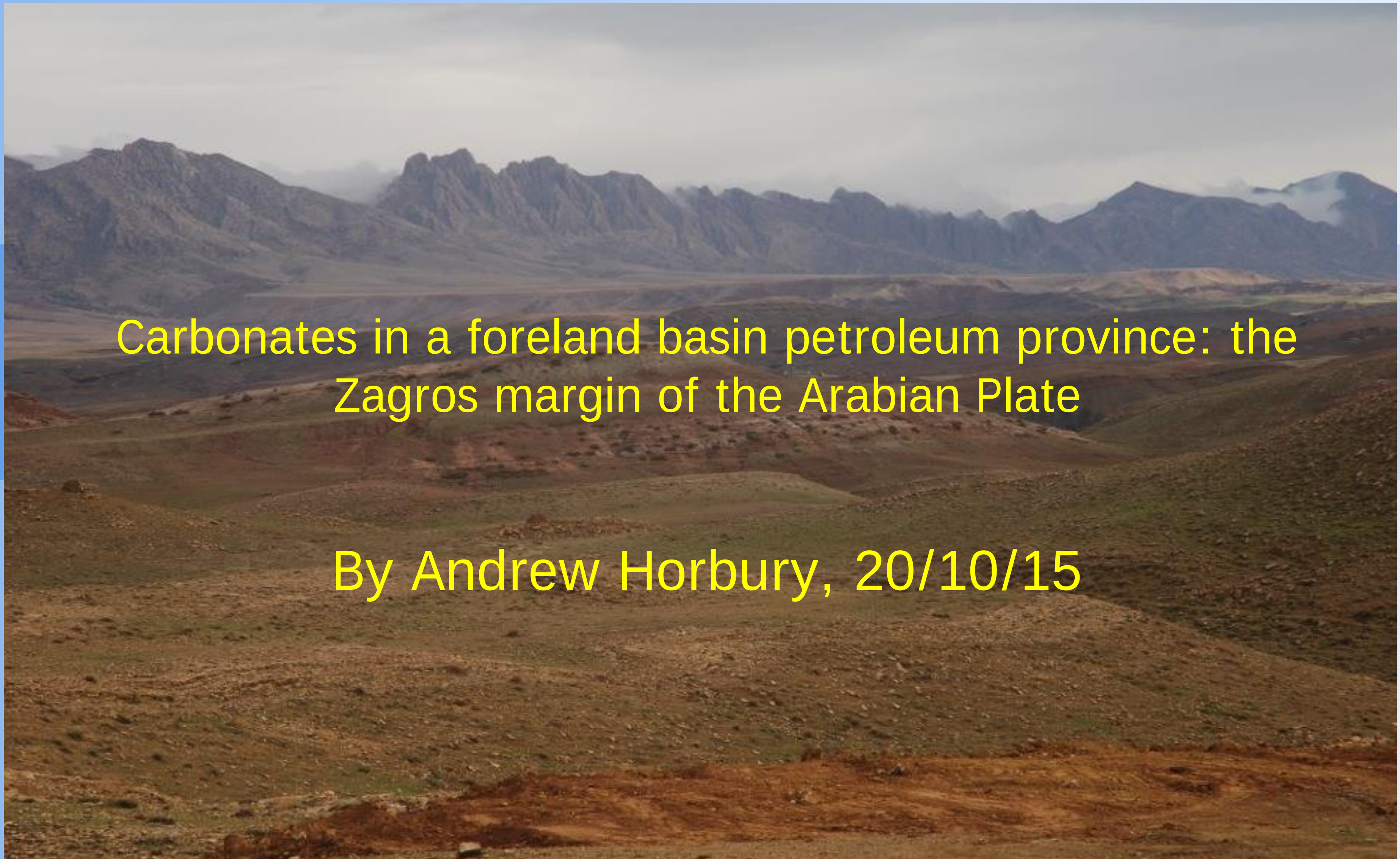


Carbonates in a foreland basin petroleum province: the Zagros margin of the Arabian Plate

By Andrew Horbury, 20/10/15

Context

- Statement of the obvious: there is a lot of petroleum in the Middle East
- However.... much of this is reservoired in carbonates that formed during plate compression, which is unusual for a foreland basin
- Why did this happen?
- Why is this important?

Introduction

- Basin Evolution
- Pre-Foreland Geology
- Foreland Geology
- Discussion
- Conclusions

Introduction: Palaeogeog Map Legend

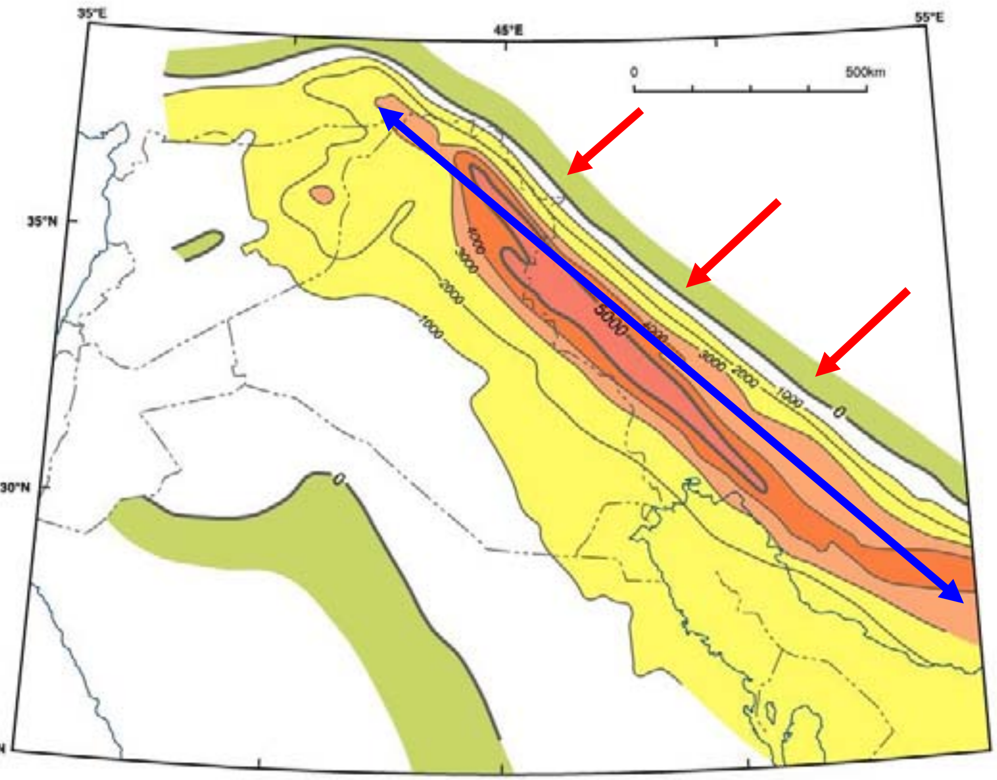
SUBSURFACE FACIES

- Shoal water carbonates
- Low energy shallow marine carbonates
- Outer ramp/ slope carbonates
- Shallow basinal/ intrashelf basin carbonates
- Deep basinal carbonates
- Supratidal/sabkha carbonates & evaporites
- Restricted circulation basinal carbonates
- Mixed carbonate-clastic lagoon
- Massive subaqueous sulphates
- Massive halite
- Coarse grained continental clastics
- Fine grained continental clastics
- Coarse shallow marine clastics
- Fine shallow marine clastics
- Clastic slope with turbidites
- Clastic basinal
- Lacustrine
- Hiatus
- Emergent
- Ophiolite
- Volcanics

Basin Evolution

Basin Evolution

- Thick Cenozoic sediment wedge



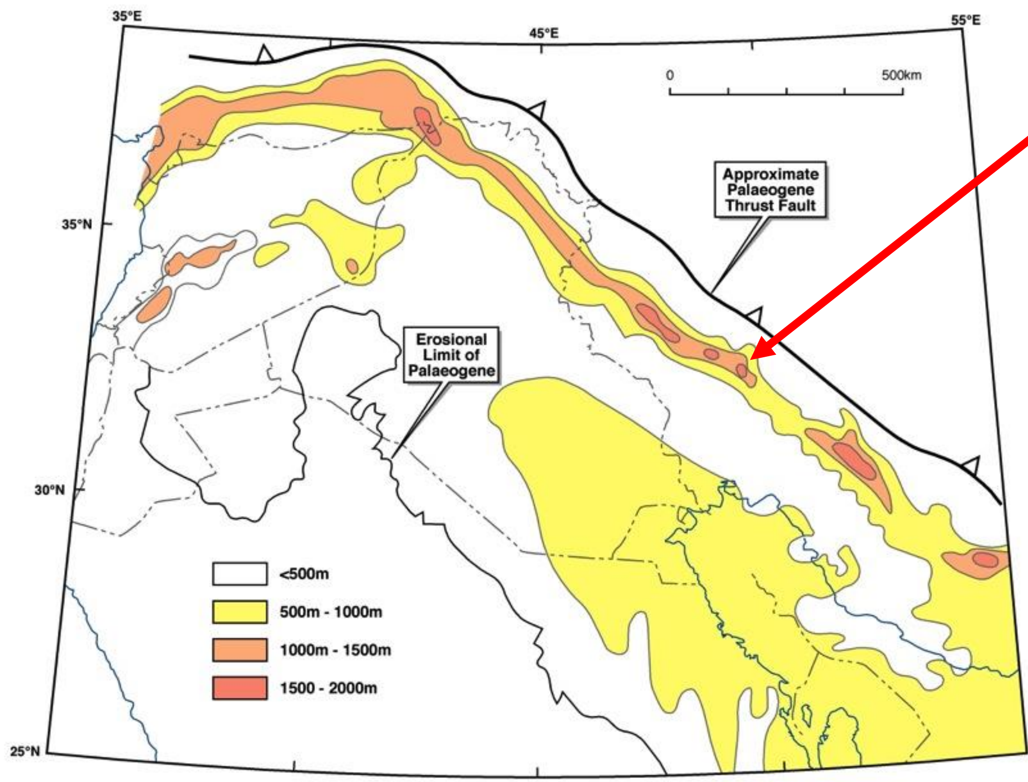
Restored Cenozoic Isopach

Basin orientation develops with respect to compression from NE

From Goff et al., 1995

Basin Evolution

- Palaeocene-Eocene



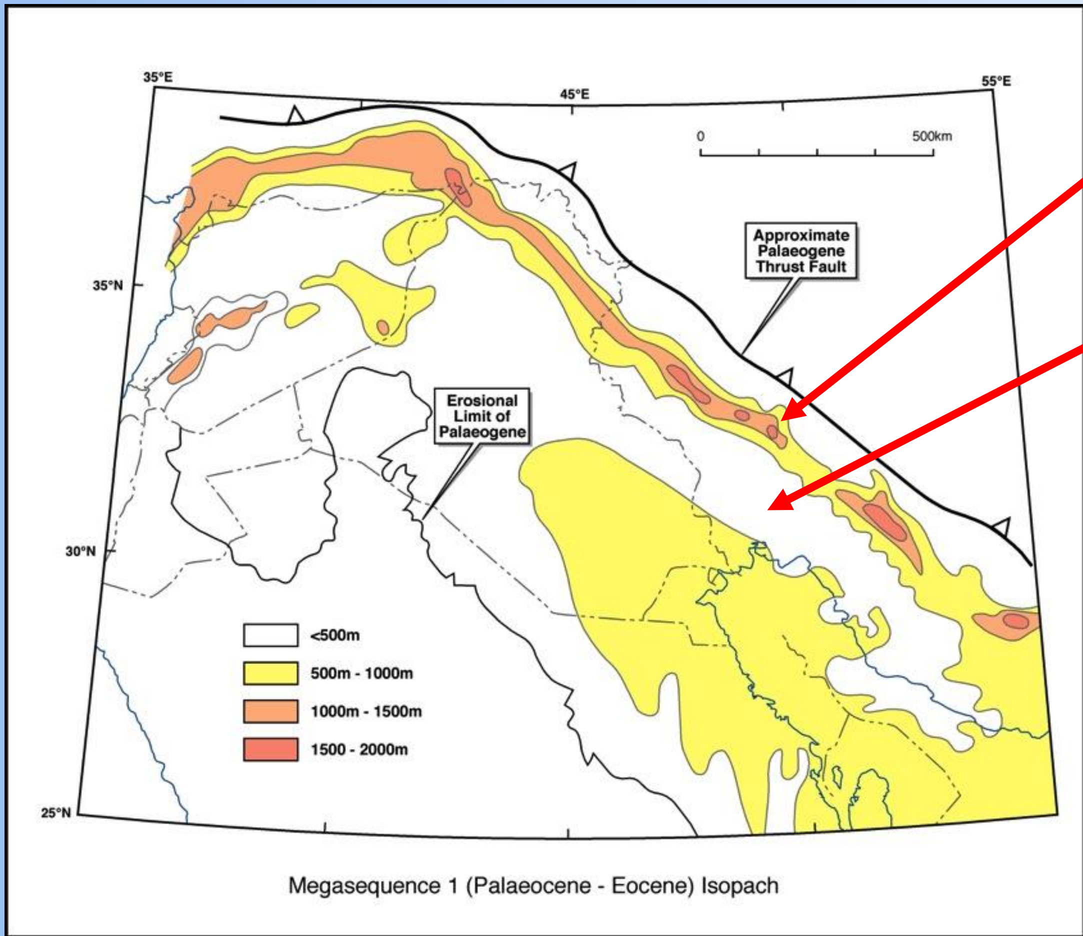
Megasequence 1 (Palaeocene - Eocene) Isopach

Sediment wedge up to 2000m thick on NE margin of basin

From Goff et al., 1995

Basin Evolution

- Palaeocene-Eocene



Megasequence 1 (Palaeocene - Eocene) Isopach

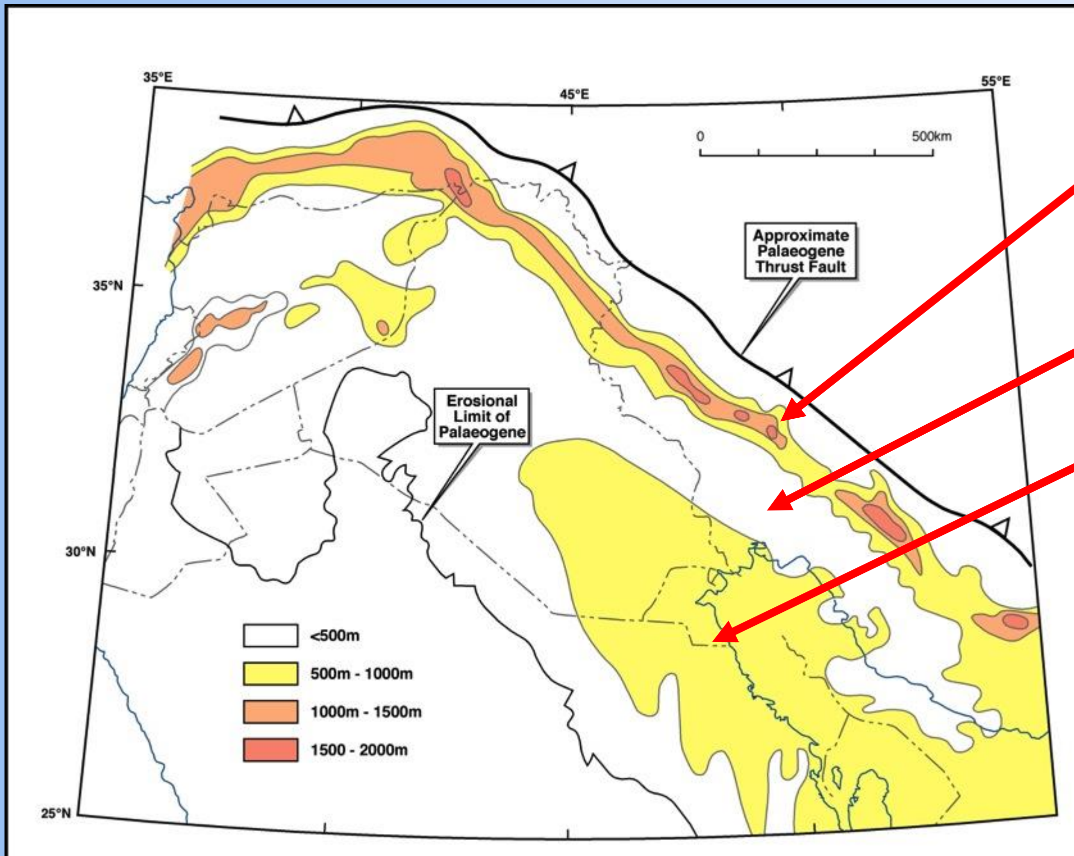
Sediment wedge up to 2000m thick on NE margin of basin

Sediment starved basin centre

From Goff et al., 1995

Basin Evolution

- Palaeocene-Eocene



Megasequence 1 (Palaeocene - Eocene) Isopach

Sediment wedge up to 2000m thick on NE margin of basin

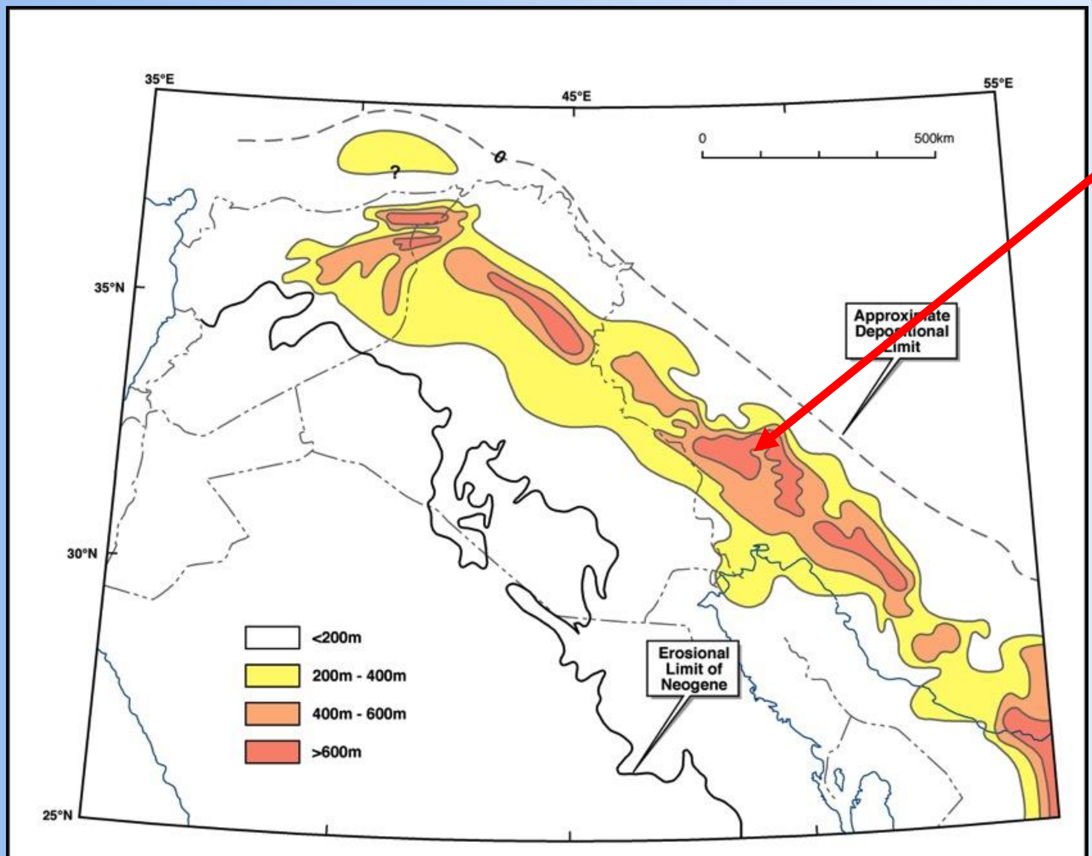
Sediment starved basin centre

Broad platform <1000m thick on SW side

From Goff et al., 1995

Basin Evolution

- Oligocene-Lower Miocene



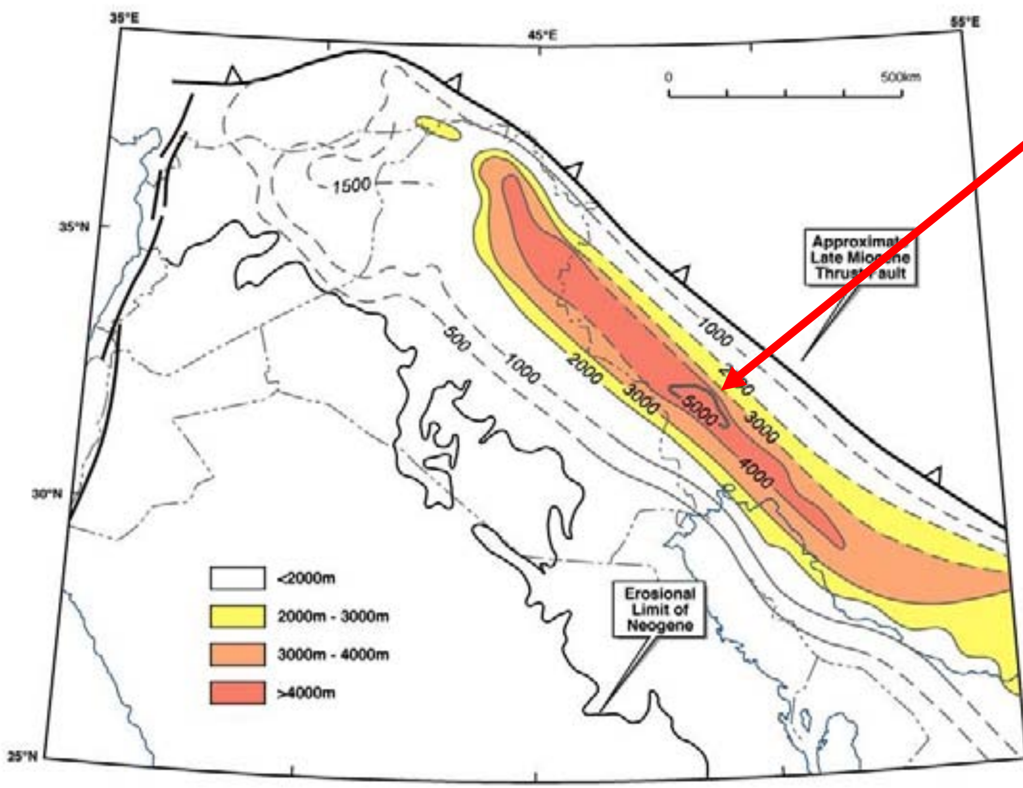
Megasequence 2 (Oligocene - Early Miocene) Isopach

Sediments >600m thick in basin centre, plug unfilled end-Eocene accommodation space

From Goff et al., 1995

Basin Evolution

- Mid Miocene - Recent



Restored Megasequence 3 (Middle Miocene - Pliocene) Isopach

Loading of second basin formed due to strong final compression; very thick (>4000m) infill in centre

