

# **Early Post-Salt Differential Topography and Its Impact on Source Rock and Shallow-Water Carbonate Facies Distributions: Examples from the Jurassic of the North Atlantic and the Southern Gulf of Mexico\***

**Rob Forkner<sup>1</sup> and Nick Ettinger<sup>2</sup>**

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<sup>1</sup>Statoil, Austin, Texas ([rfork@statoil.com](mailto:rfork@statoil.com))

<sup>2</sup>Jackson School of Geosciences, The University of Texas at Austin, Austin, Texas

## **Abstract**

A major risk to successful exploration efforts is the accurate prediction of source rock and reservoir presence. In many Mesozoic passive margin systems, differential subsidence related to early salt movement exerts a primary control on setting up both small, restricted basin centers and local highs allowing for both source rock and shallow-water carbonate deposition. This depositional motif is common in the Jurassic along much of the North Atlantic and Gulf of Mexico (GoM) margins. An integrated scheme utilizing organic geochemical, geophysical, and geological methods clarifies these relationships.

Organic geochemical characterization of samples from early post-salt restricted basin settings yields similar characteristics. Pristane/phytane ratios are usually very low (often <0.5, likely related to hypersaline conditions), C<sub>35</sub>/C<sub>34</sub> ratios are high (related to stratified waters), and C<sub>29</sub> steranes are abundant (common in carbonate-prone SR). In addition, unique diamondoid distributions likely relate to diamondoid formation within evaporite-prone settings.

Geometries observed in reflection seismic often include locally faulted basins linked to basement or salt-related movement. Infill is typically in the form of a sedimentary wedge that thickens towards the basin center and is rapidly overlapped by subsequent sedimentation. Bright reflections associated with rapidly changing composition of fill may include increasing

negative amplitude toward the center of each sub-basin, often including AVO class 4 anomalies. Bounding edges of sub-basins may exhibit mounded or shingled geometries related to deposition of shallow water carbonates. These geometries are indicative of a genetic link between sub-basin formation and fill by a complex facies mosaic - from restricted, organic-rich facies in the deepest centers to shallow-water carbonates along the rims.

Conceptual stratigraphic models for these intervals must include limited, but predictable geographic extent for facies deposited in early post-salt systems. Source rock must be considered to be locally ponded and linked to timing of salt movement. Carbonate facies distribution is controlled by local topography provided by both basement and salt-related structures. Dynamic salt-related topography also provides both barriers and catchments for sediment routing in mixed carbonate/siliciclastic systems.

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# AAPG

## Early Post-Salt Differential Topography and Its Impact on Source Rock and Shallow-Water Carbonate Facies Distributions: Examples From the Jurassic of the North Atlantic and the Southern Gulf of Mexico

Rob Forkner and Nick Ettinger



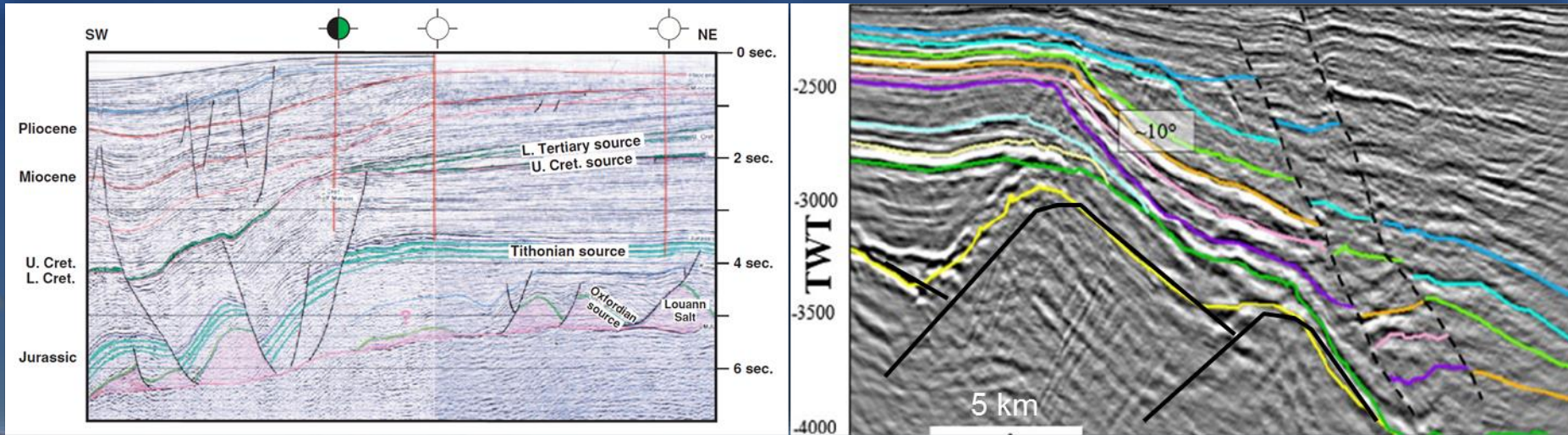
Statoil



ACE 101: Bridging Fundamentals and Innovation

# Post-rift differential topography

- Structural/halokinetic differential topography is a fundamental control on the distribution of carbonate and source rock facies

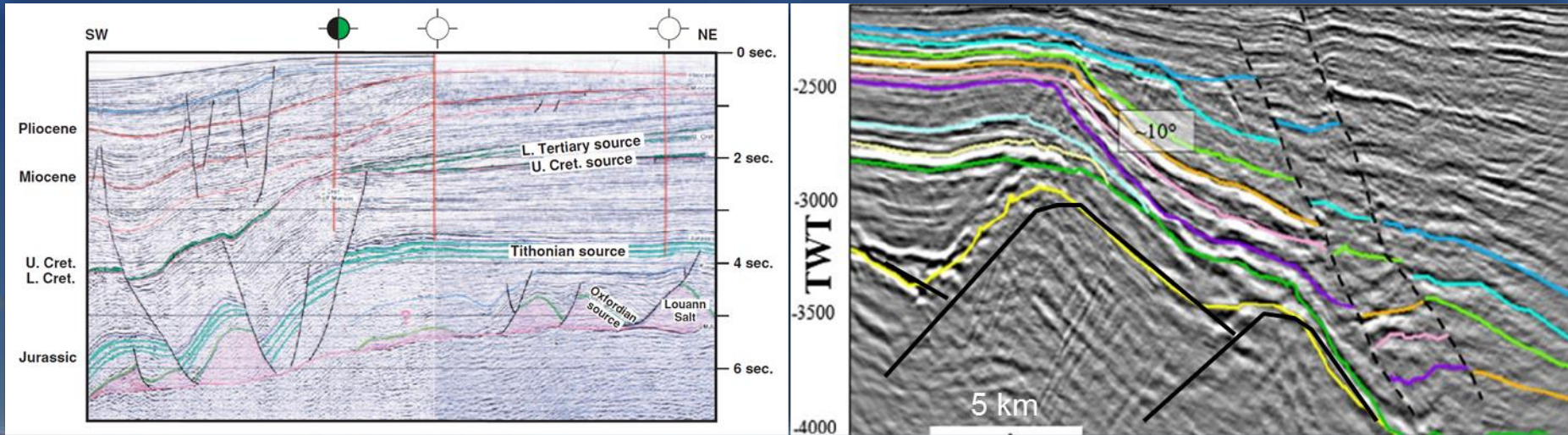


Hood et al., (2002)

Campbell, 2018

# Post-rift differential topography

- Taken holisitically, the components of these systems can be considered linked
  - Facies transitions from highs (carbonates) to lows (source).
  - Basin restriction promotes hypersalinity, oolitic prone ramps and diagenetic fluids, and discrete SR development.

