Optimization of a Mature CO_2 Flood

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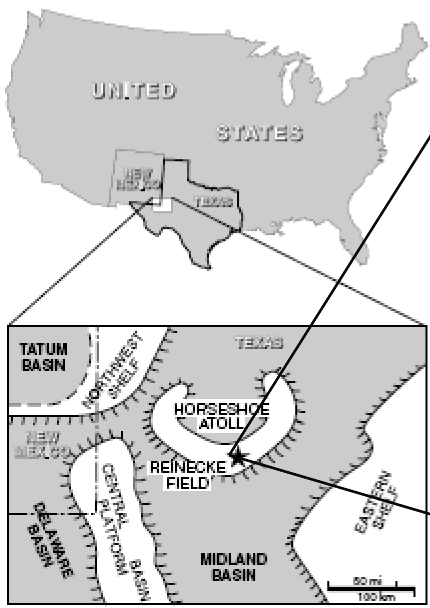
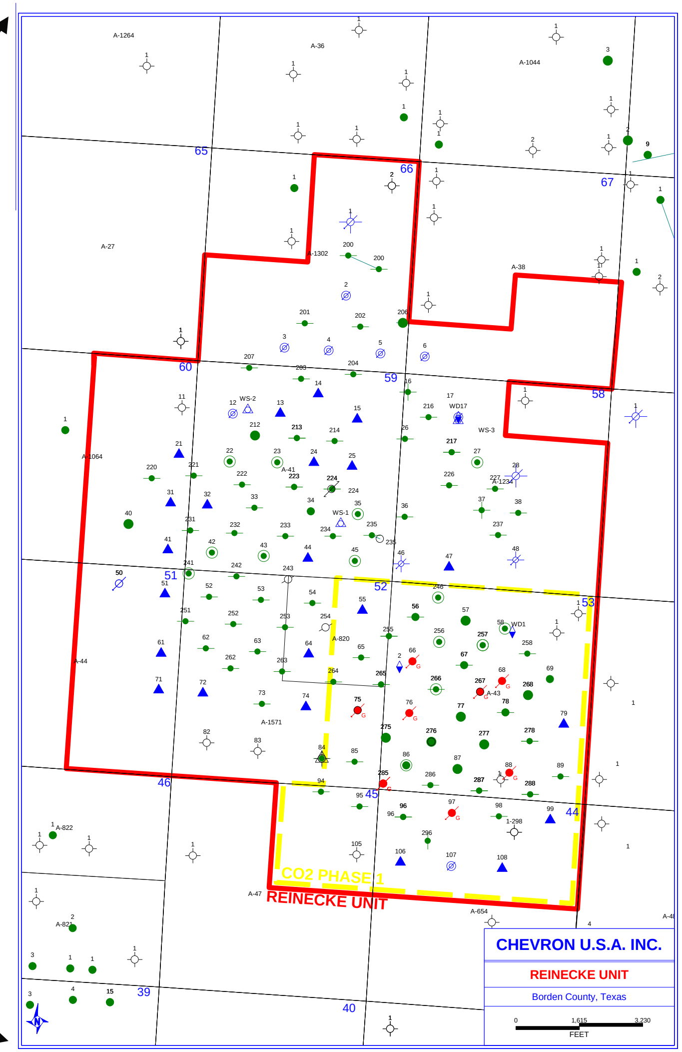
Field Data

Field Overview

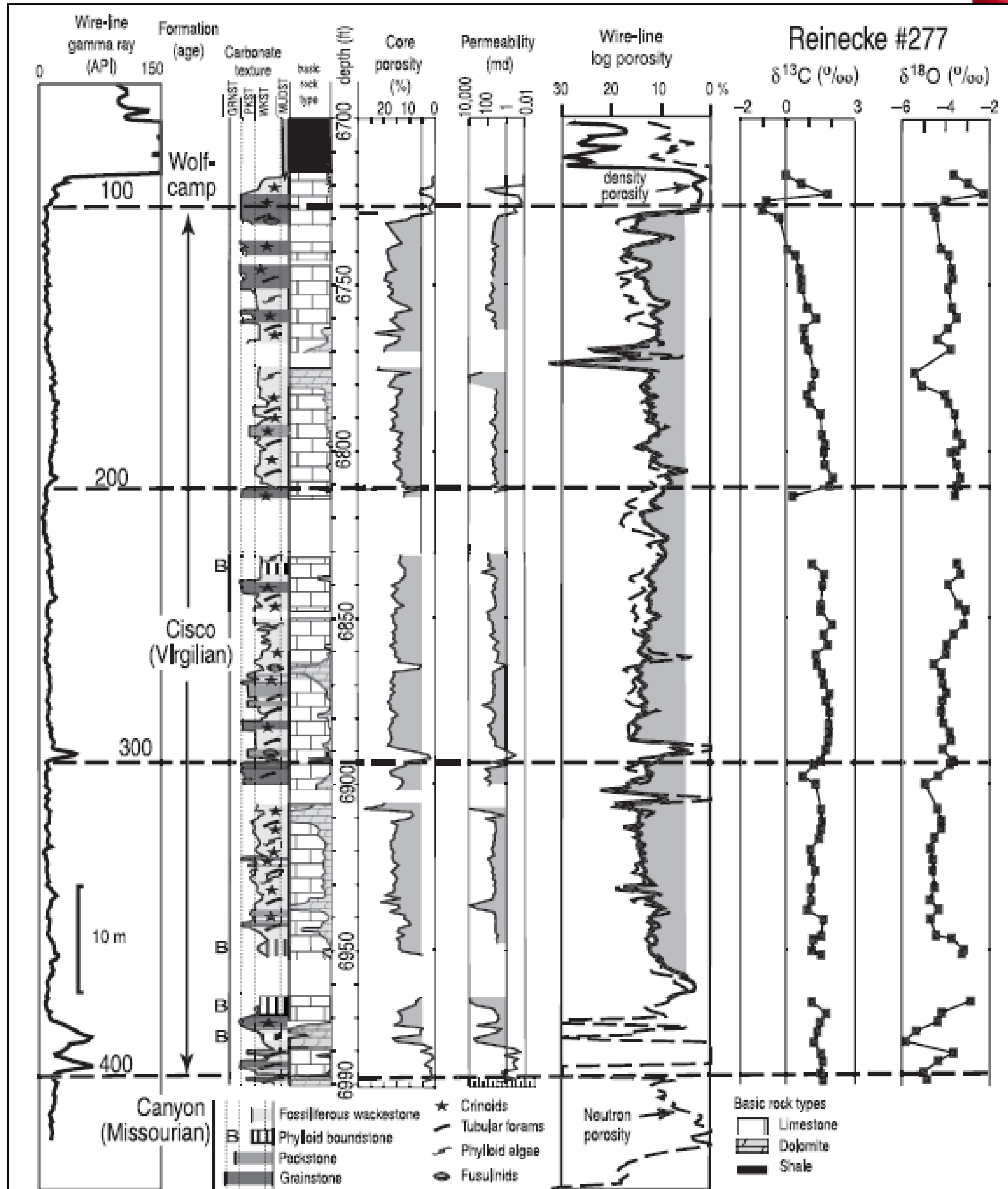
- Discovered in February 1950
- Developed with 75 wells by 1952
- Unitized for pressure maintenance in late 1971; peripheral water injection below original oil-water contact
- Initial 20-acre infill well drilled in 1984
- Final 20-acre infill well completed in 1992
- Initiated CO_2 injection in January 1998