From Goff et al., 1995

Pre-Foreland

Pre-Foreland

- Pre-Turonian, only exposed in High Zagros

Surdash area, Kurdistan

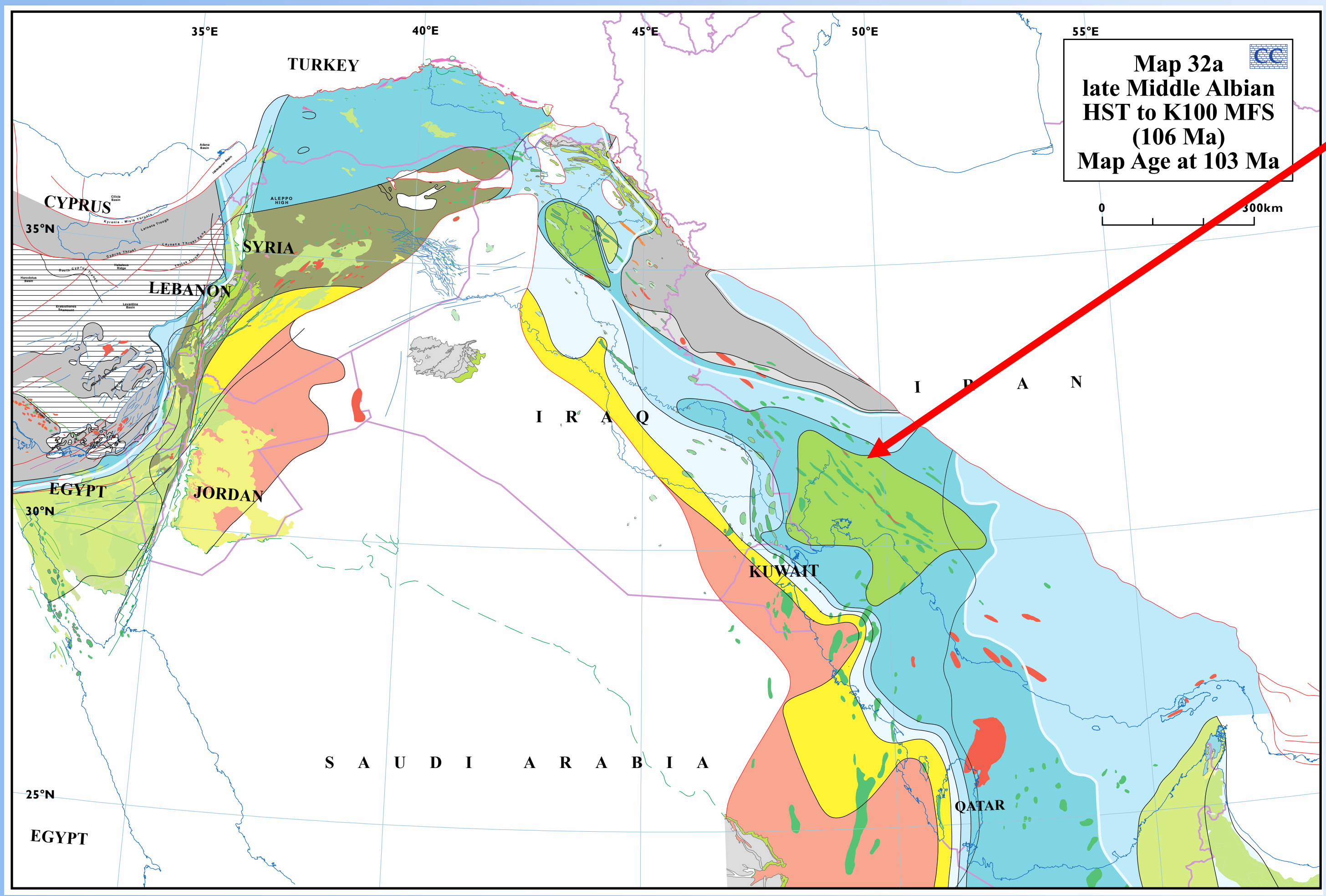
Pre-Foreland

- Source rocks largely sit in pre-foreland

Sargelu Formation, Bajocian-Bathonian, Sargelu, Iraqi Kurdistan

Pre-Foreland

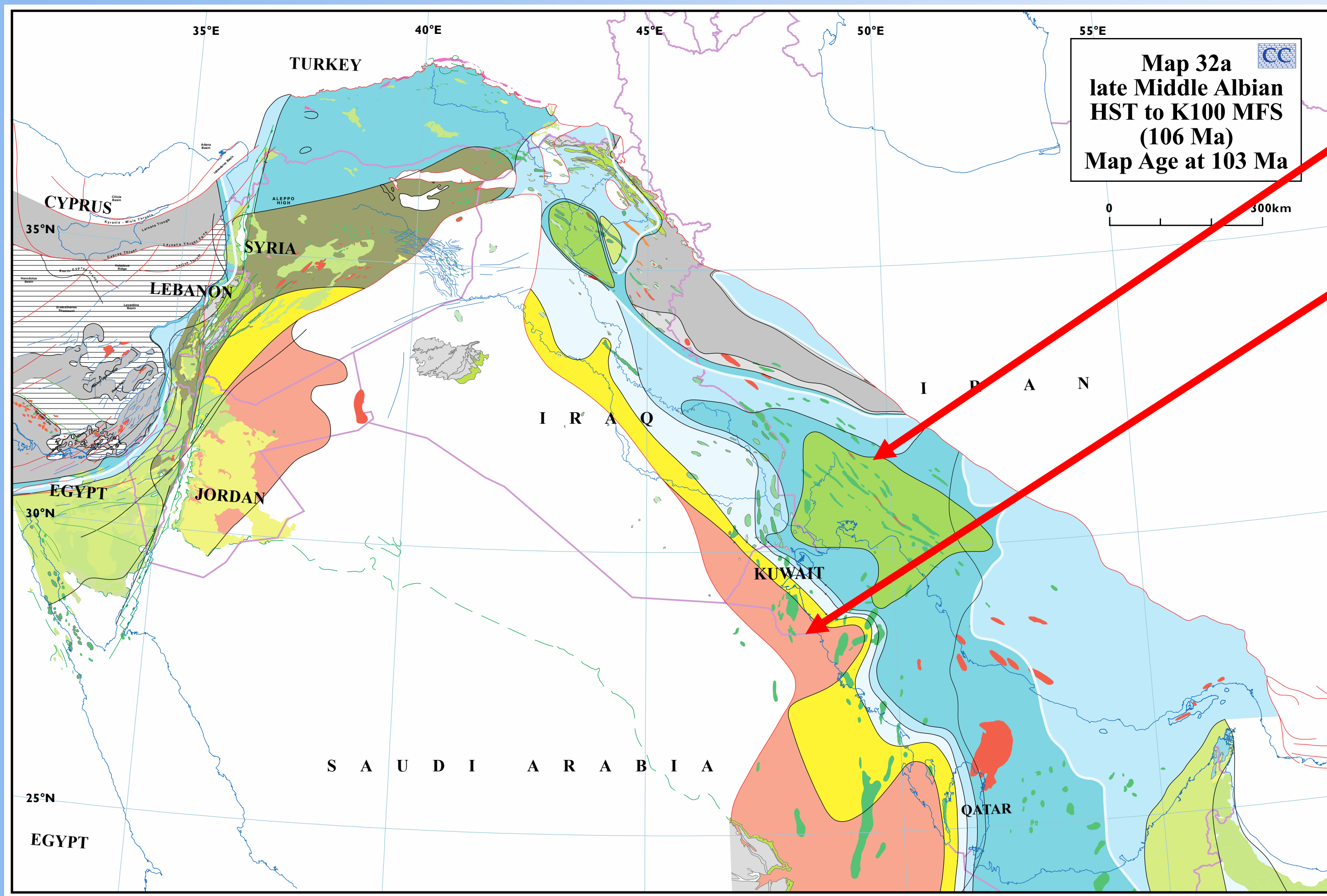
- In intrashelf basins, e.g. Kazhdumi (Albian)



Kazhdumi intashelf basin

Pre-Foreland

- Clastics enter from SW, e.g. Burgan (Albian)

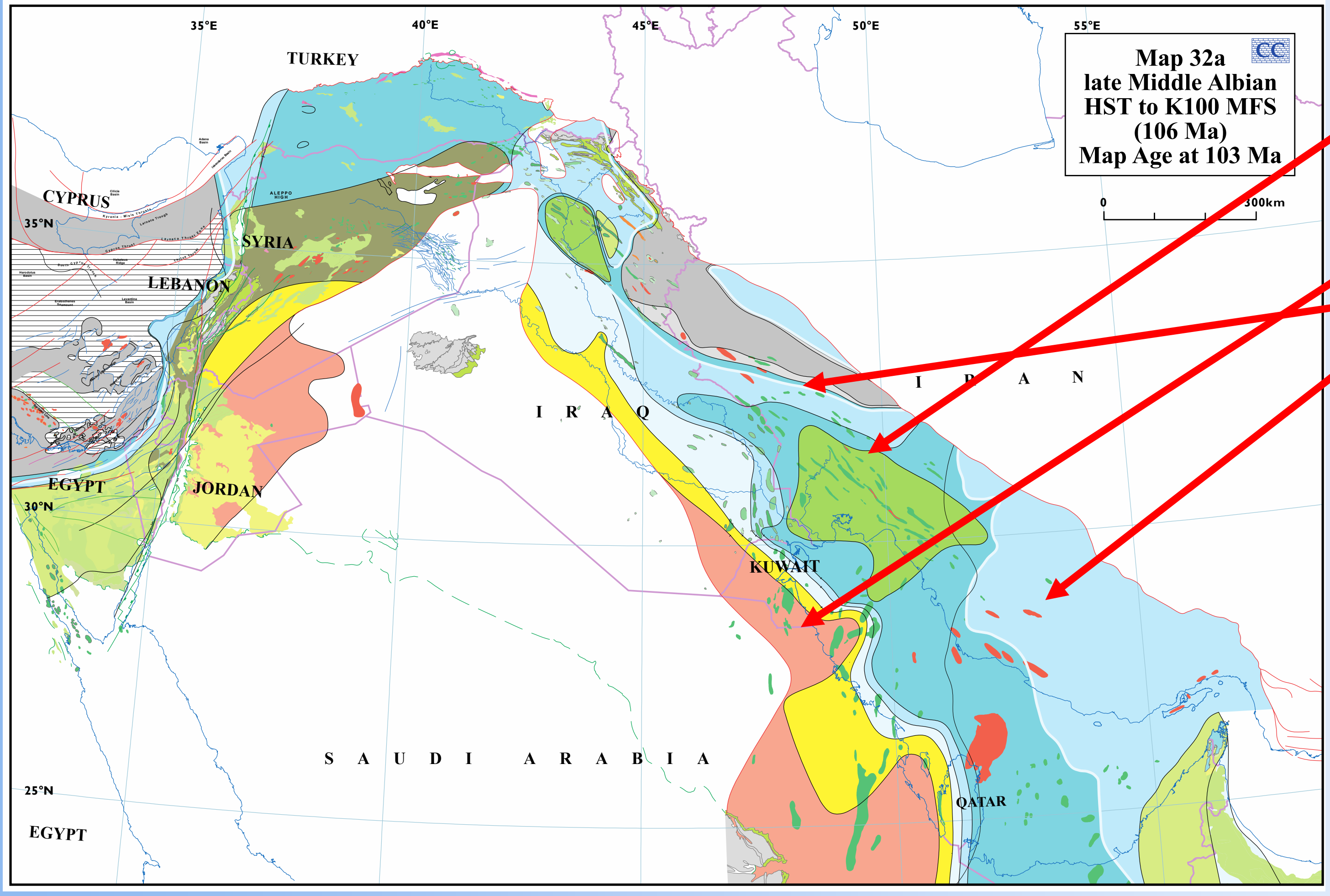


Kazhdumi intashelf basin

Burgan Fm.

Pre-Foreland

- Carbonate platforms on Tethyan side (Albian)



Kazhdumi intashelf basin

Burgan Fm.

Sarvak Fm.

Pre-Foreland

- Carbonate reservoirs of Sarvak and Qamchuqa

Qamchuqa platform

Pre-Foreland

- Carbonate reservoirs of Qamchuqa in Iraq

Qamchuqa platform above Sarmord slope facies, Qamchuqa Gorge, Iraqi Kurdistan

Pre-Foreland

- And Sarvak in Iran

Pre-Foreland

- And Sarvak in Iran

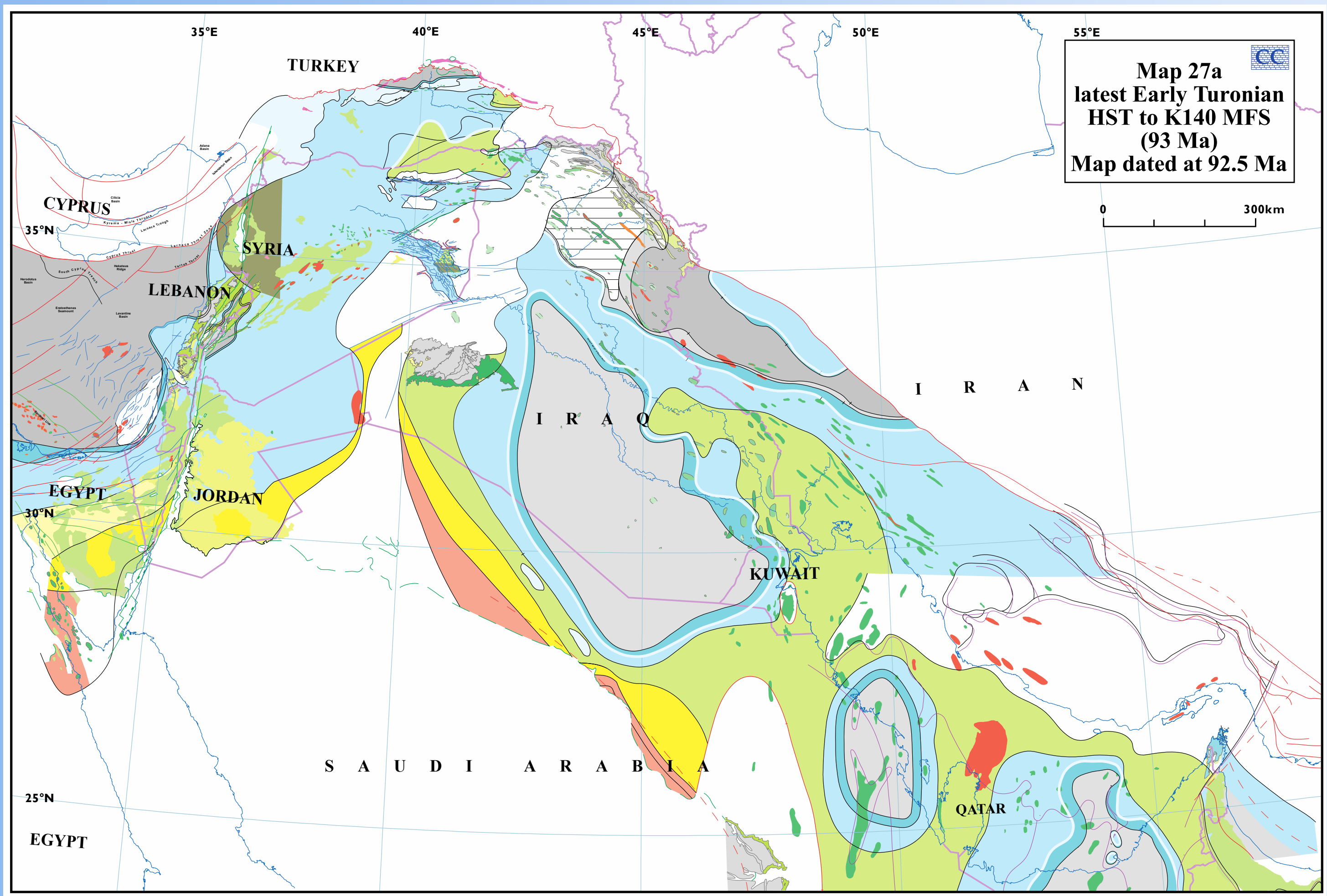
Pre-Foreland

- High temperature dolomite reservoir

Zebra dolomite fabrics, Qamchuqa platform, Qamchuqa Gorge, Iraqi Kurdistan

Pre-Foreland

- Top-Mishrif/Sarvak (end of pre-foreland)



Pre-Foreland: Summary

- Commonly developed intrashelf basins that may have highly restricted (=source rock) and often evaporitic infills
- Pre-foreland basin geometries largely independent of present-day plate margin palaeogeographic context
- Thick (1-1.5km) and often aggrading carbonate platforms around basin margins
- Most clastics enter from SW side of plate

Pre-Foreland: Petroleum Geology

- High-temperature dolomite reservoirs common
- Fracture-enhanced; dual porosity systems
- Problems: limestones generally very low porosity (in f.t.b.)
- Problems: typically poor quality intra-Pre Foreland sealing facies which usually fracture/fail within high-amplitude anticlines

Foreland

Foreland

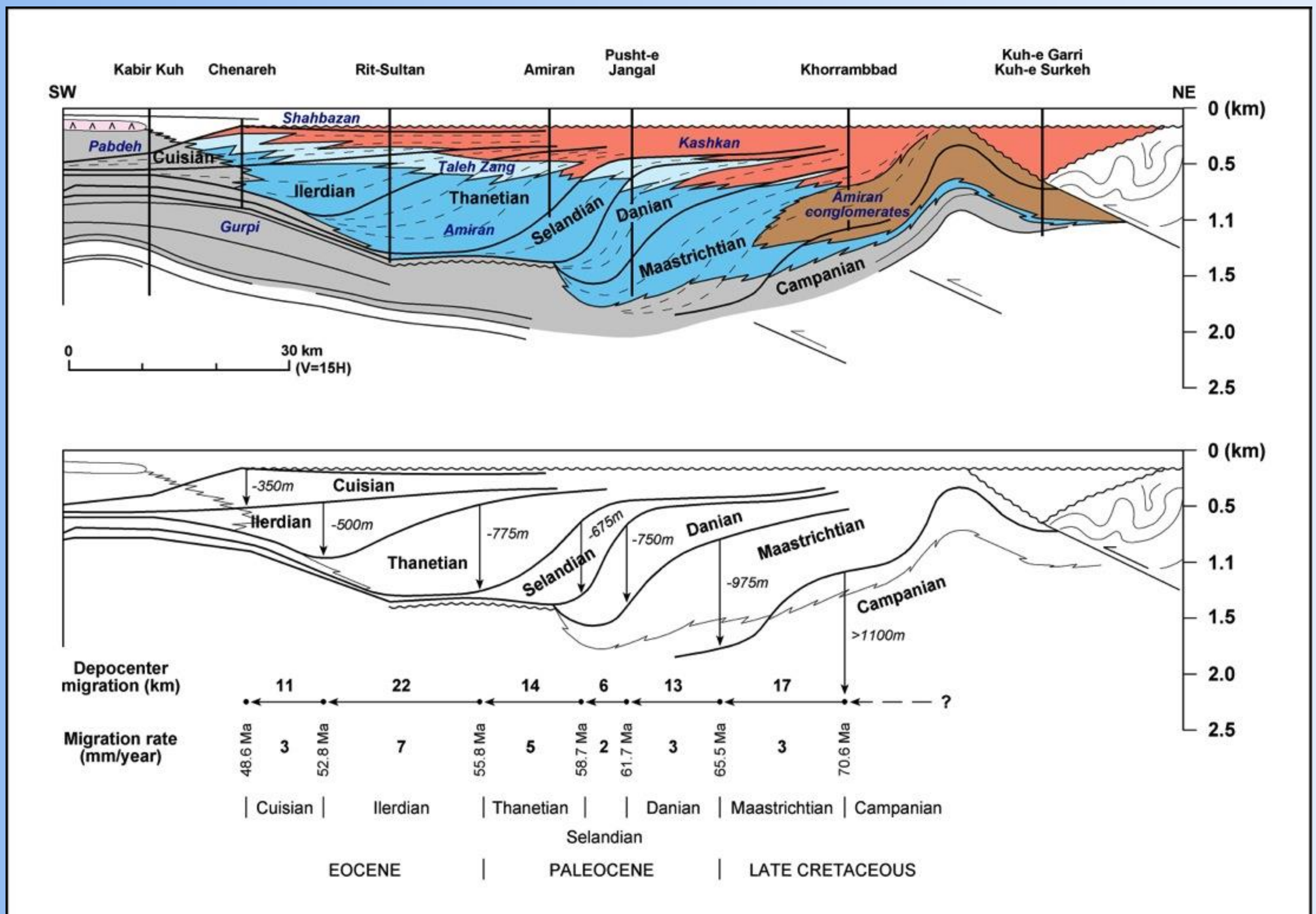
- Four phases of development:
  - Upper Cretaceous to Eocene
  - Oligocene to Aquitanian
  - Burdigalian
  - Middle Miocene to Recent

Foreland: Upper Cretaceous

From Saura
et al., 2011

Foreland: Upper Cretaceous

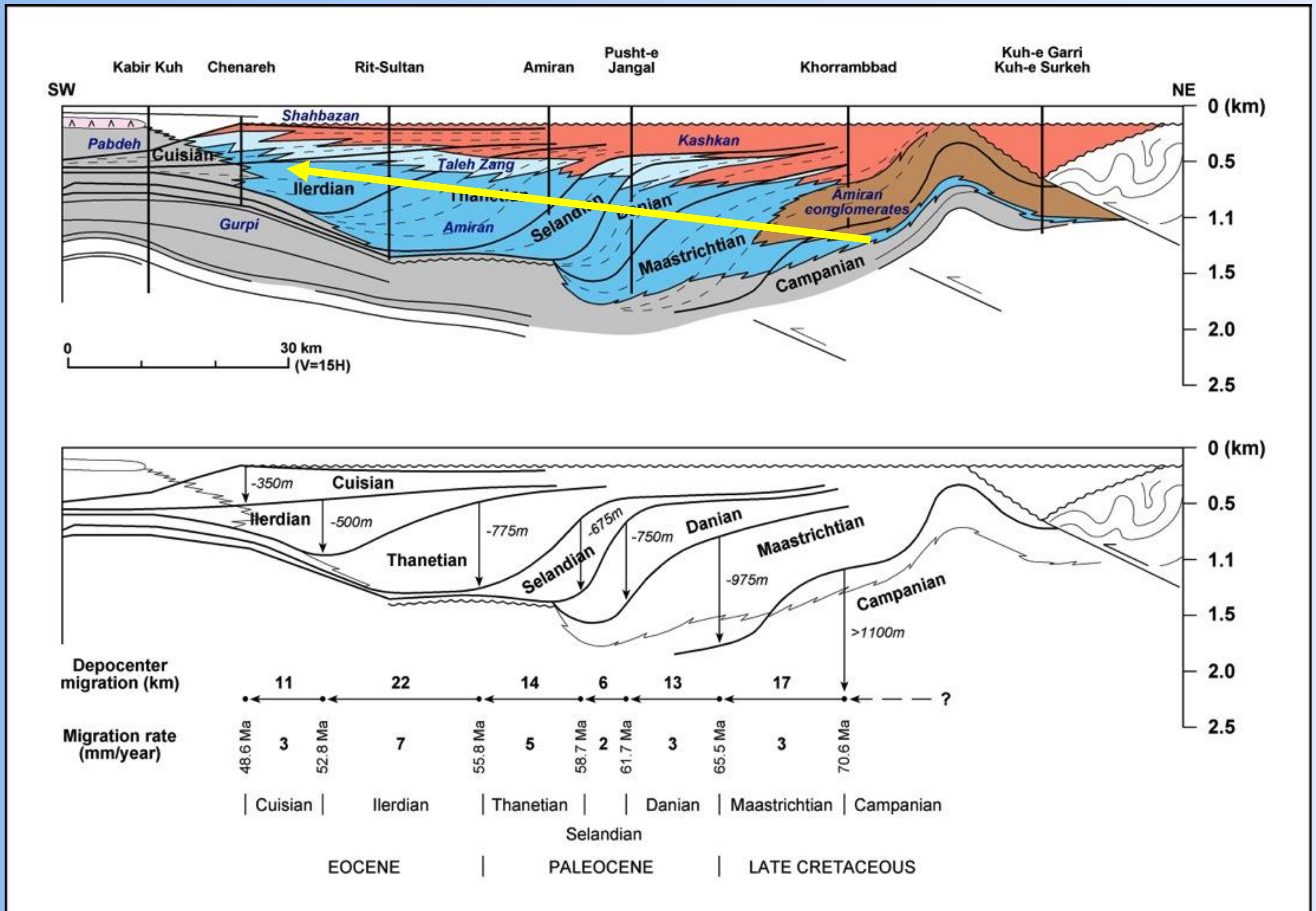
- Upper Cretaceous and Palaeogene continuum:



From Saura et al., 2011

Foreland: Upper Cretaceous

- Massive SW-prograding sediment wedge



From Saura et al., 2011

Foreland: Upper Cretaceous

- Initial drowning of Albian-Cenomanian platforms during Turonian (Kometan, Ilam)

