Facies and Stratigraphy of the San Andres Formation (Mid-Permian) Petroleum Province, Northwest Shelf of the Permian Basin, West Texas: A Resurgent Play

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Introduction

- Environments of the San Andres formation on the Northwest Shelf in West Texas
- Complex interaction between sea level, climate, and geomorphology formed “world-class” carbonate reservoirs
- Varying targets for hydrocarbon production
- Quantitative approach to indicate the geologic history of the San Andres and effects of paleoenvironment on reservoir quality
San Andres Formation Age – Middle Permian

Base Wordian 268.8 Ma ➔ lower Guadalupian
Base Roadian 272.3 Ma ➔ upper Leonardian

(Ruppel, 2019)
San Andres Reservoirs Occur on Carbonate Platforms and Shelves

San Andres production – shelf and platform carbonate reservoirs

(Dutton, 2005; Ruppel, 2019)
San Andres Reservoirs – Highest Cumulative Production of Permian Basin

San Andres production – shelf and platform carbonate reservoirs

Trend along the shelf & platform at the margin of Midland Basin

Cumulative Conventional Permian Production

San Andres 50%

All other Reservoirs 50%

(Dutton, 2005; Ruppel, 2019)
San Andres Northwest Shelf – Rimmed Carbonate Shelf

Rimmed Carbonate Shelf

Morphology: Broad, low relief (~0.6°)

Dominant lithologies: Dolomitized carbonates & anhydrites

Depositional environment: Shallow lagoon & sabkha complexes

Sedimentation pattern: Upward-shoaling prograding-aggrading sequences

Thickness: 1,200 – 1650 ft.

(Dutton, 2005; Ruppel, 2019)
Carbonate Shelf Rim Overlies a Deep-Seated Shelf Margin

Abo Reef Structure – lower Permian (Leonardian) shelf margin

(Dutton, 2005; Ruppel, 2019)
San Andres Play Fairway – West Texas

Abo Reef Structure – lower Permian (Leonardian) shelf margin

West Texas San Andres Play Fairway

Cumulative San Andres Production

- West Texas San Andres (4.0 BBOE)
- All Other San Andres Reservoirs (6.7 BBOE)

(Dutton, 2005; Ruppel, 2019)
San Andres Play Fairway – West Texas

(Ramondetta, 1982a; Ramondetta, 1982b; Ruppel, 2019)
Warming Climate and Near-Equatorial Latitude: Favorable for Sabkha Evaporites

(Blakey, 2019)
massive & nodular anhydrite
lime-rich mudstone
oolitic packstone and grainstone
algal-coated grainstone & mudstone
mudstone & pellet packstone
lime-rich mudstone
oolitic packstone and grainstone

supratidal
intertidal
subtidal
sabkha
tidal flat
lagoon
barrier bar (shelf rim)
restricted shoal
active shoal
shoal active
shoal

Inner-Shelf Environments and Facies Tract

(Ramondetta, 1982a; Ward et al., 1986)
Secondary Porosity Formed by Reflux Dolomitization

hypersaline waters: supersaturated with dolomite

dolomitizing waters

high porosity dolomite

(Saller, 2004; Ramondetta, 1982a; Ramondetta, 1982b)
Porosity Occlusion by Anhydrite Cement

hypersaline waters: supersaturated with dolomite

dolomitizing waters

Variable anhydrite plugged dolomite

(Saller, 2004; Ramondetta, 1982a; Ramondetta, 1982b)
Hierarchy of Sea Level Fluctuations

(Lopez-Gamundi, 2019; Ross and Ross, 1987; Ruppel, 2019)
**π Marker Bed Deposited at Sea Level Lowstand**

<table>
<thead>
<tr>
<th>Epoch/ Age/ Stage</th>
<th>Northern Shelf</th>
<th>Eustasy Curve</th>
<th>Major T-R Trend</th>
<th>Guad. T-R Cycles</th>
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</thead>
<tbody>
<tr>
<td><strong>Permian</strong></td>
<td></td>
<td>+100m</td>
<td>0</td>
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<tr>
<td>Guadalupian</td>
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<td>Roadian</td>
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<tr>
<td><strong>Leonardian</strong></td>
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<tr>
<td><strong>Kungurian</strong></td>
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<td><strong>Gruissan</strong></td>
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</tbody>
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(Lopez-Gamundi, 2019; Ross and Ross, 1987; Ruppel, 2019)

- **Upper San Andres**
- **Lower San Andres**
### High-Frequency Transgressive-Regressive Cycles

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<tbody>
<tr>
<td>Lower San Andres</td>
<td>Glorietta</td>
<td>+100m</td>
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<tr>
<td>Upper San Andres</td>
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(Rise) Marker

