

Visualization Process Approach to Identify Scenarios to Improve Recovery in a Mature and Stratigraphically Complex Reservoir: El Cordon Field*

M. Santisteban¹, E. Altamiranda¹, M.I. Rodriguez¹, R. Alvarez², and M. Bracho de P.²

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¹Repsol-YPF

²RPS-Scotia (AlvarezR@rpsgroup.com)

Executive Summary

- Initial production in 1954.
- Implementation of water injection in 1979.
- El Cordon reservoir produces oil and gas from Cañadon Seco, Caleta Olivia and Mina El Carmen formations.
- Very complex sedimentary environment.
- Limited lateral and vertical communication between sands.

Petrophysical Modeling

1. Well log data base for the 138 wells received for the study.
2. The 138 wells represent about 20% of the total number of 626 wells in the reservoir. 41 wells (6%) have Formation Density Logs (FDC), 6 wells (0.9%) had Sonic Logs.
3. Well log information was not areally distributed.
4. Limited tops/zones information.
5. No blue-print headers available.
6. Products were focused in determination of the key parameters for the volumetric estimation of hydrocarbons in-place.

Geocellular Model

- Improve efficiency through reservoir modeling.
- 3D representation of the reservoir features.
- Areal and vertical distribution of sand bodies.
- Control area oil in-place calculation.

OOIP Estimation

- Very complex sedimentary environment.
- Limited lateral and vertical communication between sands.
- Sands average thickness about 2.5 meters.
- Sands extend to a distance between 1-4 well spacing.
- 'Key Area' was used to calibrate probabilistic approach.

Scenarios

Base case
Well reactivation
New well drilling
Infill drilling
Water flooding
Polymer injection (screening)

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Content

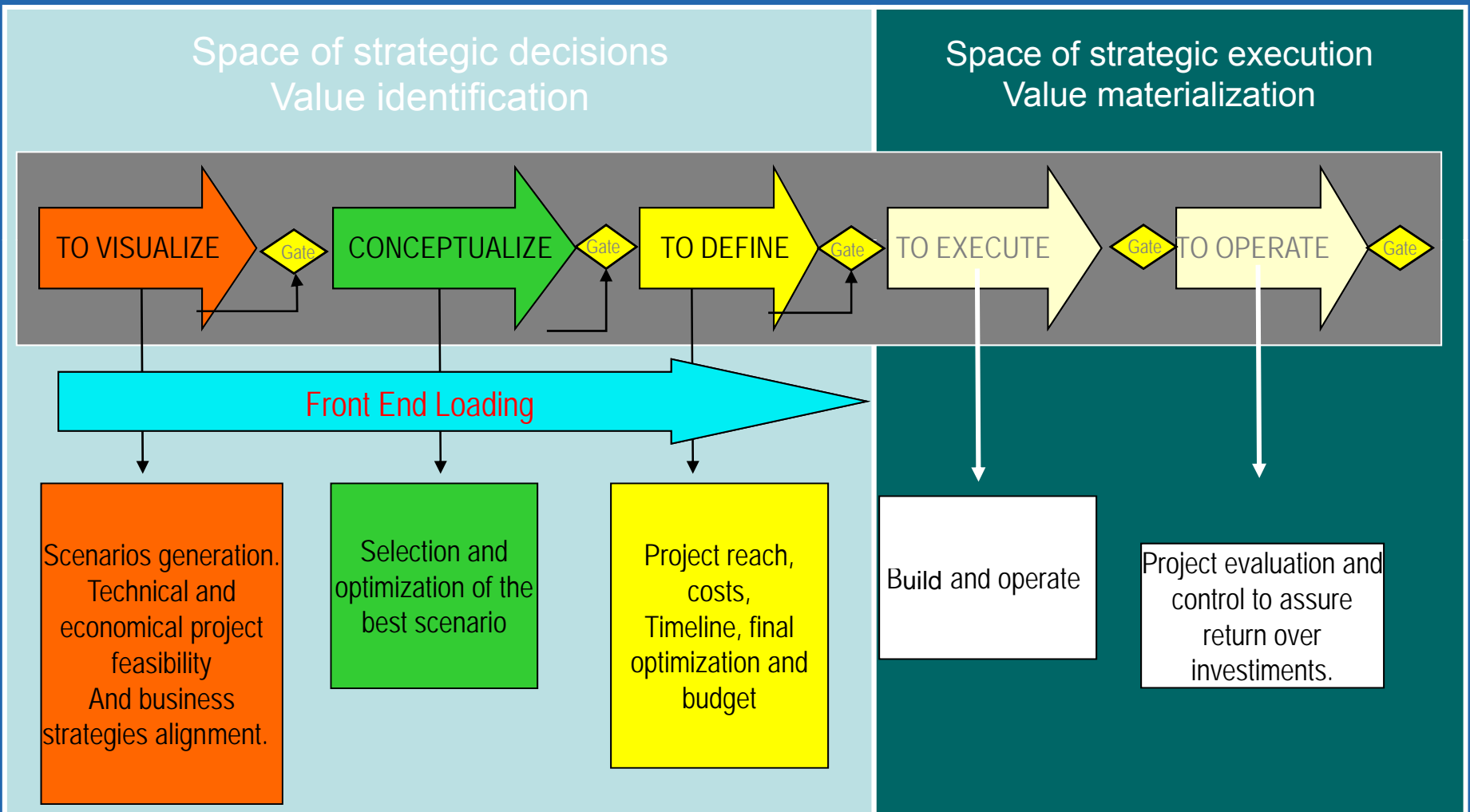
- Executive Summary
- Data Model
- G&G Overview
- OOIP Estimation
- Dynamic Model
- Scenarios
- Conclusion

Objectives

- Identify Scenarios to improve recovery
- Proved an integrated approach
- Estimate asset value

Reserve Areas

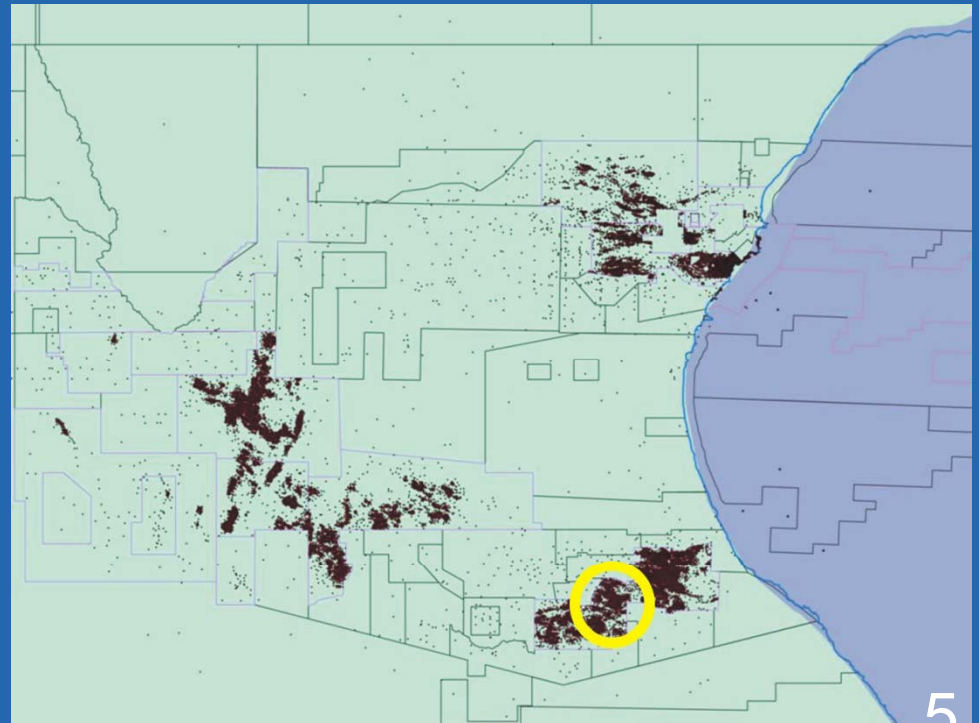
How to indentify and materialize the value



