

# **Structural Analogy Between the Inverted Structures of the Moroccan Atlas System and the Syrian Arc Structures of the Eastern Mediterranean\***

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## **Abstract**

Neotectonic inversion and uplift of the Atlas system, as the result of African-Eurasian plate convergence, is well documented in the Essaouira Basin and the western High Atlas, onshore Morocco. However, seismic reflection data acquired in the offshore Essaouira-Safi segment of the Atlantic margin of Morocco show the presence of similar compressional structures in the deepwater area as well.

These prominent structures are best imaged outboard of the widespread salt basin, some 200 km to the west from the coastline, in water depth of 2,000-4,000 m. The anticlines have a general WNW-ESE trend. Whereas the growth history of similar anticlines in the onshore part of the Essaouira Basin are poorly dated due to the erosion of the Tertiary cover, the continuous sedimentation in the deepwater offers the possibility to directly age-date the Tertiary Atlas mountain building episodes. Compressively reactivated syn-rift normal faults are responsible for these inverted structures which clearly involved the pre-Mesozoic basement.

Structurally analogous inverted features are well documented along the northeastern African-northern Arabian margin (Syrian Arc), mostly onshore. These large-scale, northeast-trending asymmetric folds and associated contractional faults are well-dated and attributed to the “Santonian event” observed in many parts of the African plate. Late Tertiary Syrian Arc style compressional features are also present in the deepwater of the Eastern Mediterranean providing the traps for recent deepwater discoveries in the Levant. Therefore the pronounced similarity between the inverted structures of the Atlas system and those of the Syrian Arc in the Eastern Mediterranean has important implications for hydrocarbon exploration in Morocco.

### **Selected References**

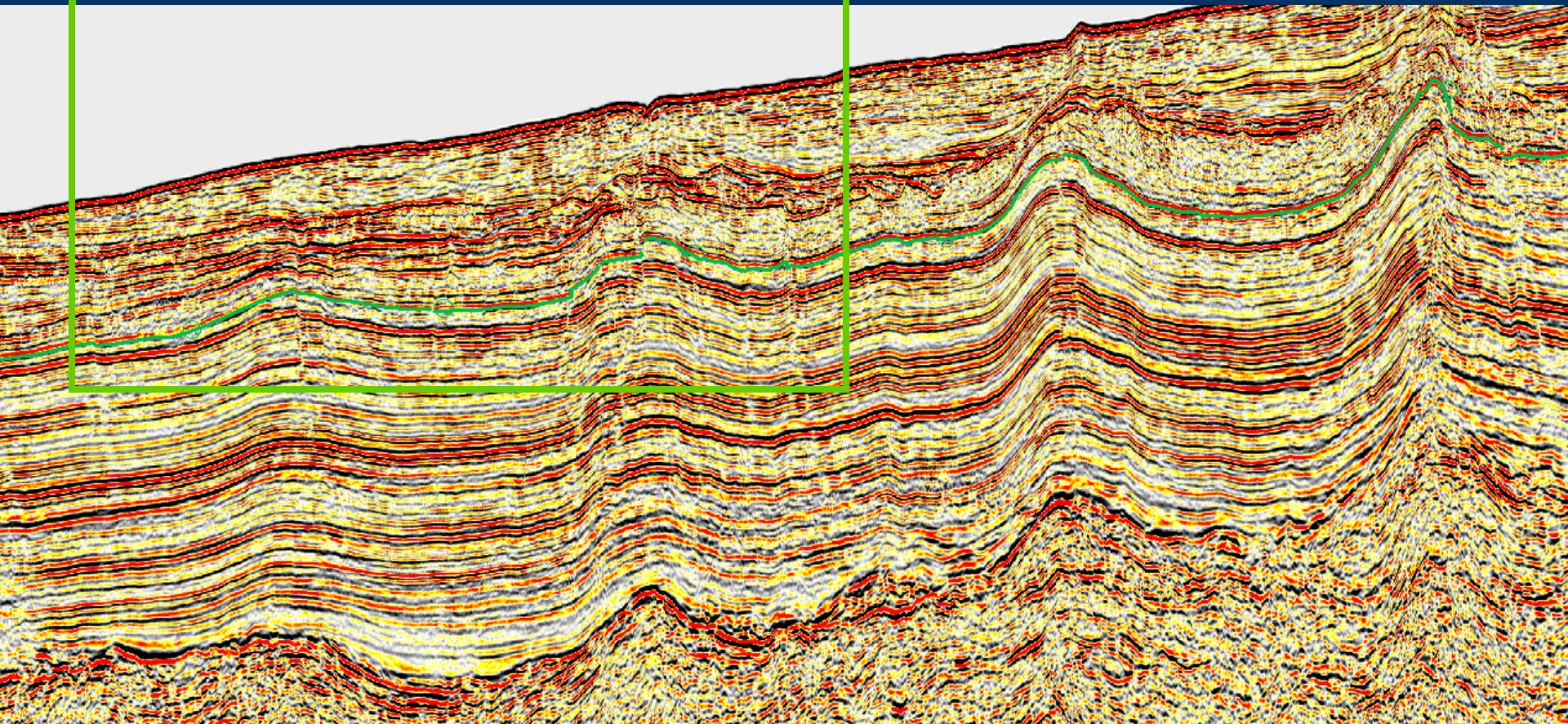
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# Structural analogy between the inverted structures of the Moroccan Atlas system and the Syrian Arc structures of the Eastern Med

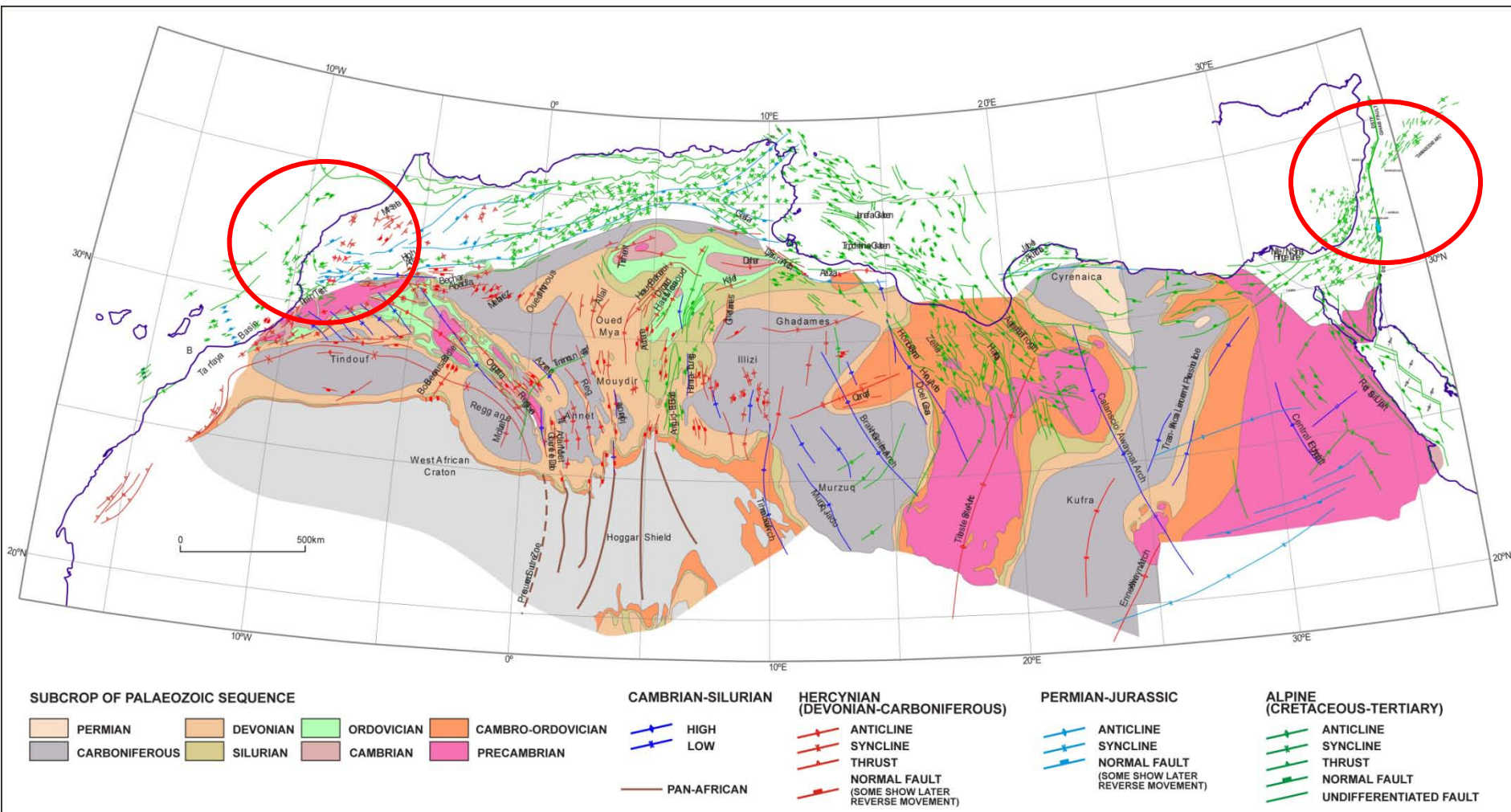
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AAPG Conference, Houston, April 12, 2011