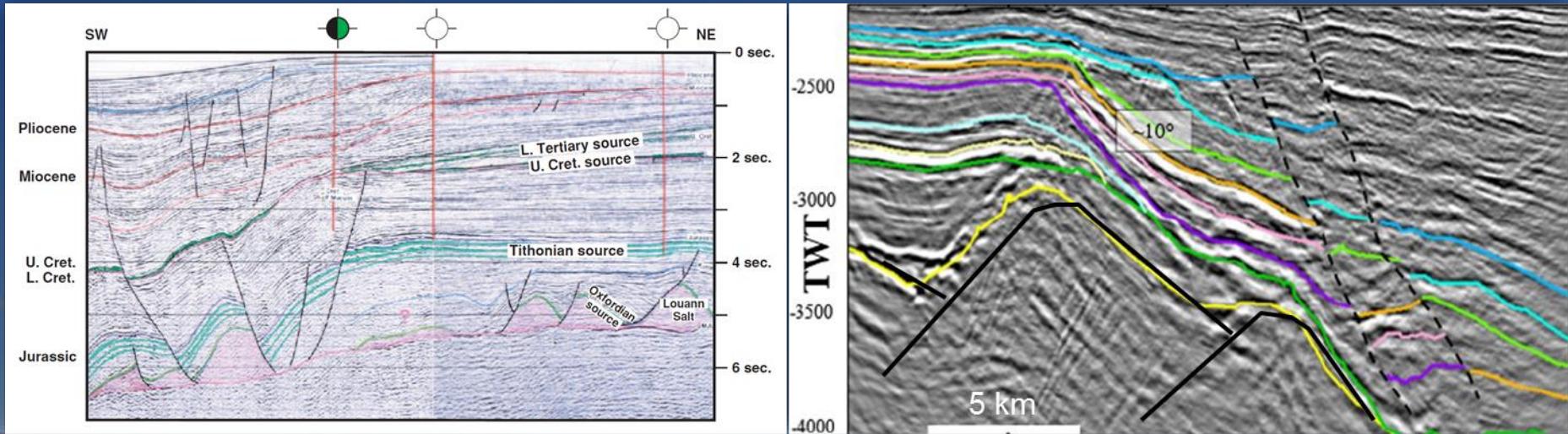


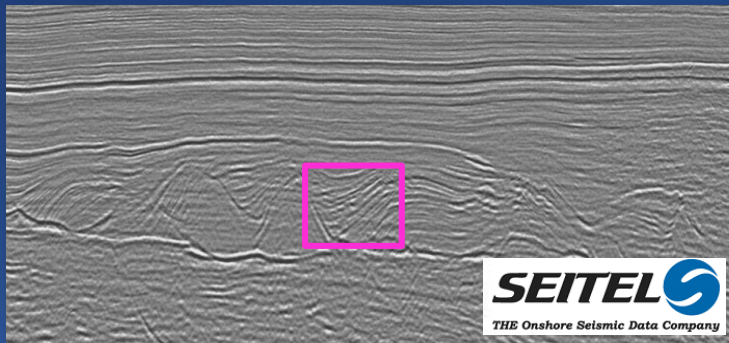
Hood et al., (2002)

Campbell, 2018

# Post-rift differential topography

- As carbonate stratigraphers, it is incumbent upon us to consider the impacts of environment on the overall biogeochemical system and resultant lithologies





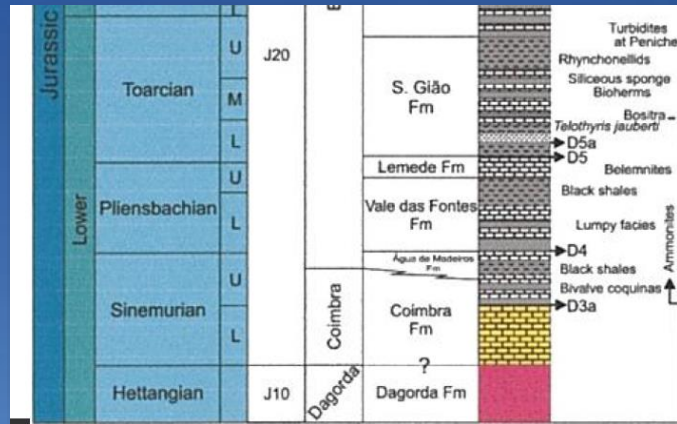
## What kind of facies transitions should we expect? Outcrop Analog: Oxfordian of Morocco

Assif El Hade section, near Tirzi, Morocco.

- Rapid facies changes into salt withdrawal minibasin.
- Callovian-Oxfordian age.
- Dark, restricted-type facies are observed in the central portion of the sediment wedge. Infill is capped by dolomitized reefal facies.



# What kind of facies transitions should we expect?

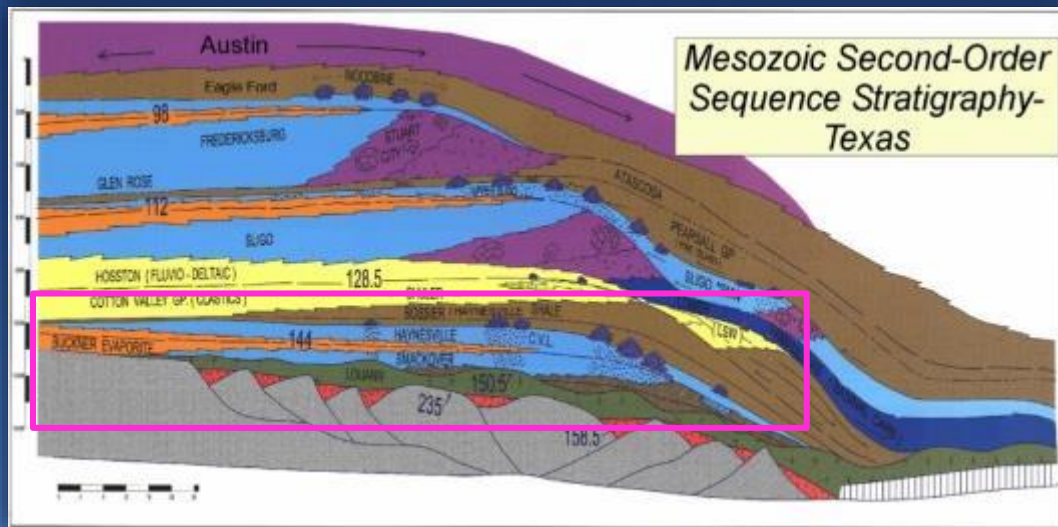
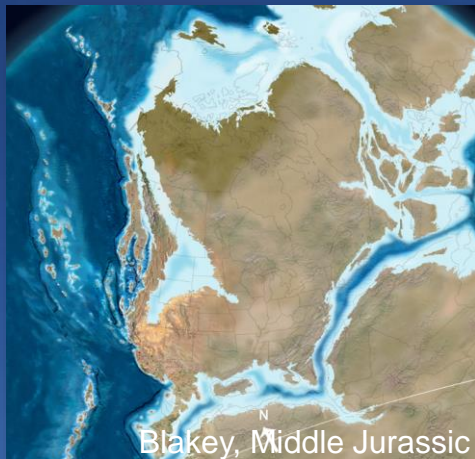


Soares and Duarte, 1997

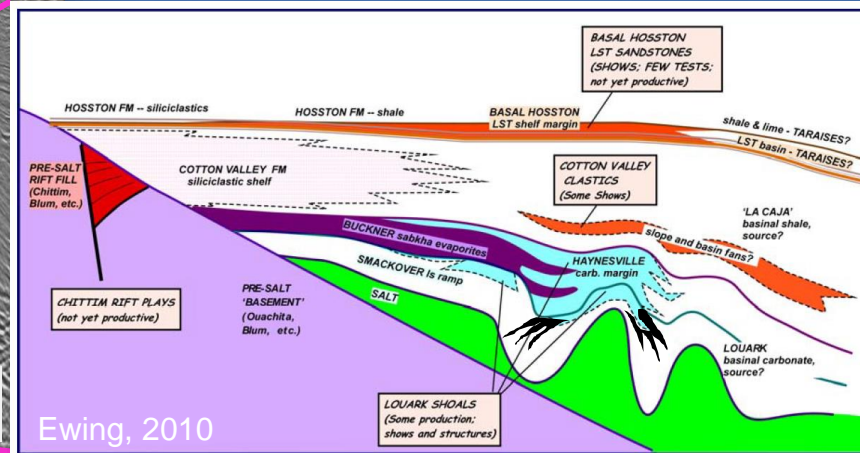
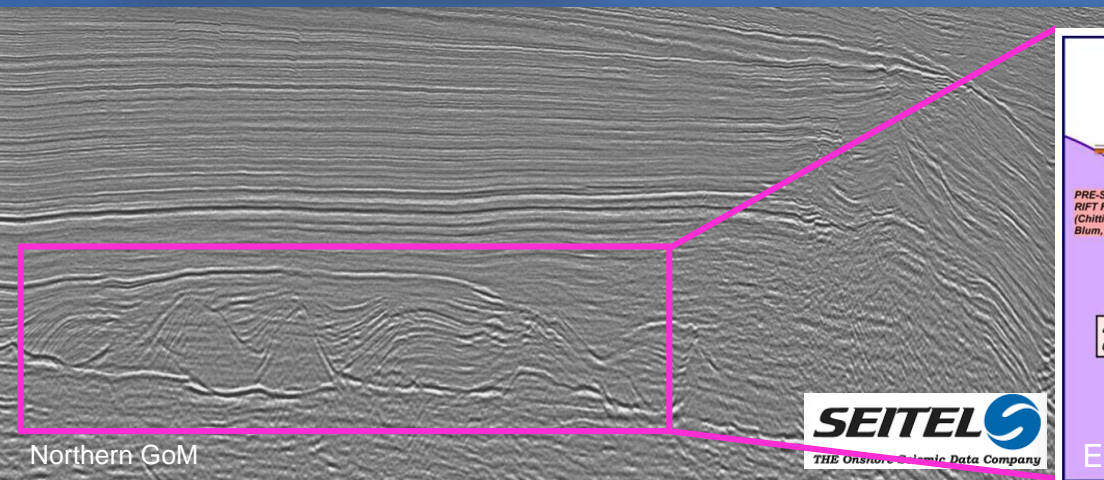
## Praia Velha, Portugal.

