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SPE-207508-MS
Reservoir Quality Of The Miocene Formation Gas Deposits, Onshore Abu Dhabi

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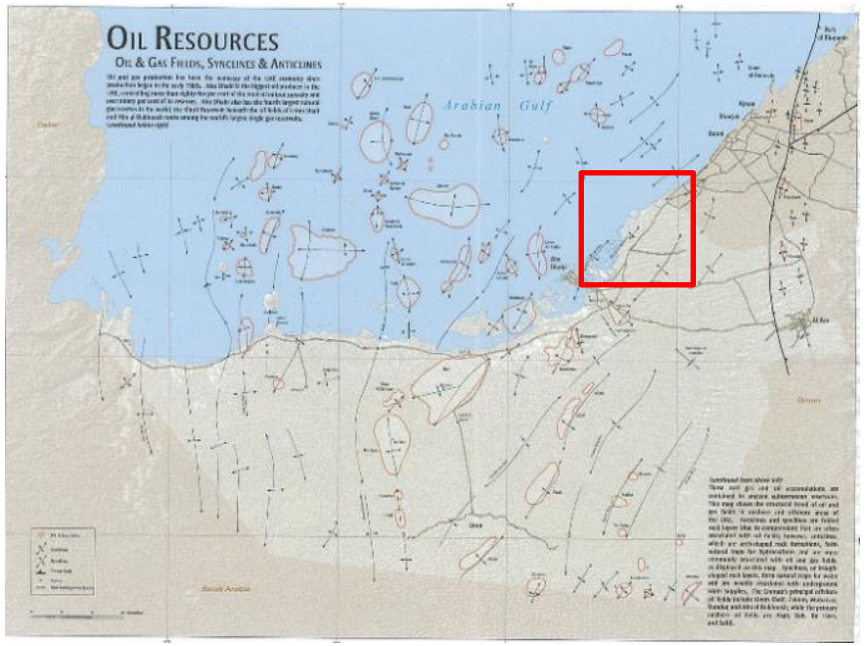
Geological Background

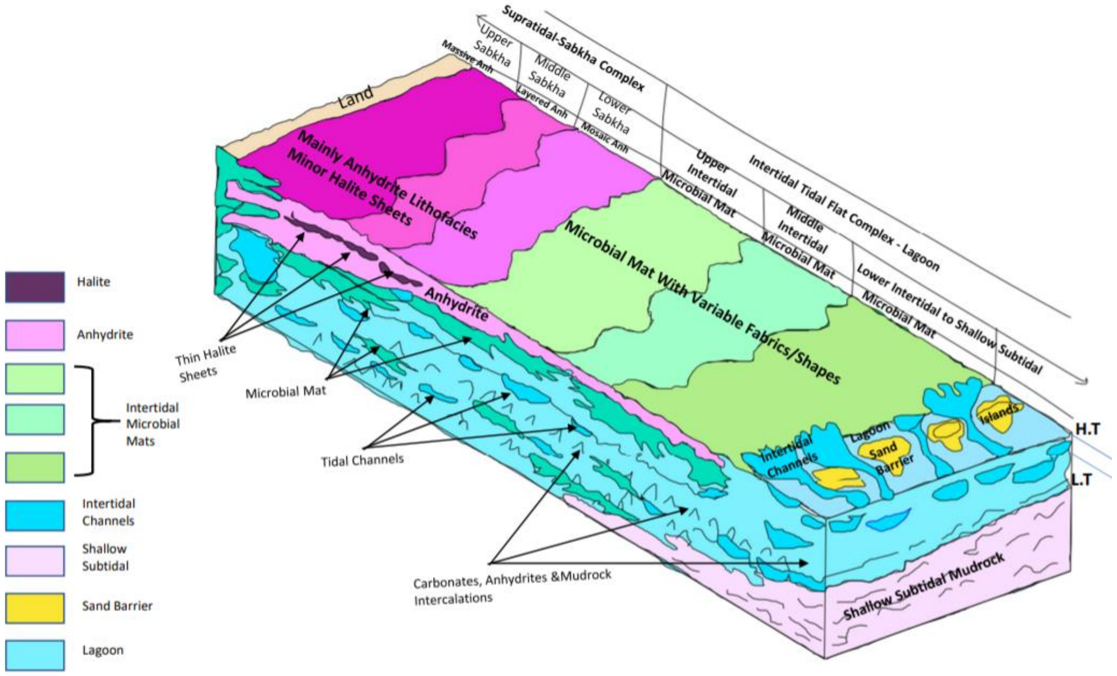
Study Location



The Middle Miocene Anhydrite Formations, in Onshore Abu Dhabi, were deposited in the foreland basin bounded by the forebulge high related to the Omani's thrust-belt.

These sediments resemble the Holocene sediments of the coastal Abu Dhabi of the United Arab Emirates in the southeastern Arabian Gulf.

Depositional Model



Previous reports indicate the Carbonate ramp displays classic example of supratidal to intertidal, tidal channels, lagoonal, tidal barrier and shallow subtidal facies belts comprising;

The intertidal domain includes the organic-rich and the microbial mat lithofacies.

Study Aims

ADNOC targeted 9 wells in the study area in order to investigate the sedimentology and reservoir potential of the Anhydrite Layers of the Middle Miocene Formation.

This study was commissioned to:

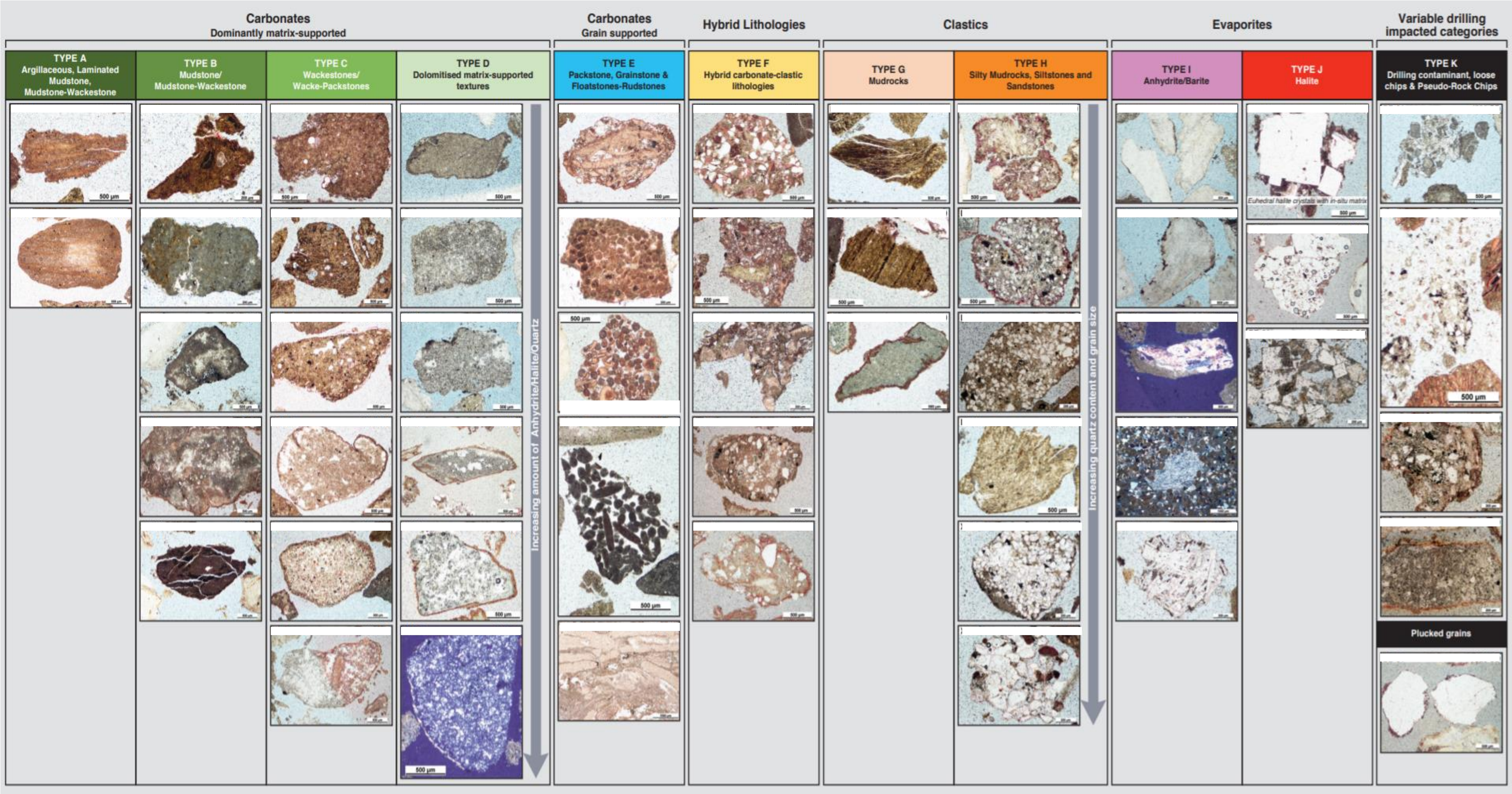
- Refine the sequence stratigraphic framework across the well dataset
- Evaluate the reservoir quality distribution and controls specifically within the identified key reservoirs Anh-1, Anh-2, Anh-3, Anh-4 and Anh-6.