Geology

- 4 Sequences
  - 100, 200, 300 and 400
  - Transgressive facies
- 3 Producing intervals
  - 50 to 100 ft thick
- South Dome ~ 1Mi^2
- Limestone 80 % reservoir
  - PHI 11%
  - K 165 mD
- Dolomite 20 % reservoir
  - PHI 8.3%
  - K 894 mD
- Shale < 1%
  - Vertical barrier



Issues vs. Opportunities

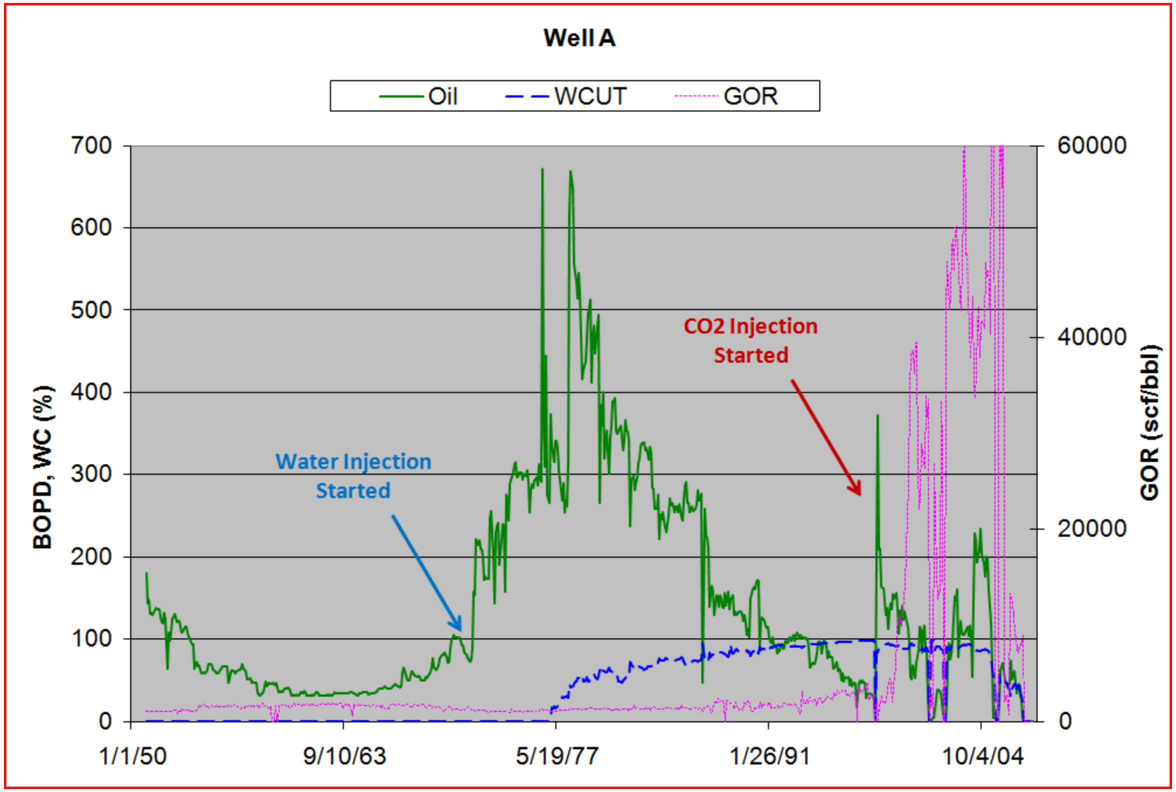
Gravity Stable CO2 Flooding

Original design basis:

- Excellent primary + secondary recovery
- Dome structure fits in gravity stable design

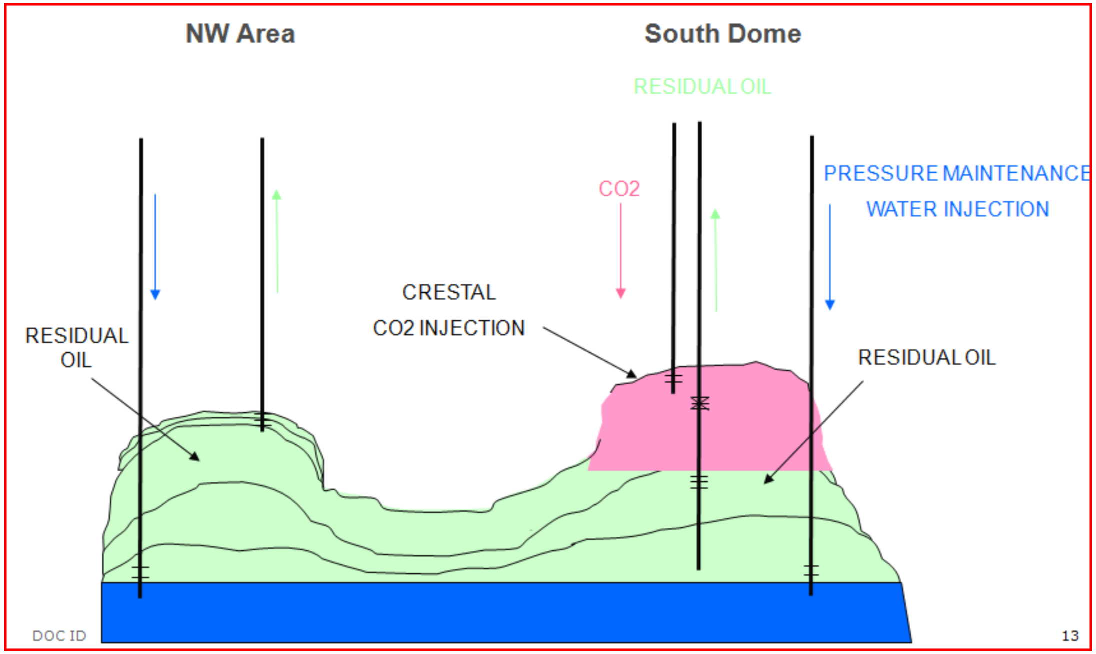
Tertiary results:

