Underexplored opportunities in the Arabian Plate: application of palaeogeographic mapping and global analogues

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Discussion points

- More than 100 years of exploration in carbonate reservoirs now calls for new exploration concepts to be contemplated.

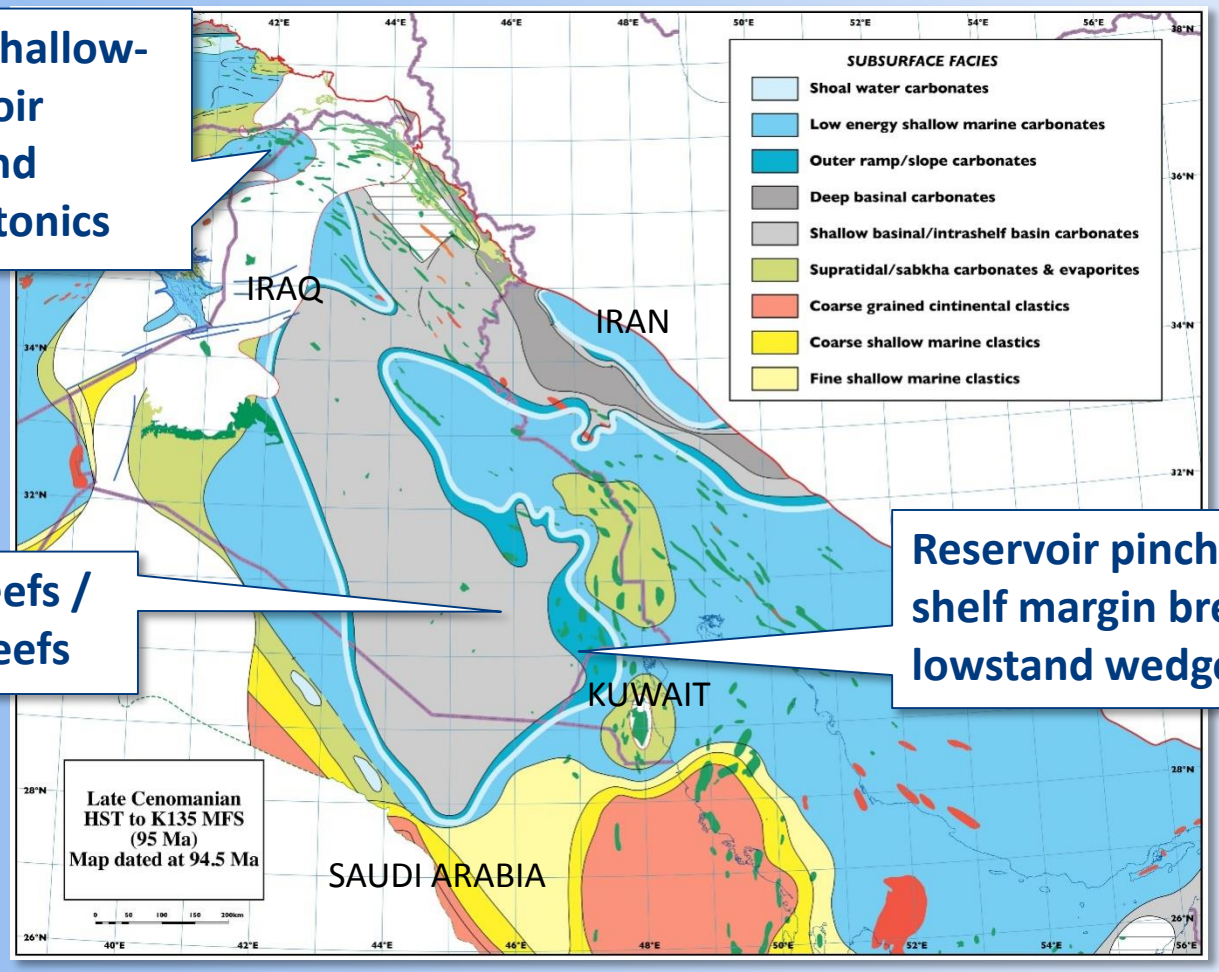
- Stratigraphic and structural complexity of the Arabian Plate provides explorationists with a host of possible play concepts:
  - Exploring stratigraphic traps
  - Exploring diagenetic traps
  - Second testing existing structures (missed pay)
  - Play concepts to high-grade exploration areas

EXPLORING STRATIGRAPHIC TRAPS

Requires application of sequence stratigraphic principles to basin dynamics and good understanding of palaeogeography

Stratigraphic traps in intrashelf basins

Interplay of shallow-water reservoir deposition and inversion tectonics



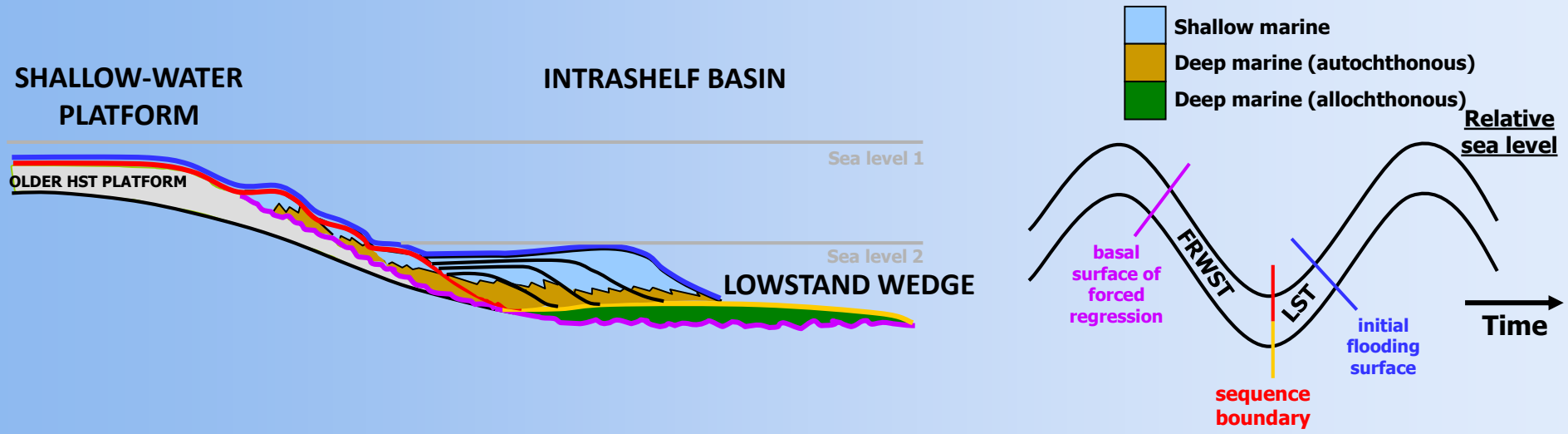
CCL in-house palaeogeography map

Isolated reefs / pinnacle reefs

Reservoir pinchout at shelf margin break – lowstand wedge play

- Development of numerous intrashelf basins on Arabian Plate leads to stratigraphic trapping possibilities

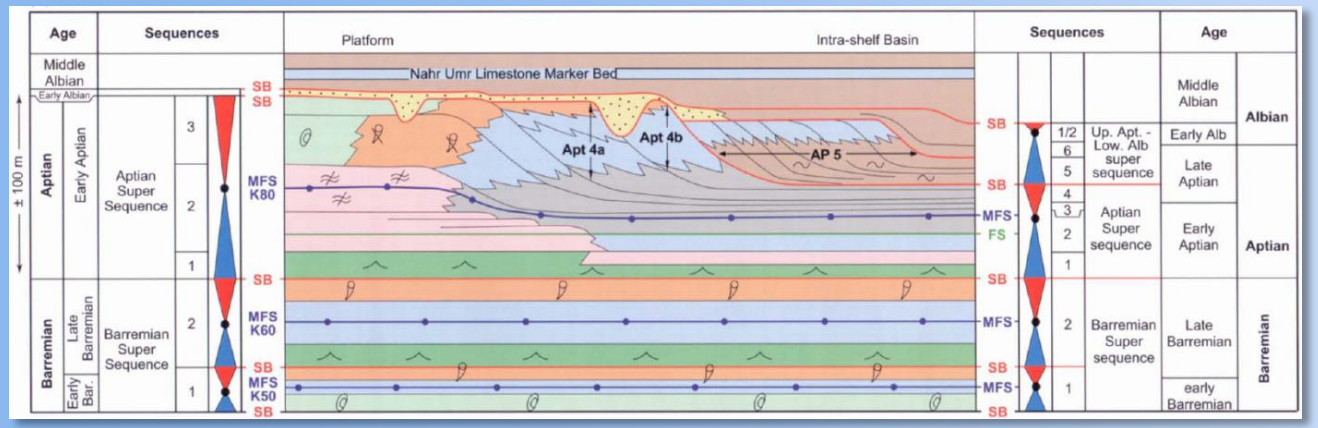
Stratigraphic traps: lowstand wedge play



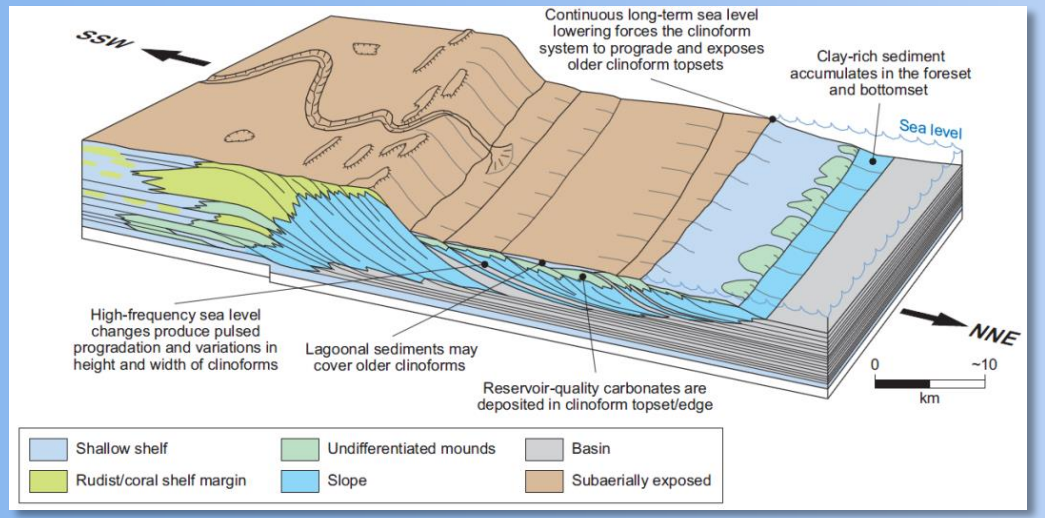
- During periods of sea level lowstand, development of shallow-water lowstand platforms flanking intrashelf basins
- Could be shallow-platformal reservoir facies and/or or reworked breccias
- Packages typically form separate reservoirs from the shelf facies themselves and may not be laterally connected

Stratigraphic traps: lowstand wedge play

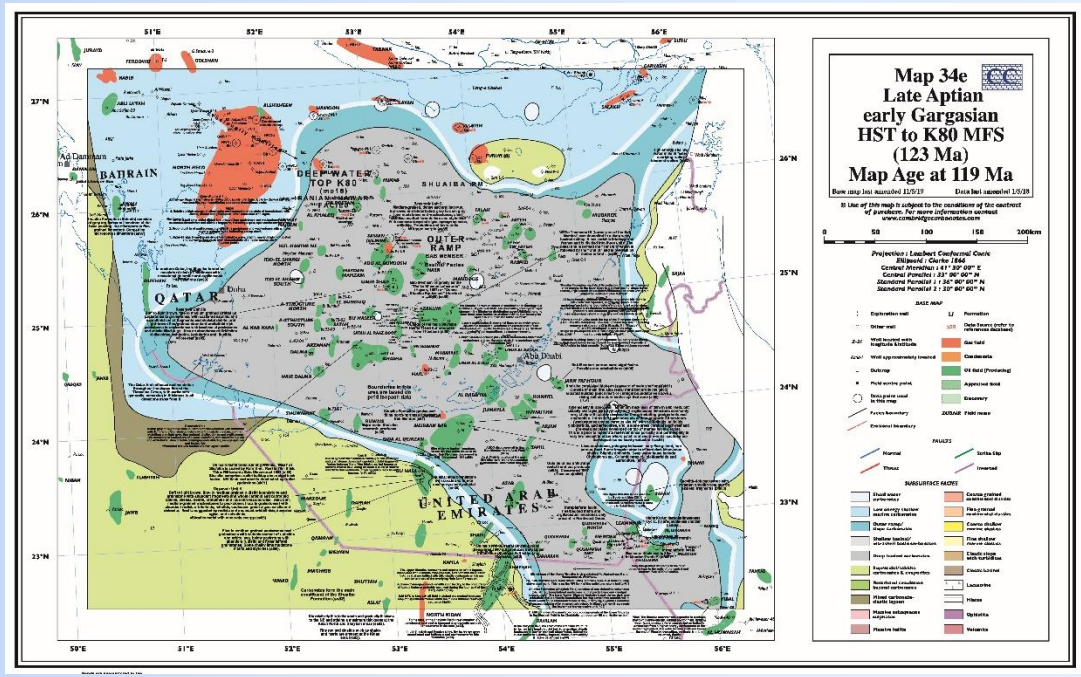
- Lowstand platforms - well documented Upper Shu'aiba prograde in Aptian Bab Basin, UAE