Qamchuqa platform,

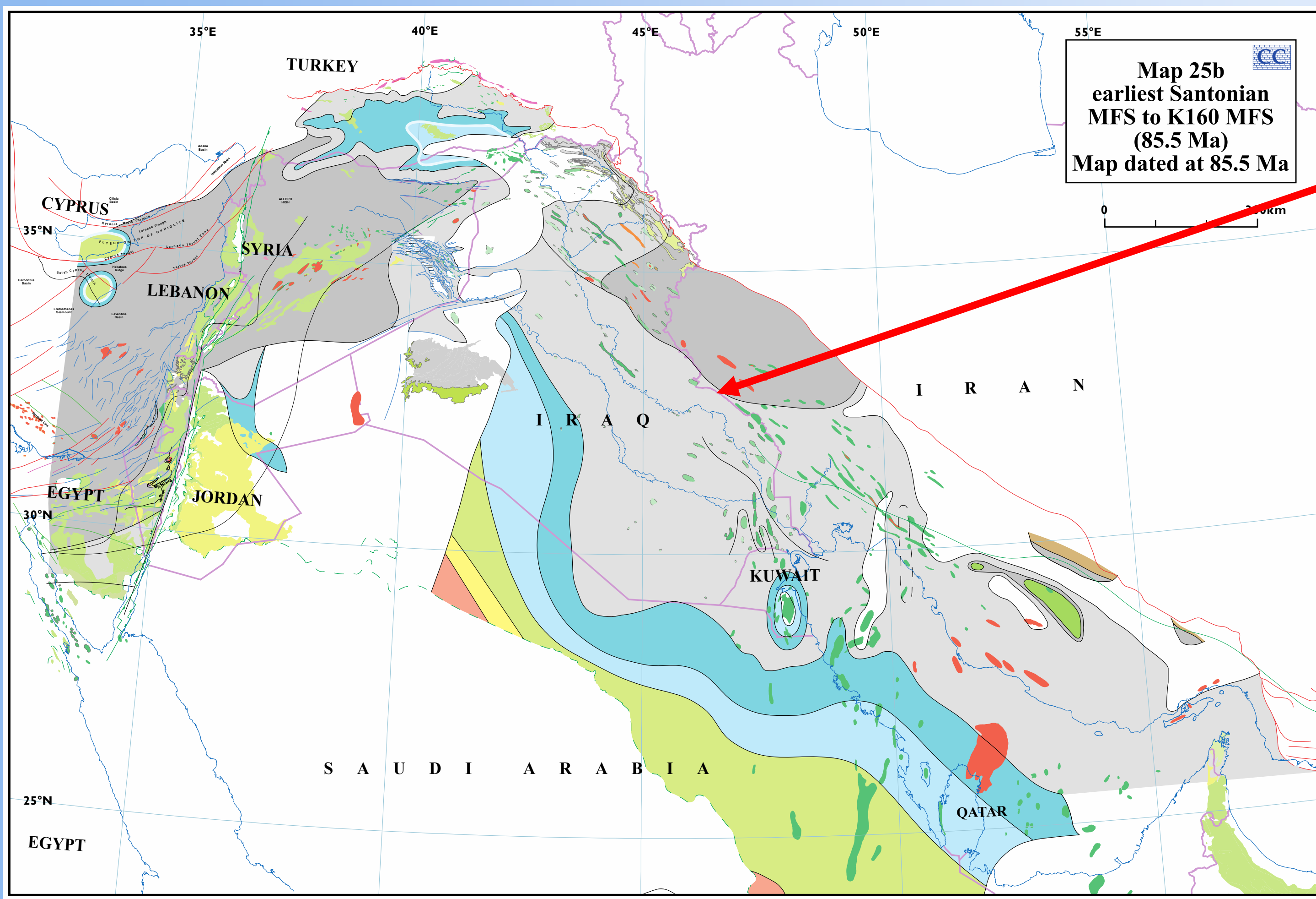
Foreland: Upper Cretaceous

- Initial drowning of Albian-Cenomanian platforms during Turonian (Kometan, Ilam)

Qamchuqa platform, Kometan basinal limestones, Qamchuqa Gorge, Iraqi Kurdistan

Foreland: Upper Cretaceous

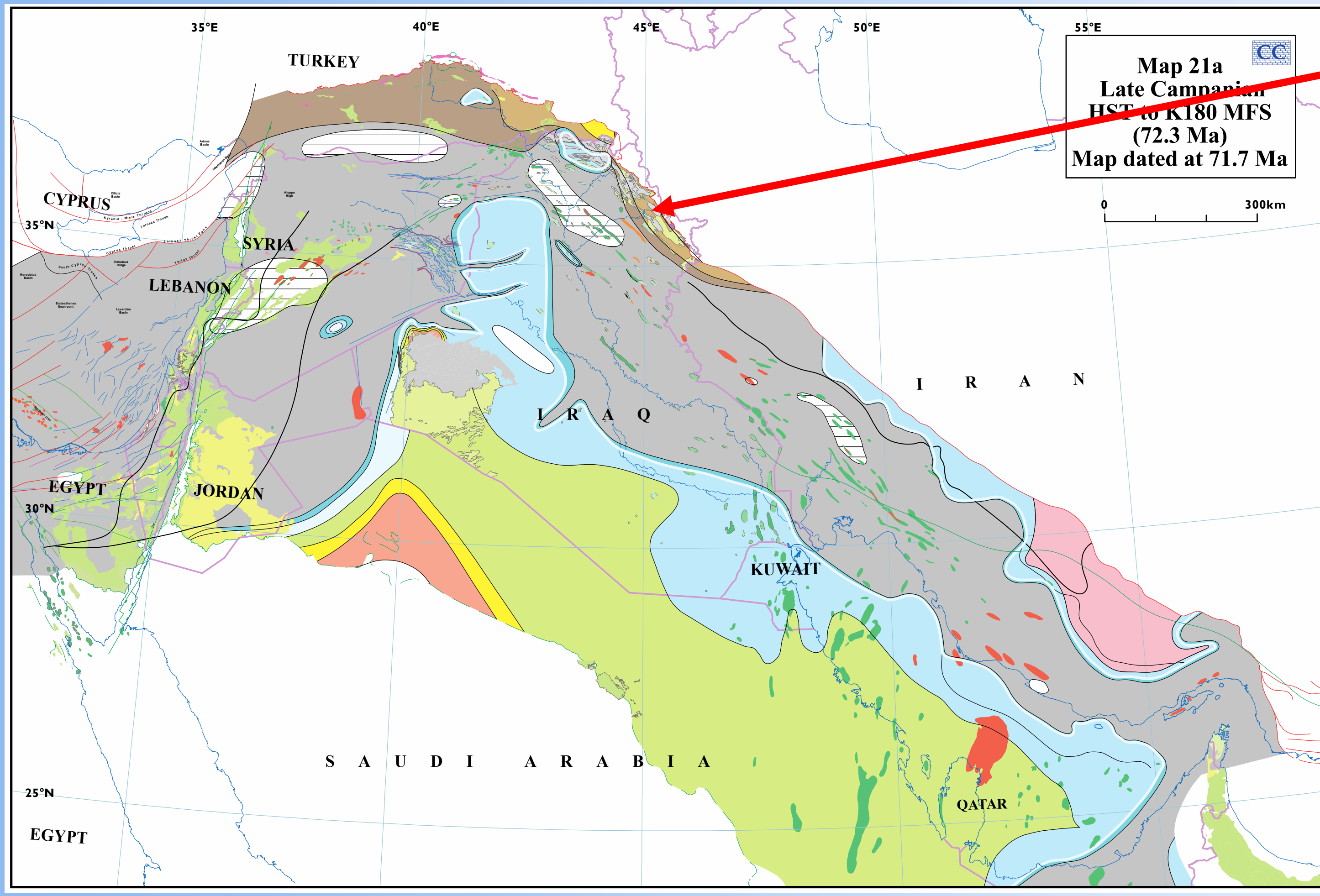
- Initially generally deeper-water (e.g. Ilam)



Ilam basinal carbonates above older Sarvak platform, Lurestan

Foreland: Upper Cretaceous

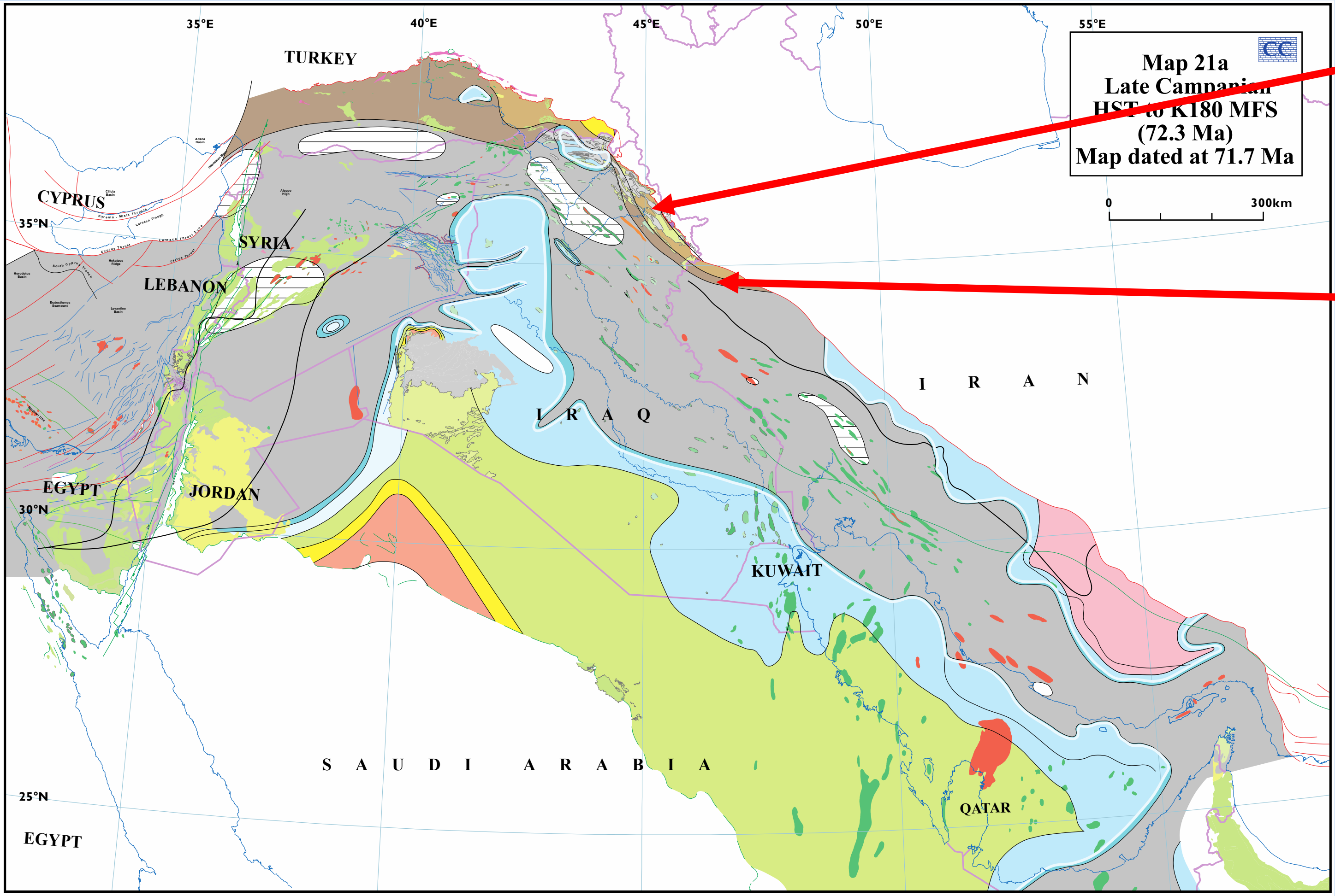
- Later development of platforms and flysch



Isolated platforms in SE Turkey and N. Iraq

Foreland: Upper Cretaceous

- Later development of platforms and flysch

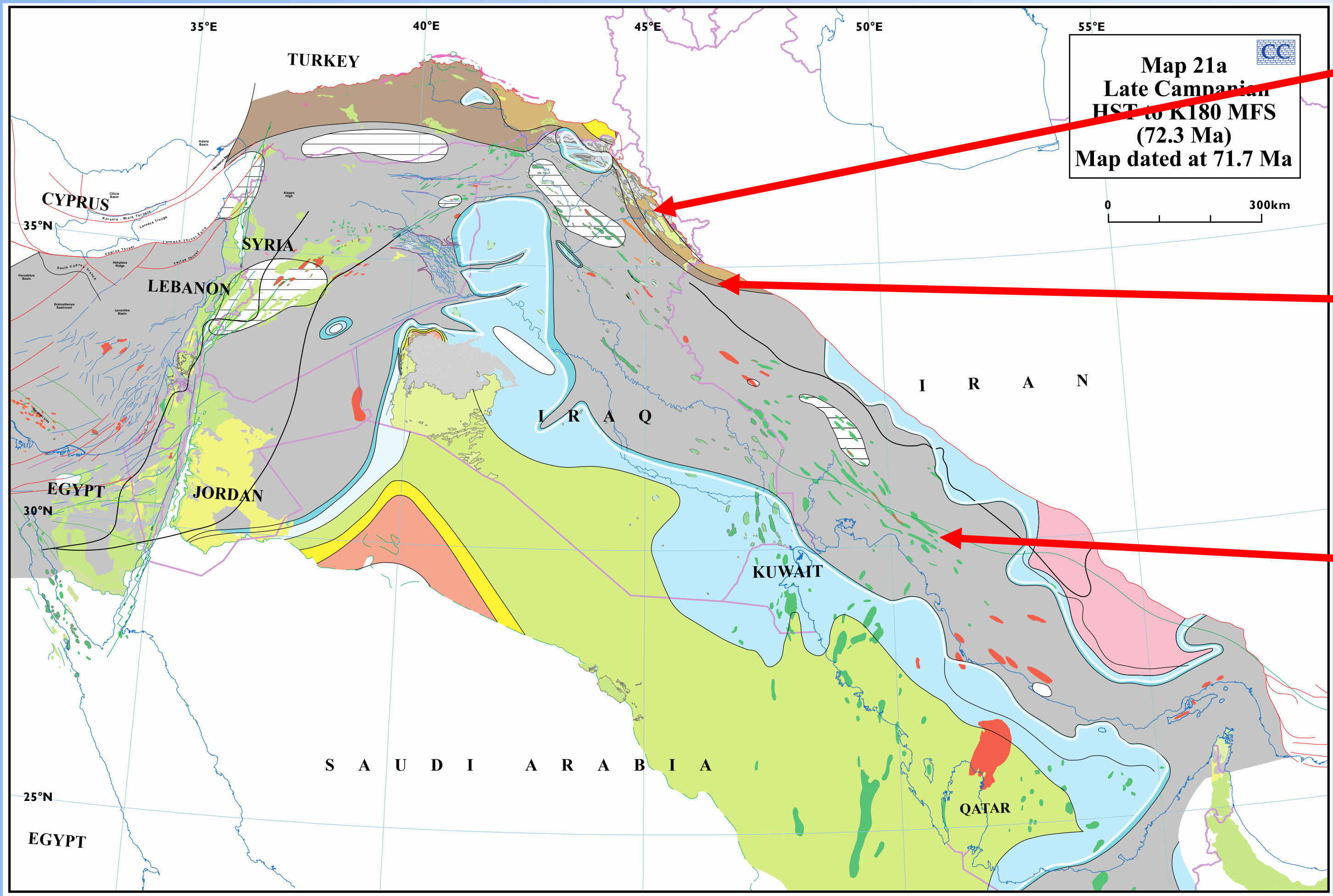


Isolated platforms in SE Turkey and N. Iraq

Flysch input off obducted ophiolites

Foreland: Upper Cretaceous

- Later development of platforms and flysch



Isolated platforms in SE Turkey and N. Iraq

Flysch input off obducted ophiolites

Deepwater marls

Foreland: Upper Cretaceous

- ‘flyschoid’ coarse clastics to marls

Kometan Formation limestones

Foreland: Upper Cretaceous

- Tanjero, Shiranish (here) in Iraq,

Kometan Formation limestones overlain by Shrianish Formation, Dokan Gorge

Foreland: Upper Cretaceous

- Gurpi (here), Amiran in Iran

Kabir Kuh, Lurestan

Foreland: Late K Petroleum Geology

- Isolated carbonate platforms (stratigraphic traps):
- Productive in SE Turkey and NW Iraq (Tawke)
- Fractured basinal carbonate reservoirs, e.g. Ain Zalah, produce best where fractures tap pre-Foreland ‘sump’ reservoir
- Sealed by flyschoid clastics
- Risk of poor topseal and thief sands is high

Foreland: Late K Petroleum Geology

- Also acts as moderate quality marly seal (sometimes!) to pre-foreland reservoirs

Shiranish over Qamchuqa, Dokan, Iraqi Kurdistan

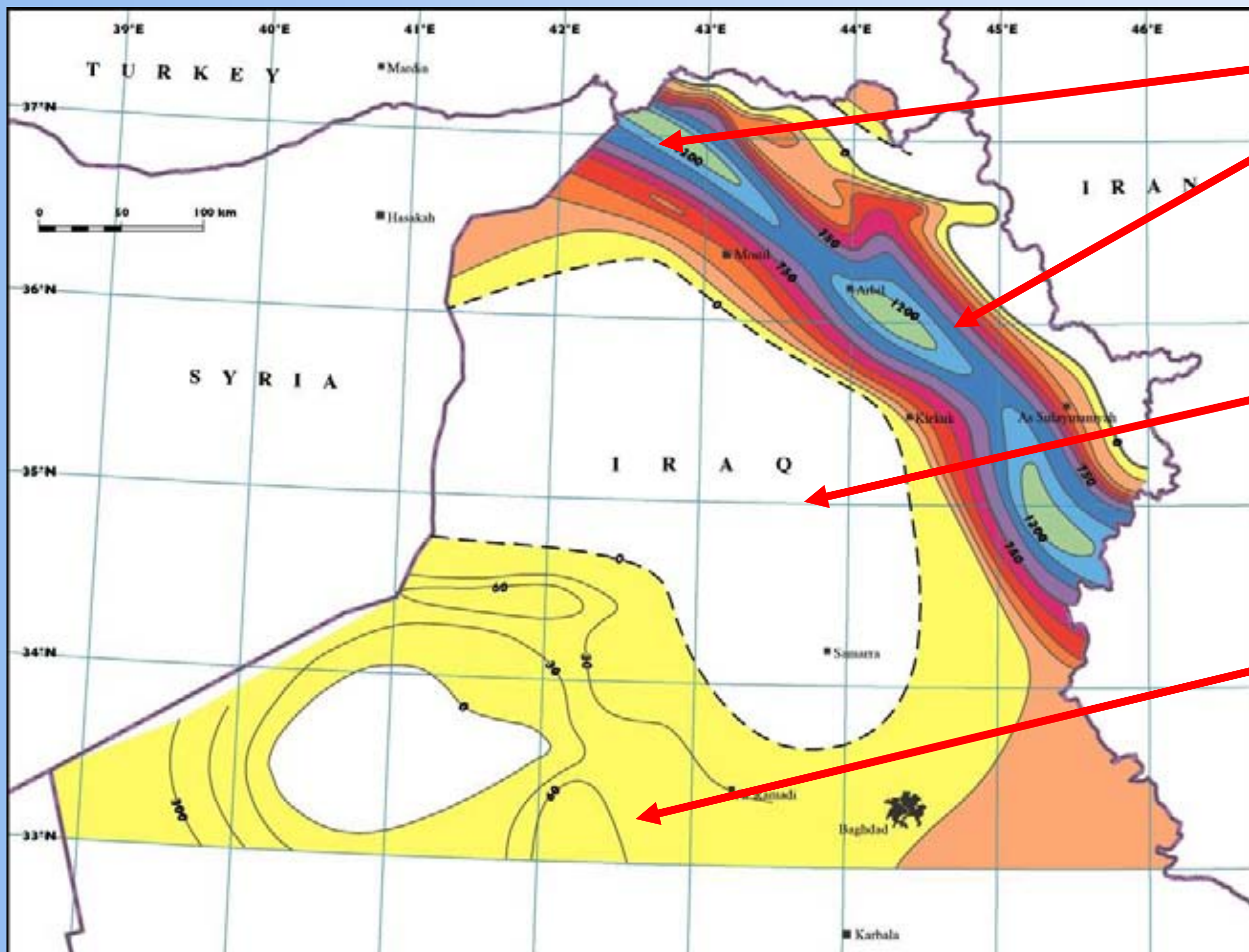
Foreland: Palaeocene-Eocene

Foreland: Palaeocene-Eocene

- 2 sequences:
  - Palaeocene to Early Eocene
  - Middle-Late Eocene

Foreland: Palaeocene-Eocene

- Palaeocene to Early Eocene isopach



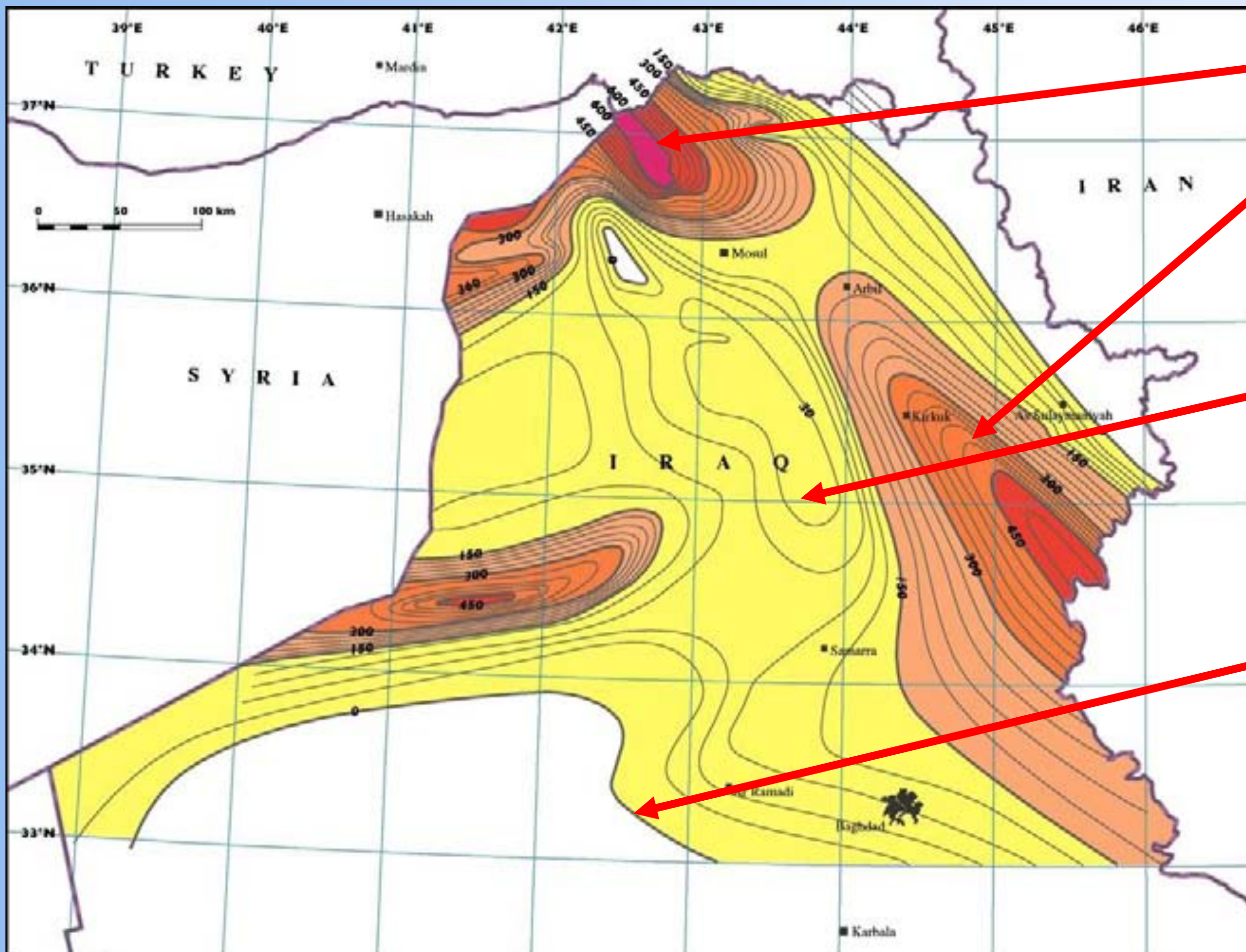
Flyschoid wedge

Sediment starved basin centre

SW carbonate shelf

Foreland: Palaeocene-Eocene

- Middle-Late Eocene isopach (similar elements)