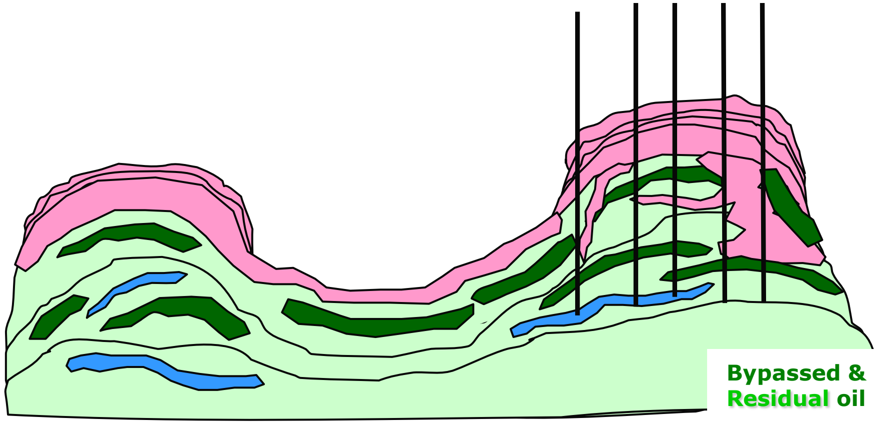
- Initial: Good CO2 responses
- Current: Late stage CO2 flood in South Dome
  High CO2 utilization factor
  High GOR and high gas production



Design Concept vs. Actual Field Observations

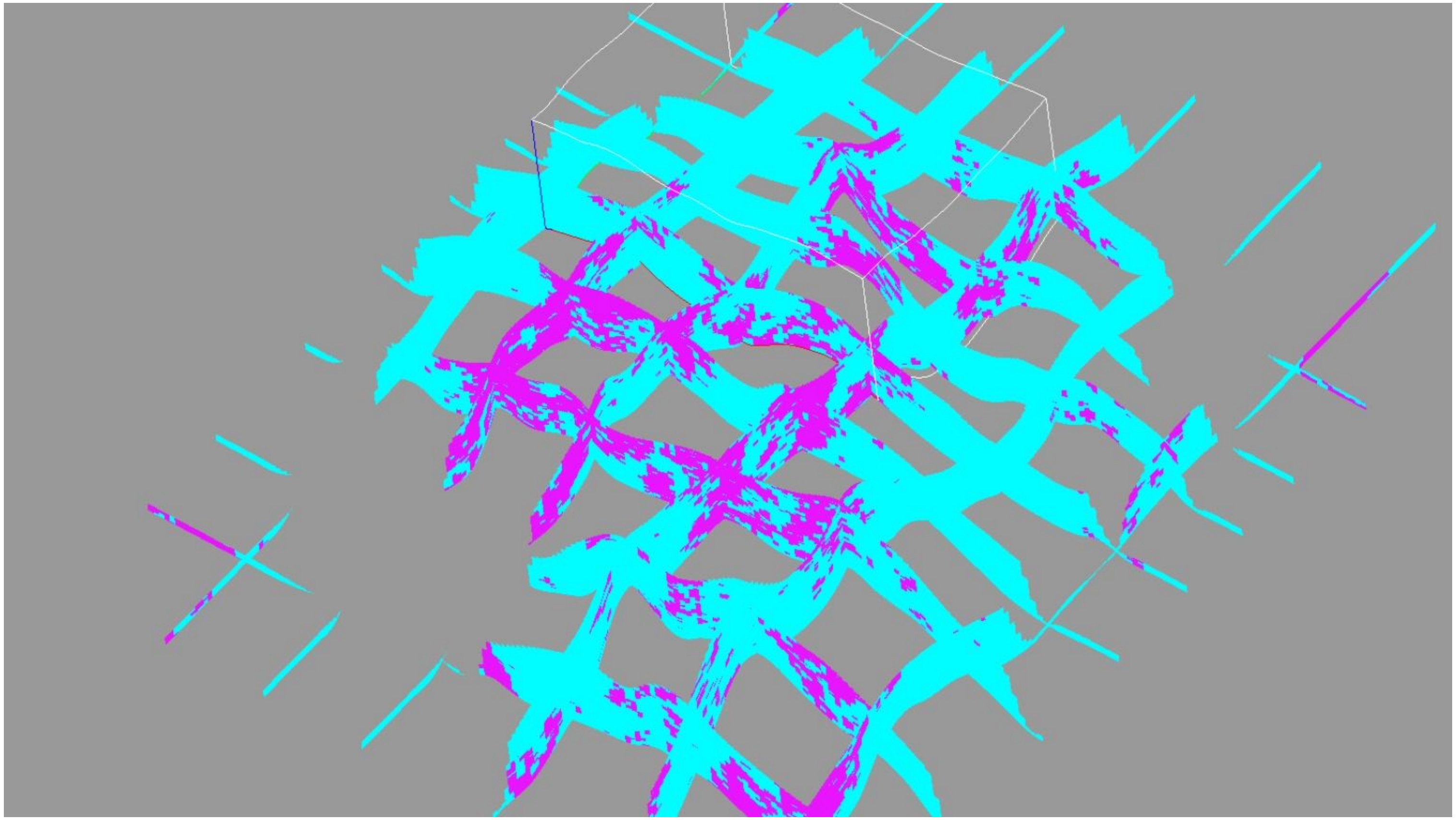
Hypothetical cartoon



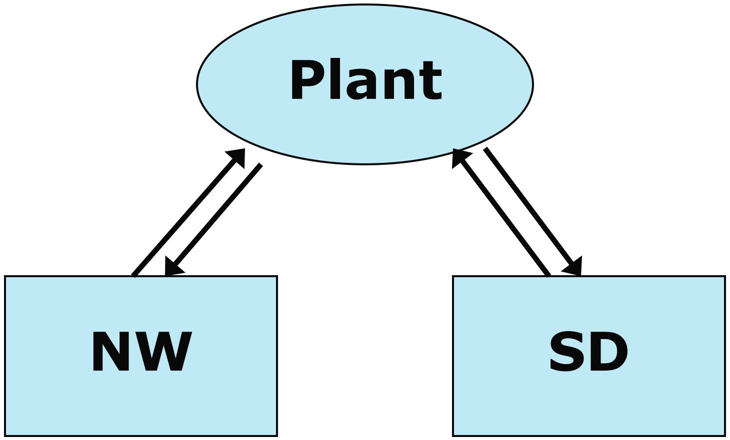


CO2 Bypass Indication

- Well response indicated vertical communication b/w zone 1&2
- Earth model indicated dolomite chimney inside South Dome