Van Buchem et al. (2010)



Pierson et al. (2010)



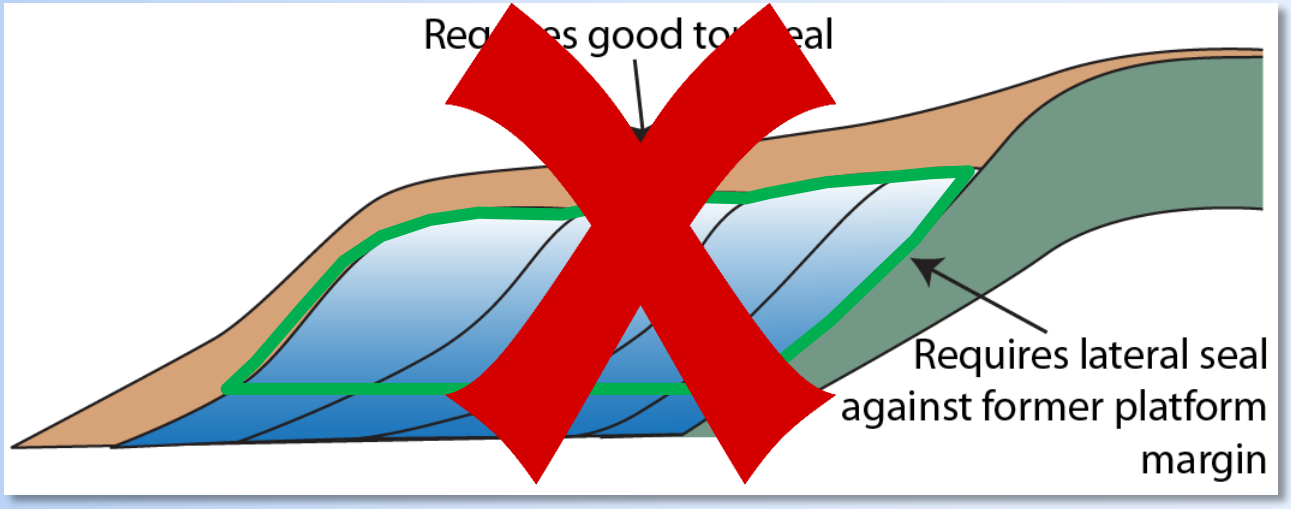
CCL in-house palaeogeography map: Late Aptian, K80 HST

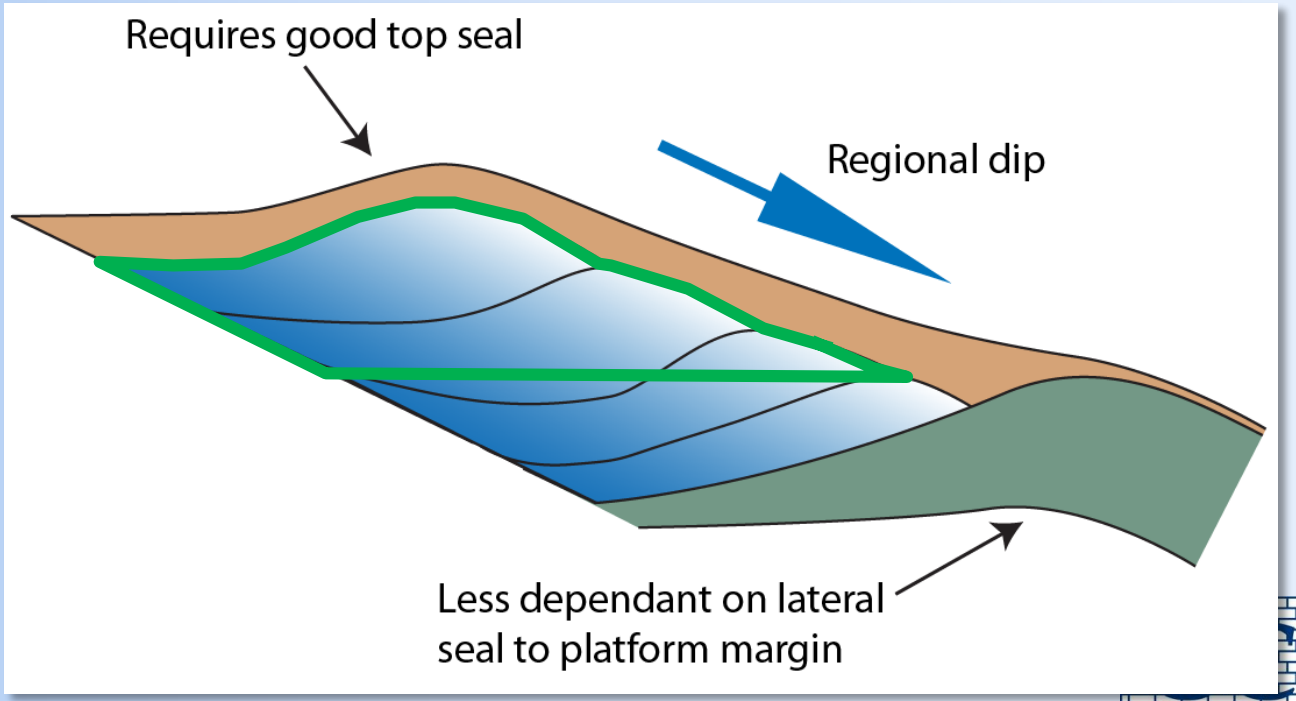
- Can this play work here, or elsewhere, as a stratigraphic trap? e.g. Kazdhumi Basin, Garau Basin, intrashelf basins in the Mishrif?

Stratigraphic traps: lowstand wedge play

Key factors

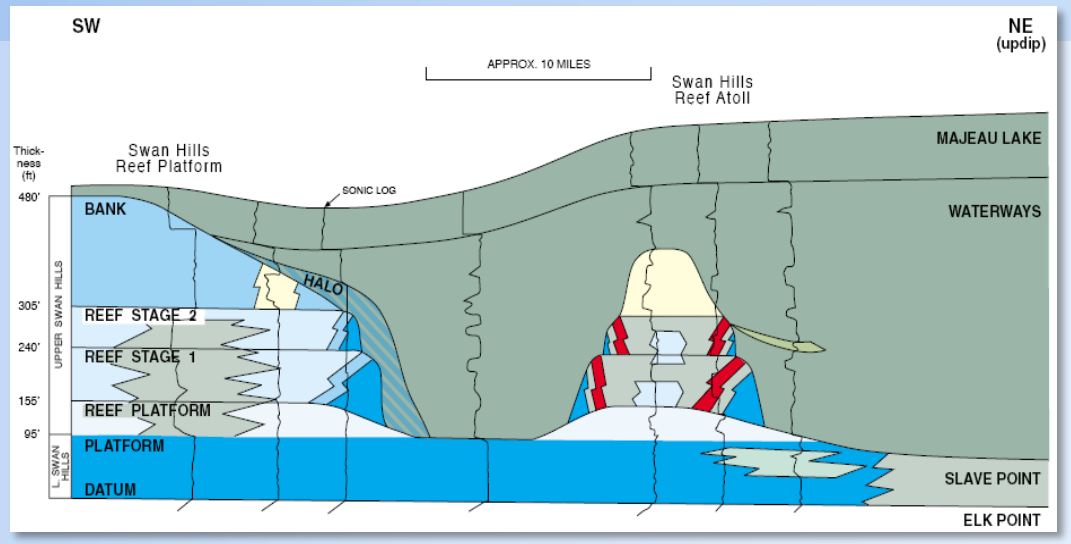
- Recognition of the play requires good understanding of basin/platform geometries and location of shelf margins
- Recognition from seismic – wedge-shaped geometries abutting against the former highstand carbonate platform, seismic amplitude anomalies (i.e. Oude field, Syria)
- Trapping mechanism
  - The sealing rocks are critical
  - Regional dip (lower risk)
- Could occur in numerous stratigraphic intervals (Jurassic/Cretaceous/Cenozoic)



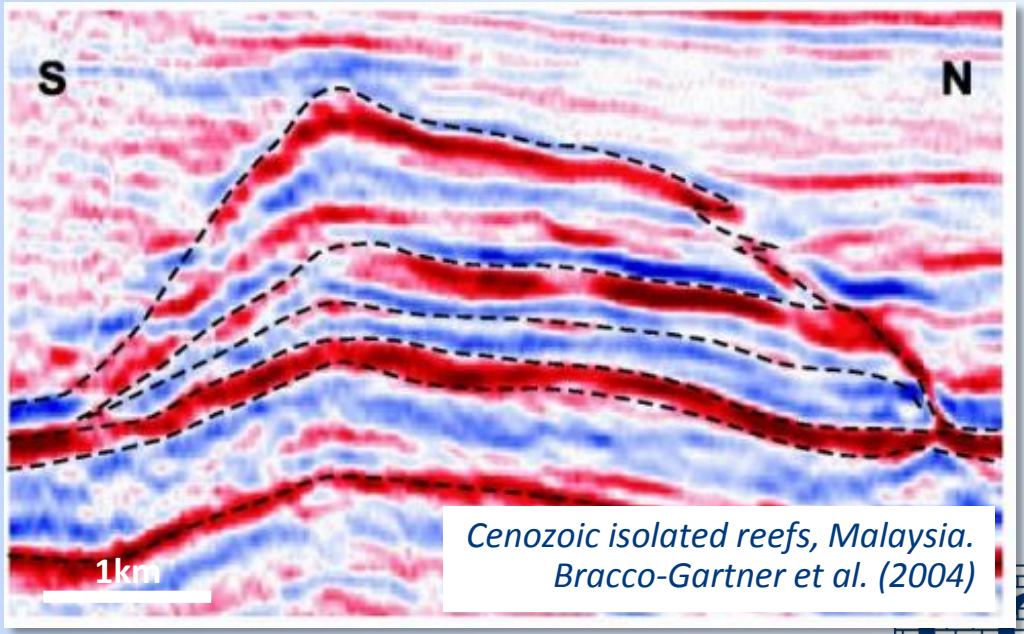


Stratigraphic traps: Isolated reefs

- Surprisingly few documented on Arabian Plate
- Very common play Worldwide - numerous field analogues: e.g. USA, Canada, SE Asia
- Isolated pinnacle reefs, that are typically surrounded by tight basinal facies



Devonian isolated reefs, Western Canada. Stoakes (1992)

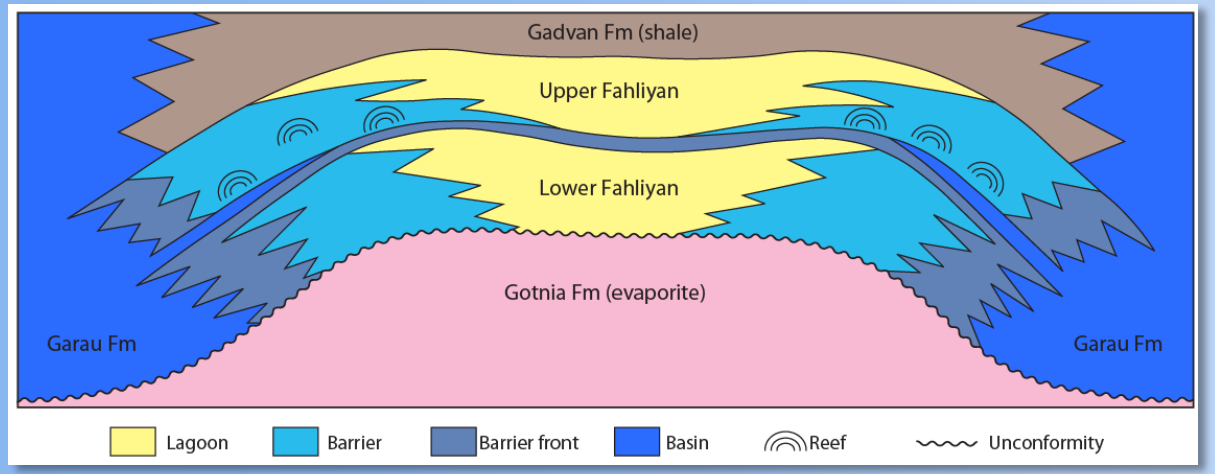


Cenozoic isolated reefs, Malaysia. Bracco-Gartner et al. (2004)

Stratigraphic traps: Isolated reefs on Arabian Plate?

