Underexplored Opportunities in the Arabian Plate: Application of Global Analogues*

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Abstract

Historic exploration for petroleum on the Arabian Plate his rightly focused on the abundance of four-way dip closure traps. However, once these usually easy-to-define structures have been drilled, exploration ceases to be quite so straightforward and new play concepts need to be considered. This is particularly true in geographically limited areas such as Kuwait, Qatar or Bahrain.

Fortunately, the stratigraphic complexity of the Arabian Plate and typical subtlety of the contained carbonate depositional systems provides explorationists with a host of concepts that can be considered whilst revising previously worked-over areas. Possibilities fall into two basic categories:

1) Second-testing of already tested four-way dip closure structures in order to reassess those instead as combination traps.

2) Various categories of more purely stratigraphic pinch-out trap which are time- and location-dependent.

Second-testing is important because many very large structures are written off because it has been assumed that one well is sufficient to test the entire structure, when in fact it is much better to think of an anticline and its likely spill point(s) as a bulk rock volume within which there are reservoir ‘sweet spots’ that are highly productive. For example, if it had been the extremely

disappointing at the northwest end of the Kirkuk Structure which had been tested in 1927, it is quite possible that many more decades might have passed before the southeast end and its prolific Oligocene reservoirs were tested. There are many other examples where known production is highly variable along strike and these emphasise the importance of not just being dependent on one well for full appraisal; looking for such opportunities requires careful re-consideration of seismic facies as well as integration of regional facies data.

Exploration for more purely stratigraphic traps depends on our application of sequence stratigraphic principles to basin dynamics. The Arabian Plate shows numerous examples, commonly around the margins of intrashelf basins, where reservoirs pinch-out updip into tight lateral facies equivalents and offer the possibility of subtle but volumetrically large traps. Likely examples may be suggested for the margins of many of the Jurassic intrashelf basins, the Cretaceous Bab and Shilaif basins in the southern Gulf, and many as yet unnamed basins in both Iran and Iraq, of Triassic to Cretaceous age. Additional possibilities lie in looking for lowstand wedges (containing either clastics or carbonates) within these intrashelf basins as well as within the Upper Cretaceous pull-apart basin systems of the northern and northeast part of the plate (e.g. reservoirs in the Lopha Limestone or Emam Hassan limestones of Iran).

Another category of play consists of exploration for more traditional buildup stratigraphic trap plays, which may be expected locally within some of the larger intrashelf basins and are proven locally within the developing foreland basin geology along the Zagros margin. A sub-category here consists of carbonate platforms of Palaeogene age that seeded on end-Cretaceous inversion anticlinal highs, and which can be seen as field analogues (Jebels Sinjar and Bishri) but have not so far yielded subsurface production. The final category of play concept is a diagenetic trap. Principally this consists of looking for hydrothermal dolomite trap analogous to the Trenton-Black Rock reservoirs of the U.S. Palaeozoic, where dolomitized fault zones with enhanced porosity have lateral seals provided by the undolomitized tight host limestones. In these cases, quite commonly, it is not possible to map any structural closure whatsoever and the trap is entirely due to diagenesis.

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Discussion points

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)

EXPLORING STRATIGRAPHIC TRAPS

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

Stratigraphic traps in intrashelf basins

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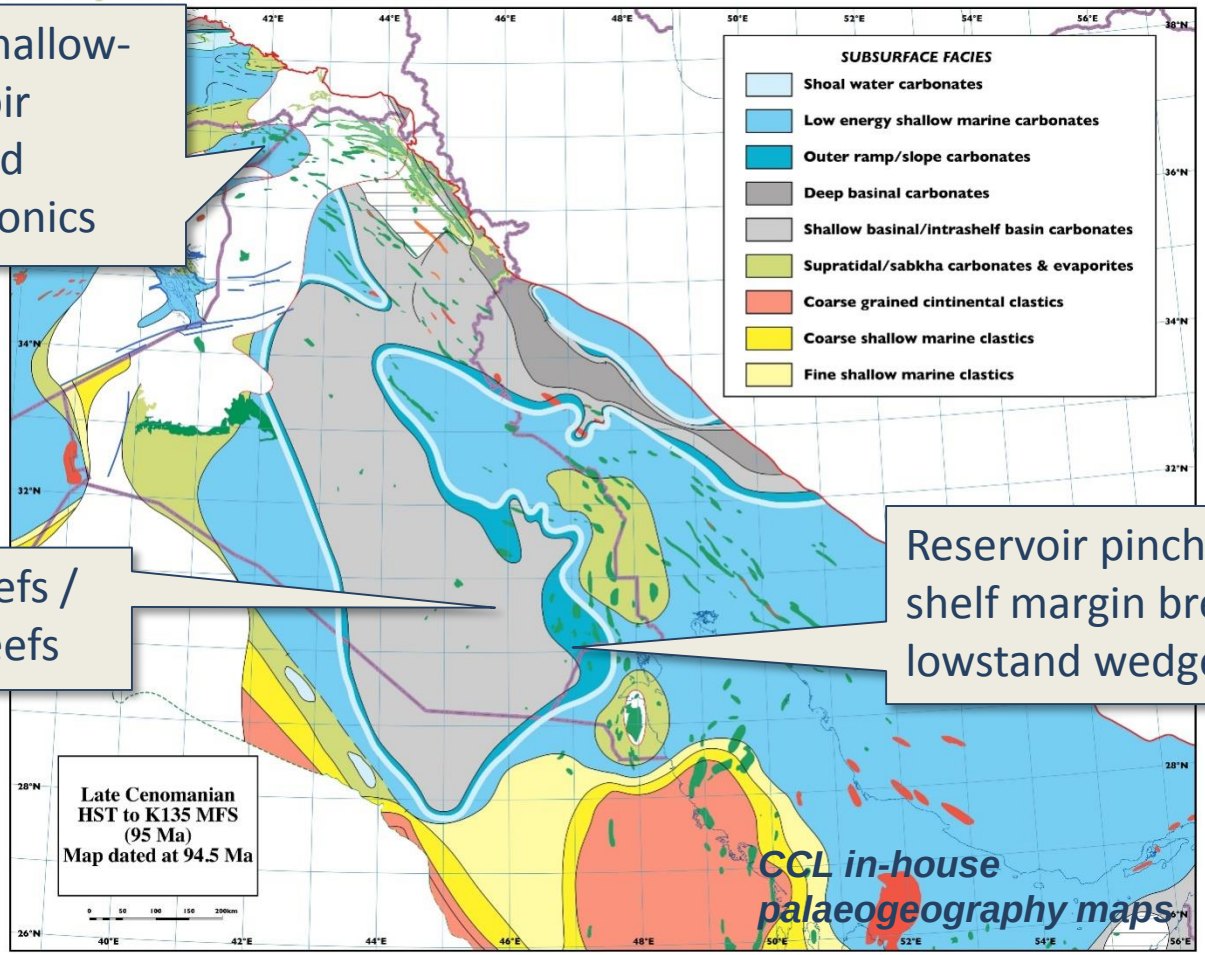
Interplay of shallow-water reservoir deposition and inversion tectonics

