKATTAM FM		Open Marine
	EARLY		THEBES FM		Open Marine
PALEOCENE			ESNA SHALE FM		Open Marine
CERTACEOUS	LATE		SUDR FM		
			MATULLA FM		Shallow Marine
			WATA FM		
			ABU QADA FM		Open Marine
			RAHA FM		Shallow Marine
	EARLY		NUBIA (A)		Alluvial to Shallow Marine
JURASSIC					
CARBONIFEROUS			NUBIA (B)		
DEVONIAN			NUBIA (C)		
PRE-CAMBRIAN			BASEMENT		

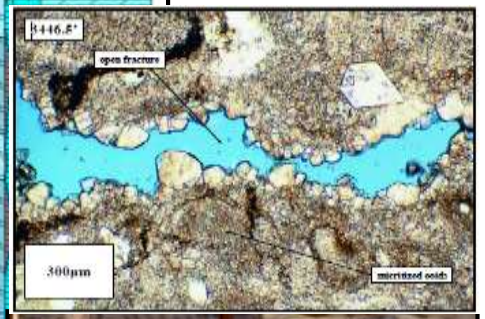
Miocene Reefal Facies (Hammam Faraun Member)



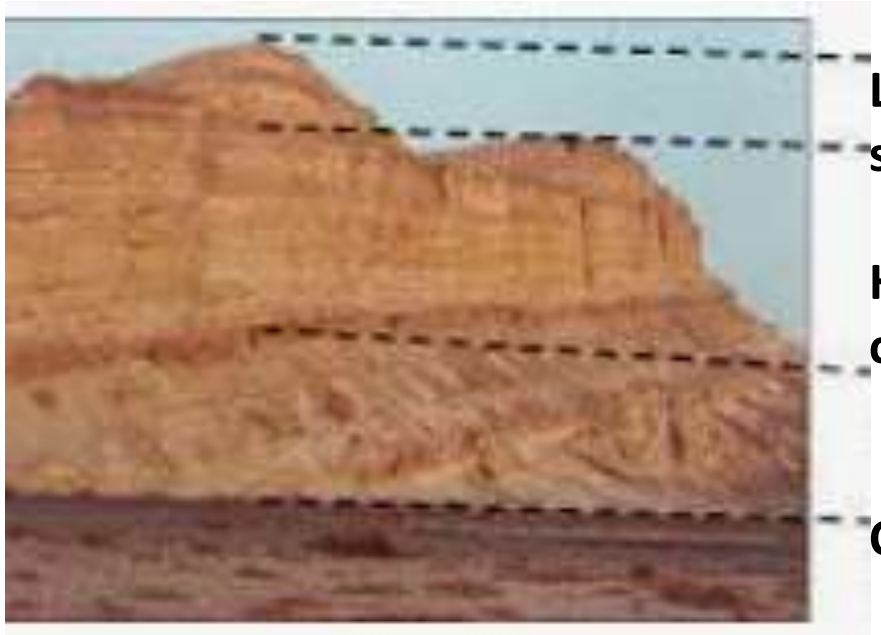








Eocene Carbonate Reservoirs



Low quality reservoir

Limestone and shale interbeds with some chert nodules

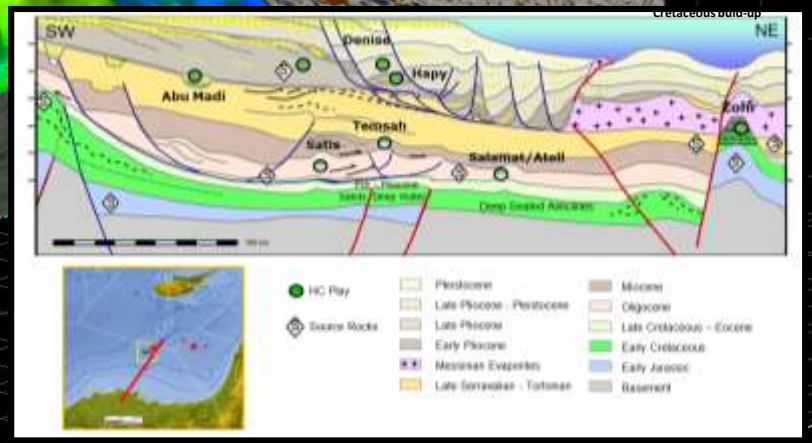
Hard thinly bedded limestone with chert bands and concretions

Chalky limestone & marl with chert

High quality reservoir

Zohr Discovery

- Outstanding biogenic gas accumulation (٣٠ TCF of GOIP) in the Cretaceous carbonate platform complex. Gas area is expected to cover about ١٠٠٠km٢
- World class depositional carbonate reservoir with excellent petrophysics especially in the reefal facies
- ٦٢٤ m of continuous HC pay hydraulically connected
- Innovative ”Play” not recognized in previous exploration campaigns in Egypt



Concluding Remarks …..