- Hettangian Dagorda evaporite contact with Sinemurian lower Coimbra Fm. Carbonates
- Rapid facies changes (few meters to 10s of meters)
- Interbedded carbonates, marls, and shales predominate the source-prone interval

# Example: Oxfordian of GoM



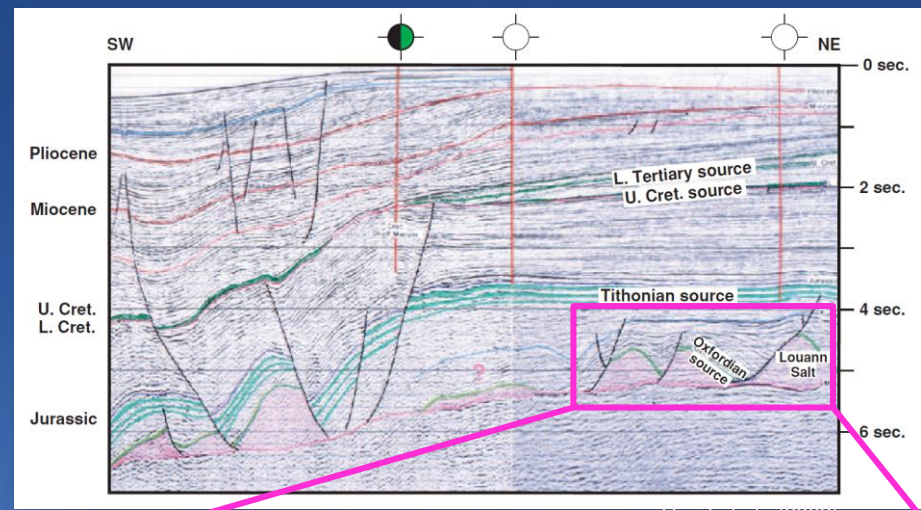
Goldhammer (1999)



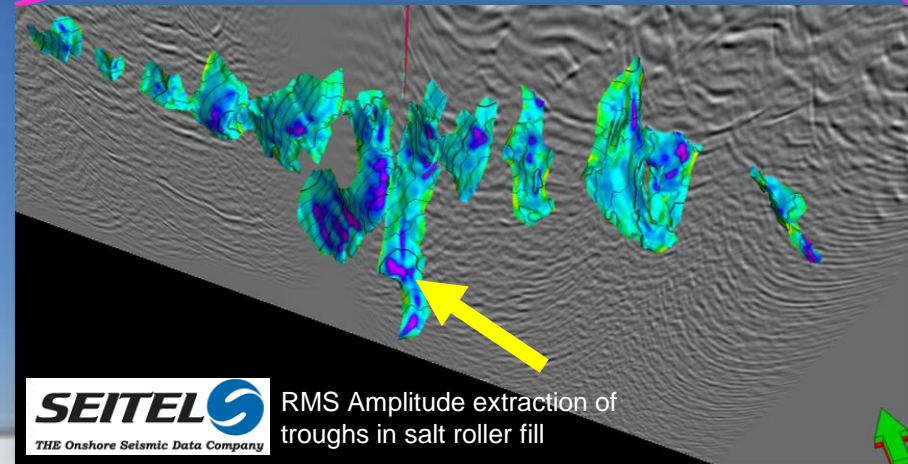
Ewing, 2010

# Mini basins related to salt withdrawal are absolutely critical to GoM Jurassic SR thickness and richness:

- Presence of highest amplitude reflection in mini-basin lows is suggestive of a link between basin geometry and reflection
- Oxfordian (Smackover / Santiago) mini basin center: 7.23% TOC; mini basin margin: 0.85% TOC
- Kimmeridgian (Haynesville / Taman) mini basin center: 5.23% TOC; mini basin margin: 0.66% TOC
- Tithonian (Bossier / Pimienta) mini basin center: 4.6% TOC (high-volatility flowing oil); mini basin margin <1% TOC. Jarvie, (2017)
- Basins range from 2-10 km wide, and ca. 2km long



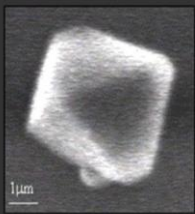
Hood et al., (2002)



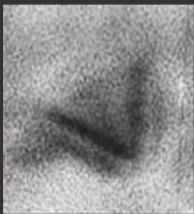
# Biomarkers and Diamondoids



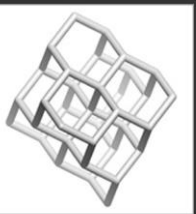
Diamond



Micro-crystalline



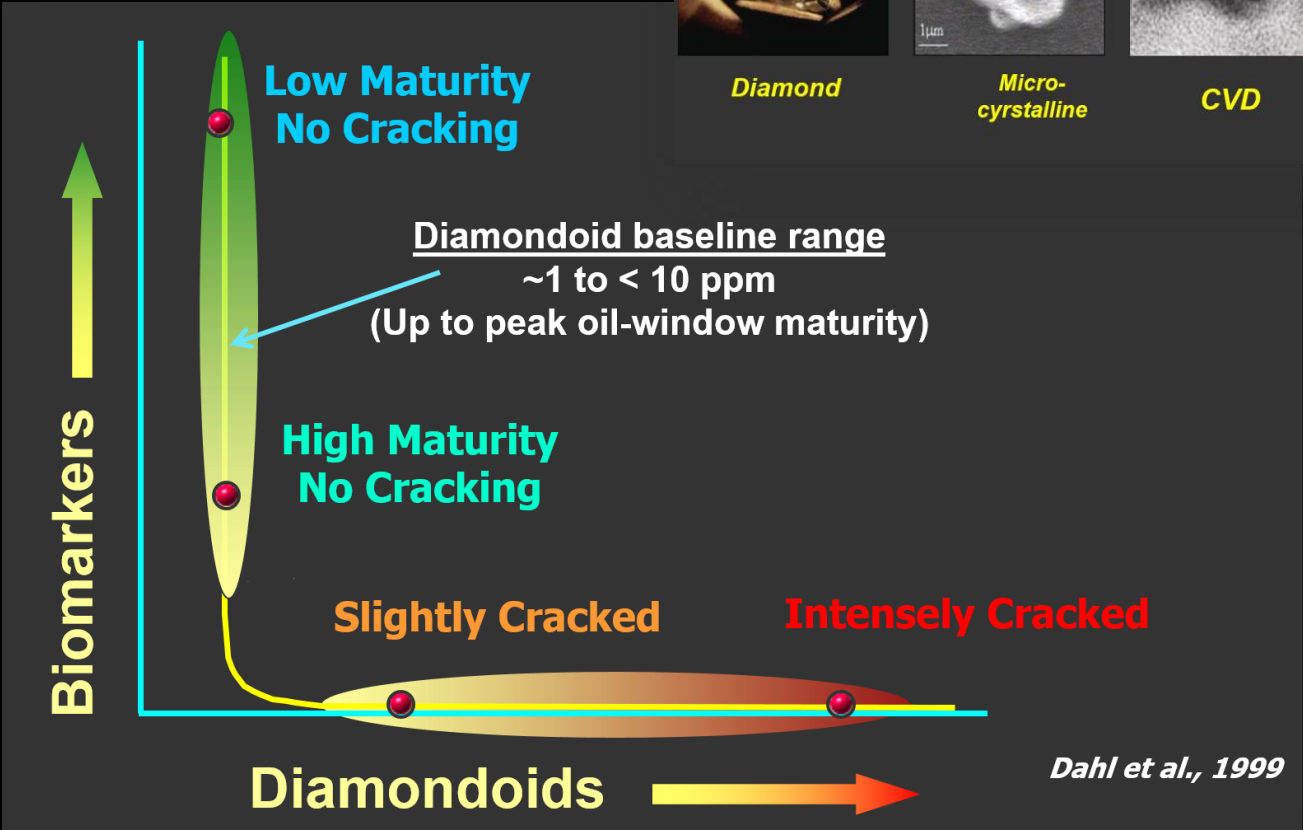
CVD

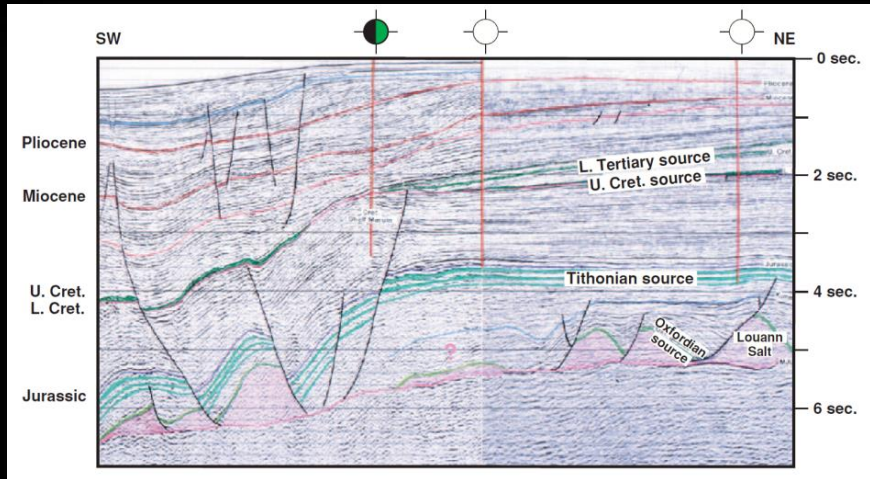


Higher Diamondoid  
0.5-2nm



Adamantane





Hood et al., (2002)