Key factors – what to explore for

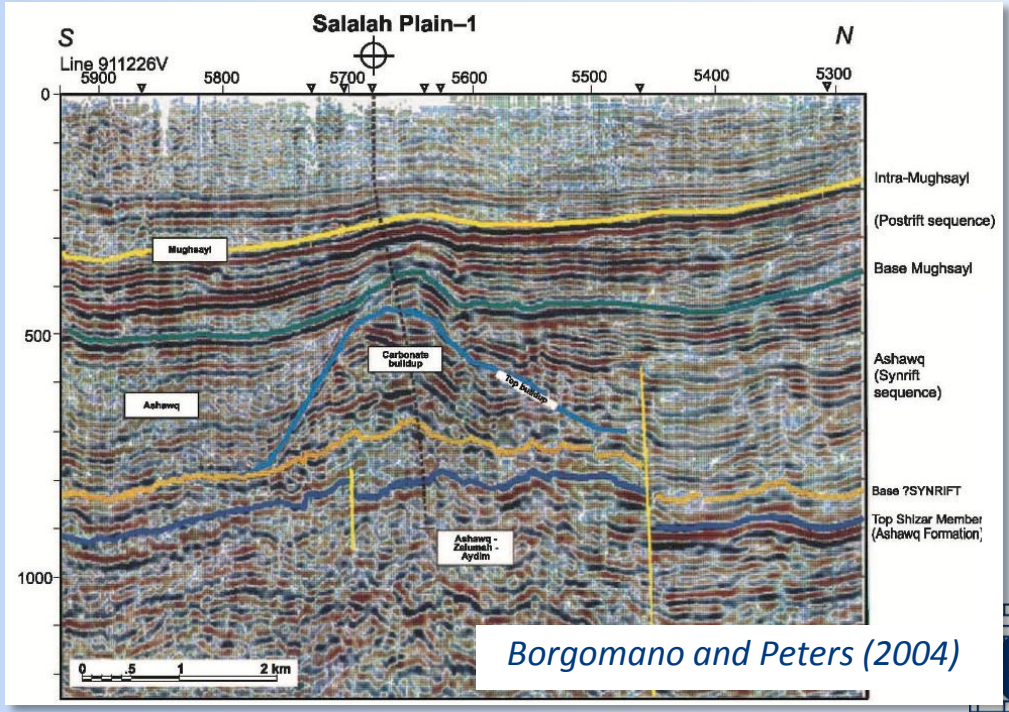
- Often seeded on antecedent topography at the start of long lived transgressions.
- Seeded on salt structures
- Recognition: mounded features on seismic, demonstrable “self built” geometries
- Source/seal/reservoir/trap all-in-one
- Potential play type in Jurassic/ Cretaceous/ Cenozoic intrashelf basins



Lasemi and Kondroud (2008)

Known examples

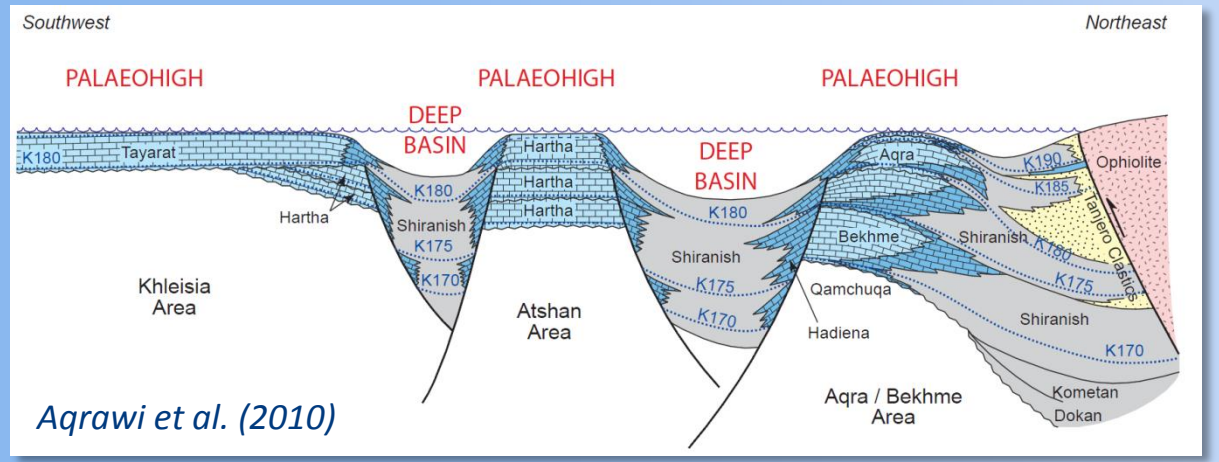
- Early Cretaceous: Darquain field, Iran
- Late Cretaceous: Mishrif UAE (i.e. Umm Al Dalkh field); Shu’aiba UAE (incipient buidups: i.e. Jarn Yaphour, Mandous)
- Paleogene: Oman (Salalah Plain); Syria (Jebels Sinjar and Bishri) on Cretaceous inverted highs



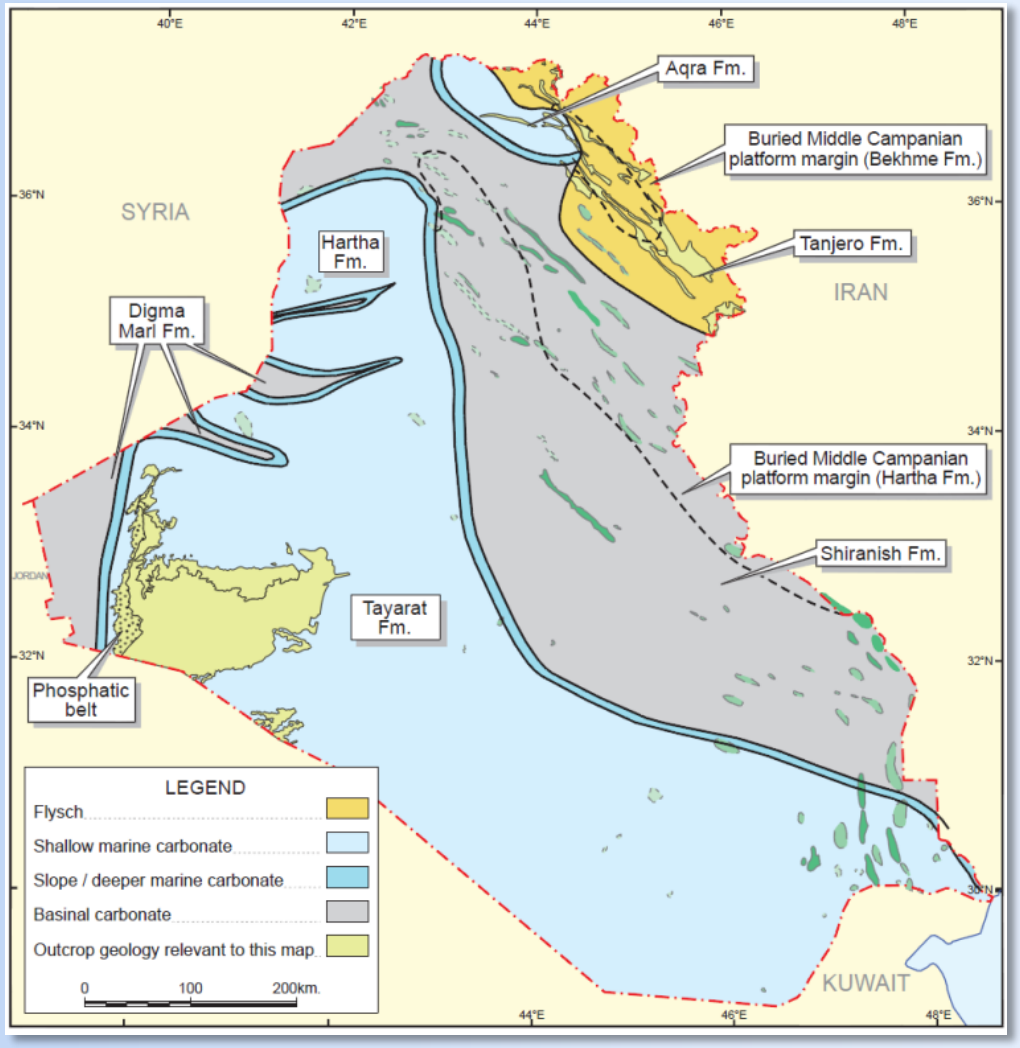
Borgomano and Peters (2004)

Stratigraphic traps: inverted palaeohigh “synclines”

- Late Cretaceous extension, fault-block development
- Shelf carbonate reservoir, matrix porosity
- Best reservoir facies deposited on palaeohighs

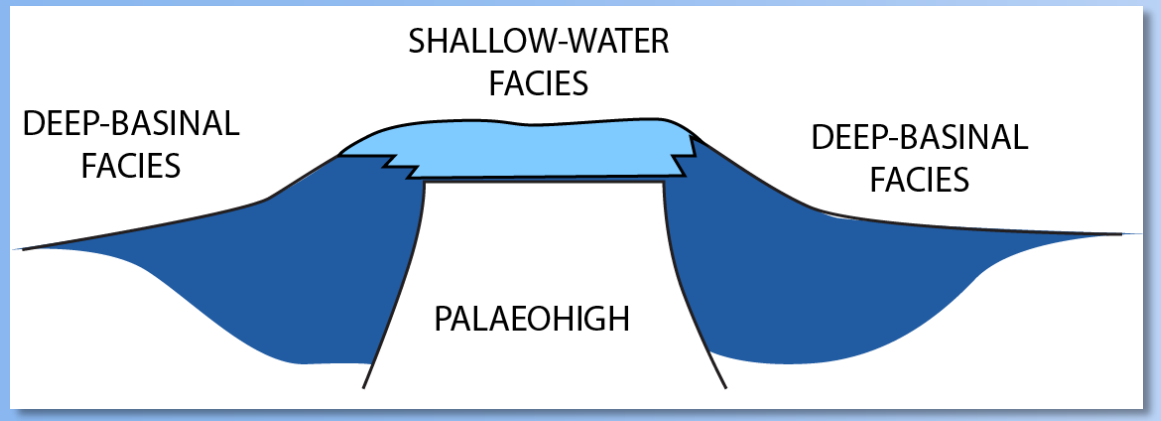


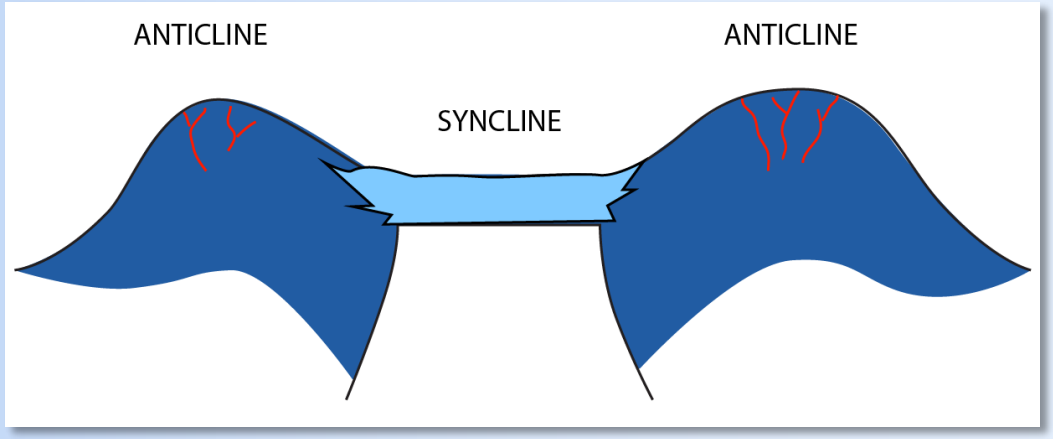
Aqrawi et al. (2010)



Late Campanian-Maastrichtian palaeogeography map

Stratigraphic traps: inverted palaeohigh “synclines”

