Depositional Controls and Sequence Stratigraphy of Lacustrine to Marine Transgressive Deposits in an Active Rift Basin, Lower Cretaceous Bluff Mesa, Indio Mountains, West Texas*

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Abstract

Successful hydrocarbon exploration in former rift basins of the South Atlantic pre-salt has generated interest in understanding depositional, diagenetic, and stratigraphic controls on pre-salt deposits. However, most studies to date have focused on attributes and controls on pre-salt lacustrine carbonate reservoir systems and little work has been done on the overlying marine sealing facies. Currently our standard sequence stratigraphic model of marine transgression of rift systems involves a single pulse of marine flooding over fluvially incised valleys resulting in backstepping of fluvial and estuarine siliciclastic facies within the erosionally confined zone of an incised valley. However, the pre-salt systems of the South Atlantic involve deep and broad alkaline lakes containing microbial carbonate facies that were deposited on rift structurally generated geomorphic surfaces. Using an outcrop analogue, this study aims to provide a depositional and stratigraphic model for marine transgression of lacustrine rift basin sediments that are similar in age, tectonic regime, and climatic setting to the pre-salt sealing facies of the South Atlantic.

The Lower Cretaceous Bluff Mesa Formation was deposited on the eastern margin of the Chihuahuan Trough failed rift and is exposed within multiple Laramide-age thrust panels in the Indio Mountains of West Texas. The mixed carbonate-siliciclastic system thins from 360m to 220m across the study area and contains six fourth-order sequences that record the transition from fluvio-lacustrine to shallow marine deposition. Sequences 1-2 are characterized by lacustrine siltstones or thin marine wackestones during highstands and fluvial-lacustrine sandstones during lowstands. Sequences 4-6 are composed of exclusively marine facies characterized by thick ooid grainstones and fossiliferous packstones deposited during highstands and shoreface to shelfal sandstones during lowstands. Sequence 3 records a significant rise in base level and the onset of marine deposition with lowstand fluvial sandstones overlain by thick marine carbonates during highstand. The presence of thin marine limestones in sequences 1and 3 suggest that periodic marine incursion occurred during highstands but the basin was still primarily an enclosed rift lake. This idea is supported by analysis of carbonate-associated sulfate from septarian nodules of lacustrine and marine origin. The observed succession of mixed terrestrial-marine sequences suggests transgression of rift basins involves multiple pulses.
References Cited

Blakey, R.C., 2003, Detailed Paleogeography Maps: online resources available at the University of Northern Arizona Department Of Geology, URL:https://www2.nau.edu/rcb7/globaltext2.html.


Abstract

Successful hydrocarbon exploration in former rift basins of the South Atlantic pre-salt has generated interest in understanding deposition, diagenesis, and stratigraphic controls on pre-salt deposits. However, most studies to date have focused on attributes and controls on pre-salt lacustrine carbonate reservoir systems, and little work has been done on the overlying marine shallowing facies. Currently our standard sequence stratigraphic model of marine transgression of rift systems involves a single pulse of marine flooding over fluvially incised valleys resulting in backstepping of fluvial and estuarine siliciclastic facies within the extensionally confined zone of an incised valley. However, the pre-salt systems of the South Atlantic involve deep and broad alkaline lakes containing microbial carbonate facies that were deposited on rift structurally generated geomorphic surfaces. Using an outcrop analogue, this aims to provide a depositional and stratigraphic model for marine transgression of lacustrine rift basin sediments that are similar in age, tectonic regime, and climatic setting to the pre-salt sealing facies of the South Atlantic. The Lower Cretaceous Bluff Mesa Formation was deposited on the eastern margin of the Chihuahua Trough failed rift and is exposed within multiple Laramide-age thrust panels in the Indio Mountains of West Texas. The mixed carbonate-siliciclastic system thins from 360m to 220m across the study area and contains six fourth-order sequences that record the transition from fluvio-lacustrine to shallow marine deposition. Sequences 1-2 are characterized by lacustrine siltstones or thin marine wackestones during highstands and fluvial-lacustrine sandstones during lowstands. Sequences 3-6 are composed of exclusively marine facies characterized by thick mudstone and shallow-water shelf and backshore sandstones during highstands and shoreface to shelfal sandstones during lowstands. Sequence 3 records a significant rise in base level and the onset of marine deposition with lowstand fluvial sandstone overlying thick marine carbonates during highstand. The presence of thin marine limestones in sequences 1 and 3 suggest that periodic marine incursion occurred during highstands, but the basin was still primarily an enclosed lake. This is supported by analysis of carbonate-associated sulfate from septarian nodules of lacustrine and marine origin. The observed successional mix of terrestrial-marine sequences suggests transgression of rift basins involves multiple pulses.

Objectives

1. Document spatial and temporal trends in lithofacies distributions, geobody geometries and cyclicity in order to construct a sequence stratigraphic framework for the Bluff Mesa.
2. Compare the model with predictions made using the standard sequence stratigraphic model for marine transgression of lacustrine rift basin sediments that are similar in age, tectonic regime, and climatic setting to the pre-salt sealing facies of the South Atlantic.