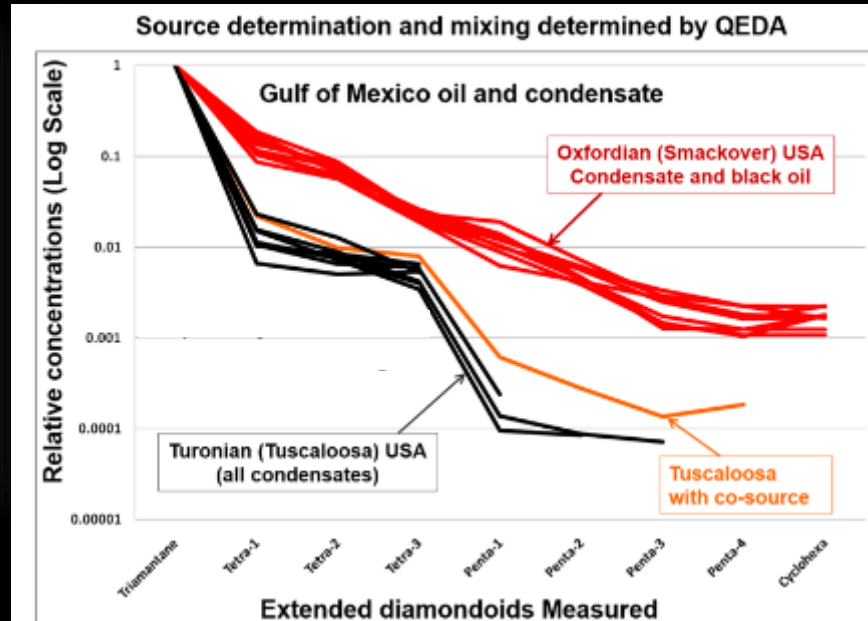
## Compiled general Jurassic HC Characteristics from GoM as related to source

**Oxfordian:** Likely marly SR deposited in restricted, hypersaline environment

- Pristane/phytane ca. 0.6;  $\leq 1$  usually indicates anoxia;  $< 0.5$  typically indicates contribution of phytane from halophilic bacteria (hypersaline conditions)
- Very high  $C_{35}/C_{34}$  ratios;  $C_{35}$  hopanes form via bacteria in anoxic, stratified waters
- Low extended tricyclic terpane ratio ( $< 1$ , likely Upper Jurassic age)
- Presence of 29, 30 bisnorhopane; can be high in reducing environments
- High abundance of  $C_{29}$  steranes as compared to  $C_{27}$ ; likely marine algal input from carbonate-prone source

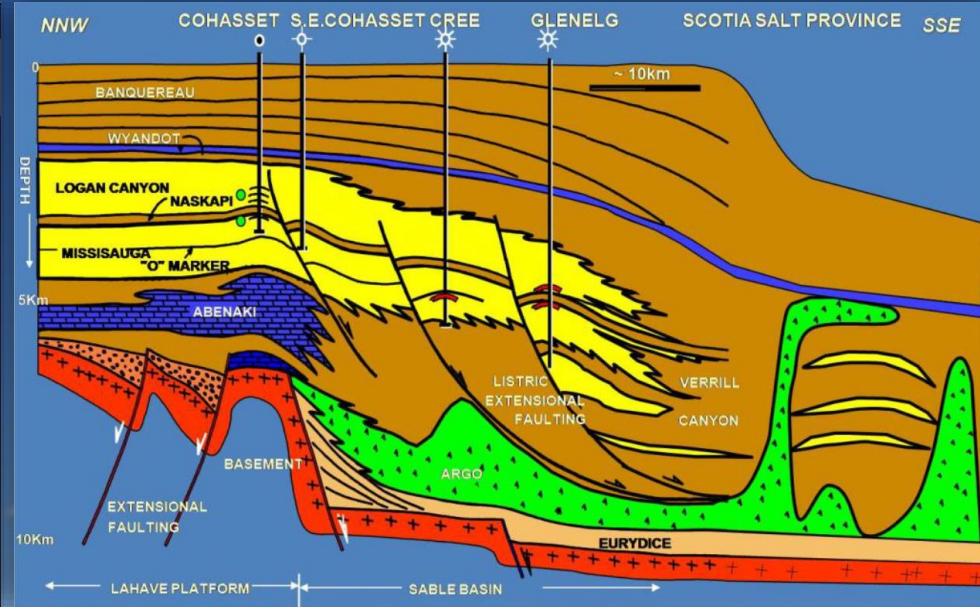
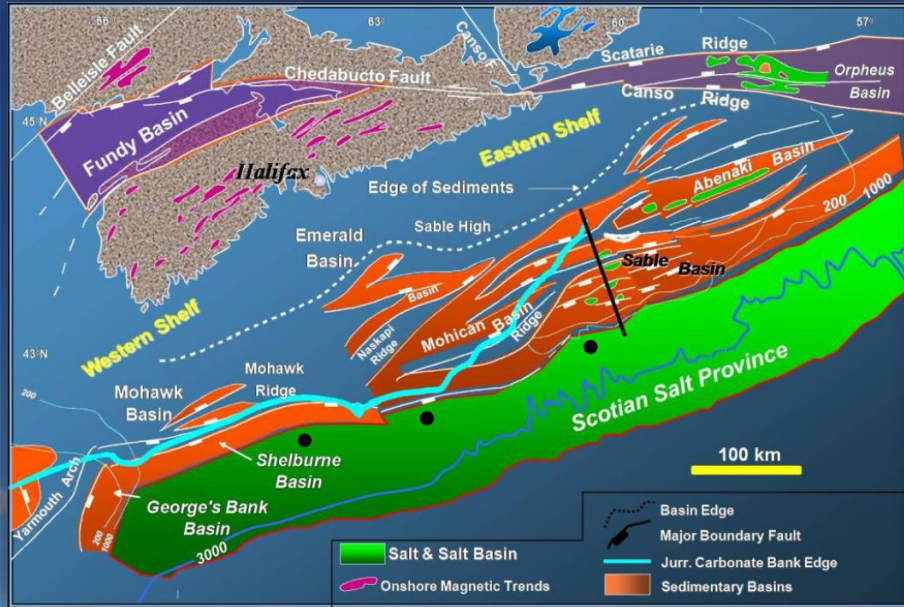
**Tithonian:** Likely organic-rich shaly limestone SR; less restricted than Oxfordian

- Pristane/phytane ca. 0.8-1.2;  $\leq 1$  usually indicates anoxia
- $C_{35}/C_{34}$  ratio  $> 1$ ;  $C_{35}$  hopanes form via bacteria in anoxic, stratified waters
- Low extended tricyclic terpane ratio ( $< 1$ , likely Upper Jurassic age)
- High  $C_{29}/C_{30}$  ratios, typical of organic-rich carbonate SR



Moldowan, Biomarkers, Inc.

# Structural/stratigraphic framework of the Scotian Basin



Enachescu et al. 2010

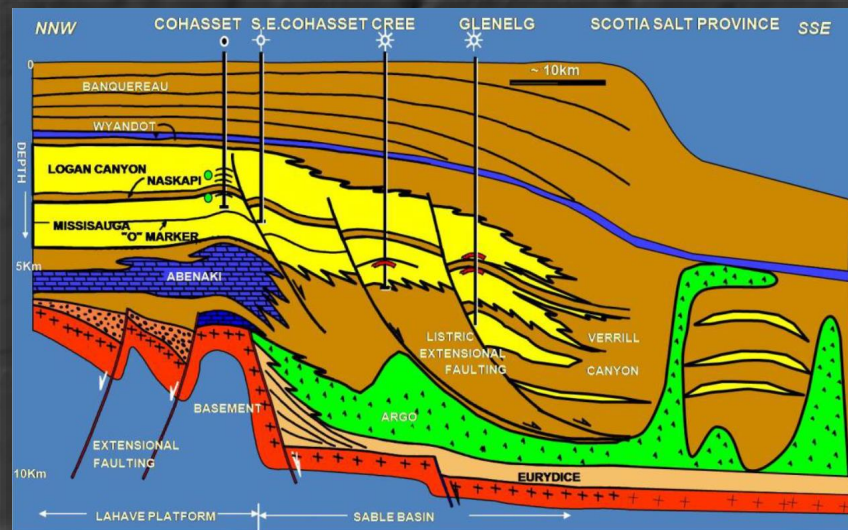
# Organic Geochemical Characterization of Oil Samples

- 2. Balmoral
- 3, 4. Cohasset
- 6. Panuke
- 1. Alma
- 7. Sable Island
- 5. Intrepid
- 8. Venture

Aspy

Cheshire

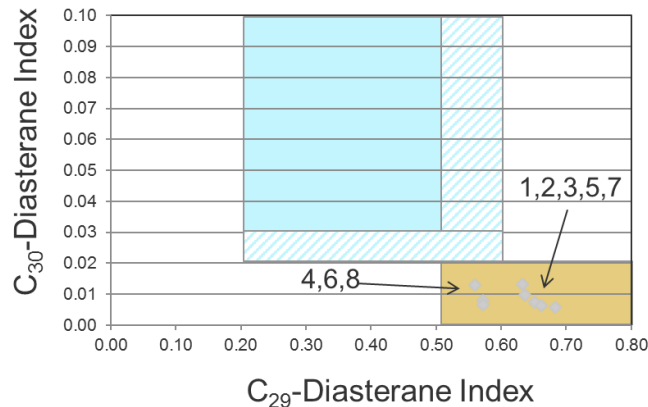
Monterey Jack



250000m

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Sterane data from Deep Panuke and Sable fields indicates a mixed marine/non-marine shale typical of a deltaic source