Upper San Andres

Lower San Andres

(Lopez-Gamundi, 2019; Ross and Ross, 1987; Ruppel, 2019)
Tight Supratidal Anhydrites & High Porosity Subtidal Dolomites

- Porosity
  - supratidal
  - intertidal
  - subtidal
  - lagoon
  - subtidal shoals

(Saller, 2004; Ramondetta, 1982a; Ramondetta, 1982b)
Cyclical Stacking of Porous & Tight Facies

High-Frequency T-R Cycles

upward-shoaling progradational-aggradational

(Ramondetta, 1982a; Ramondetta, 1982b; Ward et al., 1986)
interbedded dolomite & anhydrite

thick porous dolomite

(Ramondetta, 1982a; Ramondetta, 1982b)
Intercrystalline Macroporosity – Vugular Pores Increase With Depth

(SEM images courtesy of Monadnock Resources, LLC)
Intercrystalline Macroporosity – Vugular Pores Increase With Depth

(Oversized grain-moldic pores)

(SEM images courtesy of Monadnock Resources, LLC)
Thick Reservoir Facies Grade Northward to Discrete Beds

interbedded dolomite & anhydrite

thick porous dolomite

(Ramondetta, 1982a; Ramondetta, 1982b)
Compaction Drape and Fracturing Atop Low-Relief Structures

North

1. lagoonal mudstones
2. carbonate shoal: Cycle 1
3. compaction
4. fractures in limestone between shales
5. fractures on crest

South

1. Ramp
2. carbonate shoal: Cycle 2
3. carbonate shoal: Cycle 3
4. propagation of fractures under the overburden

Deposition of Carbonates

Shallow Burial and Compaction of Mudstones

Further Burial and Compaction

Abo Reef Trend
Outcrops in Guadalupe Mts. - ~150 mi. From W. Texas Reservoirs

(Kerans, 2014; Ruppel, 2019)
Progradational-Aggradational San Andres Shelf Migration

Guadalupe Mts.

Rio Hondo  Rio Penasco  Algerita Escarpment

Anhydrite and anhydrite dolostone
Restricted marine peloidal wk-pk and peritidal
High-energy ramp-crest grainstones
Outer ramp fusulinid-dominated facies
Open marine limestones and dolostones
Deeper-water mudstones (Cutoff)

(Kerans, 2014; Ruppel, 2019)
Oil Fields Occur in Increasingly Younger Strata – Offsetting Basinward

(Kerans, 2014)
Sabkha Evaporites Extend Southward During Mid-Permian Regression

San Andres at margin of Midland Basin open marine waters

Continued sea level fall: supratidal sabkhas extend over the Midland Basin

(Blakey, 2019)
Structure Map of the $\pi$ Marker – The Base of the Reservoir Seal

(Ramondetta, 1982a; Ramondetta, 1982b)
Inner-to-Outer Shelf Reservoir Architecture

Matador Uplift

Abo Trend

Nonporous zone
Major Porosity Zone
Oil Field
Structural High

Upper San Andres seal

( Ebanks, 1990; Ramondetta, 1982a; Ramondetta, 1982b)
Migration and Successive Trapping in Updip Porosity Pinchouts

(Ebanks, 1990; Ramondetta, 1982a; Ramondetta, 1982b)
**Vertical Oil Saturation Profile**

**main pay zone:**
- vertical target – occurs on low-relief structures

**transitional oil zone:**
- water-laden interval (decreasing oil saturation with depth & increasing water saturation)

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(Ruppel, 2019; Trentham and Melzer, 2019)
Oil Saturation Decreases With Depth; Water Saturation Increases

**Vertical Oil Saturation Profile**

- **Oil-water contact**: Water-laden interval (decreasing oil saturation with depth & increasing water saturation)
- **Main pay zone**: Vertical target – occurs on low-relief structures

(Ruppel, 2019; Trentham and Melzer, 2019)
Indication of a Larger Paleo Oil Trap and Subsequent Flushing

**Vertical Oil Saturation Profile**

- **main pay zone:**
  - vertical target – occurs on low-relief structures

- **transitional oil zone:**
  - water-laden interval (decreasing oil saturation with depth & increasing water saturation)

- **San Andres basal limestone:**
  - Minor oil saturation indicates previous saturation to the base of the reservoir

(Ruppel, 2019; Trentham and Melzer, 2019)
Uplift and Exposure of Guadalupian Strata in New Mexico

Exposure of Guad. Strata

Uplift

(Melzer, 2006; Ruppel, 2019)
Influx of Meteoric Water and Sweeping of the Lower Oil Column
Flushing of the Lower Oil Column