# Major basins and structural elements of North Africa/Levant



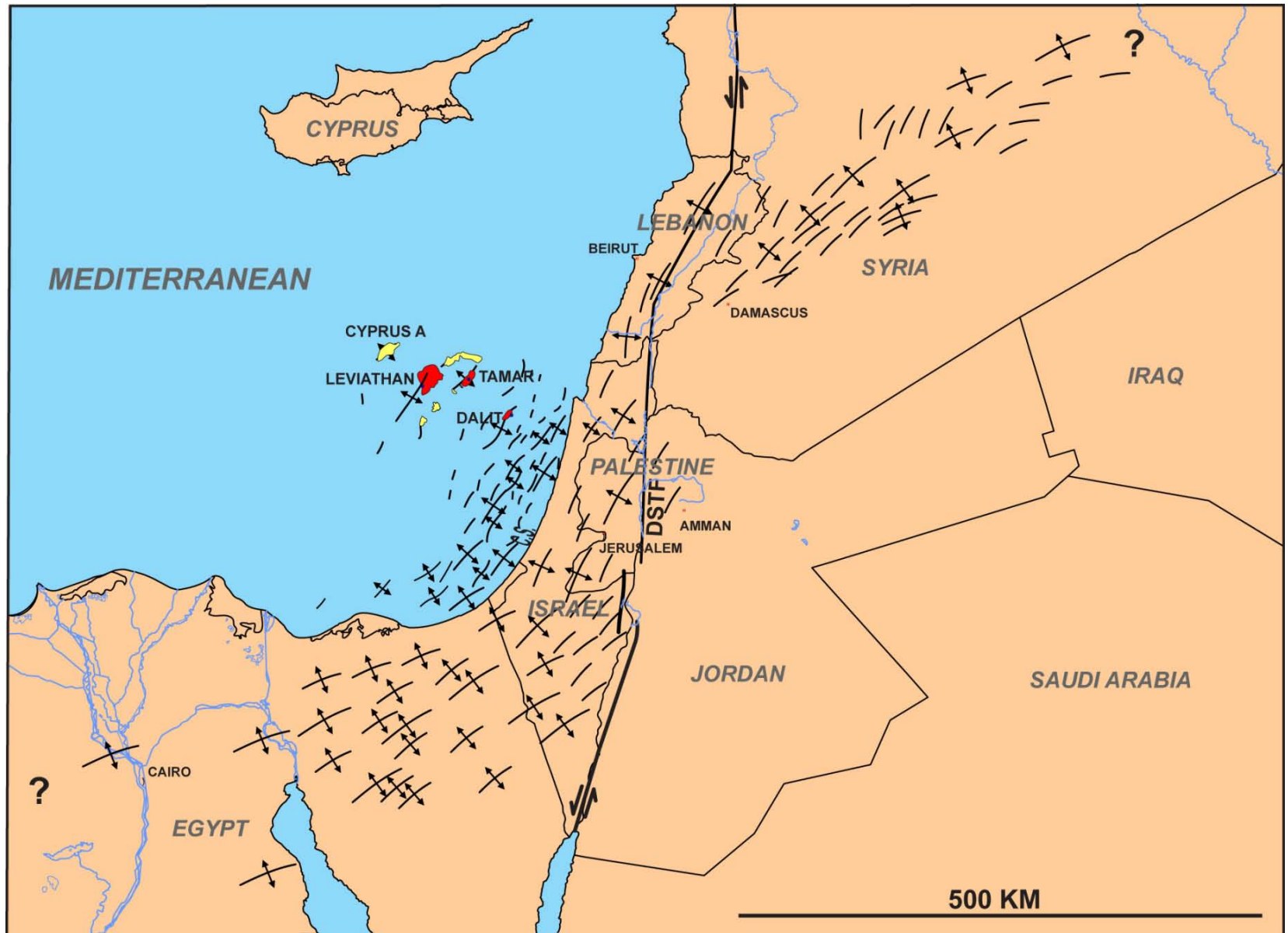
**North Africa: Craig (2006); Levant: Walley (2001) and Gardosh (2008)**

# Outline

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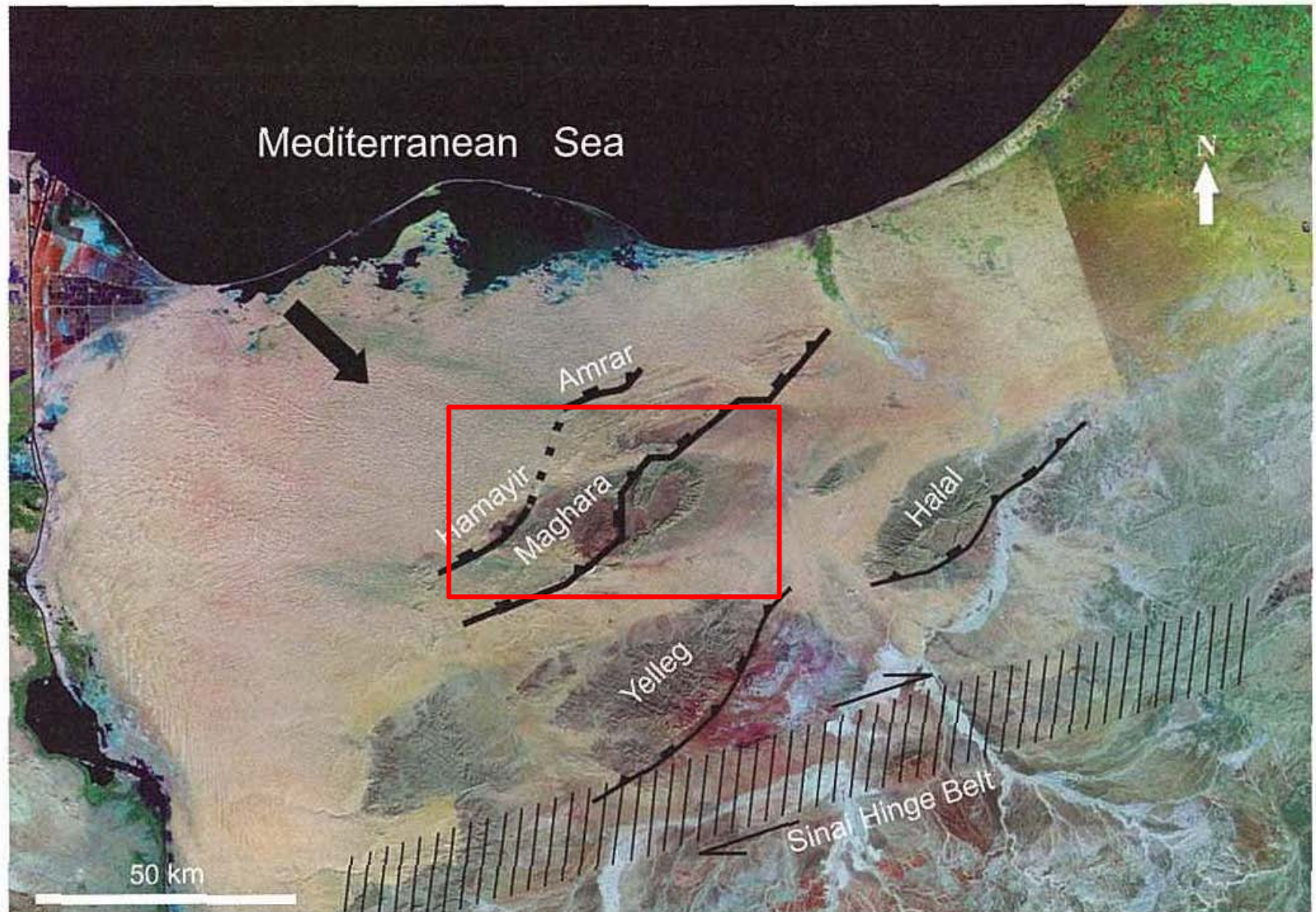
- ▶ **Introduction**
- ▶ **Syrian Arc structures in the broader East Med**
  - ▶ **Onshore Egypt**
  - ▶ **Offshore Israel**
  - ▶ **Onshore Syria**
- ▶ **Inverted structures in the Atlas system of Morocco**
  - ▶ **Onshore Jebilet**
  - ▶ **Onshore Essaouira Basin**
  - ▶ **Offshore Safi Basin**
- ▶ **Structural similarities and differences**
- ▶ **Conclusions**

# Syrian Arc structures in the broader Levant

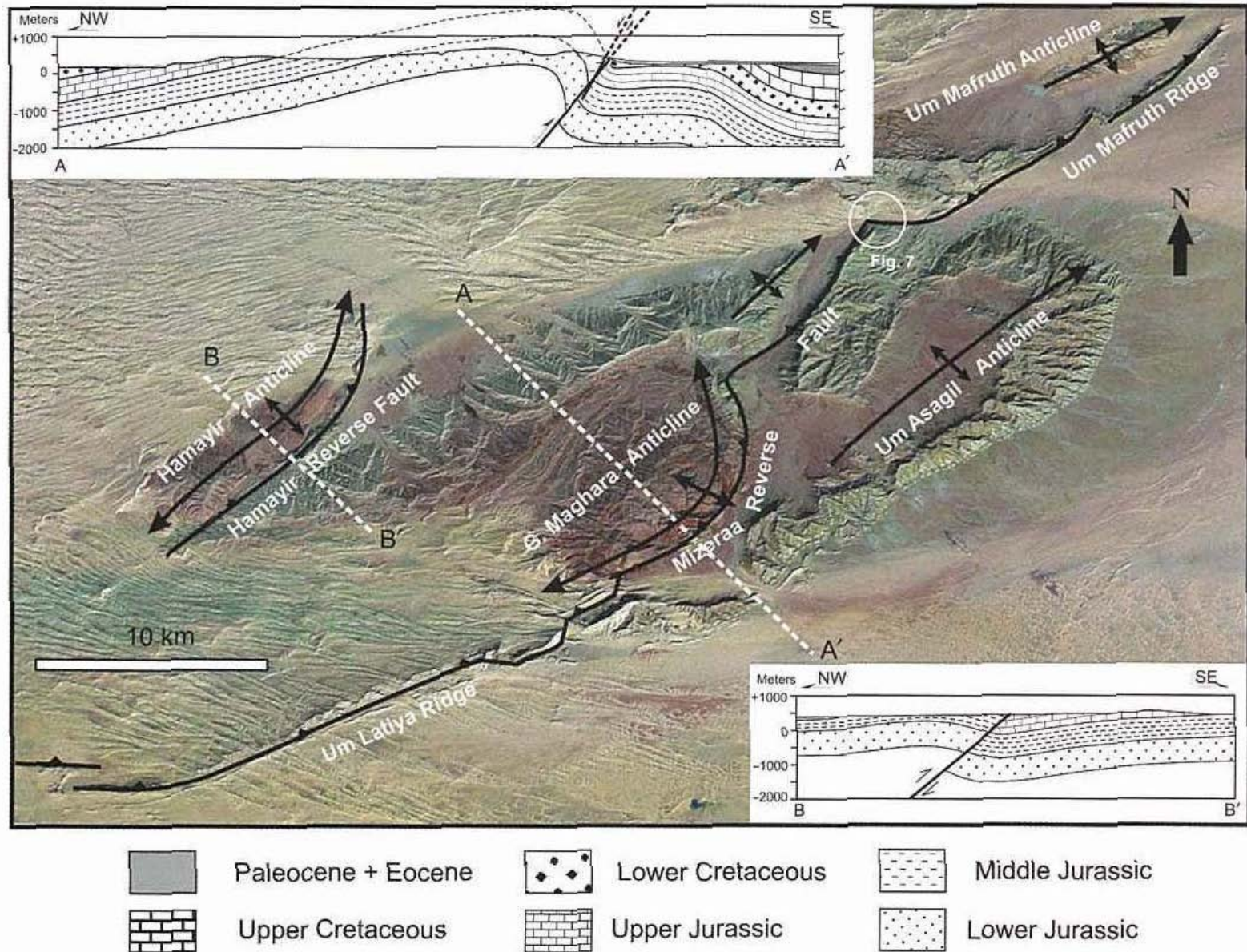


Walley (2001) and Gardosh (2008)