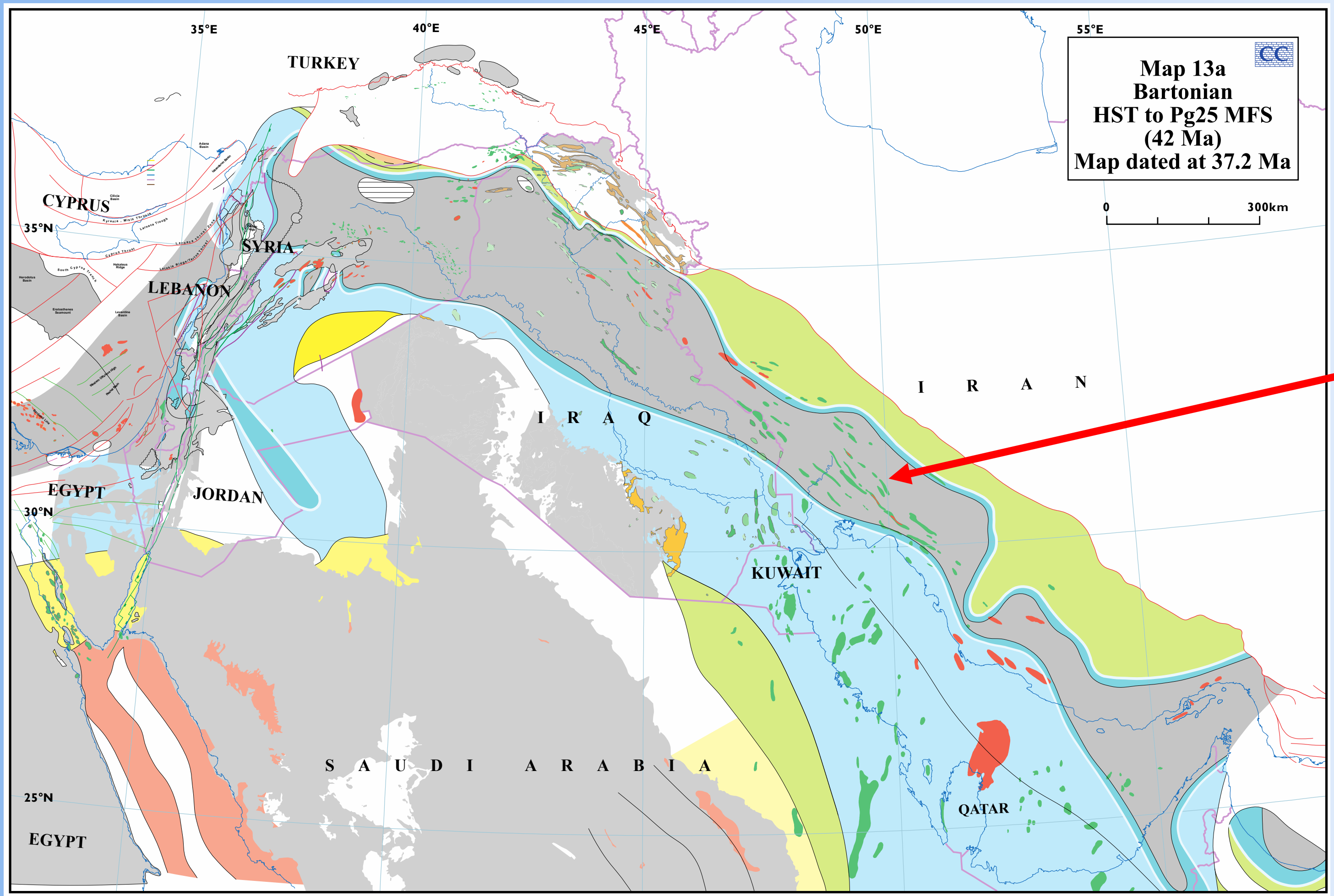
Flyschoid wedge

Sediment starved basin centre

SW carbonate shelf

Foreland: Palaeocene-Eocene

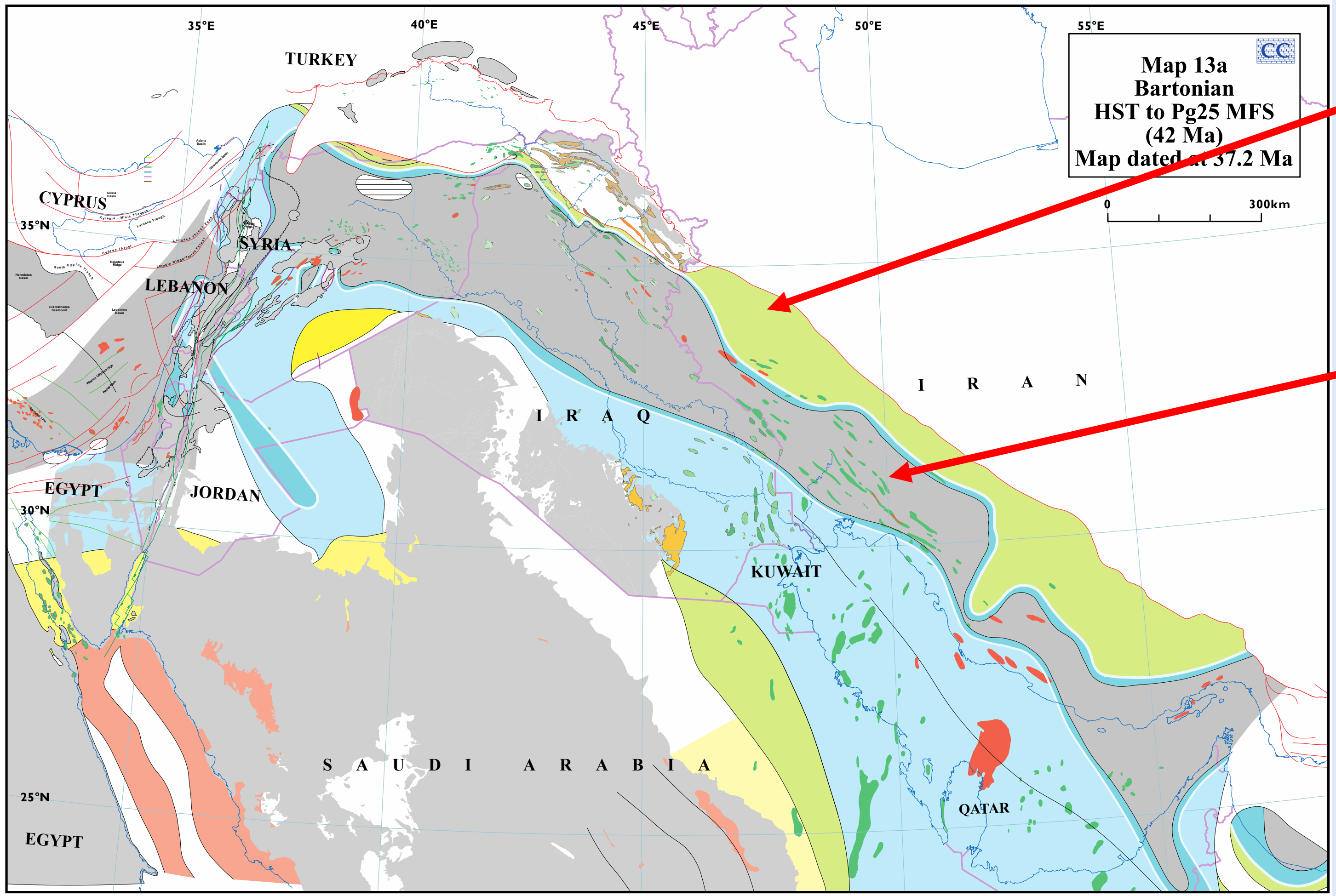
- Example: Late Eocene (Bartonian)



Basin continuous from Med to Hormuz

Foreland: Palaeocene-Eocene

- Example: Late Eocene (Bartonian)

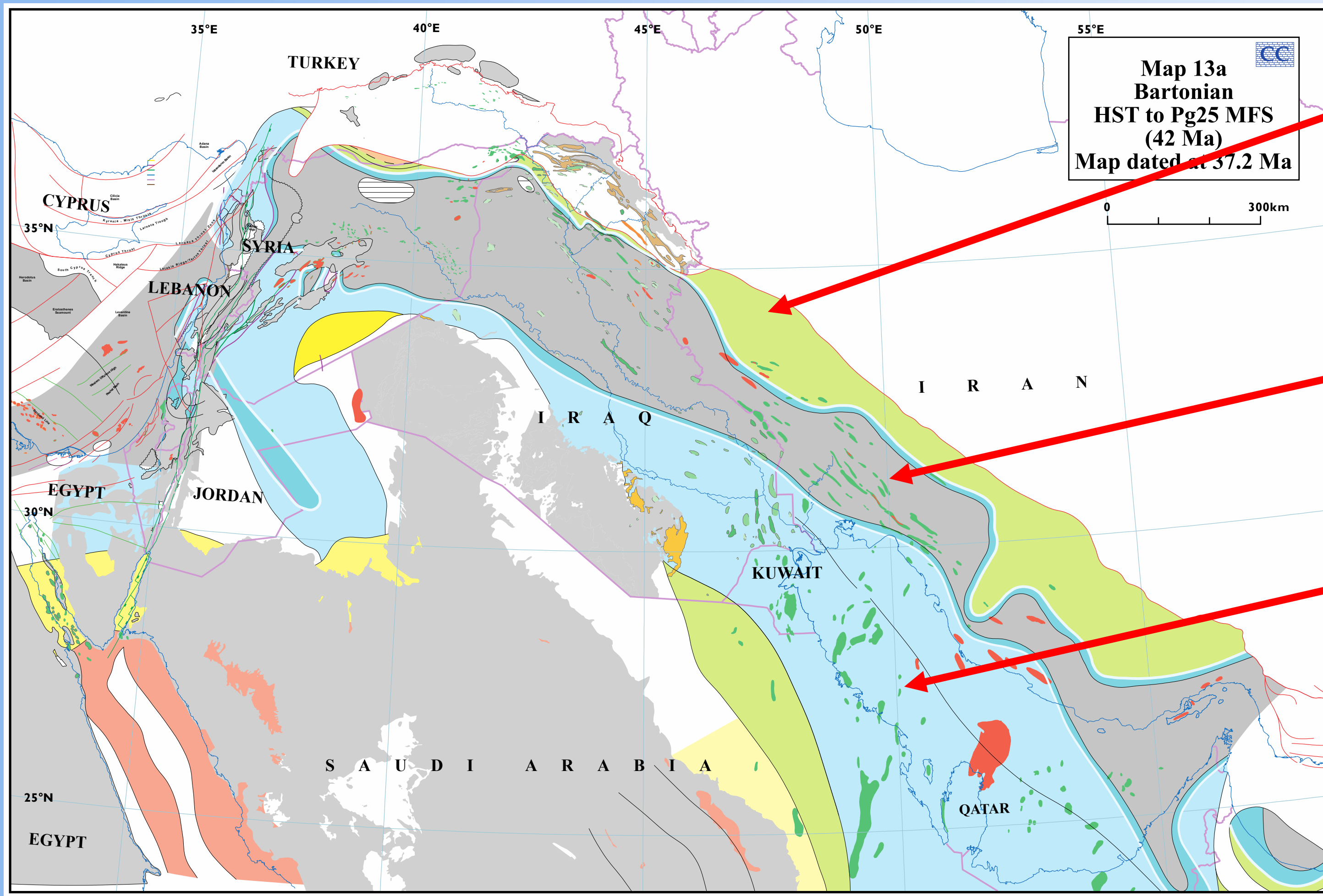


'narrow' carbonate shelf on NE side

Basin continuous from Med to Hormuz

Foreland: Palaeocene-Eocene

- Example: Late Eocene (Bartonian)



'narrow' carbonate shelf on NE side

Basin continuous from Med to Hormuz

Wide carbonate shelf on SW side

Foreland: Palaeocene-Eocene

- Eocene carbonate reservoir rocks

Jebel Bamu, Iraqi Kurdistan

Foreland: Palaeocene-Eocene

- Eocene carbonate reservoir rocks (Avanah)

Jebel Bamu, Iraqi Kurdistan

Foreland: Palaeocene-Eocene

- Ophiolite derived clastics (from the NE)

Jebel Aj Dagh, Iraqi Kurdistan

Foreland: Pal.- Eocene Summary

- Development of continuous rimmed shelf margins in Pal-Eocene
- Some isolated carbonate platforms on inversion anticlines over K basins (J. Sinjar)
- Produce as deep pay within big anticlines (Avanah and Khurmala of Kirkuk)
- Always sealed directly by Miocene evaporites
- Possible secondary reservoirs in flysch clastics but these may be very immature

Foreland: Pal.- Eocene Pet. Geology

- Produce as deep pay within big anticlines (Avanah and Khurmala domes of Kirkuk) and may be karstified beneath big sequence boundaries (Taq Taq)
- Generally poor/less predictable quality reservoir compared to Oligo-Miocene
- Almost always sealed directly beneath Miocene evaporites so only work in areas of Miocene foreland bulge

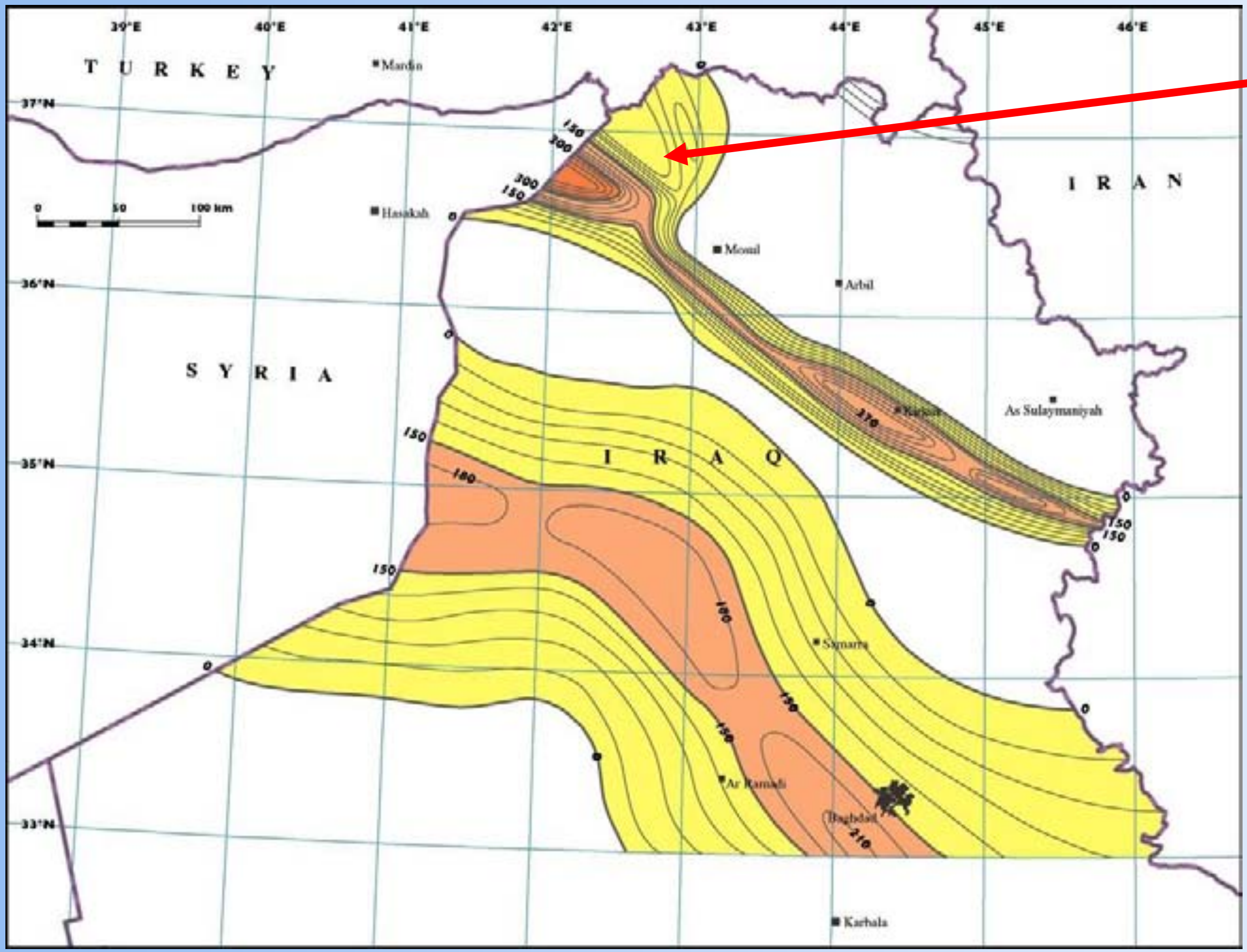
Foreland: Oligocene – Ey. Aquitanian

Foreland: Oligocene – Ey. Aquitanian

- Four sequences but all very similar
- Located almost exclusively within axis of former Eocene basin
- 'downdip' of Eocene margin

