Sequence Stratigraphy of Classic Carbonate Outcrops in West Texas and Southeast New Mexico and Application to Subsurface Reservoirs*

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Abstract

West Texas and southeast New Mexico contain many classic carbonate exposures with large vertical and lateral extents that allow delineation of major sequence stratigraphic relationships. Sequence stratigraphic relationships help to predict geometries, facies, and early diagenesis in analogous systems in the subsurface. Isolated carbonate buildups are present in Mississippian and Pennsylvanian outcrops in the Sacramento Mountains, and they grew during transgressions when accommodation (relative sea level rise) was greater than or approximately equal to carbonate sediment production. Drowned isolated buildups are commonly excellent carbonate reservoirs throughout the world, including the nearby Horseshoe Atoll.

Ramp carbonates of the Permian San Andres Formation are exposed along the western side of the Guadalupe Mountains. The San Andres has a thick lower transgressive systems tract (TST) overlain by a prograding highstand systems tract (HST). Major hydrocarbon reservoirs occur in similar sequences in the subsurface. Reservoirs are commonly shelf-crest grainstones and adjacent packstones in the HST of the upper San Andres with structures created by differential compaction over packstone-grainstone buildups in the TST of the lower San Andres.

The Capitan Formation is part of a classic carbonate shelf dominated by progradation in a 2nd order HST. Most major carbonate depositional environments occur in this system. The same stratigraphic interval occurs in the subsurface. The structural configuration of the prograding margin is dominated by basinward dip caused by differential compaction associated with the progradation. As a result, the fractured Capitan reef is generally structurally low and wet. Hydrocarbons occur in backreef carbonates and shelfal sandstones with updip, landward seals formed by impermeable lagoonal evaporites.
References Cited


Sequence Stratigraphy of Classic Carbonate Outcrops in west Texas & southeast New Mexico & Application to Subsurface Reservoirs

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Classic Carbonate outcrops in west Texas and southeast New Mexico

• Outcrops provide large, continuous exposures
  – 5-20 miles x >1000 ft (10-30 km x 300 m);
  – Field-scale and seismic scale
  – Minimal structural deformation
• Illustrate the architecture & sequence stratigraphy of the three main types of carbonate systems
  – Isolated buildups
  – Ramps
  – Shelves
• Observe all major carbonate/evaporite depositional environments
• Provide insights/analogies/visualization for the subsurface exploration and oil fields
CARBONATE SEQUENCE STRATIGRAPHIC MODEL


3 Main Carbonate Depositional Systems

1. Mounds/Isolated Buildups/Reefs
2. Ramps
3. Shelves
Layered &/or Prograding

Regression HST; Slowly rising Sea Level

Regression HST; Rapidly Rising S.L.
Sequence Stratigraphy of Classic Carbonate outcrops in west Texas and SE New Mexico
1. Mounds/Isolated Buildups/Reefs

- Mississippian of the Sacramento Mountains
- Pennsylvanian of Dry Canyon
- Reinecke

1. Sacramento Mtns: Mississippian
2. Dry Canyon: Pennsylvanian mounds
3. West Face: Permian Slope
4. Algerita Escarpment: Permian ramp
5. Slaughter Canyon: Capitan reef
CHRONO-STRATIGRAPHY FOR SACRAMENTO AND GUADALUPE MOUNTAINS

Systems shown in this presentation are shown with red rectangles.
PALEOGEOGRAPHIC SETTING OF MISSISSIPPIAN MOUNDS


Mounds decrease in size
MULESHOE Mississippian mound (100 m high, 400 m wide)

Mound flank beds
Crinoid Wk-Pk-Gnst

Mound core
Bryozoa Boundst
Southwest Side of Deadman Branch of Alamo Canyon
Transitional mound (intermediate sized) with common prograding crinoidal beds

Mounds grow during times of general transgression:
Size of mounds & buildups depend on accommodation space

Mounds decrease in size

UPPER PENNSYLVANIAN PALEOGEOGRAPHY OF THE OROGRANDE BASIN
Sedimentation in a humid climate