Presentation Agenda

- Petrographic analysis of cuttings samples.
- Depositional framework for the Middle Miocene anhydrite intervals.
- Stratigraphic architecture.
- Diagenetic overprint.
- Controls on reservoir quality within the anhydrite intervals.

Thin Section Analysis and Depositional Framework

Thin Section Sedimentology; Rock Atlas



Cuttings samples were separated into classes based on lithology and texture

Five main groups have been identified;

Carbonates, including argillaceous to non-argillaceous matrix-supported, grain-supported and dolomitised facies

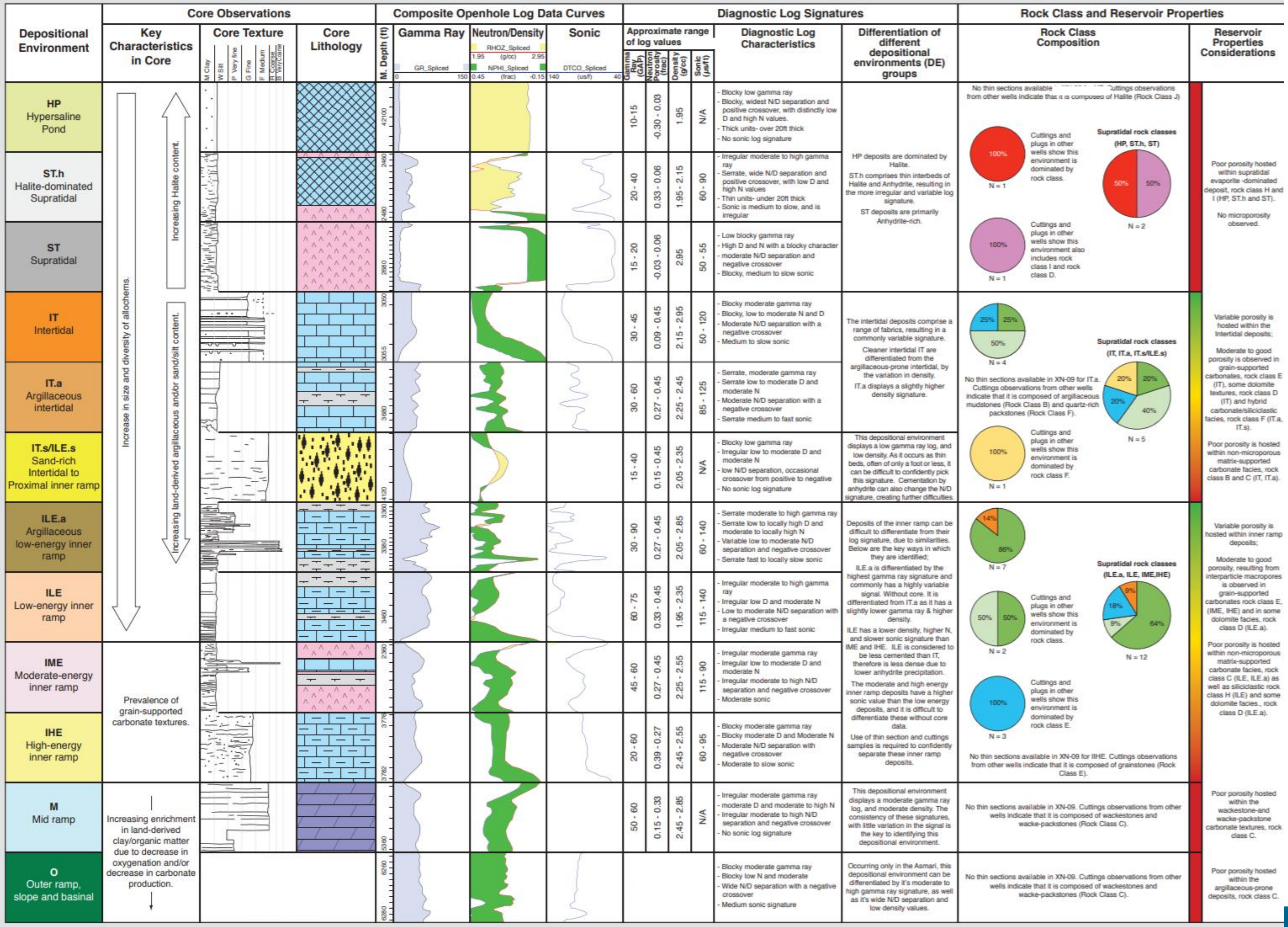
Hybrid lithologies of mixed carbonate/siliciclastic facies

Clastics, including mudrocks, siltstones and silty sandstones

Evaporites; Halite and Anhydrite

Drilling impacted samples; loose grains, drilling contaminant and pseudo rock chips

Depositional Environment Characterisation



Using two key cored wells, the log signature of the DEs has been characterised as tool for the interpretation of the other uncored wells.

Integrates;

- Key characteristics in core
- Core texture
- Core lithology
- Gamma ray, N/D and Sonic
- Diagnostic log characteristics
- Rock class compositions
- Reservoir Properties considerations

Depositional Environments (DEs)