Field Potential and Challenges



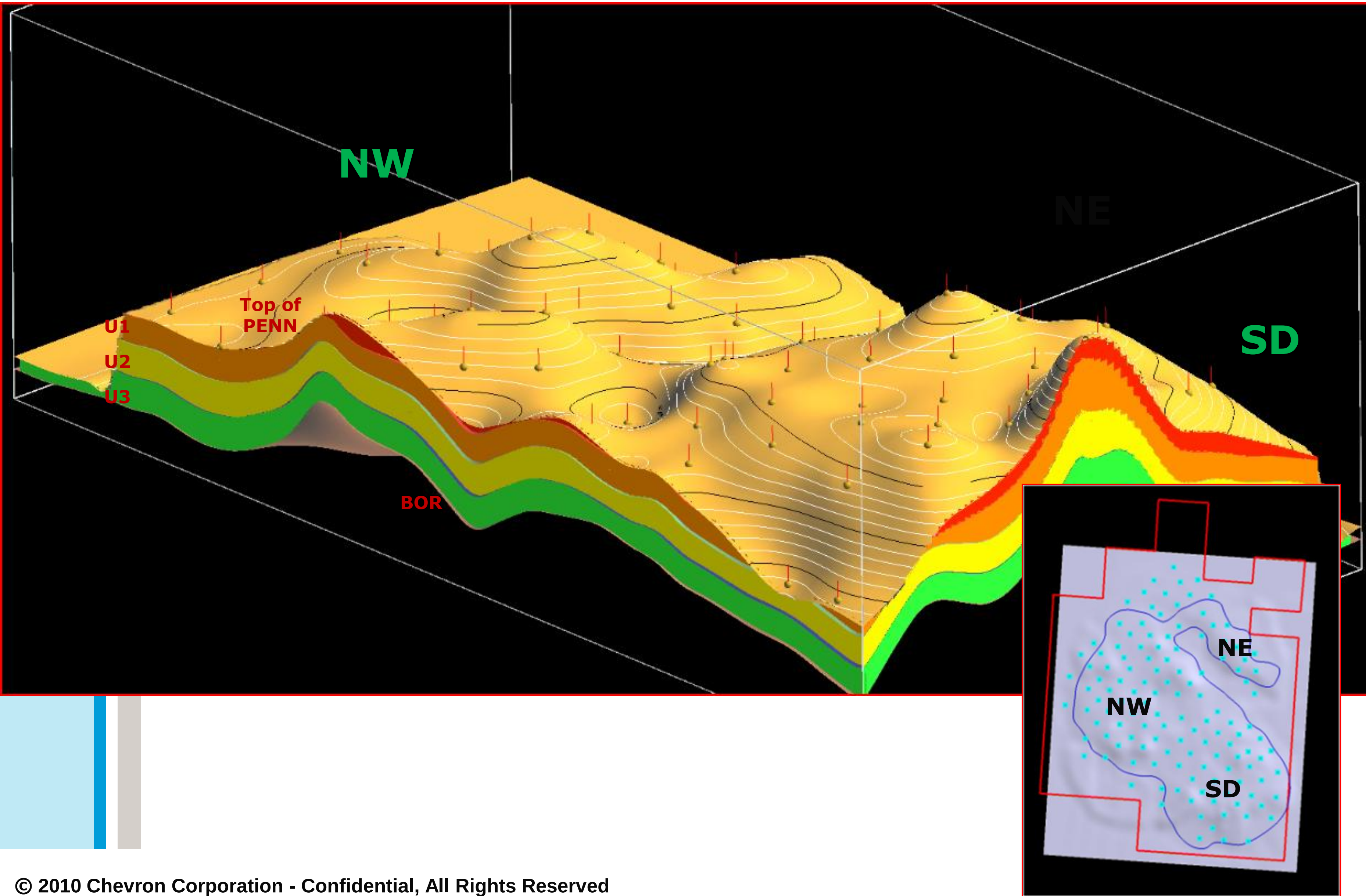
- Opportunities
  - Optimize current CO_2 flooding area
  - Expand CO_2 flooding to water flood area
  - Fully utilize current gas plant capacity & existing CO_2 facilities
  - Realize substantial tertiary oil recovery
- Challenges:
  - Limited well data
  - Aged wellbores
  - Completion strategies – commingle vs. selective
- Needs:
  - Understand current field operation
  - Develop strategies to capture opportunities identified

Reservoir Simulation

Engineering Evaluations Prior to Simulation

- Evaluated water and CO_2 flood performances
- Conducted material balance study to confirm OOIP, reservoir pressure, aquifer support
- Identified field potentials by analog study
- Sampled production fluid and reviewed previous PVT & CO_2 miscibility tests to understand reservoir fluid behaviors and miscibility requirement
- Recompiled wellbore diagrams to understand field completion history and wellbore integrity
- Analyzed MICP and centrifuge capillary pressure results to identify fluid distribution