- The presence of unconformity in the topmost part of any carbonate reservoir is significant where, the variations in the preserved thickness are largely a function of the severity of erosion. Also, it controls to a great extent the degree of dissolution and dolomitization of the underlying carbonate reservoirs.

- The non- fabric selective pores are the most common and efficient types controlling most of the carbonate reservoirs. Karstification, dissolution vugs, fracturing and early dolomitization contribute much to enhance porosity of the carbonate reservoirs.

- On the other hand, several diagenetic processes reduce porosity and damage the reservoir quality such as compaction as well as cementation and the late dolomitization phases.

- Fractures slightly improve the porosity, but they are an essential element for secondary enhancement of permeability.

In Summary…

- Carbonates reservoirs are worthy investigated and developed through building good technical experience, integrate multi-disciplinary data-set at different scales and develop solid workflow matches each different carbonate reservoir type.

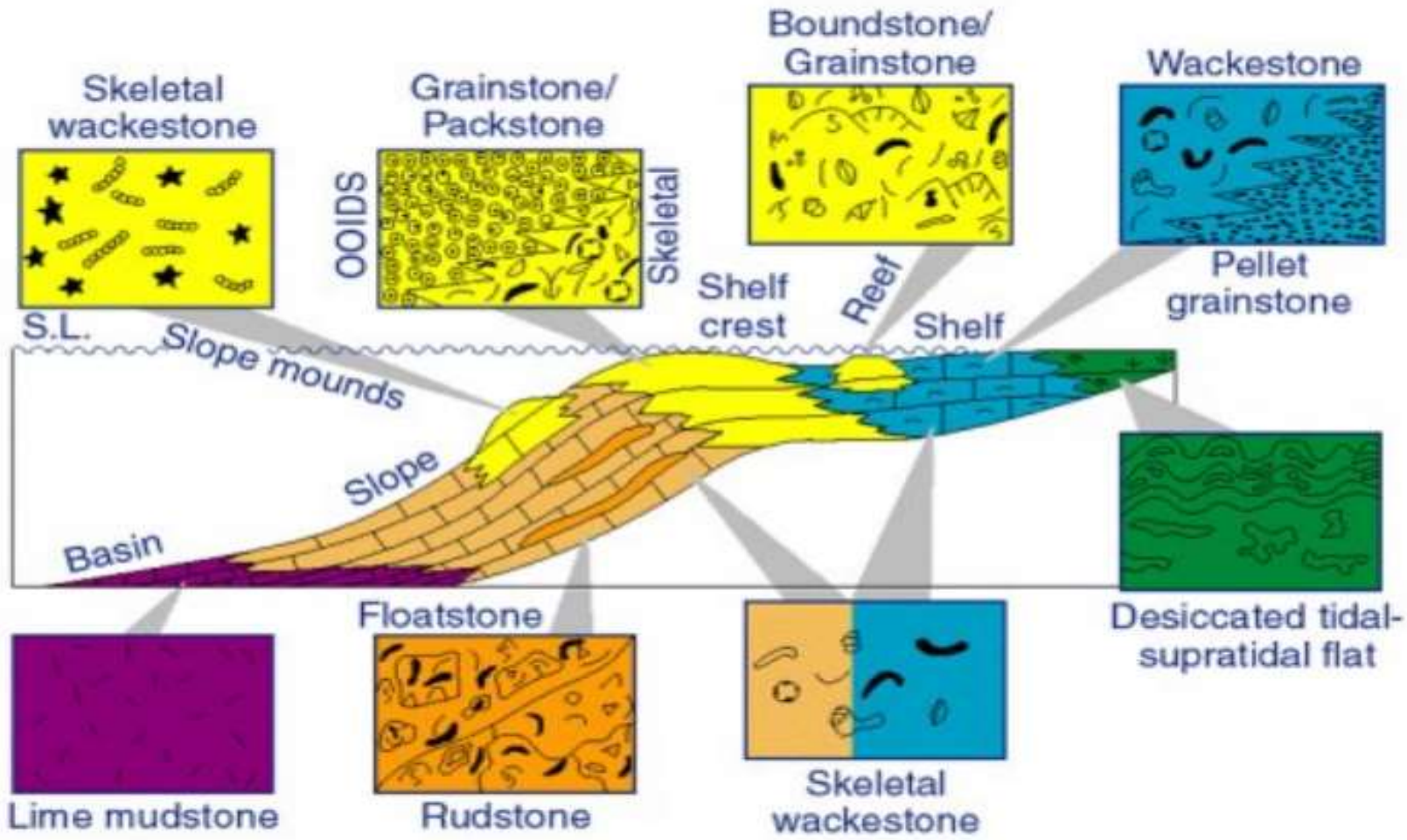
- Characterizing carbonate reservoirs presents a distinctive challenge, it is a multidisciplinary approach particularly when fully integrated using borehole logs, resistivity and acuostic images with core, petrographic, SEM, biostratigraphic data etc.

