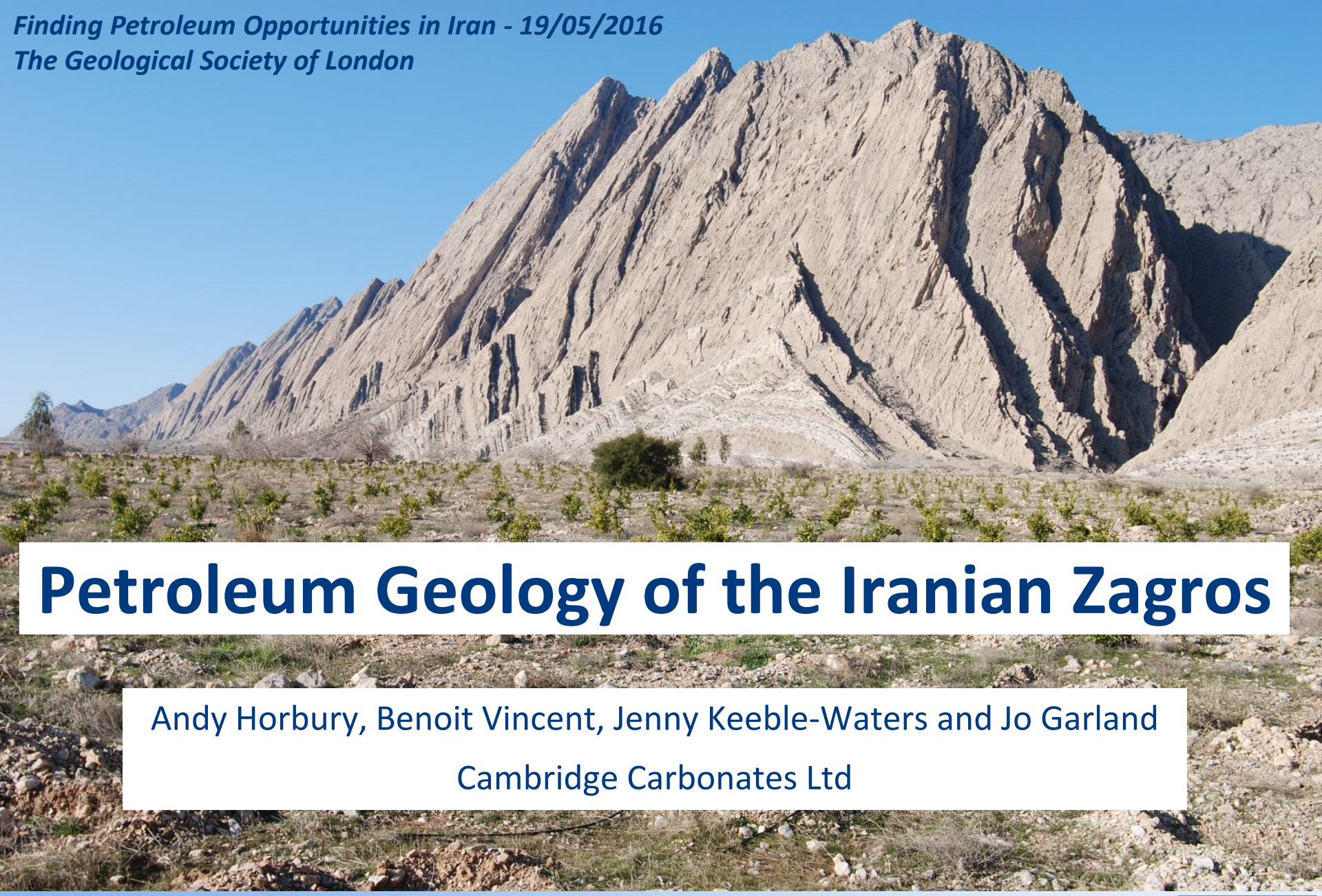
*Finding Petroleum Opportunities in Iran - 19/05/2016*
*The Geological Society of London*



# Petroleum Geology of the Iranian Zagros

Andy Horbury, Benoit Vincent, Jenny Keeble-Waters and Jo Garland

Cambridge Carbonates Ltd

# Background

CC have worked on Iran projects since the mid-1990's:

- Evolving palaeogeographic map project (originally an extension of Kurdistan work)
- Fieldwork (Lurestan, Khuzestan, Fars province) on Asmari to Cretaceous
- Field characterization of Marun and Bibi Hakimeh
- Big petrographic/CL study on dolomites in the Anaran area
- South Pars project on Khuff reservoirs
- Extensive work in adjacent areas (Iraq, Kuwait)
- Presently integrating the most recently published work into mapping project

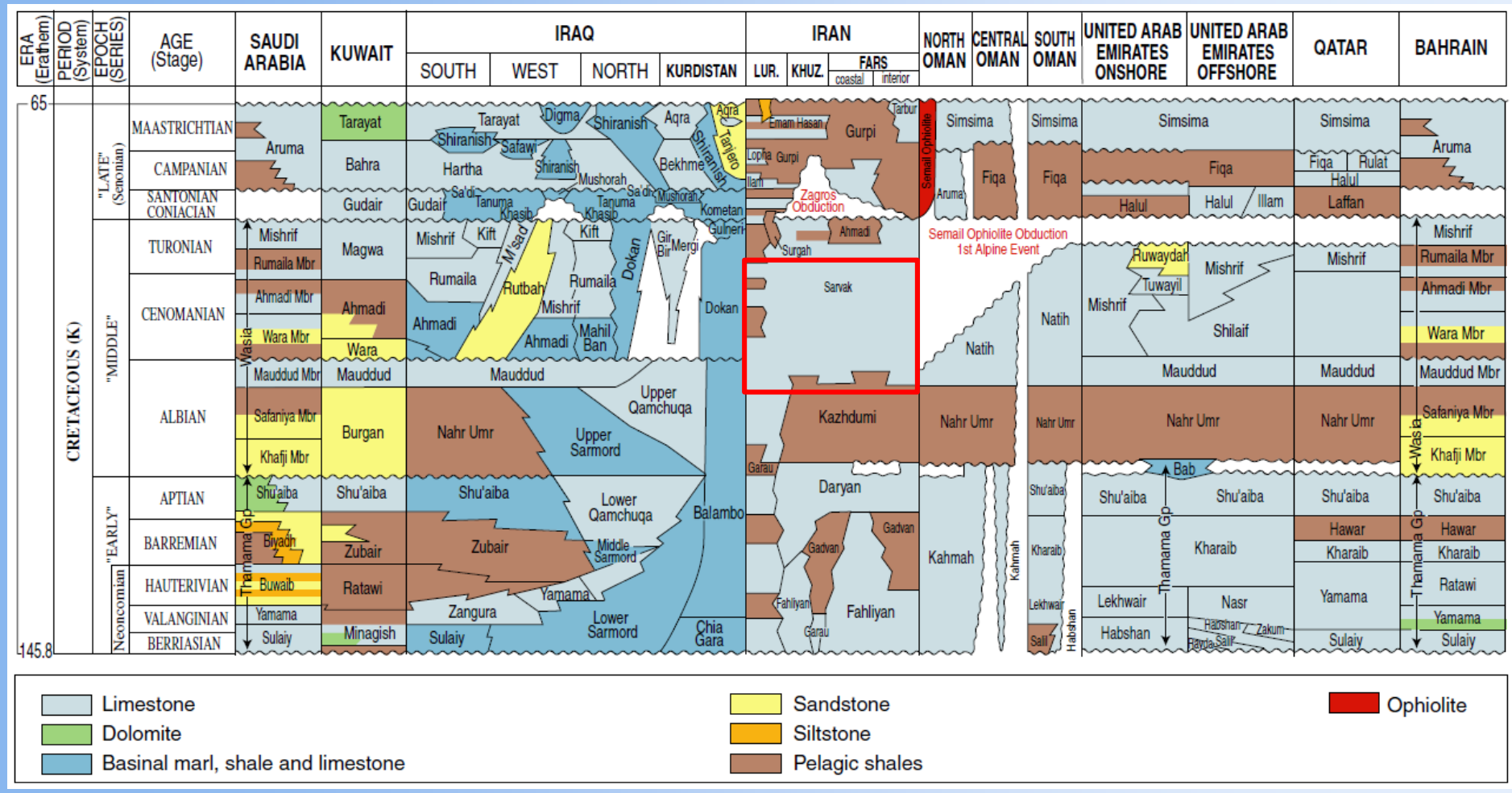
# Objectives

Stratigraphic and structural complexity of the Iranian Zagros provides explorationists with a host of possible play concepts:

- Exploring stratigraphic traps/Second testing existing structures (missed pay)
  - Cretaceous: Sarvak Formation, an example of spatial heterogeneity
  - Cretaceous: Dariyan Formation, intrashelf basins and lowstand wedges
  - Cretaceous: Ilam Formation, Late Cretaceous intrashelf basins
  - Cretaceous: Fahliyan Formation, isolated platforms
  - Cenozoic: Asmari Formation, evolution through time of reservoir heterogeneity
  - Fracturing: An added complexity
- Exploring diagenetic traps

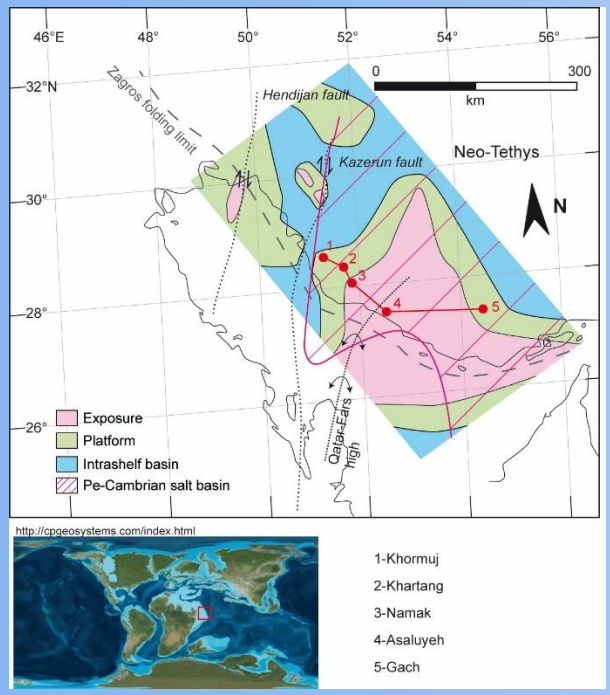
# Sarvak Formation

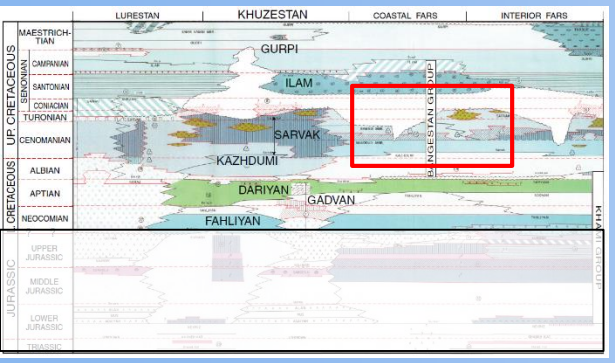
# Spatial heterogeneity – Sarvak

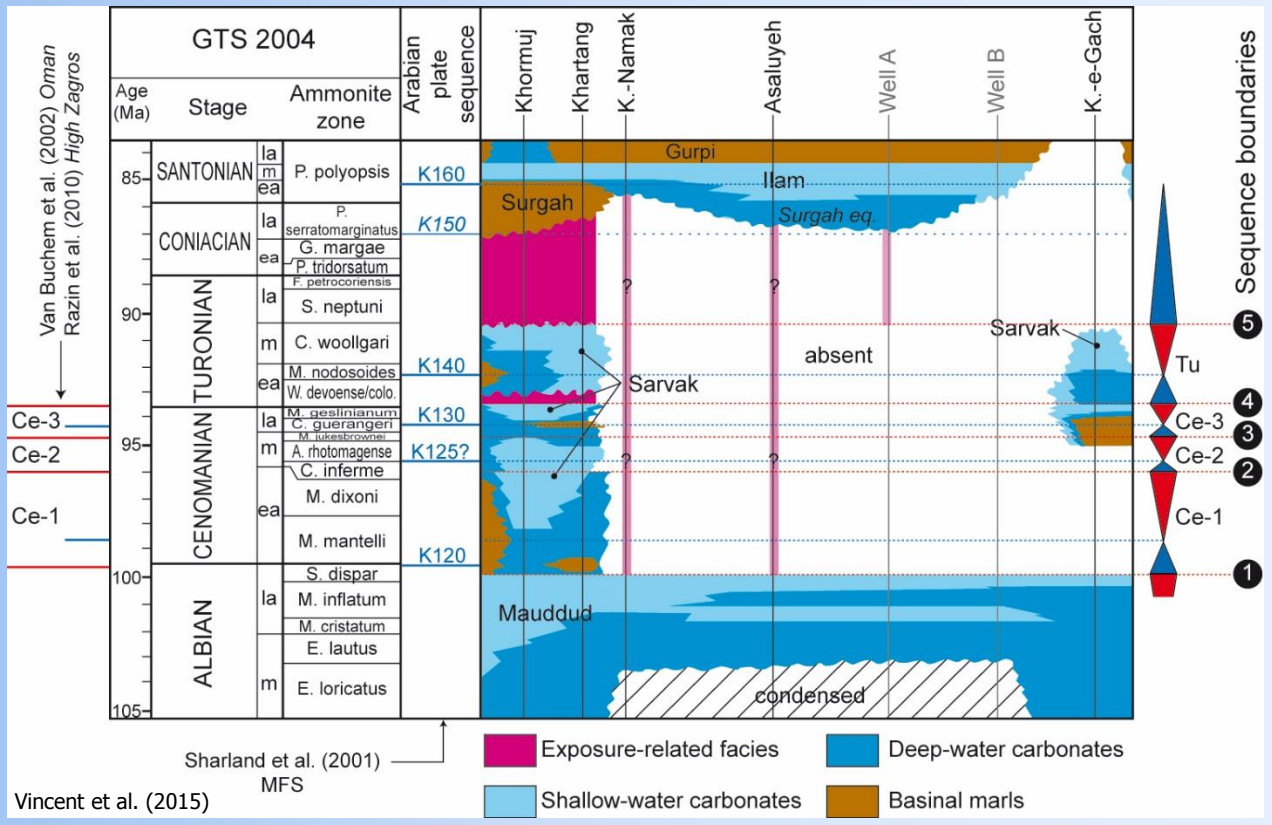



Al Husseini (2000)