3-D Earth Model Structure



Reservoir Simulation Strategies

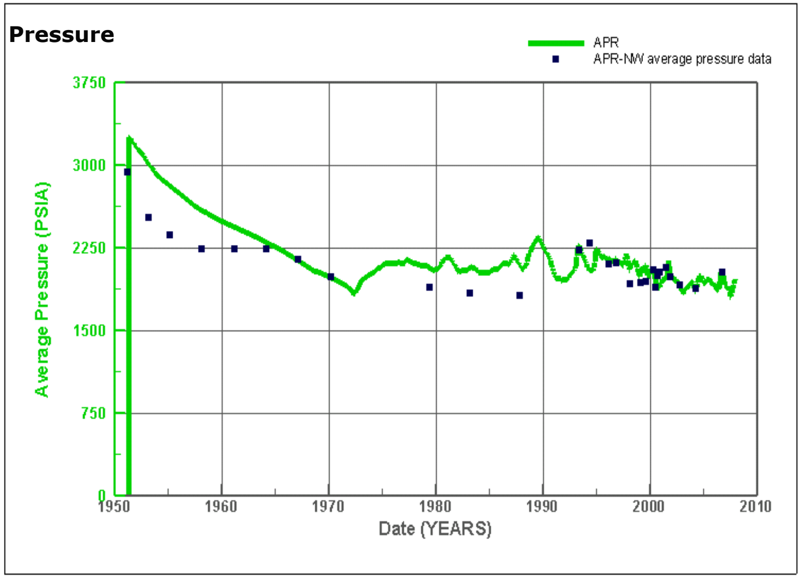
- Simplified cross-section model
- High-level history match to understand
  - ✓ Local OOIP, water flooding mechanism and residual oil distribution after WF
- Forward simulation on
  - ✓ straight CO_2 injection to understand gravity stable design
  - ✓ WAG injection to evaluate the flood efficiency and various completion scenarios for completion design

Simulation Results

- Results Observations
  - ✓ Continuous CO_2 injection with gravity stable design is ineffective in this reservoir due to the existence of the high-perm streaks and high CO_2 mobility
  - ✓ WAG could be more efficient because of its mobility modification on injectant
  - ✓ Selective completion – bottom-up is superior to others in terms of recovery

X-section Simulation History Match

APR



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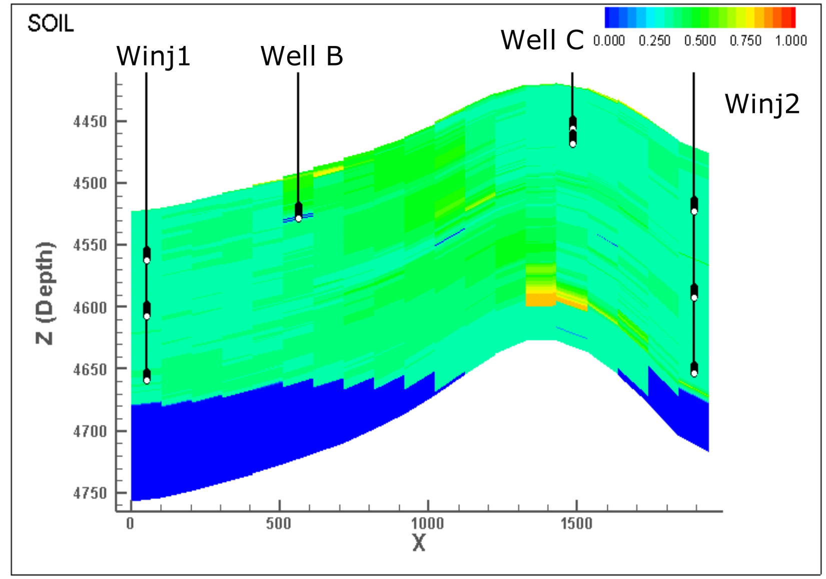

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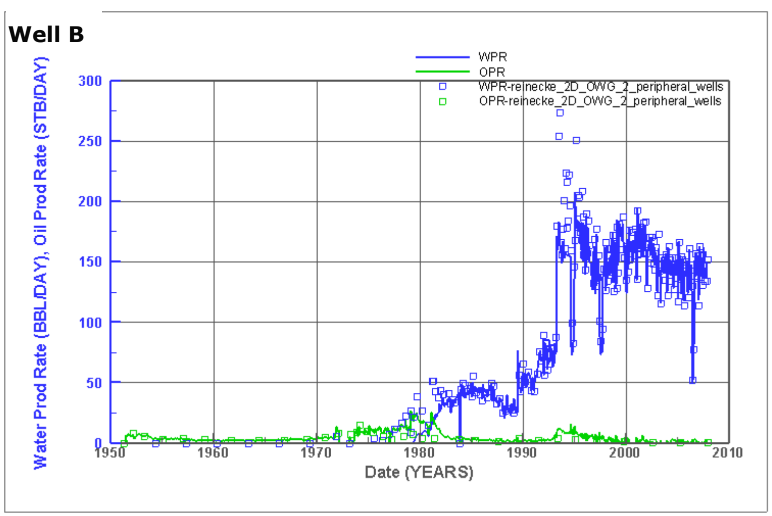
WPR, OPR



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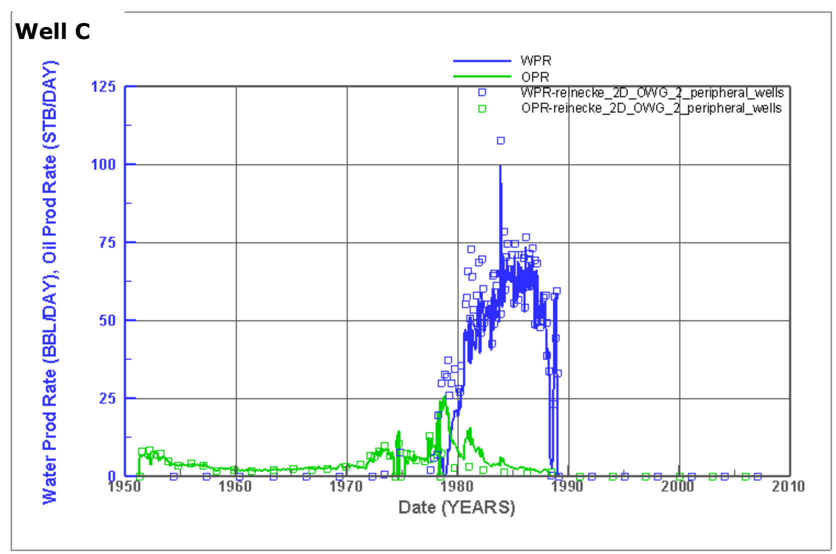

