PETROLEUM SYSTEMS OF LEBANON: AN UPDATE AND REVIEW

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Abstract

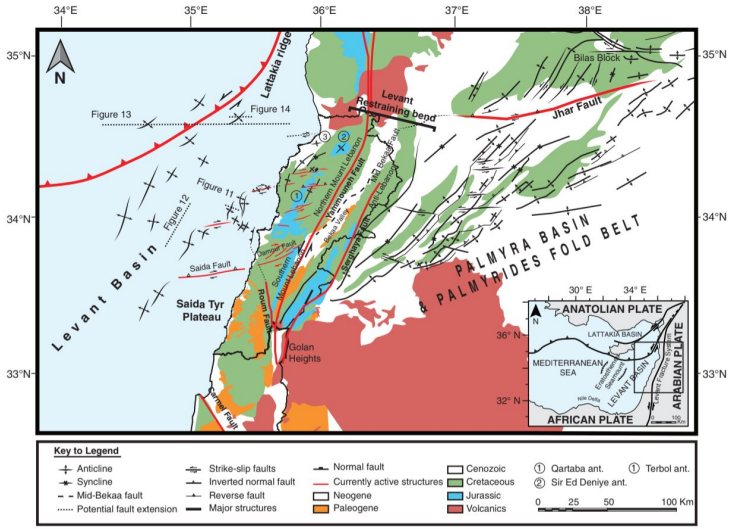
- New interpretation of the Levant margin (offshore Lebanon)
- New evaluation of the petroleum systems of the Eastern Mediterranean

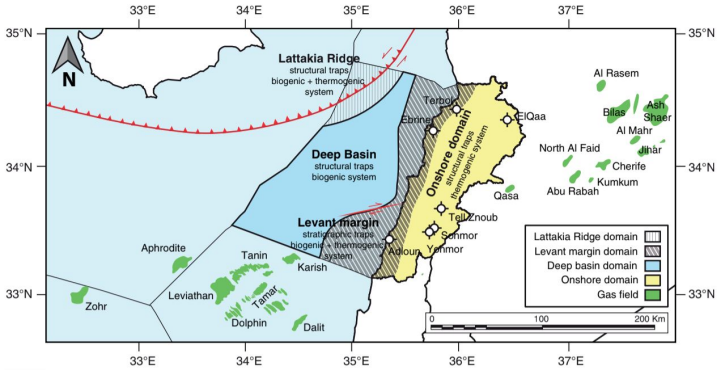
- Lebanon onshore and offshore split into 4 domains:
  - Distal Levant Basin
  - Latakia Ridge
  - Levant Margin
  - Onshore
- Domains characterised by a particular structural style and stratigraphic architecture
  - Different source reservoir trap configurations
- New division draws attention to specific areas of exploration interest
  - There are distinct petroleum systems
- New interpretation of the Levant margin
  - Focused on the carbonate dominated stratigraphy and petroleum potential of area
  - Attracted major attention after recent Zohr discovery in offshore Egypt