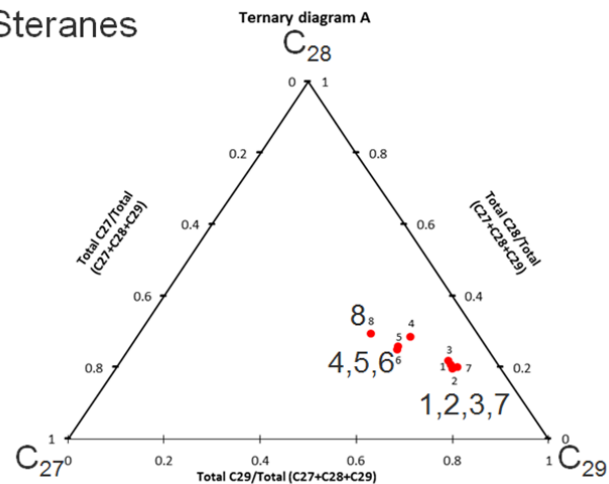
Typical marine

Restricted marine or mixed terrestrial/marine

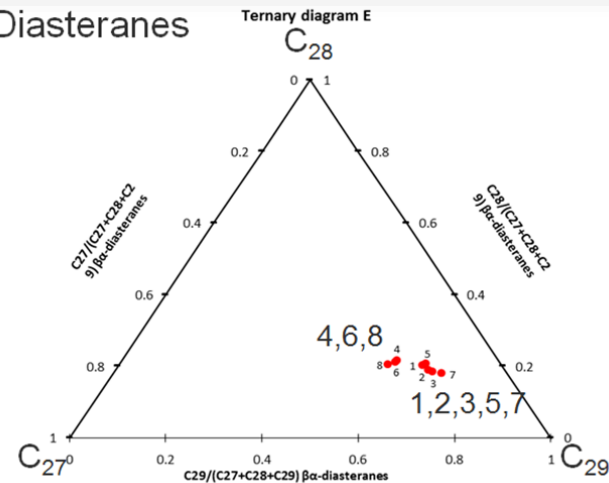
Typical deltaic – or terrestrial/marine mix

250000m

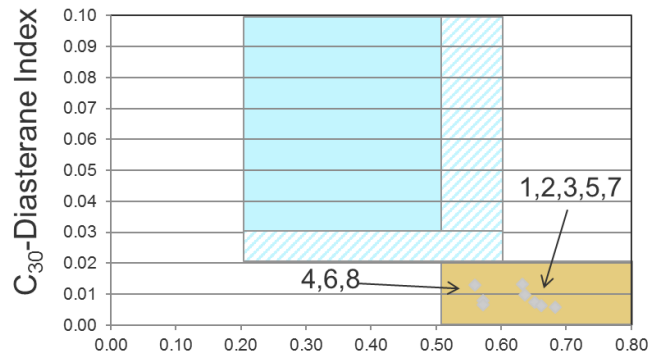
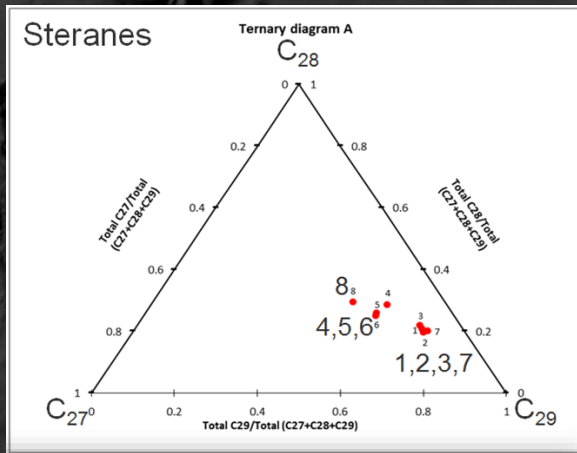
## Steranes



## Diasteranes



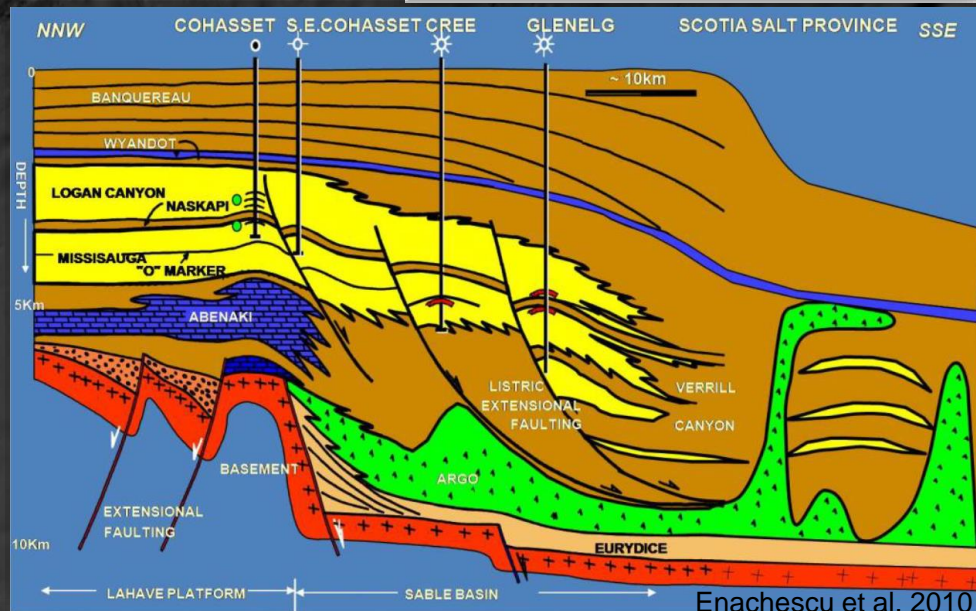
Sterane data from Deep Panuke and Sable fields indicates a mixed marine/non-marine shale typical of a deltaic source



$C_{29}$ -Diasterane Index

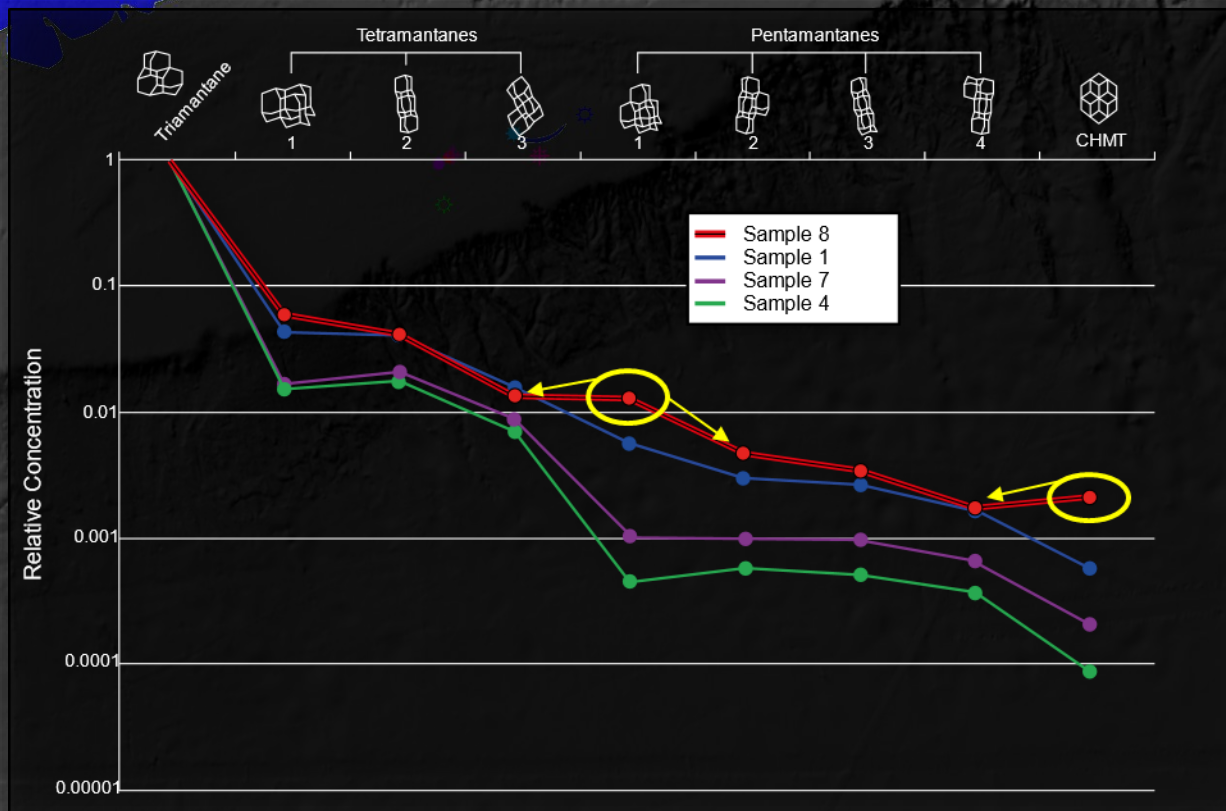
- Typical marine
- Restricted marine or mixed terrestrial/marine
- Typical deltaic – or terrestrial/marine mix