Executive Summary



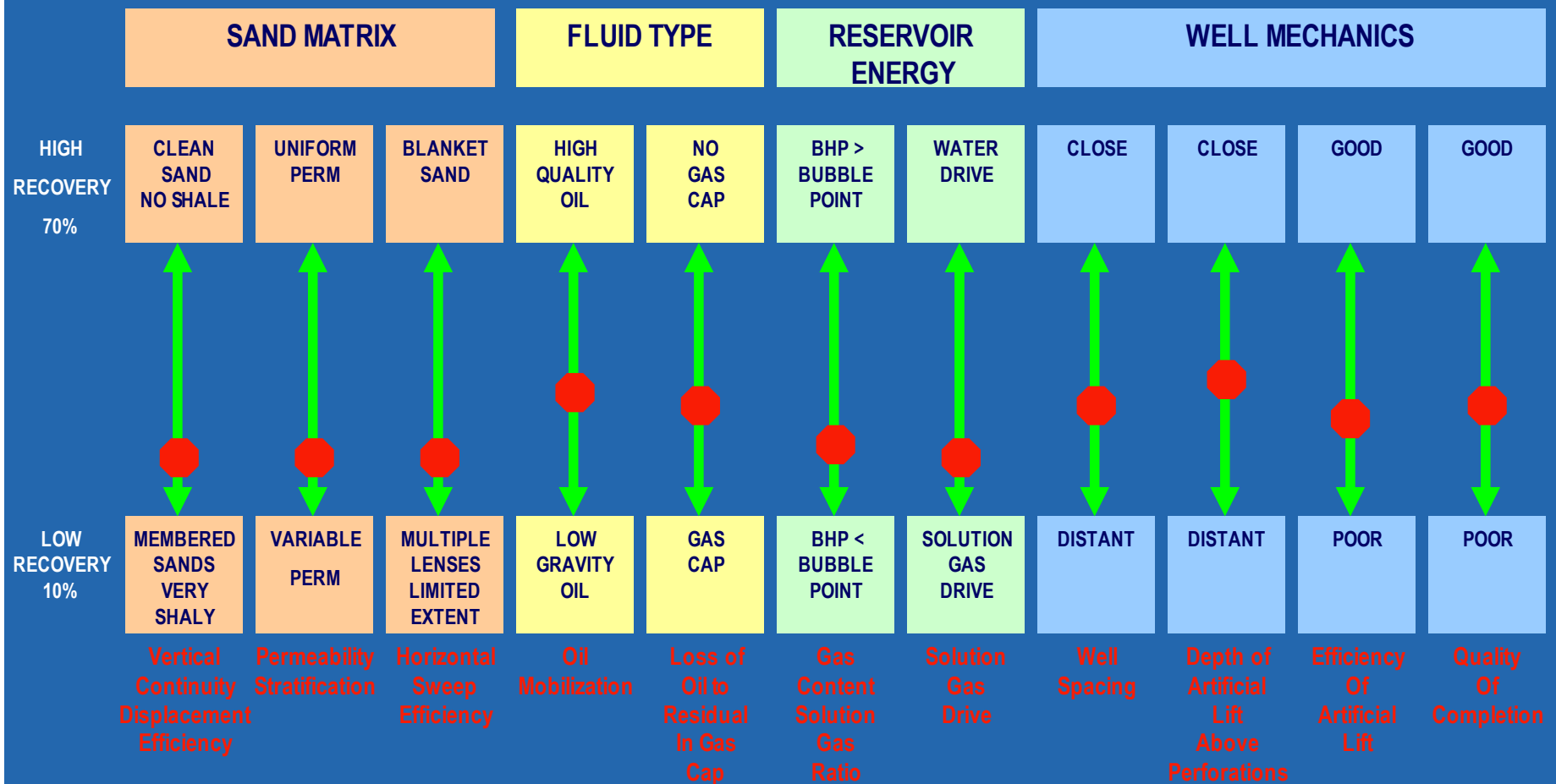
- Golfo San Jorge (GSJ) Basin
- Southern Flank
- El Cordon Field



- Initial Production in 1954
- Implementation of water injection in 1979
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Executive Summary

Efficiency Factors Scoring Technique Sandstone Reservoir Characteristics



Six scenarios were considered for maximizing reserves recovery:

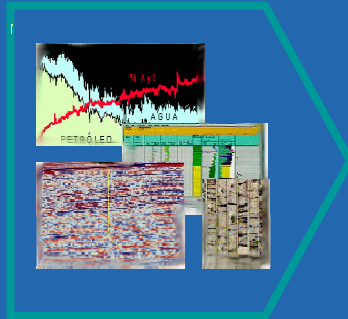
- 1. Base Case**
- 2. Well Reactivation**
- 3. New Well Drilling**
- 4. Infill Drilling**
- 5. Water Flooding**
- 6. Polymer Injection (screening)**

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Integrated Approach



Data Model



| Architecture | Petrophysics | Fluids | Historic |
|---------------------|--------------------|-------------------|---------------------------------------|
| Seismic Geologic | Well Logs Cores | P.V.T. Samples | Well Tests Production Injection |

No seismic-geologic project.
3D volume partial coverage (2/3)