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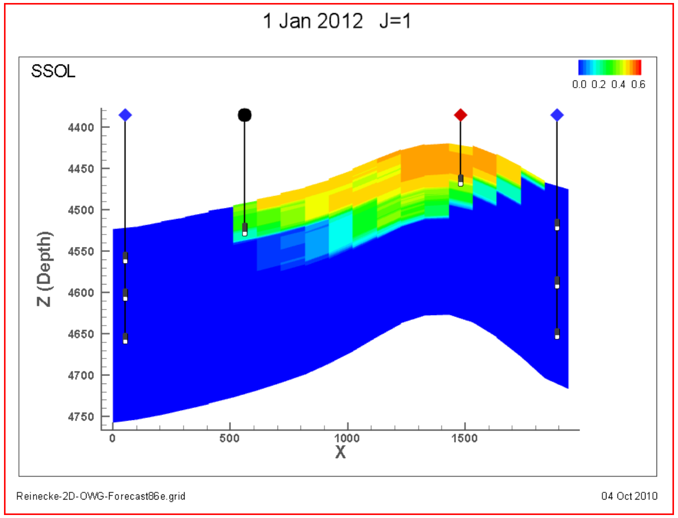
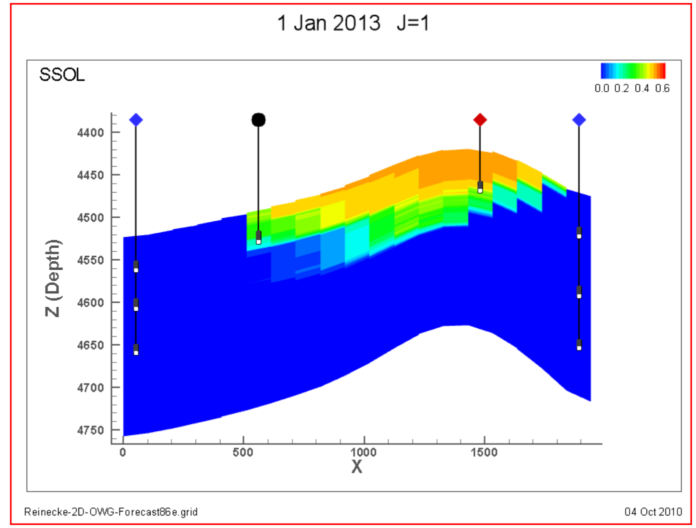
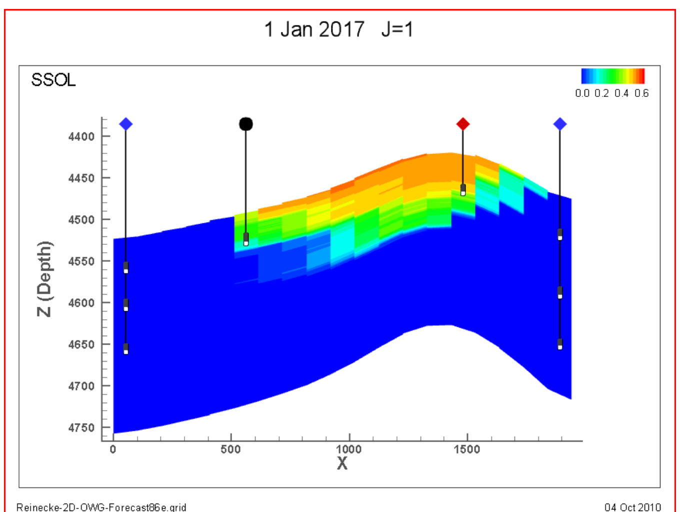
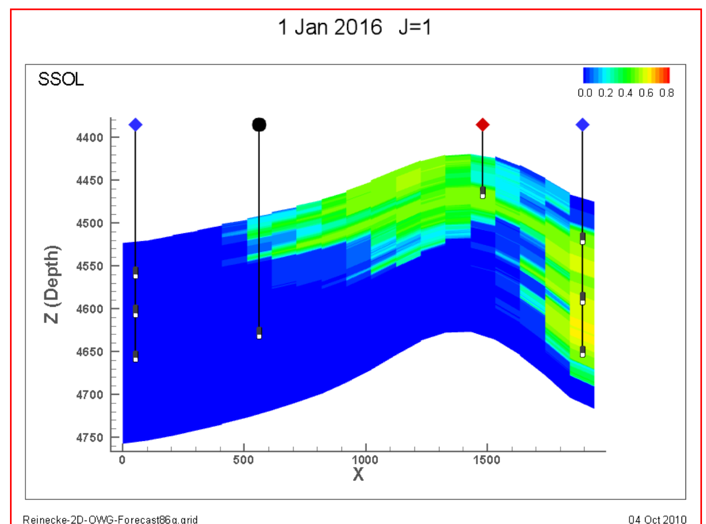
Deepen Producer Only – Solvent Saturation