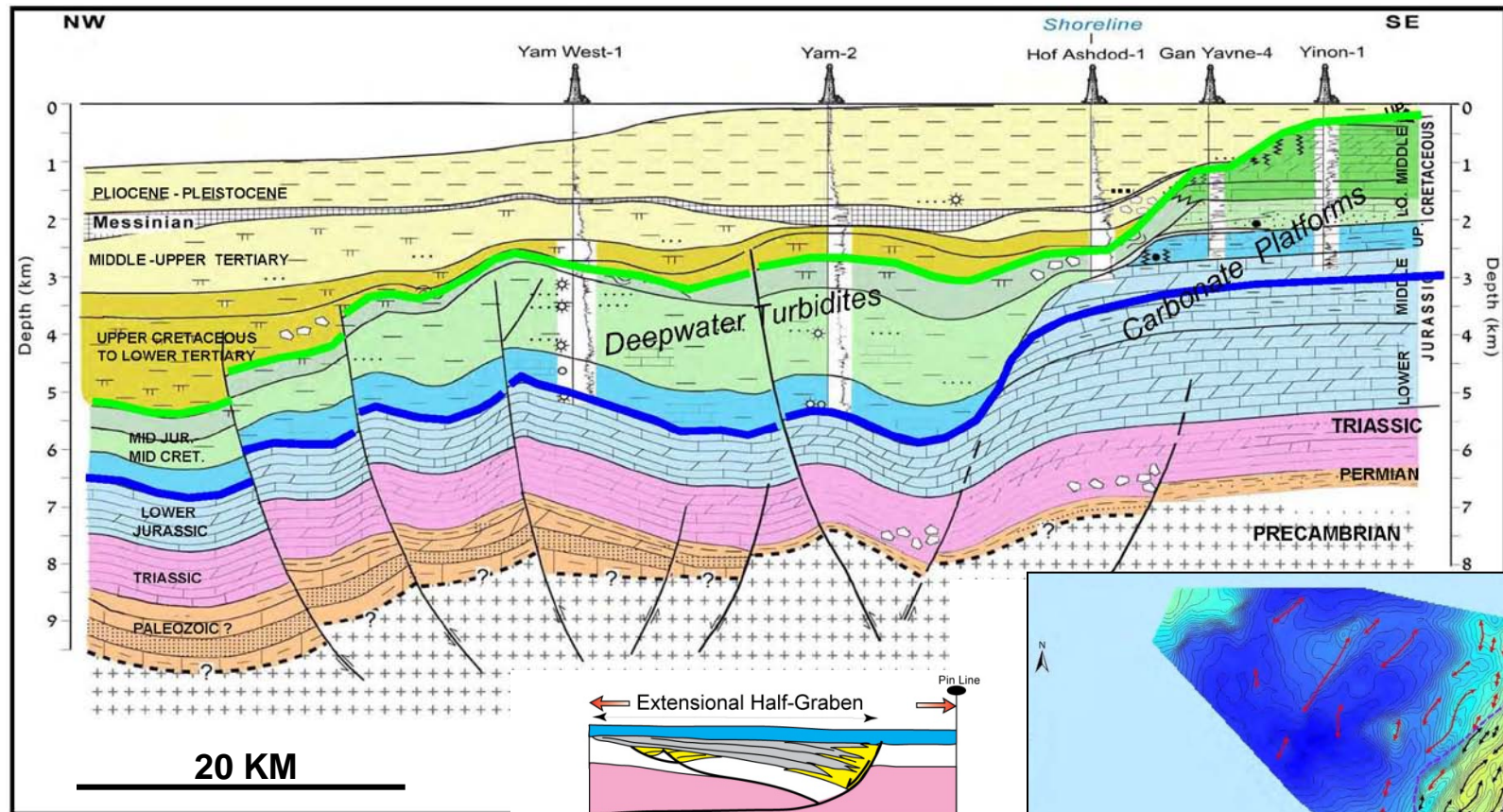
# Syrian Arc structures, onshore Sinai, Egypt



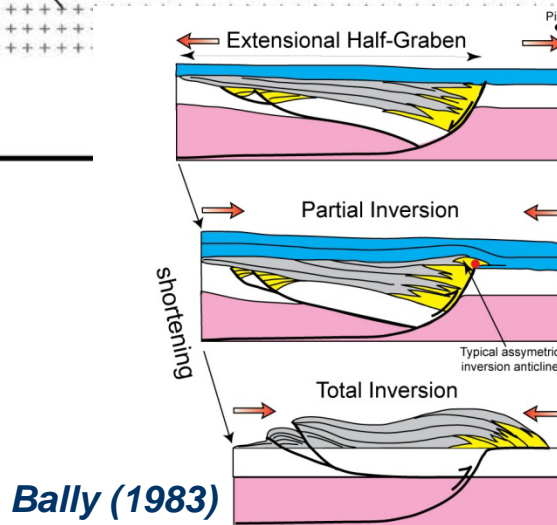
# Syrian Arc structures, onshore Sinai, Egypt



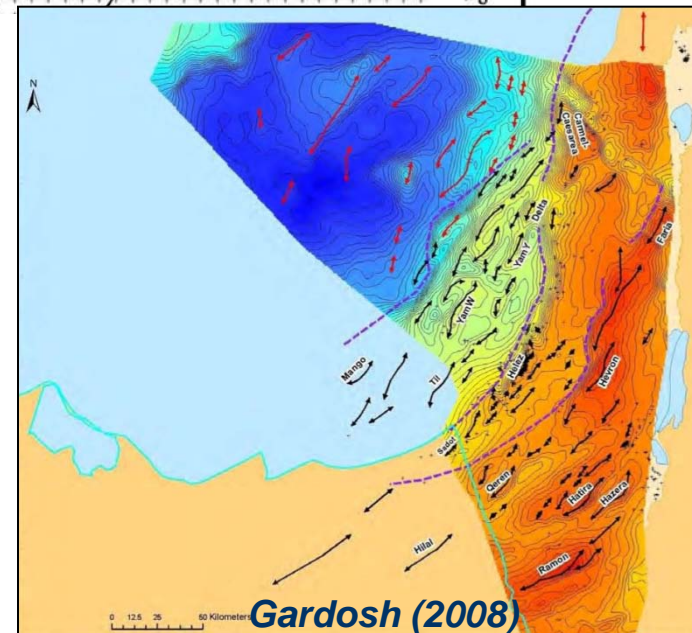
# Syrian Arc structures, offshore Israel