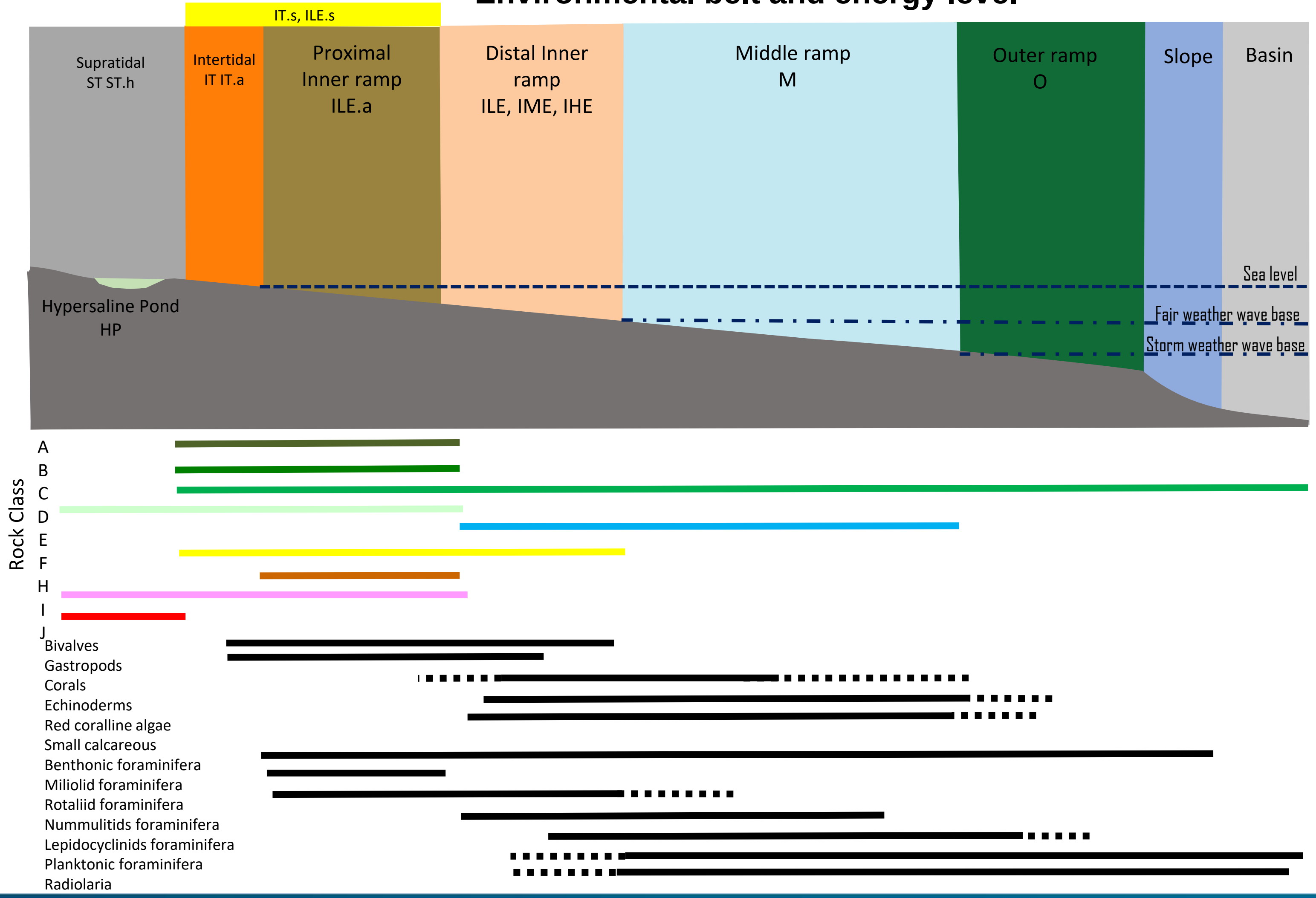
This data integrates existing core sedimentology and thin-section analysis to characterise these DEs and to provide a basic understanding of the reservoir quality from the observed rock class compositions

	Gross depositional setting	Dominant energy level / hydrodynamism		Environment	Code
CONTINENTAL	SUPRATIDAL	Variable		Supratidal	ST
				Hypersaline Pond	HP
INTERTIDAL	INNER / PROXIMAL (including lagoons where a barrier exists, *ie.* in shelf and platform models)	Variable, but typically rather low		Intertidal	IT
SUBTIDAL		Above Fair Weather Wave Base (FWWB)	Low to moderate	Low to moderate-energy inner ramp or inner shelf, inner platform or lagoon	ILE
			Moderate	Moderate -energy inner ramp or outer shelf, inner platform or lagoon	IME
			High	High-energy inner ramp or rim or shelf/platform margin	IHE
	MIDDLE / INTERMEDIATE	Between FWWB and SWWB	Low to moderate	Mid-ramp or ramp/shelf/platform slope/talus	M
	OUTER / DISTAL	Below Storm Weather Wave Base (SWWB)	Very low	Outer ramp or basin	O

Qualifier (shaliness, allochem and/or fabric)

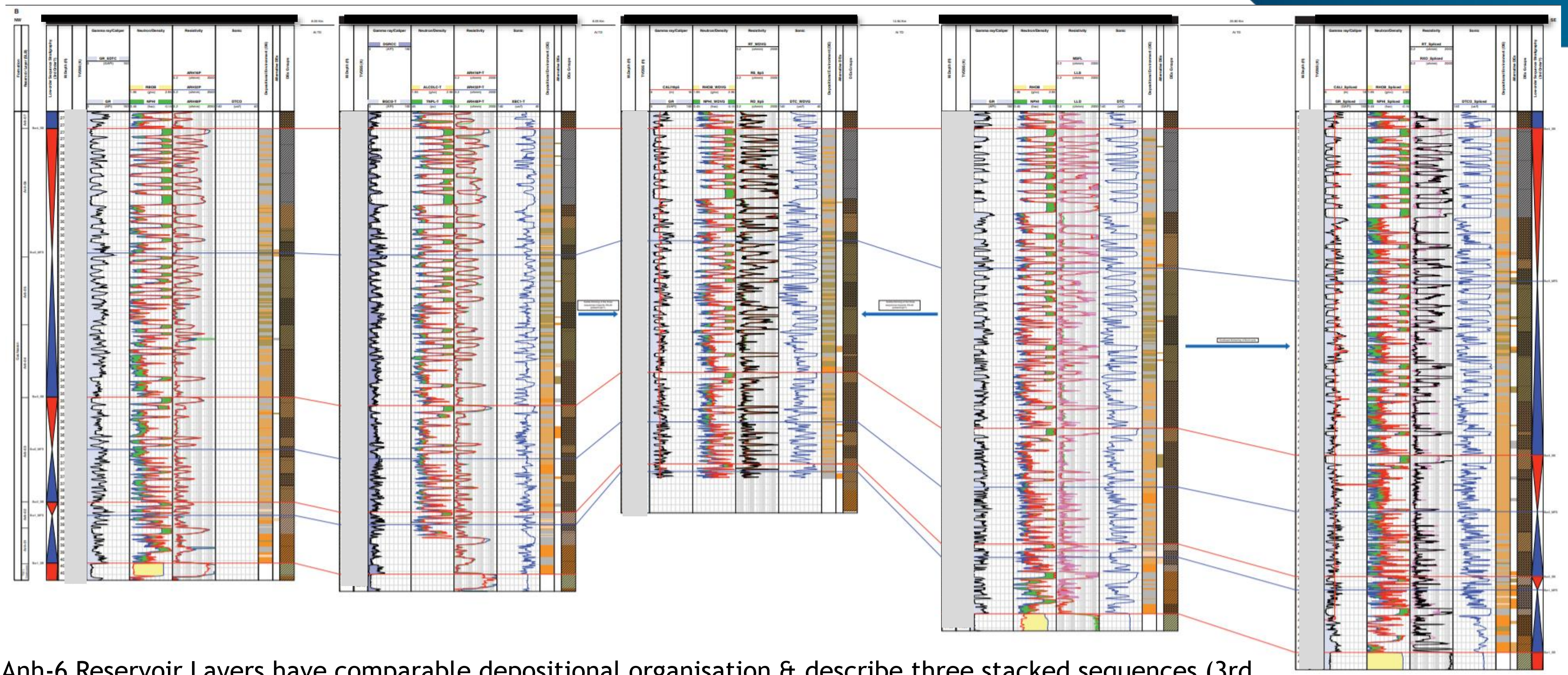
Qualifiers, after the LA code and separated it with a full stop. Maximum of two qualifiers per LA (organised as for the lithofacies scheme); two qualifiers are separated with a full stop	
a	Argillaceous-prone/rich
s	Quartz-rich
h	Halite-rich