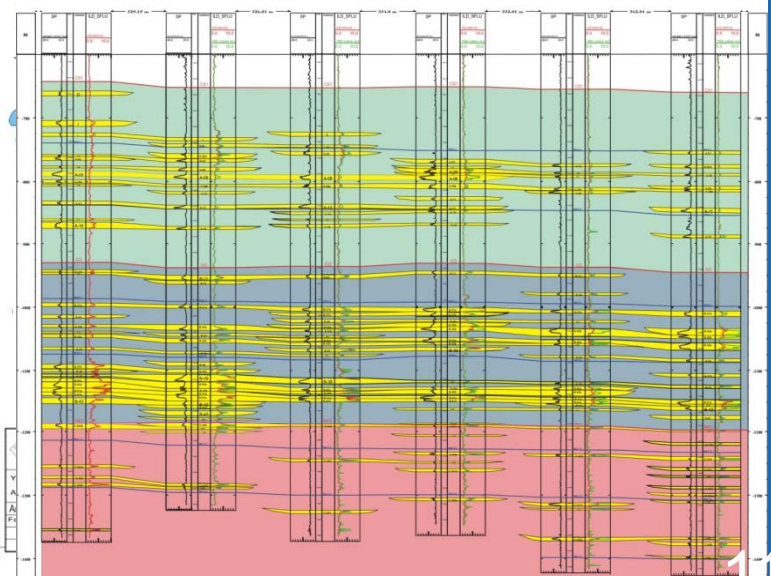
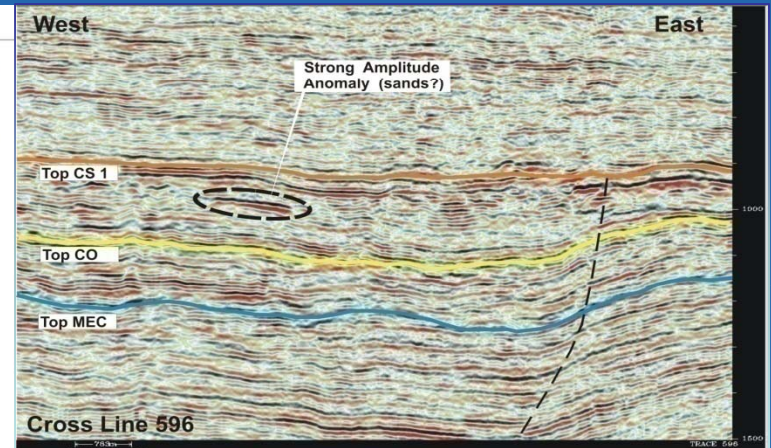
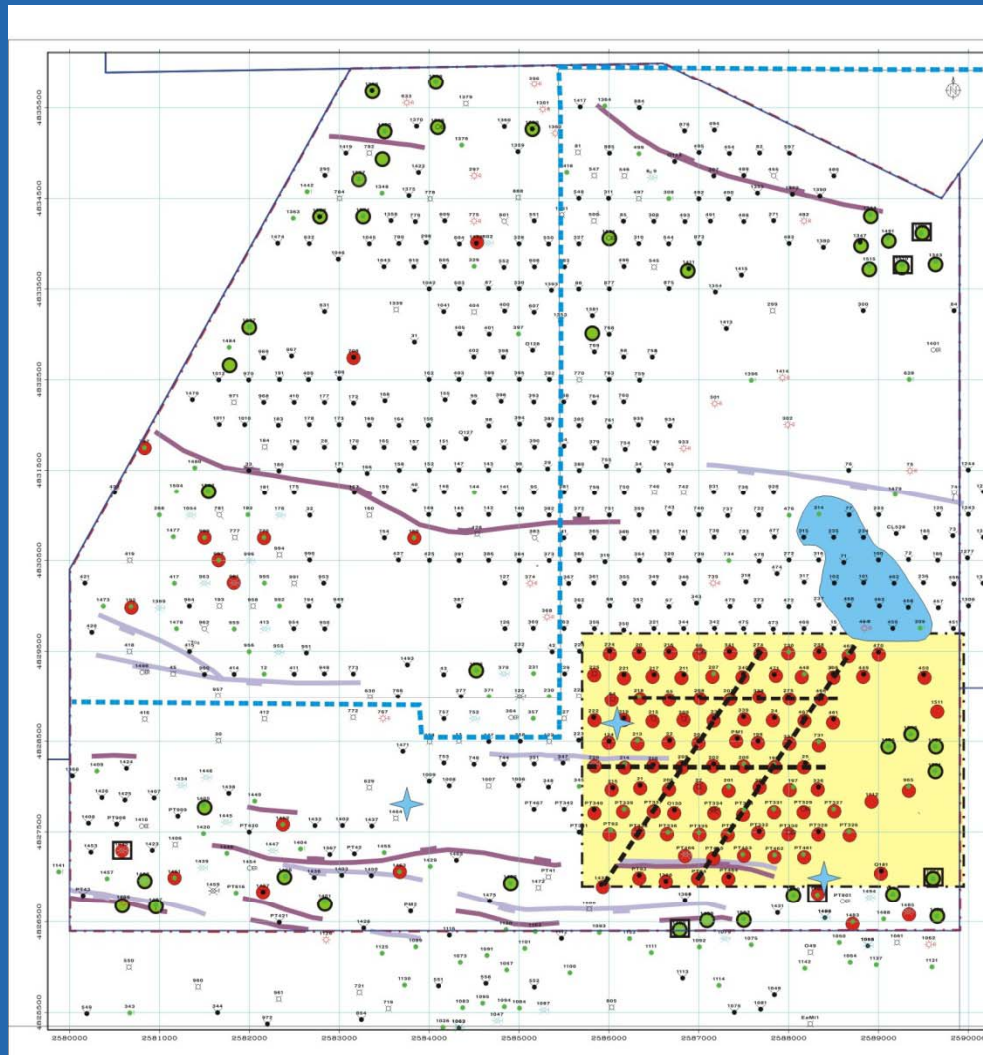
138 out of 626 well log were received (22%).
41 wells with porosity indicator (6%)
Scarce Core data (19 sample test)

1 recombined sample for PVT, Farigna's correlation used.

2 transient (built up) Production history since 1972
Scattered static pressure data
Incomplete well events and mechanic diagrams

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G & G Review

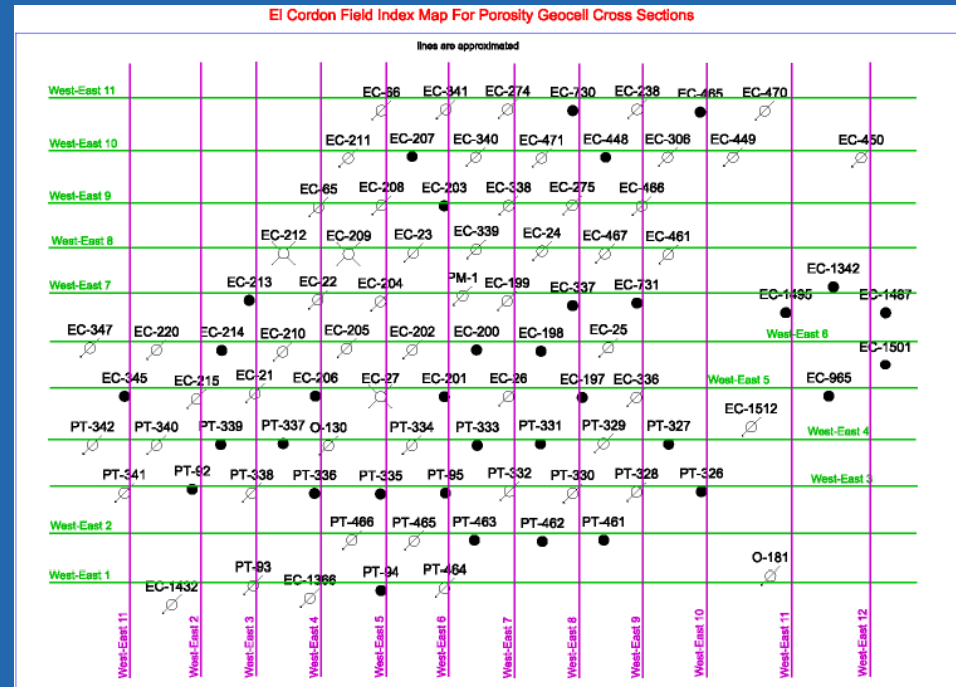
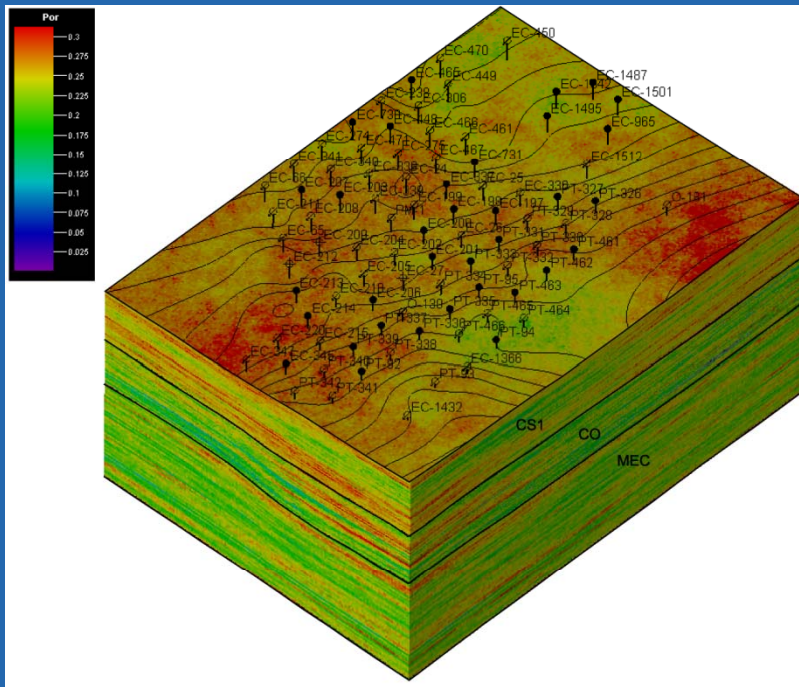