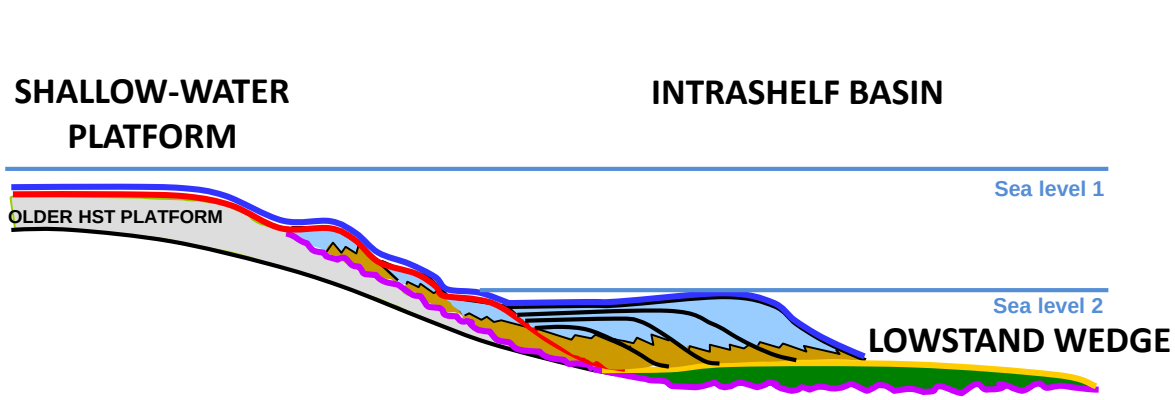


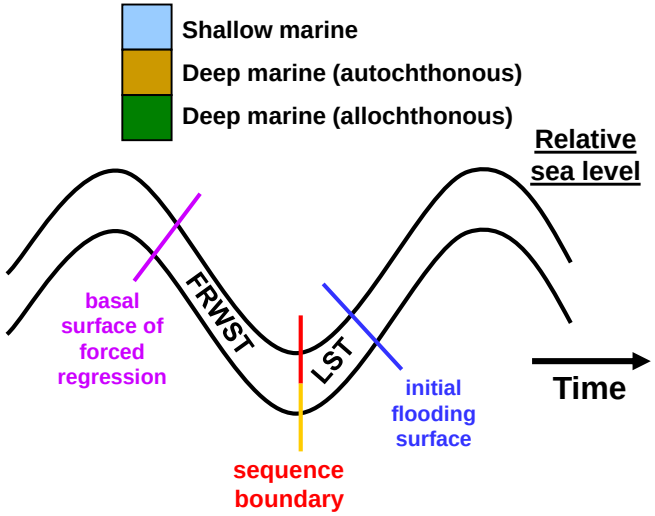
Isolated reefs / pinnacle reefs

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

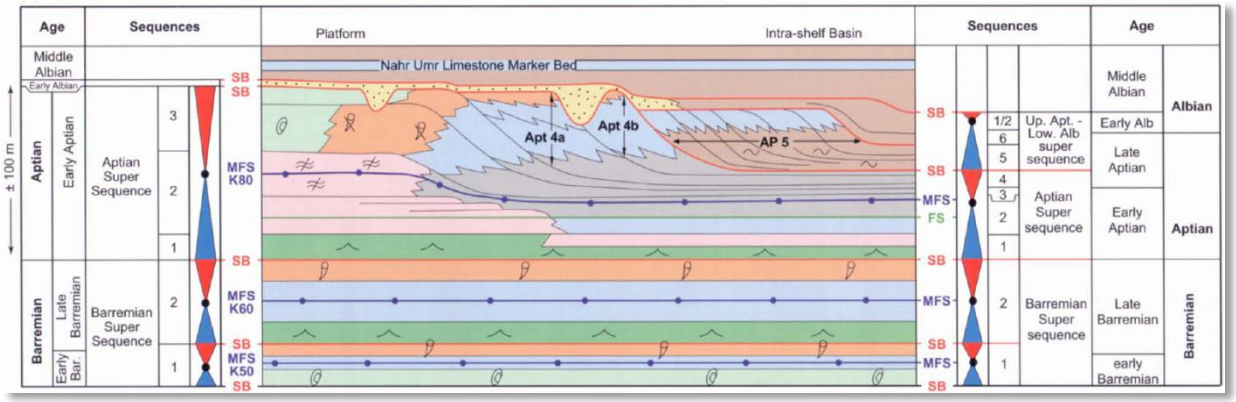




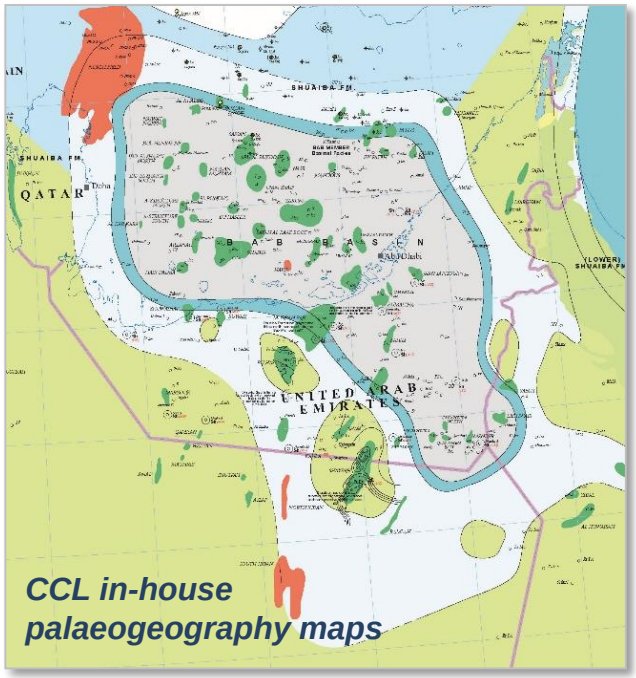
- During periods of sea level lowstand, development of shallow-water lowstand platforms flanking intrashelf basins
- Packages typically form separate reservoirs from the shelf facies themselves and may not be laterally connected
- Recognition: wedge-shaped seismic geometries abutting against the former highstand carbonate platform
- Could be shallow-platformal reservoir facies and/or or reworked breccias

Stratigraphic traps: lowstand wedge play

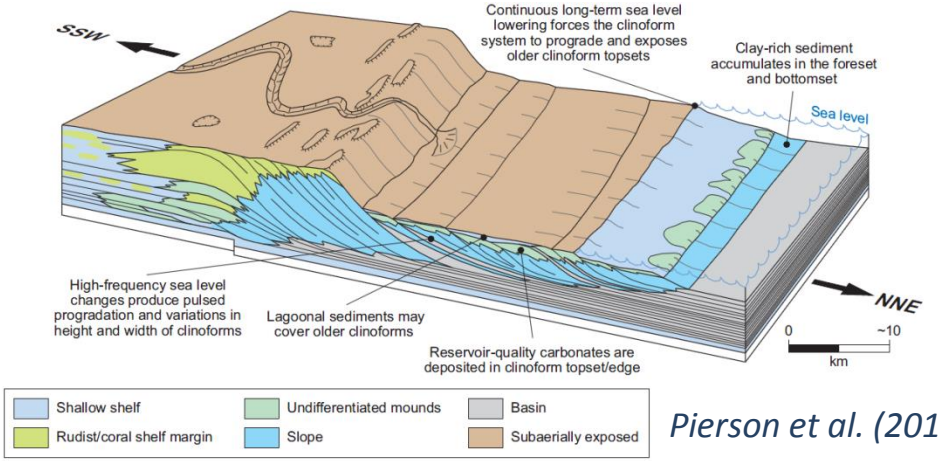
- Lowstand platforms - well documented Upper Shu'aiba progrades in Aptian Bab Basin, UAE



Van Buchem et al. (2010)



Late Early Aptian, K70 MFS



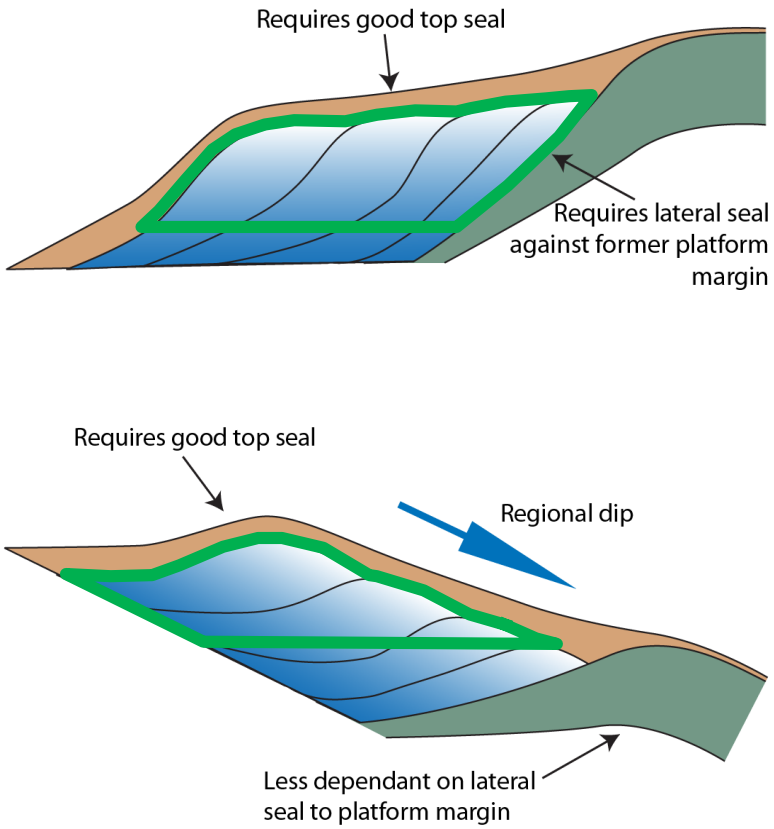
Pierson et al. (2010)

- Can this play work here, or elsewhere, as a pure 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
- Trapping mechanism
  - For pure stratigraphic traps, the sealing rocks are critical
  - Regional dip (lower risk)
- Could occur in numerous stratigraphic intervals (Jurassic/Cretaceous/Cenozoic)