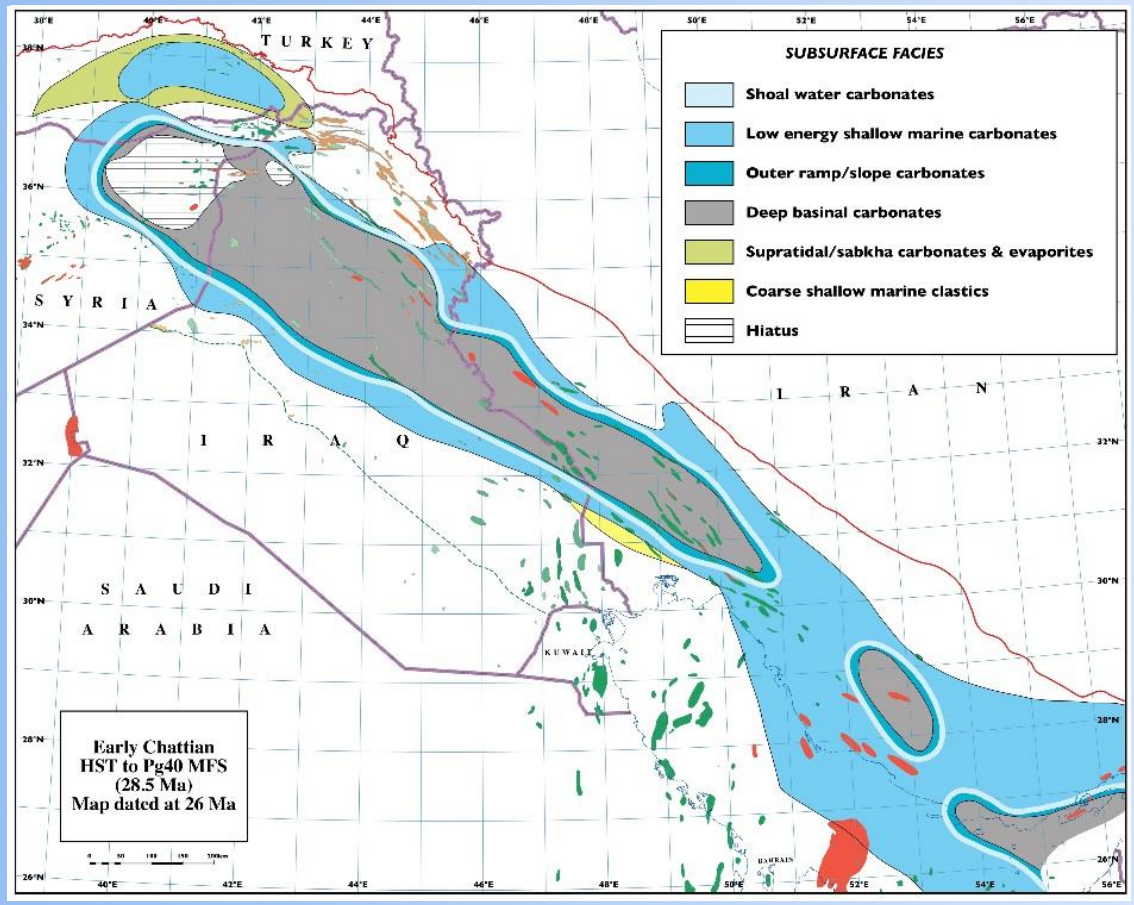




- Neogene structuration - inversion anticlines (Foothills zone)
- Major anticlines have been drilled targeting basinal facies in crestal areas, whilst the shallow shelf dominates the limbs.
- Future exploration could explore synclines/anticline limbs for shelf facies – e.g. Atshan well
- Dominantly stratigraphically trapped
- Success needs good lateral seal into basinal marls

Stratigraphic traps - summary

- Several underexplored play concepts
- Palaeogeographic and sequence stratigraphic understanding critical for reservoir prediction
- Could occur at many stratigraphic intervals



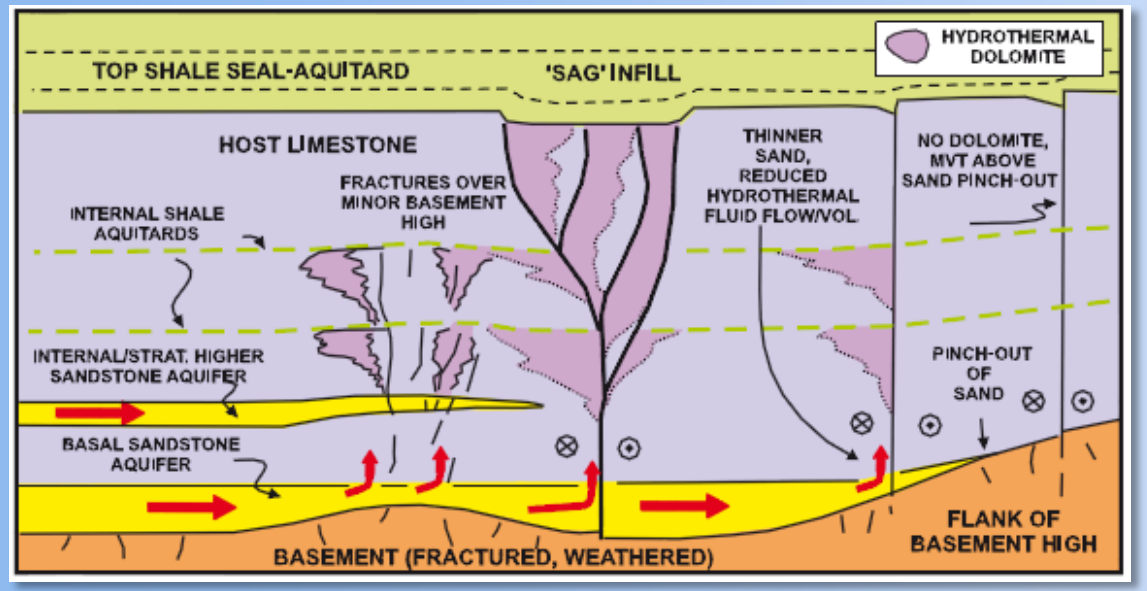
CCL in-house palaeogeography maps

EXPLORING DIAGENETIC TRAPS

- Hydrothermal dolomites
- Evaporite collapse breccias (e.g. Barsarin Fm)
- Diagenetic pinchout plays
- Carbonate stringers in evaporites (e.g. Gachsaran)

Diagenetic traps: hydrothermal dolomites

- Established play type in North America - becoming recognised more and more on the Arabian Plate
- Hot Mg-rich fluids move upwards through fractures, dolomitising surrounding host carbonates.



Davis and Smith (2006)

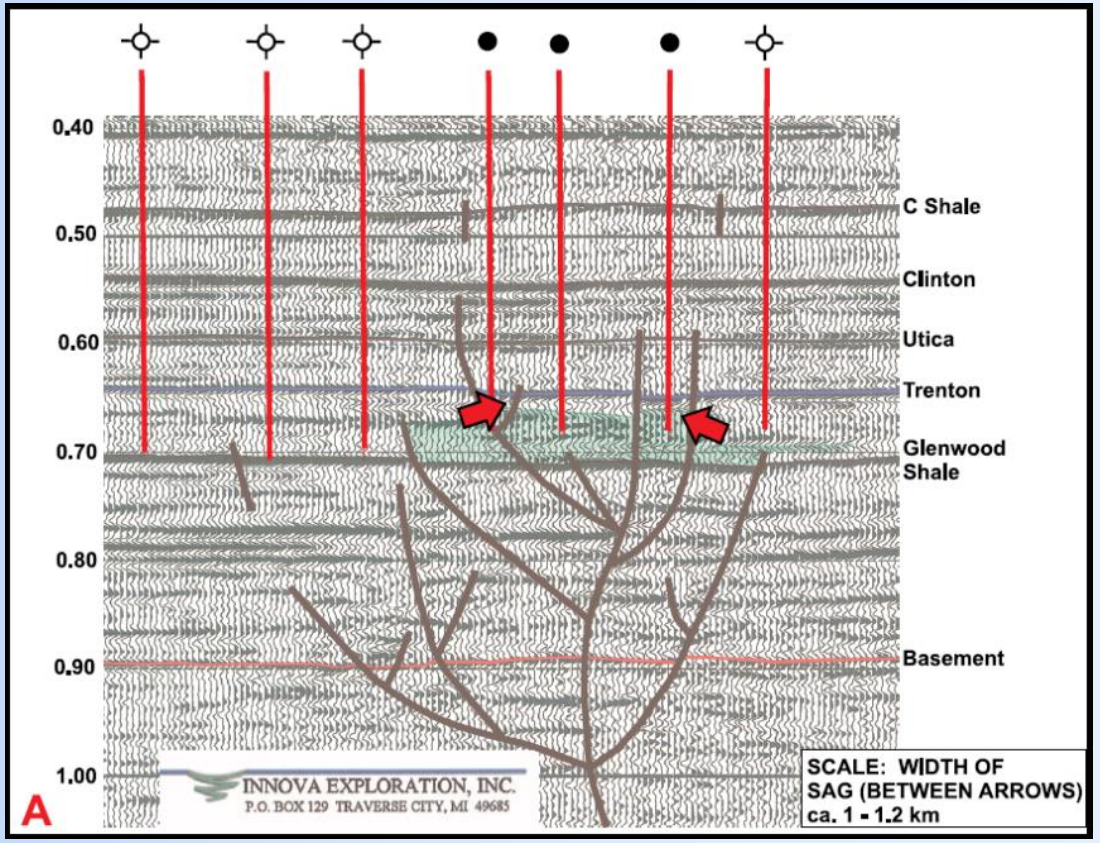
Photo courtesy of Dave Hunt and Ian Sharp

- Hydrothermal dolomites can **add additional matrix porosity** to what would traditionally be considered a **fractured reservoir.**
- Independent of deposition facies: reservoir can occur in any part of a carbonate depositional system

Diagenetic traps: hydrothermal dolomite analogues

- **DIAGENETIC TRAPS** - Sealed laterally by tight limestones, top seal shales or tight limestones.
- Known dolomite bodies up to 6.5km wide (generally ~1km), 10's km long along strike

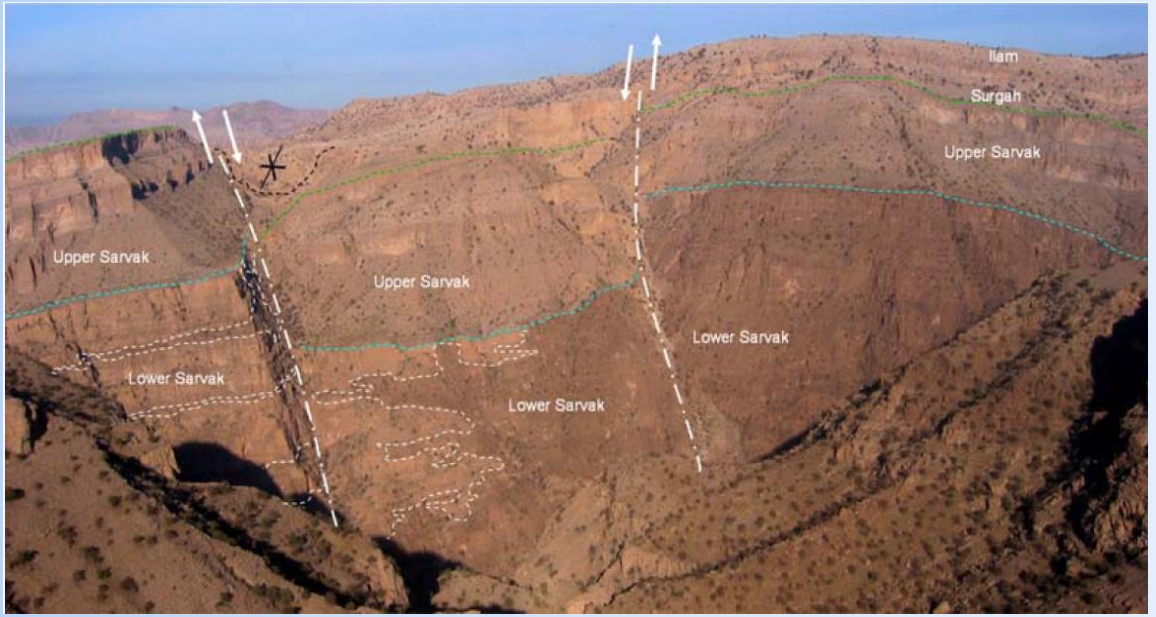
Field	Dimensions
Northville (Michigan Basin)	1 km x 10.5 km
Albion-Scipio (Michigan Basin)	1.6 km x 56 km
Stoney Point (Michigan Basin)	12 km2
Crystal (Michigan Basin)	1.6 km x 0.32 km
Vernon (Michigan Basin)	2 km x 9.5 km
Goldsmith/Lakeshore (Appalachian Basin)	0.400 - 1.2 km x 14 km
Glodes Corners field (Appalachian Basin)	0.7 km x 10 km
Ladyfern (WCSB)	15 km x 6.5 km
Rosevear (WCSB)	2 x 2 km x 11 km
Reinecke (Midland Basin)	2.2 km x 1.5 km



Davis and Smith (2006)

Diagenetic traps: HTD examples in the Middle East

★ subsurface ★ outcrop



Diagenetic traps: HTD examples in the Middle East

subsurface outcrop

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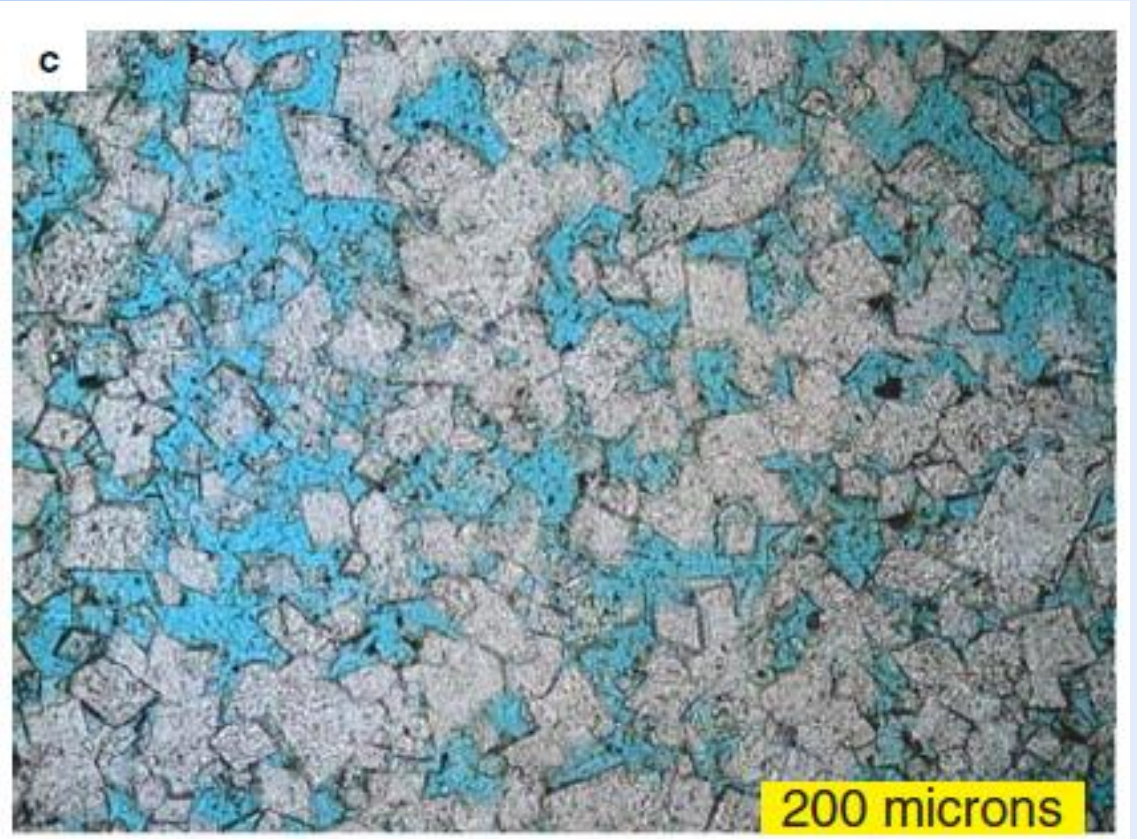