Depositional cycles/sequences (110 ky frequency; 50-100 m amplitudes) can be divided into 3 main parts related to sea level rises and falls.
Patches of light gray internal sediment (I) are bounded by curved phylloid algal blades that were dissolved.
Red Shale, Crossbedded Conglomeratic Sandstones (fluvial) Deposited during Lowstands of Sea Level
Onlapping Lowstand systems tract

SCHEMATIC CROSS SECTION, DRY CANYON, SACRAMENTO MOUNTAINS
UPPER PENNSYLVANIAN

Incised Lowstand Fluvial Channel

Axis of La Luz Anticline

100 FEET ~30 M

Onlapping Lowstand systems tract

Sequence Boundary
Depositional cycles/sequences (110 ky frequency; 50-100 m amplitudes) can be divided into 3 main parts related to sea level rises and falls.
CARBONATE MOUND OIL FIELD: REINECKE FIELD, HORSESHOE ATOLL

4 sequences represent 4 intervals of sea-level rise and fall during ice-house time.

Caliche crust (soil zone) represents subaerial exposure during low sea level (sequence boundary).

Reinecke South Dome
Oil Saturations from
Fluid Flow Simulation

50% of OOIP recovered from primary + bottom water injection

Mounds/Isolated Buildups Key Features

• Grow during transgressions when accommodation (subsidence + eustatic SL rise) >, = sediment production

• Commonly single tanks with good reservoir characteristics

• Drowning of buildups and covering by drapes of deepwater muds creates seals critical for stratigraphic traps

• Buildups onlapped by shallow marine carbonates or siliciclastics generally do not have good lateral seals
Guadalupe Mountains:
Large Scale Stratigraphy (West Face, 3)
Ramps- Algerita Escarpment (4)
Shelf- Capitan System (5)

1. Sacramento Mtns: Mississippian
2. Dry Canyon: Pennsylvanian mounds
3. West Face: Permian Slope
4. Algerita Escarpment: Permian ramp
5. Slaughter Canyon: Capitan reef
GUADALUPE MOUNTAINS

2. Ramp
3. Shelf
Layered &/or Prograding

- Evaporite
- Dolomite
- Limestone
- Sandstone
Middle Permian of the Guadalupe Mountains has sequences developed in an arid climate. From Tom Elliott, Unocal/Chevron.

Sequence Boundaries

Shelfal Carbonates

RESULT:
"RECI PROCAL SEDIMENTATION"

AFTER DIFFERENTIAL COMPACTION

(from Tom Elliott, Unocal/Chevron)
Deepwater lowstand sands onlap the preceding carbonate shelf margin forming a classic sequence boundary.
**From Saller, Arthur H., Jane W. Barton, and Ricky E. Barton, 1989, Slope sedimentation associated with a vertically building shelf, Bone Spring Formation, Mescalero Escarpe Field, southeastern New Mexico, in Crevello and others, eds., Controls on Carbonate Platform and Basin Development: SEPM Special Publication No. 44, p. 275-288.**

**NORTH DELAWARE BASIN**

**NORTH**
- **Yates**
- **San Andres**
- **Upper**
- **Middle**
- **Lower**
- **Abo**
- **Wolfcamp**
- **Atoka**

**SOUTH**
- **Yates**
- **San Andres**
- **Brushy Canyon**
- **Bone Spring Lms**
- **1st Sand**
- **2nd Sand**
- **Atoka**

**MESCALERO ESCARPE**
- **SHELF MARGIN**
- **SLOPE**
- **BASIN**

**1 km**

**TST & HST = Deposited during high sea level**

**LST = Deposited during low sea level**
ALGERITA ESCARPMENT
GUADALUPE MOUNTAINS
San Andres Ramp System

Evaporite
Dolomite
Limestone
Sandstone

Transgression (TST)
SAN ANDRES DEPOSITIONAL MODEL

PELOID MUDSTONE

Very Fine Sandstone
Nodular to Bedded Gypsum / Argydite
Dolomitic Mudstones with Evaporite Crystals
Algal Laminated Mudstones
Crossbedded Ooid Grainstones
Fusulinid / Peloid Packstone / Grainstone
Burrowed Fusulinid Wackestone
Burrowed Cherty Mudstone
Laminated Mudstone