# Spatial heterogeneity – Sarvak

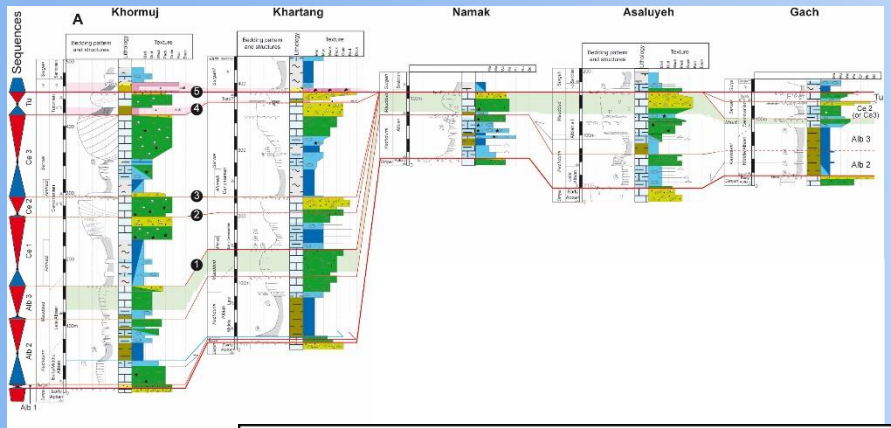


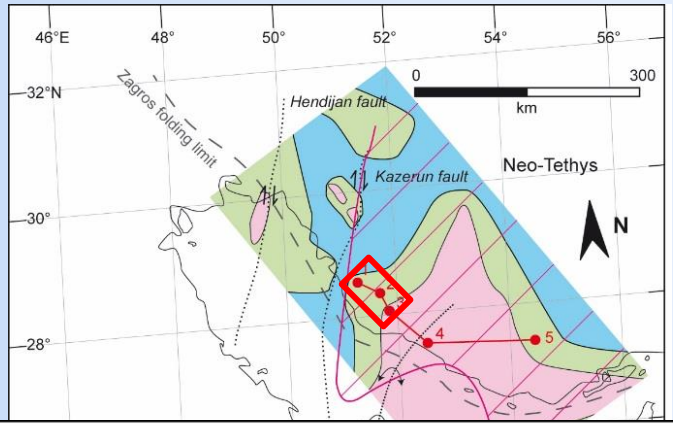



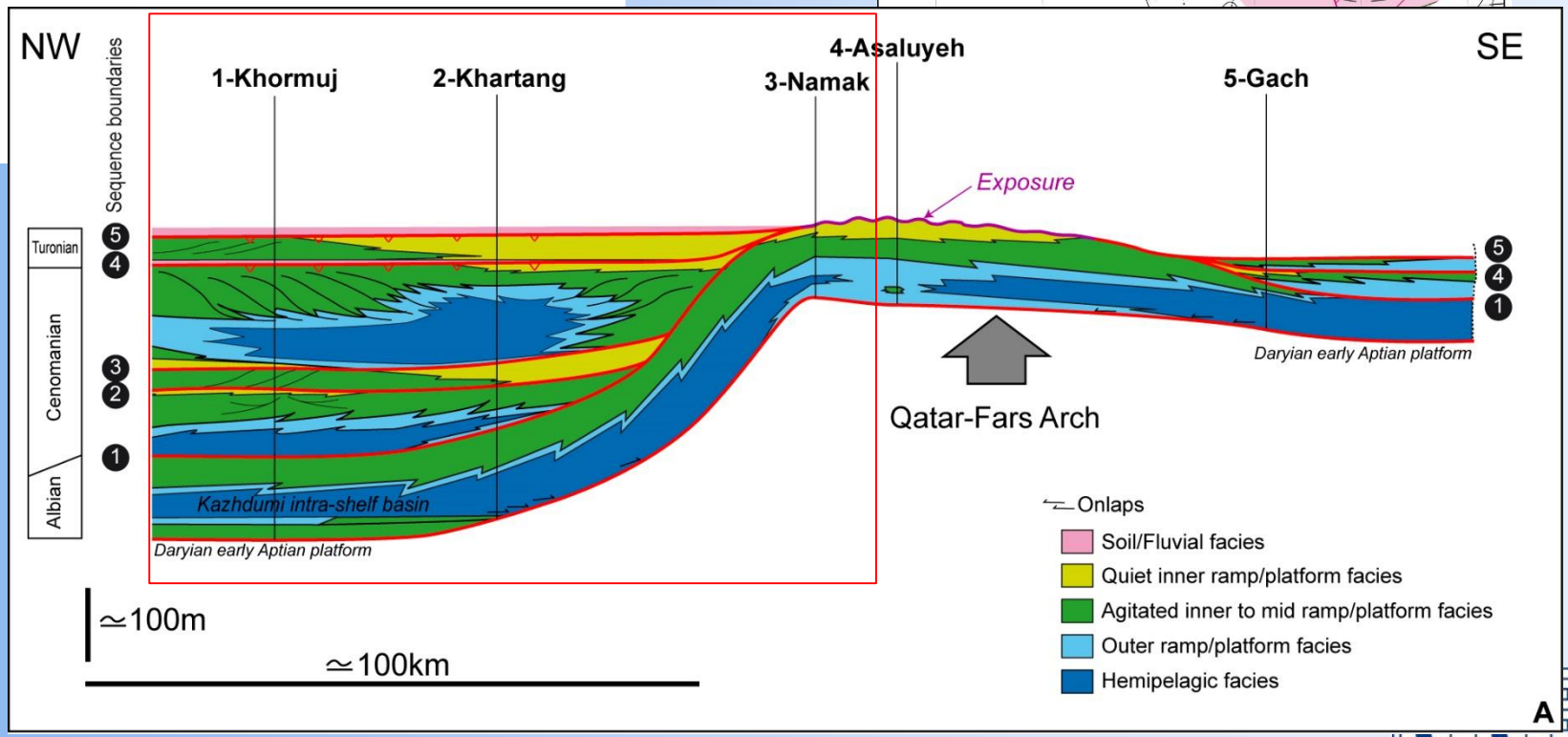

Vincent et al. (2015)

# Spatial heterogeneity – Sarvak



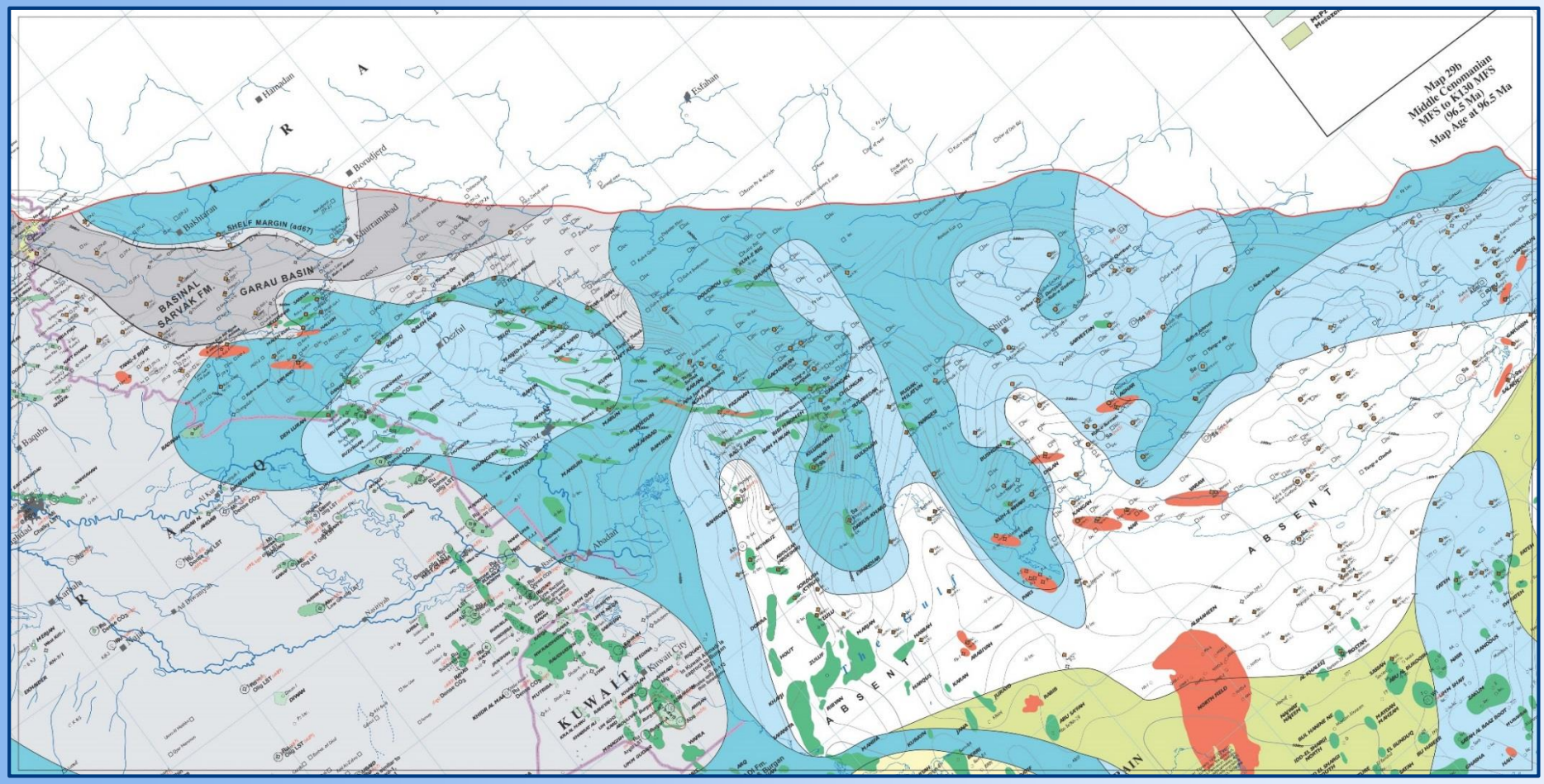

Vincent et al. (2015)