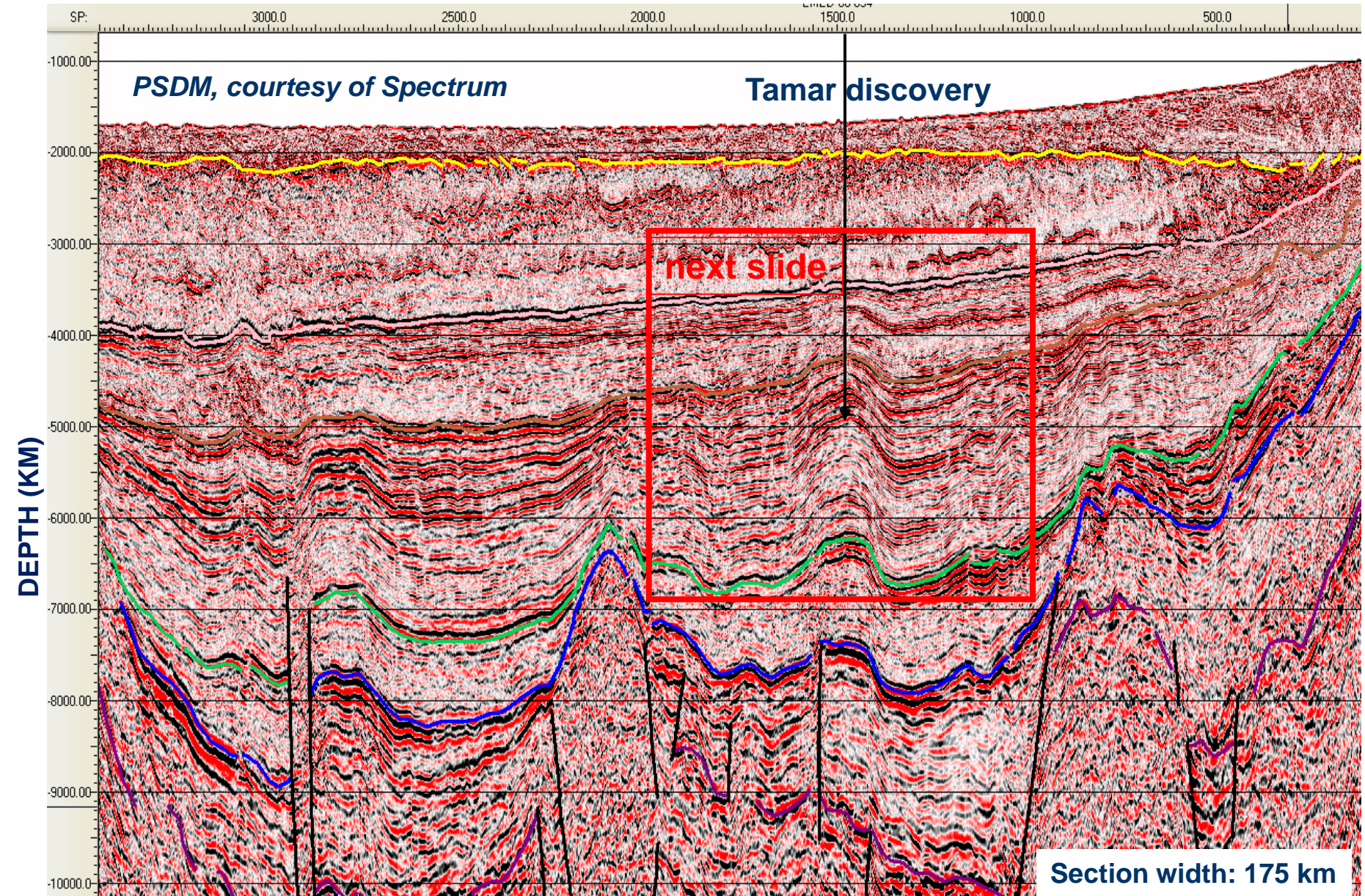
*Gardosh (2008)*



*Bally (1983)*

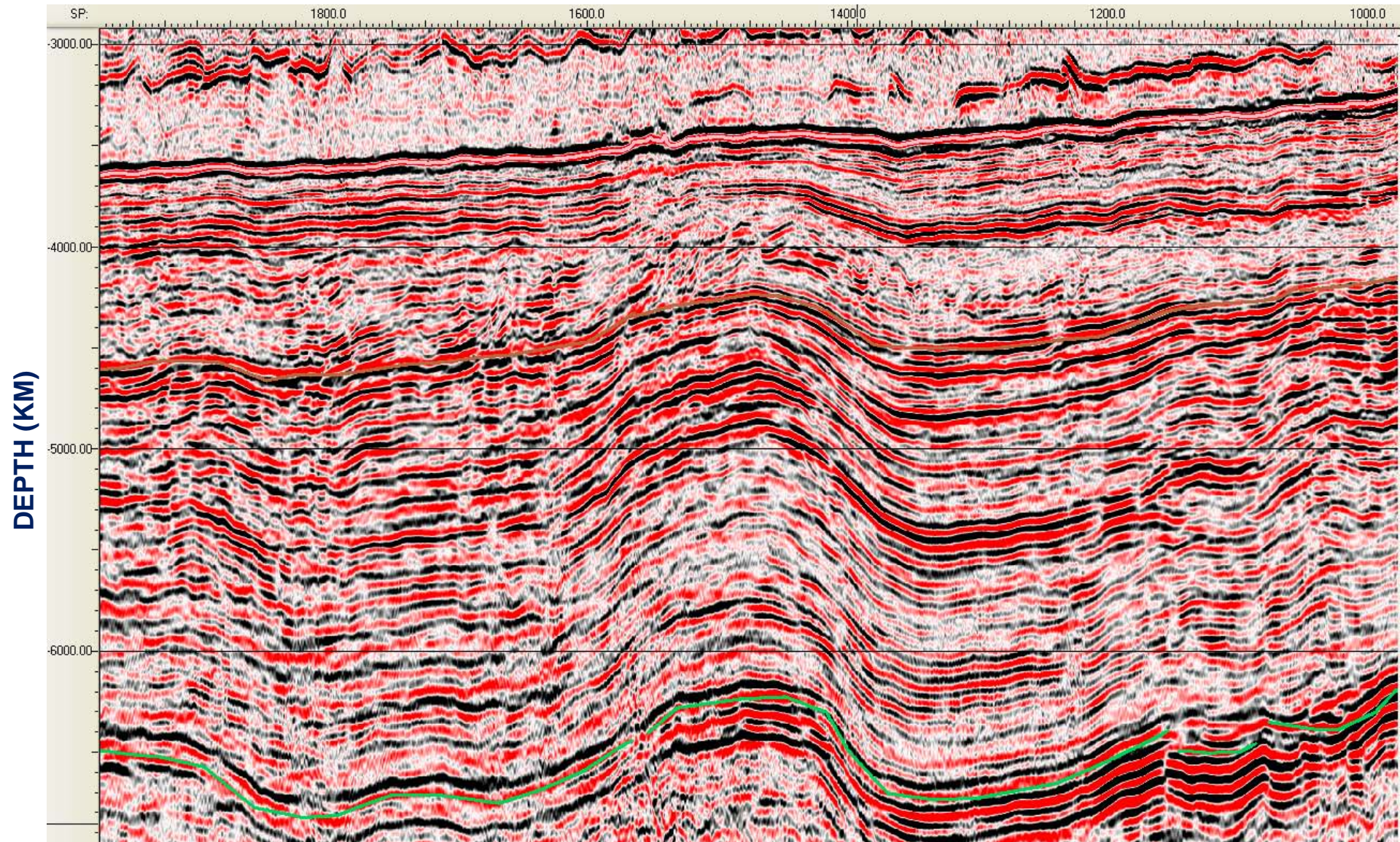


# Syrian Arc structures, offshore Israel



Top Messinian Salt: Yellow; Base Salt: Pink; Base Pliocene: Light Brown; Top Lower Cretaceous: Green; Top Jurassic: Blue; Permian Triassic horizon: Purple

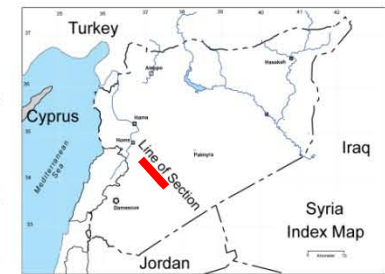
# Tamar discovery, detail



Tamar Reservoir is reported to be in the Lower Miocene  
WD=1676 m, TD = 4900 m, 140m net pay

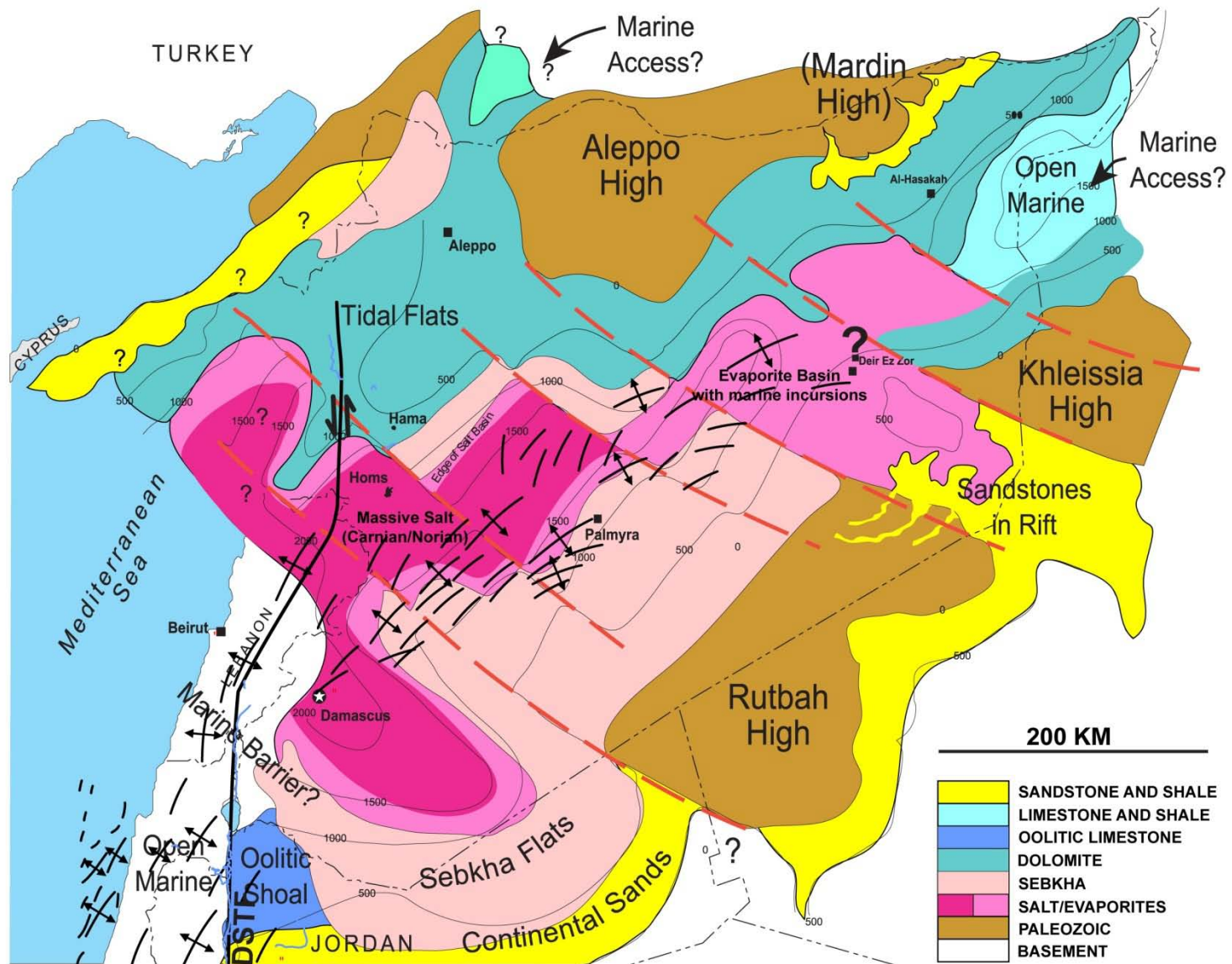
Section width: 50 km  
*PSDM, courtesy of Spectrum*