Taq Taq field. Garland et al (2010)

Diagenetic traps: HTD examples in the Middle East

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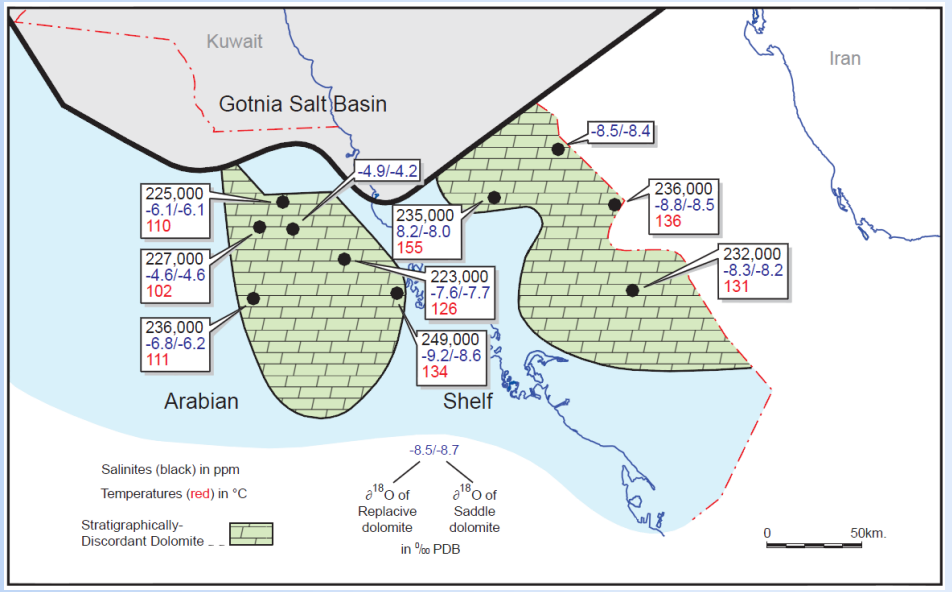
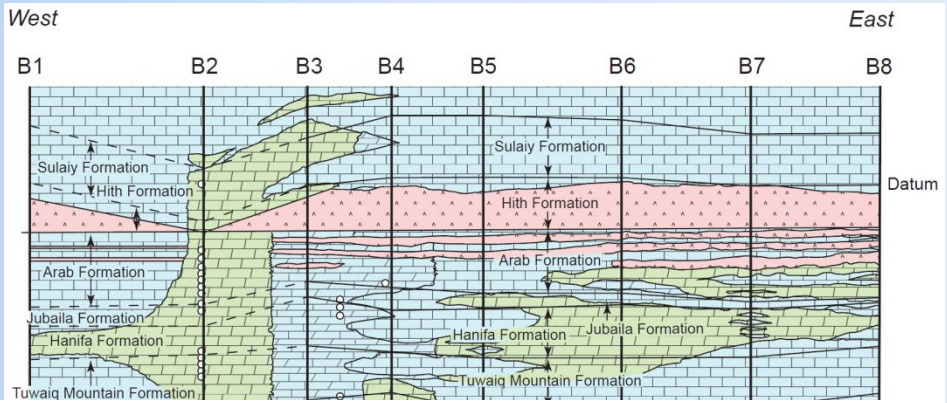




Broomhall and Allan (1987)

Diagenetic traps: HTD examples in the Middle East

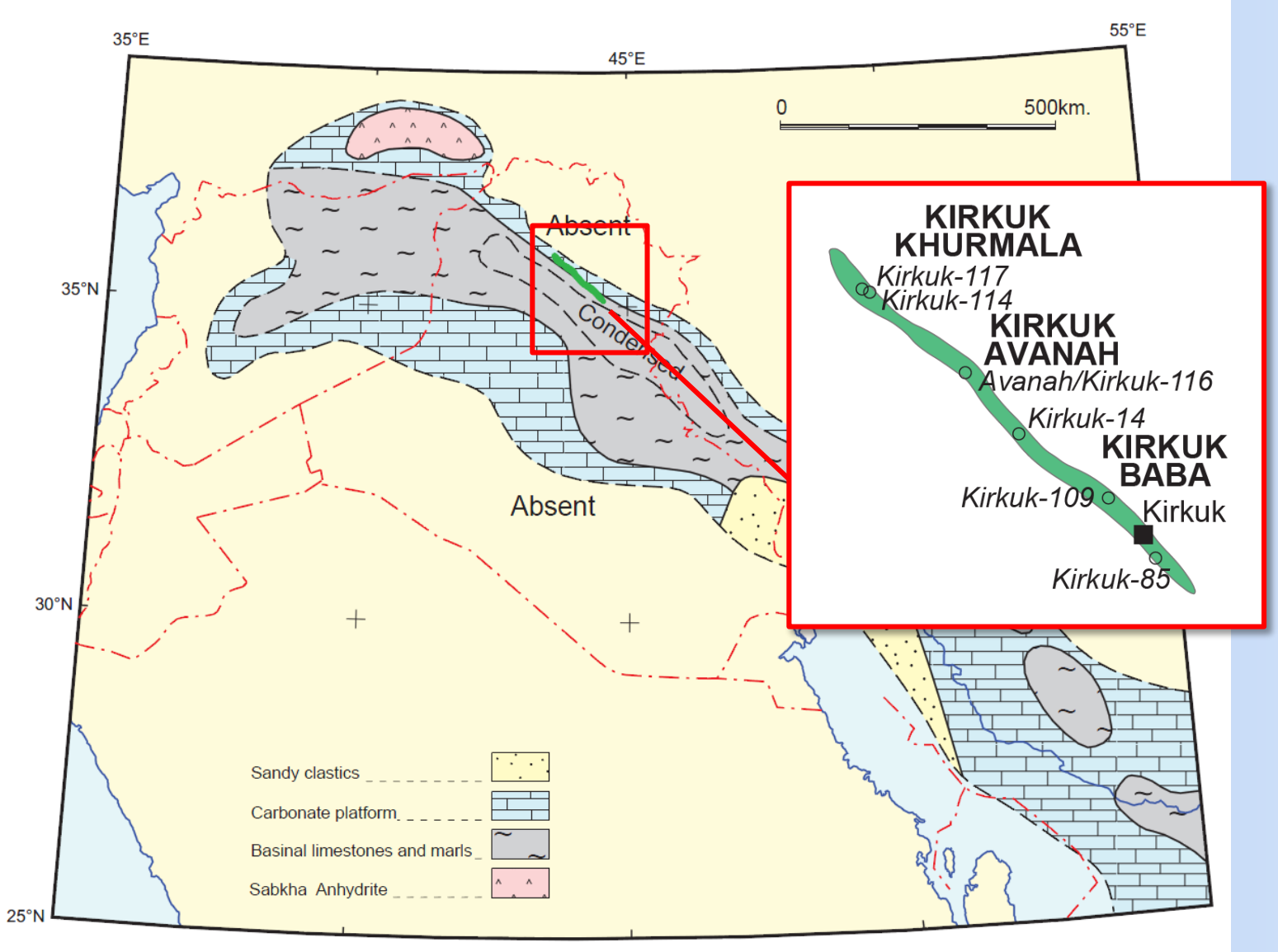
subsurface outcrop

- To date all documented hydrothermal dolomites in Middle East CONTRIBUTE to reservoir, but do NOT form diagenetic traps.
- Requires understanding of fracturing/ structuration and diagenesis
- North America – dolomites typically associated with strike slip tectonic regimes
- Middle East: most to date related to extension/ compression - however, wrench faulting exists – potential target?

SECOND TESTING EXISTING STRUCTURES

- One well is not always sufficient to test a structure
  - Structures have reservoir “sweet spots” that are more productive
- Function of
  - Facies variations
  - Variation in fracture intensity

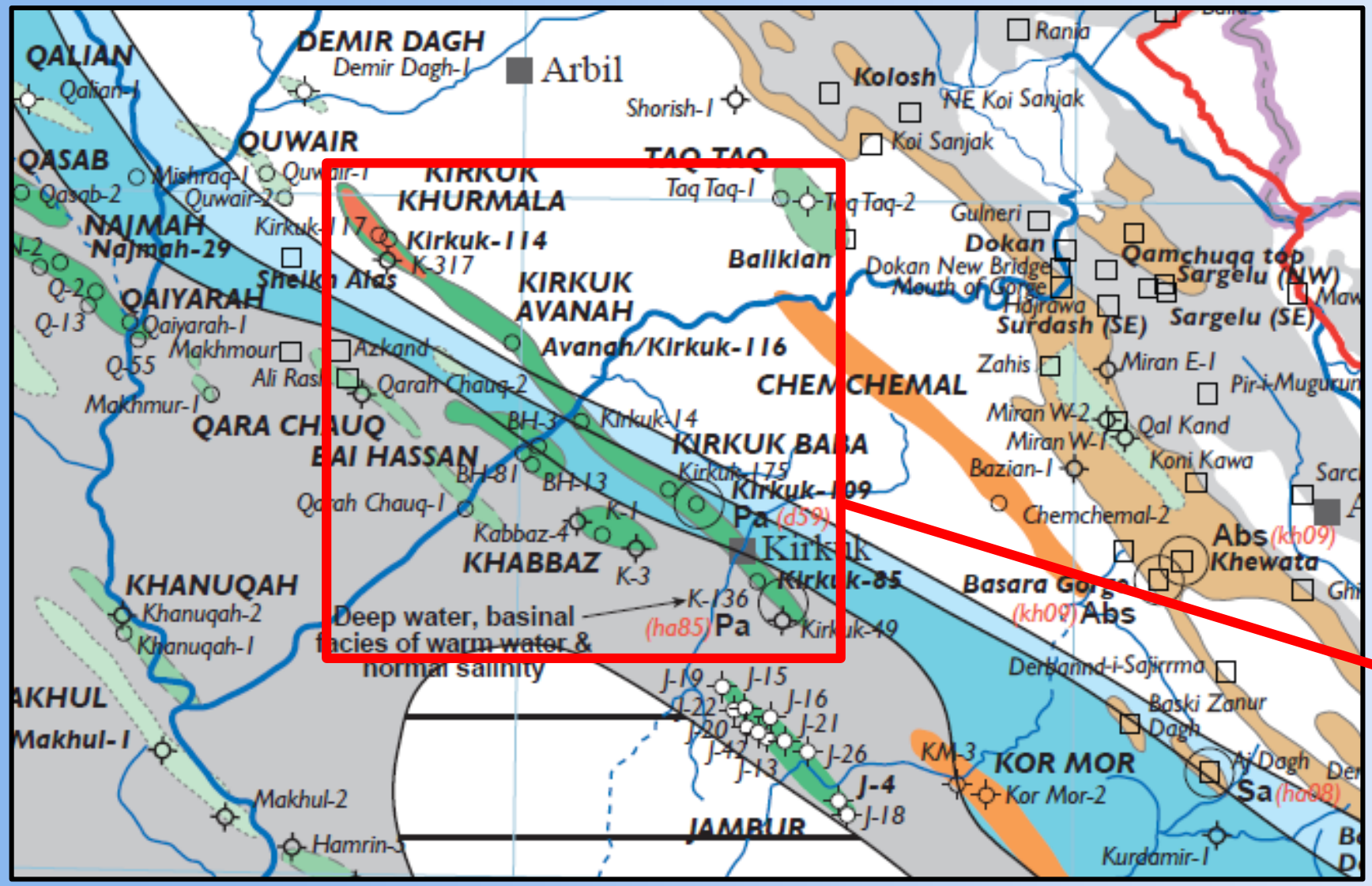
Facies variability – Kirkuk field



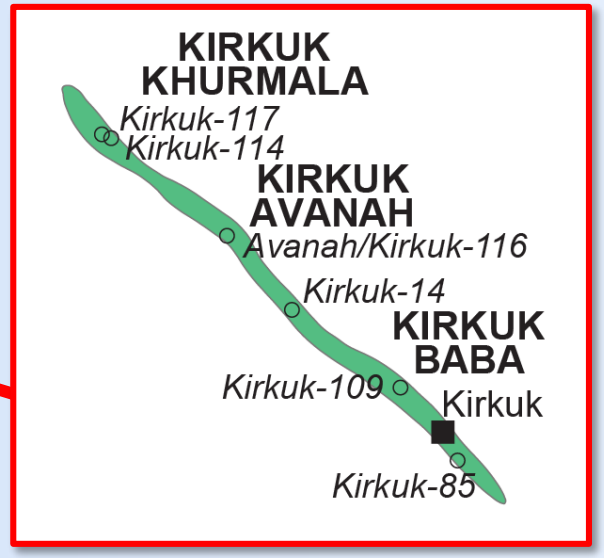
Oligocene palaeogeography map (Aqrawi et al., 2010)