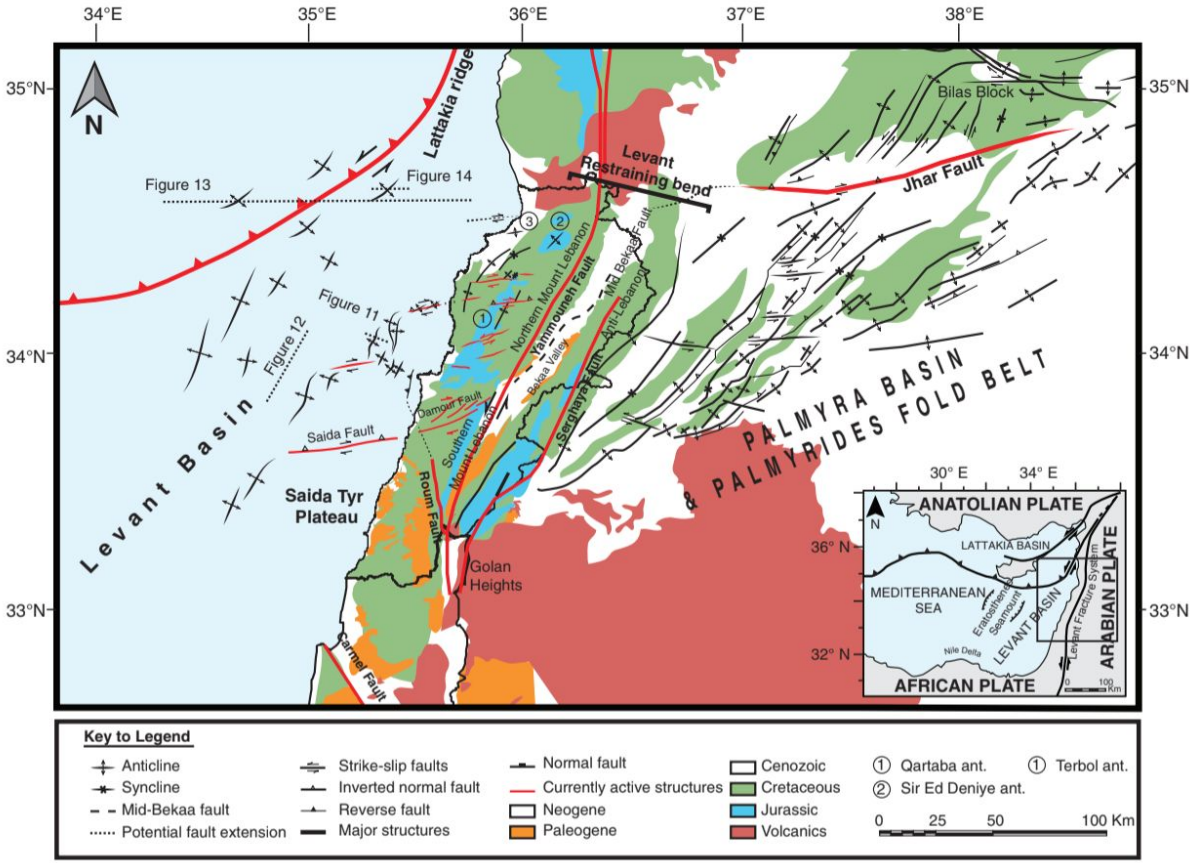
Introduction

Lebanon

- Part of the greater Levant region
- Located on active NW margin of the Arabian plate
  - Mostly by the left-lateral Levant Fracture System
- To the East:
  - Petroliferous Palmyride fold and thrust belt and
- To the West:
  - Stable foreland of the Levant Basin
- Considered to have significant exploration potential
  - 2006-2015: Discovery of more than 70 TCF (trillion cubic feet) of proven natural gas reserves
  - Gas fields include:
    - Tamar
    - Leviathan
    - Aphrodite
    - Zohr