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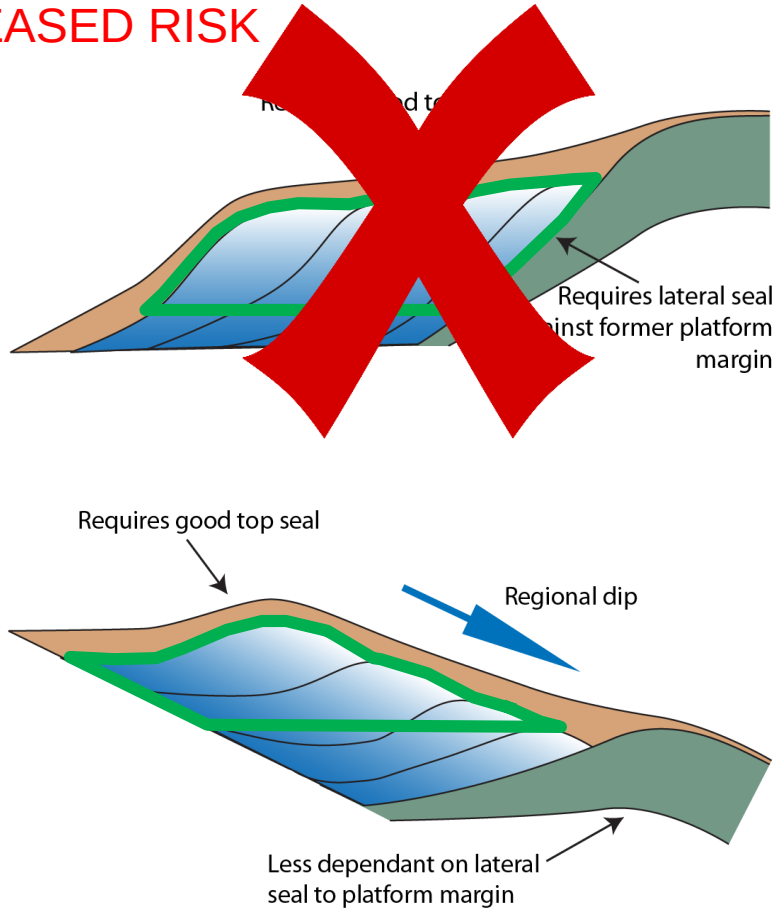
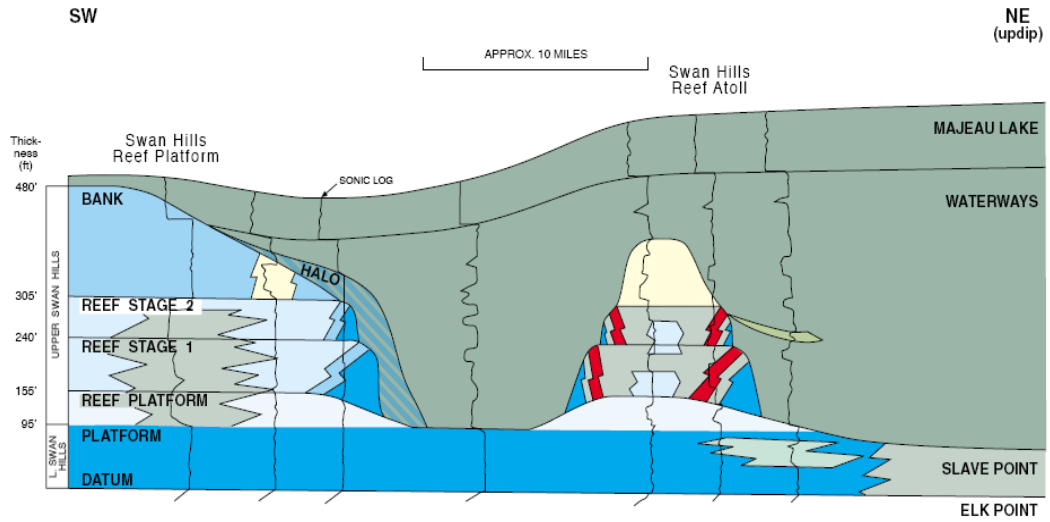
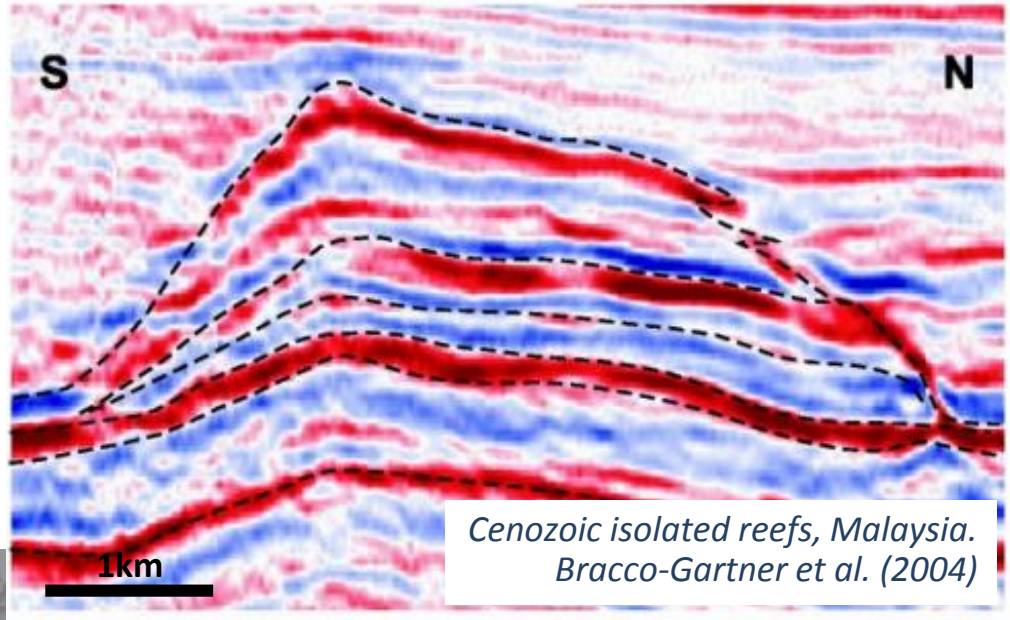


Stratigraphic traps: Isolated reefs

- Isolated pinnacle reefs, that are commonly surrounded by tight basinal facies
- Often seeded on antecedent topography at the start of long lived transgressions
- Surprisingly few documented on Arabian Plate
- Numerous field analogues worldwide: e.g. USA, Canada, SE Asia
- Recognition: mounded features on seismic, demonstrable “self built” geometries

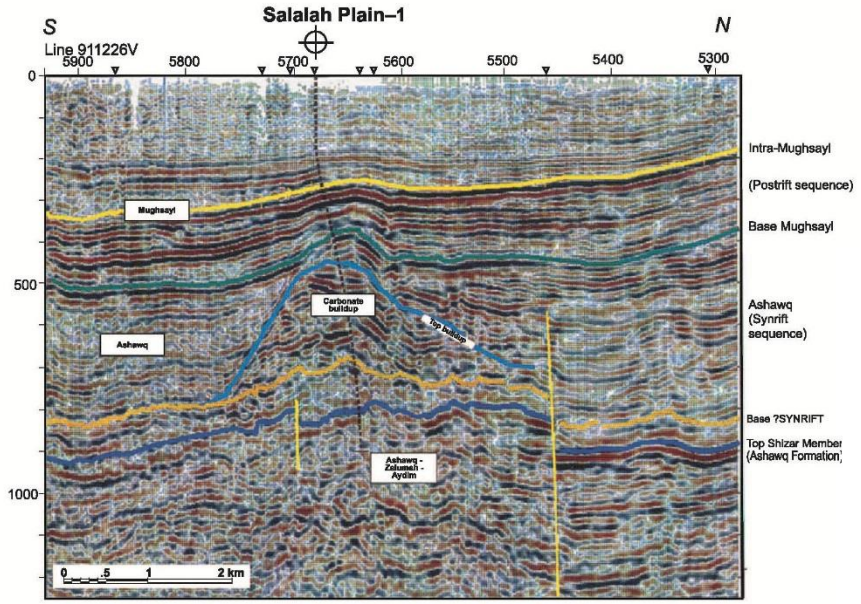


Devonian isolated reefs, Western Canada. Stoakes (1992)



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

Stratigraphic traps: Isolated reefs on Arabian Plate?