- Correlation based mainly on cores, resistivity image sedimentological facies analysis and their petrophysical characteristics is an approach for high resolution reservoir anatomy to clarify the lateral facies changes and consequently to solve many problems related to the reservoir geometry and shed light on reservoir connectivity
- The presence of double poro-perm system (Low-Perm. Matrix vs Fractures/Vugs) results in low recovery.

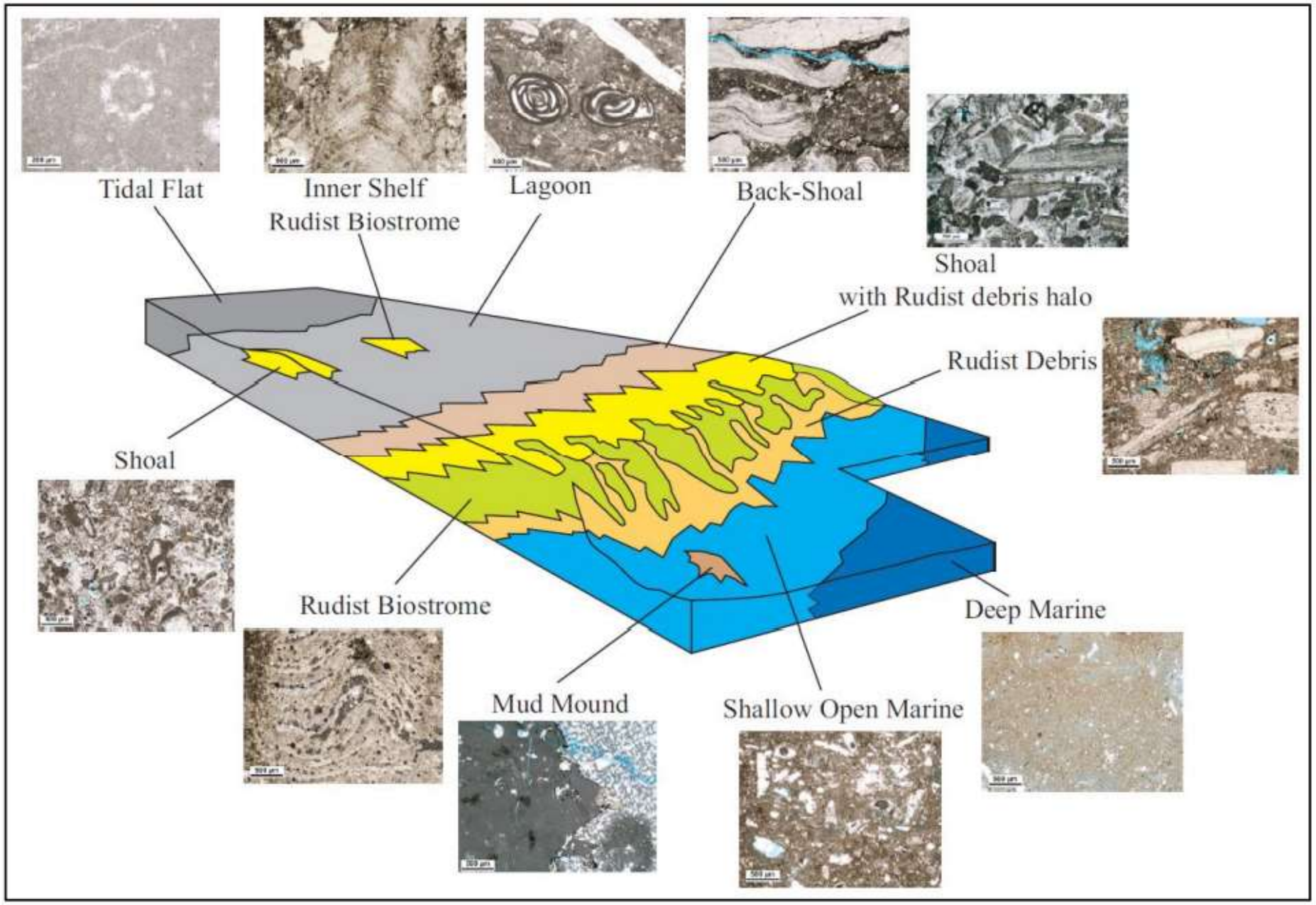
- Appropriate applied reservoir stimulation techniques require integrated studies by geologists and engineers to achieve the production optimization goal.

Mohsen Abdel Fattah

Carbonate Facies Belts with Textural Styles



Carbonate Facies within the different environmental settings



Carbonate Reservoir Characterization Challenges

- Original rock fabric/pore-system is generally altered by post depositional process (Diagenesis and fracturing).
- Heterogeneity in carbonates can include variable; chemistry, mineralogy, pore types, pore connectivity and sedimentary facies.
- Carbonate reservoirs can not be characterized by traditional Methodologies
  - Extensive core work is required.
  - Advanced logging are required for calibration and correlation; BHI, NMR, WSTT, etc.

Gigascopic	Megascopic	Macroscopic	Microscopic