Environmental belt and energy level



Stratigraphic Architecture: Correlations

Anhydrite Layers| NW-SE *Correlation Panel*



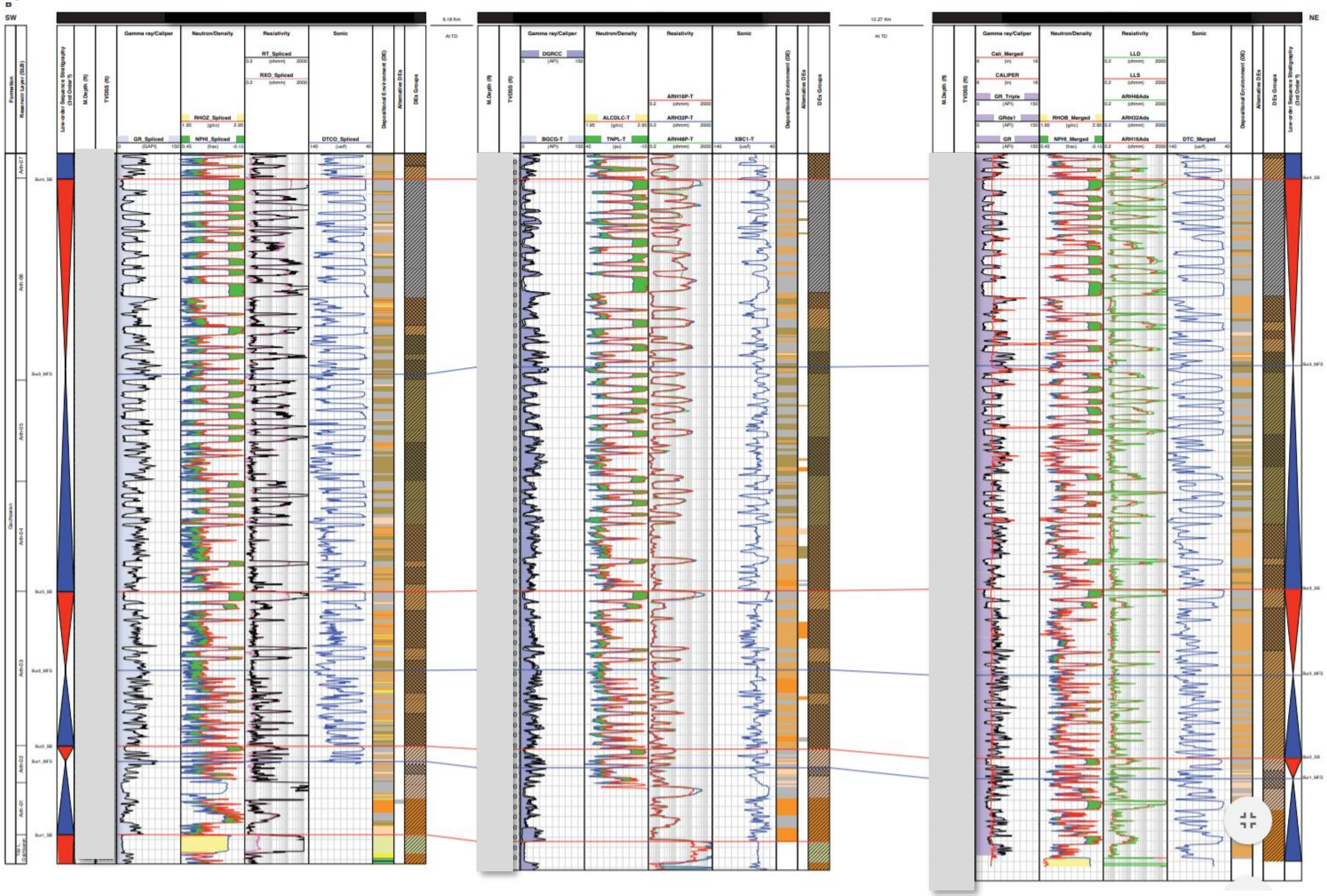
Anh-1 to Anh-6 Reservoir Layers have comparable depositional organisation & describe three stacked sequences (3rd order?): Bur1, Bur2 and Bur3 in ascending order.

Bur1 and Bur2 are characterised by an upward transition from intertidal-dominated deposits to low-energy inner ramp-dominated sedimentation and display reasonably consistent thickness across the area.
Bur3 deposits imply an initial upward deepening from argillaceous intertidal-dominated (IT.a) to argillaceous subtidal-dominated (ILE.a) setting, followed by an upward shallowing into intertidal (IT) and supratidal sabkha-dominated (ST) environment.

Anhydrite Layers| SW-NE *Correlation Panel*

SW

NE

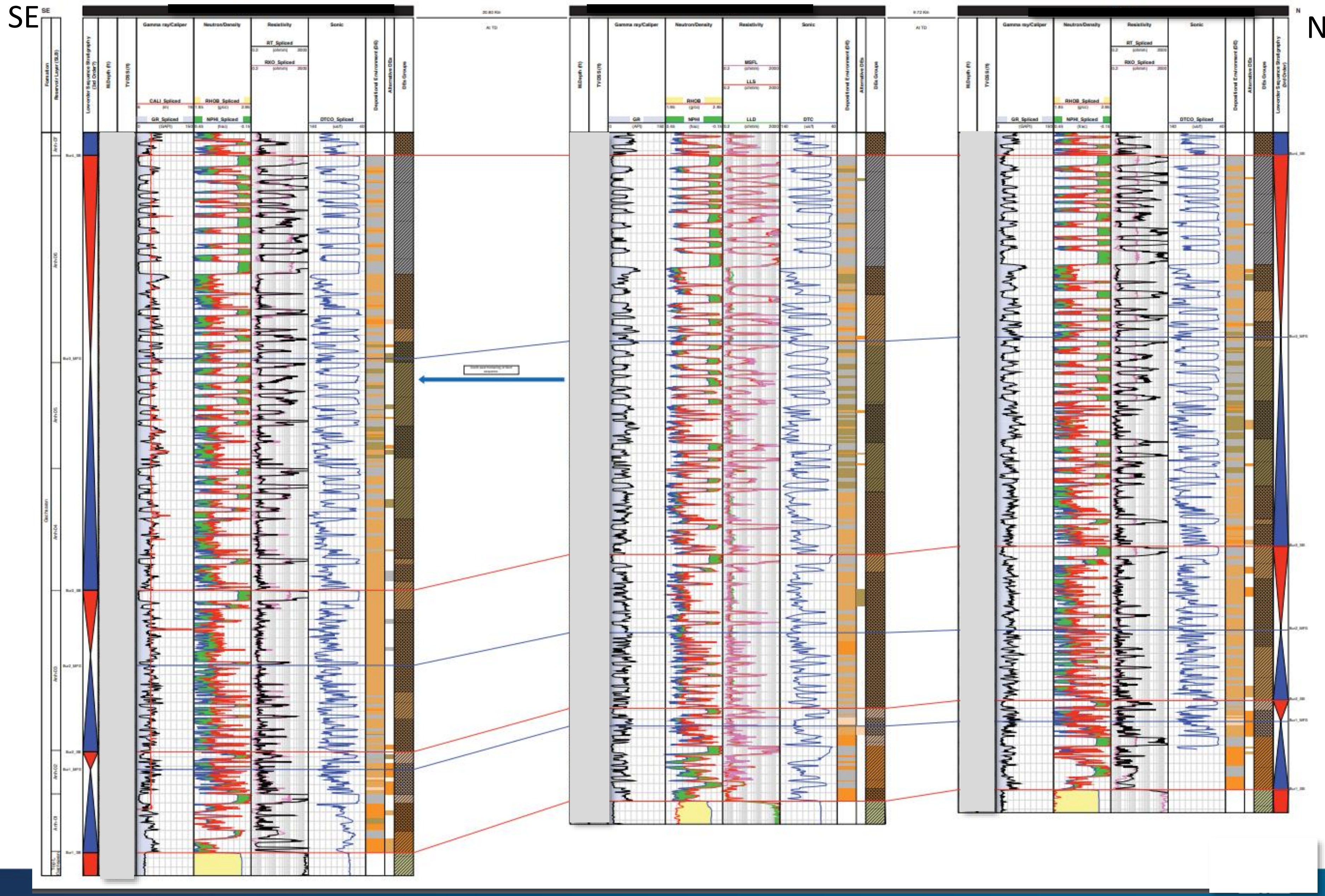


The Anh-1 to Anh-6 Reservoir Layers describe three possible 3rd order sequences, interpreted to correspond to Bur1, Bur2 and Bur3.

The overall thickness and vertical organisation of these cycles is consistent across the correlated wells, with intertidal-dominated deposits (IT) evolving upward into variably argillaceous subtidal-dominated sediments (ILE, ILE.a).

Above Bur3_MFS a return to shallower intertidal (IT.a) and supratidal-dominated (ST) conditions is noted.