- CO_2 couldn't sweep the lower zones effectively due to high perm channeling



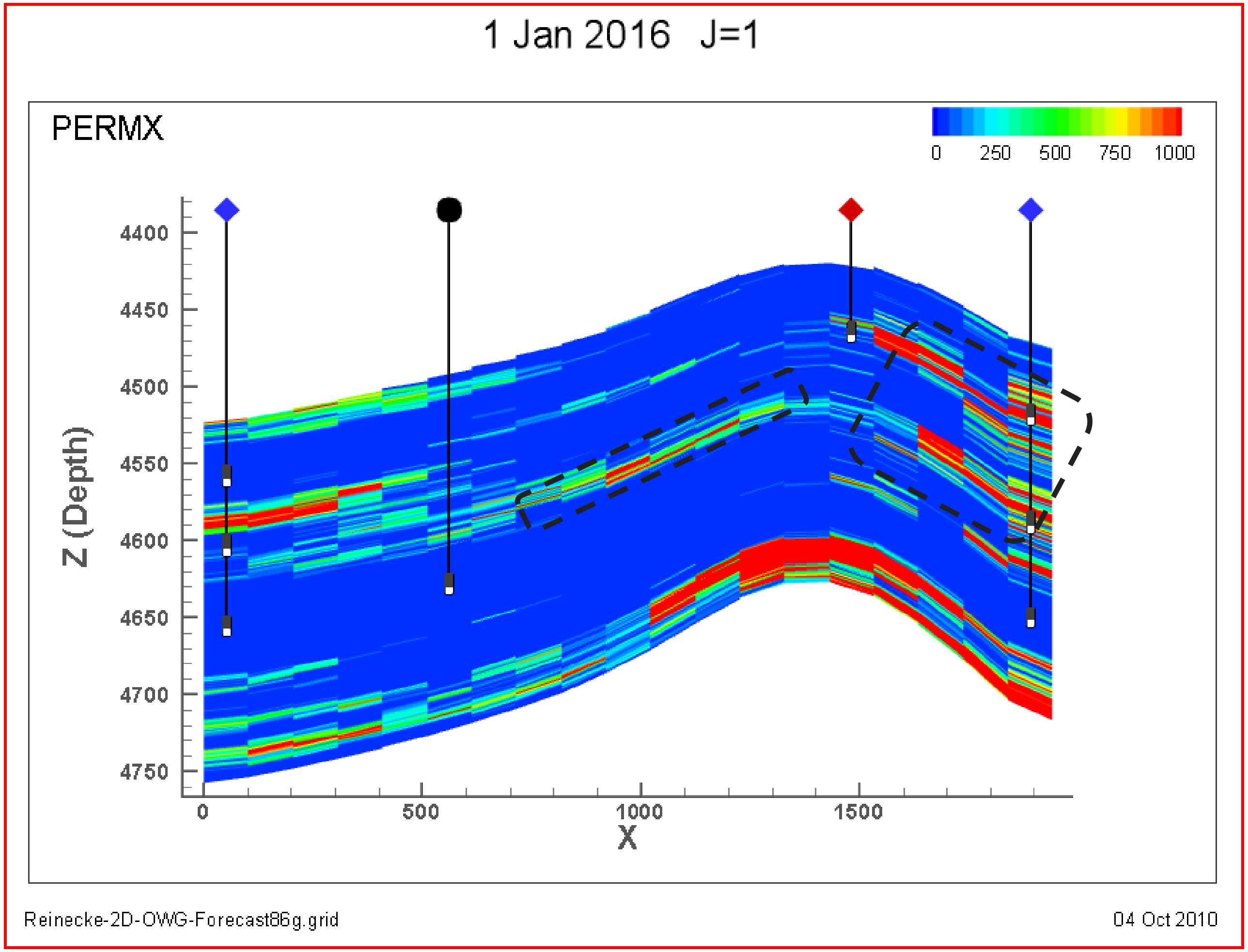






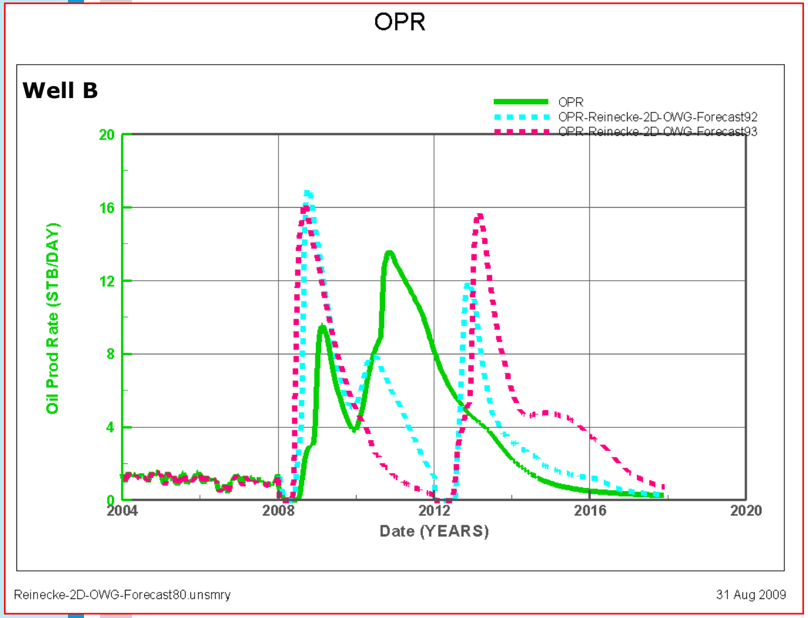
Impact of High & Low Perm Strikes

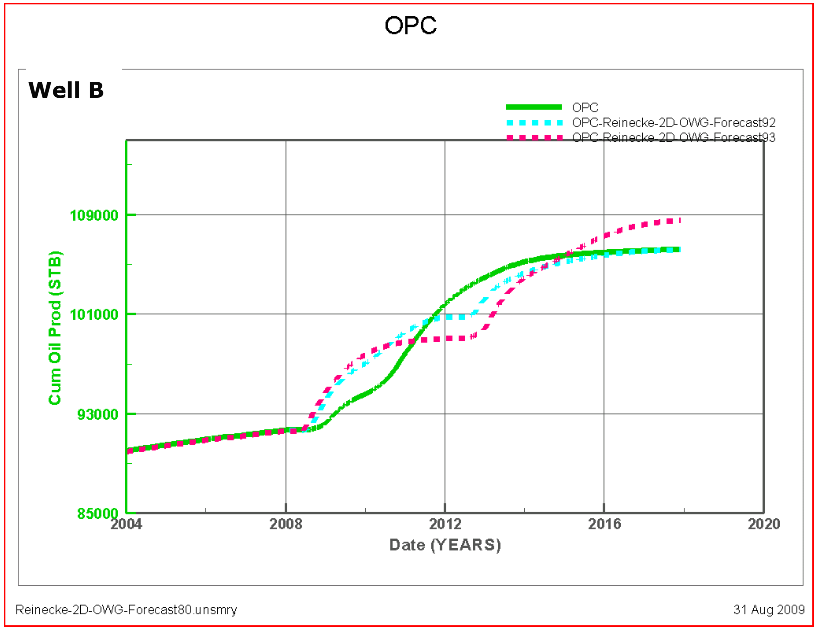
- Reservoir quality will affect CO_2 sweeping path and efficiency
- Reservoir quality will impact completion strategy



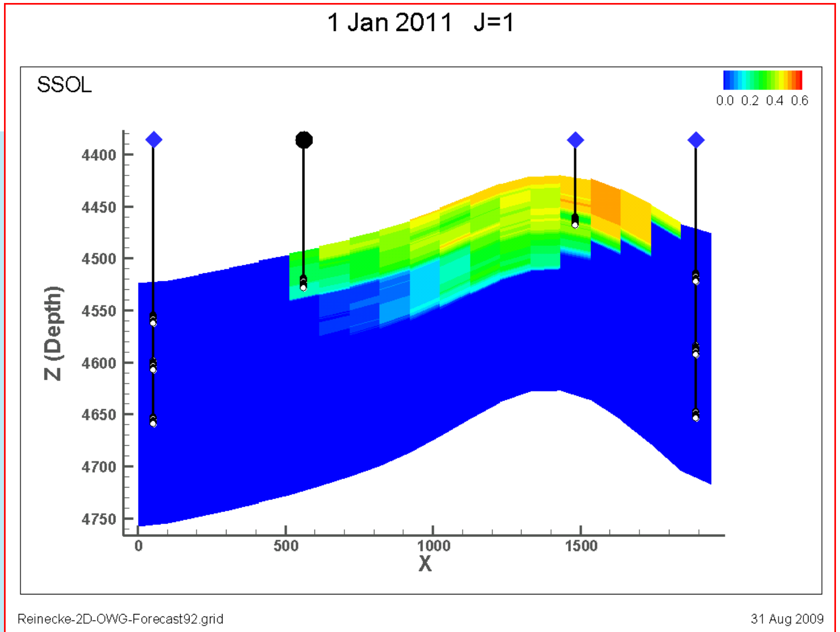
Completion Strategy Comparison – BOPD & Cum