1. Wells log data base for the 138 well received for the study
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G & G Review

Geocellular Model

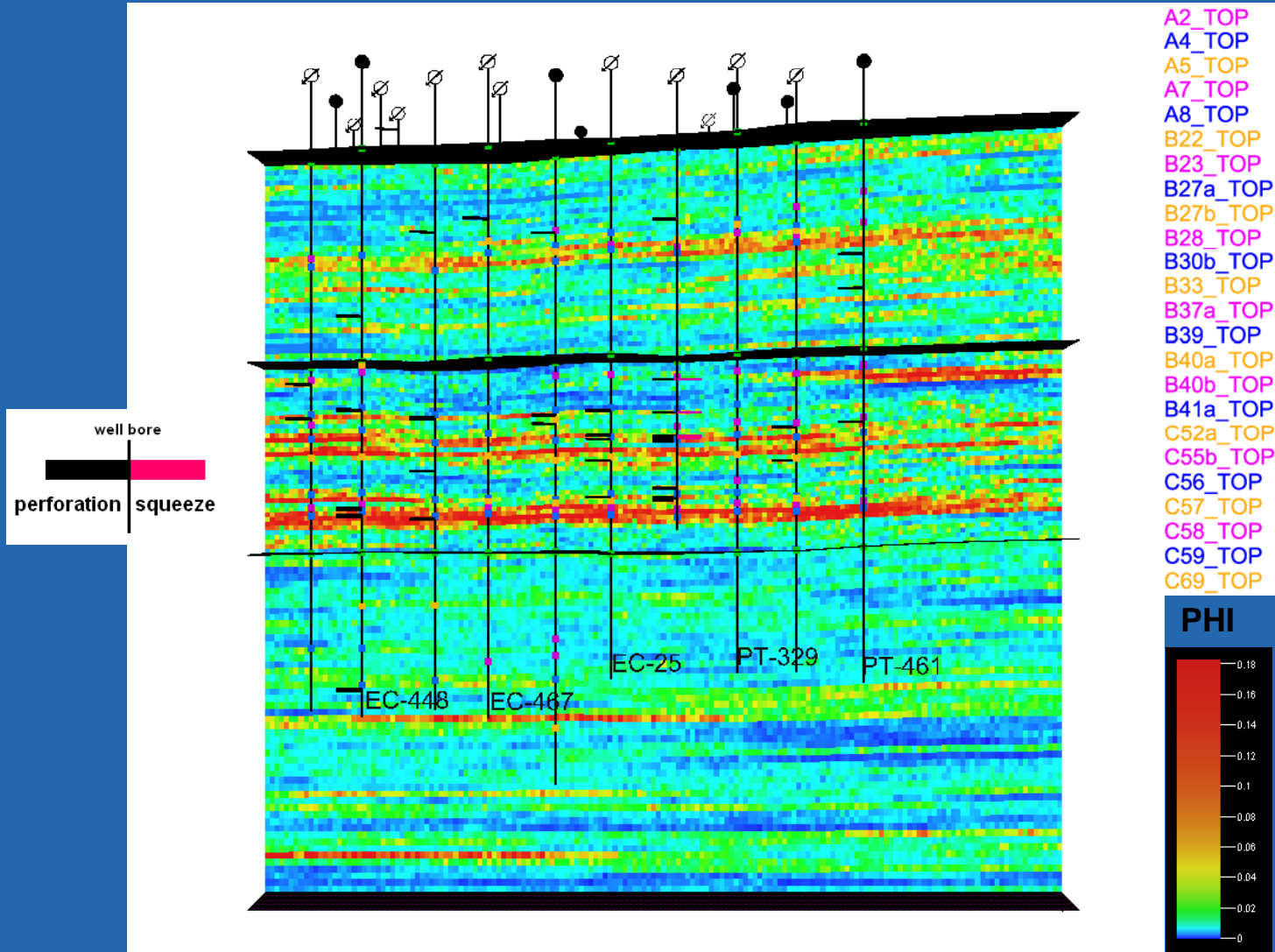
- Improve efficiency through reservoir modeling
- 3D representation of the reservoir features
- Areal and vertical distribution of sand bodies
- Control Area Oil in-Place calculation



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Geocellular Model

Cross Section – Porosity Distribution



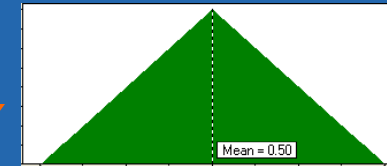
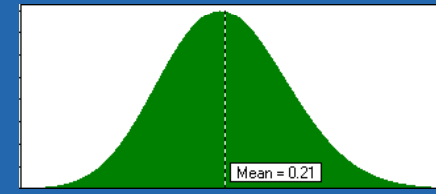
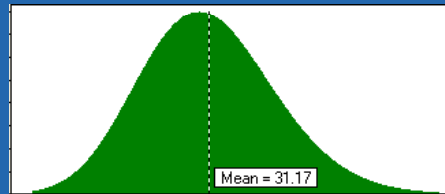
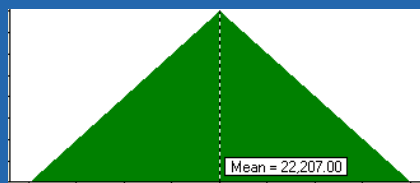
- ## Mapa estructural al Tope Mbro. CO



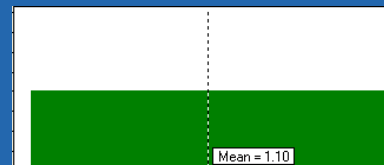
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OOIP Estimation