Anhydrite Layers| SE-N ***Correlation Panel***

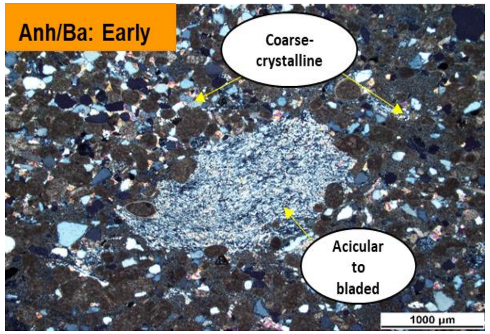


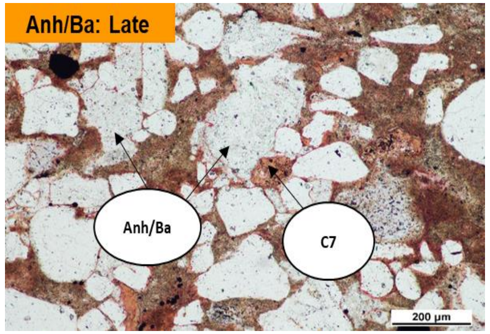
Anh-1 to Anh-6 Reservoir Layers describe three low-order (3rd?) sequences comprising Bur1, Bur2 and Bur3.

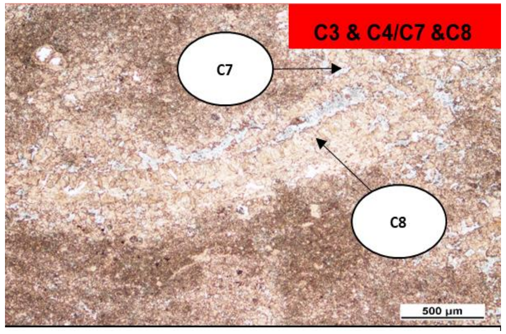
Their thickness and vertical evolution is comparable across transect 3, with only a subtle thickening of Bur3 noted towards the south-east of the area of interest.

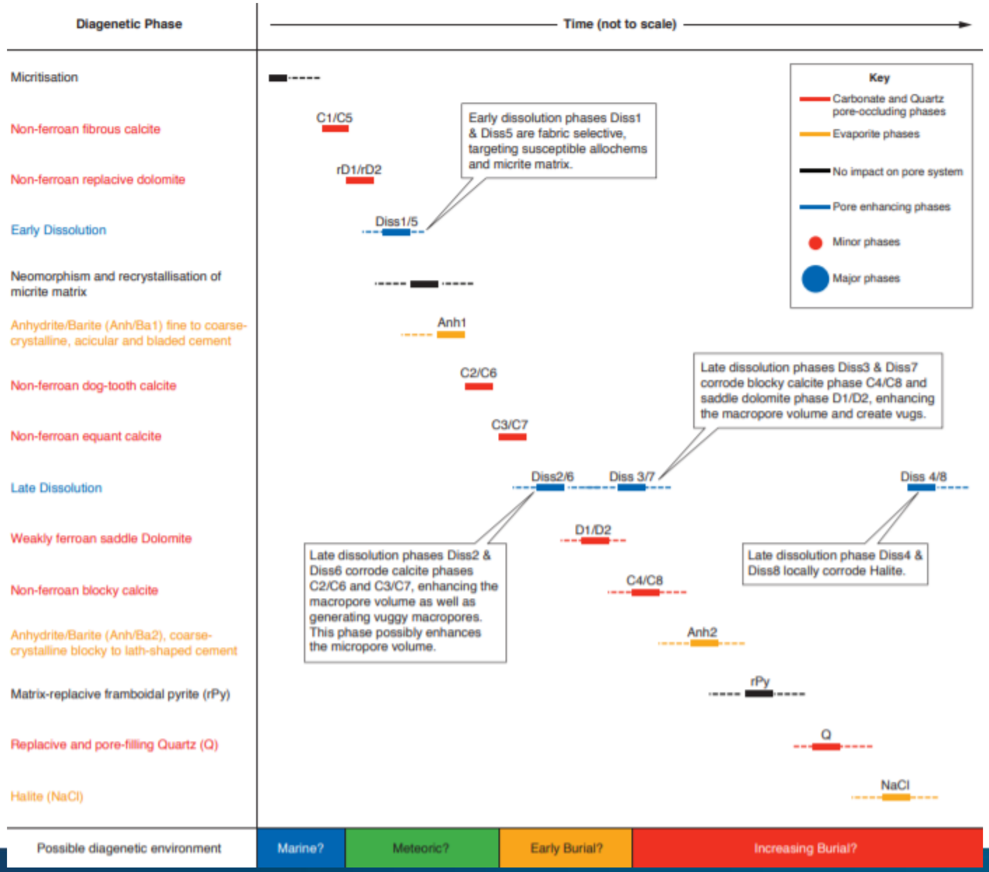
Diagenetic Overprint and Reservoir Quality

Key pore occluding phases







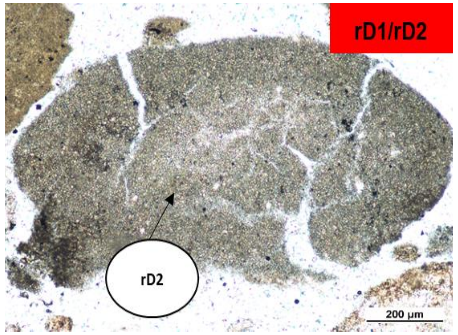


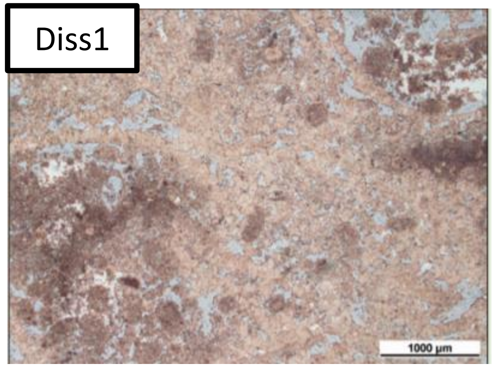
Key phases which negatively impact the pore systems in the Miocene anhydrite intervals have been identified.

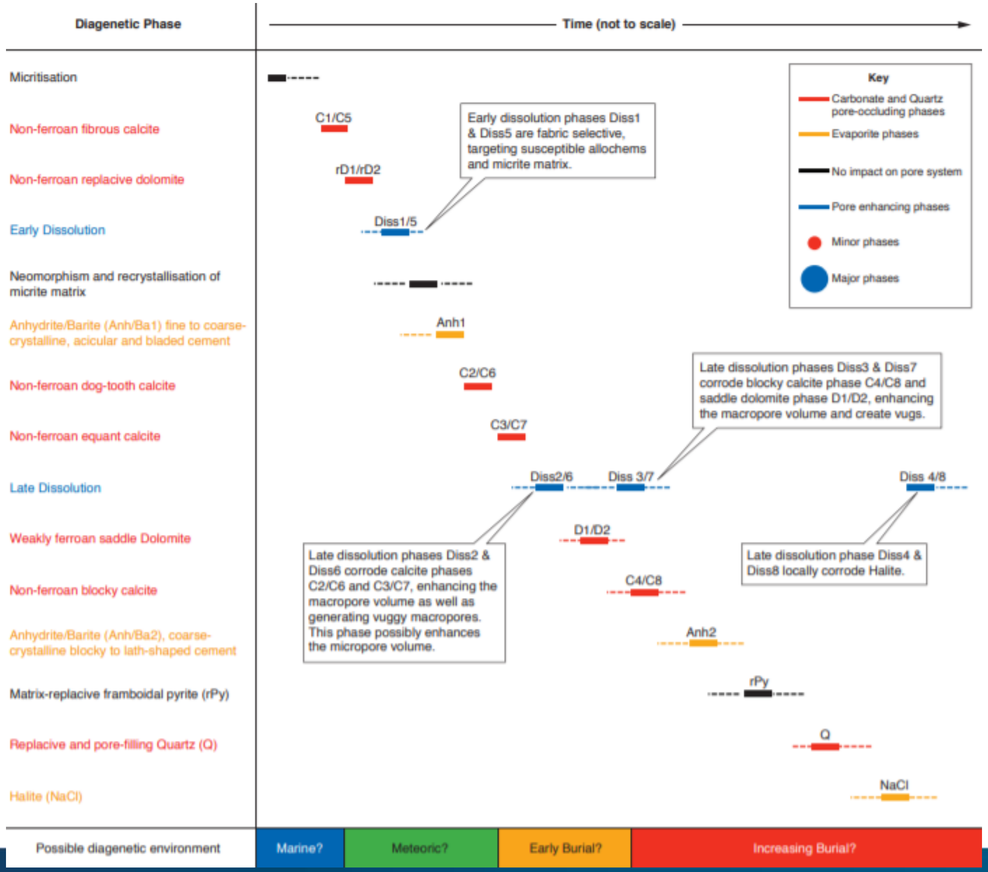
These include;