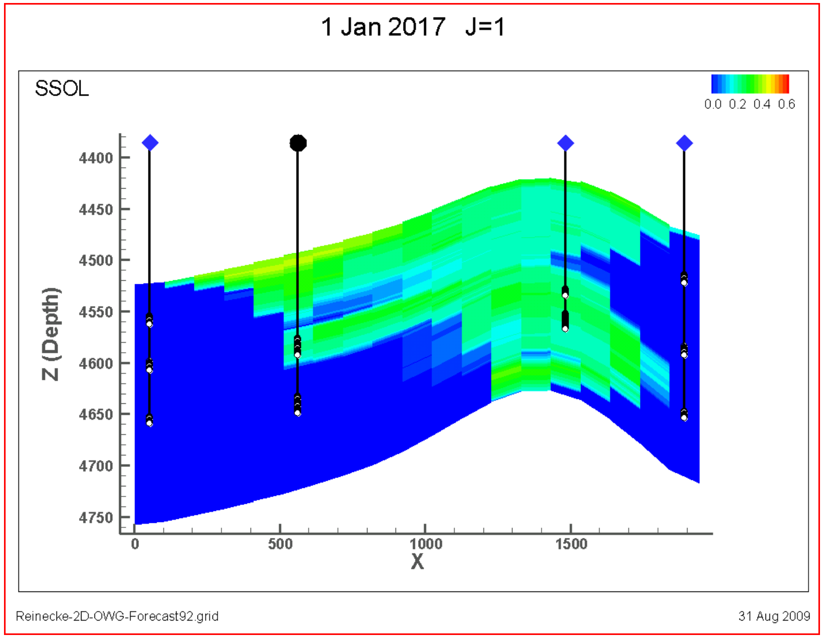
- Bottom-up completion is better than Top-down
- Selective provides better early production than commingle

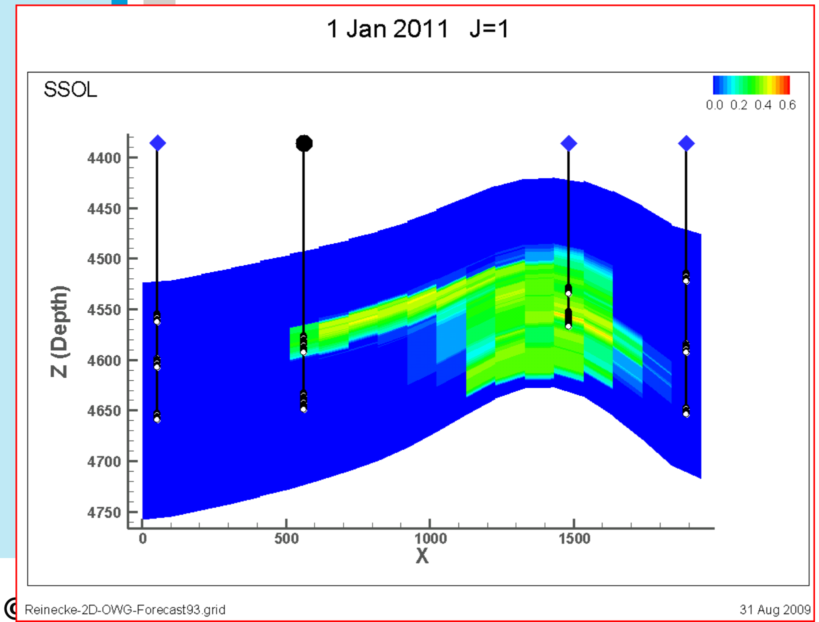


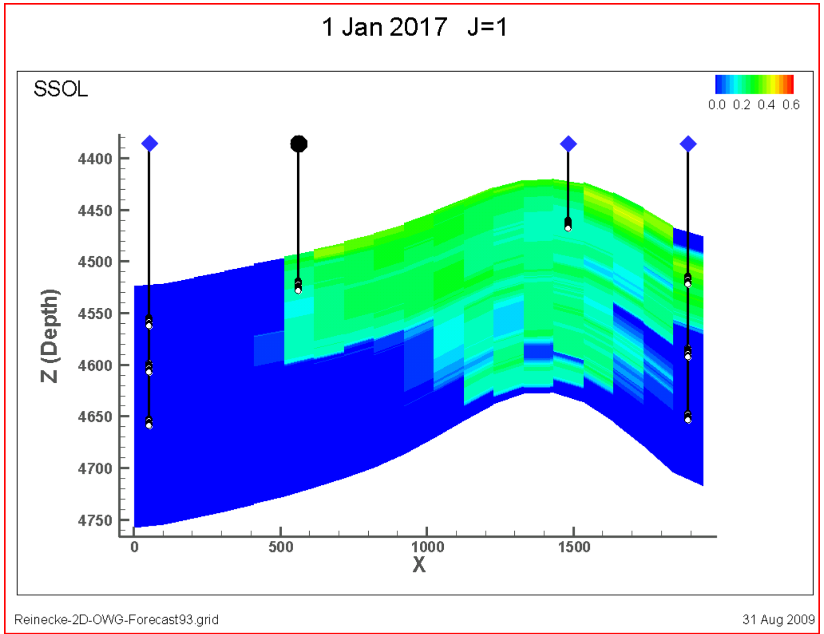


Completion Strategy Comparison – Solvent Saturation









Conclusions & Recommendations

Summary

- Lessons Learned
  - ✓The heterogeneity of the reservoir highly compromised the original gravity-stable design.
  - ✓It's critical to understand the impact of vertical communication on CO_2 flood efficiency.
- Best Practice
  - ✓Cross-section reservoir simulation can be used to understand reservoir recovery mechanisms and provide forecasts that allow the selection of the proper injection strategy.
- Conclusion
  - ✓A bottom-up completion with WAG could be more effective for this reservoir