Foreland: Oligocene – Ey. Aquitanian

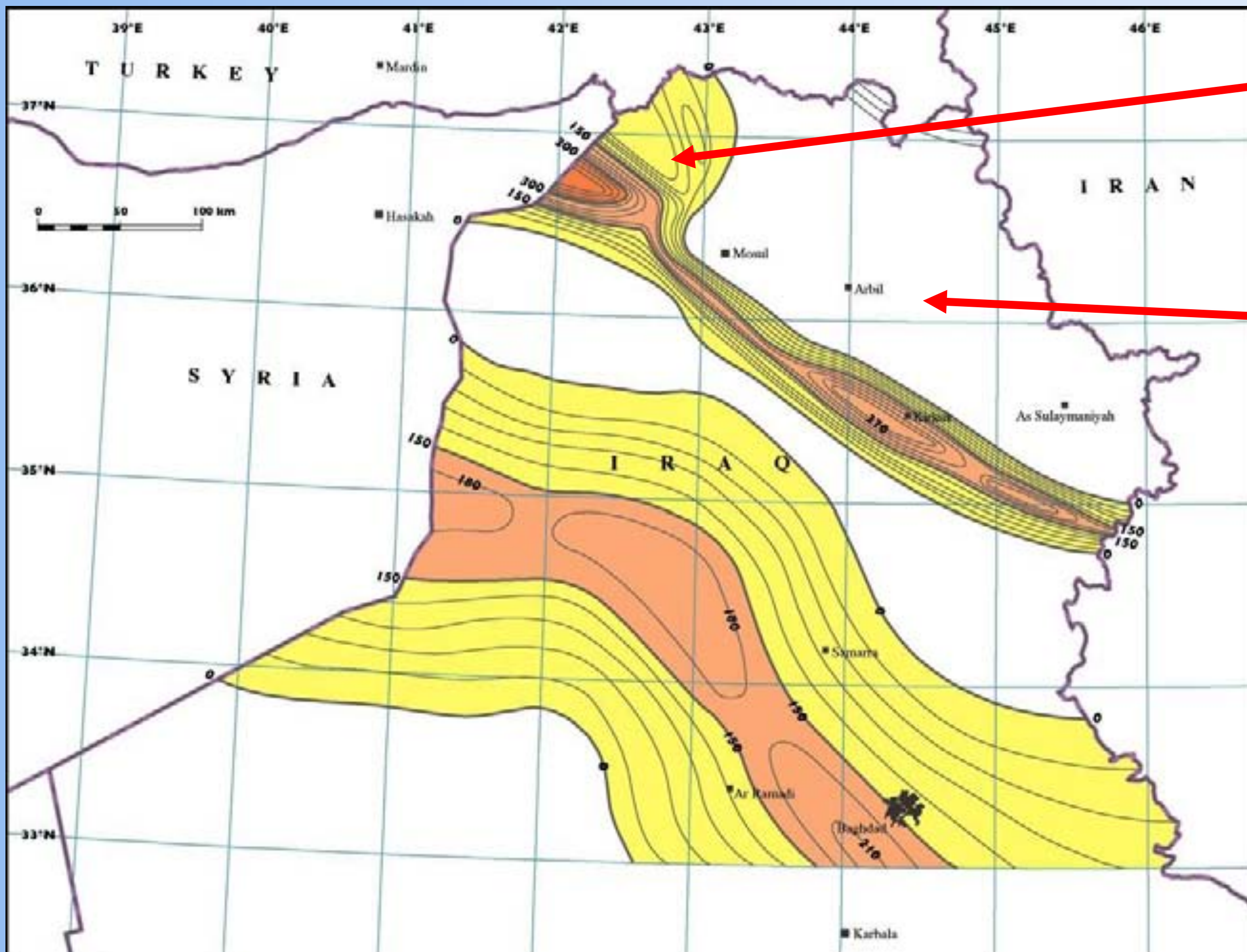
- Oligocene isopach



Narrow attached rimmed shelf in north

Foreland: Oligocene – Ey. Aquitanian

- Oligocene isopach

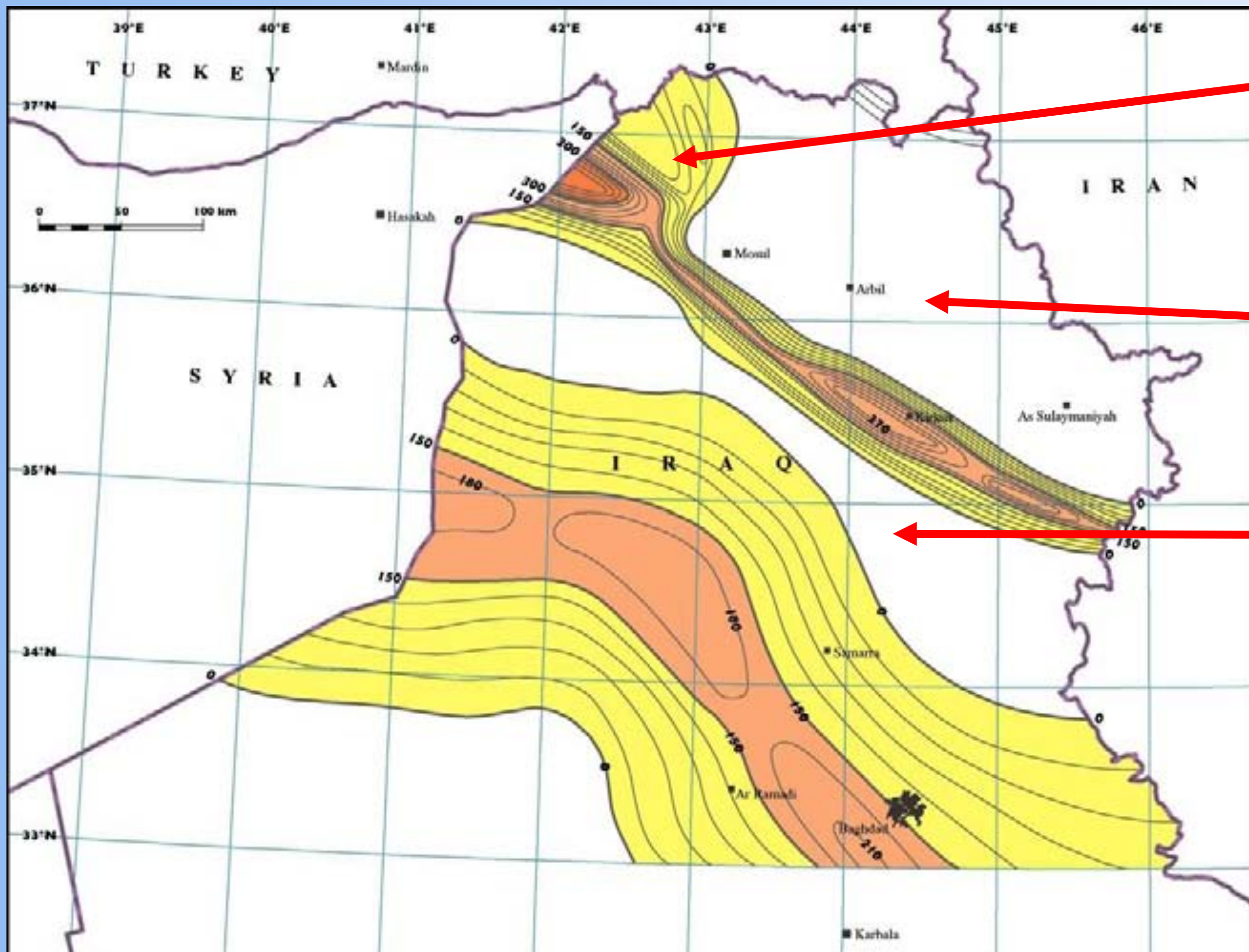


Narrow attached rimmed shelf in north

Uplifted area of exposed Eocene

Foreland: Oligocene – Ey. Aquitanian

- Oligocene isopach



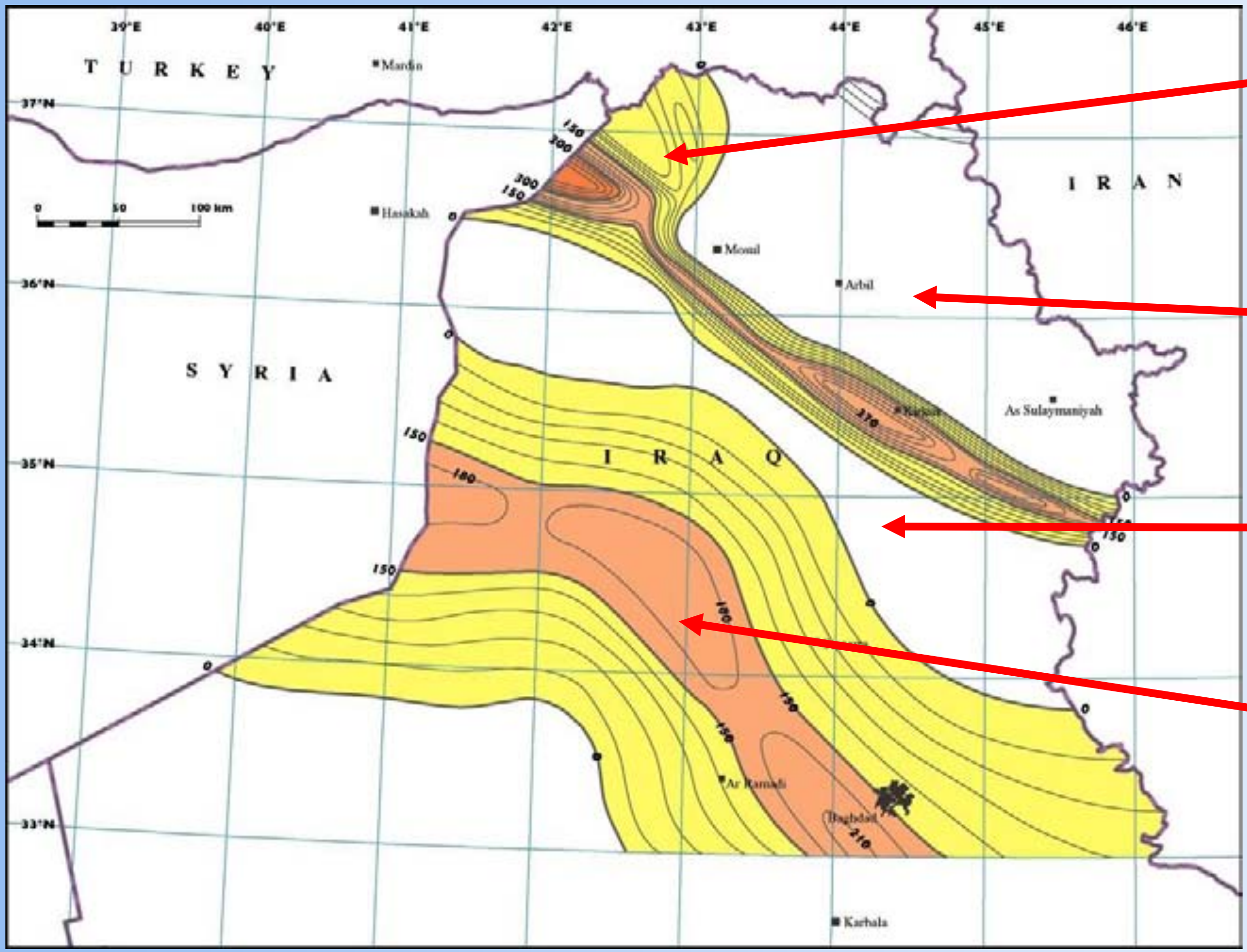
Narrow attached rimmed shelf in north

Uplifted area of exposed Eocene

Starved basin centre

Foreland: Oligocene – Ey. Aquitanian

- Oligocene isopach



Narrow attached rimmed shelf in north

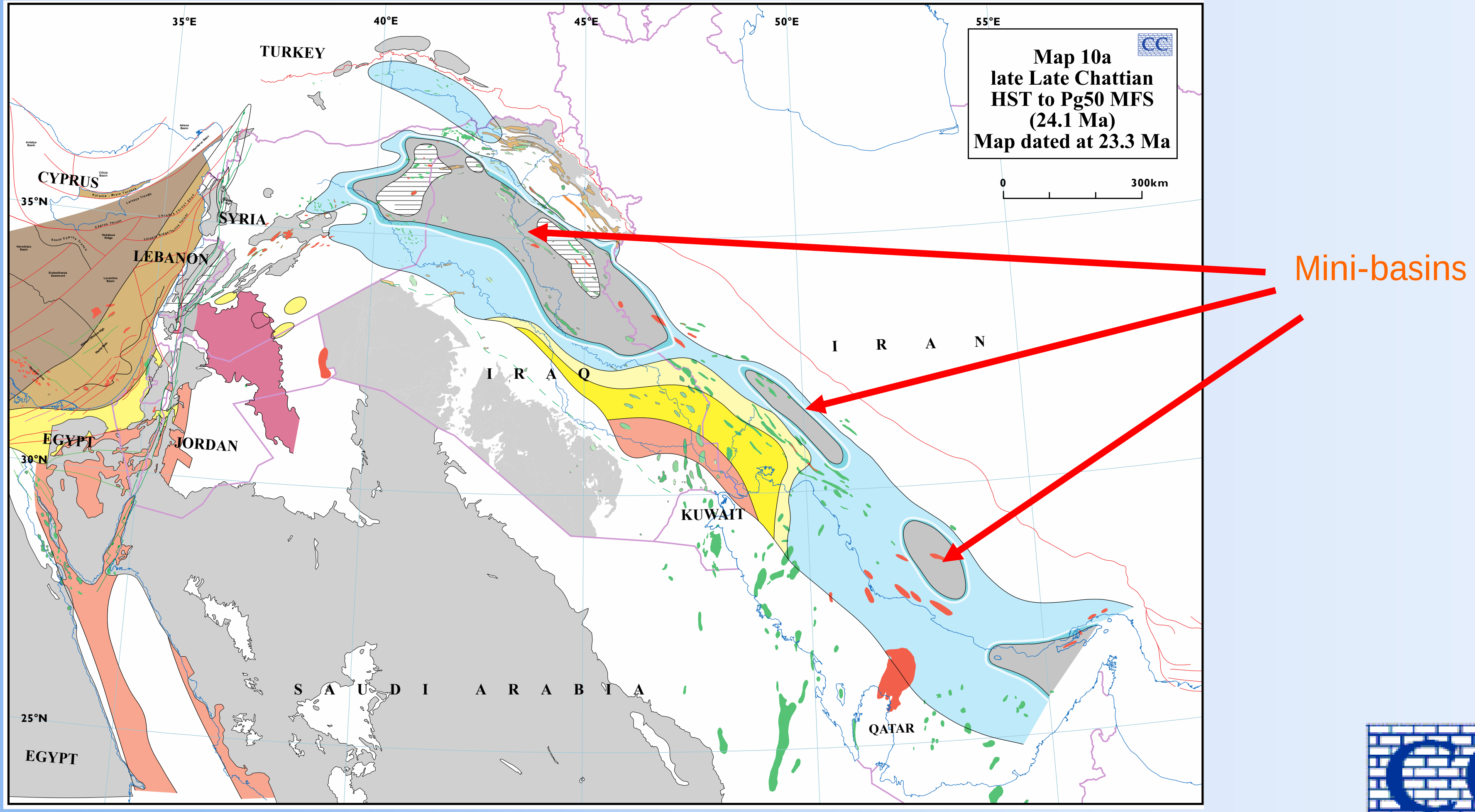
Uplifted area of exposed Eocene

Starved basin centre

Wide attached rimmed shelf in south

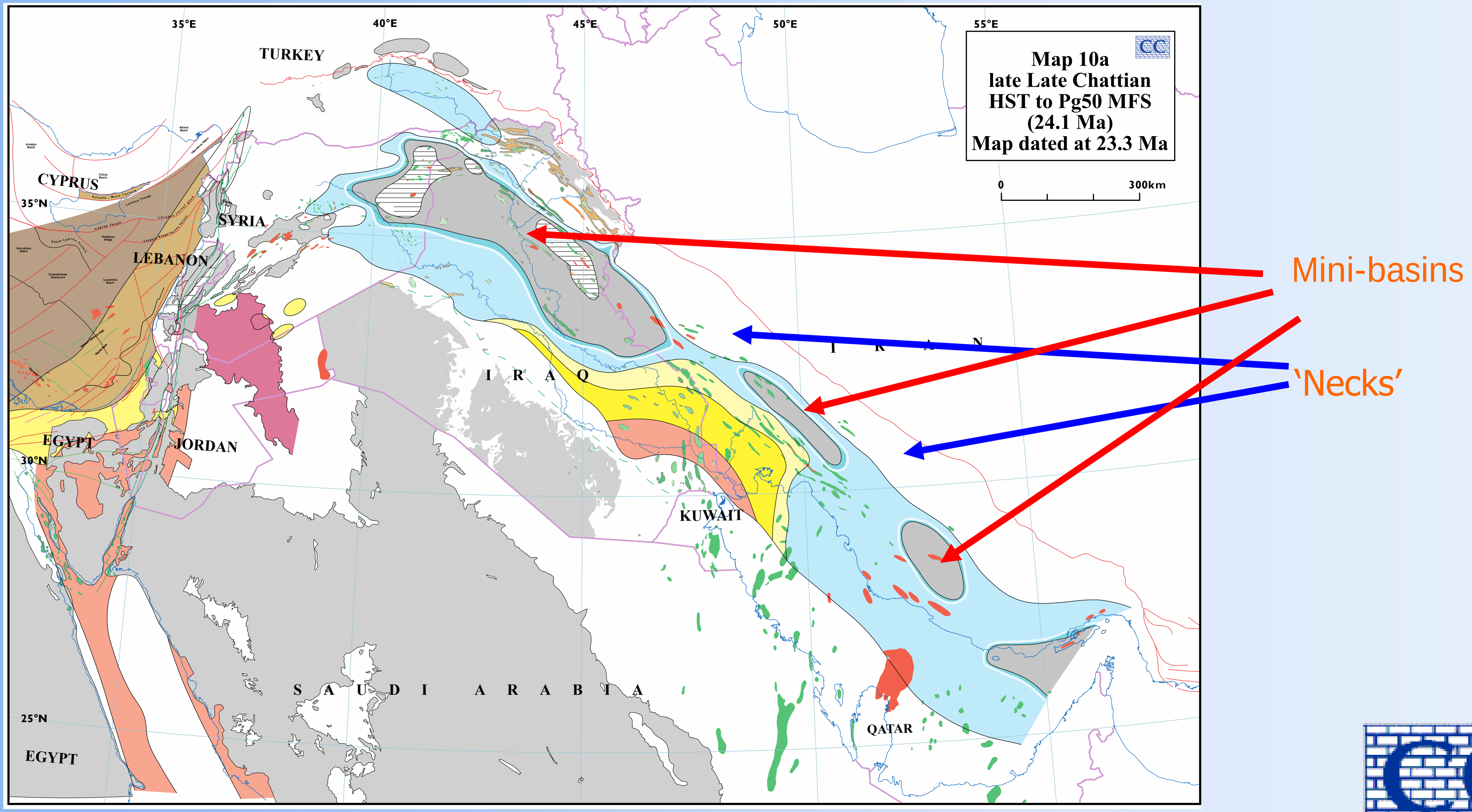
Foreland: Oligocene – Ey. Aquitanian

- Oligocene (latest Chattian)



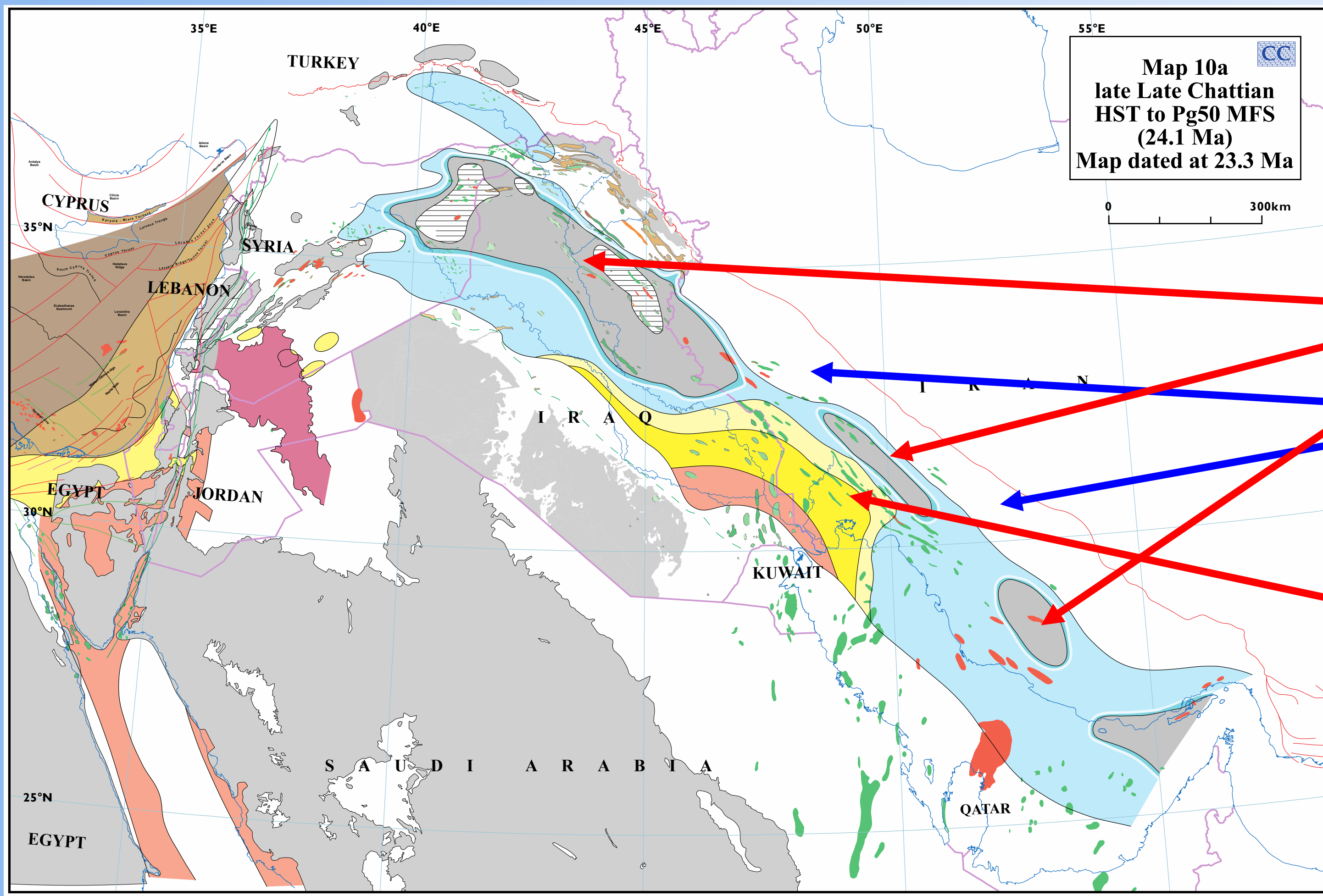
Foreland: Oligocene – Ey. Aquitanian

- Oligocene (latest Chattian)



Foreland: Oligocene – Ey. Aquitanian

- Oligocene (latest Chattian)



Mini-basins

'Necks'

Clastics derived from uplift in Red Sea area

Foreland: Oligocene – Ey. Aquitanian

- Progradational and offlapping carbonates

Courtesy N. Pickard

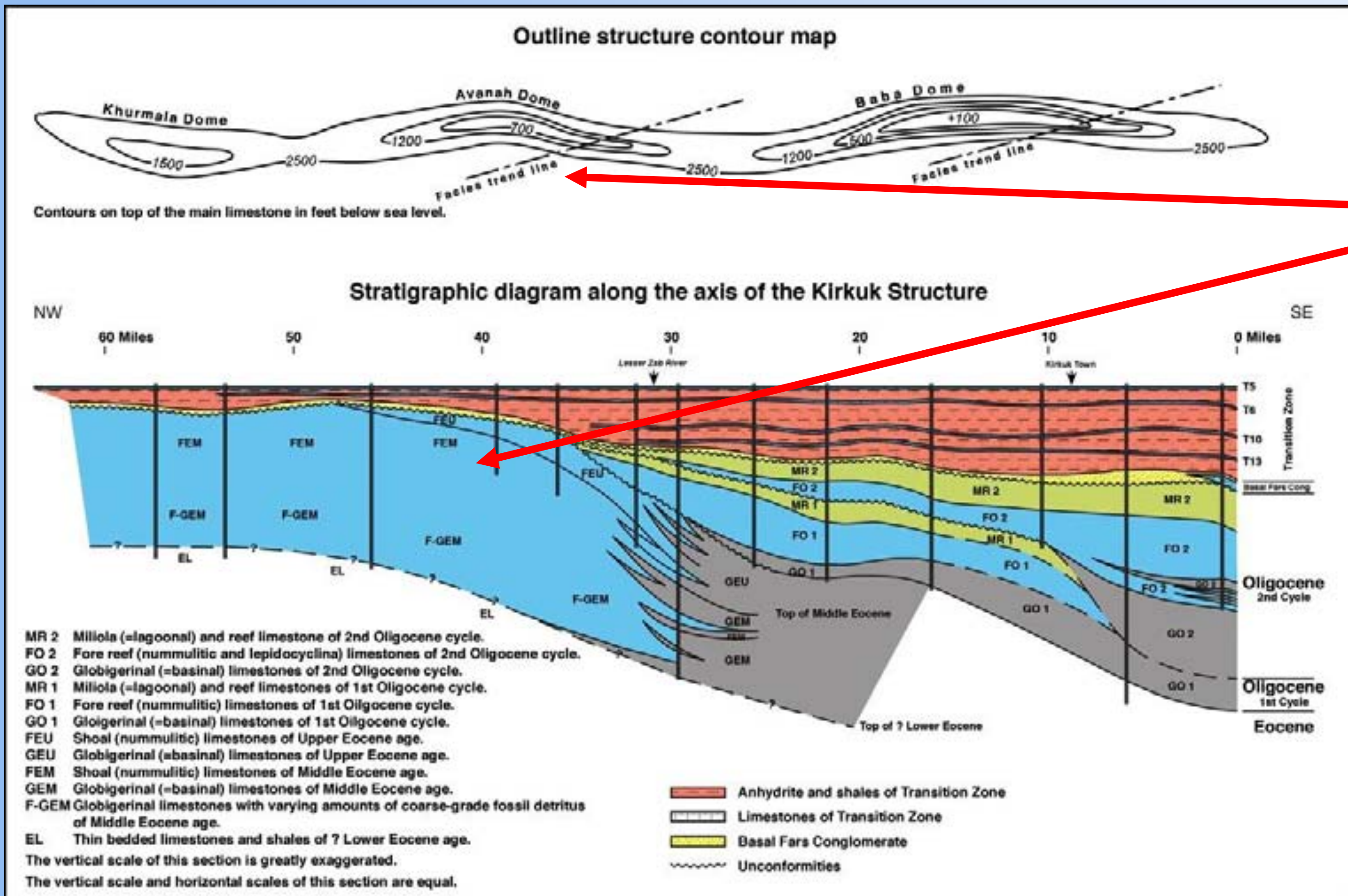
Foreland: Oligocene – Ey. Aquitanian

- Progradational and offlapping carbonates

Tang-e Gurguda, Iran

Foreland: Oligocene – Ey. Aquitanian

- Shingled/offlapping reservoir, e.g. Kirkuk

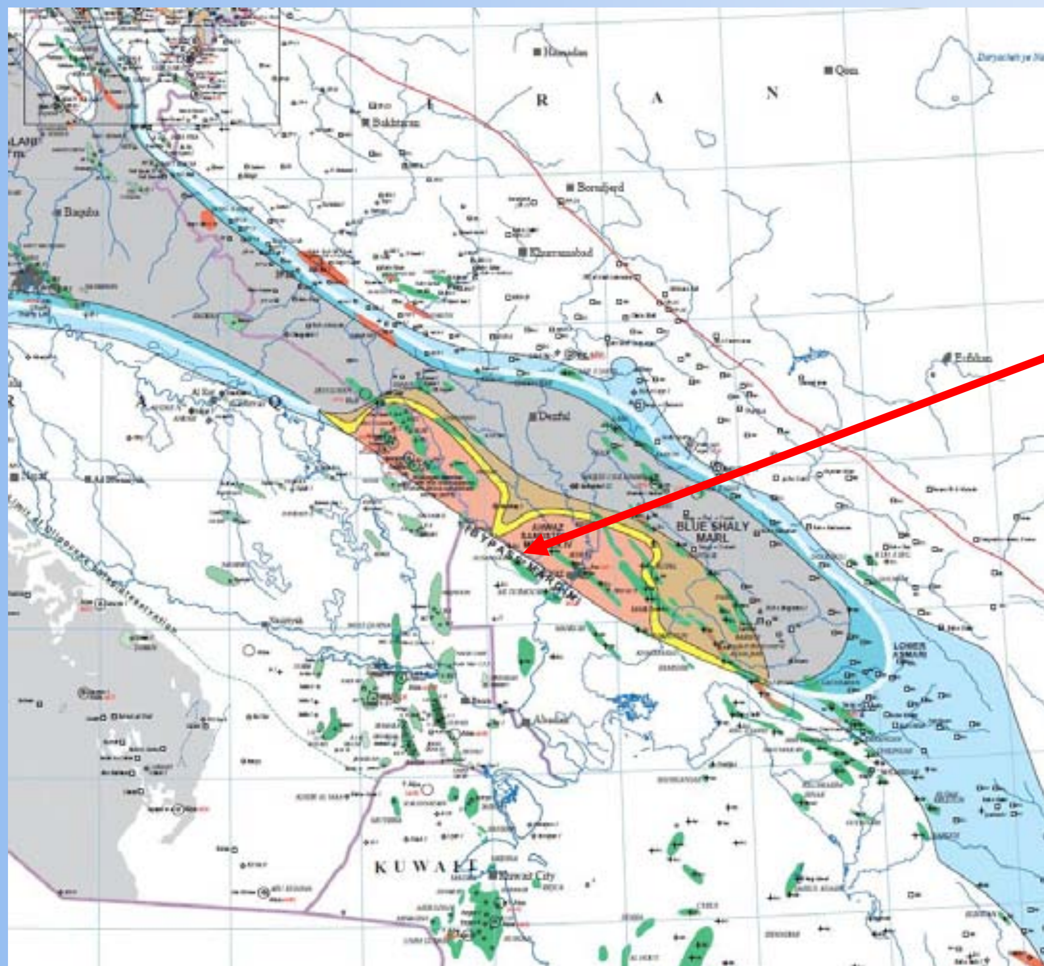


Due to local uplift in NW of structure (?inversion of underlying Cretaceous basin?)