- Early and late pore-occluding anhydrite cement phases. These two phases are differentiated by their crystal morphology. Early = acicular to bladed. Late = blocky
- Equant calcite cement phases line and occlude macropores
- Early phase of dolomite variably replaces carbonate textures

Key pore enhancing phases





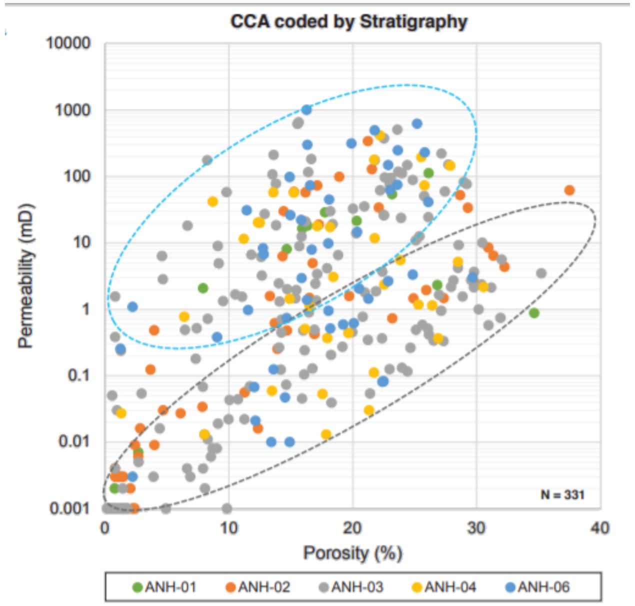


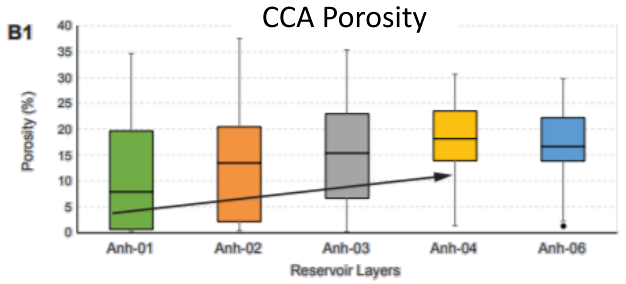
Key phases which positively impact the pore systems in the Miocene anhydrite intervals have been identified.

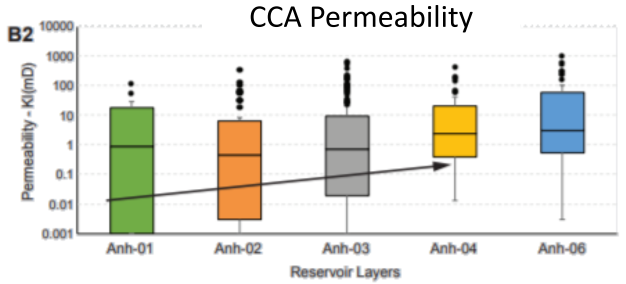
These include;

- Early phase of dolomite variably replaces carbonate textures
- Early phase of dissolution (Diss1/Diss5) forms secondary interparticle macropores, vugs and possibly enhances the micropore volume

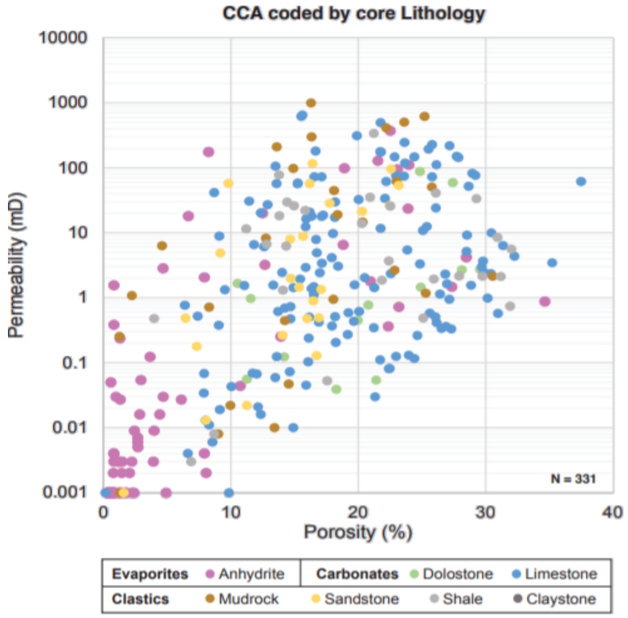
Anhydrite Layers Reservoir Characteristics

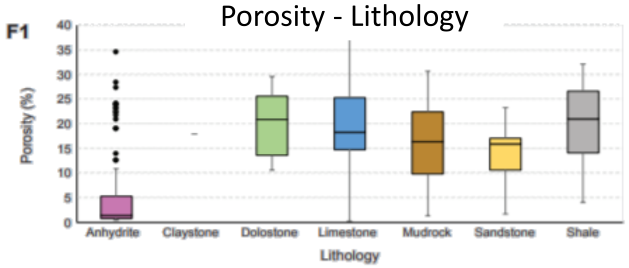


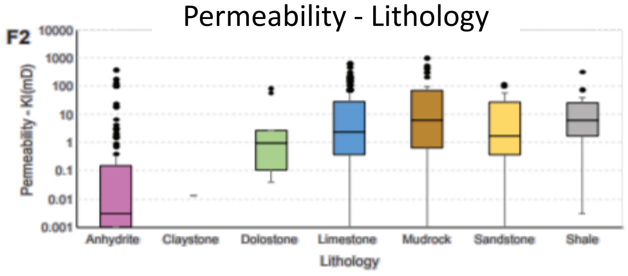




- The CCA data displays a broad range of porosity and permeabilities, commonly with 4-5 orders of magnitude variation of permeability for a given porosity and appears to form two broad clusters.
- Average porosity and permeability per reservoir layer appears to increase from Anh-01 to Anh-04.
- The better average porosities and permeabilities are typically hosted in Anh-4.
- The poorest average porosity and permeability is hosted in Anh-1.
- Some of the very high permeability values, particularly within low porosity rocks, in this dataset may relate to microfractures.

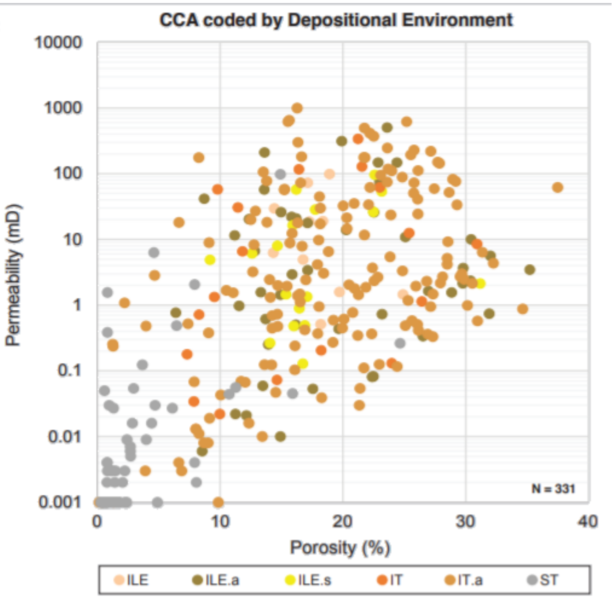


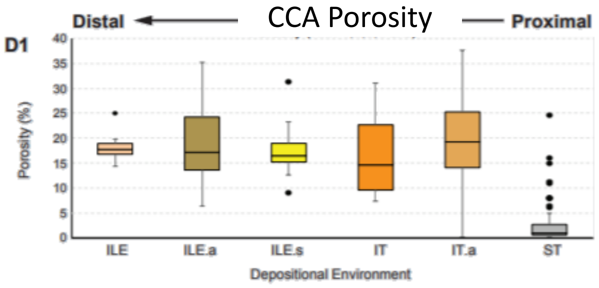


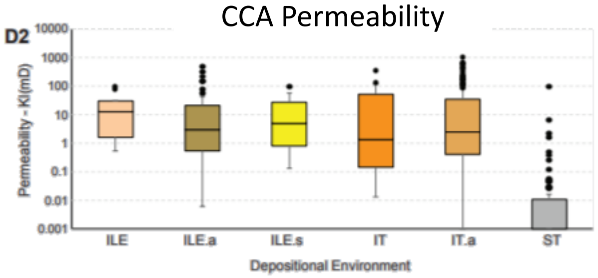


- Wide range of porosity and permeability values occur within Limestone, Mudstone, Sandstone and Shale.
- Anhydrite hosts the poorest average porosity and permeability values.
- The mudrock and shales record the best average permeabilities, with average porosities being slightly better with the shales.
- Average porosities for Dolostone and shales are similar but the latter display higher average permeabilities.
- Average limestone and sandstone permeabilities are similar but the latter display average lower porosities.