# Spatial heterogeneity – Sarvak


Khormuj section

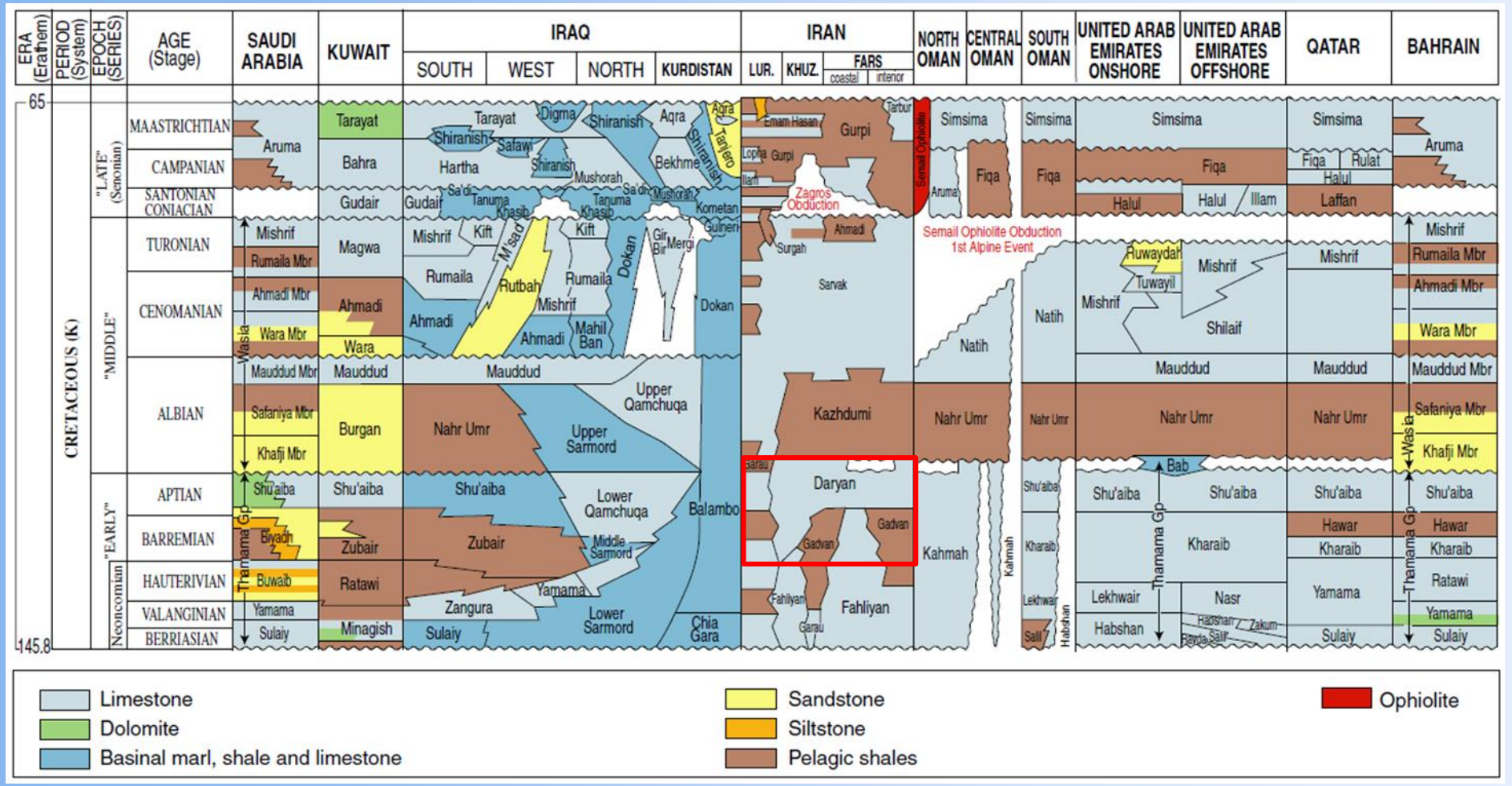
# Spatial heterogeneity – Sarvak



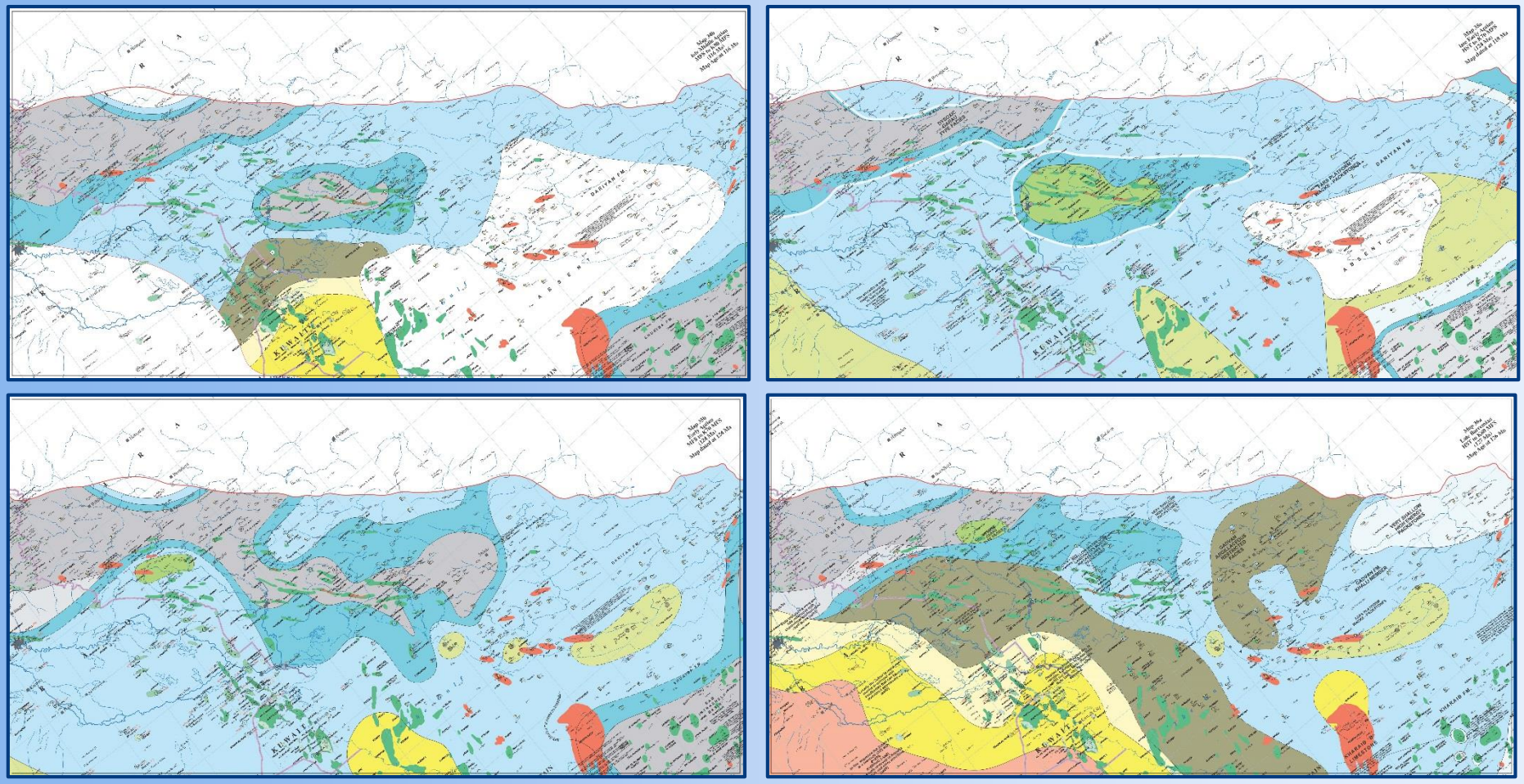

Middle Cenomanian, MFS to K130 MFS, Map age 96.5 Ma

# Dariyan Formation

# Dariyan Formation

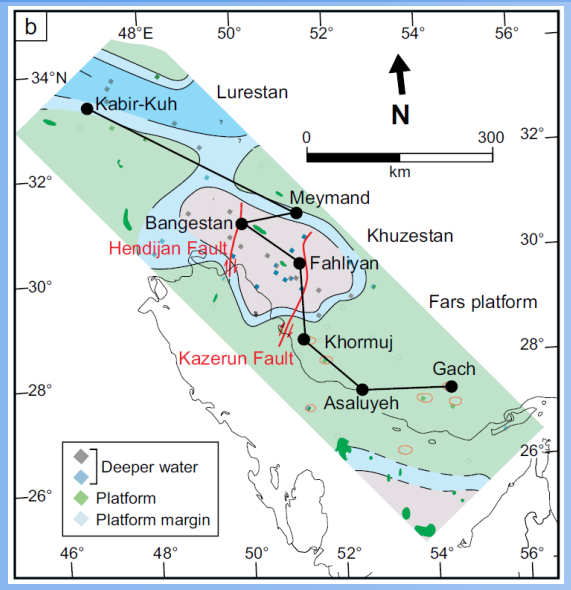


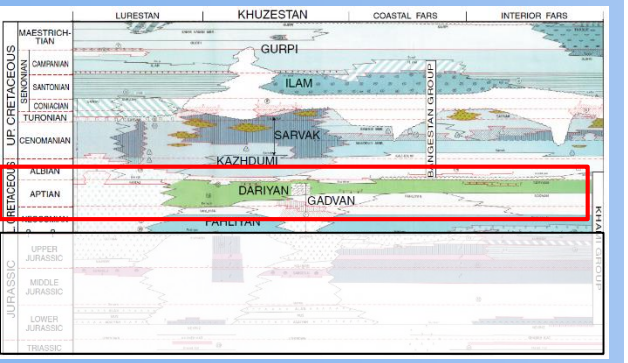
# Intrashelf basins and lowstand wedges – Dariyan

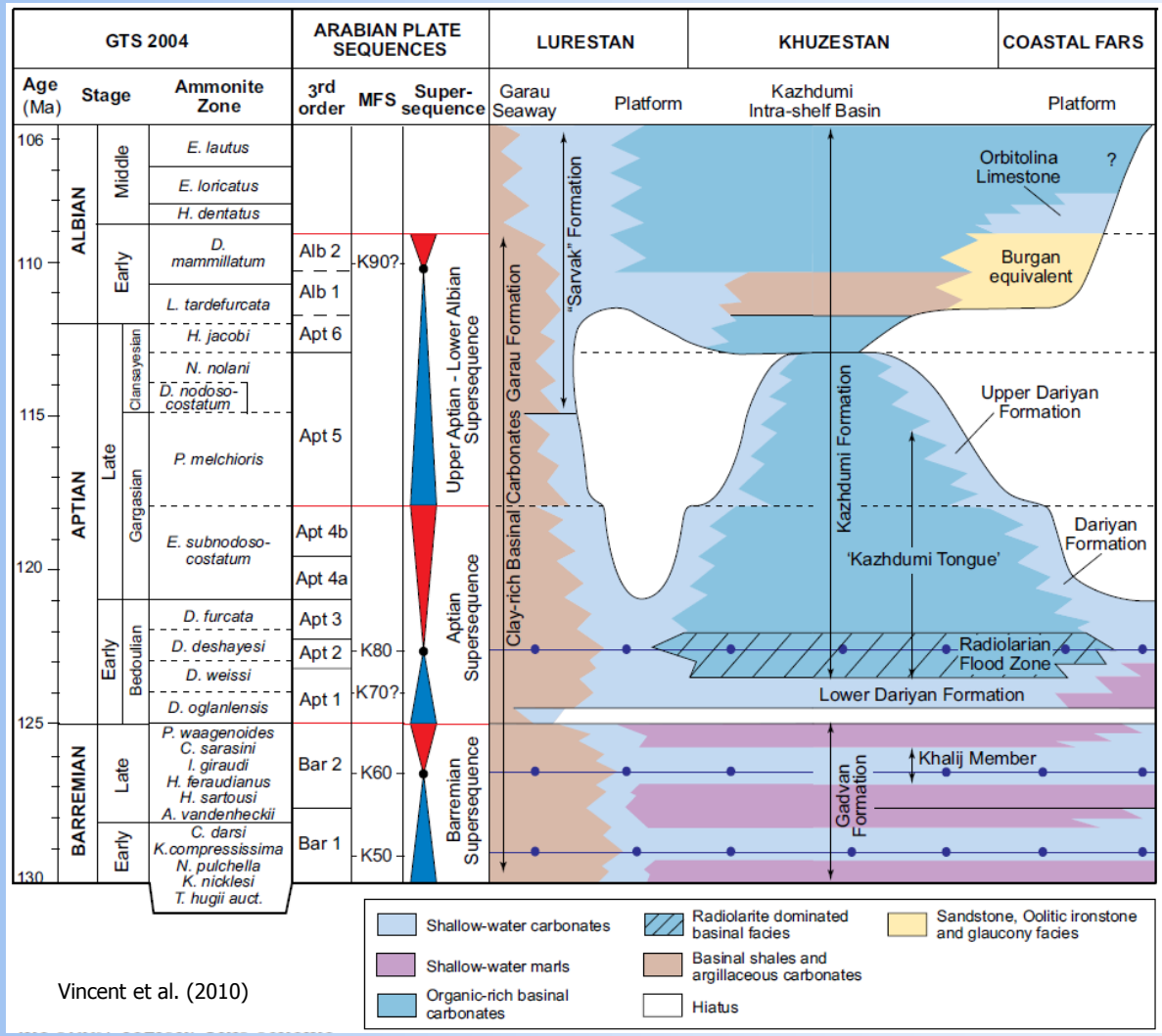


Maps of the Aptian showing development and infill of the Kazhdumi intrashelf basin

# Intrashelf basins and lowstand wedges – Dariyan

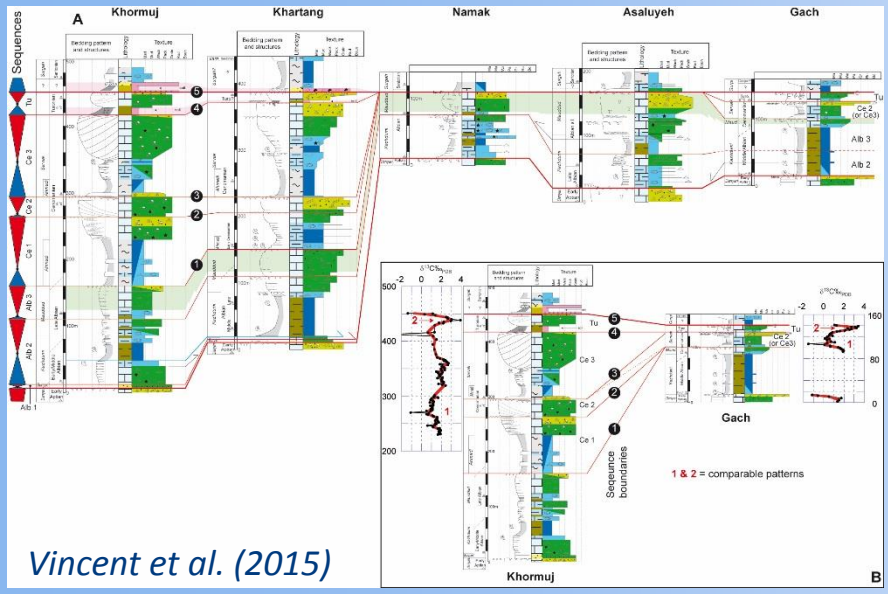


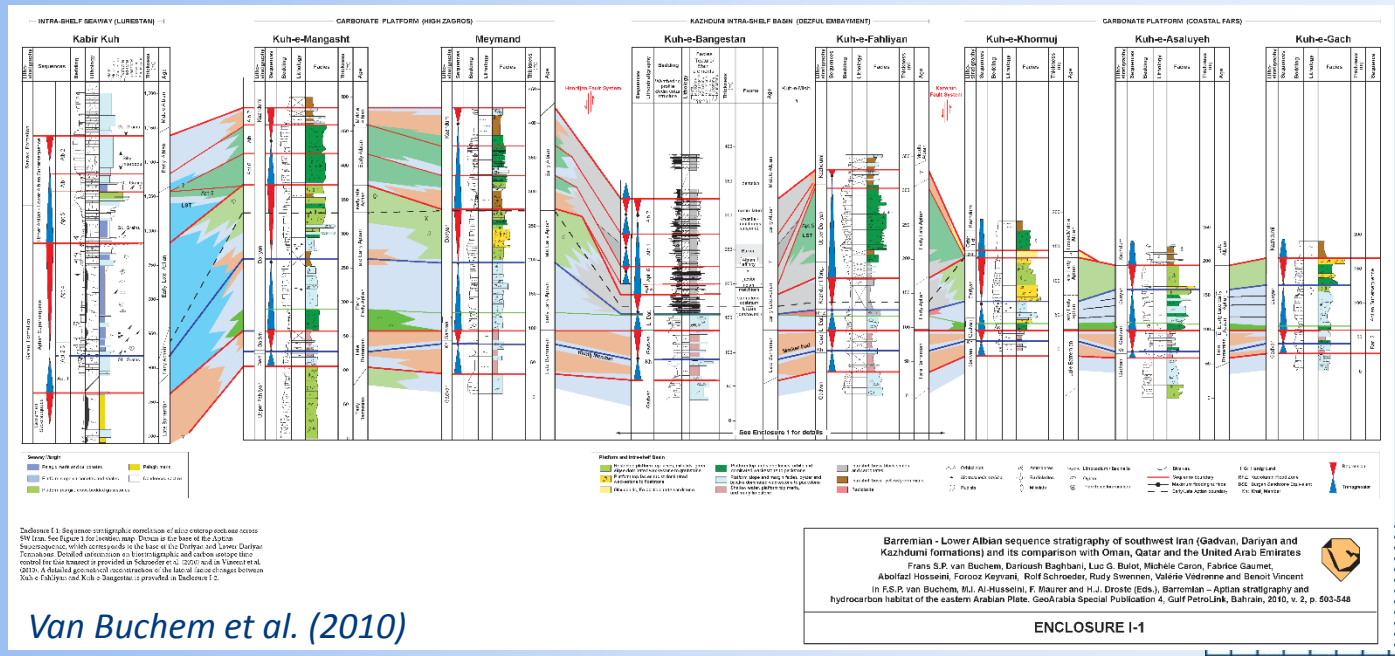




Vincent et al. (2010)

# Intrashelf basins and lowstand wedges – Dariyan



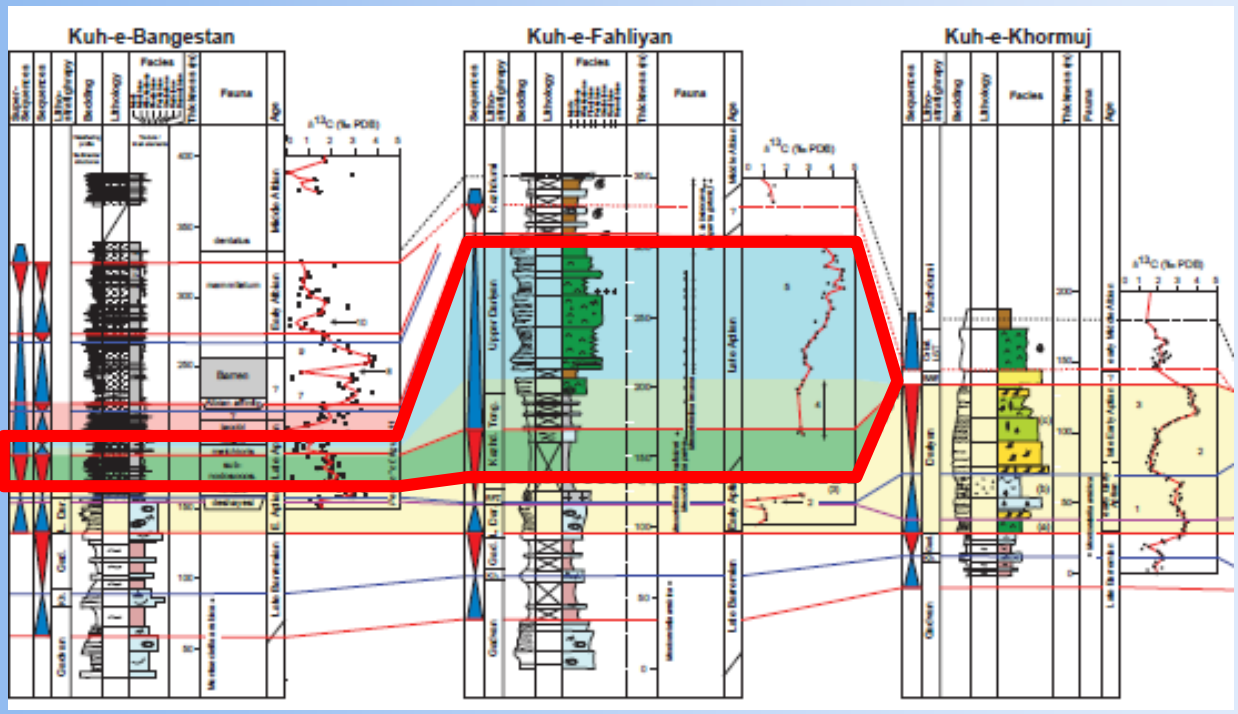

*Vincent et al. (2015)*




*Van Buchem et al. (2010)*

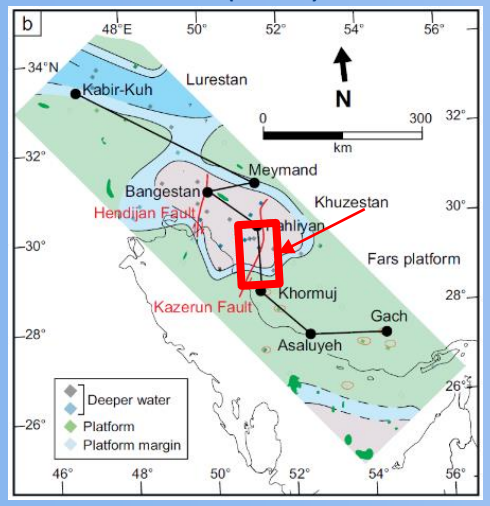
# Intrashelf basins and lowstand wedges – Dariyan