Borgomano and Peters (2004)

- Potential play type in Jurassic/ Cretaceous/ Cenozoic intrashelf basins

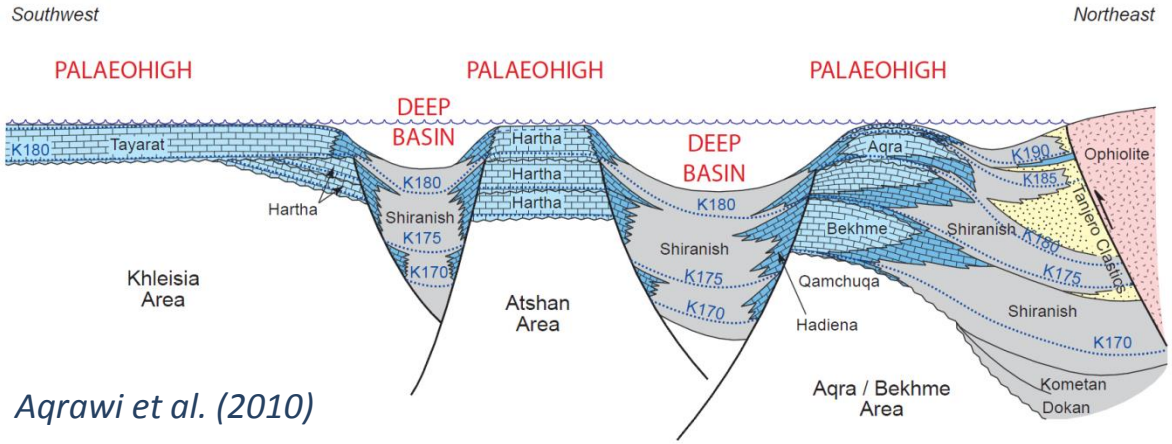
<u>Key factors</u>

- Source/seal/reservoir/trap all-in-one
- Recognition of the play requires seismic mapping of buildup geometries

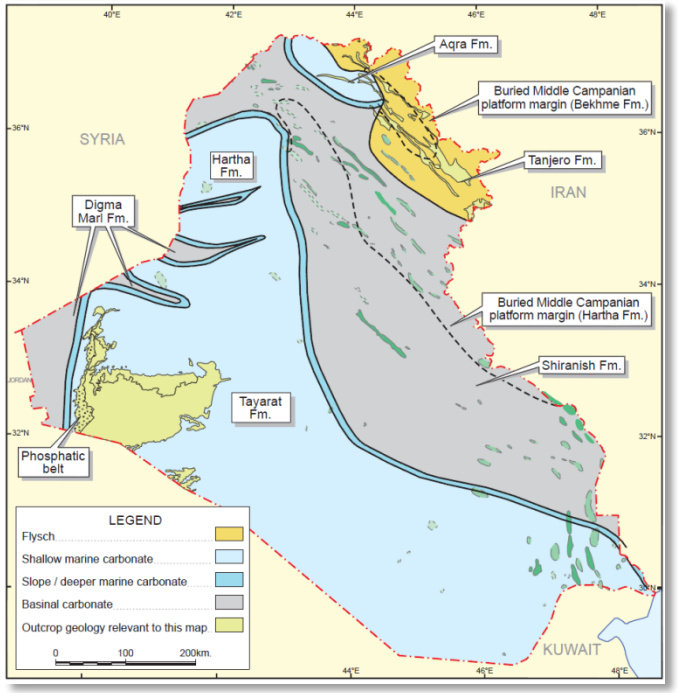
- Paleogene buildups
  - Oman (Salalah Plain)
  - Syria (Jebels Sinjar and Bishri) on Cretaceous inverted highs
- Early Cretaceous – Darquain field, Iran
- Late Cretaceous
  - NE Syria and SE Turkey

Stratigraphic traps: inverted palaeohigh "synclines"

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

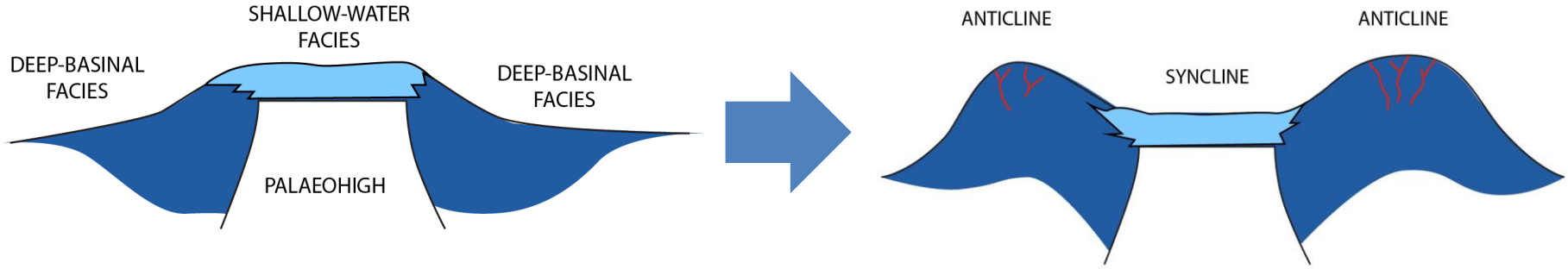


Aqrawi et al. (2010)

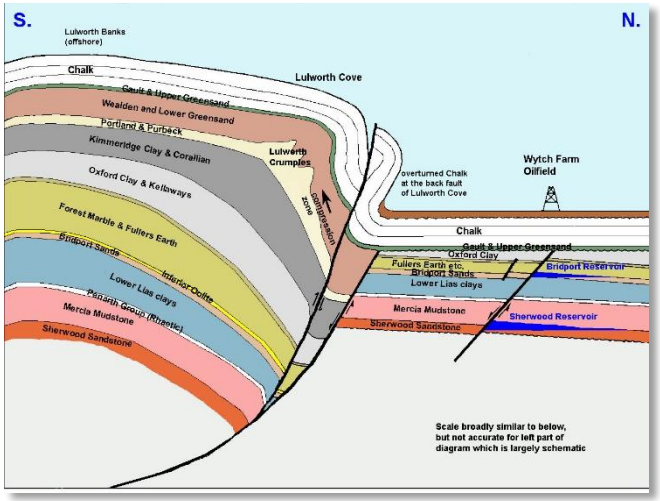


Late Campanian-Maastrichtian palaeogeography map

Stratigraphic traps: inverted palaeohigh “synclines”

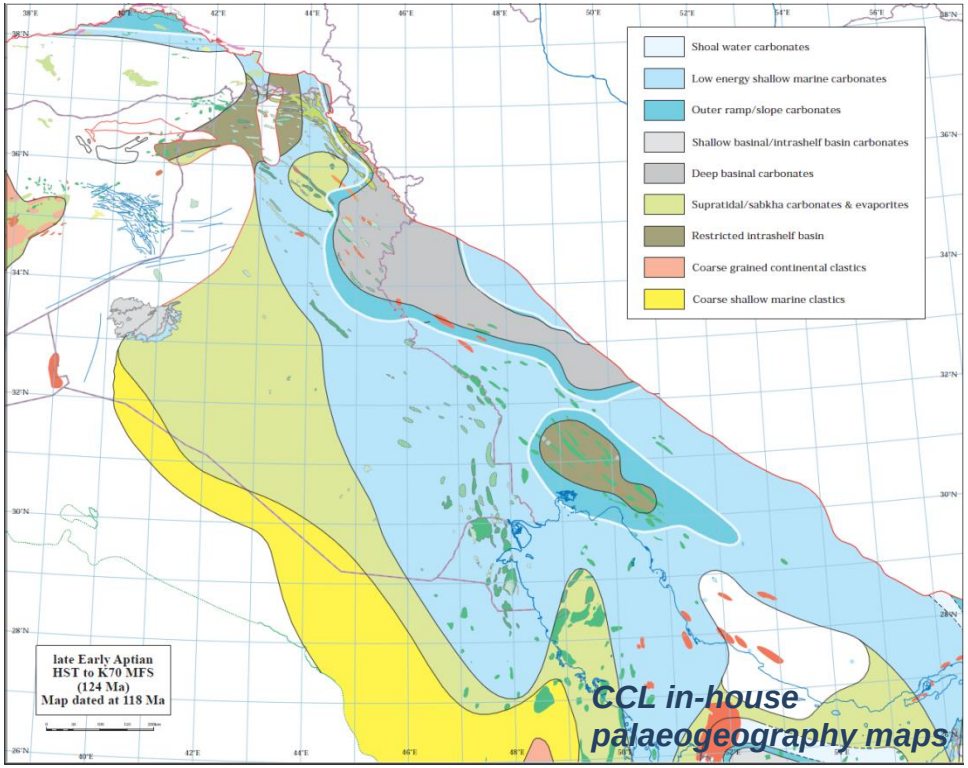


- Neogene structuration - inversion anticlines (Foothills zone)
- Major anticlines have been drilled targeting basinal facies in crestal areas, whilst the shallow shelf dominates the limbs.
- Future exploration could explore synclines/anticline limbs for shelf facies – e.g. Atshan well
- Dominantly stratigraphically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