# NW



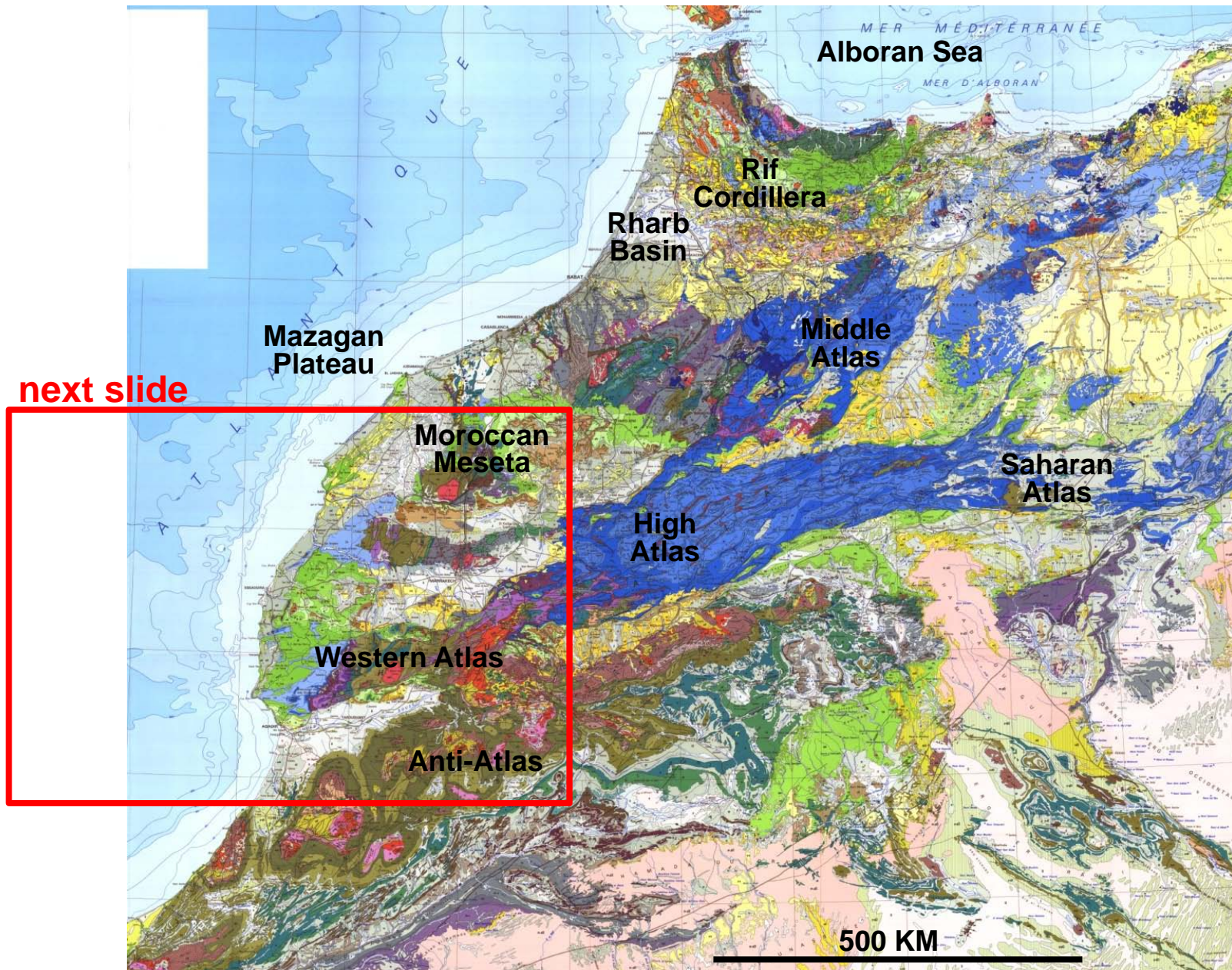
**Wood, 2001**

# Onshore Syria, Upper Triassic lithofacies

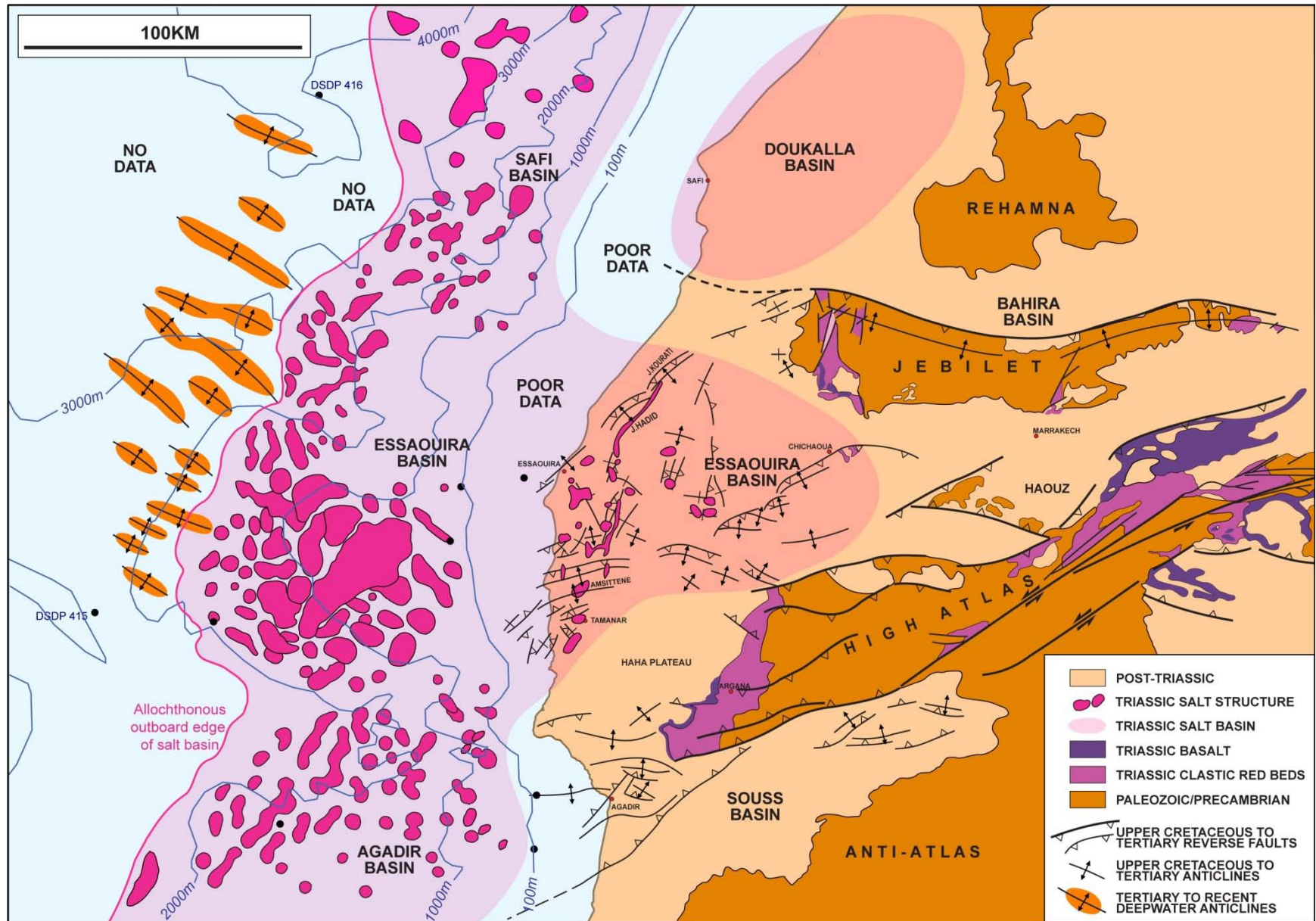


Wood, 2001

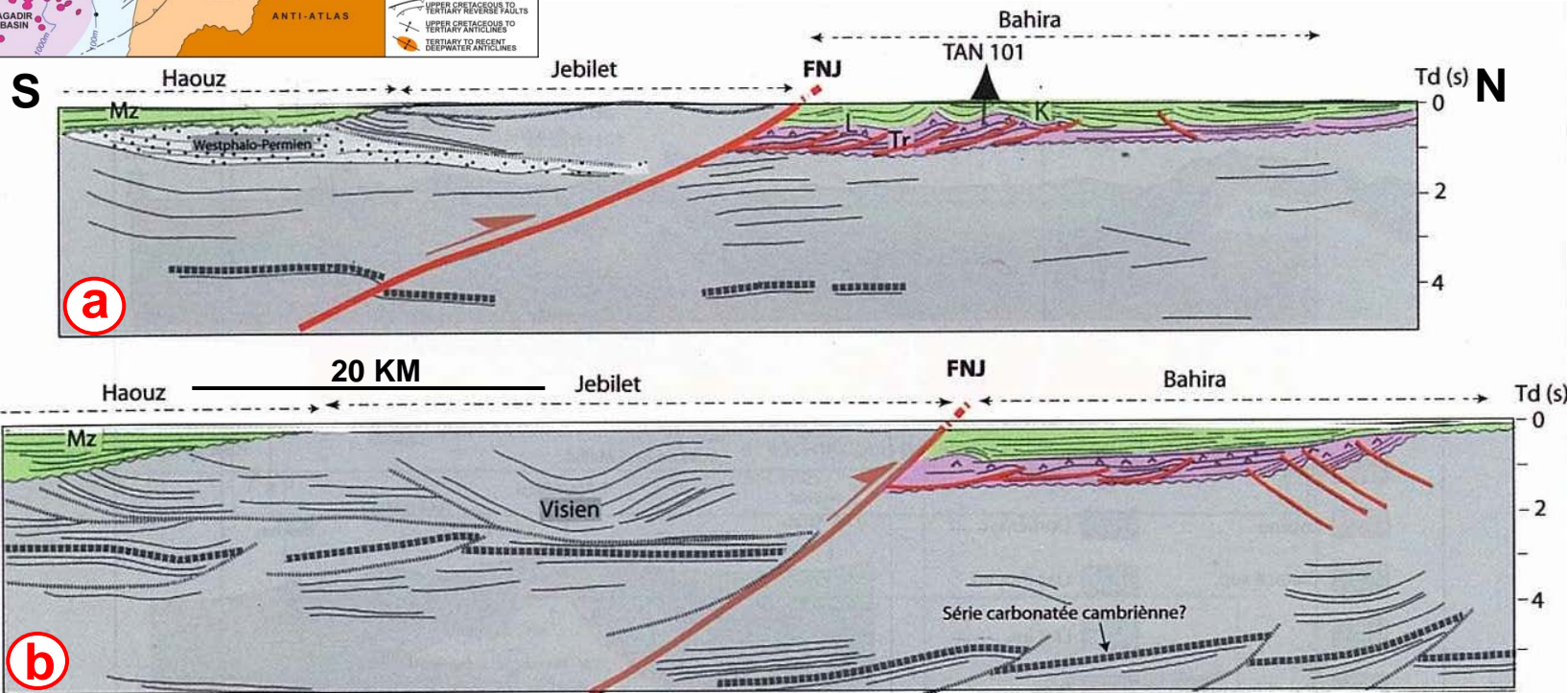
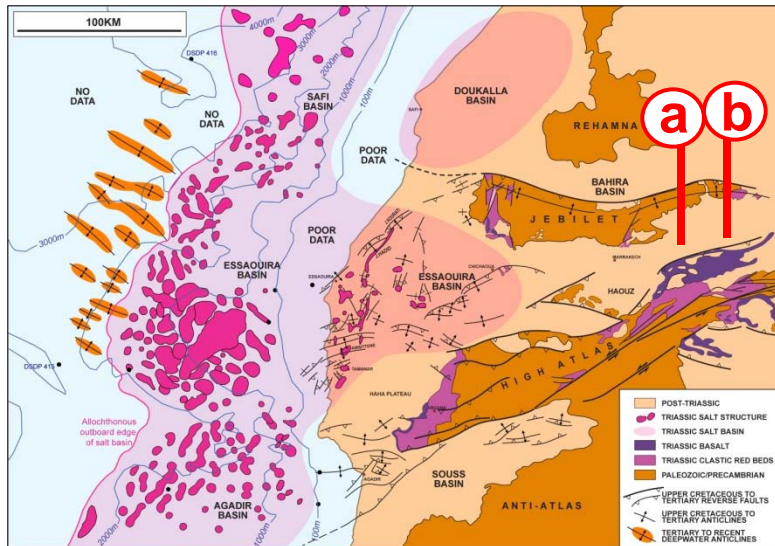
# Morocco, regional geology