**Kazhdumi intrashelf basin**

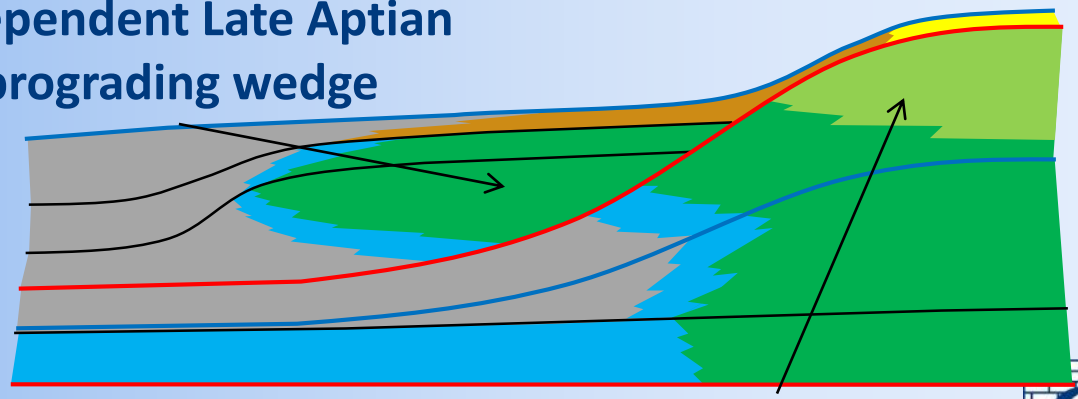



**Fars platform**

*Vincent et al. (2010)*

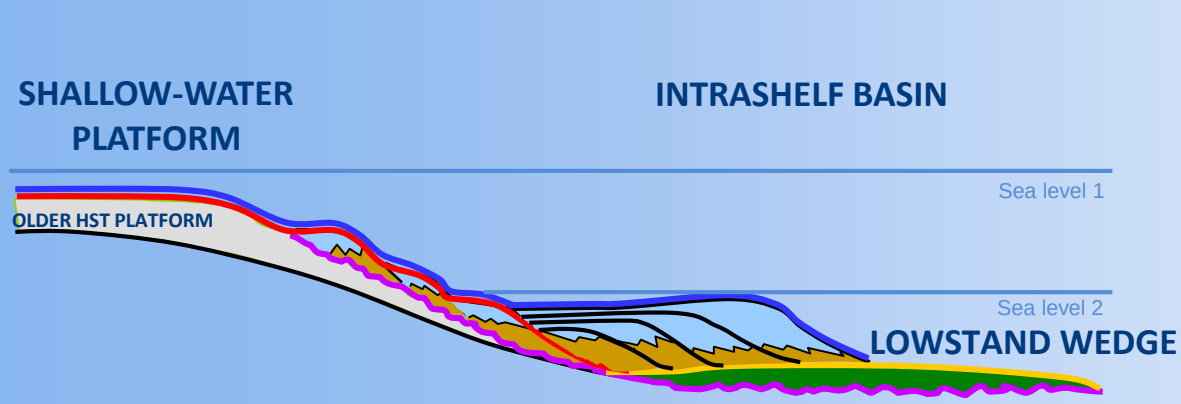


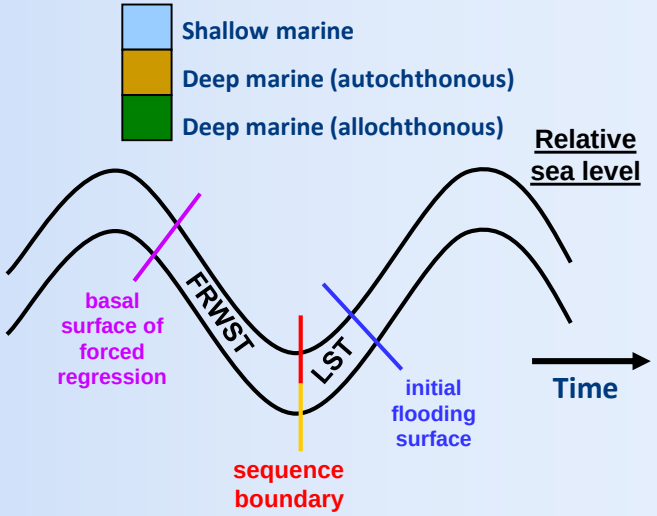

**Independent Late Aptian prograding wedge**



**Early Aptian platform**

# Intrashelf basins and lowstand wedges – Dariyan



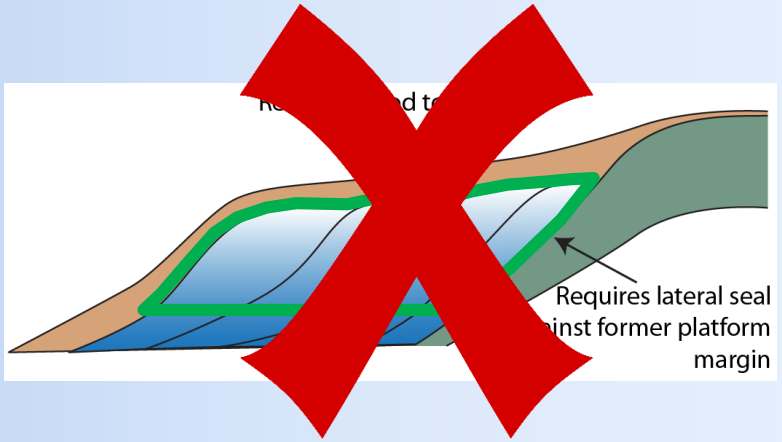



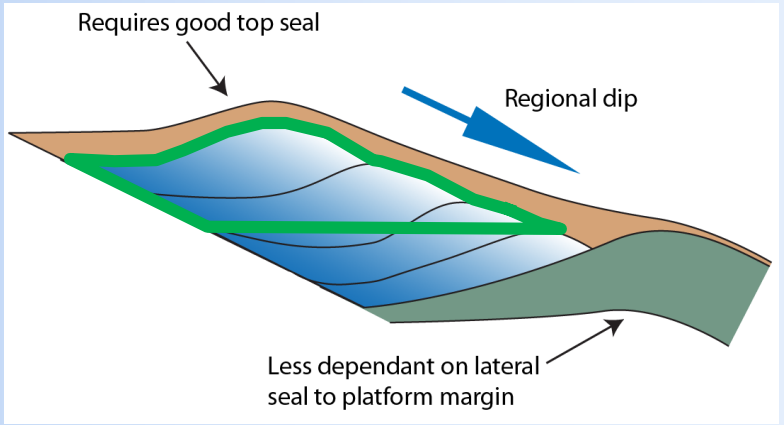

- During periods of sea level lowstand, development of shallow-water lowstand platforms flanking intrashelf basins
- Packages typically form separate reservoirs from the shelf facies themselves and may not be laterally connected
- Recognition: wedge-shaped seismic geometries abutting against the former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

# Intrashelf basins and lowstand wedges – Dariyan

**Key factors**

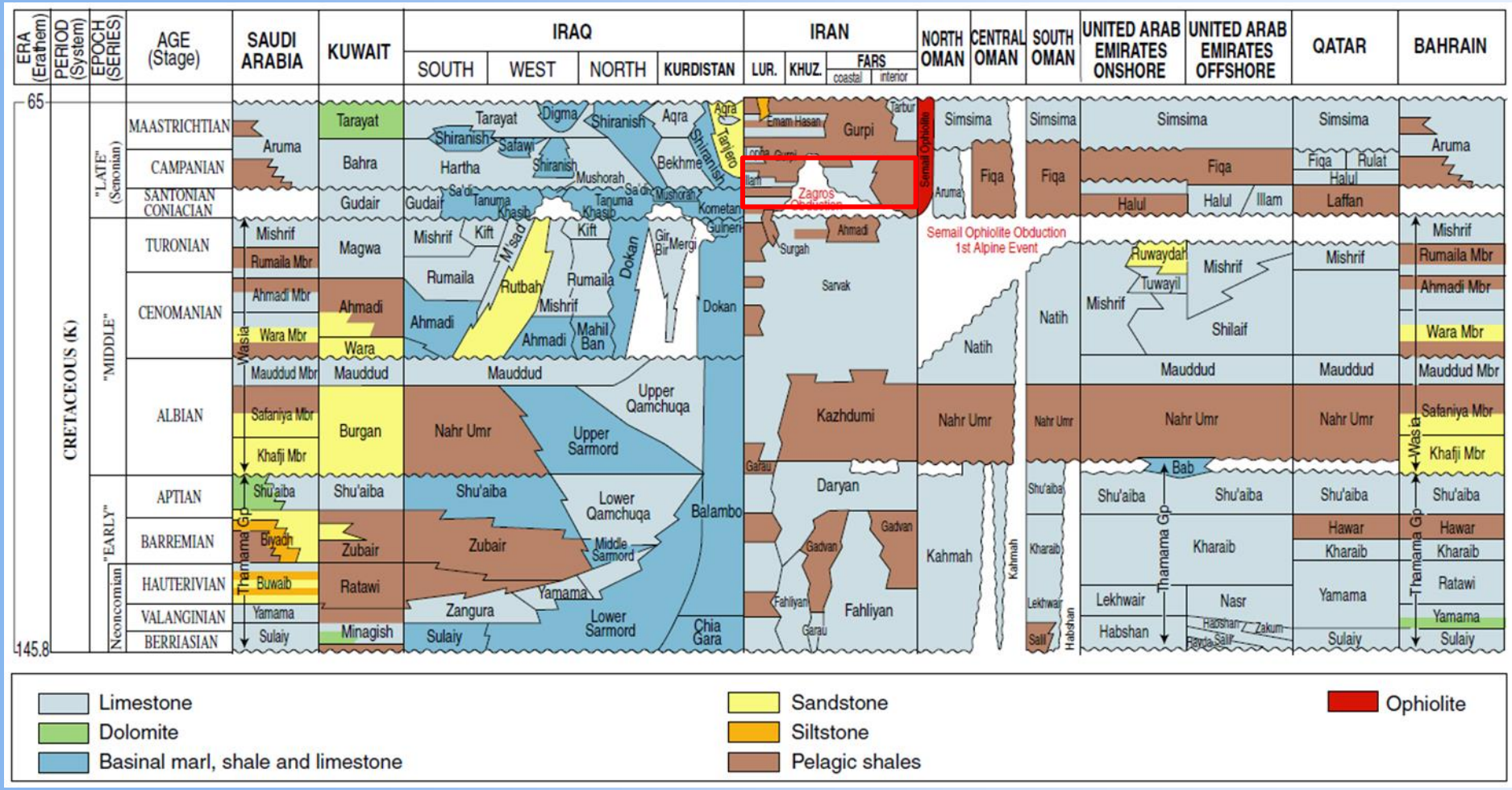
- Recognition of the play requires good understanding of basin/platform geometries and location of shelf margins
- Recognition from seismic – wedge-shaped geometries
- Trapping mechanism
  - For pure stratigraphic traps, the sealing rocks are critical
  - Regional dip (lower risk)
- Could occur in numerous stratigraphic intervals (Jurassic/Cretaceous/Cenozoic)