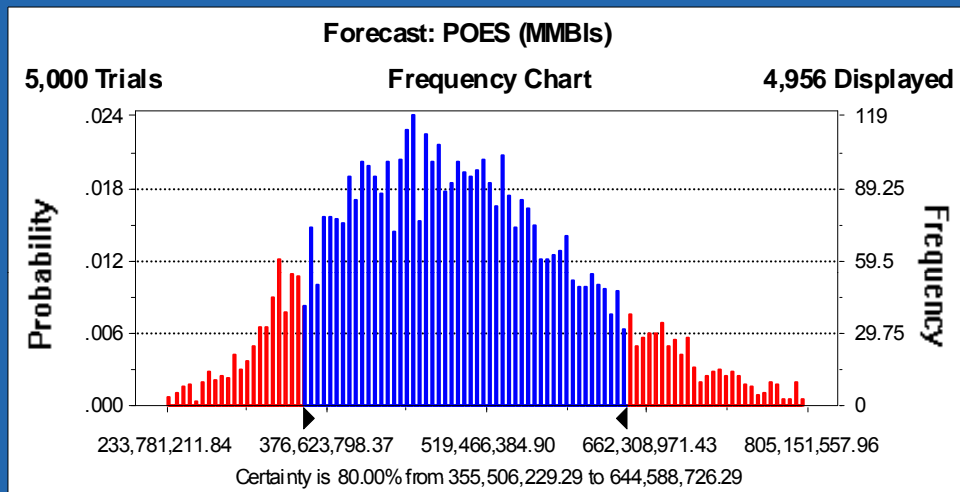
Probabilistic Approach



$$\text{POES} = \frac{7758 * A * \text{ANP} * \phi * (1-S_w)}{\beta_{oi}}$$



OOIP Estimation



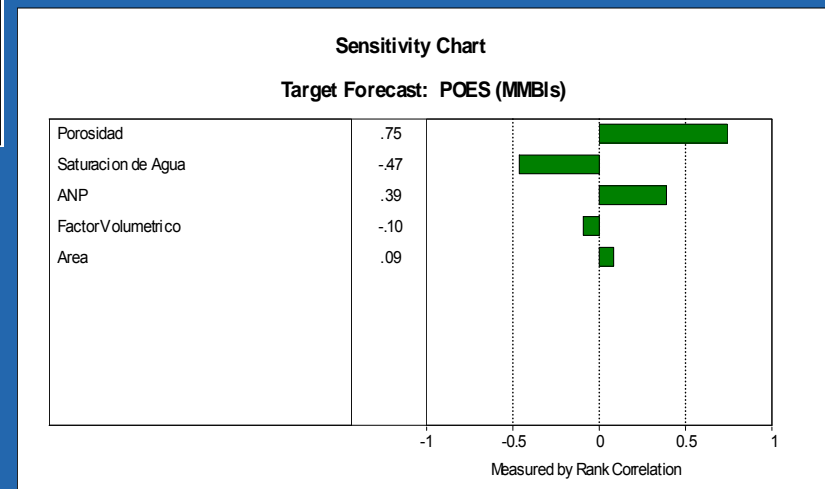
| POES P₁₀ | POES P₅₀ | POES P₉₀ |
|----------------------------|----------------------------|----------------------------|
| 355,506,229.29 | 484,591,381.34 | 644,588,726.29 |

| Statistics: | Value |
|-----------------------|------------------|
| Trials | 5000 |
| Mean | 493,597,486.42 |
| Median | 484,591,381.34 |
| Mode | --- |
| Standard Deviation | 113,279,634.89 |
| Variance | 1.28E+16 |
| Skewness | 0.47 |
| Kurtosis | 3.24 |
| Coeff. of Variability | 0.23 |
| Range Minimum | 199,377,471.94 |
| Range Maximum | 1,021,898,528.82 |
| Range Width | 822,521,056.88 |
| Mean Std. Error | 1,602,015.96 |