# Inverted structures in the Essaouira and Safi Basins



# Tertiary inversion of the Jebilet, Morocco



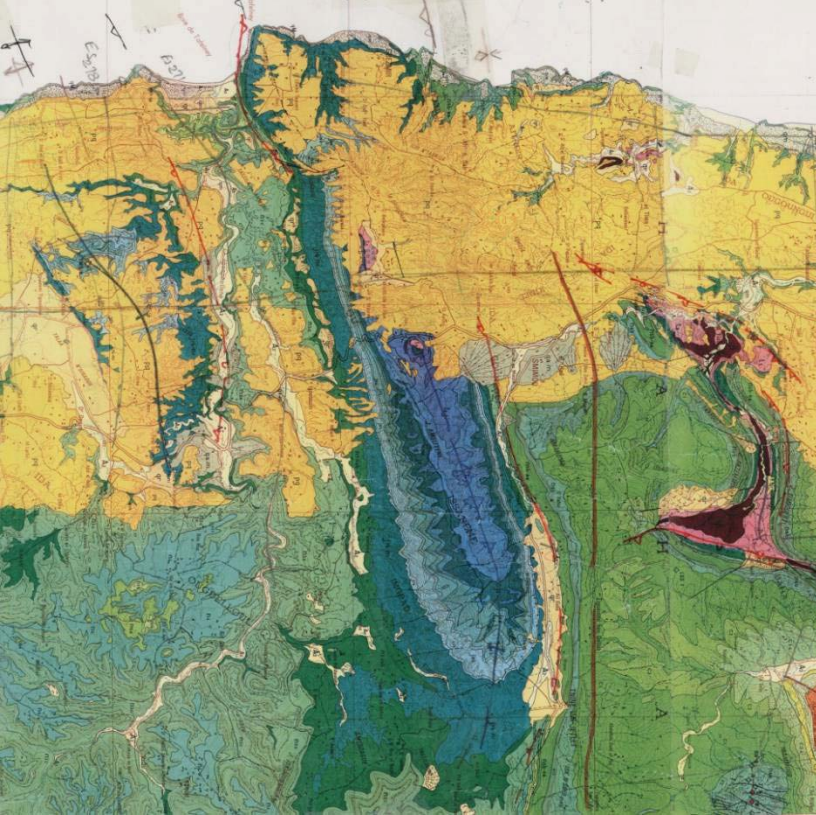
Hafid et al., 2006

Paleozoic

Mesozoic

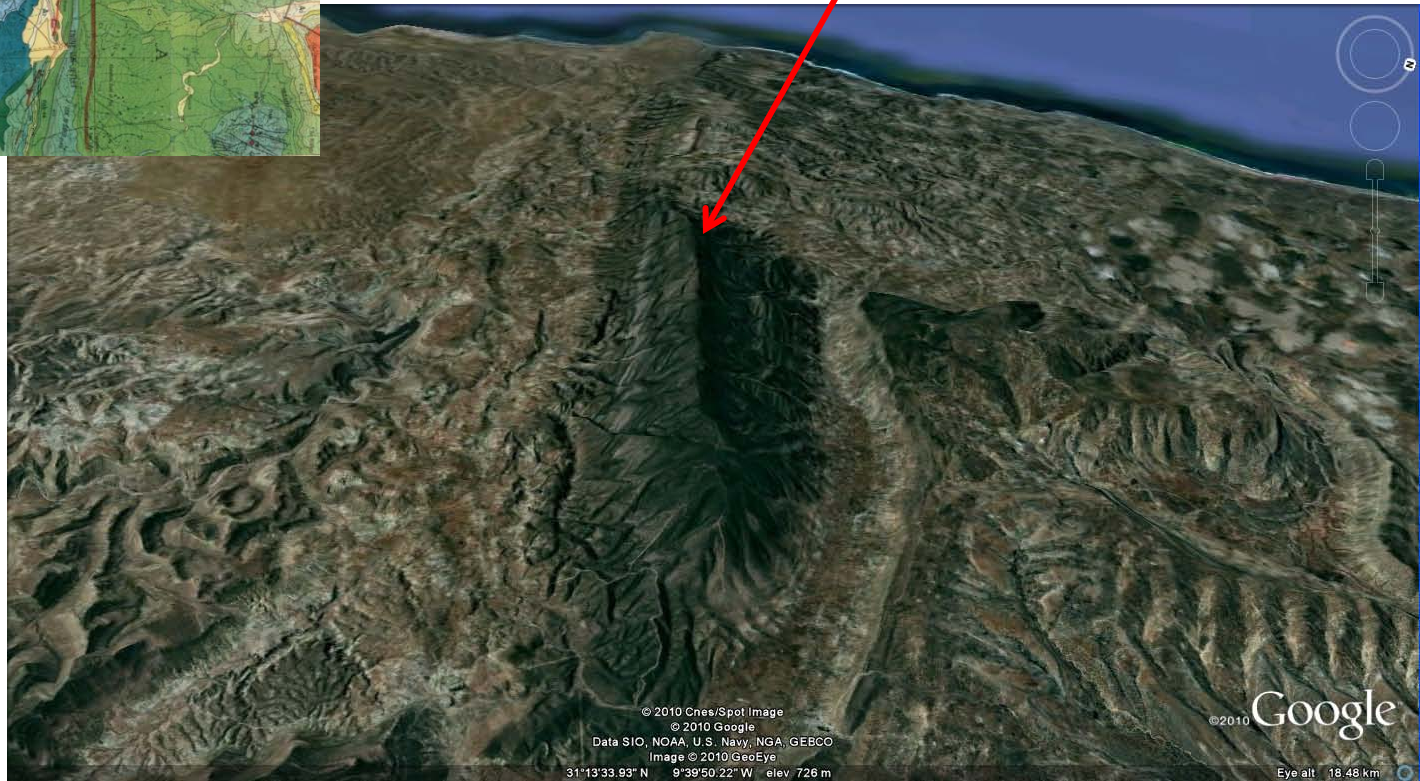
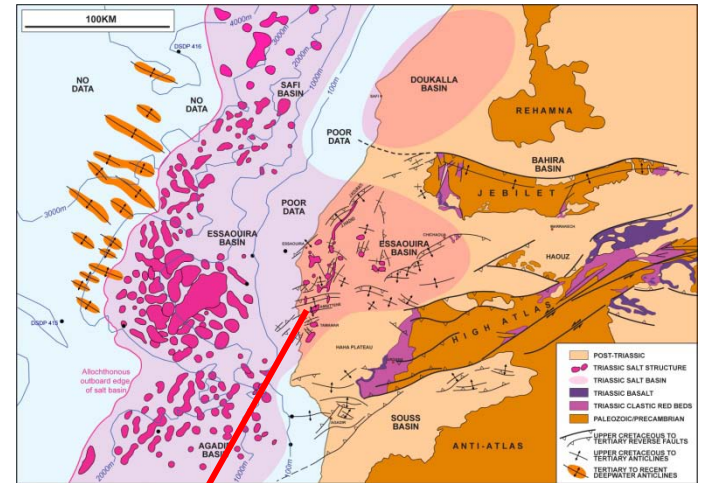
FNJ : North Jebilet Fault