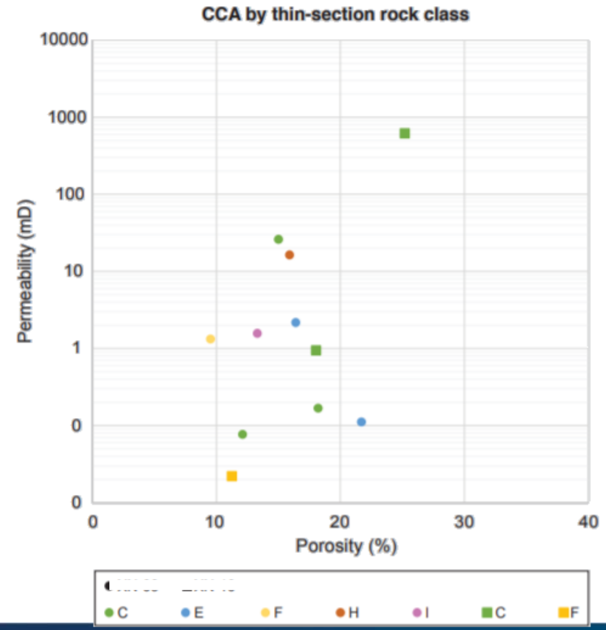
Anhydrite Layers Reservoir Characteristics







- CCA data has been coded by depositional environment, based off the interpreted log signatures and historical core log data.
- The most proximal, Supratidal (ST), evaporite-dominated deposits host the poorest average porosity and permeability values
- The best average porosity are found within the argillaceous-dominated intertidal (IT.a) deposits. This depositional environment also displays the greatest range in porosity and permeability values
- The best average permeability is found in the low-energy inner ramp (ILE) deposits.



- Rock Class C, composed of matrix-supported carbonates, hosts the widest range of porosity and permeability values and occurs within ILE, ILE.ap, and IT.a.
- Rock Class E, composed of grain-supported carbonates, hosts slightly higher porosity and lower permeability values and is evident in IT and IME.
- Rock Class F is composed of sand-dominated packstone deposits, hosts lower porosity and porosity and permeability, and are typical within ILE.s
- Low confidence that the limited number of TS samples represent the range of potential CCA properties present within the rock classes
- No samples of rock classes A, B, D, G or J observed from cuttings are represented by the sampling of the CCA data.

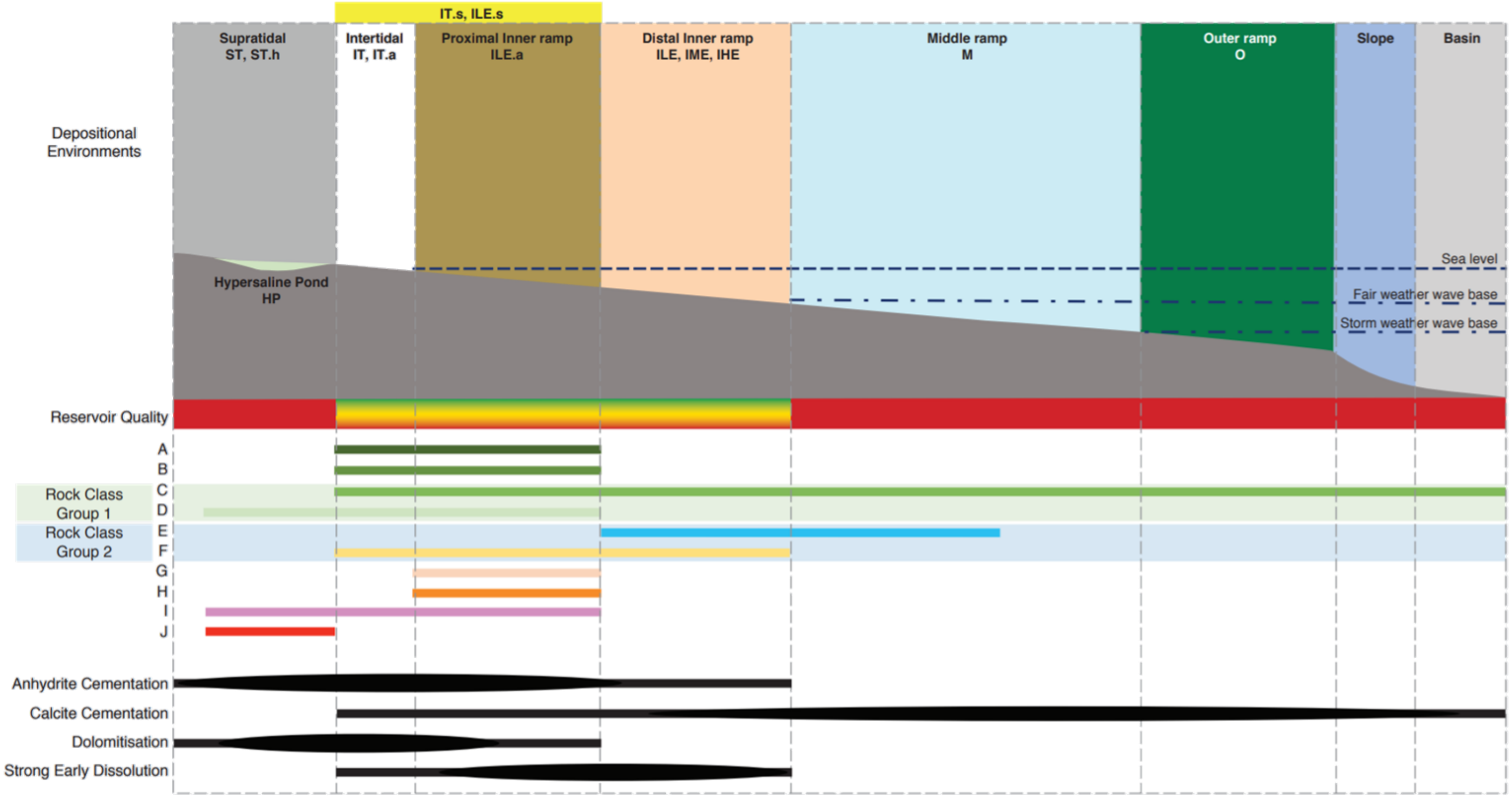
Controls on Reservoir Quality

Good Reservoir Quality

- Intertidal environments & Proximal Inner Ramp environments - wide range of porosity and permeability as they are impacted by varying calcite/anhydrite cementation and strong early dissolution
- Distal Inner Ramp environments - affected by varying calcite/anhydrite cementation and early dissolution, and host a wide range of porosity and permeability values from poor to good