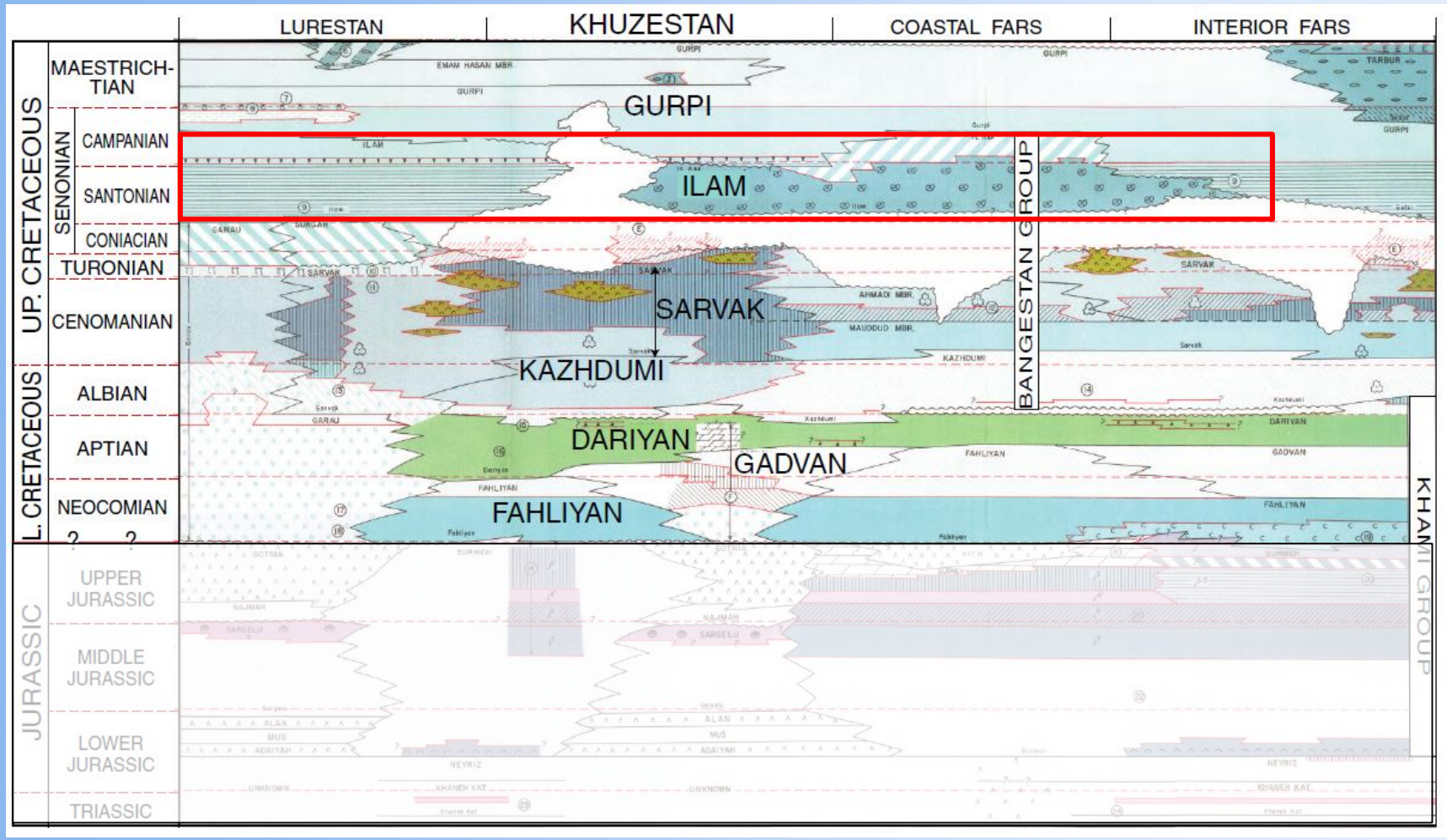



# Ilam

# Ilam

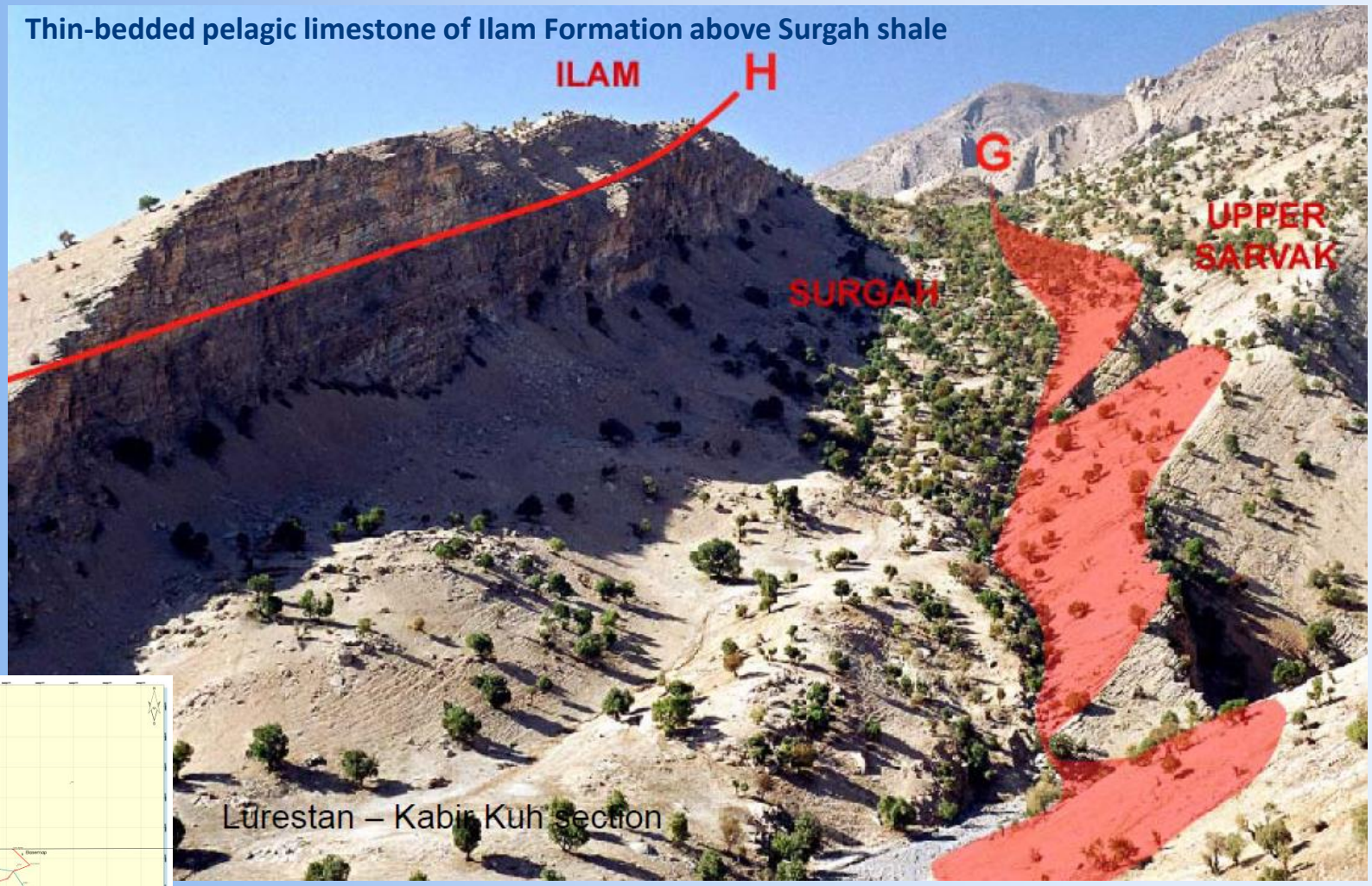

ERA (Erathem)
PERIOD (System)
EPOCH (SERIES)
AGE (Stage)
SAUDI ARABIA
KUWAIT
IRAQ
SOUTH
WEST
NORTH
KURDISTAN
IRAN
LUR.
KHUZ.
FARS
coastal
interior
NORTH OMAN
CENTRAL OMAN
SOUTH OMAN
UNITED ARAB EMIRATES ONSHORE
UNITED ARAB EMIRATES OFFSHORE
QATAR
BAHRAIN
65
145.8
CRETACEOUS (K)
"LATE" (Senonian)
"MIDDLE"
"EARLY"
Neocomian
MAASTRICHTIAN
CAMPANIAN
SANTONIAN
CONIACIAN
TURONIAN
CENOMANIAN
ALBIAN
APTIAN
BARREMIAN
HAUTERIVIAN
VALANGINIAN
BERRIASIAN
Semail Ophiolite Obduction
1st Alpine Event
Zagros Obduction
Limestone
Dolomite
Basinal marl, shale and limestone
Sandstone
Siltstone
Pelagic shales
Ophiolite

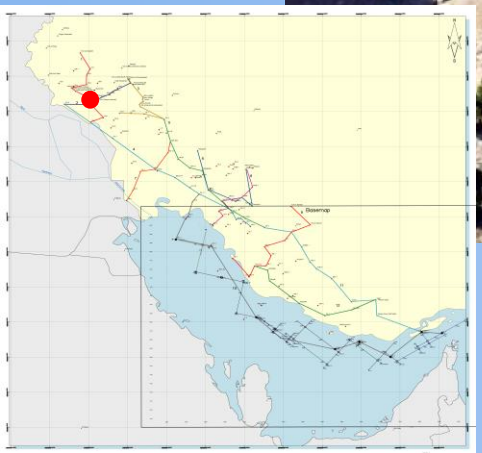
# Ilam Intrashelf Basins: Upper Cretaceous




James and Wynd (1965)

# Ilam Intrashelf Basins: Upper Cretaceous



## Kabir-Kuh section – Lurestan

# Ilam Intrashelf Basins: Upper Cretaceous

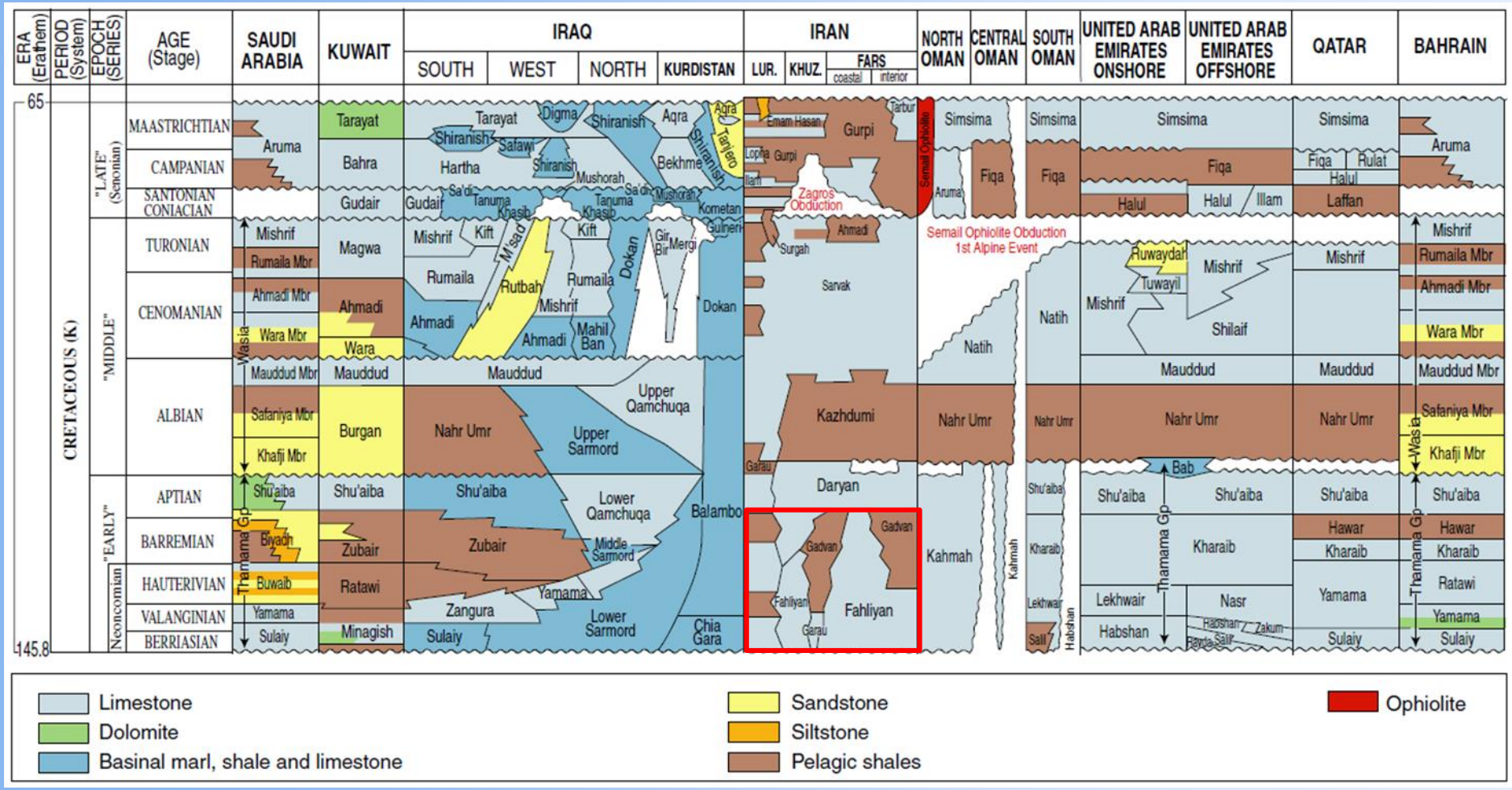
## Ilam shallow platform facies (Fars)



## Ilam deep water facies (Lurestan)


# Fahliyan

# Fahliyan


ERA (Erathem)
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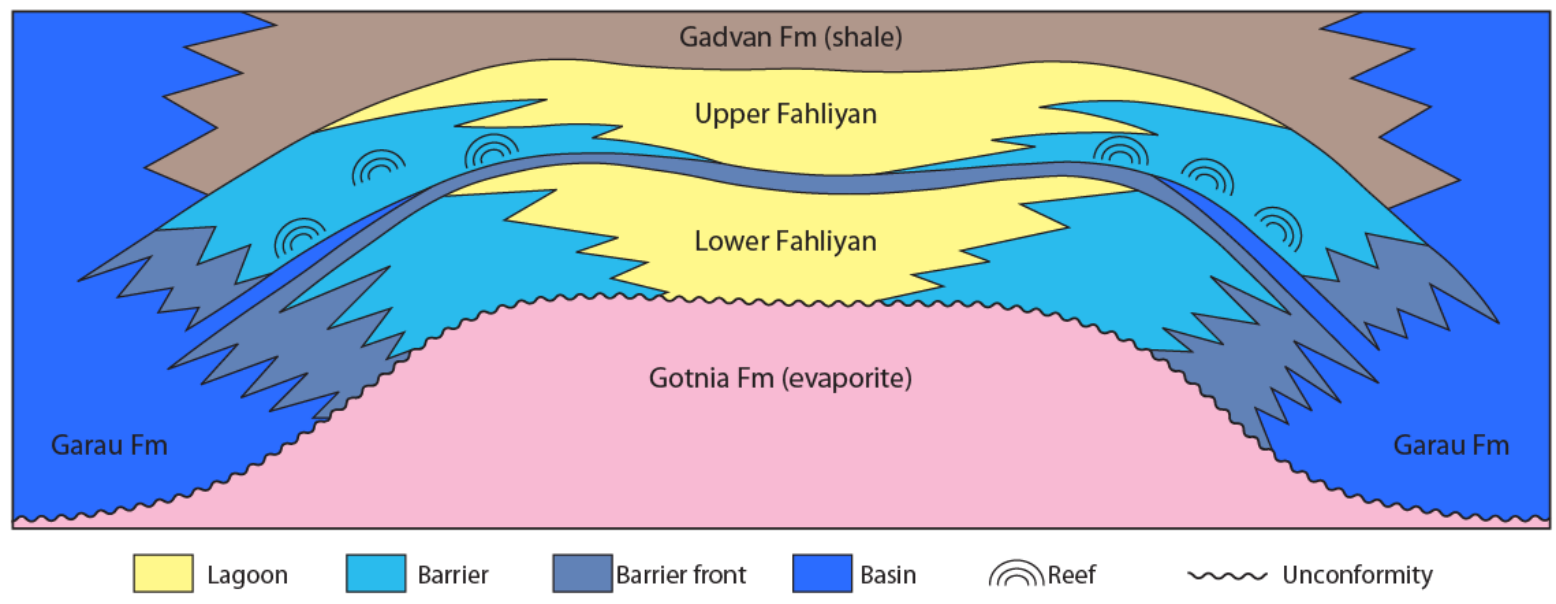
VALANGINIAN
BERRIASIAN
Aruma
Tarayat
Bahra
Gudair
Magwa
Ahmadi
Wara
Mauddud
Burgan
Shu'aiba
Zubair
Ratawi
Minagish
Mishrif
Rumaila Mbr
Ahmadi Mbr
Wara Mbr
Mauddud Mbr
Safaniya Mbr
Khafji Mbr
Wasia
Thamama Gp
Biyadh
Buwaib
Yamama
Sulaiy
Digma
Shiranish
Safawi
Hartha
Mushorah
Bekhme
Aqra
Taq'ero
Sa'di
Tanuma
Khasib
Kifft
Kifft
M'sad
Rutbah
Rumaila
Dokan
Gir
Bir
Mergi
Kometan
Gulneri
Mahil
Ban
Upper Qamchuqa
Upper Sarmord
Lower Qamchuqa
Middle Sarmord
Lower Sarmord
Balambo
Zangura
Chia Gara
Tarbur
Emam Hasan
Gurpi
Lopha
Illam
Zagros Obduction
Semail Ophiolite
Ahmadi
Surgah
Sarvak
Kazhdumi
Garau
Daryan
Gadvan
Fahliyan
Kahmah
Simsima
Fiqa
Aruma
Semail Ophiolite Obduction
1st Alpine Event
Natih
Nahr Umr
Shu'aiba
Kharaib
Lekhwair
Habshan
Salil
Ruwaydah
Tuwayil
Mishrif
Shilaif
Bab
Halul
Illam
Laffan
Rulat
Hawar
Nasr
Zakum
Rayda
Sulaiy
Limestone
Dolomite
Basinal marl, shale and limestone
Sandstone
Siltstone
Pelagic shales
Ophiolite