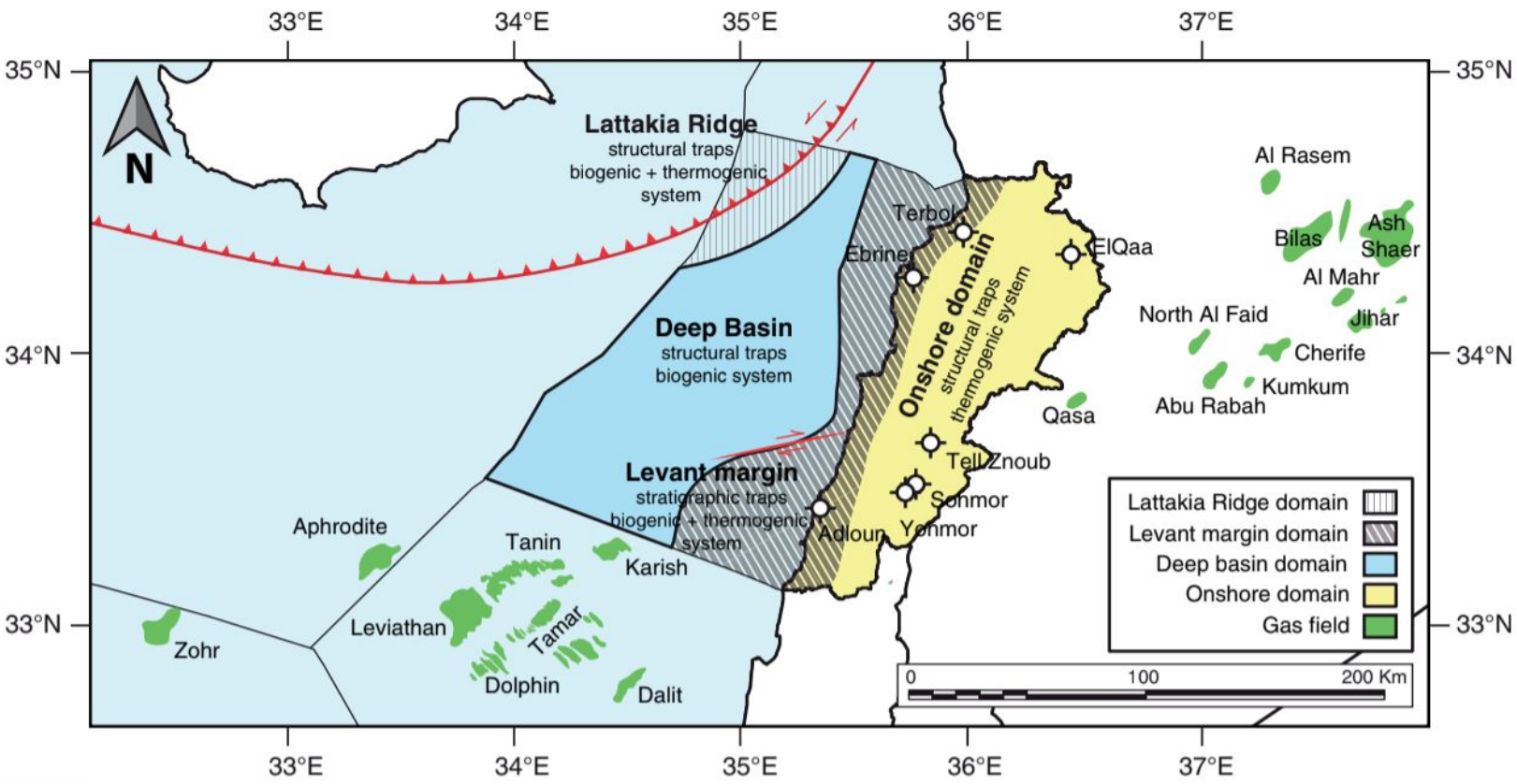






Main structural elements of Lebanon, the Levant Basin and part of Syria.

Map compiled from Barrier et al., 2014; Ghalayini et al., 2014; Ghalayini et al., 2016; and Brew et al., 2001.



Map showing the geological domains of Lebanon as discussed in this study, together with hydrocarbon discoveries in nearby countries.

Methods and Data

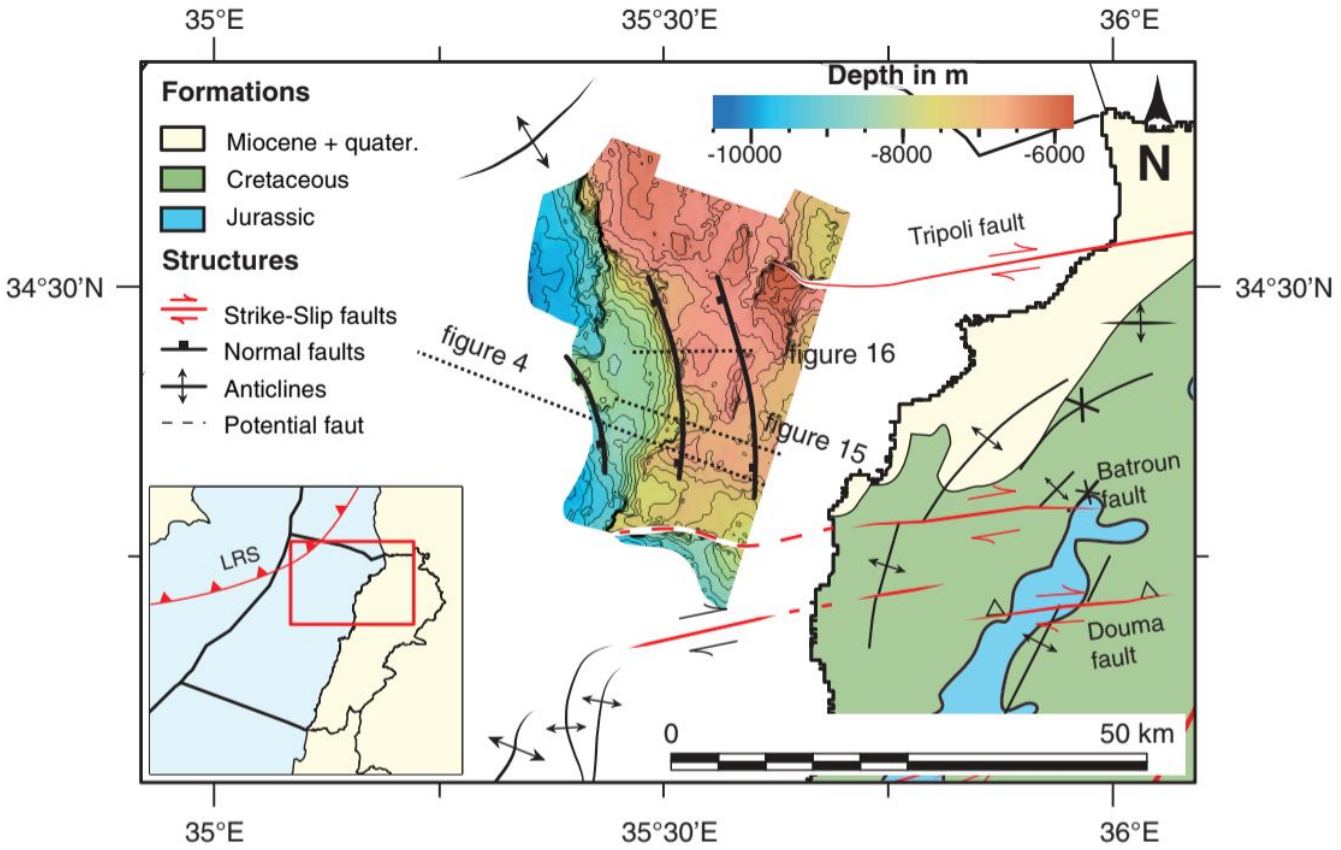
Five Seismic Lines Along North and South Offshore Margin