After Daniel, 1954

Foreland: Oligocene – Ey. Aquitanian

- Ghar, Ahwaz clastics enter from SW



Lowstand bypass of exposed shelf, sediment source area in vicinity of Red Sea, bank up in front of shelf margins

Foreland: Oligocene – Ey. Aquitanian

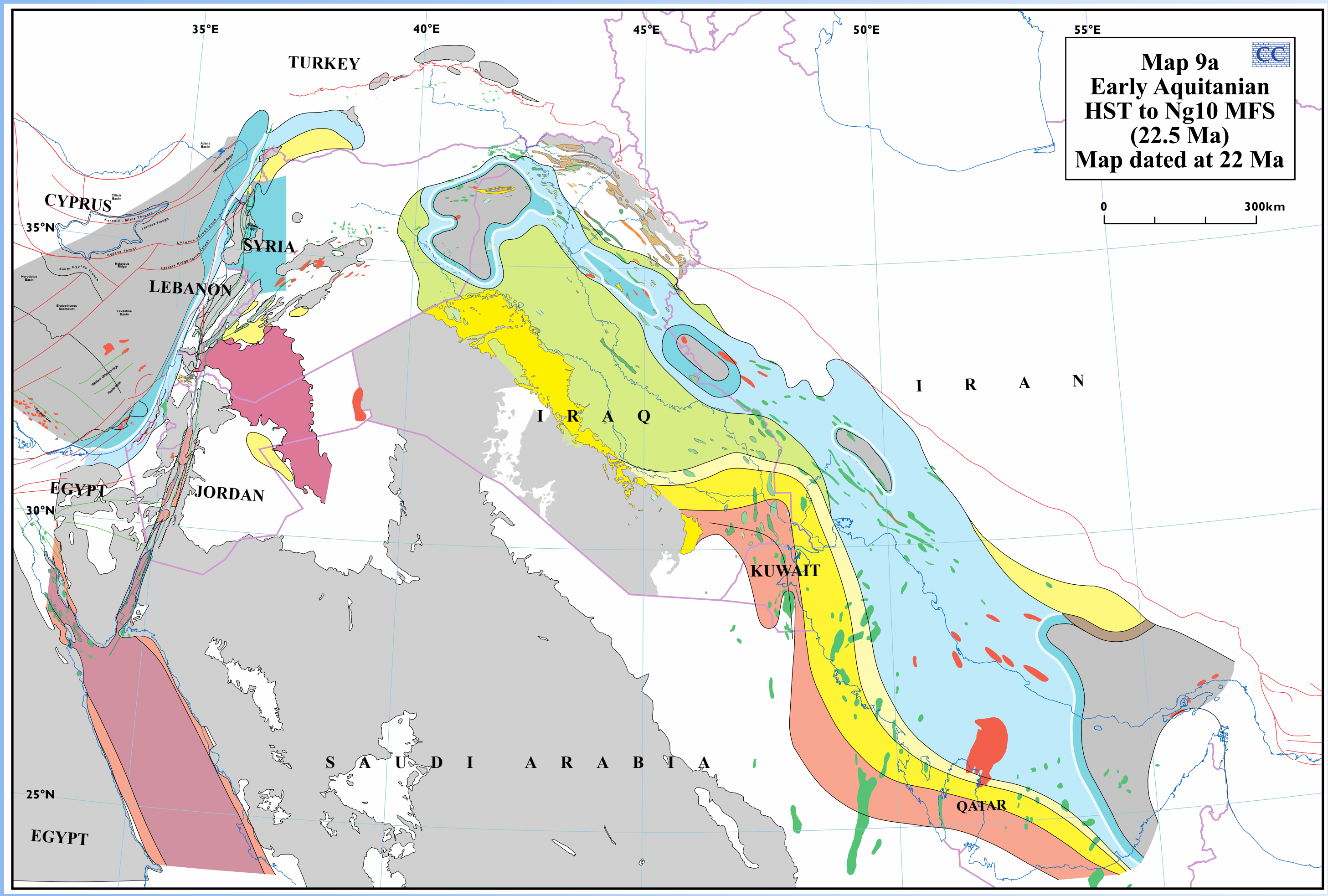
- BUT stacked stratigraphy = even subsidence

L. Fars
Jeribe Fm.
Bajawan Fm.
Base-Bajawan conglom
Sheik Alas Fm.
Avanah Fm.

Jebel Aj Dagh, Iraqi Kurdistan (some 50km SE of Kirkuk)

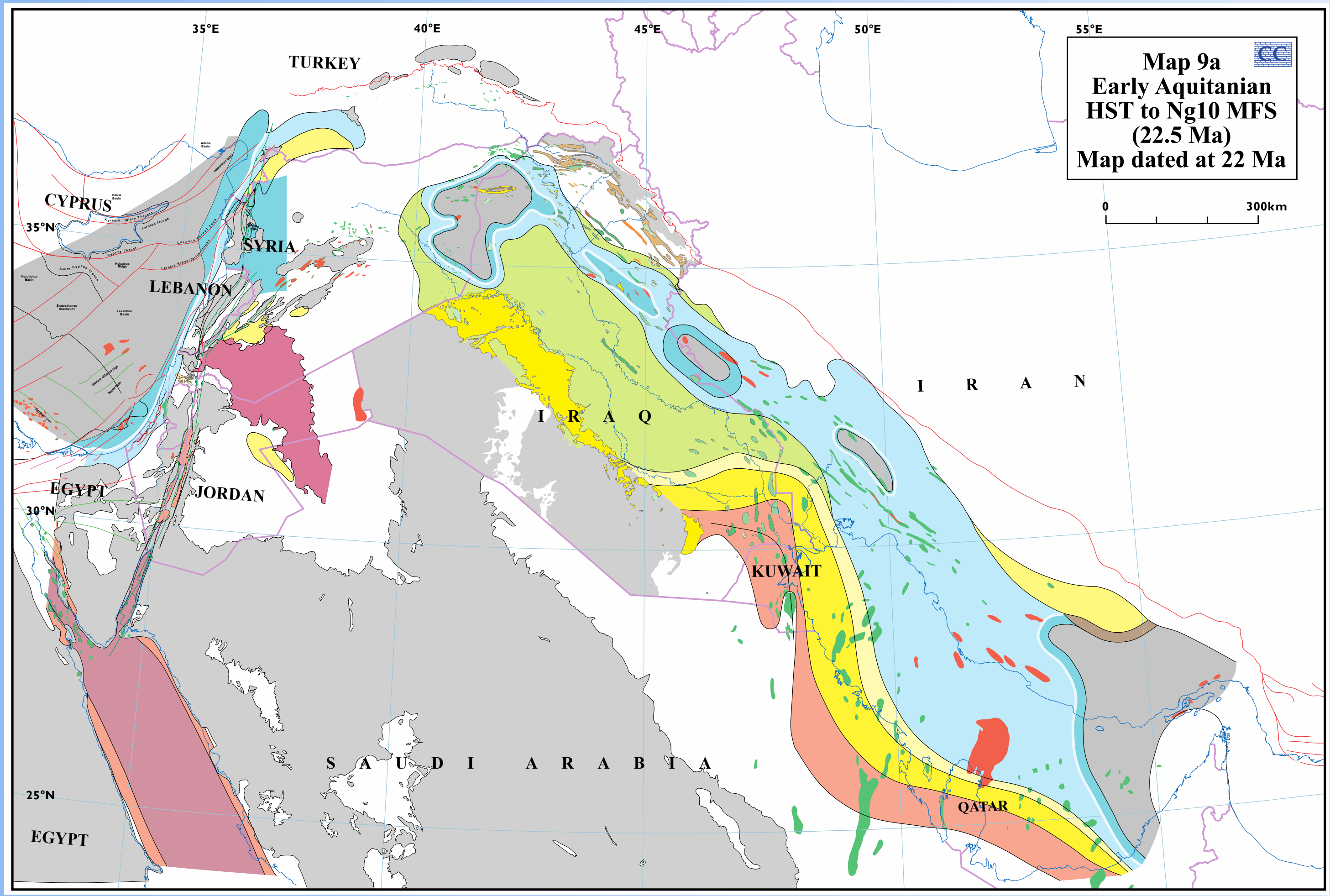
Foreland: Oligocene – Ey. Aquitanian

- Ey Miocene: Ey Aquitanian



Foreland: Oligocene – Ey. Aquitanian

- Ey Miocene: (Euphrates, Middle Asmari)



Foreland: Oligocene – Ey. Aquitanian

- Aquitanian reservoir rocks

Foreland: Olig. – Ey. Aquit., Summary

- Offlapping, narrow, land-attached carbonate shelves on NE side of basin, whose rimmed margins are continuous
- Affected by local tectonics (foreland uplift) and karstification e.g. Kirkuk
- Lowstand-dominated clastics on SW margins (Ghar, Ahwaz SST)
- Progradation ‘necked off’ basins progressively, increasing restriction

Foreland: Olig. – Ey. Aquit., Summary

- Some organic rich rocks with very high TOC’s develop in deeper-water Serikagni (Iraq) and upper Pabdeh (Iran) fms.
- Leads to development of first lowstand drawdown anhydrites (basal anhydrite) that appear in very latest Oligocene

Foreland: Olig. – E.Aquit. Pet. Geology

- Best reservoir in the margins rather than basin centre work best;
- Reservoirs of Lower/Middle Asmari, Kirkuk Group, Euphrates; Ahwaz SST also;
- Optimum facies are fore-reef; reef/lagoon tighter;
- Main pay within big anticlines (Lwr. Asmari and Ahwaz Sandstone in Dezful embayment; Kirkuk Gp. of Kirkuk; Euphrates in Ajeel, and Middle Asmari in Naft Khaneh)

Foreland: Olig. – E.Aquit. Pet. Geology

- Reservoir varies strongly in a dip sense, but homogeneous along-strike, is vertically thick and can be massive
- Sealed directly by Miocene evaporites; locally by Aquitanian evaporites (Dhiban, Kalhur) but more commonly the younger Gachsaran/Lower Fars-Fatah of Middle Miocene age
- Potential intrabasinal source rocks but these will only work only in areas of deepest burial

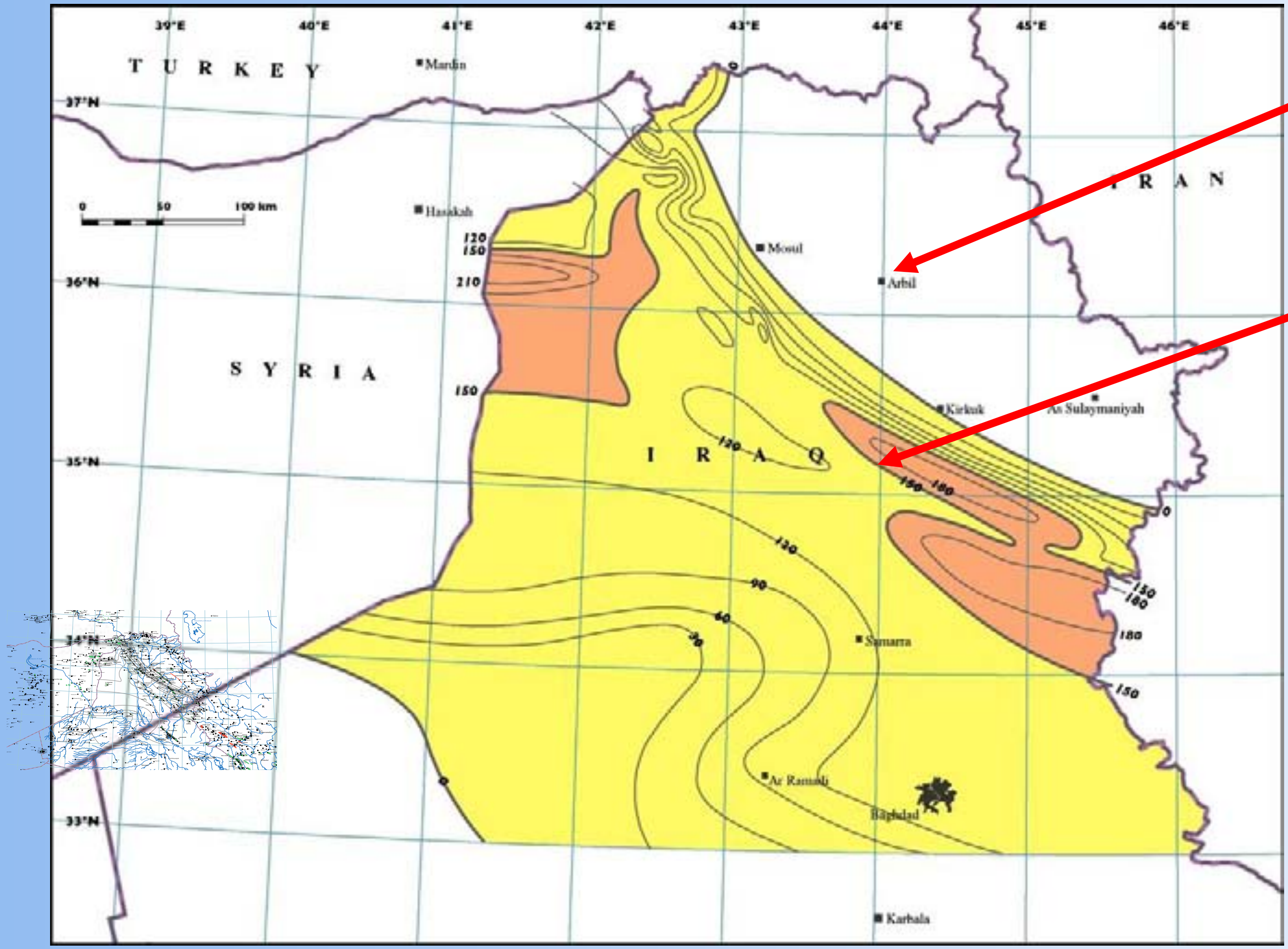
Foreland: Lt Aquitanian-Ey Burdigalian

Foreland: Lt Aquitanian-Ey Burdigalian

- Significant lowstand at base of interval
- Simple couplet of drawdown evaporite plug overlain by carbonate shelf

Foreland: Lt Aquitanian-Ey Burdigalian

- Early Miocene: isopach

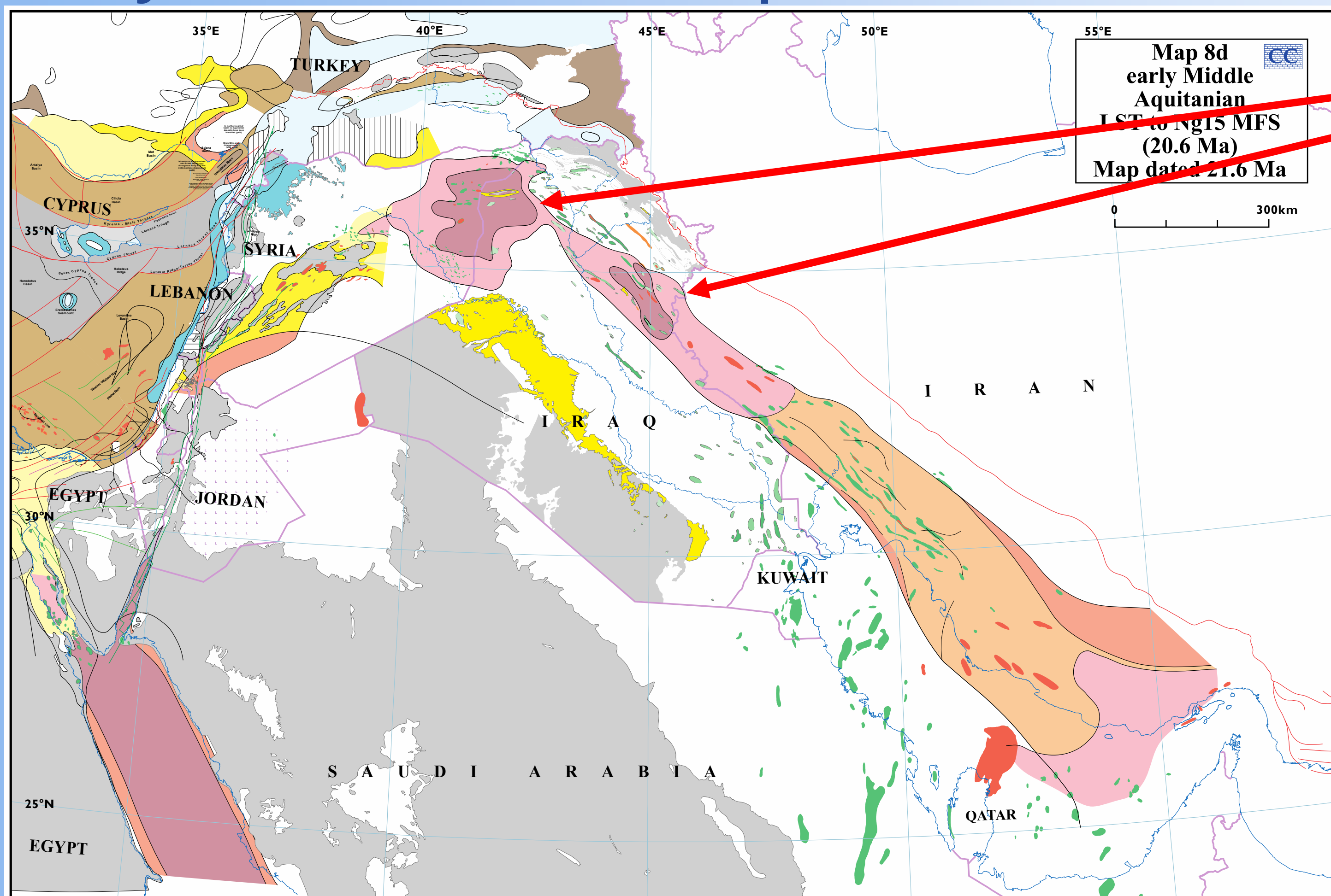


Absent over foreland bulge

Extensive shelf system dominates basin centre

Foreland: Lt Aquitanian-Ey Burdigalian

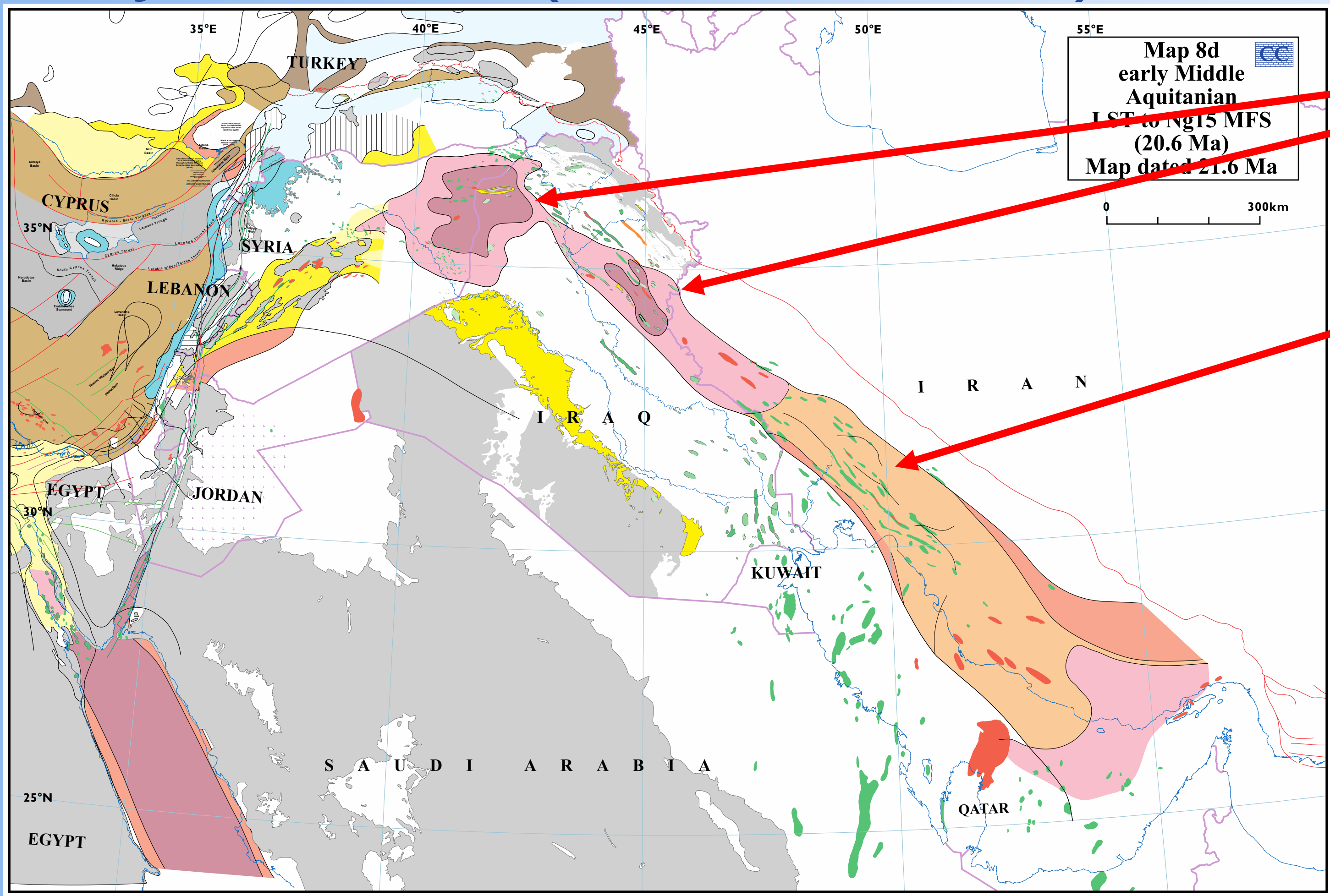
- Early Miocene: Mid Aquitanian lowstand



Halite basin centre plug

Foreland: Lt Aquitanian-Ey Burdigalian

- Early Miocene: (Dhiban, Kalhur)

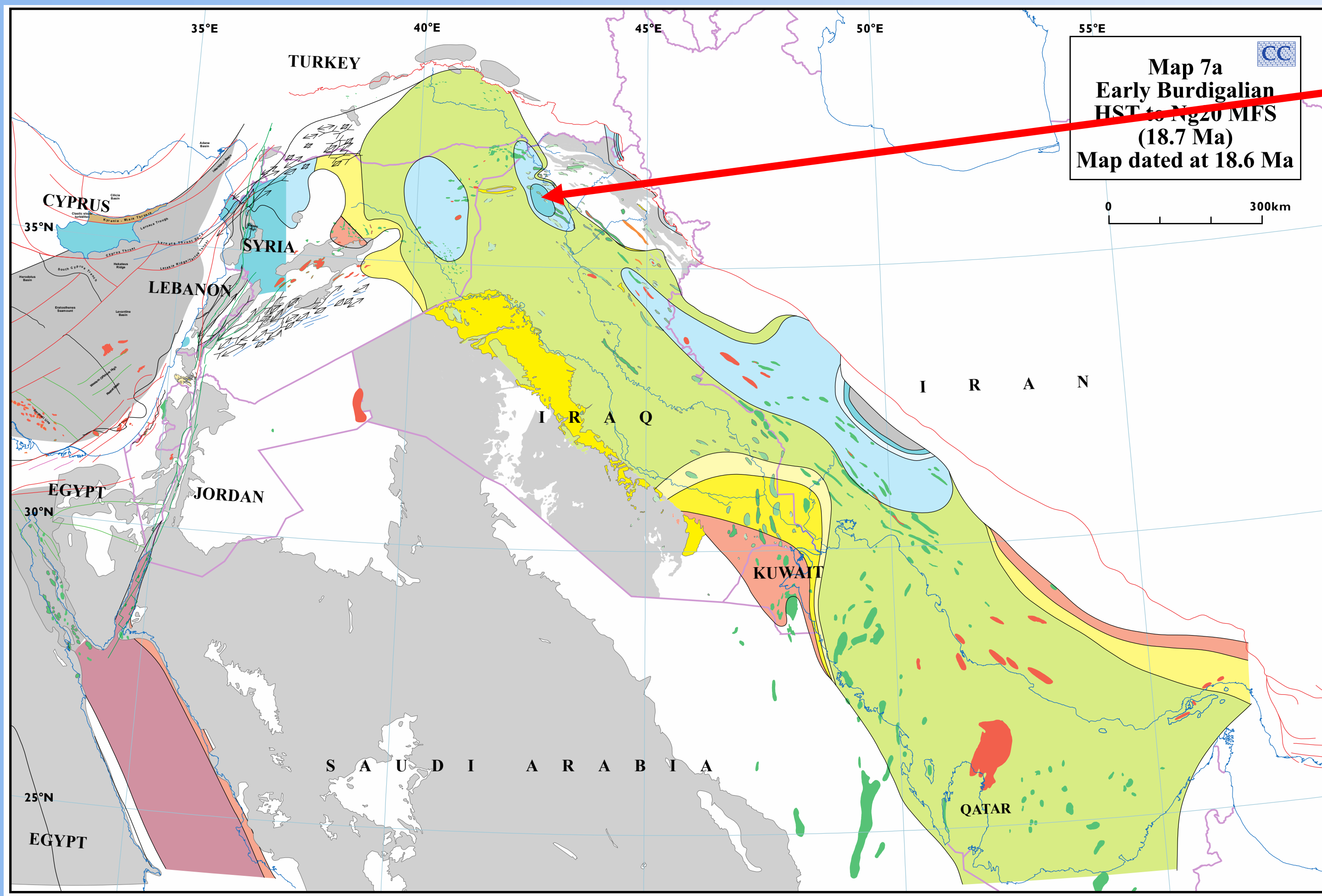


Halite basin centre plug

Local coarser clastics

Foreland: Lt Aquitanian-Ey Burdigalian

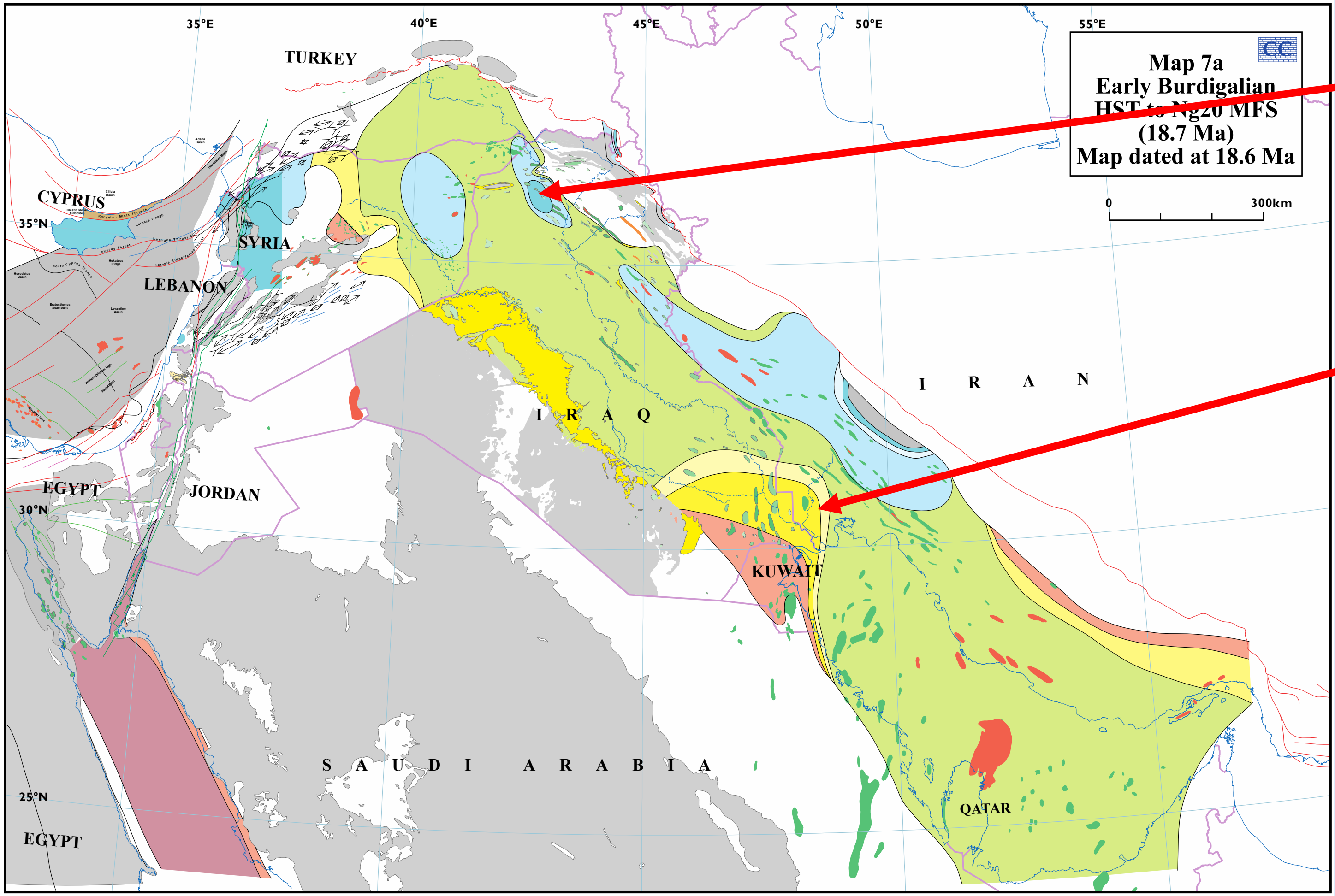
- Early Miocene: Early Burdigalian



Extensive restricted shelf

Foreland: Lt Aquitanian-Ey Burdigalian

- Early Miocene: (Jeribe, U. Asmari)