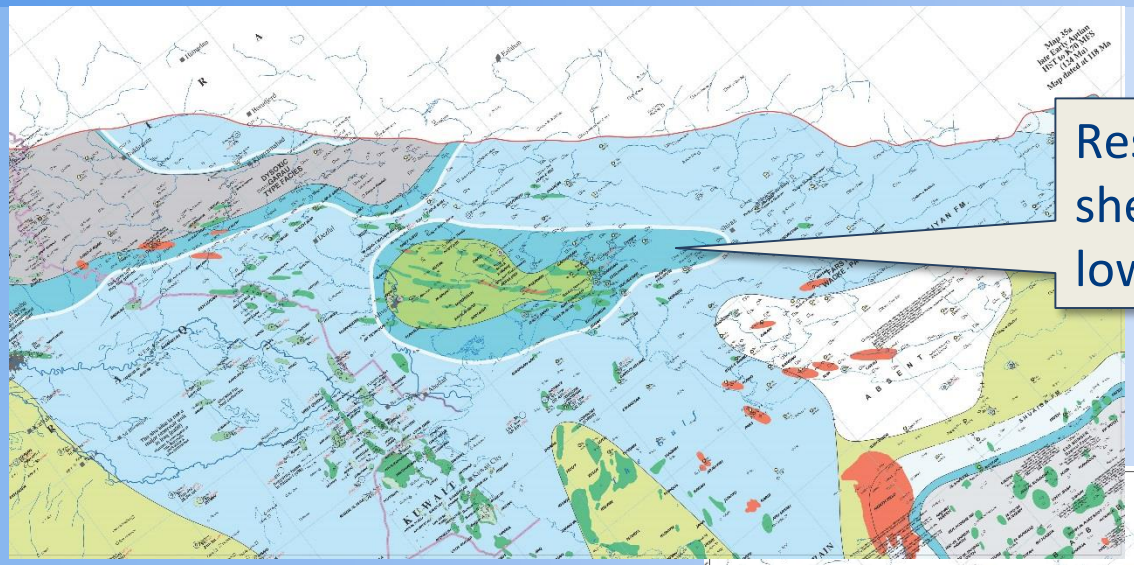
# Stratigraphic traps: Fahliyan isolated platforms



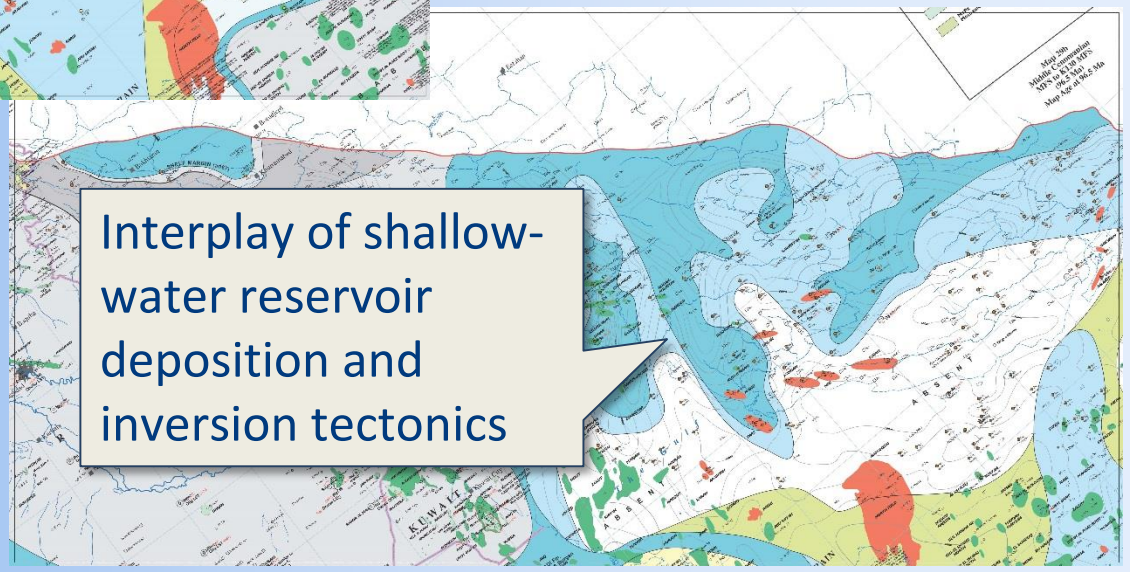

*Lasemi and Kondroud (2008)*

- Early Cretaceous – Darquain field
- Source/seal/reservoir/trap all-in-one
- Recognition of the play requires seismic mapping of buildup geometries

# Summary: opportunities in Cretaceous basins




Reservoir pinchout at shelf margin break – lowstand wedge play

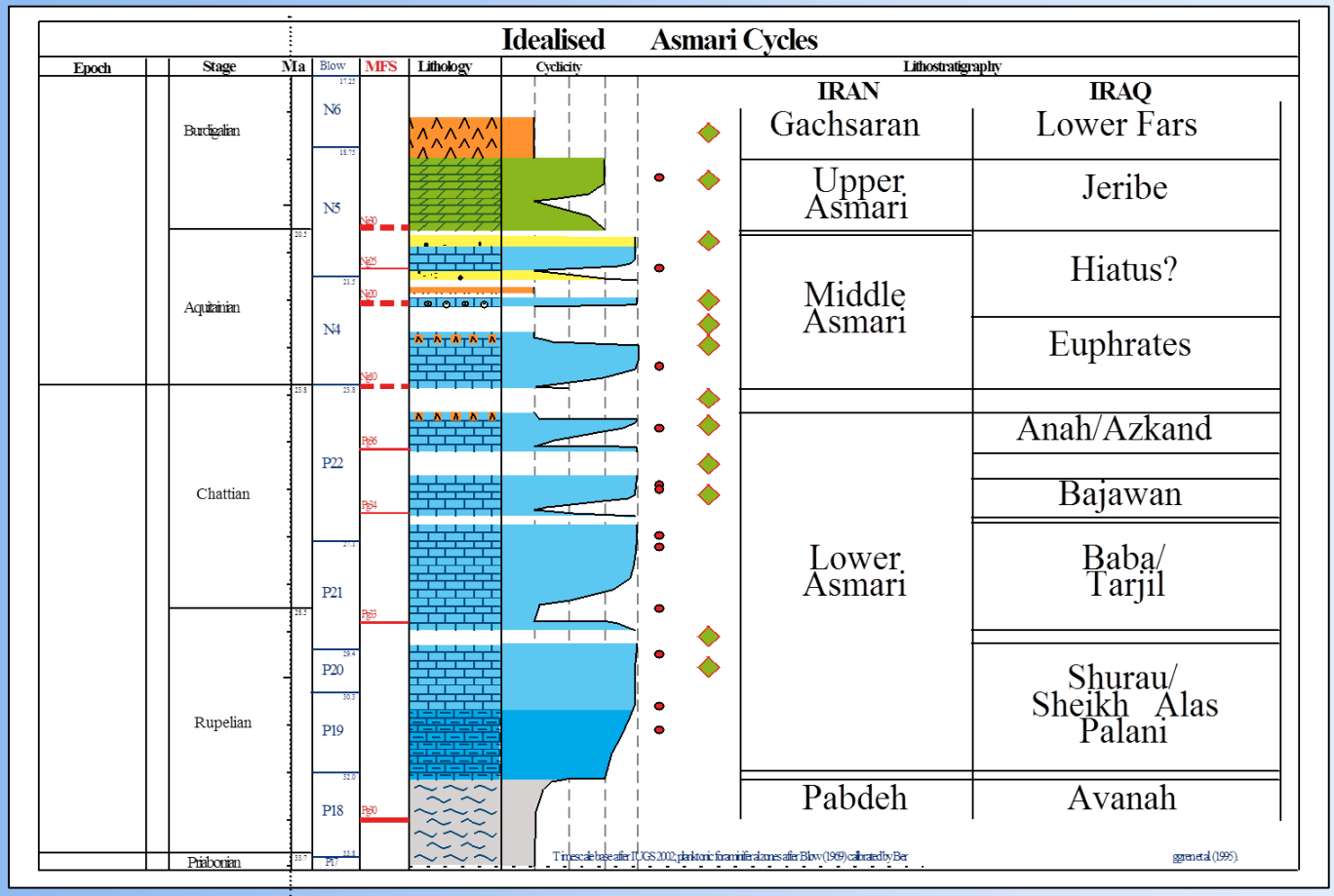



Interplay of shallow-water reservoir deposition and inversion tectonics

- Development of numerous intrashelf basins within the Iranian Zagros leads to stratigraphic trapping possibilities

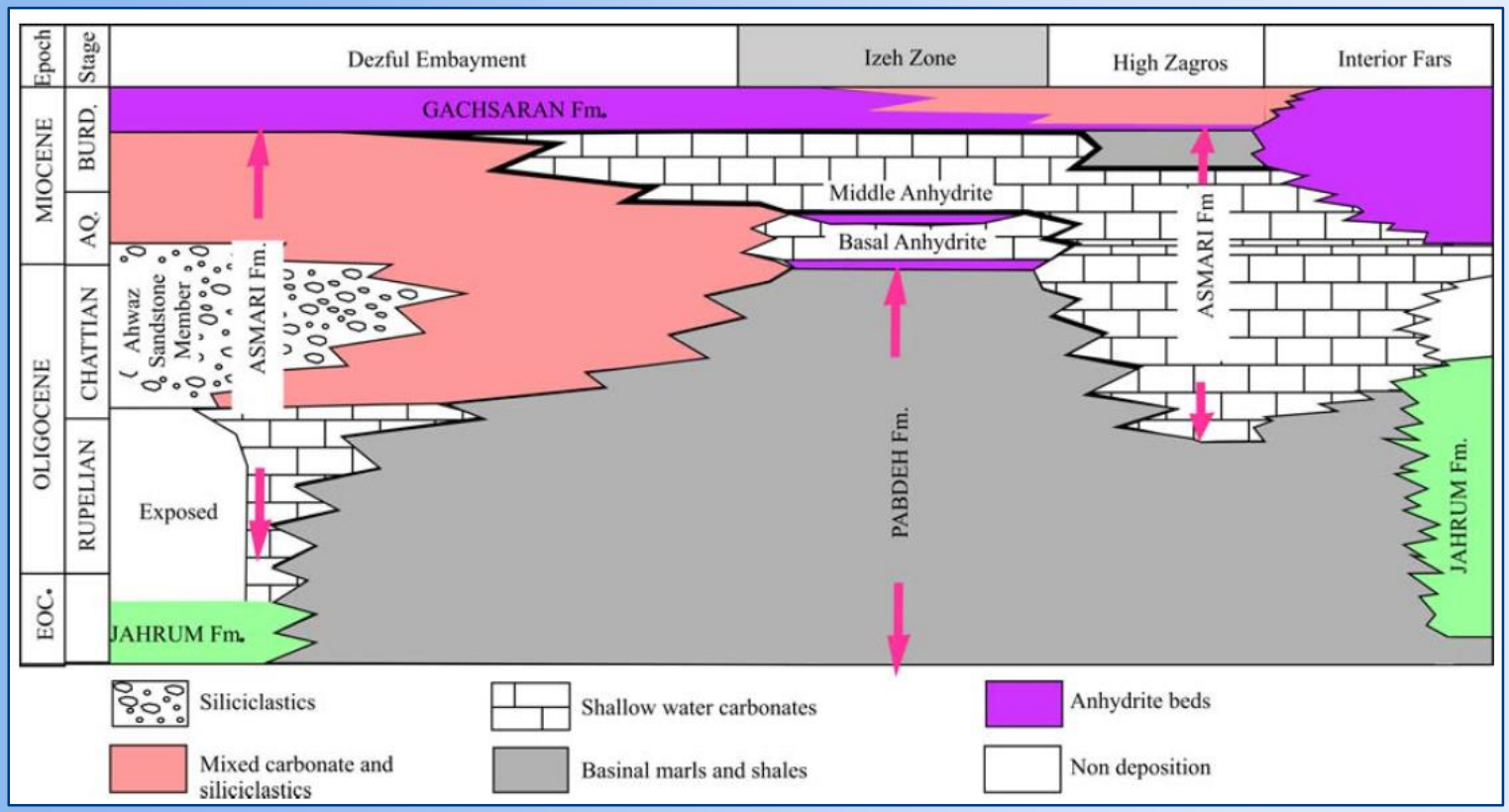
# Asmari (Cenozoic)

# Iranian and Iraqi Oligo-Miocene lithostratigraphy




- Shoals upwards.
- Becomes more restricted up section.