# Amsittene Anticline, Morocco

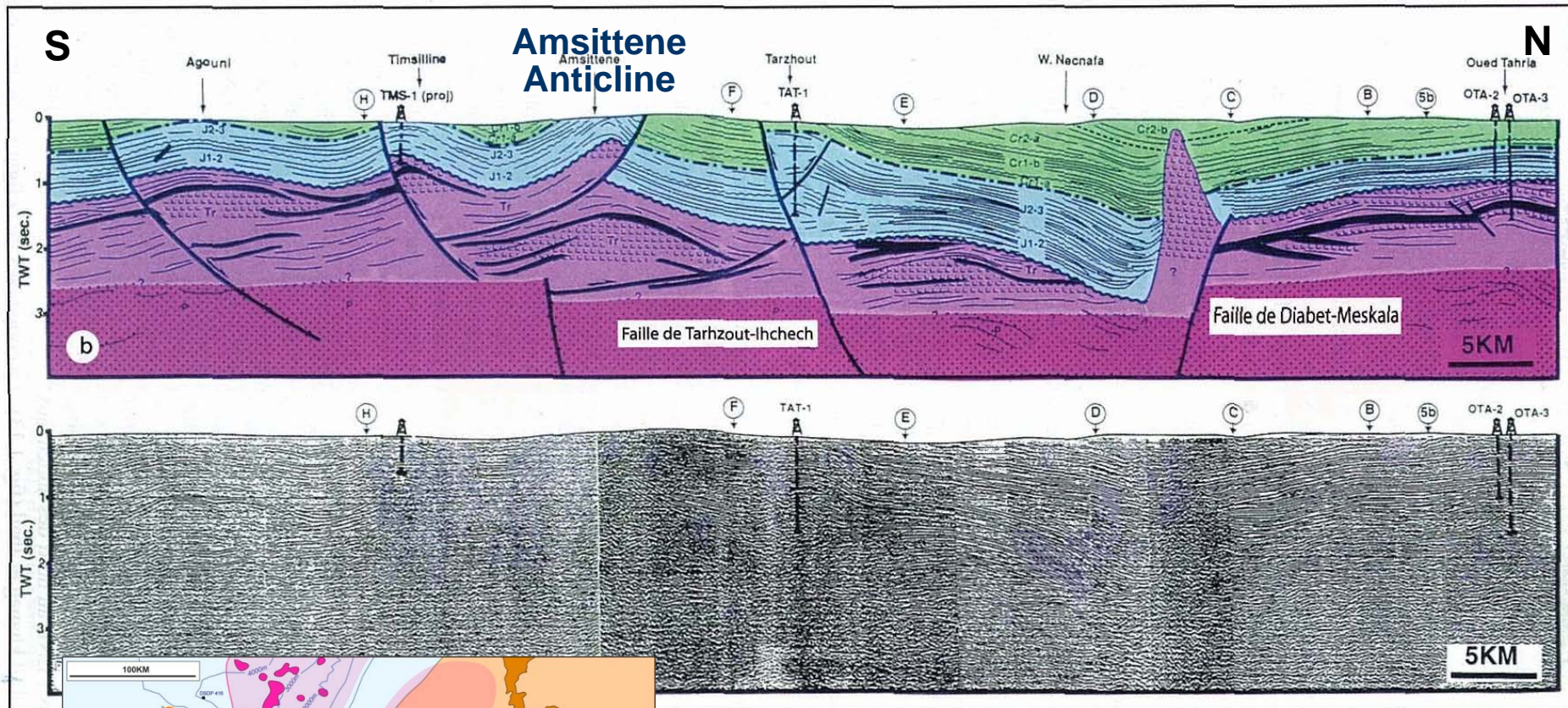


~20 KM

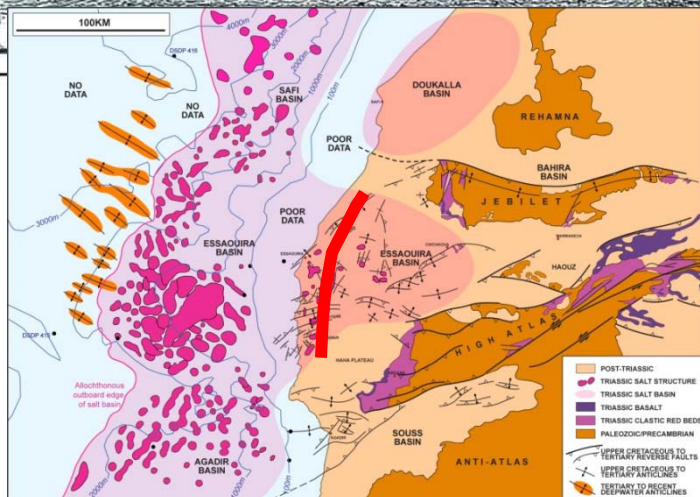
NORTH  
↓



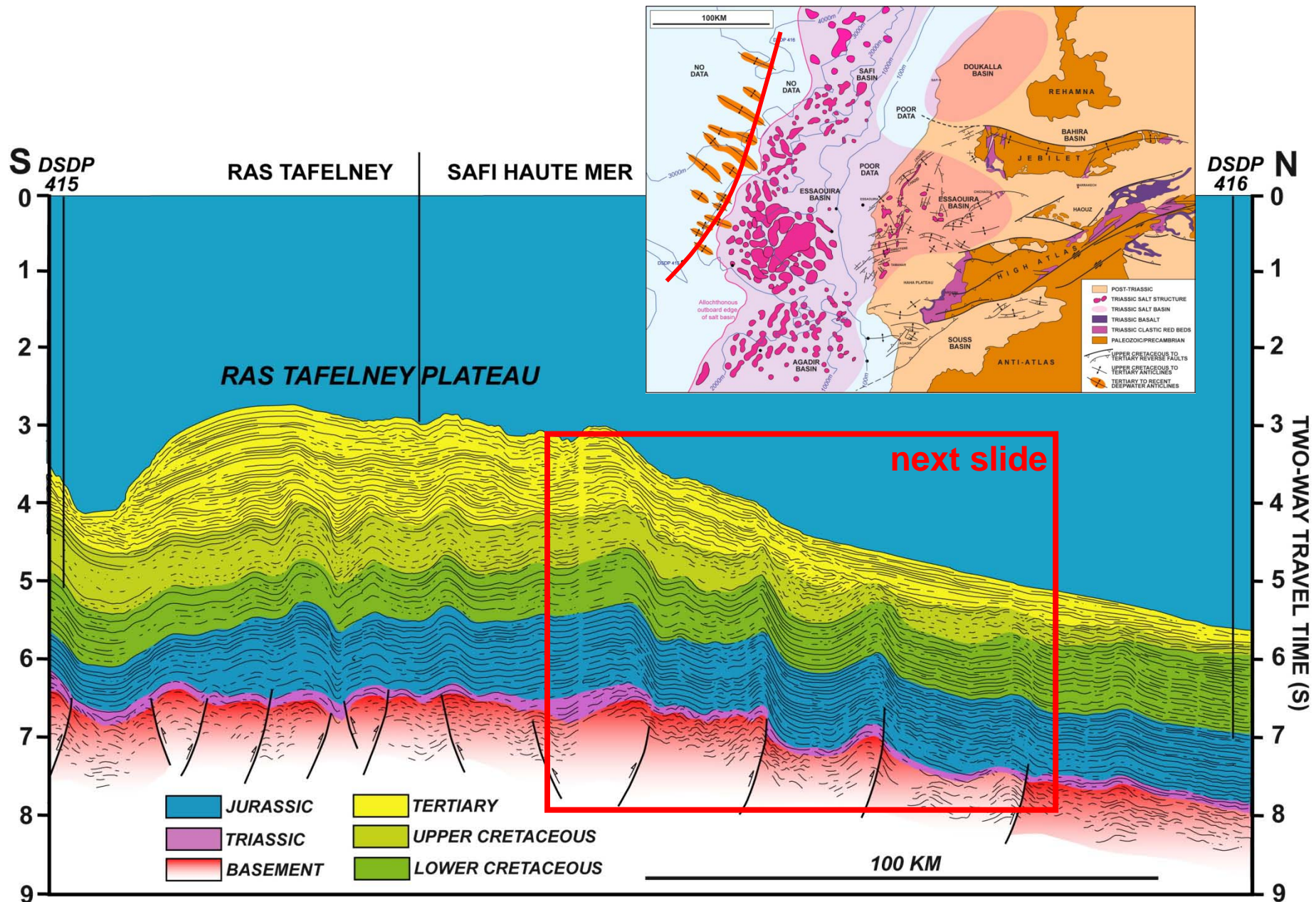
## Tertiary inversion, onshore Essaouira Basin, Morocco



***Hafid, 2006***

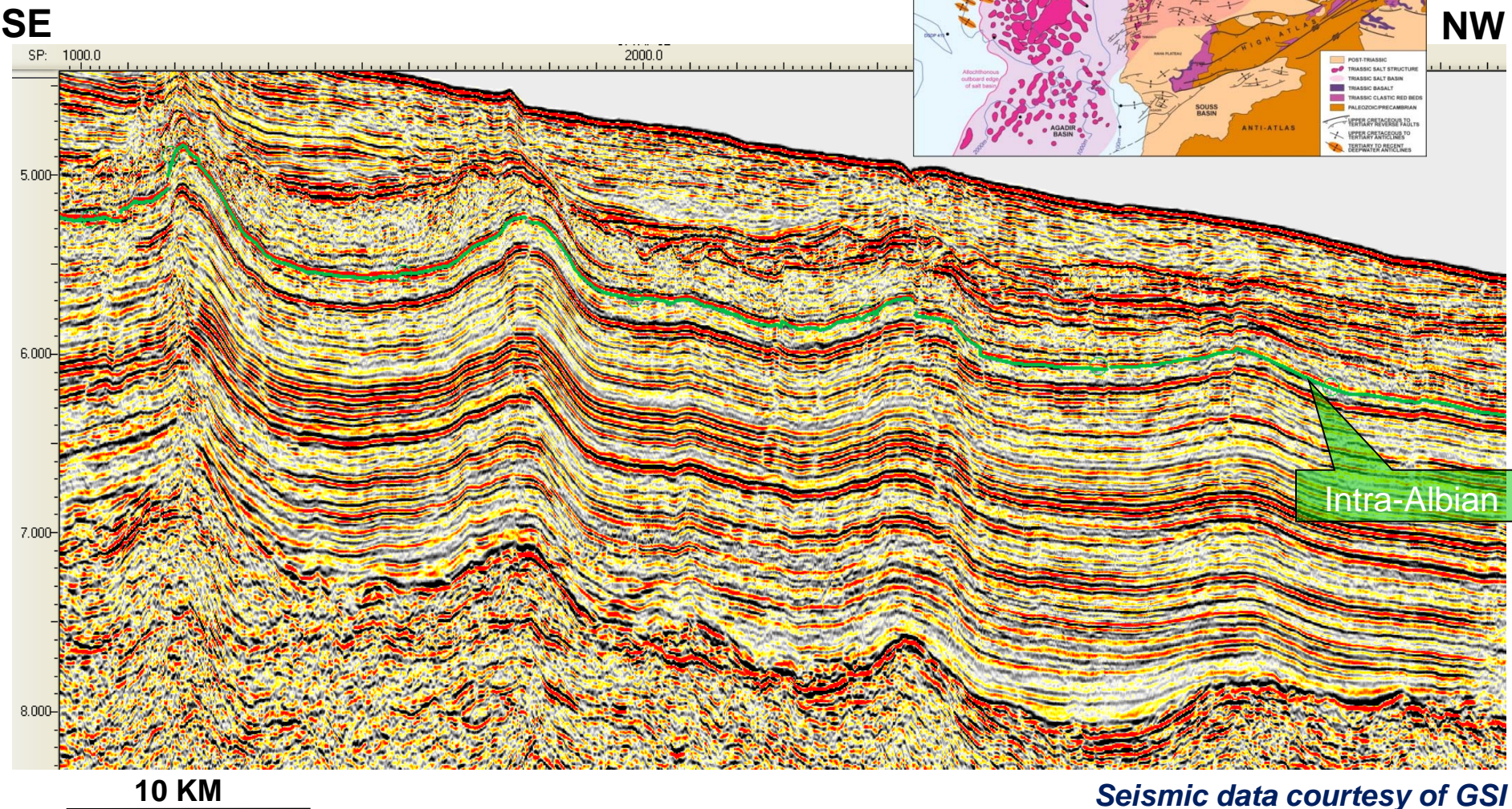
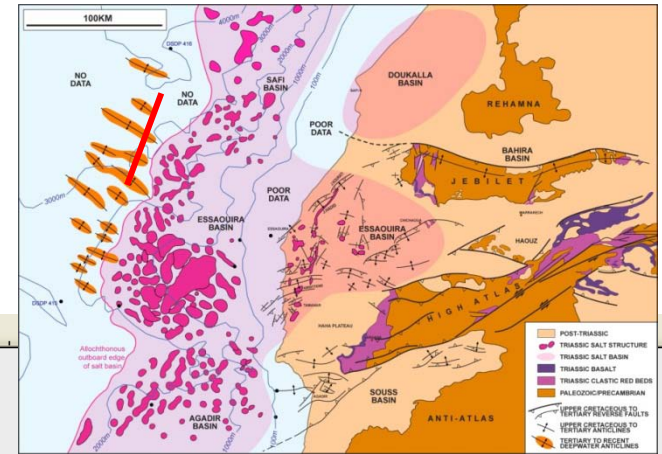


# Mid-Tertiary inversion in deepwater Morocco



# Sub-regional 2D line, deepwater Morocco

WNW-ESE inverted anticlines are best imaged outboard of the salt basin, some 200 km to the west from the coastline, in water depth of 2,000-4,000 m