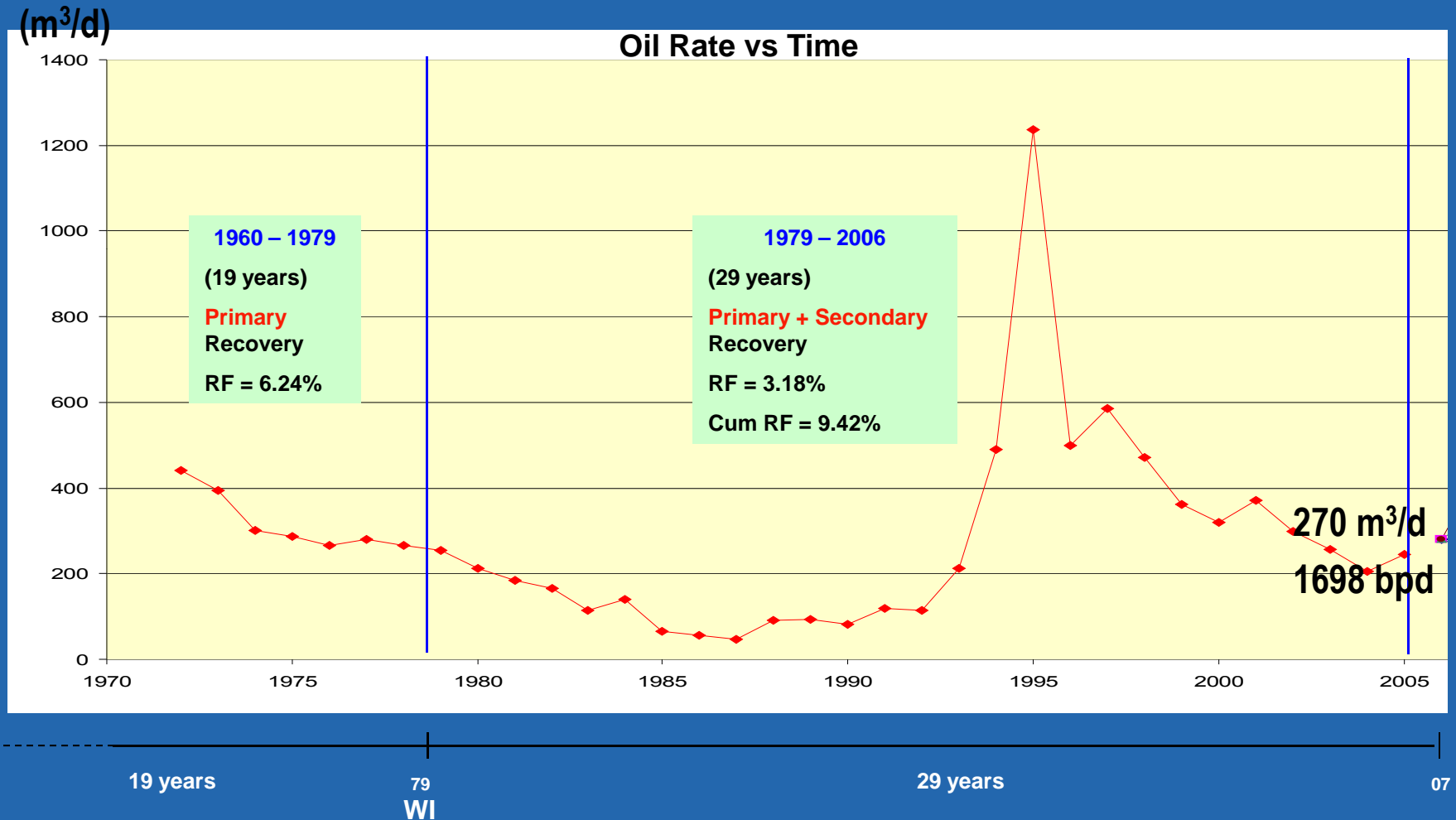
OOIP: 484,6 MMBIs

N_p May 06: 45,6 MMBIs

RF May 06 : 9.4% 9.4%



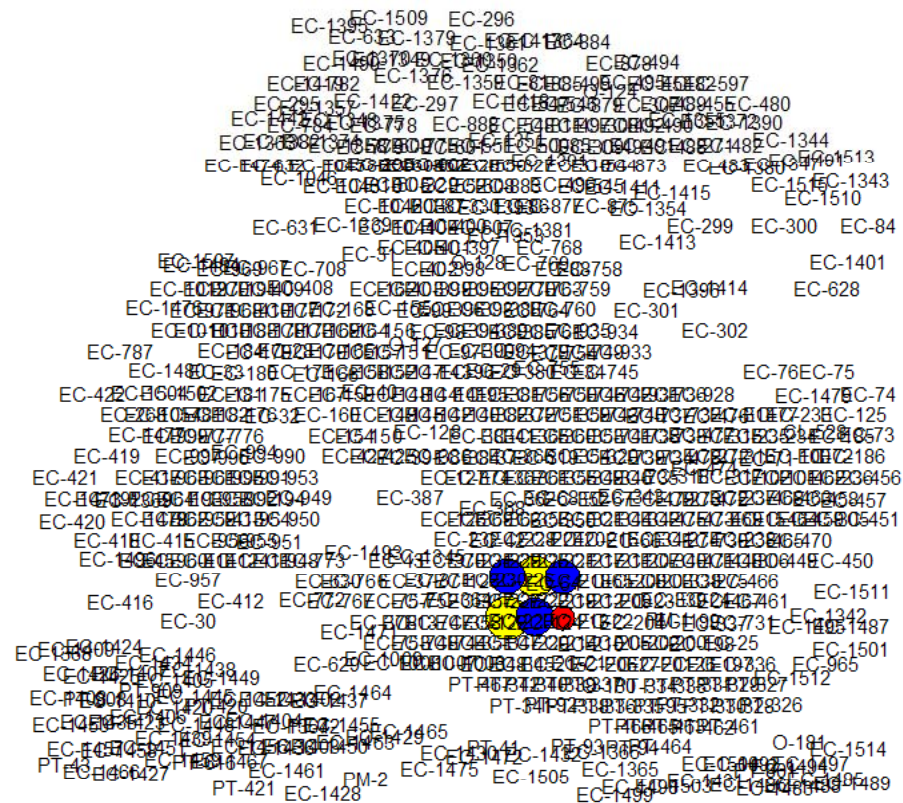
Reservoir Production History



Waterflooding

Field water injection history

DATE:1979/06



Inyección de Agua (Cal Day) (m3/d)

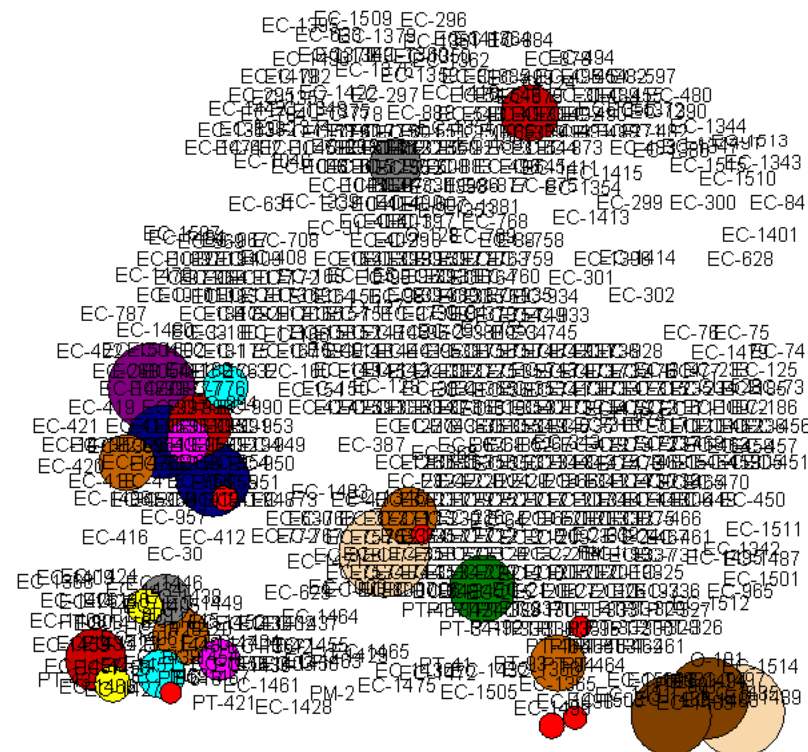


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Waterflooding

Field water injection history

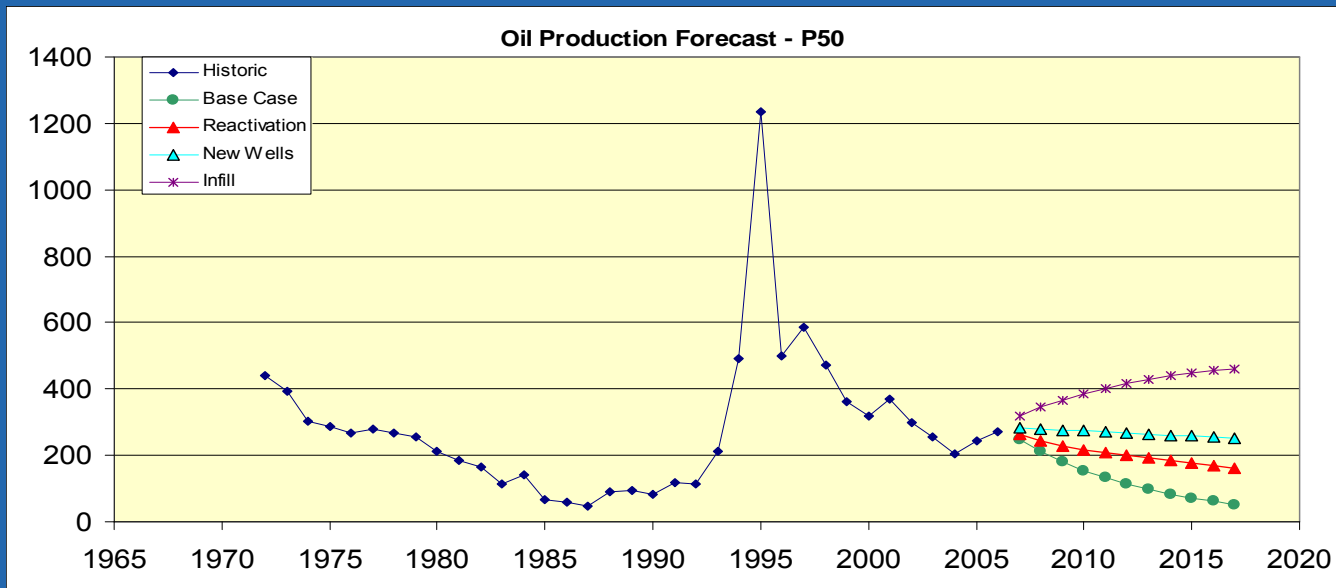
DATE:2006/05



Inyección de Agua (Cal Day) (m3/d)



Base Case
Well Reactivation
New well drilling
Infill drilling
Water flooding
Polymer injection (screening)



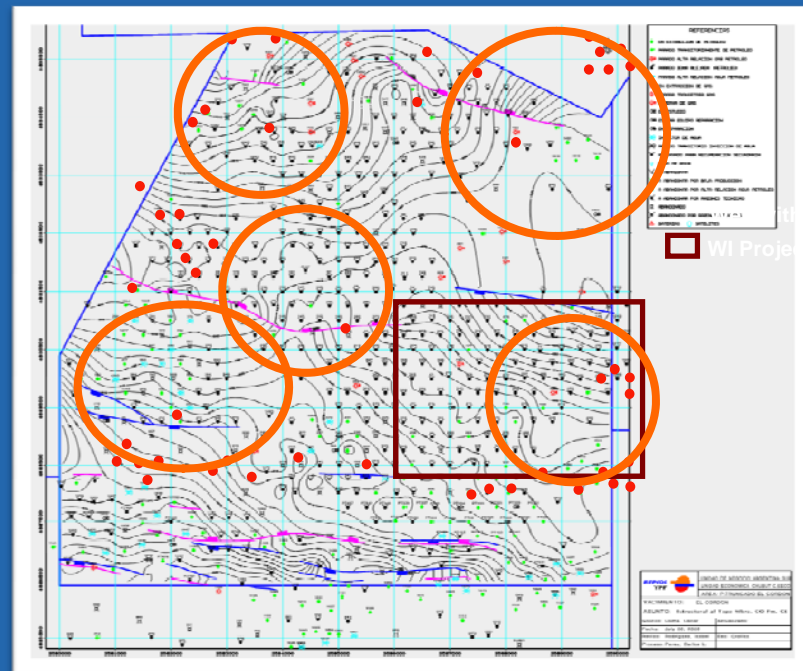
- Review of historical production behavior of all wells in the field.
- Probabilistic distribution modeling for Oil Rate, GOR, Water Cut, Number of wells, emphasizing wells reactivated in the last 2 years .
- Analysis of fracture results .
- Four profiles for each scenario: Low (P10), Most likely (P50), High (P90), and a Maximized case : P90 + 25% increase in the number of wells are considered to illustrate the maximum RF.
- $RF_{2017} (P50) = 14.47\%$, includes all scenarios
- $RF_{2017} (Max) = 21.13\%$, includes all scenarios