250000m

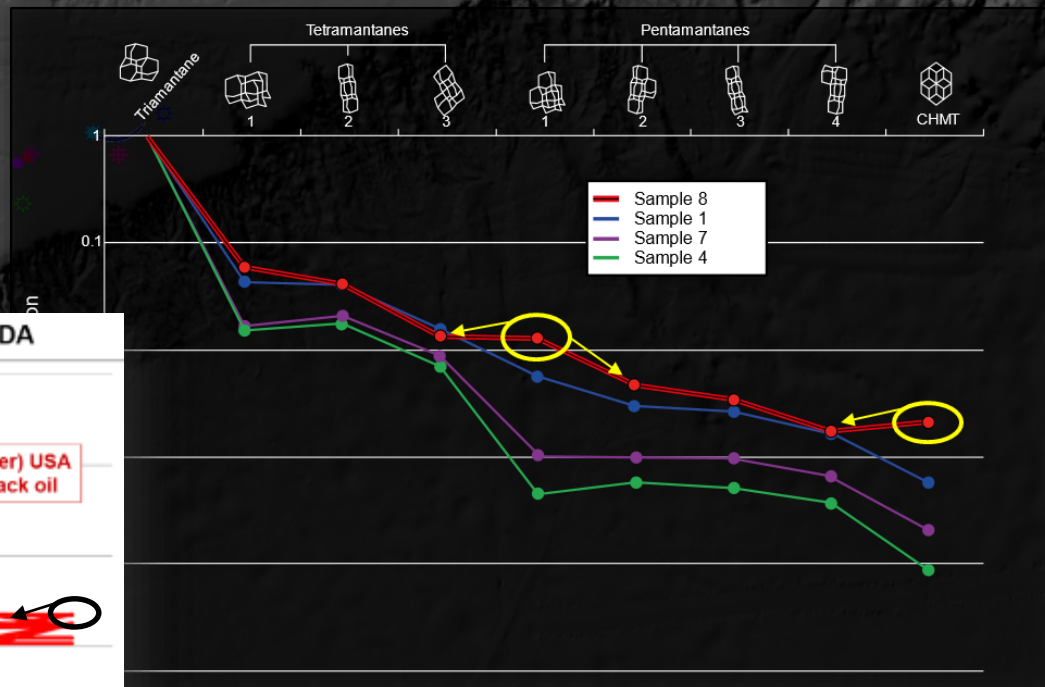


Enachescu et al. 2010

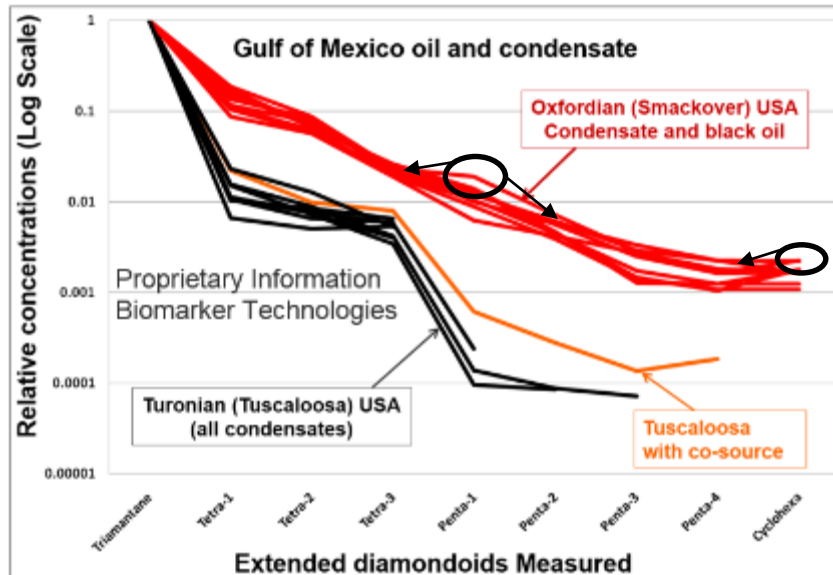
# Quantitative Extended Diamondoid Analysis



# Quantitative Extended Diamondoid Analysis



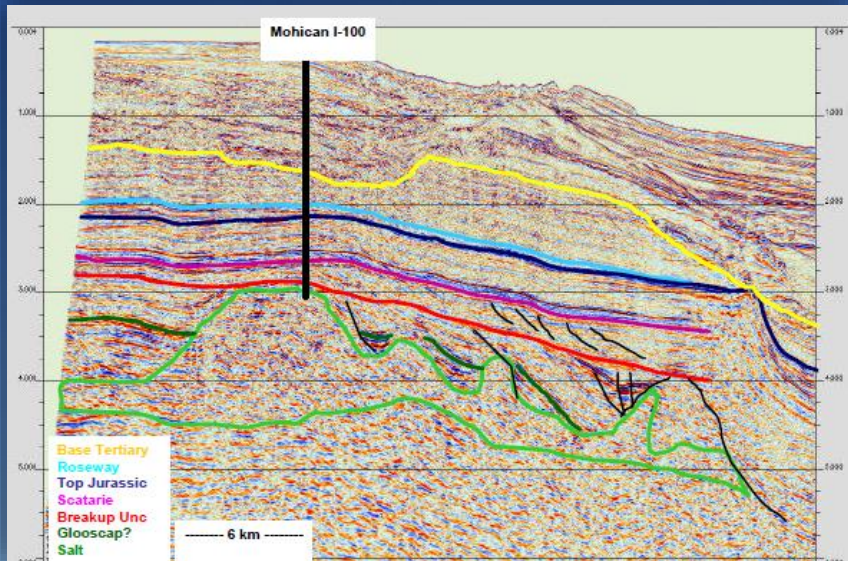
Source determination and mixing determined by QEDA