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

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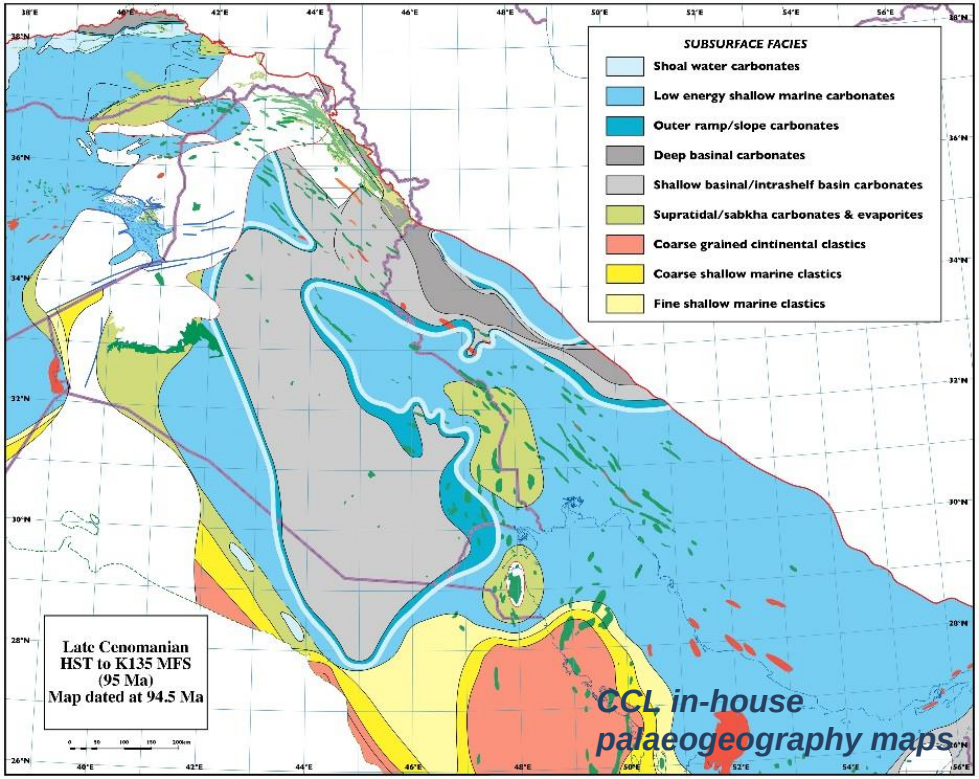

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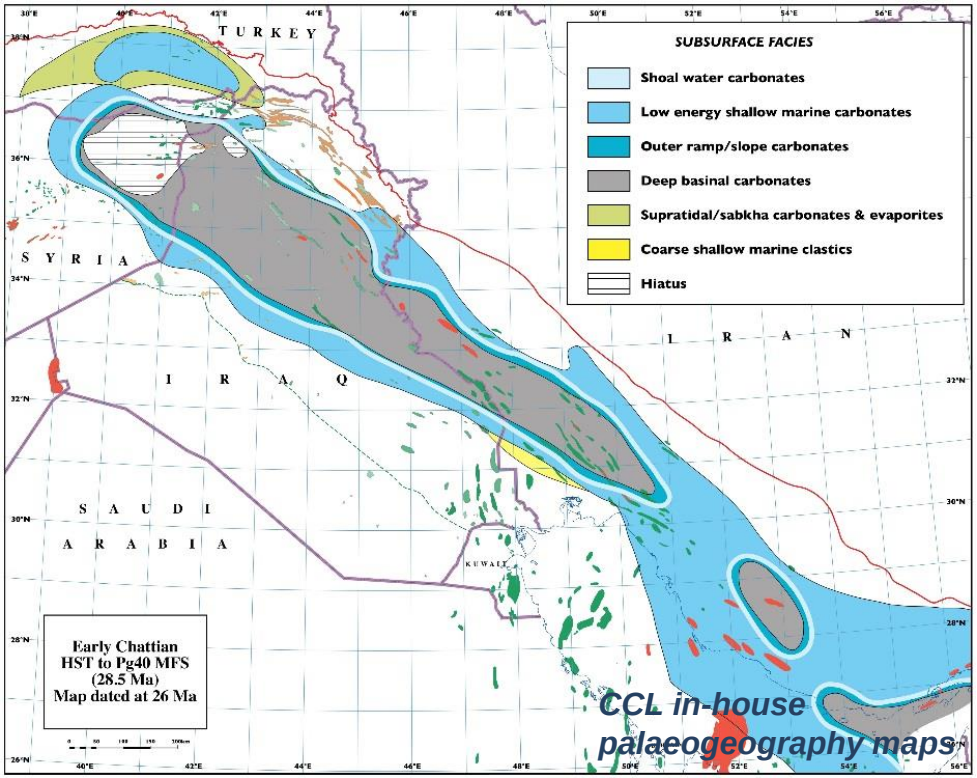


EXPLORING DIAGENETIC TRAPS

- Hydrothermal dolomites
- Evaporite collapse breccias (e.g. Barsarin Fm)
- 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

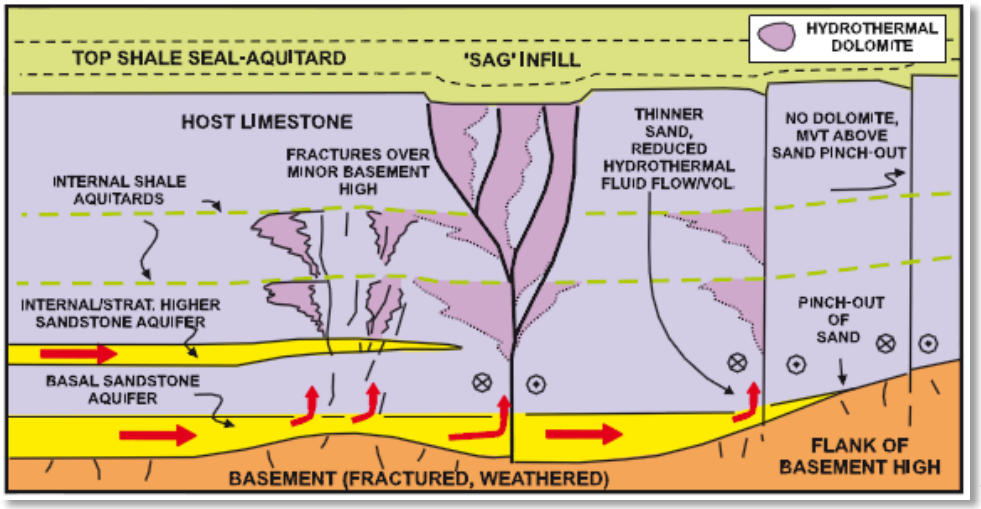


Photo courtesy of Dave Hunt and Ian Sharp

Davies and Smith (2006)

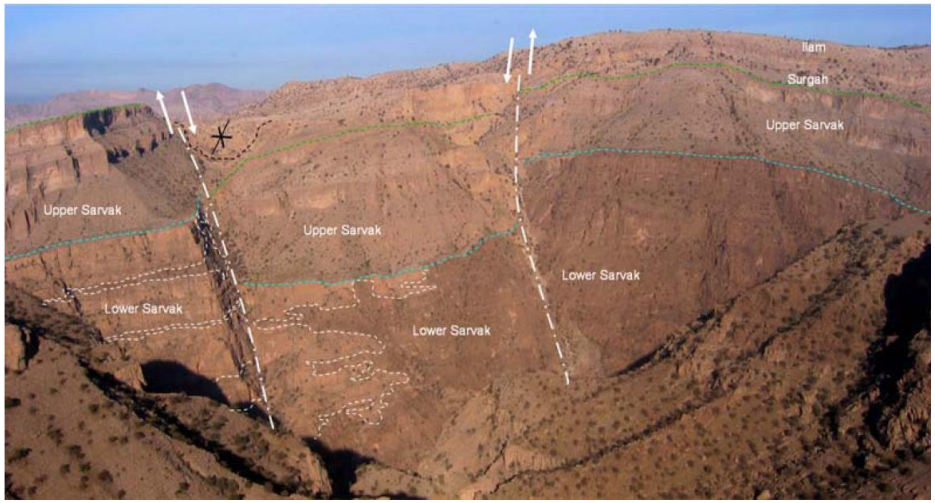
- Hydrothermal dolomites can add additional matrix porosity to what would traditionally be considered a fractured reservoir.
- Independent of deposition facies: reservoir can occur in any part of a carbonate depositional system

Diagenetic traps: HTD examples in the Middle East

- To date all documented hydrothermal dolomites in Middle East CONTRIBUTE to reservoir, but do NOT form diagenetic traps.