Data

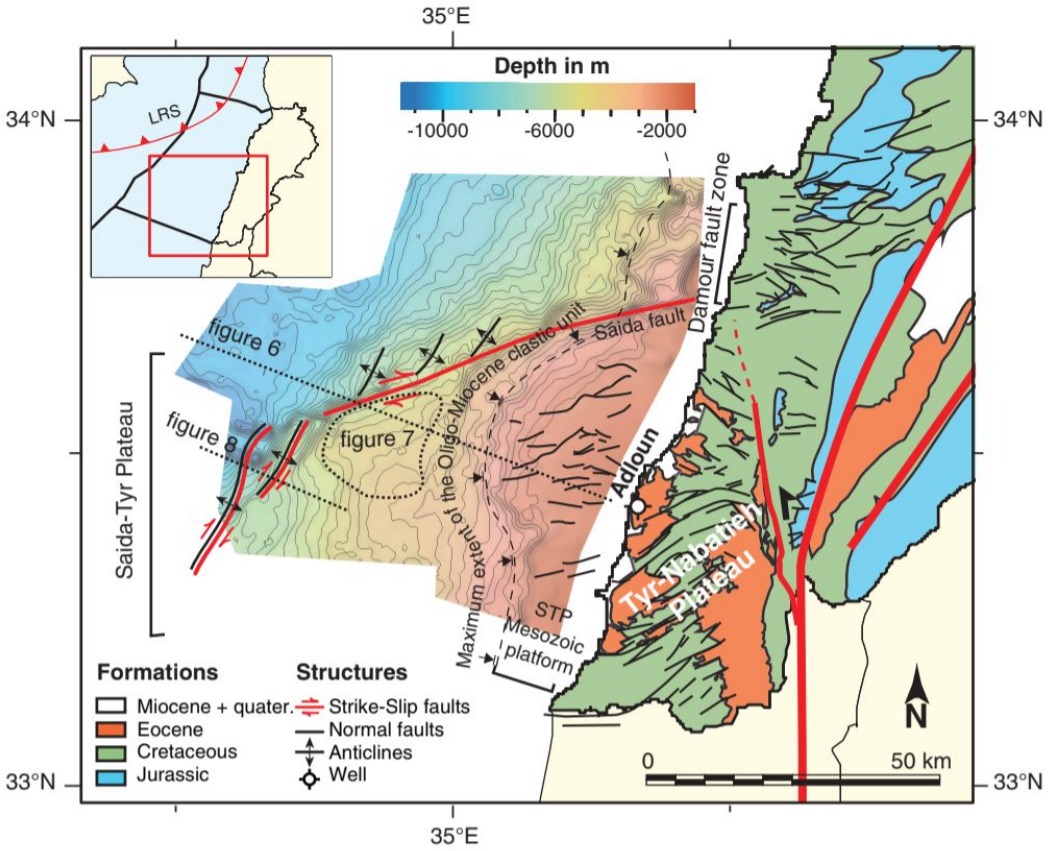
- Prestack depth migrated 3D seismic cube (2012 by PGS)
  - Streamer length= 7050m at a spacing of 12.5m with 25m shot point intervals