- Super-giant field, 38 BBO STOOIP
- 100 x 4km, 600m column height
- Main reservoirs – Palaeogene shallow-marine reefal carbonates. High matrix porosities, with fractures.
- 3 culminations
- Baba Dome tested first – production rates of 80,000 BOPD in 1934
- Khurmala Dome – considerably poorer matrix properties

Facies variability – Kirkuk field



- Facies control of matrix pore systems
- Structural grain cross-cuts facies belts



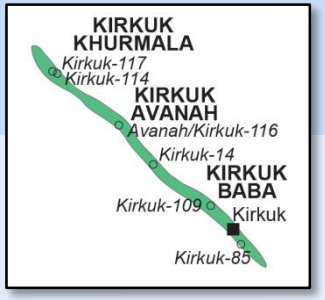
CCL in house palaeogeography maps: Oligocene MFS to Pg30)

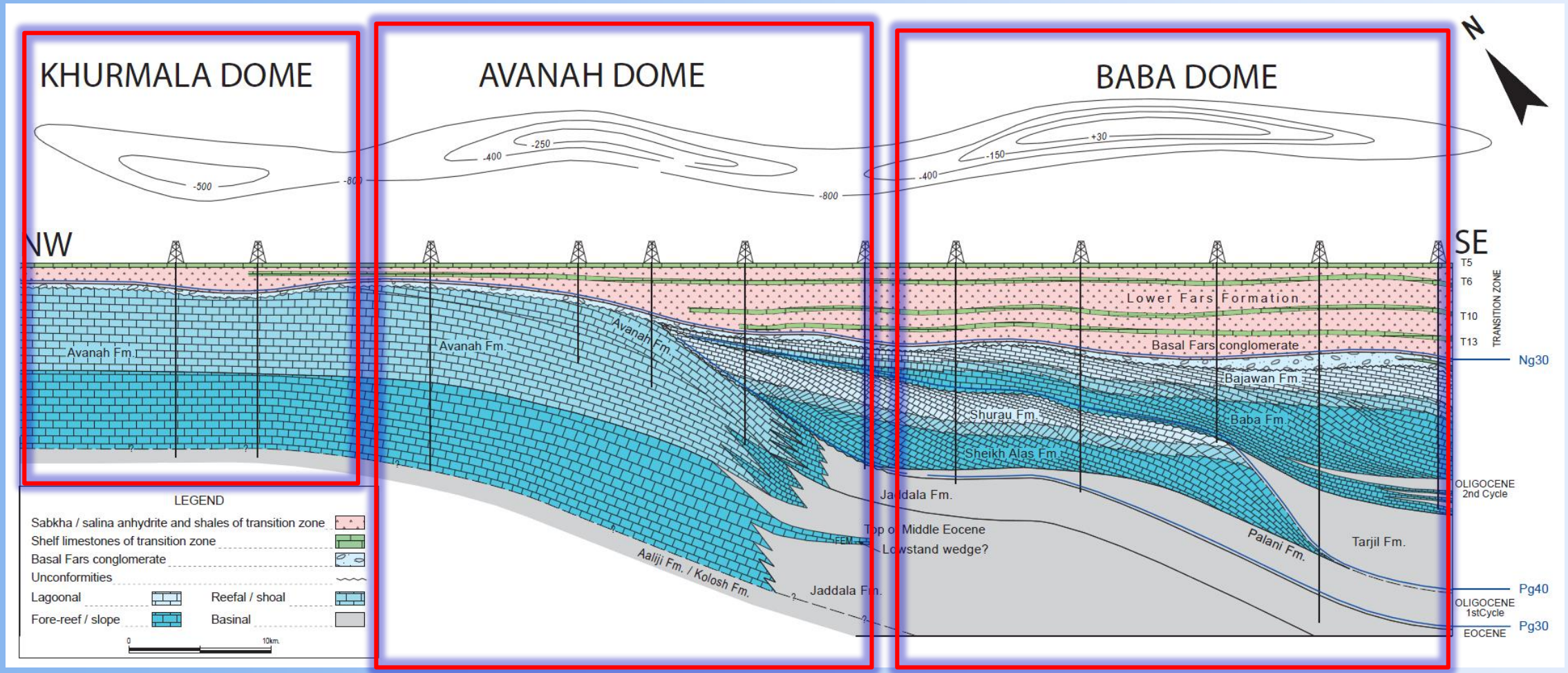
Facies variability – Kirkuk field

Poor matrix properties. Baba and Shiekh Alas Formations not present. Avanah Formation tight.

Baba and Shiekh Alas Formations not present. Porous shoal limestones in Avanah Formation.

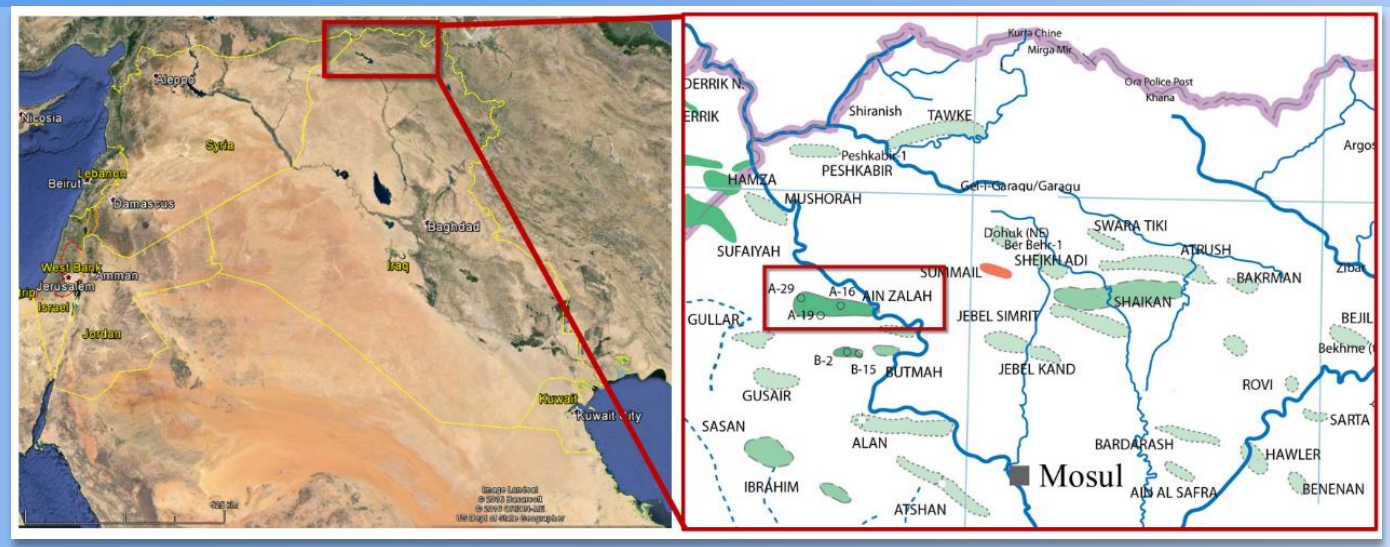
Mulitiple pay – porous Baba Formation/ Shiekh Alas reef and fore-reef facies



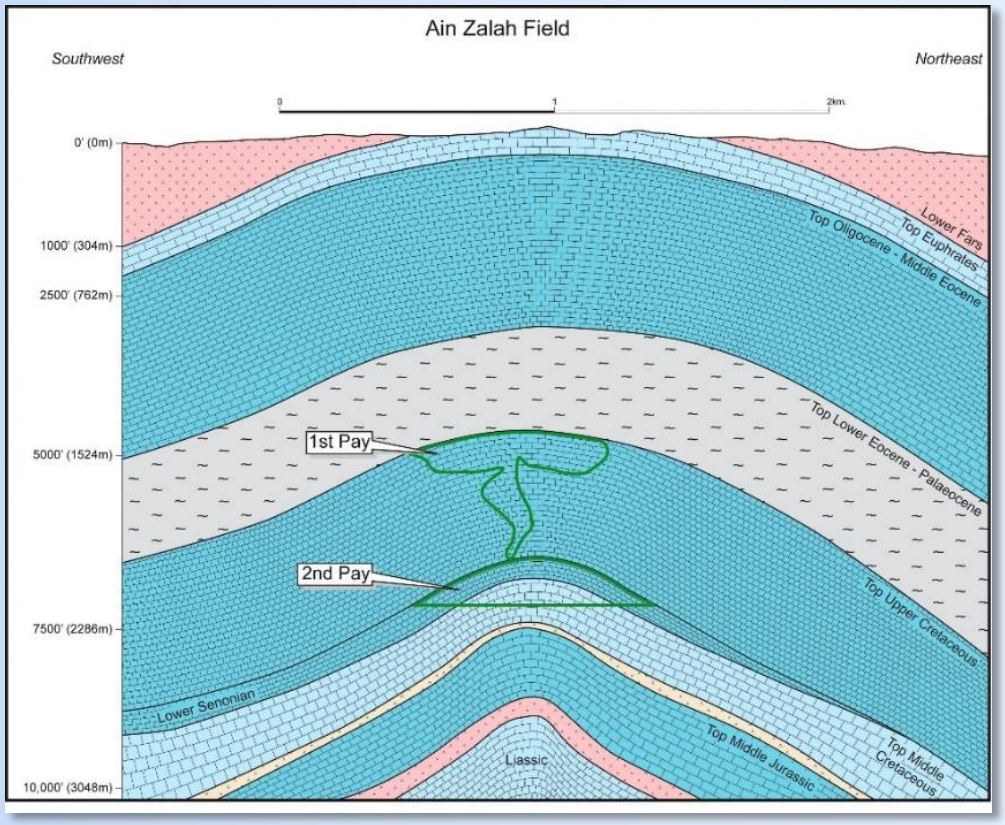


Reservoir zones along the Kirkuk structure, after Daniel (1954)

Fracture intensity, Ain Zalah Field

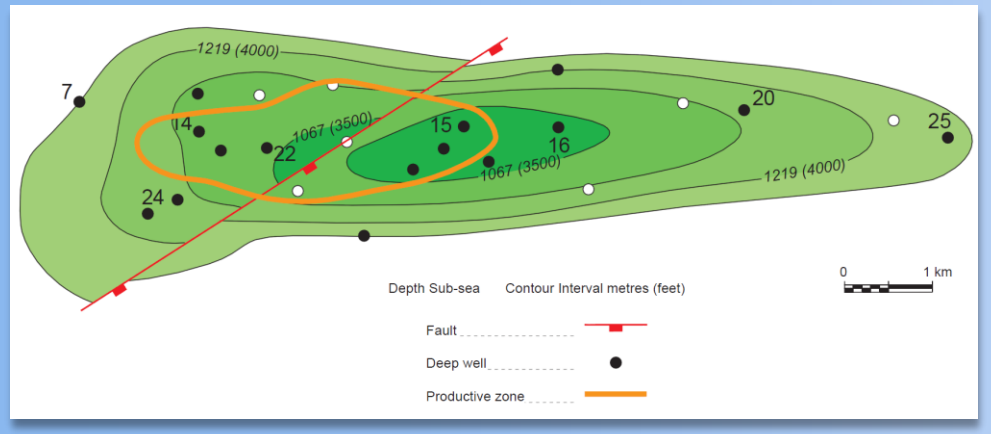


Aqrawi et al. (2010) after various sources



- Complex E-W anticline
  - End Cretaceous folding and Neogene compression
  - Structure sealed by Palaeocene Aaliji shales
- Two pay zones
  - 705m pelagic carbonate mudstone of Shiranish Fm type 1 reservoir
  - 610m non-productive zone with rare fractures that connect the pays
  - 402m Shallow marine dolomite Qamchuqa and Mushorah fms type 2 reservoirs

Fracture intensity, Ain Zalah Field



Aqrawi et al. (2010)
after various sources

- Main reservoir – Late Cretaceous (Shiranish Formation) fractured marly carbonates. No matrix permeability.
- Productive area is offset from crest of structure
- Relates to early diagenetic effects at the end Cretaceous
  - Inversion → exposure of the Shiranish Fm → resulted in recrystallisation → Miocene compression "offset" this recrystallised area
- The area of "recrystallisation" more brittle than the surrounding argillaceous marls and thus prone to fracturing.