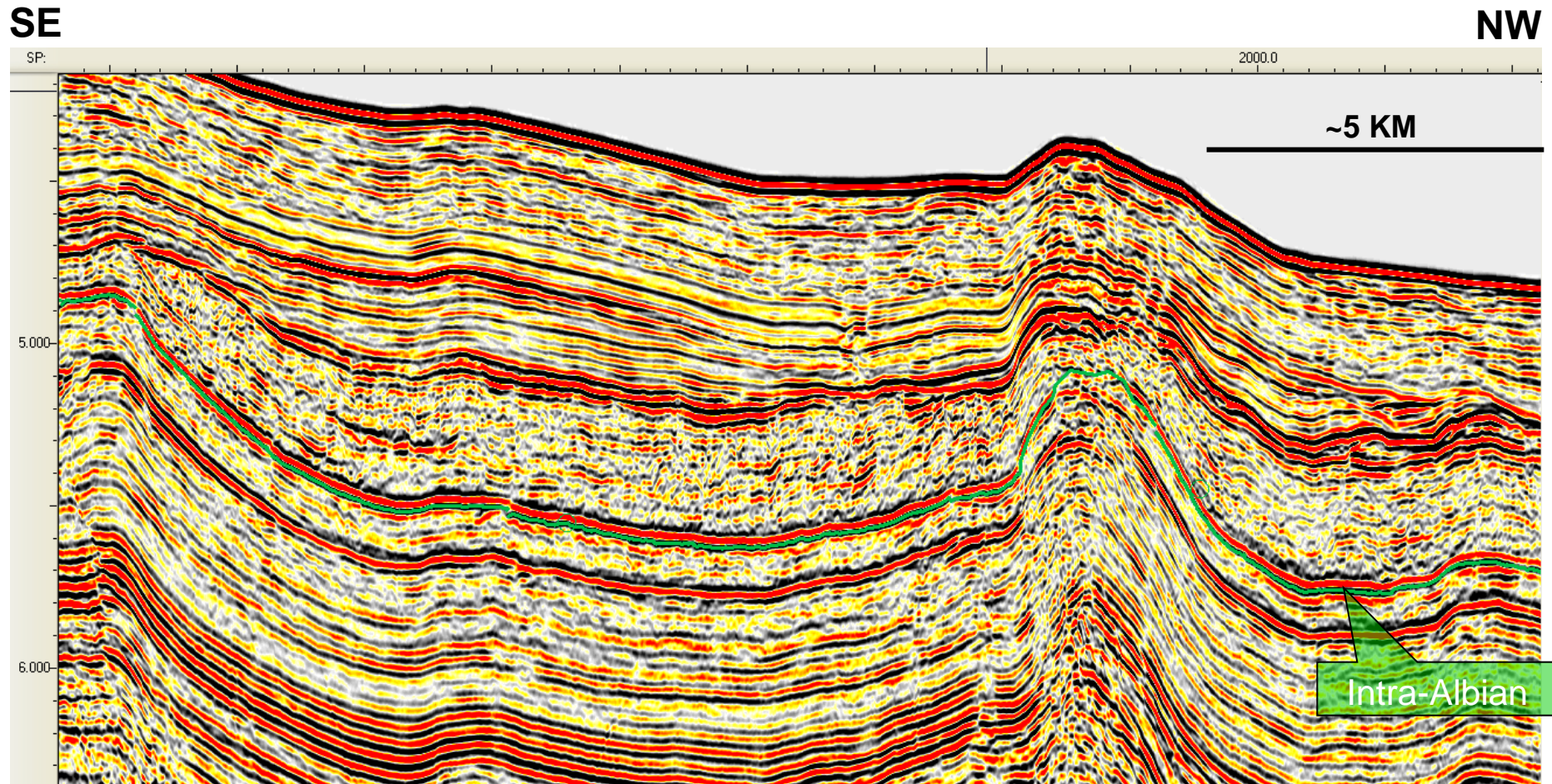


# SE

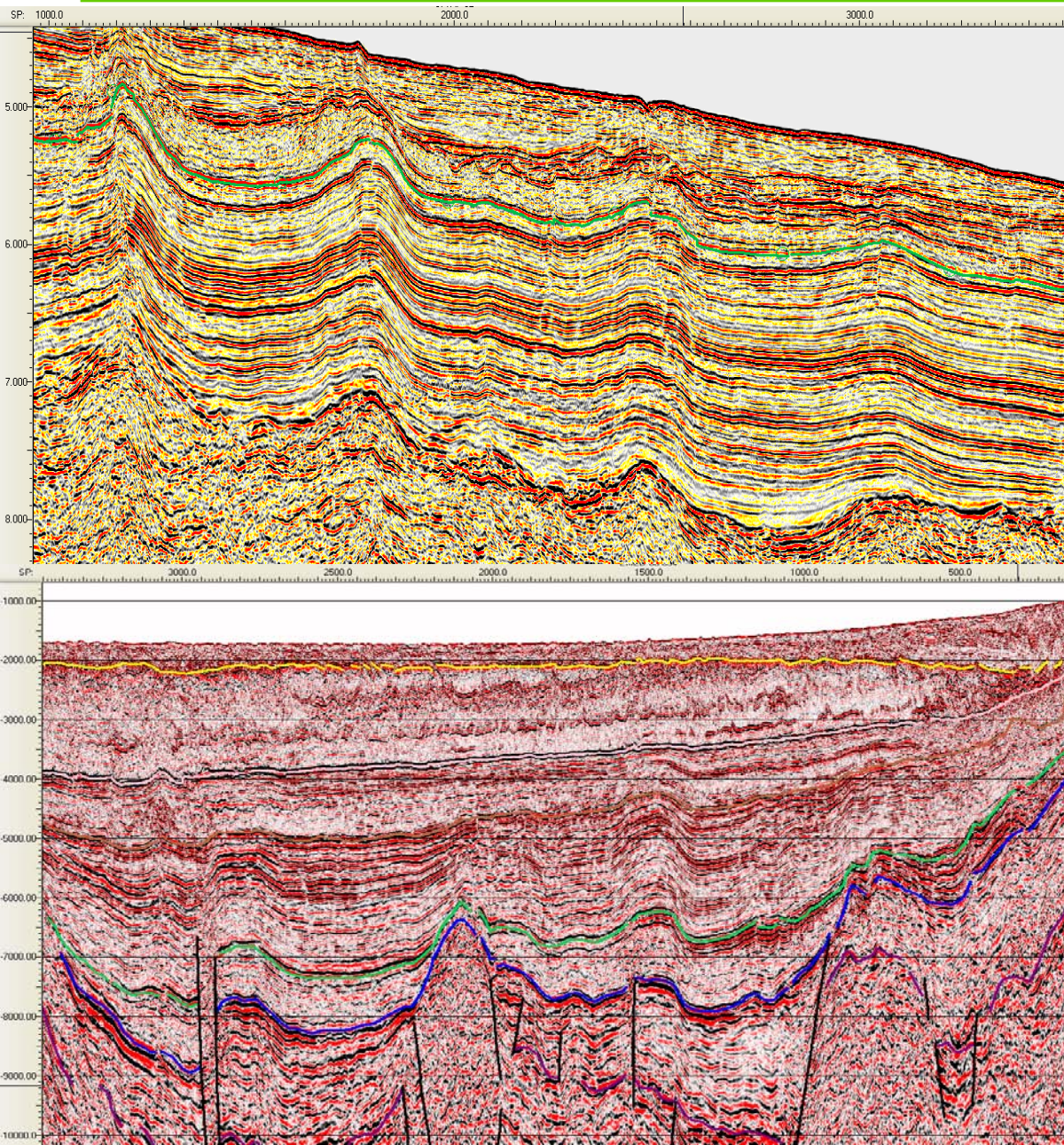


**Seismic data courtesy of GSI**

# Seismic detail, deepwater Morocco



# Inversion tectonics, Morocco and Levant: conclusions



## Similarities:

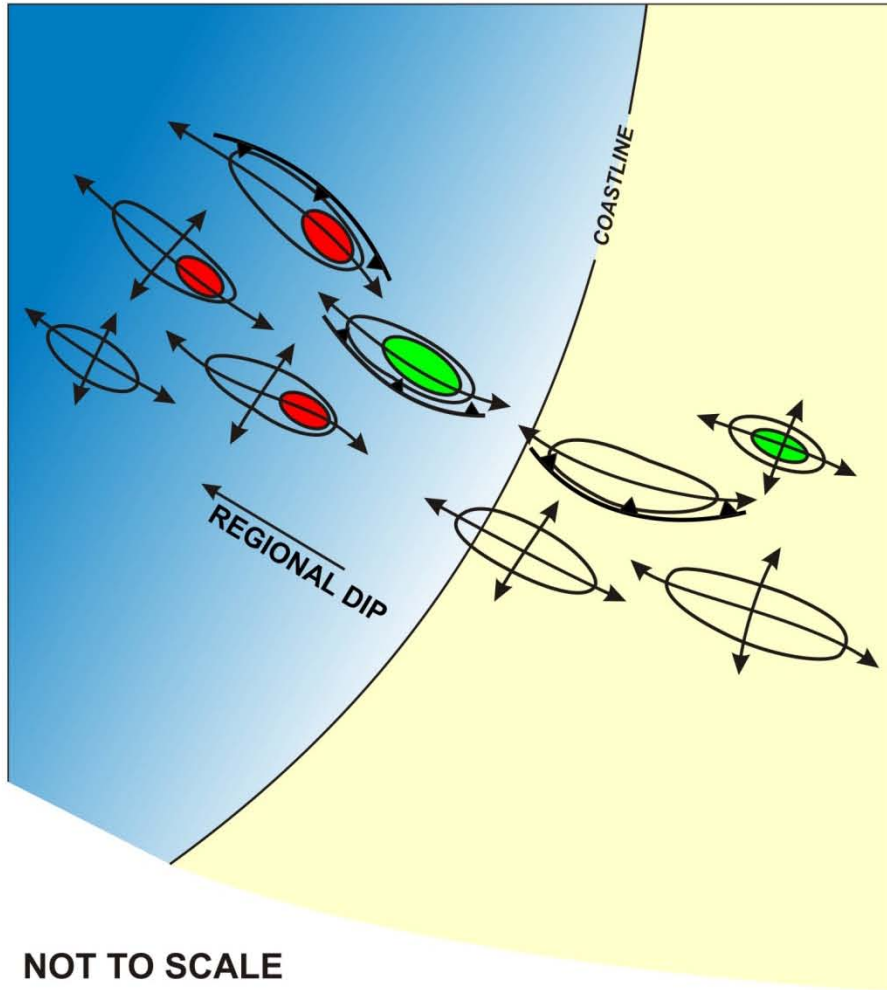
- Basement involved deformation
- Inversion of pre-existing rift fabric
- Multiple phases of shortening
- Relatively small shortening
- Most onshore structures drilled
- Un(der)explored play in deepwater
- Triassic salt detachment(s)
- Locally neotectonic deformation

## Unique to Morocco:

- syn-rift/post-rift detachment
- inversion trend perpendicular to coastline

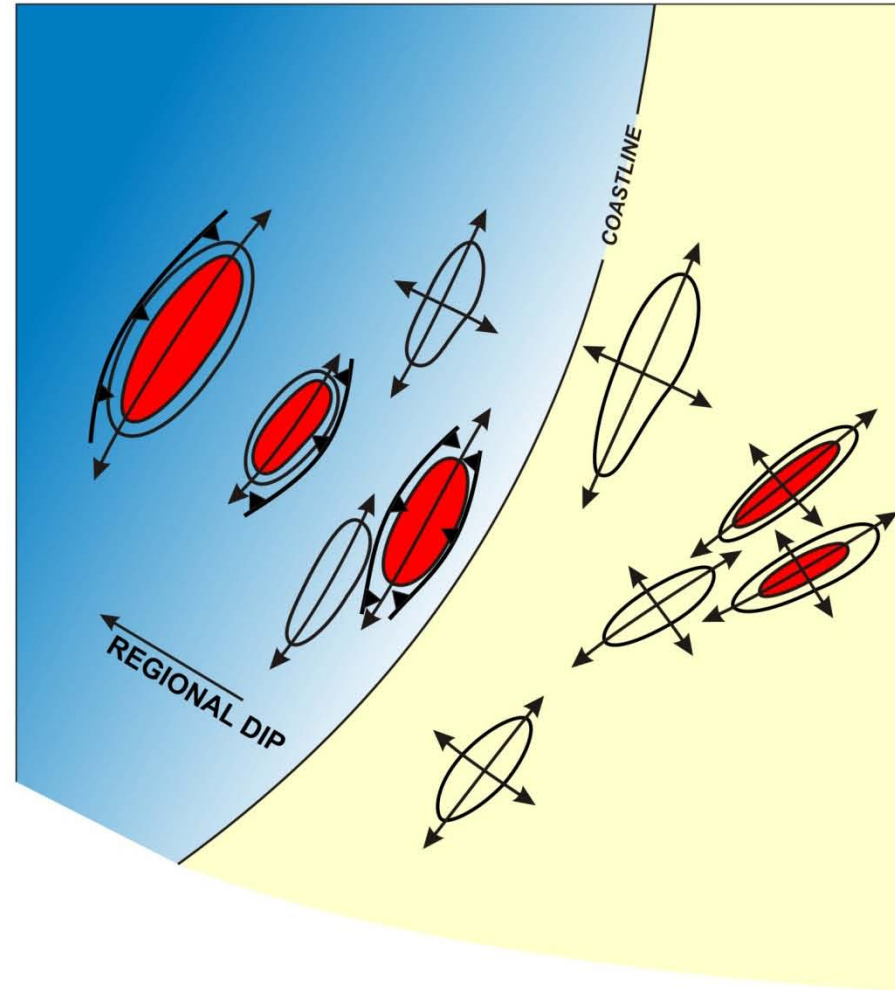
# Inversion trend versus present-day coastline

## MOROCCO



NOT TO SCALE

## LEVANT



# Acknowledgements

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**GSI (Houston)**  
**OMV (Vienna)**  
**ONHYM (Rabat)**



*Typical surface anticline, western High Atlas, Morocco*