Thinking and Methodology Leading to a Major Sweetspot in Tight Sands - A Deep Eocene Misoa Sands Discovery*

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Abstract

The methodology and thoughts that led to the discovery of the giant “Tomoporo-Profundo” Field is reviewed to outline the power of a multidisciplinary integration associated with a 4-D diagenetic modeling. Our previous work in Lake Maracaibo demonstrated that very high porosity and permeability at great depth were likely linked to an early oil migration along a fault system. In Zulia Oriental, located east of Lake Maracaibo, deeply buried thick sandstones sequences are present but porosity is apparently absent.

The integrated work combined seismic with sedimentology, structural geology, and geochemistry. The data consisted of cores from a few wells and scattered 2D seismic lines. Vitrinite data was available for each of the 20 existing wells and gave us a good understanding of the basin burial history.

We generated predictive maps of various geological parameters for each horizon through time. Porosity evolution through time was calculated for each interval of interest in 9 hypothetical wells. One 2-D seismic line strongly indicates an early compression activity (late Eocene) in an area close to a major fault that extends to the west to a short lived oil kitchen (Oligocene). The porosity destruction by quartz cement growth was thought to have stopped with the hydrocarbons filling the structural trap; implying the possible existence of a deeply buried “island” of sandstones with some 25% porosity among otherwise very tight sandstones.

A 3-D seismic was acquired on the prospective area with a subsequent discovery of a giant oil field; the “Tomoporo-profundo” Field.
References


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Thinking and Methodology Leading to a Major Sweetspot in Tight Sands
a Deep Eocene Misoa Sands Discovery

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  Quartz cement modeling
  
  – The authors would like to thank PDVSA Intevep and PDVSA for permission to publish this material. All of the diagrams are taken from illustrations that were presented with permission at conferences; they correspond to:
    
    - Chatellier et al. 1998, 1999 and 2000
    - Perez et al. 1998, 1999a and 1999b
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Talk Outline

How it started – the problem

Preliminary results and follow-up

Methodology

   Basin modeling

   Quartz cement modeling

Integration with structure and geochemistry

Outstanding result
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Geographic Location

Lake Maracaibo
Venezuela
Colombia
Brazil
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Geographic Location

Zulia Oriental

Venezuela

Colombia

Brazil
How it started

Deeply buried sands
Most sands are tight
Some very porous beds

Main Study area
- Bachaquero
- Centro Lago
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The deeply buried Misoa C Sands remained “tight” until … Tomoporo
Main results:

A minor oil migration from the Perija Kitchen could only fill some of the deeply buried Misoa Sands

Preserving porosity

Deep Eocene Diagenetic Bachaquero Study

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Perija Kitchen

Icotea

Pueblo Viejo

Lake Maracaibo
QUARTZ CEMENT from PETROGRAPHY

Outstanding quartz cement overgrowth with well defined ghost rim (residual insoluble particles)

0.5 mm
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Petrography from 8 wells

Consistent trends !!!

Grain Size

mm

0.500

0.375

0.250

0.125

0 4 8 10 12

Quartz overgrowth
Quartz cement
Petrography
Versus
Cathodoluminescence
LIMITATION OF MICROSCOPY

Quartz cement hardly identified in fine to very fine grained sandstones
!!!!! Finer grain ==> more quartz cement

Location of quartz cementation
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Petrography versus Cathodoluminescence

Zulia Oriental

<table>
<thead>
<tr>
<th>Wells</th>
<th>North</th>
<th>South</th>
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<tbody>
<tr>
<td>Well 3</td>
<td>[Diagram]</td>
<td>[Diagram]</td>
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<tr>
<td>Well 4</td>
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<td>Well 1</td>
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<td>Well 2</td>
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<td>Well 10</td>
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<td>Well 11</td>
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<td>Well 12</td>
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<tr>
<td>Well 13</td>
<td>[Diagram]</td>
<td>[Diagram]</td>
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</tbody>
</table>

Same samples studied by

- Petrography
- C.L.

Cathodoluminescence is essential
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Hot Cathodoluminescence

Microscopy

Cathodoluminescence

Courtesy University of Texas
Zulia oriental

20 wells drilled in deep Eocene

All of them encountered very thick sands

All of the sands were tight
1. Burial History
   a) Temperature > 80 degrees C
   b) Time
2. Petrography
   a) Grain size
   b) Composition
   c) Remaining Porosity
3. Cathodoluminescence
   a) Precise estimate of quartz cement
   b) Calibration of kinetics
Successive basin tilts led to intricate burial histories
FIRST TASK

Burial parameters

Vitrinite reflectance
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First Problem:
overcooked basin

Vitrinite reflectance data indicates that Zulia Oriental is overcooked

A new seismic interpretation shed new light on the burial history of the area
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Revisiting the evidences of overcooking

Abnormally high Ro

Lake Maracaibo

20 km

3&4
Evidence of overcooking, 1

Extrapolating Ro data to source rock (5000’ deeper) suggested overcooking (Ro = 4.1)

Extrapolation to La Luna -> Ro = 4.1
Evidence of overcooking, 2

Extrapolating Ro data to source rock suggested overcooking (Ro = 4.9)

Well 4
Inconsistencies

Wells 3 & 4 are a few hundred metres apart.