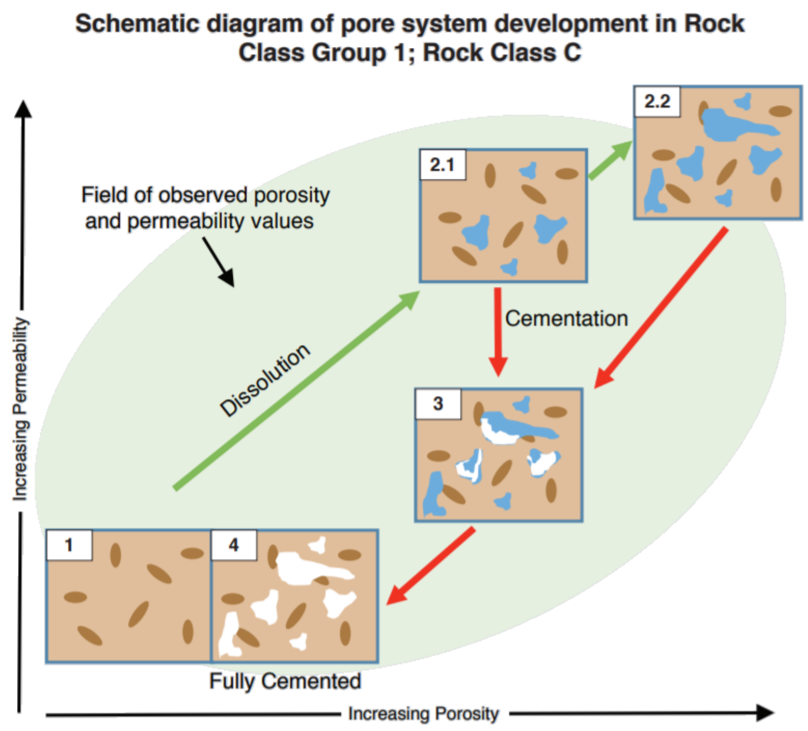
Poor Reservoir Quality

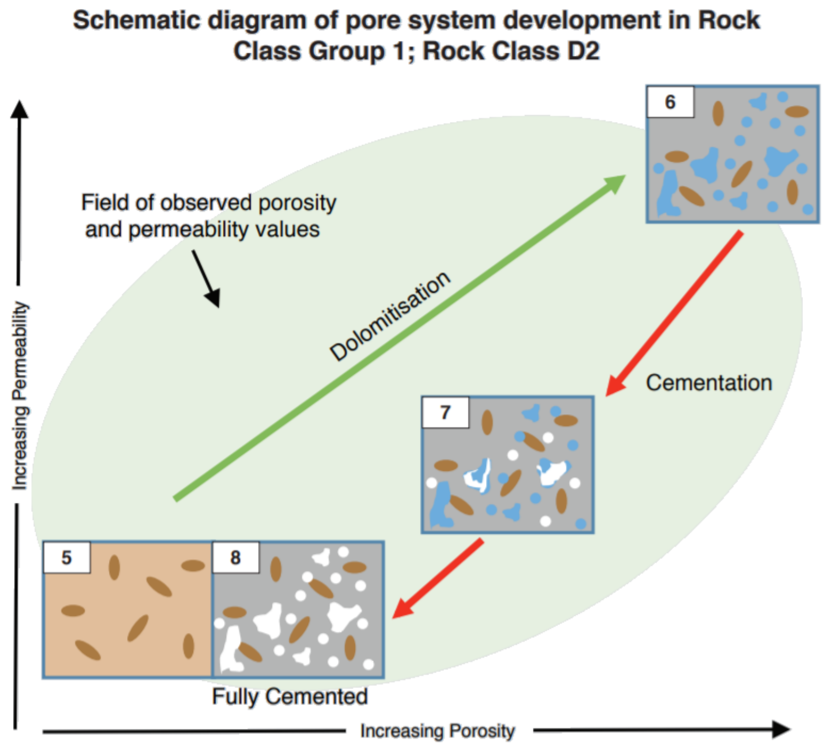
- Supratidal Environments - dominated by halite and anhydrite cementation
- Middle Ramp, Outer Ramp and Basin - least diverse rock class assemblage and calcite cementation is dominant



Rock classes A, B G, H I and J are not included in the following schematic figures as they are considered to be non-reservoir as they are highly cemented and contain no macroporosity or microporosity

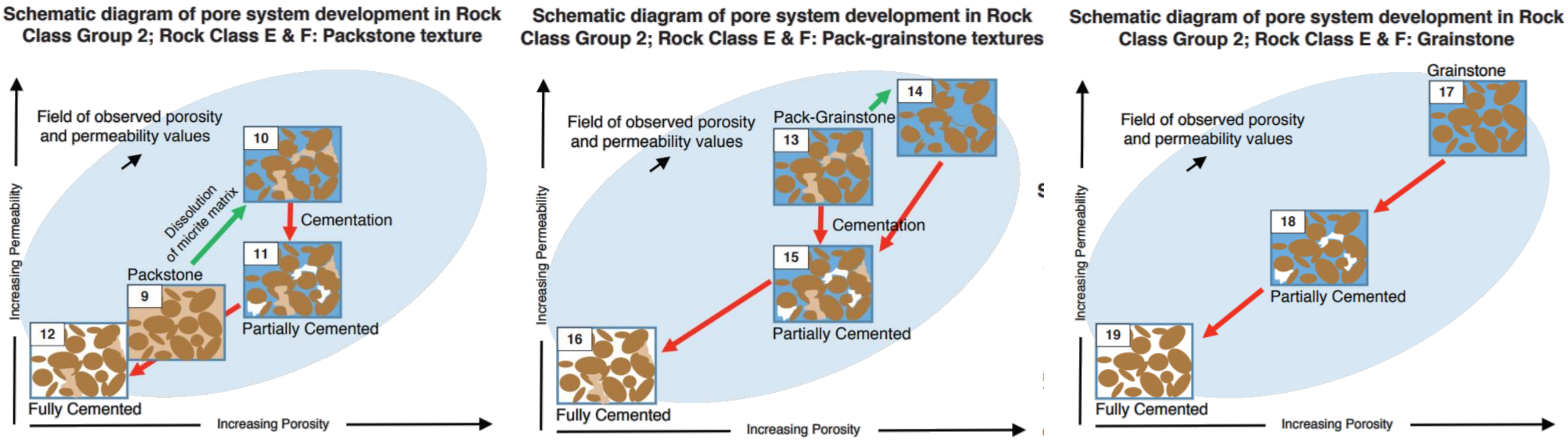
Controls on Reservoir Quality





- These facies would initially have hosted low porosity and permeability, consisting of rare macropores, and matrix-hosted micropores (1,5)
- Pervasive early dolomitisation created intercrystalline macropores (6).
- Early dissolution (green arrow) enhanced the macropore volume, creating secondary macropores and vugs in both the dolomitised and undolomitised facies (2.1, 2.2).
- Subsequent cementation (red arrow) by calcite and evaporite cements partially (3,7) to completely (4,8) occlude these macropores.

Controls on Reservoir Quality



- These clean and quartz-rich grain-supported textures would initially have hosted low (packstone, 9), moderate (pack-grainstone, 13) or high (grainstone, 17) porosity and permeability, dependent on the initial proportion of primary interparticle macropores.
- Early and late dissolution phases enhanced the macropore volume, creating secondary macropores and vugs (green trend arrows). Dissolution did not impact the quartz grains.
- Subsequent cementation by calcite and evaporite cements partially (11, 15, 18) to completely (12,16,19) occludes both primary and secondary macropores (red trend arrows).

Key Conclusions for Reservoir Quality

- The carbonate-dominated depositional environment groups (IT.a, IT, ILE.a and ILE) within the anhydrite layers (Anh-1 to Anh-6) likely host the best reservoir quality.

- Within these carbonate-dominated layers, the thicker, homogenous carbonate deposits would be more favorable to vertical and lateral flow than thinner interbedded carbonates and anhydrites, which may present as baffles or barriers to vertical flow.

- As the targeted anhydrite layers Anh-1, Anh-2, Anh-3, Anh-4 and Anh-6 (which comprise three stacked sequences: Bur1, Bur2 and Bur3) have comparable depositional organisation throughout the study area, it is likely that any reservoir quality variations within these deposits are minor.

- The south-eastwards thickening of the Bur3 cycle is characterised by a subtle increase in thickness of the subtidal (ST) and intertidal deposits (IT). Within an increase in the thickness of the carbonate-dominated intertidal deposits, this may result in enhanced reservoir quality in the south-east of the area

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