- Decline of the production curve to estimate ultimate recovery under current conditions
- Diagnostic Plot: Oil cut vs NP, to validate reserves estimation
- Economic limit was assumed as $Q_o=2 \text{ m}^3/\text{day}$
- Incremental Recovery: 514 Mm^3 @ year 2017
- Incremental Recovery Factor: 0.67% @ year 2017
- Ultimate Recovery Factor: 10.07% @ year 2017

- Currently more than 400 wells shut-in
- In the last 3 years, 15 wells/year have been reactivated.
- Probabilistic distribution for these wells shows:
 - * P10 case: $Q_o = 0.71 \text{ m}^3/\text{day}/\text{well}$
 - * P50 case: $Q_o = 1.99 \text{ m}^3/\text{day}/\text{well}$
 - * P90 case: $Q_o = 5.32 \text{ m}^3/\text{day}/\text{well}$
- P10, P50, and P90 Scenarios were considered
- Production improvement for P90 considers:
 - * Review fracture techniques
 - * High density, high penetration, under-balance.

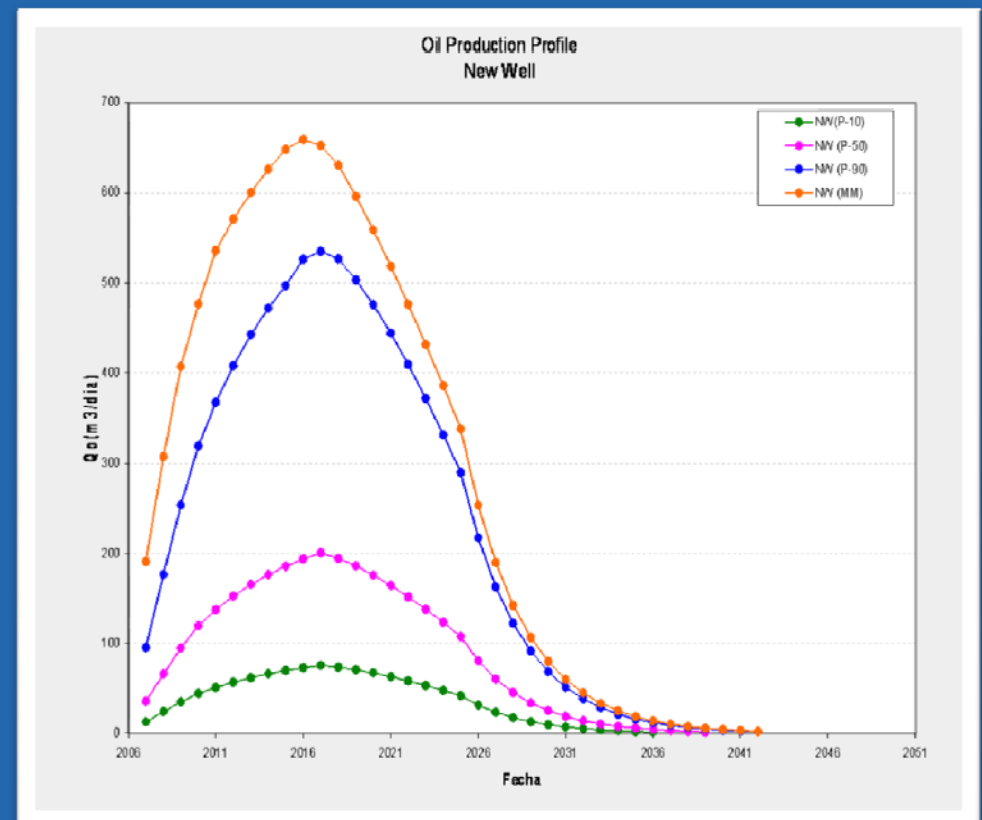
RPS New Well Drilling (330 m spacing)

- Undeveloped areas near to good producer wells.
- Latest drilling in some of these areas has demonstrated good potential.
- Oil rate probabilistic distribution for these wells based upon the new wells.



New Well Drilling (330 m spacing)

- **P10:**
 - Incremental Reserves: 210 Mm³
 - Incremental RF: 0.27%
 - Ultimate RF (react +base) : 10.31%
- **P50:**
 - Incremental Reserves: 305 Mm³
 - Incremental RF 0.72%
 - Ultimate RF (react +base) : 10.76%
- **P90:**
 - Incremental Reserves: 815 Mm³
 - Incremental RF: 1.80%
 - Ultimate RF (react +base) : 11.84%
- **Maximized:**
 - Incremental Reserves: 1136 Mm³
 - Incremental RF: 2.69%
 - Ultimate RF (react +base) : 12.73%

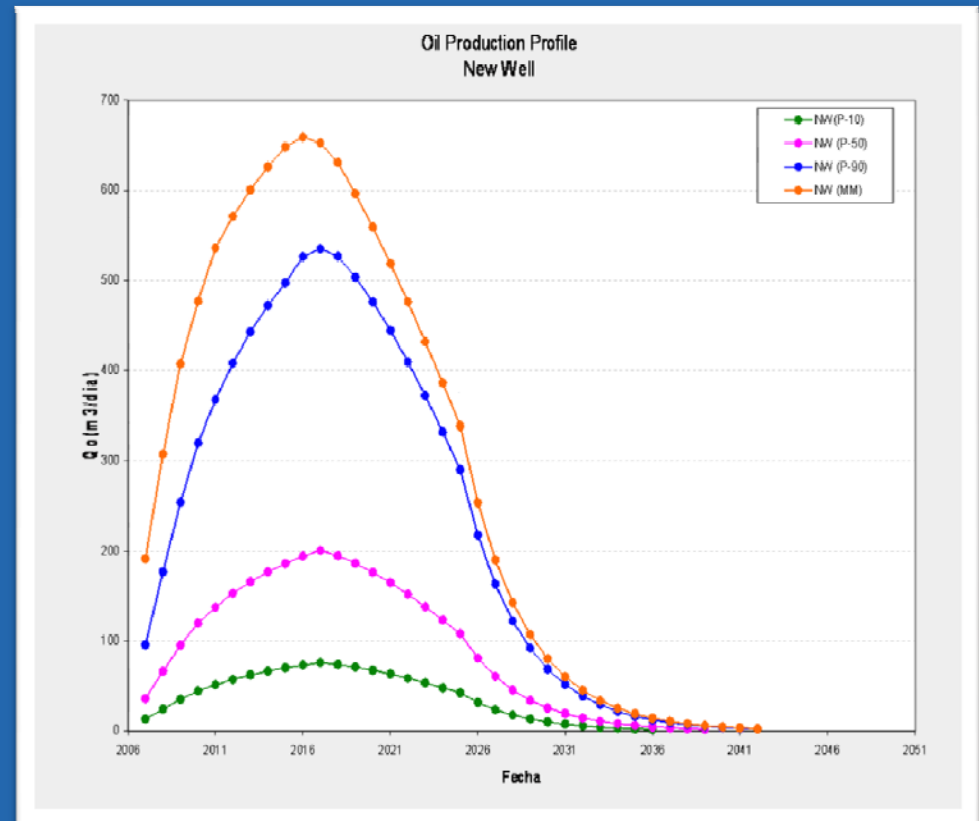


Infill Drilling (165 m spacing)