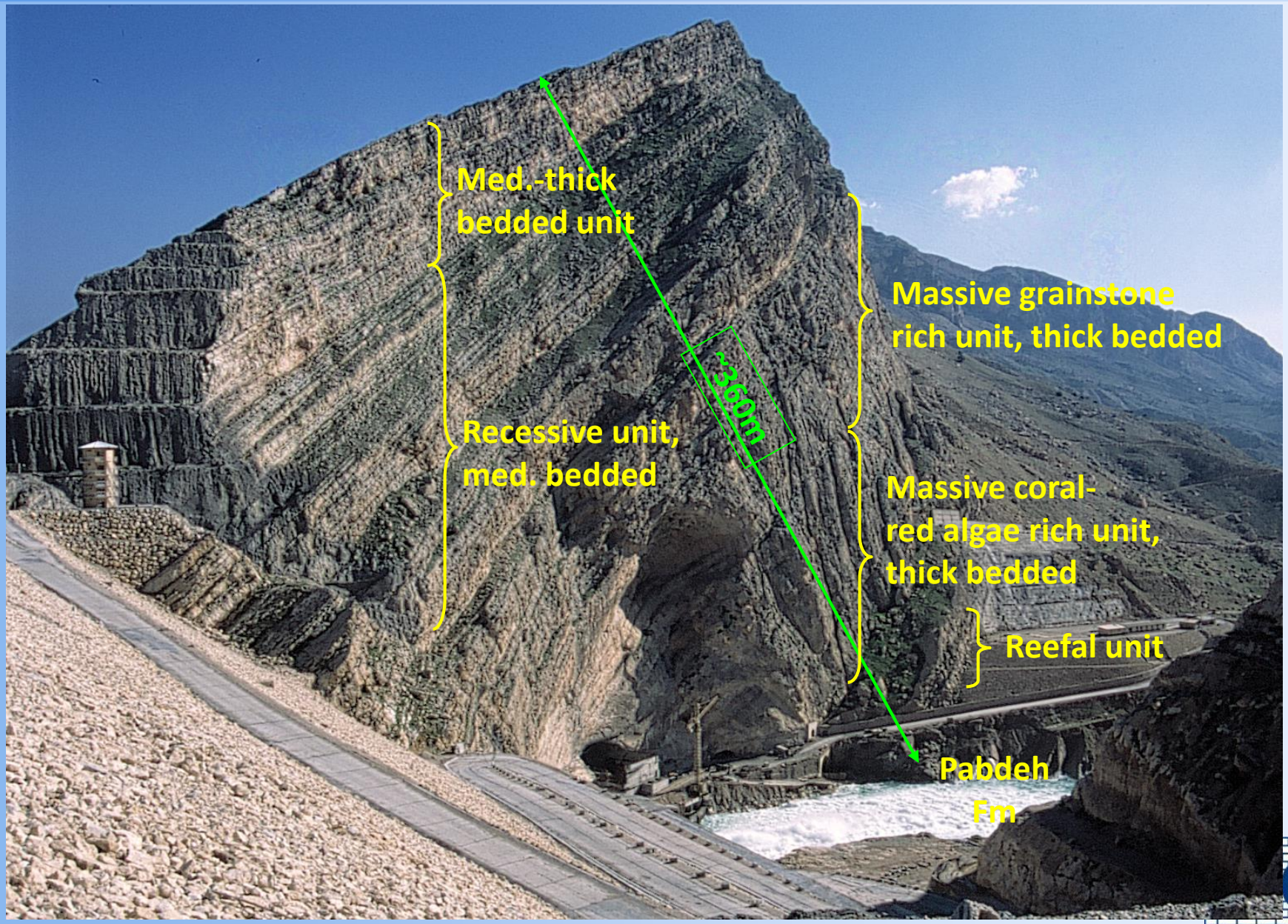
# Chronostratigraphic scheme for Iranian Cenozoic




*Saleh & Seyrafian (2013), based on Van Buchem et al. (2010). Middle anhydrite corresponds to Kalhur Mb in Lurestan.*

- Significant vertical variation in lithology, dependant on area.
- Notable diachroneity across the Zagros.

# Full stratigraphy



# Outcrop illustrations of key stratigraphic intervals


*Google Earth (2016)*

*Source: Jo Garland_on the road to Pahleh.*


*Source: Neil Wakefield_Tunggul Jaguda. Adjacent to Gachsaran oil field.*




*Google Earth (2016)*

- Overview of the Pabdeh Formation.
- Interbedded thin limestones and mudstones.
- Darker layers are laminated and contain high TOC.
- Top of Pabdeh – organic rich mudstone.

- Asmari Fm carbonates overlying Pabdeh Fm marls.
- Oligocene age progradational slope systems.

# Outcrop illustrations of key stratigraphic intervals

*Source: Jo Garland_on the road to Pahleh.*

- Upper Kalhur Member.
- Evaporitic
- Chicken wire textures

*Source: Jo Garland_on the road to Pahleh.*

- Overview of top Asmari – Gachsaran boundary.
- Gachsaran: Reddish colouration/ Evaporitic/ Forms the seal to the Asmari reservoir/ In this locality, halite at base is missing (dissolved) but is present in subsurface.

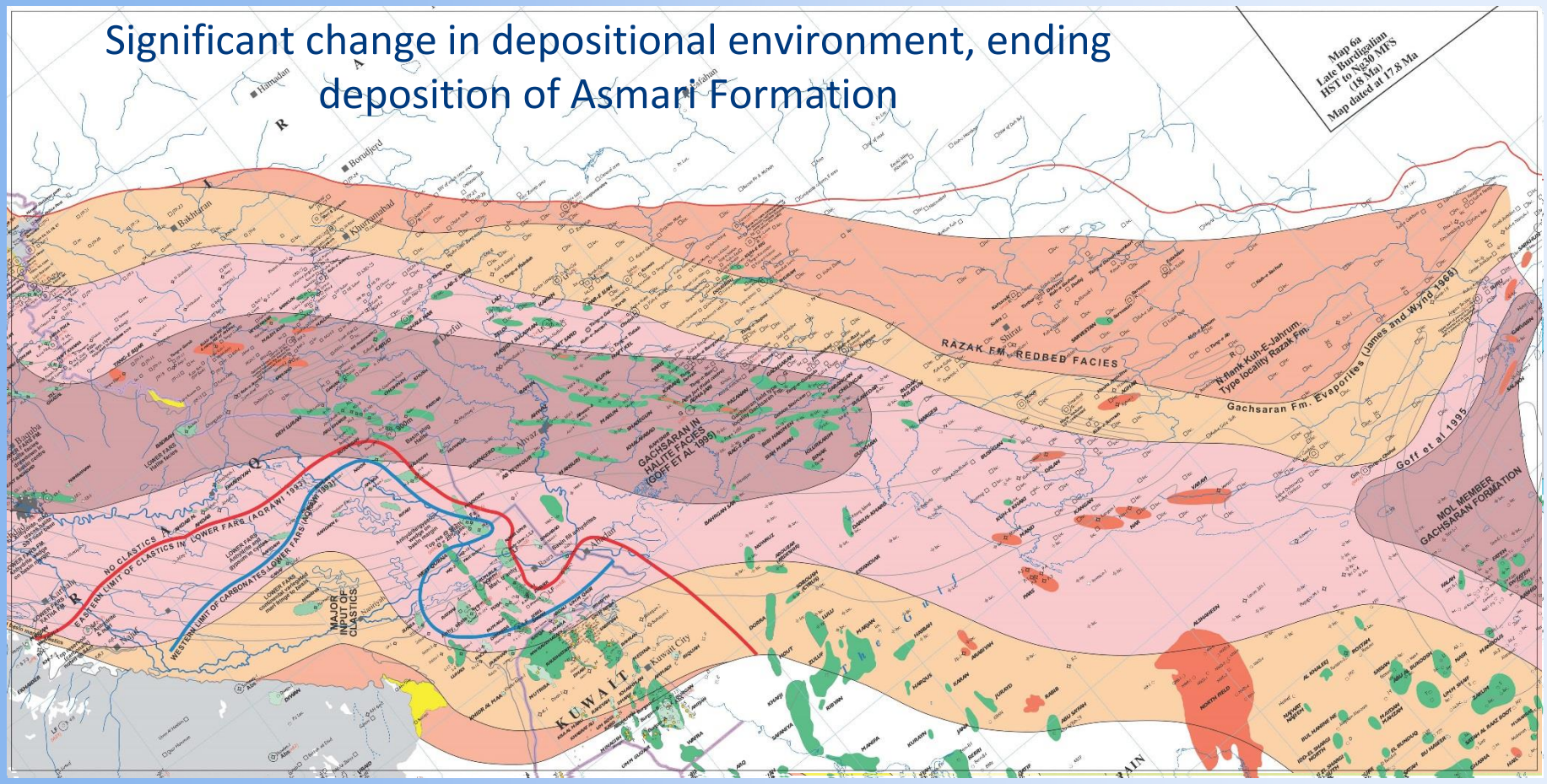
# Key features of Asmari Formation

- Notably diachronous
- Many of the giant oil fields are multi-reservoired.
- Early Asmari reservoirs differ significantly from middle and late Asmari reservoirs.

- Early: very thick reservoirs of limited extent.
- Mid to Late: Laterally extensive, laterally homogeneous BUT vertically heterogeneous.

- Reservoirs have different ages and different source rocks – dependant on location.
- Factors controlling reservoir quality: diagenesis (particularly dolomitisation and dissolution), structural deformation, stratigraphic architecture, lithological variation.
- Asmari stratigraphy is in anticlines that run sub-parallel to facies belts = Cenozoic wouldn't expect too much variation along strike compared to Cretaceous.

# Key stratigraphic intervals: Palaeogeographic maps




Ma Late Burdigalian, HST to Ng30 MFS, Map dated at 17.8 Ma

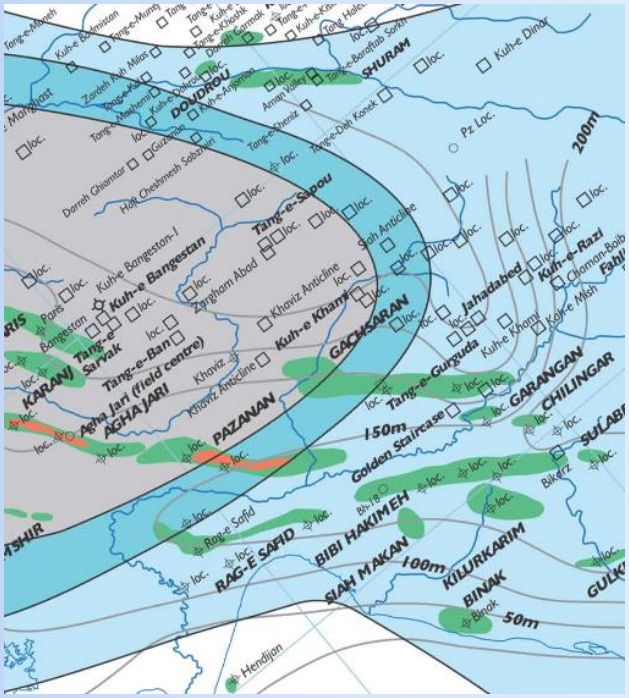
# Second testing existing structures: Asmari

# Second testing existing structures: Asmari

- Much stratigraphically constrained pay in Iran
- 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

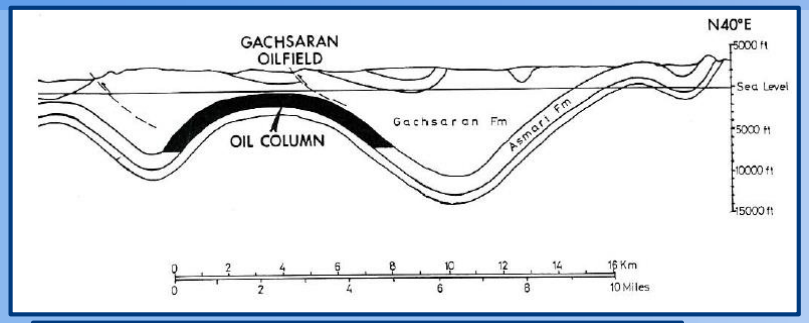
# Second-testing existing structures: Asmari

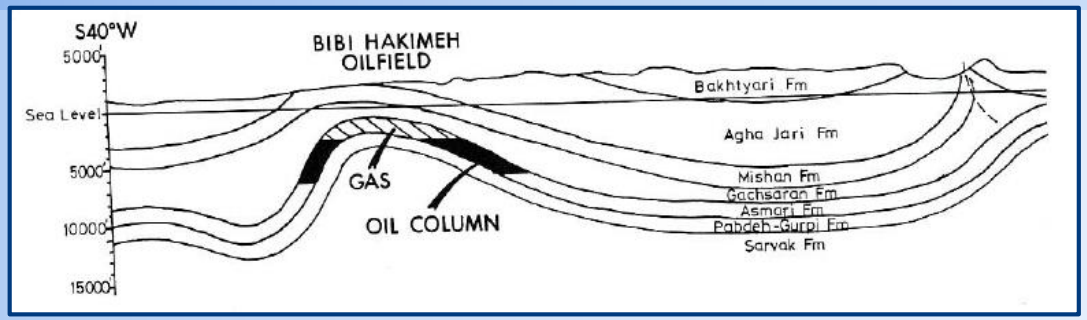
- Single tests of anticlines may lack validity given heterogeneity of many of the reservoir systems (e.g. fractures, facies, diagenesis)
- Need a good understanding of reservoir distribution
  - Facies belts/palaeogeography
- Need a good understanding of structuration/ fracturing/ diagenesis
  - Fracture intensity can be variable across a structure.
  - Late compression may be tangential to basement structure and/or facies → variations in fracturing.

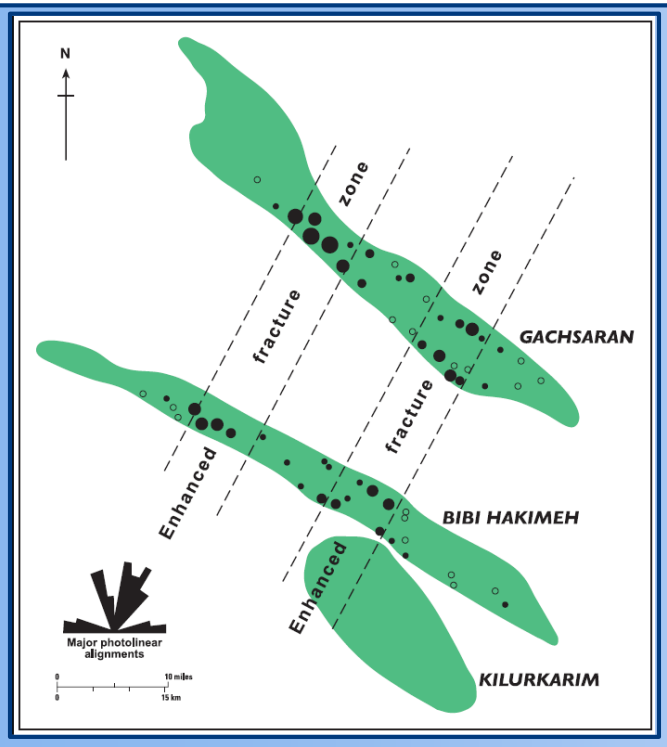



*Early Rupelian palaeogeography (TST to Pg30 MFS)*

# Fracture intensity, Gachsaran + Bibi Hakimeh Fields




*Adapted from McQuillan (1985)*

*Solid circles: proportional to maximum allowed production rates.*

*Open circles: non-commercial/non-producing wells.*

- Classified as 'giant' oil fields. Elongate asymmetrical folds.
- Main reservoir: Oligo-Miocene fractured carbonates (Asmari Formation).
- Reservoir capped with thick evaporitic Gachsaran Formation.
- Poor matrix permeability, moderate porosity.
- 2 fracture sets (early and late).
- High production wells lie in areas of enhanced fracturing related to trends of basement features.
- Dolomitisation likely to be important for higher density fracturing.