Interpretation

- Performed on depth-converted sections
  - Time to depth conversion done using velocity model built from stacking velocities
- Entirely based on seismic facies interpretation and regional correlation with nearby countries
  - No wells have been drilled offshore Lebanon when data was interpreted



Map of the offshore margin of northern Lebanon



Map of the offshore margin of southern Lebanon

Petroleum Systems

Source Rocks and Maturity

The Distal Levant Basin and Latakia Ridge

- Permian and Triassic
  - May have generated petroleum between 90 and 34 Ma in the Levant Basin
- Upper Jurassic (Kimmeridgian)
  - May have generated thermogenic oil between the Late Cretaceous and Late Miocene
- Upper Cretaceous (Campanian)
  - Modelled to have generated hydrocarbons between 34 and 16 Ma
- Paleocene and Eocene
  - May have generated hydrocarbons during the Oligocene and may still be active in some parts
- Oligocene and potential biogenic source rocks
  - Modelled to have begun generating thermogenic hydrocarbons at around 6 Ma
  - Currently in the maturity window
  - Bio- May have occurred between 18.5 and 6 Ma in the Levant Basin
  - Bio- May still be generating in the Latakia Ridge

The Levant Margin and Onshore

- Upper Permian/Lower Triassic
  - Amanus Dolomites in Triassic reservoirs in the Palmyrides
    - May be promising in the Levant margin and onshore
- Potential Permian and Triassic
  - Modelled to have generated hydrocarbons between 75 Ma and present day
- Kimmeridgian
  - Modelled to have generated oil between the Oligocene and present day
  - Currently in oil window deeply buried beneath the Bekaa valley
- Campanian
  - Appear not to have been buried deep enough in Mount Lebanon to generate hydrocarbons
  - Currently in the maturity window
  - Minor generation may have occurred in the Bekaa valley and along the margin

Reservoir Rocks

- Distal Levant Basin
  - Potential reservoir rocks occur in the Oligo-Miocene succession
  - Consist of deep water sandstones
- Latakia Ridge
  - Potential reservoirs may be located in the Upper Miocene
  - Suggests an increased sand content in the base Oligocene
- Levant Margin
  - Deeply buried Jurassic platform carbonates and fracture-associated hydrothermal dolomites
  - Lower Cretaceous sandstones may form reservoirs
- Onshore
  - Potential reservoirs are present in the pre-Jurassic succession.
  - Effective reservoirs may occur in the Permian to Lower Triassic Amanus Formation and in the Lower to Mid Triassic Kurrachine Formation
    - Shales interbedded with sandstones and siltstones
    - Dolomites and sandstones
  - Potential reservoirs in the Bekaa region may include:
    - Jurassic limestones protected from meteoric invasion
    - Lower Cretaceous sandstones of the Chouf Formation
    - Upper Cretaceous Senonian fractured carbonates
    - Eocene nummulitic limestones

Seals

- Distal Levant Basin
  - Paleocene/Eocene shales and other highly overpressured deposits could seal the underlying reservoirs and prevent vertical hydrocarbon migration
  - Oligo-Miocene intraformational shales or claystones may constitute good seals for Miocene reservoirs
  - Oligo-Miocene Unit
    - Normal faults may either form lateral seals at the present day or act as conduits for hydrocarbon migration
    - Observed to crosscut the Tamar, Aphrodite, and Leviathan fields in the south and don't seem to affect reservoir continuity
- Latakia Ridge
  - Cap rocks are the same as those in the Distal Levant Basin
    - Complex deformation and extensive fracturing in the former area has probably affected the sealing potential
- Levant Margin
  - Lower Triassic evaporites of the Kurrachine Formation
  - Kimmeridgian volcanics
    - May constitute a good seal for deep reservoirs
  - Cretaceous claystones, marls, and basalts
- Onshore
  - Upper Triassic evaporites of the Kurrachine Formation
    - Could seal underlying dolomitic reservoirs and protect them from meteoric influence
  - Jurassic and Cretaceous age intraformational volcanic, marly and shaly units
    - May provide a seal for Jurassic and Cretaceous reservoir units in the Bekaa
  - Paleocene calcareous shales
    - May form a good seal as well as a barrier to meteoric infiltration In the Bekaa