Second-testing existing structures

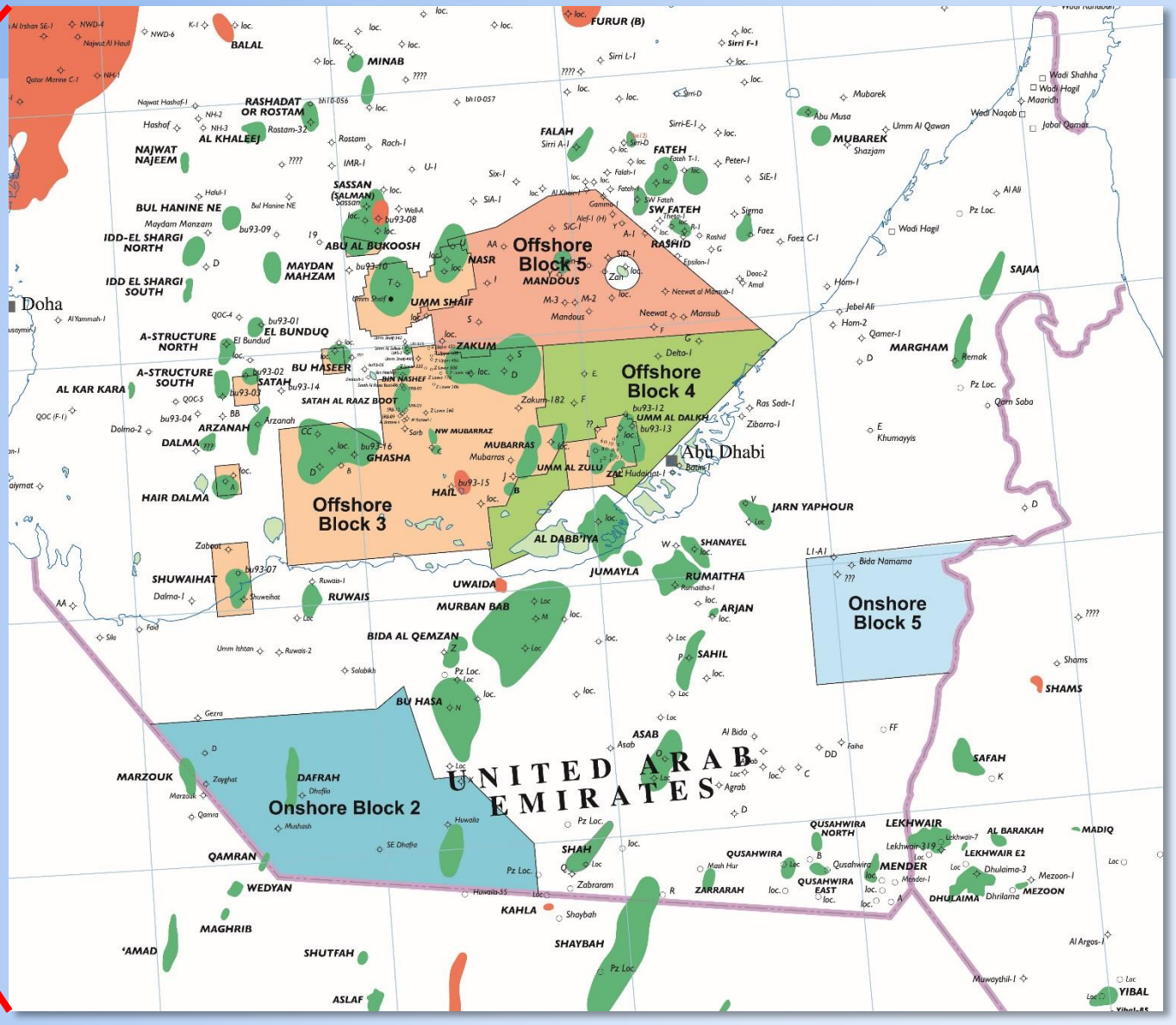
- Single tests of anticlines may lack validity given heterogeneity of many of the reservoir systems (e.g. fractures, facies, diagenesis)
- Need a good understanding of reservoir distribution
  - Facies belts/palaeogeography
- Need a good understanding of structuration/ fracturing/ diagenesis
  - Highest fracture concentration not always at crest of structure
  - Late compression may be tangential to basement structure and/or facies → variations in fracturing

UNDEREXPLORED OPPORTUNITIES IN BID ROUNDS

- Use of palaeogeographic mapping
  - Understanding source-reservoir-seal relationships
  - Potential for stratigraphic trapping

UAE BID ROUND

- Very mature basin
- Reservoirs Permian, Jurassic, Cretaceous
- What remains to be discovered?