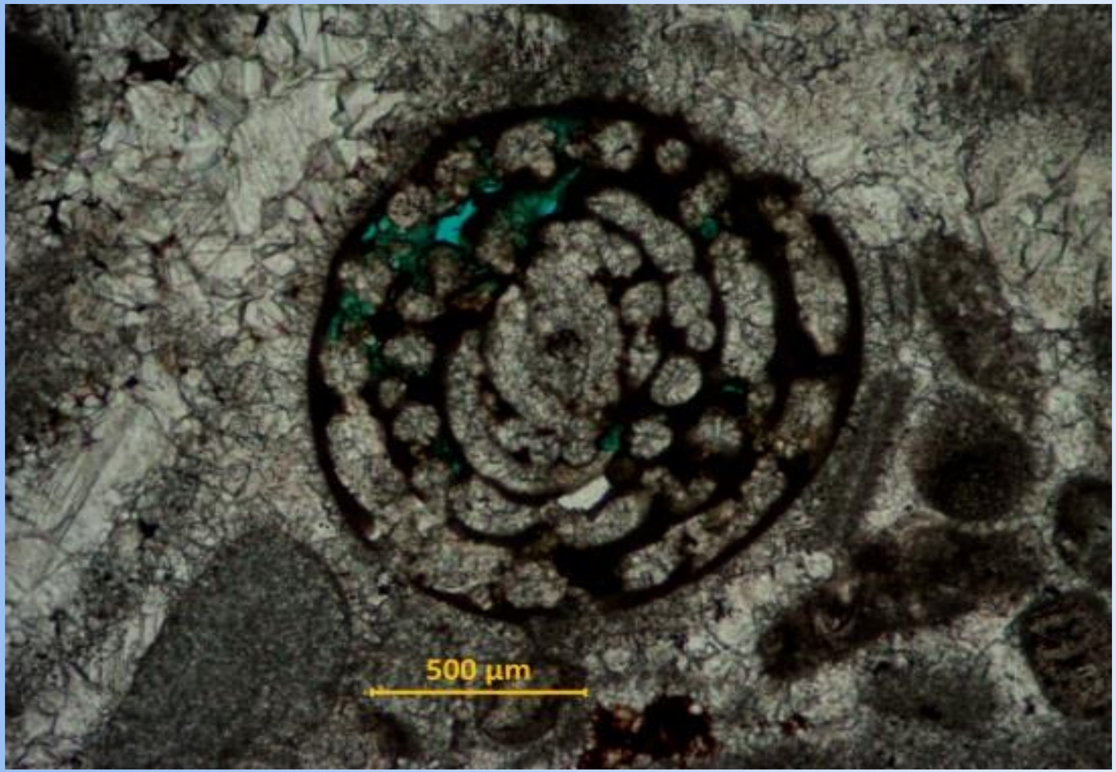


Extensive restricted shelf

Continued clastics on SW margin

Foreland: Lt Aquitanian-Ey Burdigalian

- Burdigalian reservoir rocks



Foreland: Lt Aquitanian-Ey Burdigalian

- Burdigalian reservoir rocks

Foreland: Lt Aq. - Ey Burd. Summary

- Major u/c and onlap above older rocks (locally Albian in Govanda area) indicates renewed foreland uplift
- Extensive sheet-like basin centre restricted shelf, no significant lateral facies changes, no obvious shelf margins or basinal facies
- Continued input of clastics from SW

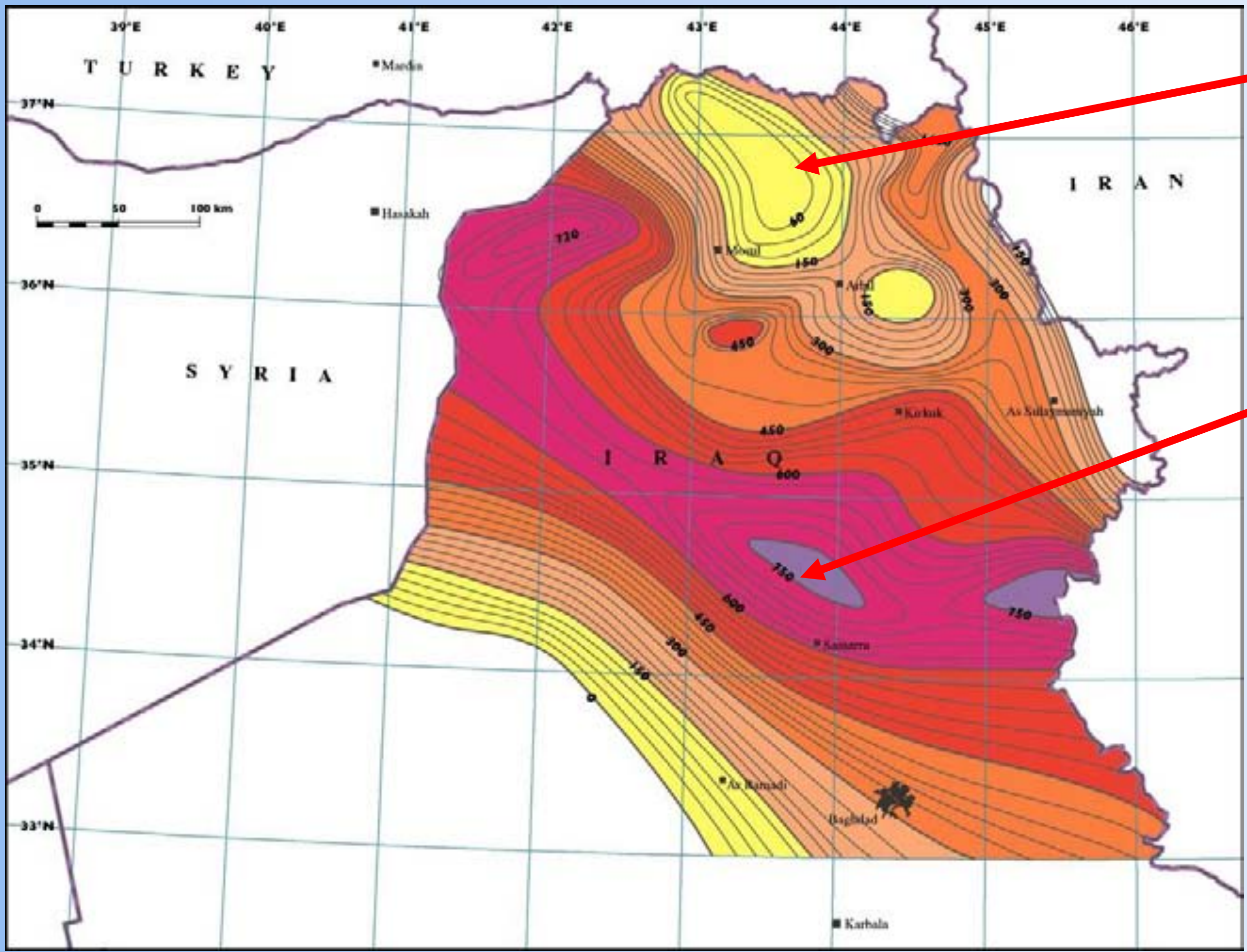
Foreland: Lt Aq. - Ey Burd. Pet. Geol.

- Often reservoir quality is enhanced due to dolomitization
- Produce within big basin centre anticlines (Jeribe in East Baghdad, Hamrin; Upper Asmari of Naft Khaneh)
- Sealed directly by Miocene evaporites
- Lateral continuity in dip and strike directions, but much vertical heterogeneity (cyclicity) with anhydrite interbeds leading to significant strong layering and compartmentalization

Foreland: Middle Miocene

Foreland: Middle Miocene

- Miocene: Lt. Burdigalian – Langhian isopach

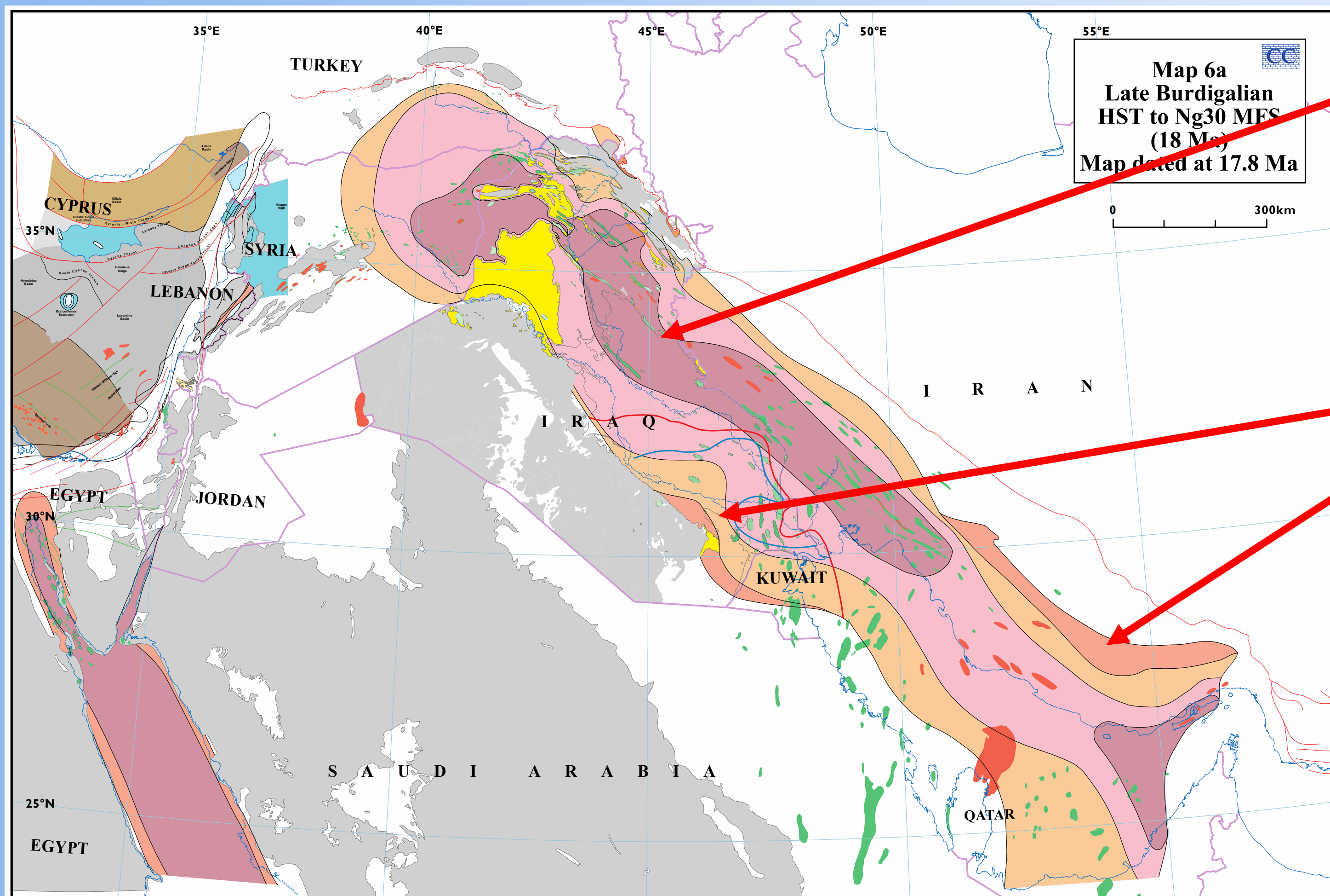


Isopach thin over foreland high

Isopach thick in basin centre

Foreland: Middle Miocene

- Late Burdigalian - Langhian



Halite in basin centre

Redbed clastics appear on basin margins

Foreland: Middle Miocene

- Fatha (Lower Fars) / Gachsaran (regional
  S

Flank of Jebel Aj Dagh, Iraqi Kurdistan

Foreland: Late Miocene-Pliocene

Foreland: Late Miocene-Pliocene

- 'Upper Fars' fine grained continental clastics

Near Kor Mor, Iraqi Kurdistan

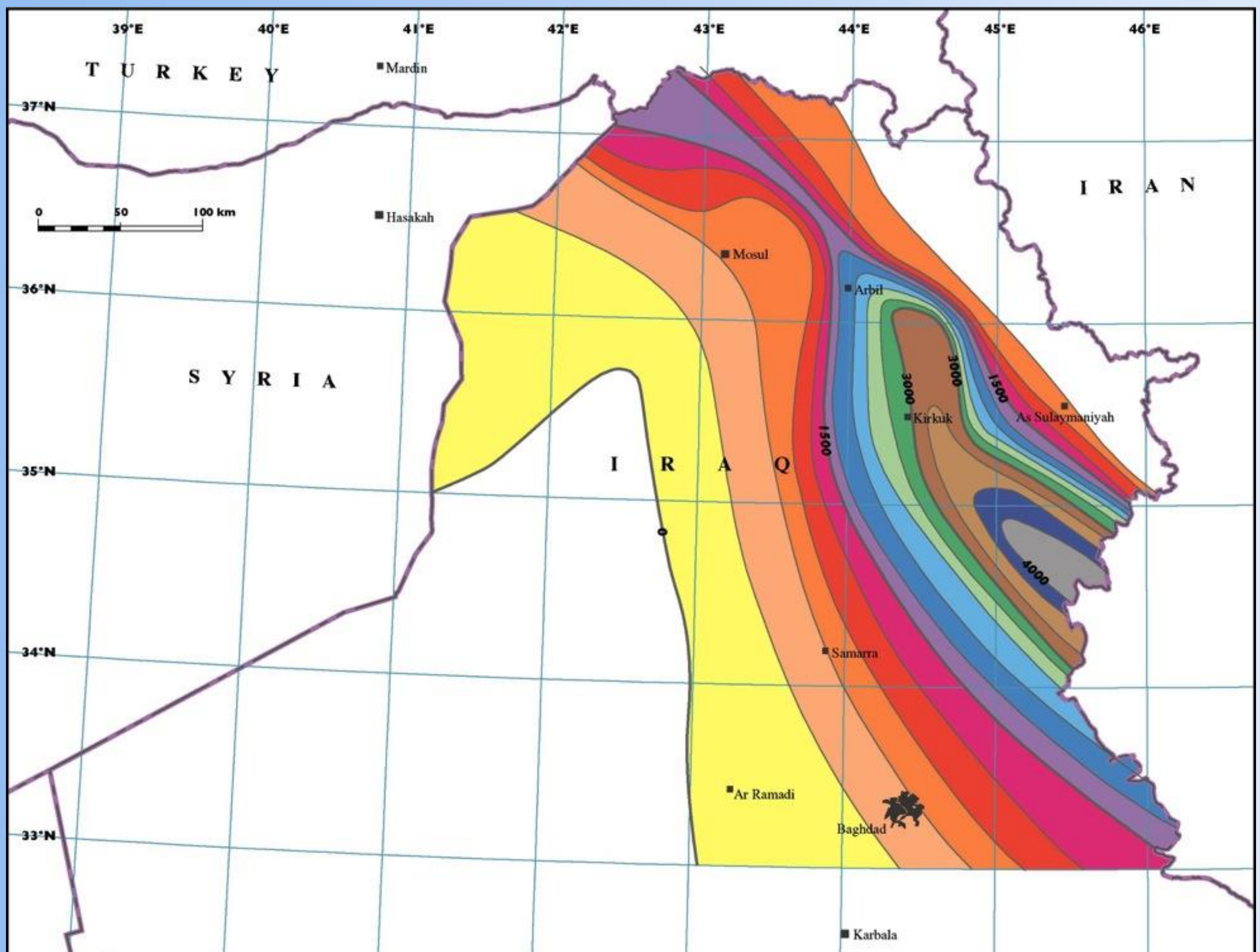
Foreland: Late Miocene-Pliocene

- ‘Upper Fars’ and Bakhtiari: final alluvial infill

Qara Dagh, Iraqi Kurdistan

Foreland: Late Miocene-Pliocene

- Upper Fars and Bakhtiari: burial up to 5-6km



Foreland: Late Miocene-Pliocene

- Bakhtiari unconformable over Shiranish (Lt K)

Dokan
Iraqi
Kurdistan

Foreland: Late Miocene-Pliocene

- Late Pliocene compression: Pleistocene onlap onto Pliocene

Near Derbendikhan, Iraqi Kurdistan

Foreland: Late Miocene-Pliocene

- Late Pliocene compression: development of high relief/amplitude anticlines ('whalebacks')

Mish Anticline, Iran

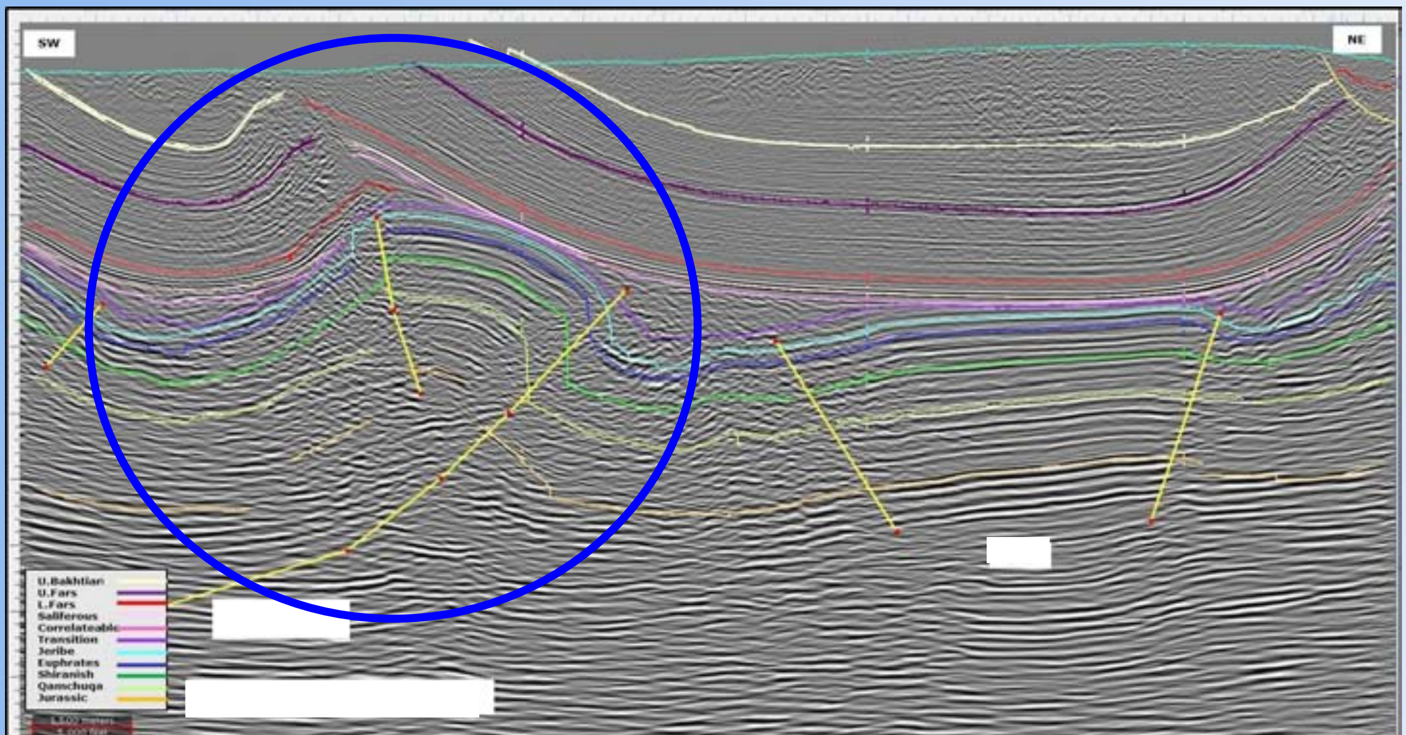
Foreland: Late Miocene-Pliocene

- Elongated and commonly over 100km long

Sulaimaniyah area, Iraqi Kurdistan

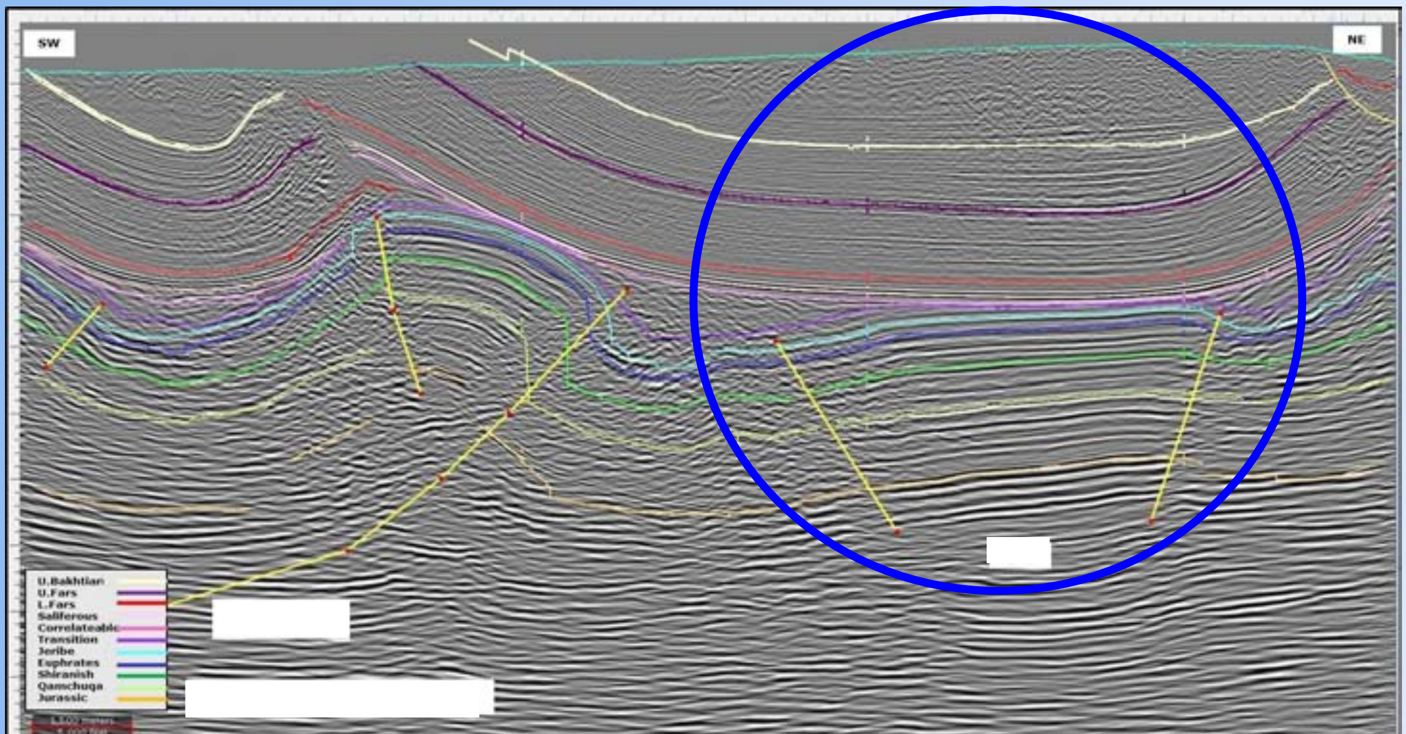
Foreland: Late Miocene-Pliocene

- Easily visible on seismic as at surface



Foreland: Late Miocene-Pliocene

- BUT also some beneath surface synclines



Foreland: Summary

- Onset of ophiolite obduction and collision of island arcs along NE margin of plate in Turonian
- Beginning of intra-plate compression and foreland basin development along whole margin
- Evidence of local structural uplift throughout foreland phase (e.g. Kirkuk, Jebel Sinjar)