Methods

Outcrop Analysis

5 stratigraphic sections were measured documenting lithology, geobody geometries, sequence boundaries, and structural features.

Aerial Photography

Aerial photos were taken using a go pro camera attached to a 3DR Solo drone and were processed using Agisoft PhotoScan.

Petrographic Analysis

Thick section analysis documented faunal assemblages, mineralogy, sedimentary structures, and diagnostic features.

Geochemical Analysis

Isotopic sulfur compositions of septarian concretions were obtained by isolating carbonate associated sulfate.

Study Area

Above: Basins and platforms of the Cretaceous Border Rift System during the Jurassic. Modified from Dickinson and Lawton (2001), Stiem and Dickinson (2010), and Mauel et al. (2011).

Left: The Chihuahua Trough and the South Atlantic Rift during the Cretaceous (120 MA). Modified from Blakely (2003) and Budhathoki et al. (2010).

Above: Regional stratigraphy of the Chihuahua Trough from southwest (trough center) to northwest (trough margin).

Top Left: Cross-section showing typical Cretaceous syn-rift sediment distributions from the trough center to the northeast margin. Location of cross-section in figure to the left. Modified from Underwood (1962), Haenggi (2002), and Budhathoki (2013).

Left: Distribution of Jurassic evaporites within the Chihuahua Trough. Modified from Haenggi (2002).

Regional mountain belts and detailed Indio Mountain geologic map (inset). Aerial photo is located on panel #3. Modified from Page (2011) and Li (2014).
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Facies Table

<table>
<thead>
<tr>
<th>Facies</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Conglomerate</td>
<td>Light to dark tan, gray, medium-coarse detrital, crossbedded fluvial conglomerate</td>
</tr>
<tr>
<td>Sands</td>
<td>Sandstone: medium to dark grey, thick, massive, lenticular, tabular, shoreface sandstone</td>
</tr>
<tr>
<td>Silt</td>
<td>Siltstone: tan to dark green, fine to medium grained, cross laminae, and rare dark brown, poorly exposed/ledge former</td>
</tr>
<tr>
<td>Mud</td>
<td>Shaly siltstone, sandy siltstone, sandy mudstone, mudstone</td>
</tr>
</tbody>
</table>

Facies Associations

A. Chihuahua Trough

- Conglomerate
- Breccia
- Muddy conglomerate
- Muddy sandstone
- Muddy siltstone

B. Chihuahua Trough

- Conglomerate
- Breccia
- Muddy conglomerate
- Muddy sandstone
- Muddy siltstone

Geochemistry

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sulfur Content</th>
</tr>
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<tbody>
<tr>
<td>0.5%</td>
<td>1.8%</td>
</tr>
<tr>
<td>0.7%</td>
<td>3.2%</td>
</tr>
<tr>
<td>0.9%</td>
<td>4.5%</td>
</tr>
<tr>
<td>1.1%</td>
<td>5.8%</td>
</tr>
</tbody>
</table>

Summary of sulfur content in sediments. 3 additional samples from the Upper Yucca were tested but sulfur content was too low for isotopic analysis. Global sulfur curve modified from Claypool et al. (1980).
Nature of Contacts

3. Max flood surface #3 represents a significant increase in base level - Tectonism which permanently reconfigured the basin? - Higher order eustasy? May represent transgression preceding the K-Ar sequence boundary (Haj, 2014).

4. Sequence #6 likely coincides with global sequence A3 or A4 with Cox Sandstone deposition having initiated by A5. Modified from Snedden and Liu (2010).

Conclusions and Future Work

1. Detailed mapping has shown that multiple transgressions occurred before the basin was finally drowned. Geochemical and thin section analysis show that the basin returned to a lacustrine environment following initial marine transgression. These results suggest that pre-salt carbonate lacustrine reservoirs may be separated from overlying evaporite seal facies by several pulses of marine/non-marine transgressive/regressive cycles and therefore marine carbonate facies may represent a significant component of the upper pre-salt reservoir. This is contrary to the current model which places lacustrine carbonate facies directly below the evaporite sealing facies.

2. Syn-depositional faulting was a minor depositional control on the observed scale. Changes in bed thickness across faults are generally minor and facies changes are rare (for example, presence of a sandy limestone below max flood surface #3 on the downthrown section (EC) but not on the horst (EI)).

3. Evaporite deposition would have occurred during sequence #2 had conditions been ideal. The lack of evaporites in the Indio Mountains is likely a function of basin geometry and tectonics. Future work would benefit from the inclusion of outcrops located closer to the center of the Chihuahua Trough where conditions were ideal.

4. It is unclear whether the transgression recorded by the max flooding surface of sequence #5 was related to a local tectonic event or global eustasy. Future work will focus on identifying planktonic foraminifera that may act as an age constraint and tie transgression to the global sea level curve.

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Drone Data: Myra Guerrero and Guillermo Vargas

Selected References

Blakey, R.C., 2003, Detailed Paleogeography Maps: online resources available at the University of Northern Arizona Department of Geology, URL: https://www2.nau.edu/rcb7/globaltext2.html.