★ subsurface ★ outcrop

Diagenetic traps: HTD examples in the Middle East



Anaran, Iranian Zagros. Sharp et al. (2010)

★ subsurface ★ outcrop

Diagenetic traps: HTD examples in the Middle East

★ subsurface ★ outcrop

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Diagenetic traps: HTD examples in the Middle East

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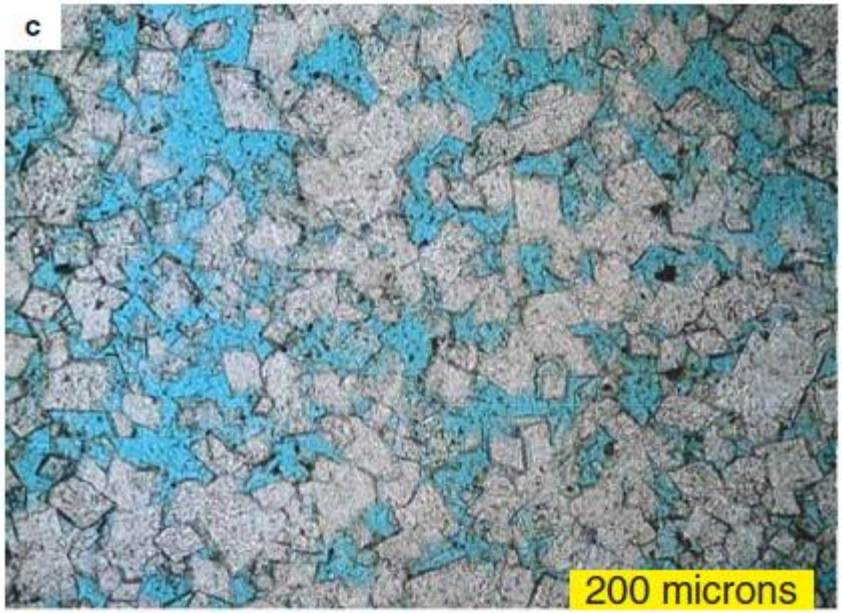
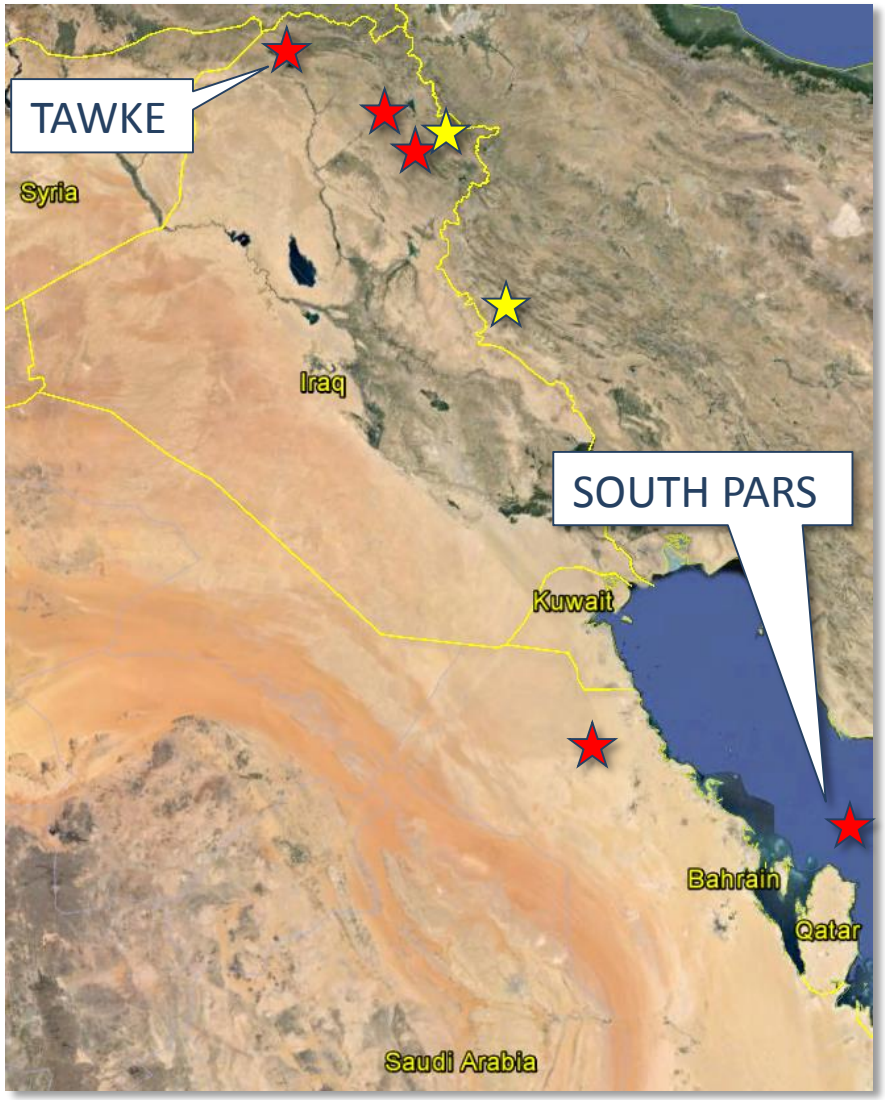


Taq Taq field. Garland et al (2010)

★ subsurface ★ outcrop

Diagenetic traps: HTD examples in the Middle East



★ subsurface ★ outcrop

Diagenetic traps: HTD examples in the Middle East

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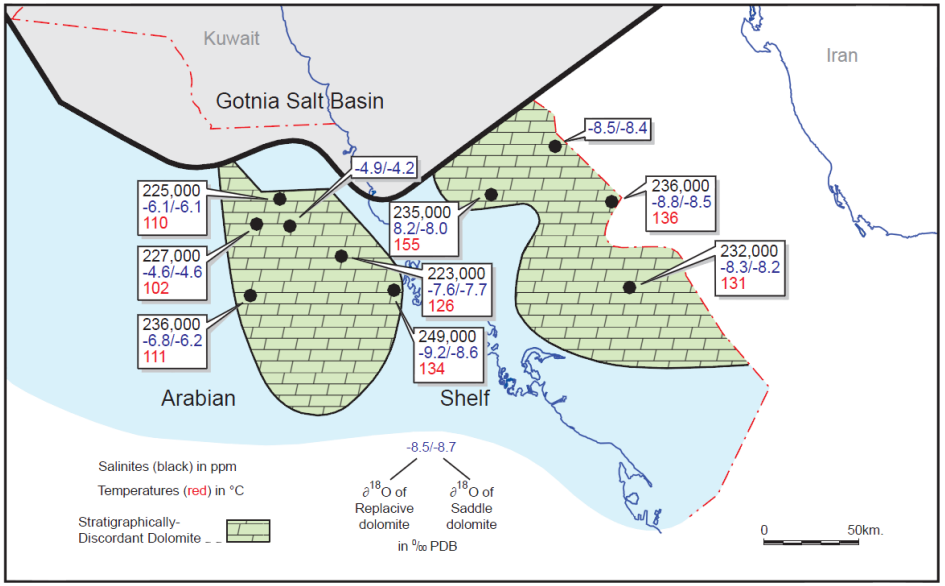
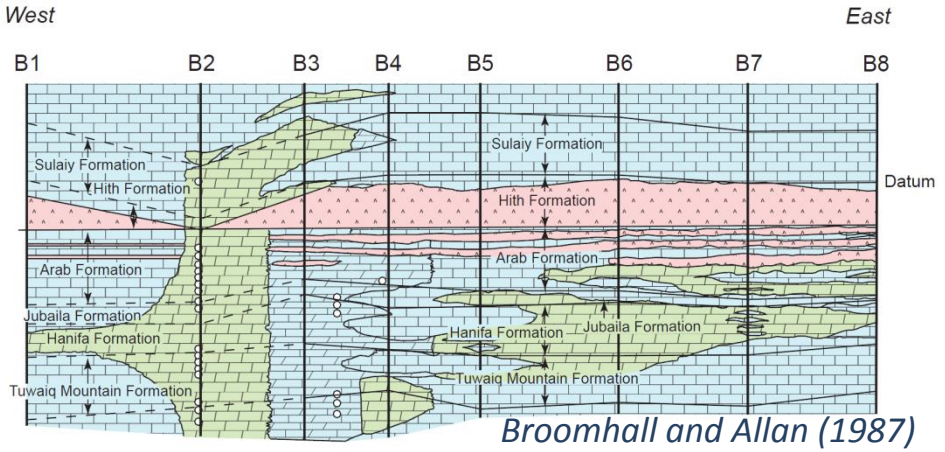