(Trentham et al., 2015)
Resurgent Play Extends Beyond the Flanks of Legacy Fields

<table>
<thead>
<tr>
<th>Zone Type</th>
<th>Description</th>
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<tr>
<td>Main Pay Zone (MPZ)</td>
<td>Vertical target – on structural highs</td>
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<tr>
<td>Transitional Oil Zone (TZ)</td>
<td>150-300 ft. thick water-laden interval below oil-water contact</td>
</tr>
<tr>
<td>Residual Oil Zone (ROZ)</td>
<td>No primary oil recovery</td>
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(Melzer, 2006)
Petrophysical Analysis Indicates Prograding-Aggrading Shelf
Methodology:

1. Calculate oil-in-place from petrophysical analyses

2. Indicate the depth of most saturated 100 ft. reservoir interval

3. Contour similar depths
Results:

The depth of the “best 100 ft.” interval indicates the depth of the restricted shelf margin.

Moving basinward (southeast), the depth of the restricted shelf margin indicates progradational-aggradational shelf migration.
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The depth of the “best 100 ft.” interval indicates the depth of the restricted shelf margin.

Moving basinward (southeast), the depth of the restricted shelf margin indicates progradational-aggradational shelf migration.
Core Properties Within the “Best 100 Ft.” of Reservoir

San Andres Whole Core
- Limits of vertical field
- In Field core, n = 25 wells with 1,285 core points
- Off Structure core, n = 41 wells with 1,518 core points

San Andres Petrophysics
- Limits of vertical field
- Petrophysical analysis, n = 73 wells
Core Properties Indicate Porosity Enhancement on Paleo-Structural Highs

Porosity of “In Field” & “Off Structure” Core Points

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<tr>
<th>Area</th>
<th>P90</th>
<th>P50</th>
<th>P10</th>
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<tr>
<td>In</td>
<td>3.3</td>
<td>8.3</td>
<td>13.3</td>
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<tr>
<td>Out</td>
<td>2.2</td>
<td>6.3</td>
<td>11.5</td>
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San Andres Whole Core
Limits of vertical field
- In Field core, n = 25 wells with 1,285 core points
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in field
off structure
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San Andres Whole Core
- Limits of vertical field
- In Field core, n = 25 wells with 1,285 core points
- Off Structure core, n = 41 wells with 1,518 core points

Porosity enhancement of “in field” reservoir facies
Core Properties Indicate Permeability Enhancement on Paleo-Structural Highs

Permeability of “In Field” & “Off Structure” Core Points

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<th>P90</th>
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<tbody>
<tr>
<td>In</td>
<td>0.03</td>
<td>0.47</td>
<td>4.00</td>
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<tr>
<td>Out</td>
<td>0.03</td>
<td>0.30</td>
<td>3.00</td>
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Permeability enhancement of “in field” reservoir facies
Core Properties Indicate Greater Water Saturation in “Off” Structure Reservoir

Water Saturation of “In Field” & “Off Structure” Core Points

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<tr>
<td>In</td>
<td>15.9</td>
<td>29.8</td>
<td>58.2</td>
</tr>
<tr>
<td>Out</td>
<td>20.4</td>
<td>36.4</td>
<td>63.4</td>
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greater water saturation in “off” structure reservoir
Reservoir Quality Diminishes Off the Flanks of Legacy Fields

- Porosity enhancement by secondary dolomitization
- Porosity occlusion in lagoonal or intertidal facies
- Paleo-waterflood and sweeping of the lower oil column
The San Andres Fm. on the Northwest Shelf in W. Texas represents a “world-class” carbonate hydrocarbon reservoir – formed by the complex interactions of supratidal and subtidal environments during a hierarchy of sea-level fluctuations and increasingly arid climatic conditions.

A paleo-waterflood flushed the lower oil column of the reservoir, leaving a distribution of distinct targets for production that vary in oil-water saturation, distribution, and method of production.

Petrophysical and core analyses of these targets provide a quantitative method of analysis of the prograding-aggrading migration of shelf environments, and the diminishing reservoir quality, moving from the “in field” to “off” structure reservoir.
References


References

Ramondetta, P.J., 1982a, Facies and Stratigraphy of the San Andres Formation, Northern and Northwestern Shelves of the Midland Basin, Texas and New Mexico: Bureau of Economic Geology, The University of Texas at Austin, doi: 10.23867/ri0128d.

Ramondetta, P.J., 1982b, Genesis and Emplacement of Oil in the San Andres Formation, Northern Shelf of the Midland Basin, Texas: Bureau of Economic Geology, The University of Texas at Austin, doi: 10.23867/ri0116d.