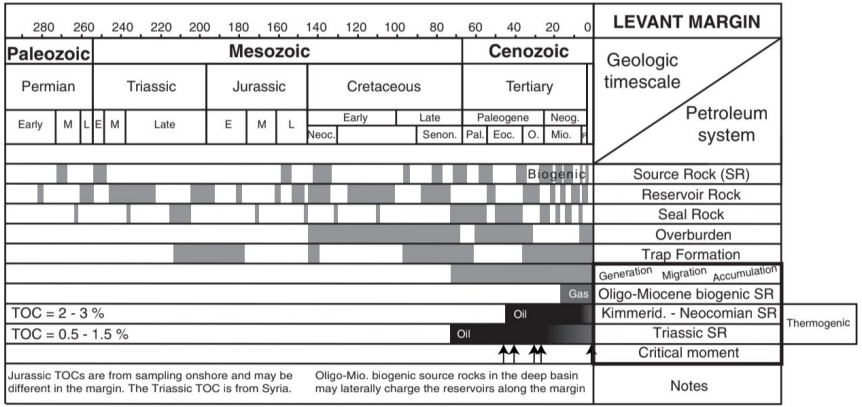
Traps

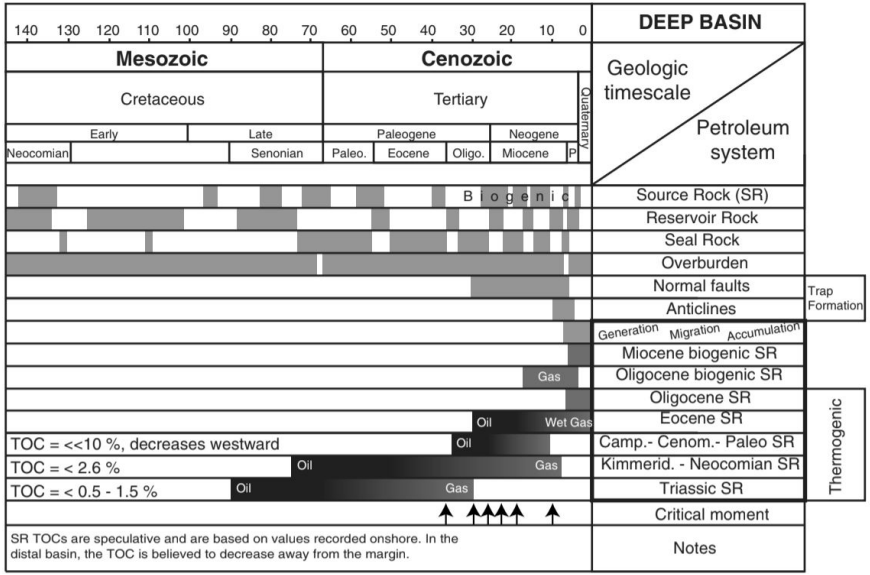
- Distal Levant Basin
  - NE-SW trending anticlines in the Oligo-Miocene
    - Detaching on the Eocene unconformity
    - Folded immediately before or at the onset of the Messinian Salinity Crisis
  - NE-SW trending Late Miocene transpressional anticlines and positive flower structures
  - Oligo-Miocene tilted fault blocks
    - Developed during the Early Miocene
- Latakia Ridge
  - Symmetrical anticlines in the Cenozoic interval underlain by deep seated SE verging thrust faults
    - Providing four way closures
- Levant Margin
  - Potential stratigraphic traps may occur within the Mesozoic platform carbonates and include:
    - Pinch outs of the Early Cretaceous sands sealed by Cretaceous carbonates
    - Pinch outs of Oligo-Miocene clastic units onto underlying Mesozoic strata and sealed by intra-Miocene shales
  - Structural traps include:
    - Inversion structures such as reactivated ENE-WSW strike slip faults