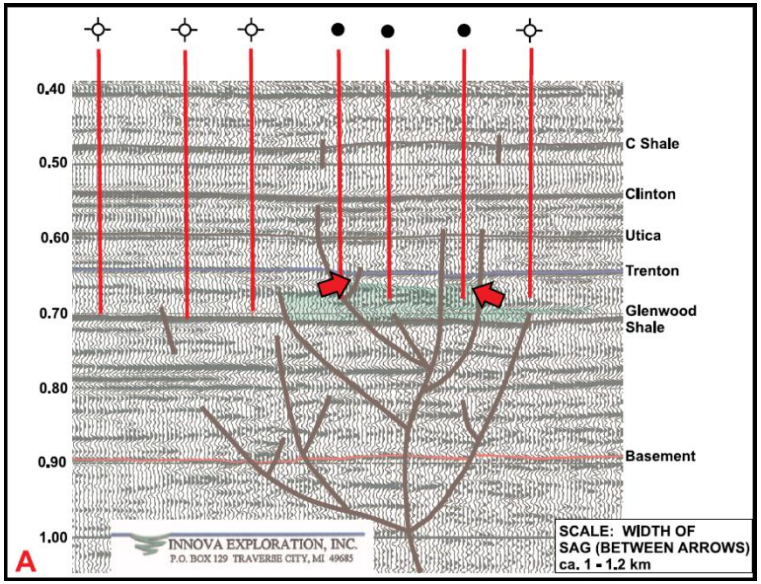


Broomhall and Allan (1987)

★ subsurface ★ outcrop

Diagenetic traps: hydrothermal dolomite analogues

- >50 fields in North America where HTD contributes to production
- DIAGENETIC TRAPS - Albion-Scipio, USA; Goldsmith-Lakeshore, Canada
- Sealed laterally by tight limestones, top seal shales
- Known dolomite bodies up to 7km wide (generally ~1km), 10's km long along strike
- North America examples – associated with wrench faulting
- Middle East
  - Most to date related to extension/ compression
  - However, wrench faulting exists – potential target?
- Requires understanding of fracturing/ structuration and diagenesis

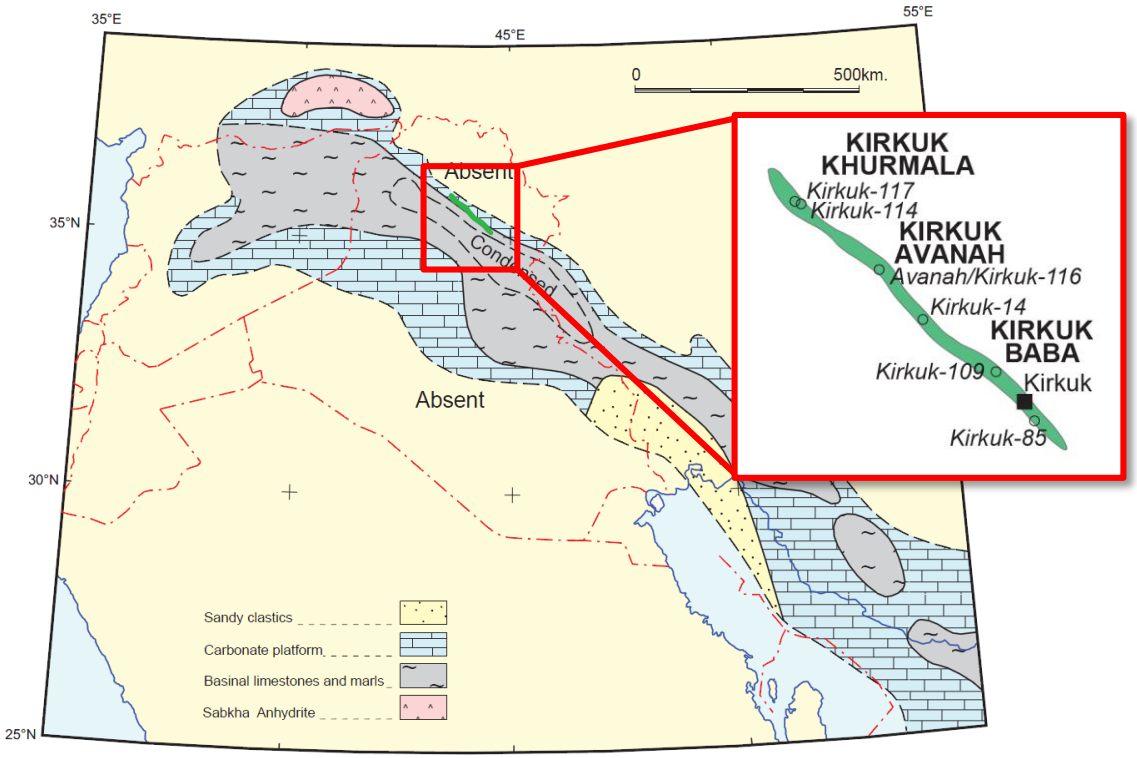


Davies and Smith (2006)

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

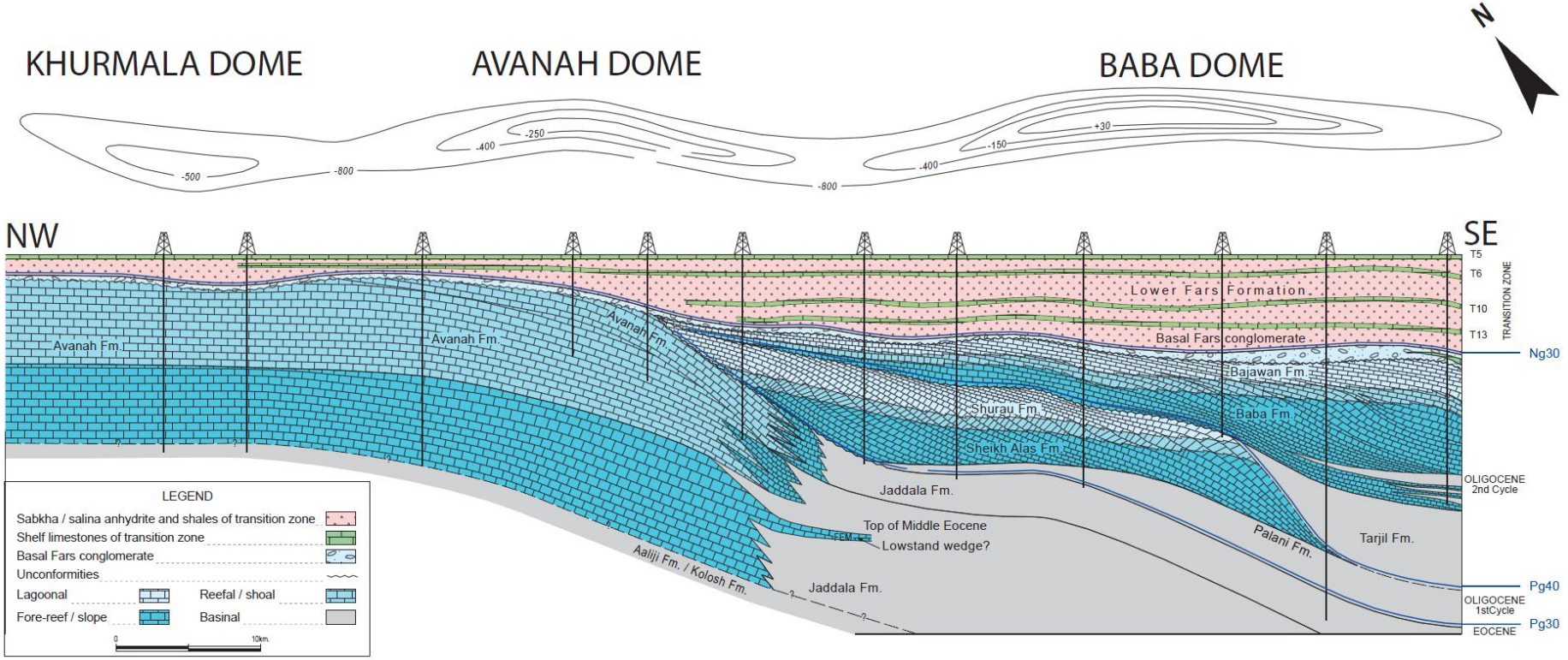
Facies variability – Kirkuk field



Oligocene palaeogeography map (Aqrawi et al., 2010)