It does not make sense.

After Chatellier et al, 1998
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Original interpretation was 6500 feet of erosion

New interpretation
shale tectonics
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SHALE TECTONICS IN ZULIA ORIENTAL
EXAMPLE

Line ZO-91C-19

0.0 1.0 2.0 3.0 4.0

1700 1800 1900 2000

'Cretaceous / Paleocene

MISOA

TRUJILLO

CRETACEOUS / PALEOCENE

3.5 km

'Pull-down' of seismic reflectors

Withdrawal syncline'

'Draping' of sediments over shale ridge

Vertically-stacked channels or turbidite fans

Listric normal faults

Shale 'rollers'

After Chatellier et al., 1998
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EFFECT OF SHALE MOBILITY on Ro vs Depth trends

Original size, original location, original Ro/dpth slope

Final size, final location, final Ro/dpth slope (much shallower slope than the original)

After Chatellier et al., 1998
Conclusions from Burial History

The area has much more potential than previously thought
Quartz cement Modeling
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Simulation results

INPUT

Burial data:
$T^\circ$ and time

Cathodo:
% Quartz cement

Petrography:
% Porosity
Effect of Grain Size on Well 5 Porosity

![Graph showing the effect of grain size on porosity over time. The graph compares fine-grained and medium-grained rock fractions.](image)
Timing of quartz and calcite cement

Well 1

Calcite cement 31-33 MY

Quartz Cement theoretical

End of Quartz cement precipitation

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MODELING

• Modeling for wells with good burial history
  – (9 wells)

• Results
  – maps of porosity through time

• Integration with structure and geochemistry
RESULTS FROM MODELING
Example from WELL 1

Different composition for B and C sands

Porosity %

Quartz cement %

Base Misoa C

Top Misoa B

SB-49

SB-41.5
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RESERVOIR QUALITY MAPS

- For sandstones with upper fine-grain size
- Maps of reservoir quality (porosity) for each horizon
  - top B sup
  - Top B inf
  - Top C sup
  - Top C inf
  - Base C inf
- Every 5 million years
  - 45, 40, 35, 30, 25, 20, 15, 10, 5 MY and today
Top C Sands 40 Ma

Still good porosity in Zulia Oriental

19.8% to 26.4%
RESULTS FROM MODELING (2)

Top C Sands
30 Ma

Huge porosity loss in Northeastern part of Z.O.
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Why is hydrocarbon migration important?

Time of HC Entrapment

OIL
EMPLACEMENT
STOPS
DIAGENESIS

==> preserve Reservoir quality
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RESERVOIR QUALITY
for 1st expulsion phase

Level studied = SB-49
Top of Misoa C sands

At time of 1st migration
all > 20% porosity

View @ 40 M.Y.

Combination 1st & 2nd migrations

- Porosity <10%
- Porosity 10%<<15%
- Porosity >15%
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RESERVOIR QUALITY for 2nd expulsion phase

Level studied = SB-49
Top of Misoa C sands

Top of zone of interest (up to 900m thick)

View @ 10 M.Y.

<table>
<thead>
<tr>
<th>Porosity</th>
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<tbody>
<tr>
<td>&lt;10%</td>
<td></td>
</tr>
<tr>
<td>10%&lt;&lt;15%</td>
<td></td>
</tr>
<tr>
<td>&gt;15%</td>
<td></td>
</tr>
</tbody>
</table>
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Looking for prospects

Searching for structures existing at time of first migration and on the migration path

View @ 10 M.Y.

- Porosity <10%
- Porosity 10%<<15%
- Porosity >15%

Path of first migration

Prospective area
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Path of first migration
CONCLUSIONS 1

- A simple diagenetic model did the job
  - Burial history
  - % Quartz cement from C.L.
  - Porosity from petrography
  - Composition from petrography
  - Grain size from petrography

- Added filters (change in grain size, calcite cement)

- Timing of migration is vital
  - Hydrocarbon emplacement stops diagenesis
CONCLUSIONS 2

• Integration with the tectonic model
  – creation of traps
  – preservation of traps

• Integration with the migration history
  – e.g., 2 phases of migration
  – Structural trap in Tomoporo area at time of first migration
    • good porosity

• Final results
  – Location for new seismic
  – New drilling discovery well 17,400 barrels per day
  – “Tomoporo Profundo” Field >1 Billion bbls (official reserves)
  – **Biggest discovery** in Venezuela since El Furrial Trend discovery