OOID GRAINSTONE

Eolian / Alluvial Plain
Evaporative Lagoon
Restricted Lagoon
Tidal Flat
Carbonate Shoals / Ramp Crest
Lower Shoreface
Outer Ramp / Upper Slope
Slope
Basin

BURROWED FUSULINID PACKSTONE

BURROWED MUDSTONE
Algerita Escarpment


(Photo courtesy of Carlos Collantes)
LAWYER CANYON

- Cycles with Ooid Shoals
- Lagoonal Mudstones
- Deep-water Mudstone
- Lagoonal Gypsum

Prograding
HST

MFS

Deepening
TST

SB

SB

MFS

TOP GLORIETA

Lagoonal Gypsum

SB

UPPER SAN ANDRES

MIDDLE SAN ANDRES

Fusulinid Wackest & Packstone

Grain-rich Transgressive ST

Deepening TST

SB
Increase in water saturation at 1.0 mobile fluid volume injected.

Vacuum producing zone
Depositional facies and textures occur in predictable patterns.
Average porosity = 7.4%; Average Permeability = 15.7 mD

From Saller, Arthur, Lauren Bierly, David Shafer, and Leigh Owens, 2012, Contrasting Styles of San Andres Reservoirs: Vacuum Versus Slaughter Fields, Middle Permian, West Texas and Southeast New Mexico: AAPG Search and Discovery Article #20168
Capitan Reef Rims Delaware Basin
<table>
<thead>
<tr>
<th>LAMINATED BASINAL CARBONATE MUDS</th>
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Lamar member of Bell Canyon Fm (Permian Capitan system);
Potential source rock
Gravity flows in basinal mudstones

Basinal, near toe-of-slope

<table>
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<tr>
<th>BEDDED GYPSUM &amp; DOLOMITE (LAGON)</th>
<th>PELLOID MUDSTONE &amp; WACKESTONE WITH STROMATOLITES</th>
<th>PISOLITIC SHELF CREST</th>
<th>OOID-PELLOID GRAINSTONE</th>
<th>BACKREEF BIOLAST PACKSTONE-GRAINSTONE</th>
<th>REEFAL BOUNDSTONE WITH MARINE CEMENT</th>
<th>SLOPE WACKESTONE, PACKSTONE &amp; MEGA-BRECCIAS</th>
<th>LAMINATED, ORGANIC-RICH MUDSTONE</th>
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Capitan slope. Conglomerates of reef and slope debris.

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Bioclast-intraclast Packstone-Grainstone
Capitan Reef, McKittrick Trail

Average Geopetal Dip 10° @ 124° to the SE (basinward); n = 28

Overlying fall-in beds have a similar dip and orientation

Dasyclad packstone-grainstone

Backreef, bioclastic packstone-grainstone with large gastropod

Dasyclad packstone-grainstone
Fractured reef and slope

Shallow marine cycles
Domal stromatolites

Massive gypsum

Dolomite Mudstone with evaporite molds

Restricted Lagoonal Dolomite
Well Log Cross Section NE Delaware Basin

DEPOSITIONAL/SEQUENCE STRATIGRAPHIC MODEL FOR THE CAPITAN SYSTEM

Capitan age reservoirs are in backreef carbonates & sandstones. Although permeable, the Capitan is generally wet (an aquifer).
GUADALUPE MOUNTAINS

Ramps & shelf systems

- Layered &/or prograding
- Commonly stratified
- Predictable lateral distribution of facies
- Differential compaction causes basinward dip
- Evaporitic lagoonal and sabkha facies may cause updip seals & stratigraphic traps

- Evaporite
- Dolomite
- Limestone
- Sandstone

WEST FACE

DELAWARE BASIN

TRANSGRESSION

REGRESSION (HST)

SHELF

REGRESSION (HST)

ALGERITA
GUADALUPE MOUNTAINS

- Ramps & shelf systems
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Transgression; Rapidly Rising S.L.

1,000-2,000 M

LOWSTAND SAND & SHALE

SHELL MARGIN CARBONATE

SHELF CARBONATE

BASINAL CARBONATE

SLOPE CARBONATE
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