UAE BID ROUND

LEGEND

Systems Tracts

HST

TST

LST

MFS

Depositional Environment/lithology

Low energy shallow-marine carbonates

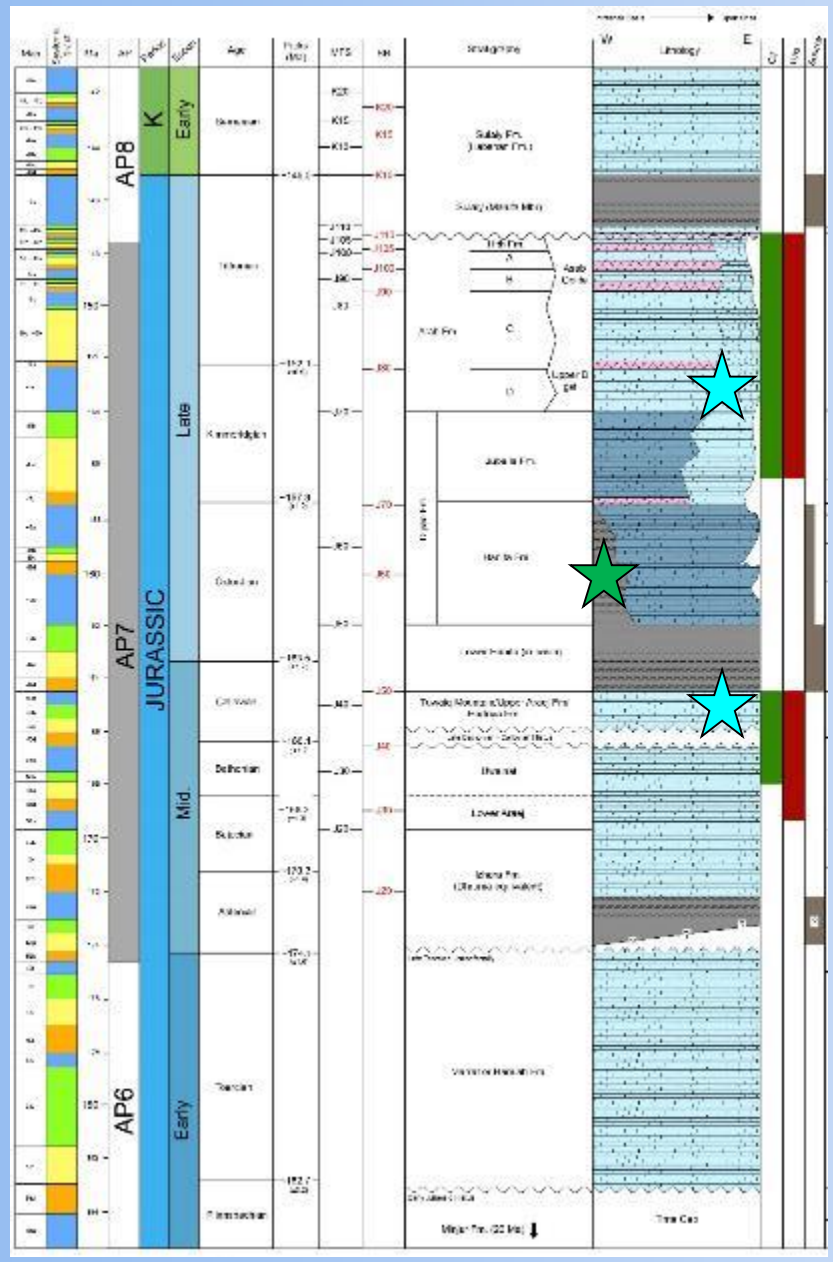
Shoal water carbonates

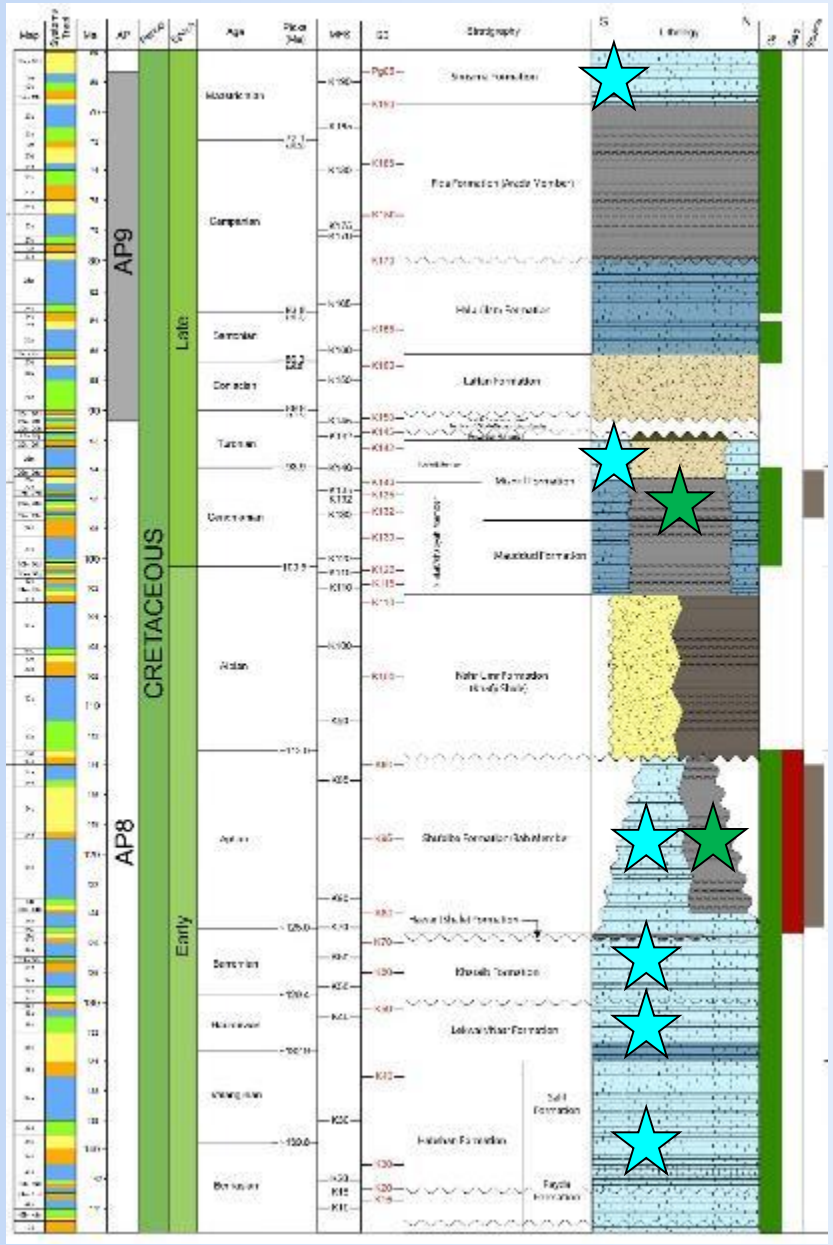
Outer ramp/slope carbonates

Coarse/fine continental clastics

Intrashelf basinal carbonates

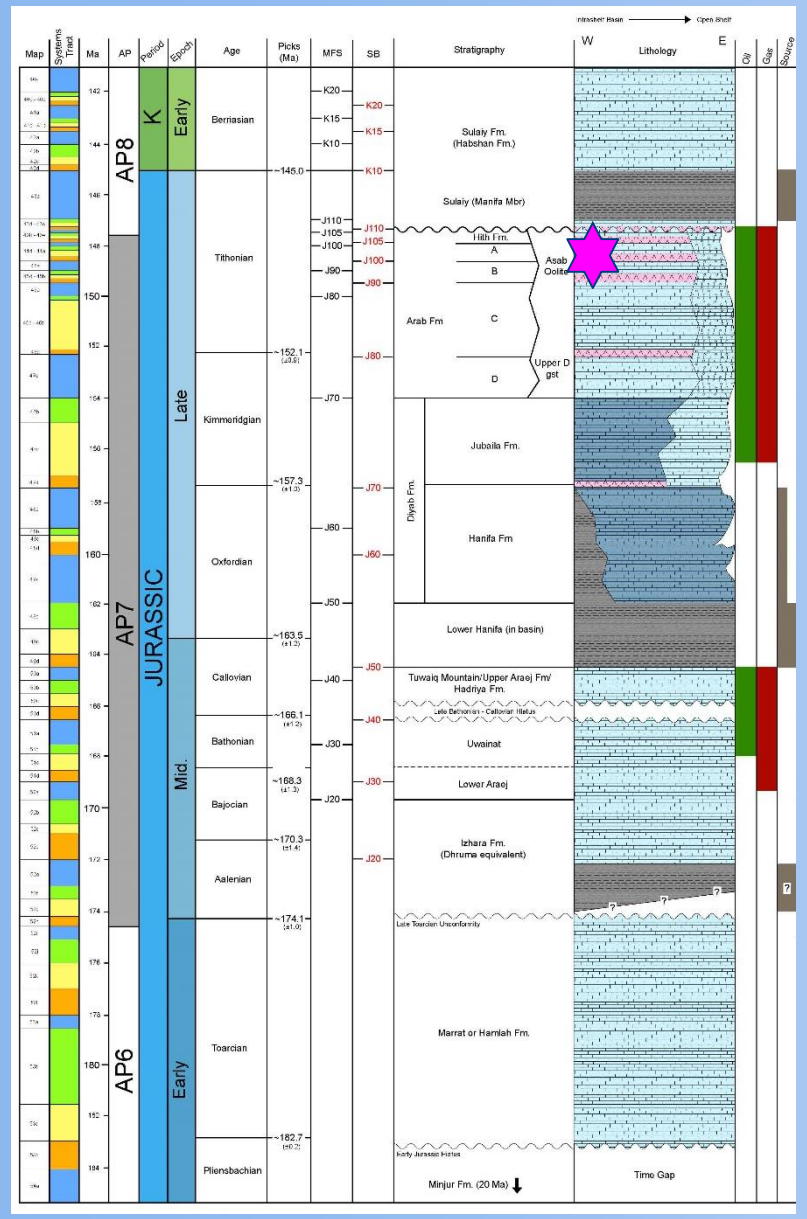
Mixed clastic-carbonate lagoon

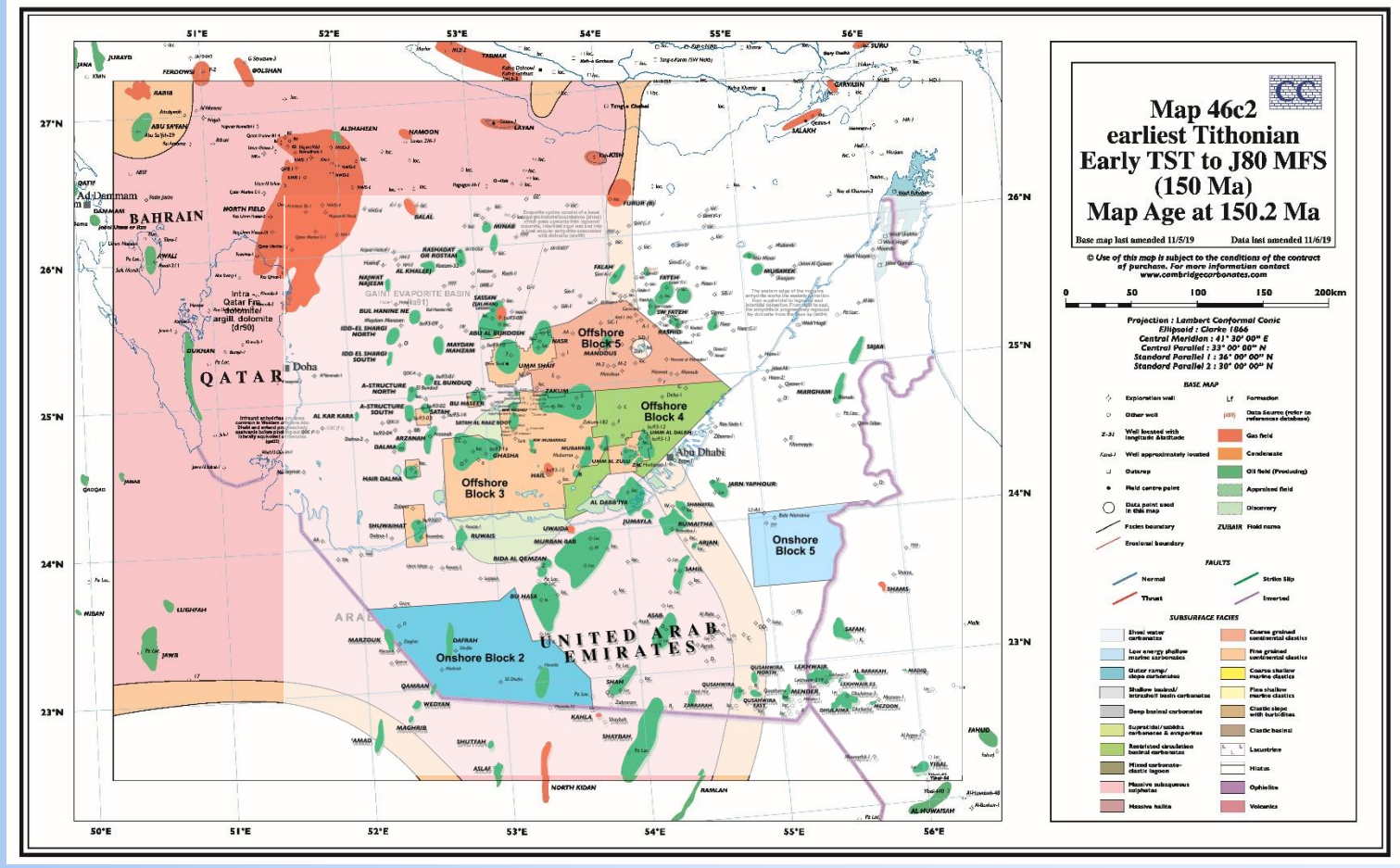




(CCL)

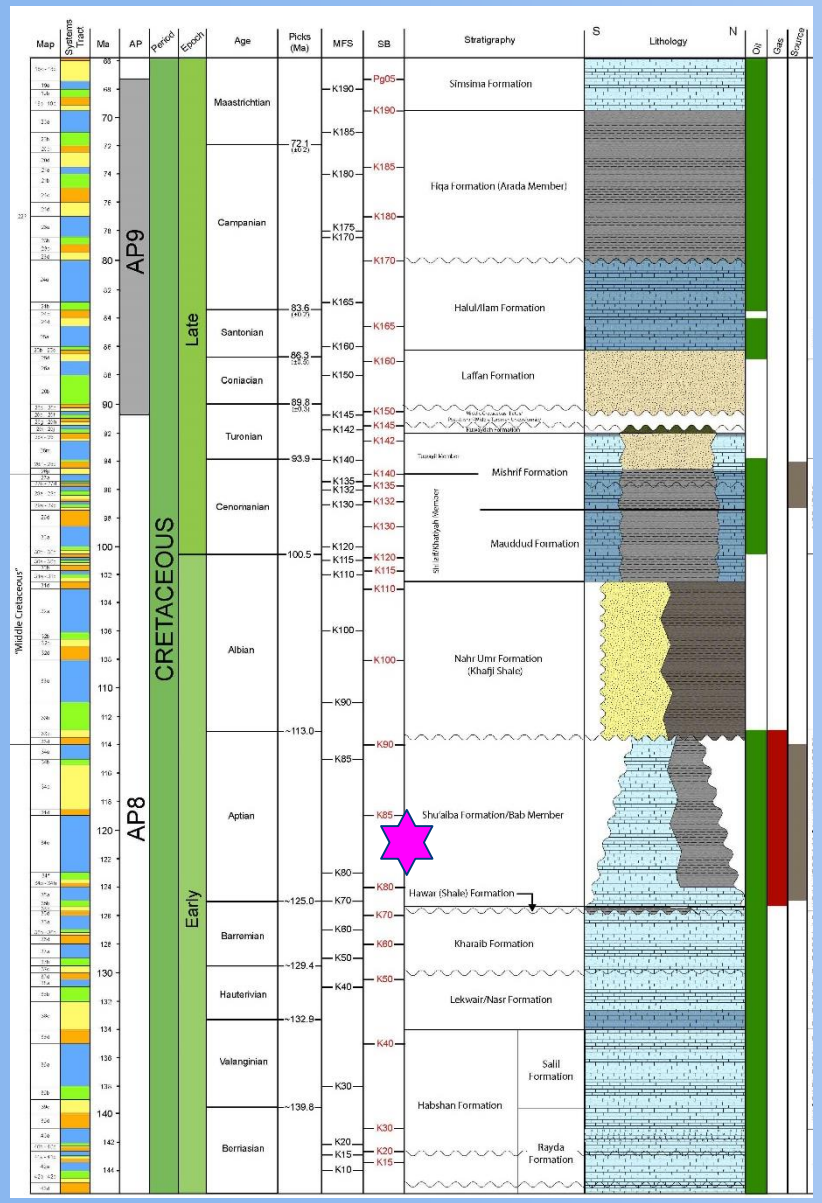
UAE - Source-reservoir-seal triplets

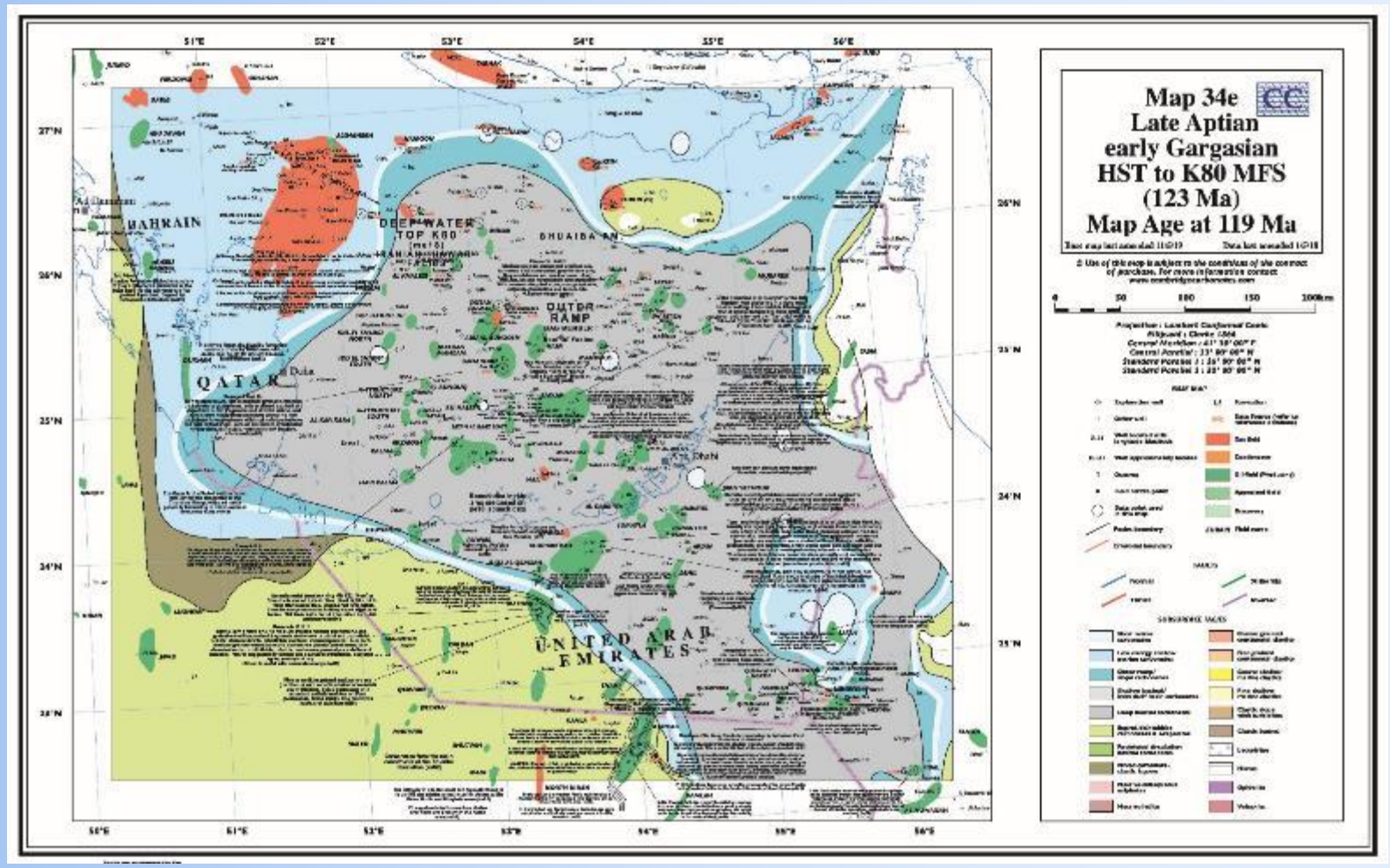




CCL in-house palaeogeography maps

UAE – Stratigraphic trapping potential





CCL in-house resources

Conclusions

- Even though there has been exploration in the Middle East for more than 100 years, there is still considerable potential on the Arabian Plate.
- Future success could relate to
  - Evaluating missed pay (single well tests of structures)
  - Evaluating stratigraphic and/or diagenetic trapping mechanisms
- Requires a good regional palaeogeographic understanding of basins in a sequence stratigraphic framework
- Requires a good understanding of the burial history, diagenesis and fracture studies
- Global analogues can be used to ground-truth these potential plays