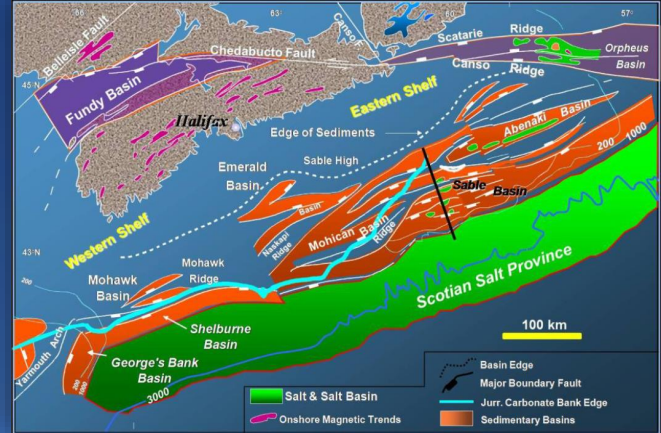
# Post-rift differential topography

NNW

SSE

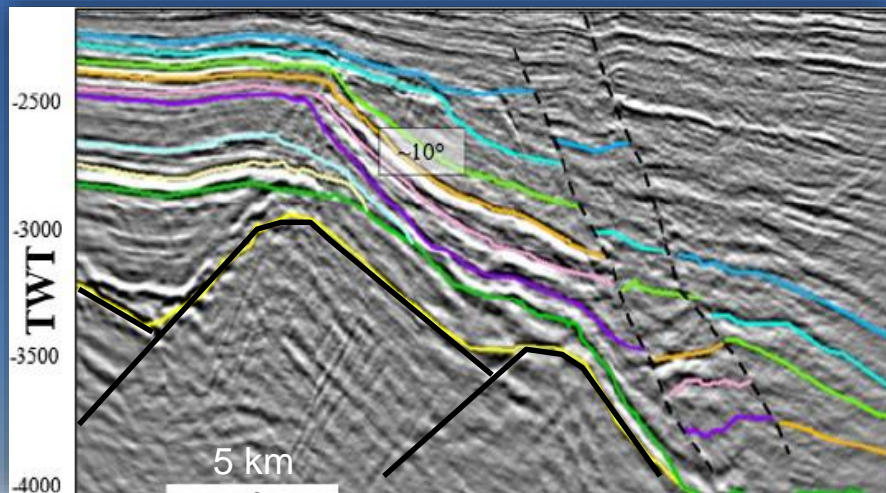


C-NSOPB Report, 2005



NNW

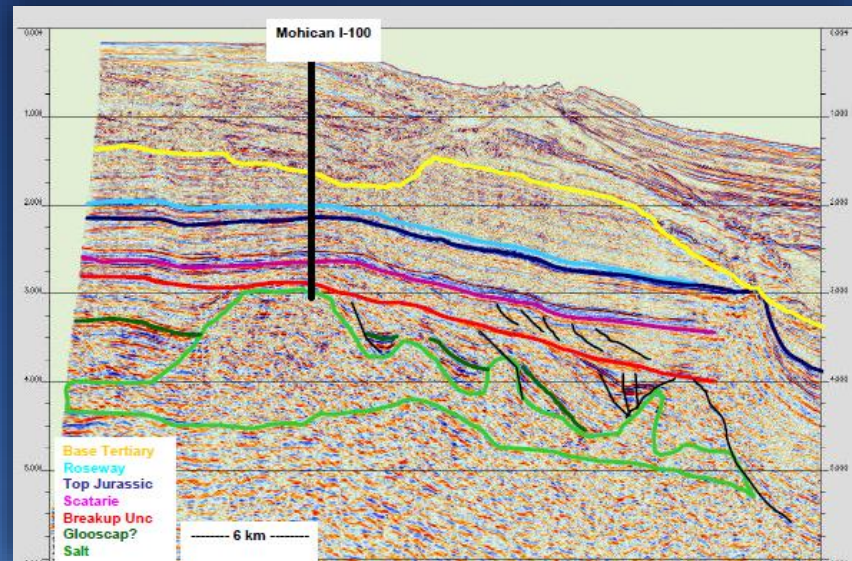
SSE



Campbell, 2018

NNW

SSE

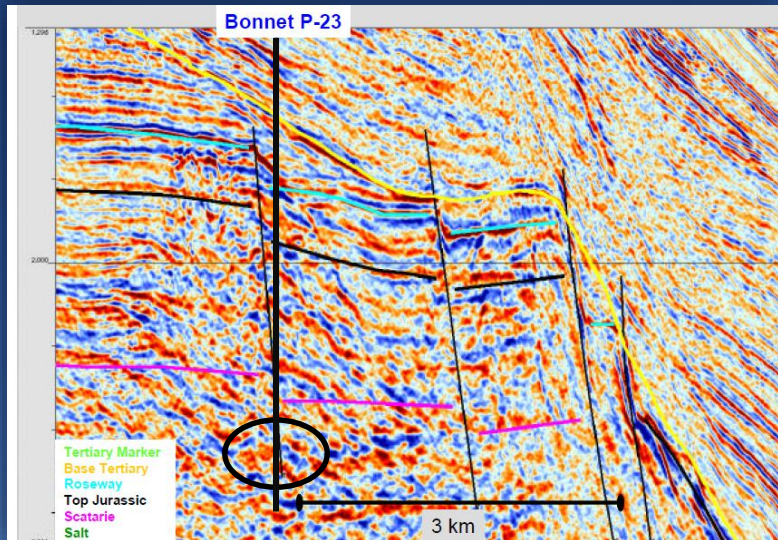


Sulphur isotopic composition of Mohican Eurydice Fm. match that of H<sub>2</sub>S in Deep Panuke

C-NSOPB Report, 2005

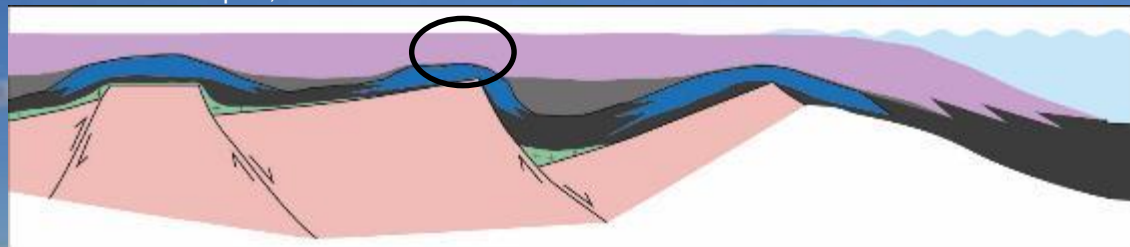
NNW

SSE



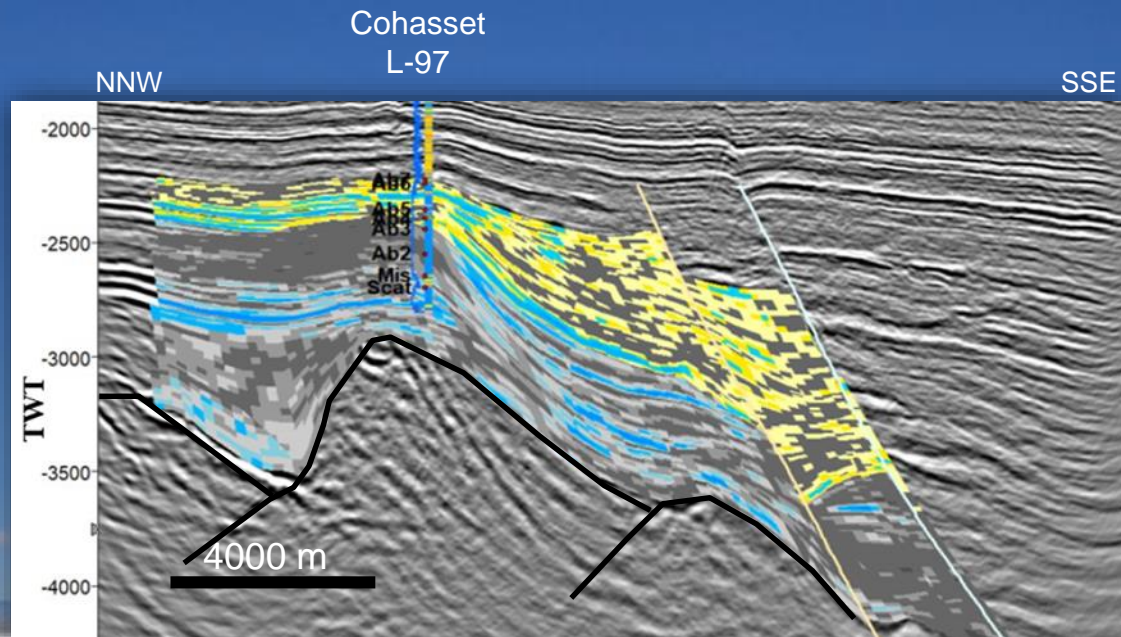
C-NSOPB Report, 2005

Oil Staining in Lower  
Jurassic of Bonnet P-23

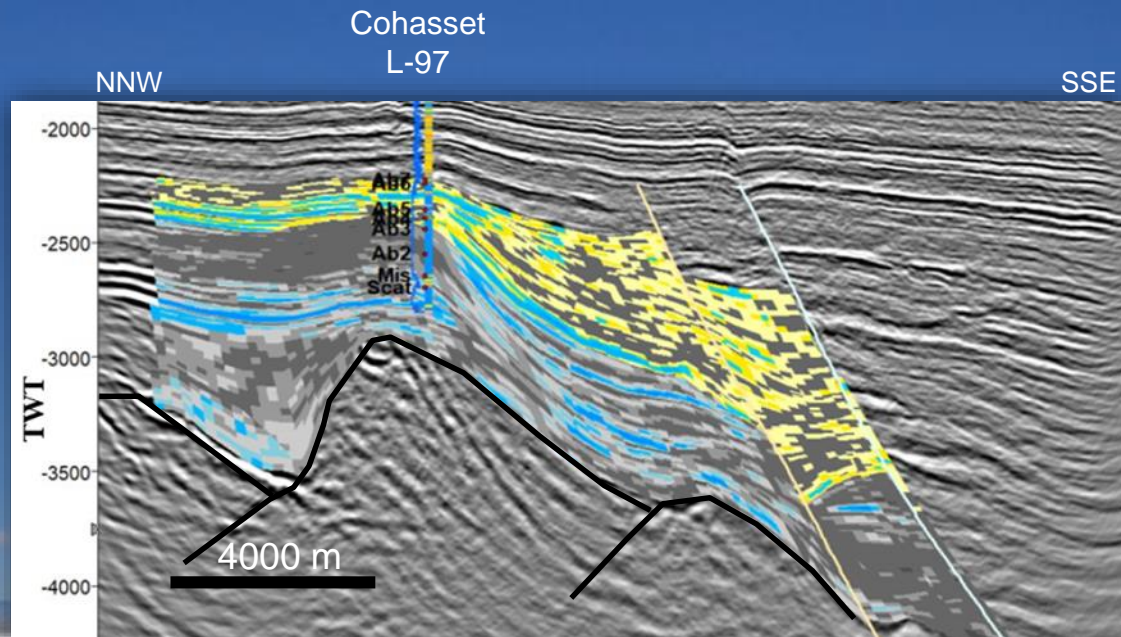


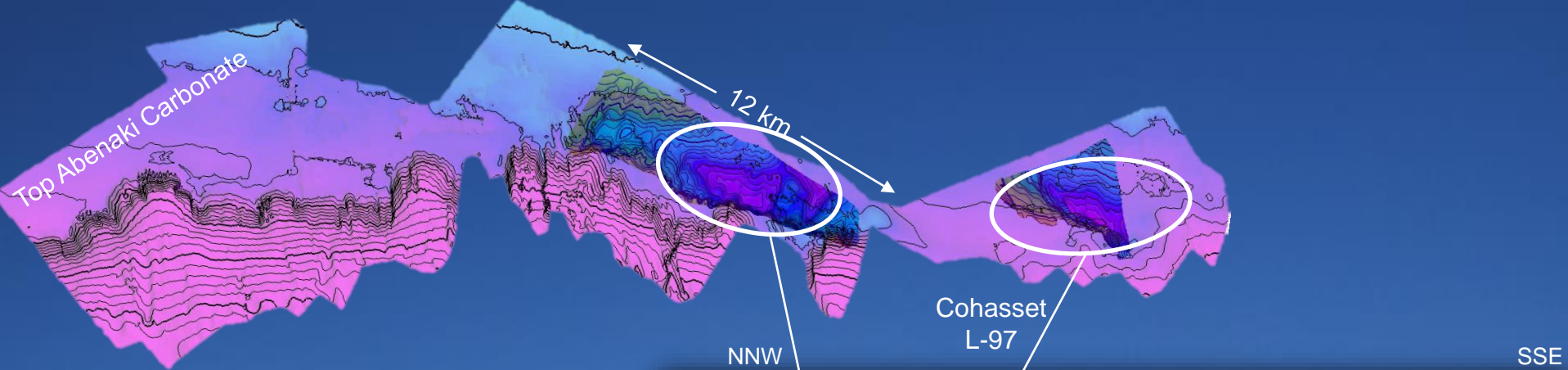
Modified after Weissenberger et al. 2006

