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*

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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), C₃₅/C₃₄ ratios are high (related to stratified waters), and C₂₉ 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.

References Cited


Surface exploration case histories: Applications of geochemistry, magnetics, and remote sensing, AAPG Studies in Geology No. 48 and SEG Geophysical References Series No. 11, p. 25-40.


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

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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 holistically, 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

Hood et al., (2002)  
Campbell, 2018
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 reeval facies.
What kind of facies transitions should we expect?

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

Northern 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
Biomarkers and Diamondoids

Diamondoid baseline range
~1 to < 10 ppm
(Up to peak oil-window maturity)

Dahl et al., 1999
Complied general Jurassic HC Characteristics from GoM as related to source

Oxfordian: Likely marly SR deposited in restricted, hypersaline environment
- Pristane/phytane ca. 0.6; ≤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; ≤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
Structural/stratigraphic framework of the Scotian Basin

Enachescu et al. 2010
Organic Geochemical Characterization of Oil Samples
Sterane data from Deep Panuke and Sable fields indicates a mixed marine/non-marine shale typical of a deltaic source.
Sterane data from Deep Panuke and Sable fields indicates a mixed marine/non-marine shale typical of a deltaic source.
Quantitative Extended Diamondoid Analysis
Quantitative Extended Diamondoid Analysis

Source determination and mixing determined by QEDA

Gulf of Mexico oil and condensate

Relative concentrations (Log Scale)

- Oxfordian (Smackover) USA Condensate and black oil
- Tuscaloosa with co-source

Extended diamondoids Measured

Biomarker Technologies

Proprietary Information
Post-rift differential topography

C-NSOPB Report, 2005

Campbell, 2018
Sulphur isotopic composition of Mohican Eurydice Fm. match that of H2S in Deep Panuke

C-NSOPB Report, 2005
Oil Staining in Lower Jurassic of Bonnet P-23
Geocellular model with seismic inversion input
Geocellular model with seismic inversion input

Dolomitized bioherm
Dolomitized grainstones
Organic-rich mudstones and wackestones
Decreasing dip

Cohasset L-97

4000 m

Campbell, 2018
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
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Seitel
What kind of facies transitions should we expect?

Weissenberger et al. 2006

C-NSOPB Report, 2005