# 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

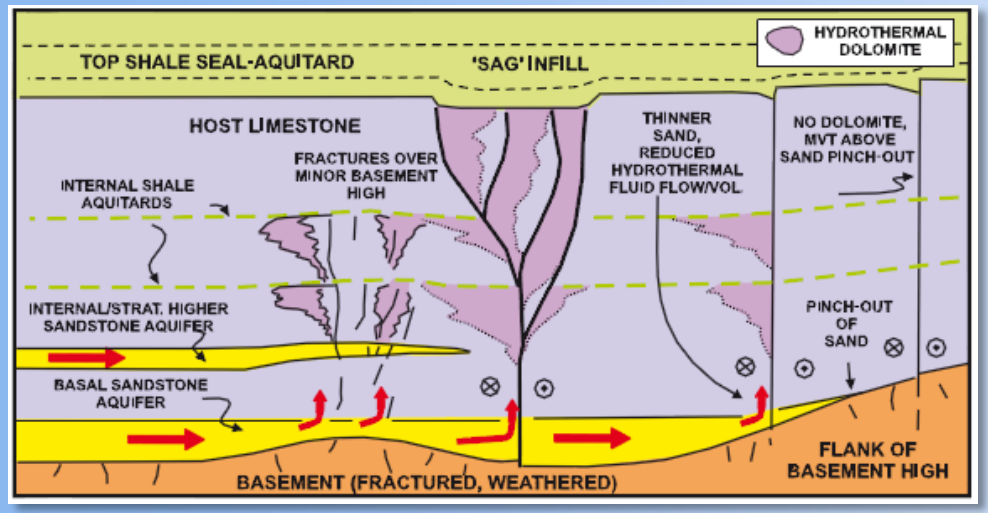
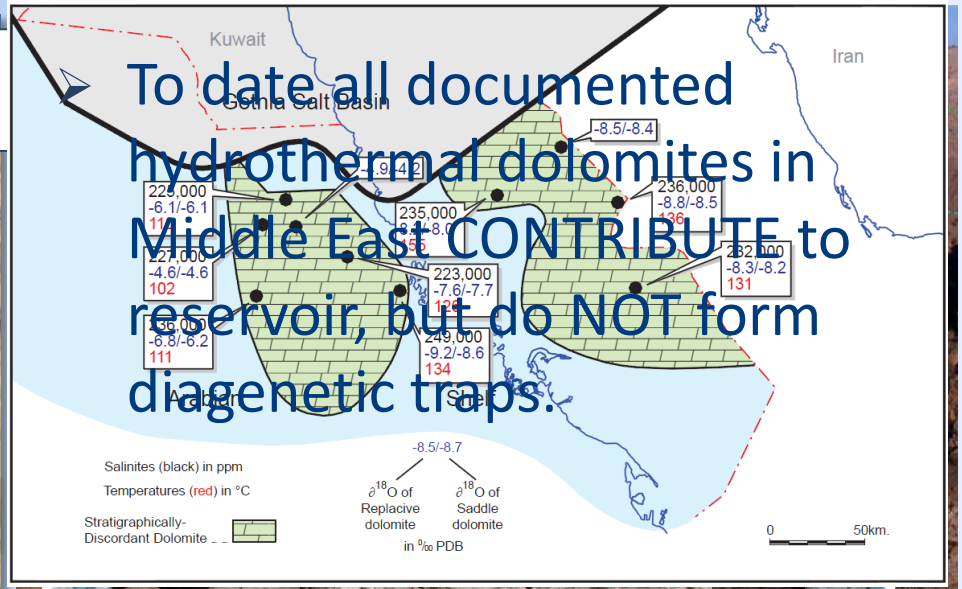



*Photo courtesy of Dave Hunt and Ian Sharp*

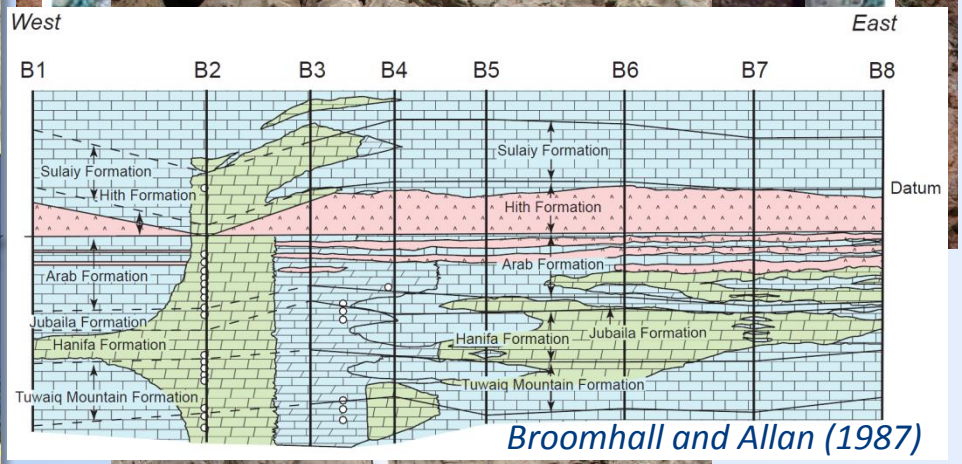
*Davis and Smith (2006)*

- 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.




*Broomhall and Allan (1987)*

★ subsurface ☆ outcrop

# Conclusions

- Requires application of sequence stratigraphic principles to basin dynamics, a good understanding of palaeogeography and structural evolution
- One well is not always sufficient to test a structure

  - Structures have reservoir “sweet spots” that are more productive
- Function of

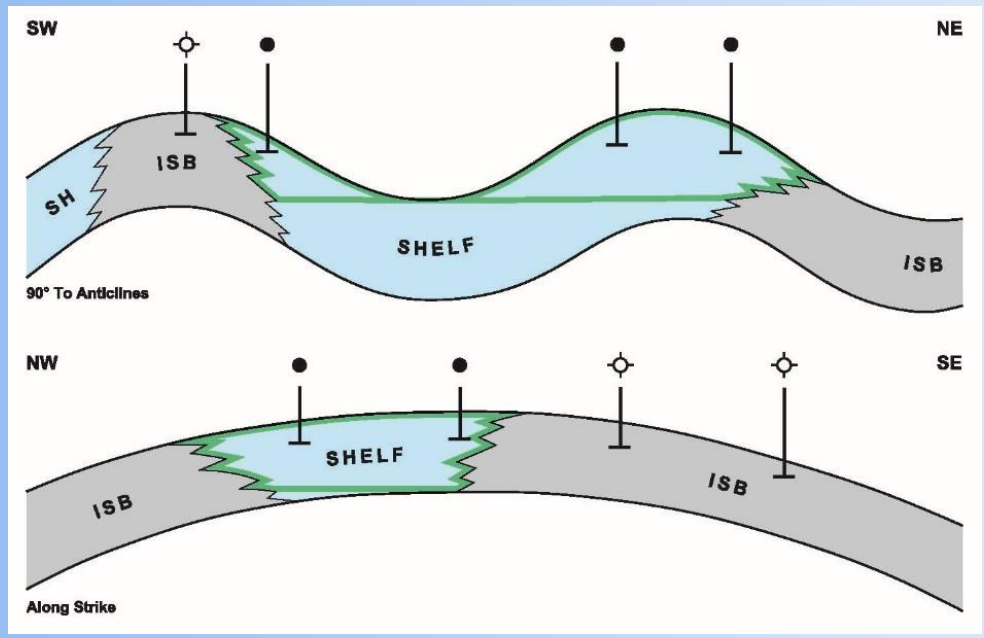
  - Facies variations

  - Variation in fracture intensity

# Conclusions

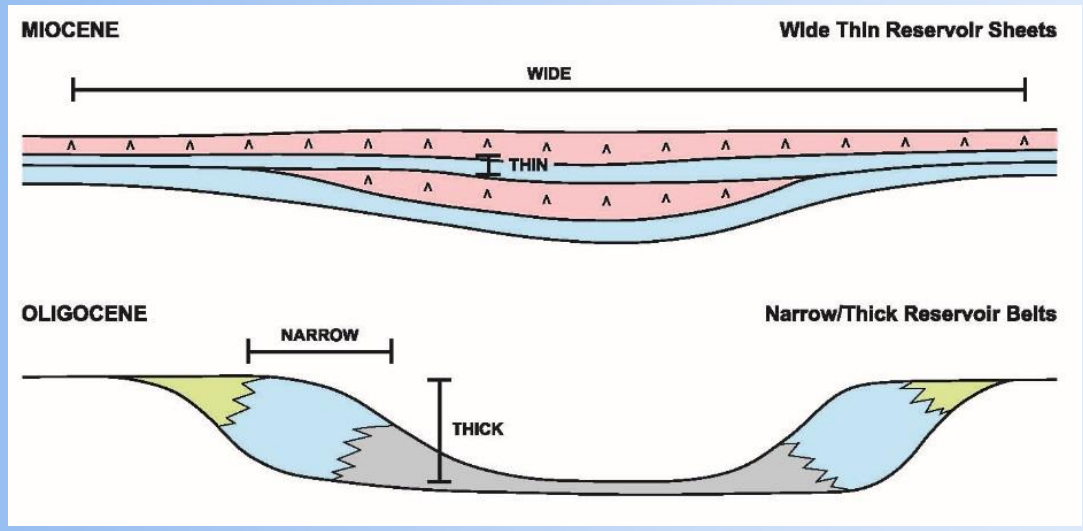
- Even though there has been exploration in Iran for more than 100 years, there is still potential in this mature basin.
- Future success could relate to
  - Evaluating missed pay (single well tests of structures)
  - Evaluating stratigraphic and/or diagenetic trapping mechanisms
- Requires a good regional 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

# Conclusions: Cretaceous




- Commonly N-S orientation of palaeogeog elements vs. NW-SE orientation of anticlines offer many interesting opportunities for heterogeneity
- Future success could relate to:
  - Evaluating effect of diagenesis within a structure, especially dolomitisation.
  - Taking into account stratigraphic traps:
  - On flanks of structures where shelf may pinch out updip into basinal carbonate
  - Within large structures where there are ‘sweet spots’ related to local shelf systems

# Conclusions: Cenozoic



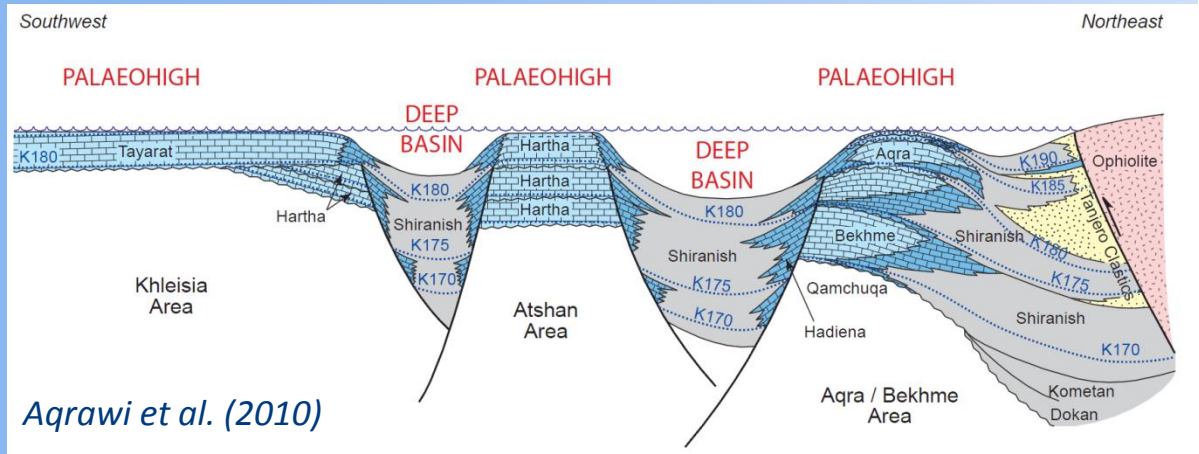

- In general palaeofacies orientations subparallel present-day anticline strike (contrast with Cretaceous)
- Future success could relate to
  - Evaluating variation in fracture intensity throughout individual anticlinal structures.
  - Evaluating effect of diagenesis within a structure, especially dolomitisation.
  - Taking into stratigraphic position:
  - Lower Asmari: Reservoirs are thick and elongate belts, however of limited dip extent.
  - Middle to Upper Asmari: vertically heterogeneous, laterally homogeneous/sheet like.

# THANK YOU …..

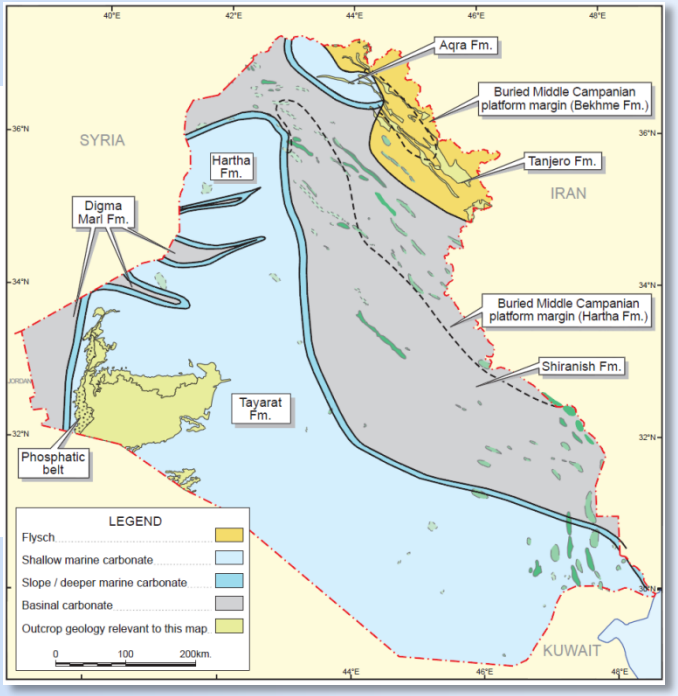
# DISCUSSION POINT

# Stratigraphic traps: inverted palaeohigh “synclines”

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

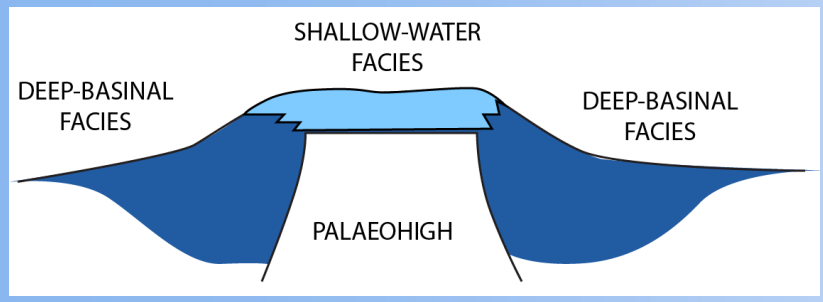


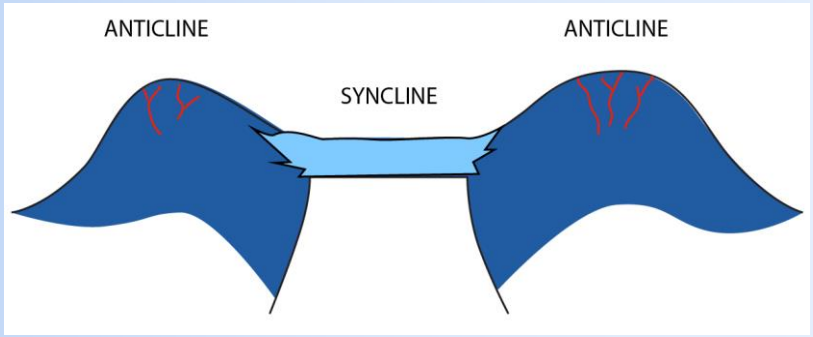

*Aqrawi et al. (2010)*




*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