Foreland: Summary

- Basin shows geometry related to present-day compressional plate margin
- Early basin was underfilled, thick clastics pond on NE margin, bordered by carbonate shelf
- Necking to form intermediate basin(s) that have carbonate shelves on margins but remain sediment starved in their centres
- Isolated basins become evaporite plugged
- Final basins are coarse clastic dominated as compression and deformation increased

Foreland: Pet. Geology Summary

- Dual porosity reservoir systems; matrix property is commonly fracture-enhanced
- World-class caprock (Gachsaran/L. Fars)
- Problems: heavy oil (<API, >sulphur)
- Problems: if either low matrix porosity or no fractures

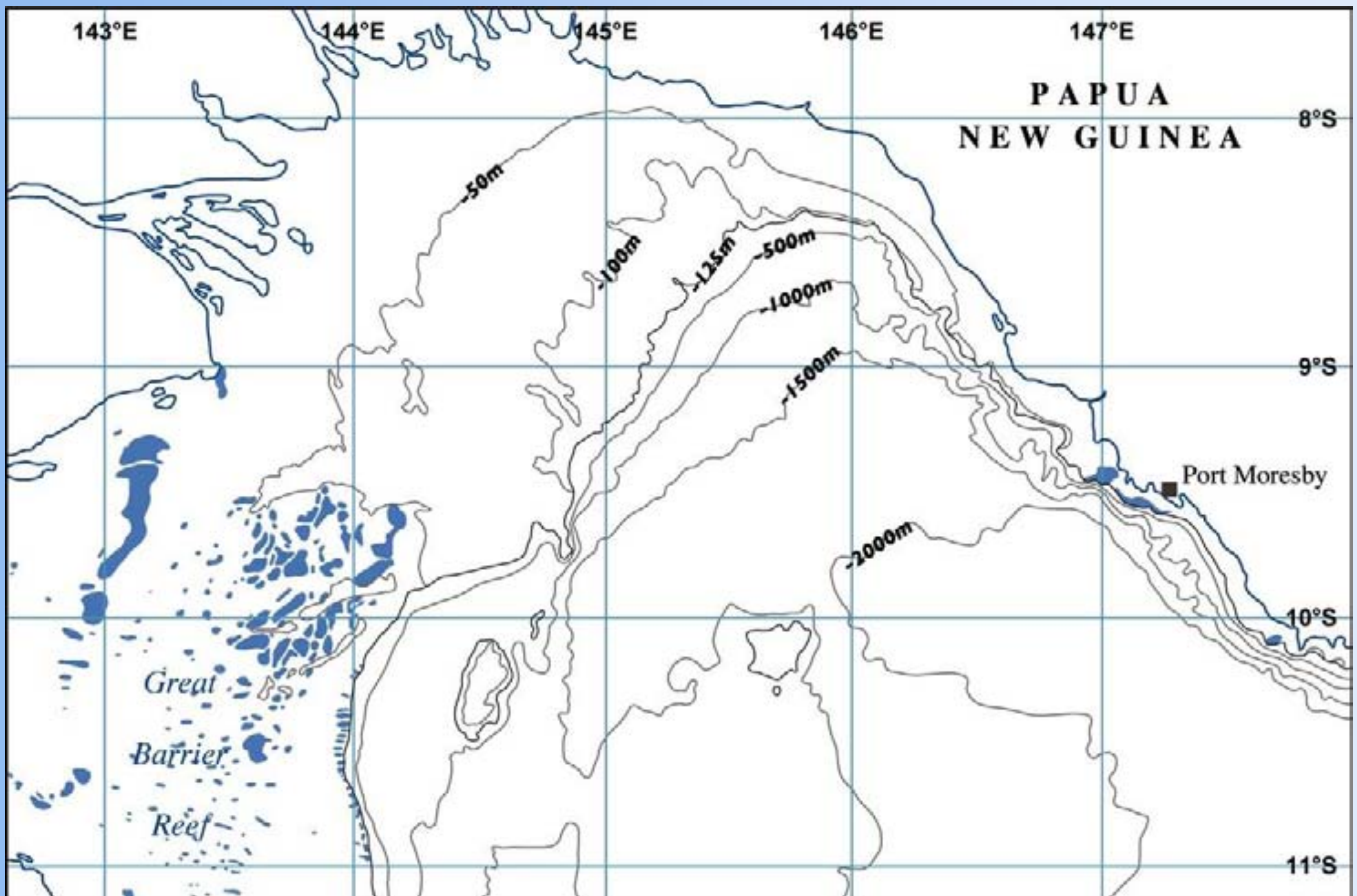
Discussion

Discussion

- Analogue: PNG/Coral Sea?

Discussion

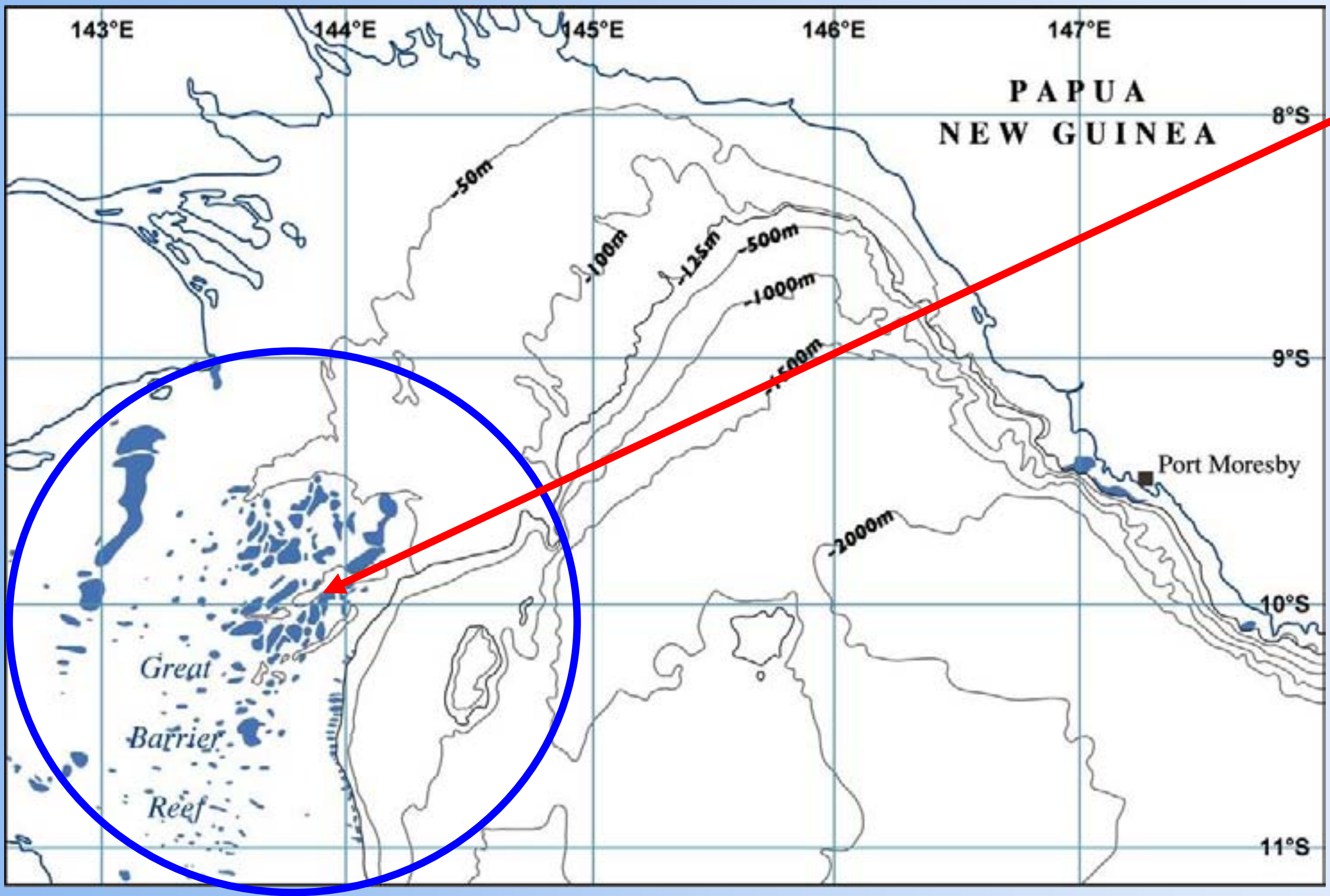
- Modern carbonates in a foreland basin



From Tcherepanov et al., 2008

Discussion

- Growing in the Coral Sea to S/SW of PNG

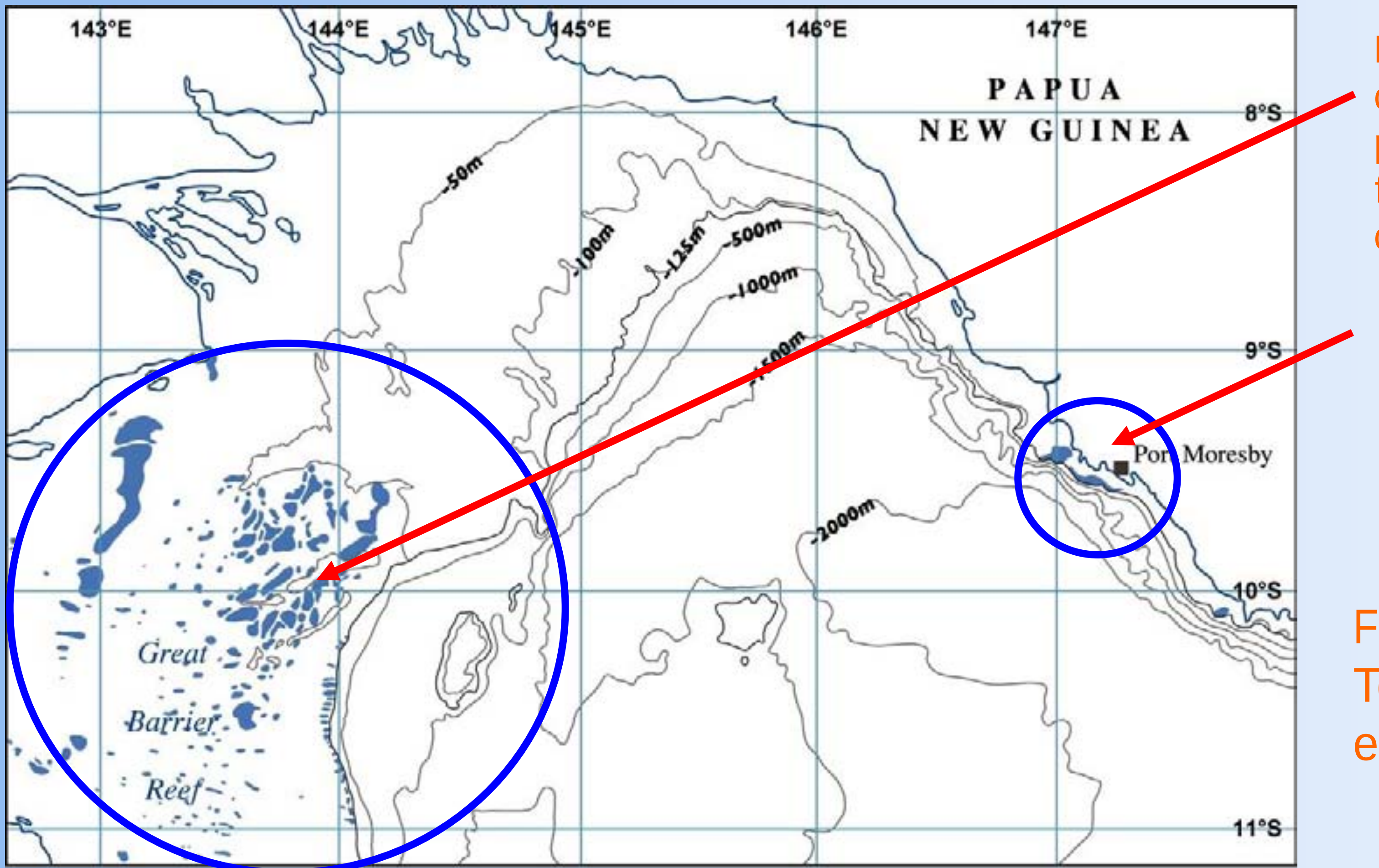


Broad carbonate province distant from source of clastic input

From Tcherepanov et al., 2008

Discussion

- Growing in the Coral Sea to S/SW of PNG



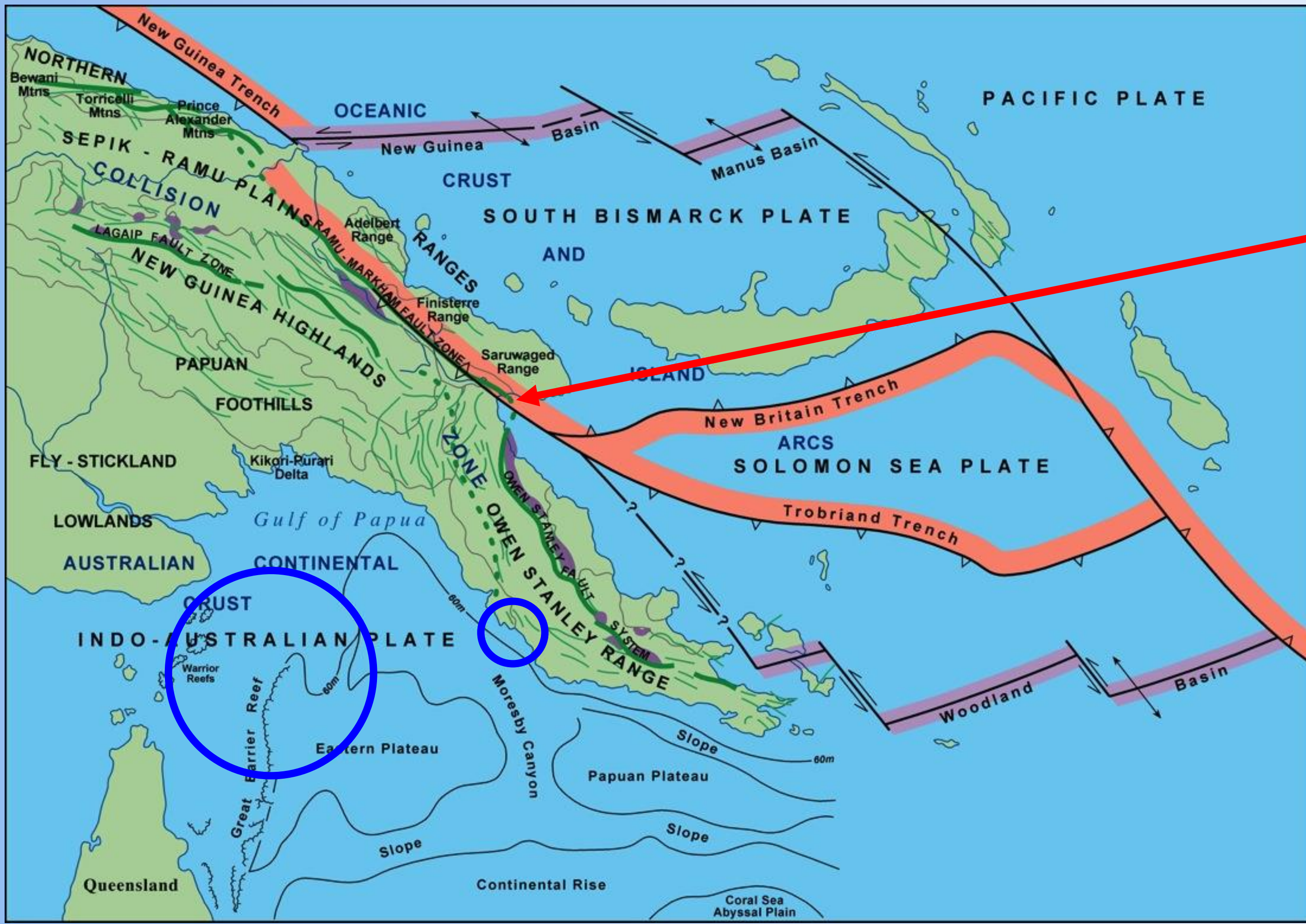
Broad carbonate province distant from source of clastic input

Narrower. more localized carbonate province close to source of clastic input

From Tcherepanov et al., 2008

Discussion

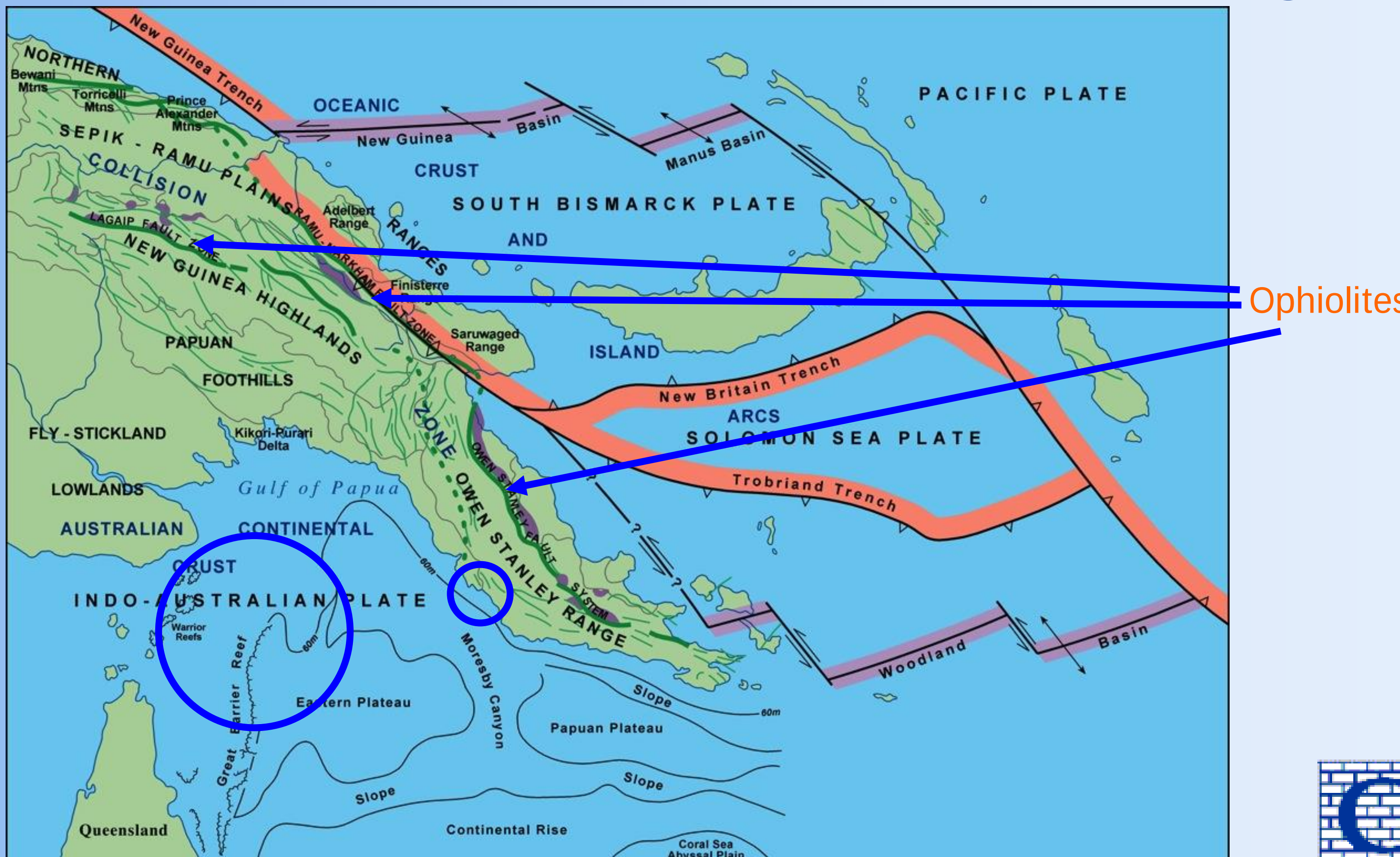
- Similar subduction zone, arc-related setting:



Compressional margin

Discussion

- Similar subduction zone, arc-related setting:



Discussion

- Both settings (Zagros in Lt K-Palaeog., PNG) allowed carbonate platforms to grow in areas of active compression
- But deformation was never so intense as to overwhelm the basin with clastic supply
- Carbonates in both cases are associated with often exceptional reservoir quality and hydrocarbon reservoirs
- Clastics ponded updip and/or seal carbonates

Conclusions

Conclusions: General

- Foreland basin development allowed creation of significant accommodation space
- Clastic input was limited because initial collision was not continent:continent
- Underfilled space was notably encroached upon by carbonate platforms (=reservoirs)
- As space restricted, basins became isolated from Tethys and significant evaporite deposits then developed during lowstands

Conclusions: General

- Progressively stronger deformation then causes input of increasingly large volumes of increasingly coarse clastics
- Loads source rocks leading to expulsion of oil, and causes fracturing of reservoirs
- Therefore we see a dominance of fractured, dual porosity carbonate reservoirs, sealed by evaporites

Conclusions: General

- Can apply lessons learnt in recent Kurdistan projects along-strike into possible new ventures in Iran; there is regional synergy
- But local complexity is always expected due to the interplay of local tectonics (e.g. basin inversion) within this compressional setting

Conclusions: Other

- Minor reservoir potential also in the very thick flyschoid Upper Cretaceous to Eocene clastics, but these are complex, poorly subdivided and with poorly understood stratigraphy, also being mineralogically immature (?diagenesis/poroperm issues),
- Some reservoir potential also in Upper Miocene and Pliocene clastics but sealing facies become a major issue at higher stratigraphic levels (caprock issue)

Many thanks for listening!

With thanks to Jo Garland, Benoit Vincent and Neil Pickard for earlier discussions on this theme, and providing graphics