# Geocellular model with seismic inversion input

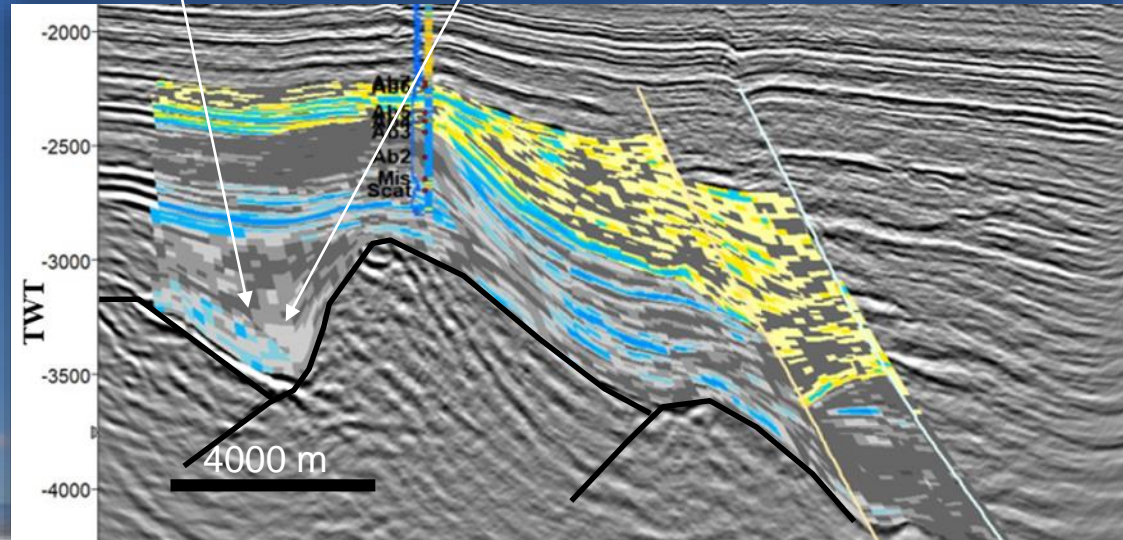


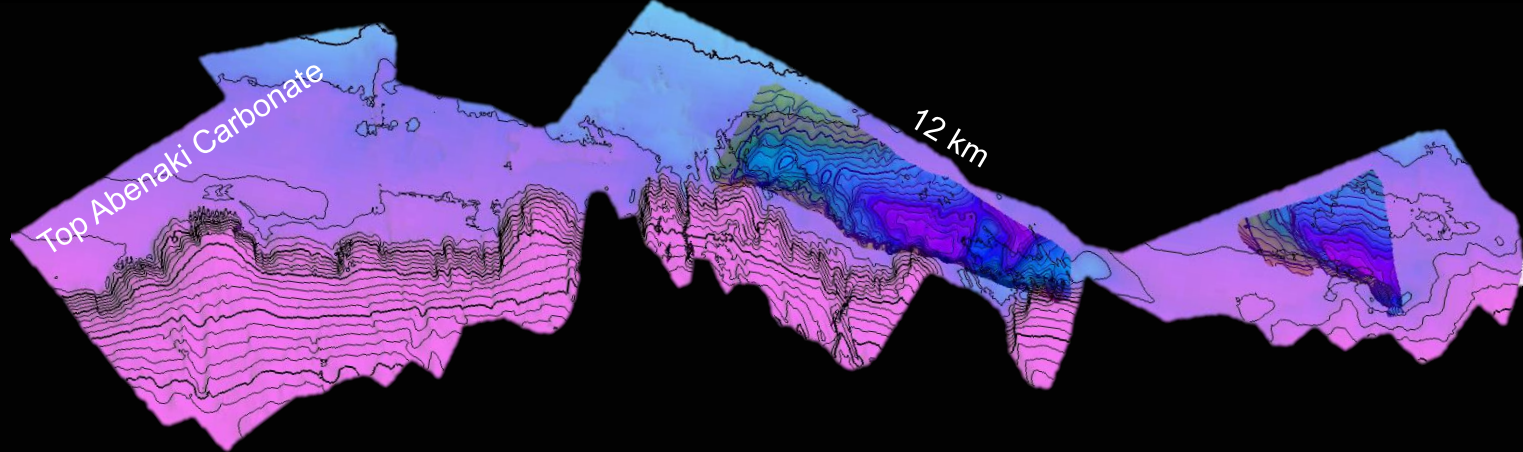
# Geocellular model with seismic inversion input





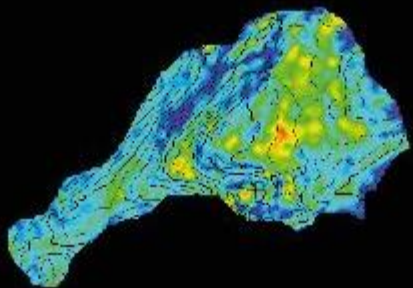
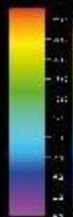
Statoil interpretation





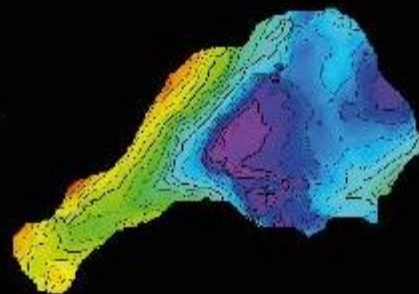
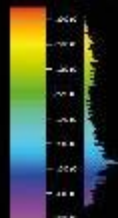
Instant.  
Amp.

Instant. Amplitude (mV) vs. Time (s)  
Scale: 1 mV = 100 nV, 1 s = 100 ms



TWT  
Structure

Two-Way Time (s) vs. Distance (m)  
Scale: 1 s = 100 ms, 1 m = 100 m



25.00 m

25.00 m

# Thoughts

- Inherent structural and/or halokinetic differential topography is a fundamental control on the distribution of carbonate and source rock facies
- Taken holisitically, the components of these systems can be considered linked:
  - Facies transitions from highs (carbonates) to lows (source)
  - Basin restriction promotes hypersalinity, oolitic prone ramps and diagenetic fluids, discreet SR development,
- Historically, these systems have rarely been considered part of a single genetic system. As carbonate stratigraphers, it is incumbent upon us to consider the impacts of environment on the overall biogeochemical system and resultant lithologies

# Thoughts

- In these particular contexts, we ought to consider the source system in the context of hypersaline restriction and rapid subsidence of what would otherwise be shallow water carbonate facies
- It does no good to think of these facies as some sort of offshore member of a sequence stratigraphic model, or to ignore them
- in any of these cases the facies transitions can be remarkably rapid and place source facies in close stratigraphic proximity to reservoir
- If we as carbonate sedimentologists are doing a more complete job we'd be looking at the restricted source facies as a component of the broader depositional system

# Acknowledgements

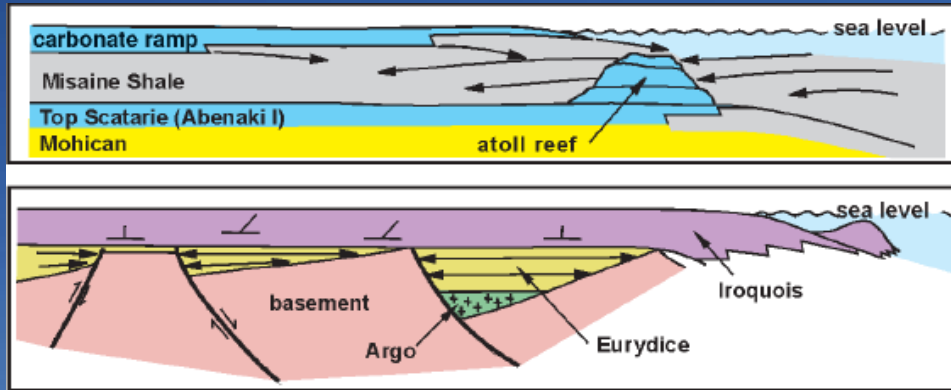
Statoil / Equinor: John Cody, Jennifer Young, Andrea Fildani, Lorena Moscardelli, Ian Lunt, Laura Zahm, Ian Sharp

Biomarkers, inc.,: Mike Moldowan, Jeremy Dahl

University of Coimbra: Luis Duarte

Seitel

# What kind of facies transitions should we expect?



Weissenberger et al. 2006