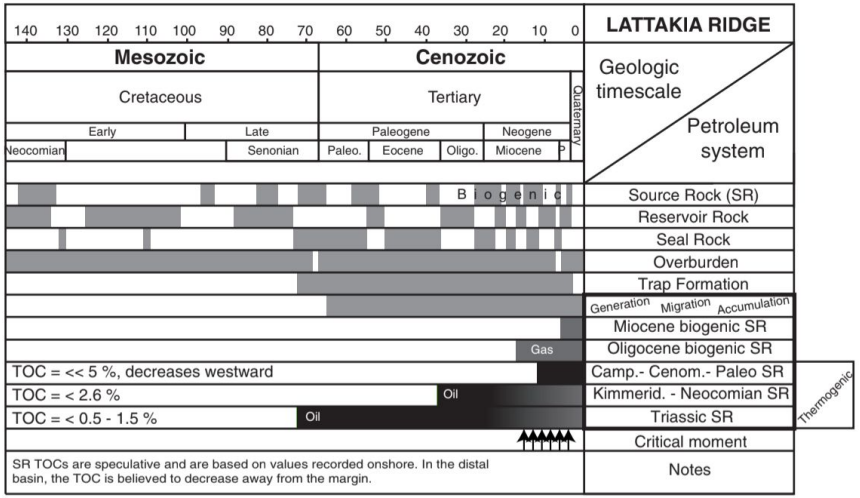
Migration

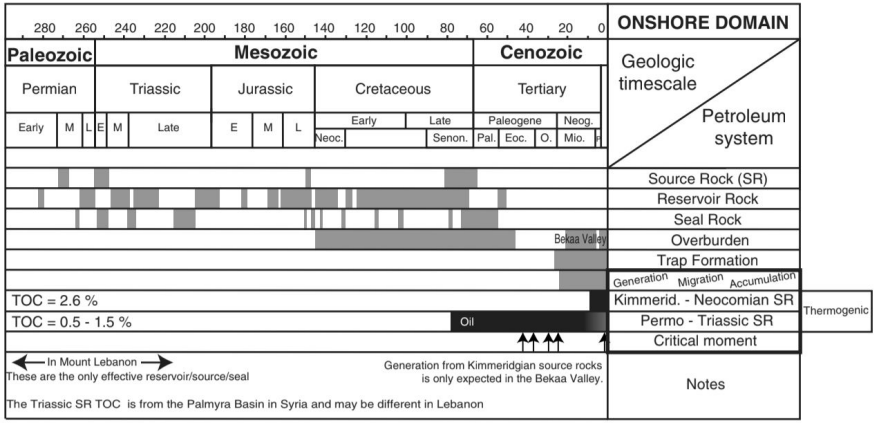
- Distal Levant Basin
  - Aided by intense faulting and fracturing of the Oligo-Miocene interval
  - Migration after the Oligocene could result in charging of Oligo-Miocene reservoirs
- Latakia Ridge
  - Deformation has continued until present day
  - Several faults are still active
    - May form migration pathways
- Levant Margin
  - Pre existing and reactivated faults
    - May have permitted hydrocarbon migration to occur from deep Mesozoic source rocks to shallower reservoirs
- Onshore Traps
  - Four way dip closed anticlines adjacent to the Levant Fracture System
  - Potential structural traps may be located beneath the Quaternary cover in the Bekaa valley

Petroleum Systems Charts









Conclusions

- Working petroleum systems likely present
  - Encourage further exploration in 4 domains outlined
- Use countries close by as good analogues prospects and to reduce exploration uncertainty
  - The study of potential analogues in the Palmyrides

- Distal Levant Basin
  - Oligocene-Miocene siliciclastic units have reservoir potential
  - Sandstones are proven reservoir rocks
  - Dominated by Oligo-Miocene biogenic source rocks
  - Potential structural traps include:
    - Upper Miocene four way dip closures
    - Lower Miocene tilted fault blocks
- Latakia Ridge
  - Potential reservoir rocks are mainly Oligo-Miocene siliciclastics
  - Mixed biogenic thermogenic source rock potential
  - Potential traps are Upper Cretaceous four way dip closures
- Levant Margin
  - Potential reservoirs include Mesozoic carbonates together with Lower Cretaceous and Oligocene-Miocene siliciclastics
  - Possibility of lateral migration from kitchens in the deep offshore
  - Potential traps are in general stratigraphic
- Onshore
  - Triassic dolomites and Jurassic and Cretaceous carbonates have reservoir potential
  - Potential traps include four way dip closures

Thank You