- Super-giant field, 32.5 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 – very disappointing

Facies variability – Kirkuk field



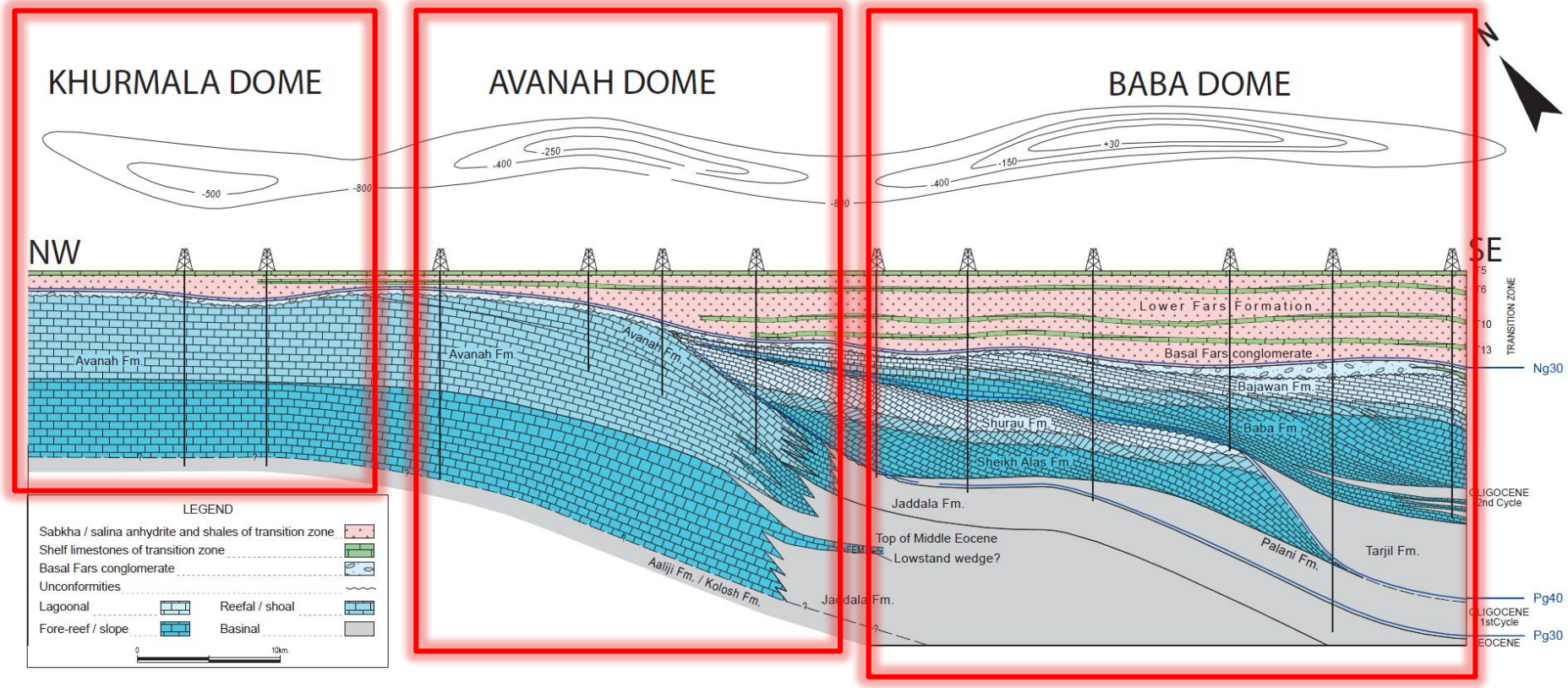
Reservoir zones along the Kirkuk structure, after Daniel (1954)

Facies variability – Kirkuk field

Undeveloped. Baba and Shiekh Alas Formations not present. Avanah Formation tight.

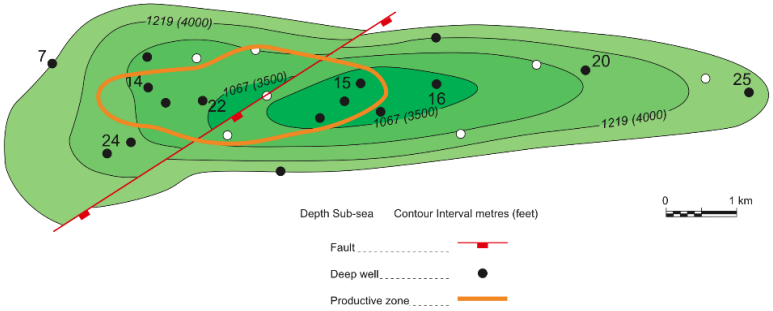
Baba and Shiekh Alas Formations not present. Porous shoal limestones in Avanah Formation.

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

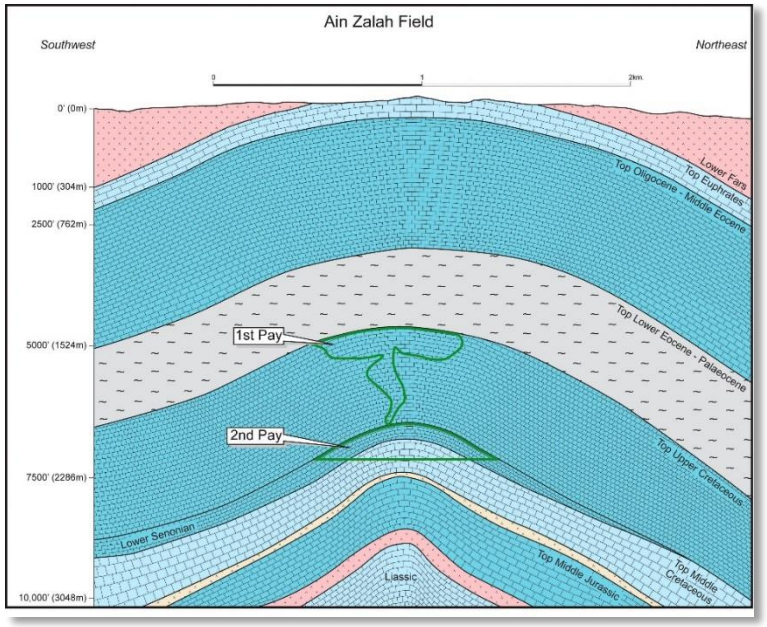


Reservoir zones along the Kirkuk structure, after Daniel (1954)

Fracture intensity, Ain Zalah Field



Elzarka and Ahmed (1983)

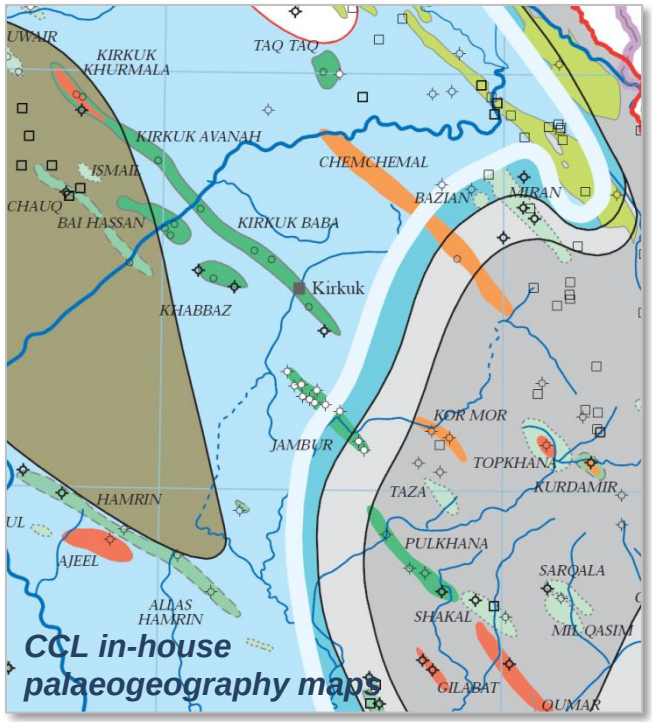


Aqrawi et al. (2010) after various sources

- 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



Latest Albian palaeogeography (K110 MFS)

Conclusions

- Even though there has been exploration in the Middle East for more than 100 years, there is still potential in this mature basin.
- 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