- IFD is a technical opportunity for reserves recovery
- Radius of drainage was modeled
- Determined that infill drilling could be considered
- Placed wells at half current well spacing.
- IFD results in acceleration of production in homogeneous reservoir and incremental recovery in heterogeneous reservoir, without reservoir continuity

RPS Infill Drilling (165 m spacing)

- **P10:**
 - Incremental Reserves: 411 Mm³
 - Incremental RF: 0.53%
 - Ultimate RF (react +base) : 10.51%
- **P50:**
 - Incremental Reserves: 1117 Mm³
 - Incremental RF 1.45%
 - Ultimate RF (react +base) : 11.49%
- **P90:**
 - Incremental Reserves: 1412 Mm³
 - Incremental RF: 1.83%
 - Ultimate RF (react +base) : 11.87%
- **Maximized:**
 - Incremental Reserves: 3909 Mm³
 - Incremental RF: 5.07%
 - Ultimate RF (react +base) : 15.11%

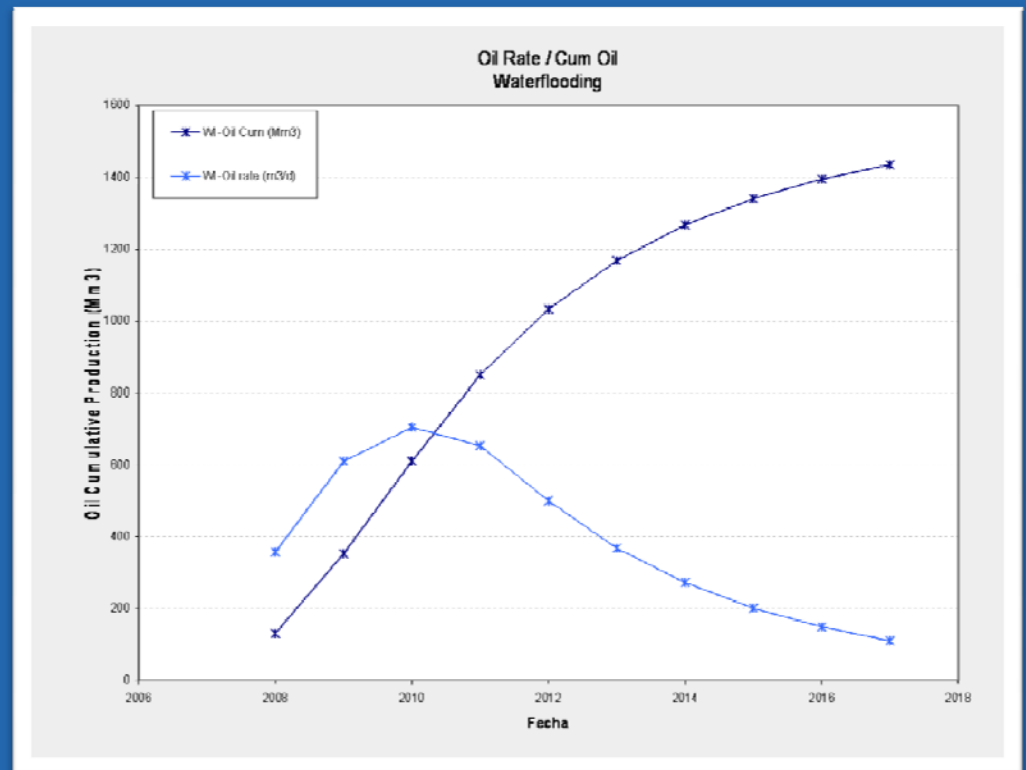


330 wells are assumed to be drilled to develop the Max Scenario

- WI since 1979.
- Small pilot areas with low contribution to the total production of the field. Recovery factor (3.18%)"
- Energy support is a high priority"
- WI scenario is baseX on analogy from current WI pilots and available studies.
- In general well production / pressure behavior reflects the waterflooding influence.

- **P50:**

- Incremental Reserves: 1436 Mm³
- Incremental RF: 1.86%
- Ultimate RF (react +base) : 11.9%
- No new wells needed-only conversions and workover
- 108 injector wells
- 162 producer wells
- Based on analog



Polymer Injection

Polymer Flooding: better displacement and volumetric sweep efficiencies

- Increasing the viscosity of water
- Decreasing the mobility of water
- Contacting a larger volume of the reservoir

| | Technical Screening Guides | EL CORDON (CS1 / CO / ME) |
|---------------------------|---|---------------------------|
| Crude Oil: | | |
| Gravity: | > 25 API | 25 / 26 / 31 |
| Viscosity | 100 cp | 27 / 26 / 12 |
| Composition Not | critical | |
| Reservoir: | | |
| Oil Saturation: | > 10% PV mobile oil | 22 |
| Type of Formation: | Sandstone, but can be used in carbonate | Sandstone |
| Net thickness (m) | Not critical | 3-4 mt |
| Average Permeability (mD) | > 10 | 250 / 200 / 150 |
| Depth (m) | < about 2743 | 1200 / 1300 / 1450 |
| Temperature (F) | < 200 F to minimize degradation | 119 / 126 / 132 |

Polymer Injection

Surfactant / Polymer Flooding:

- Lowering the interfacial tension between oil and water
- Solubilization of oil
- Emulsification of oil and water
- Mobility enhancement

| | Technical Screening Guides | EL CORDON (CS1 / CO / ME) |
|--|--|------------------------------|
| Crude: | | |
| Gravity: Viscosity < Composition | > 25 API 30 cp Light Intermediates are desirable | 25 / 26 / 31 27 / 26 / 12 |
| Reservoir: | | |
| Oil Saturation: | > 30% PV mobile oil | 22 |
| Type of Formation: | Sandstone preferred | Sandstone |
| Net thickness (m) | > 3.04 | 3-4 m |
| Average Permeability (mD) | > 20 | 250 / 200 / 150 |
| Depth (m) | < about 2435 | 1200 / 1300 / 1450 |
| Temperature (F) | < 175 F | 119 / 126 / 132 |

- Incremental Recovery Factor

Recovery Factor 2007 - 2017

| | P10 | | P50 | | P90 | | Maximized | |
|-----------------|-----|--------|------|--------|------|--------|-----------|--------|
| | Mm3 | %RF | Mm3 | %RF | Mm3 | %RF | Mm3 | %RF |
| Base Case | 514 | 0.67% | 514 | 0.67% | 514 | 0.67% | 514 | 0.67% |
| Reactivation | 109 | 0.14% | 305 | 0.40% | 815 | 1.06% | 1136 | 1.47% |
| New Wells | 210 | 0.27% | 559 | 0.72% | 1386 | 1.80% | 2075 | 2.69% |
| Infill Drilling | 411 | 0.53% | 1117 | 1.45% | 1412 | 1.83% | 3909 | 5.07% |
| Water Flooding | | | 1436 | 1.86% | 1436 | | | 1.86% |
| Incremental RF | | 1.61% | | 5.09% | | 5.35% | | 11.75% |
| Cum RF | | 10.99% | | 14.47% | | 14.72% | | 21.13% |

POES (Mm3) 77164 After Visualization
 POES (MMstb) 485 After Visualization
 Cum Oil Prod (Mm3) 2005 7733
 RF 2005 9.37%

RPS

END