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How to get the most out of your Oil Rim Reservoirs? Reservoir management and hydrocarbon recovery enhancement initiatives

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PETRONAS

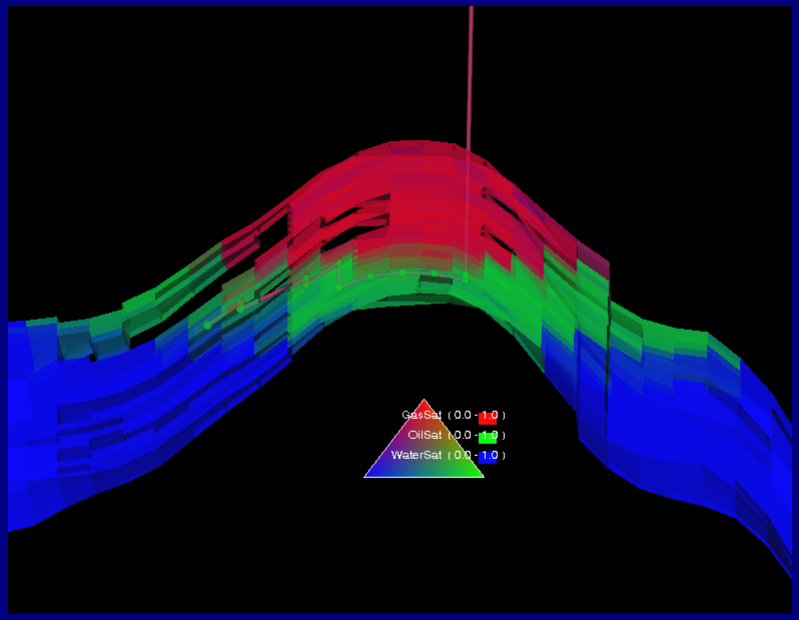
Outline:

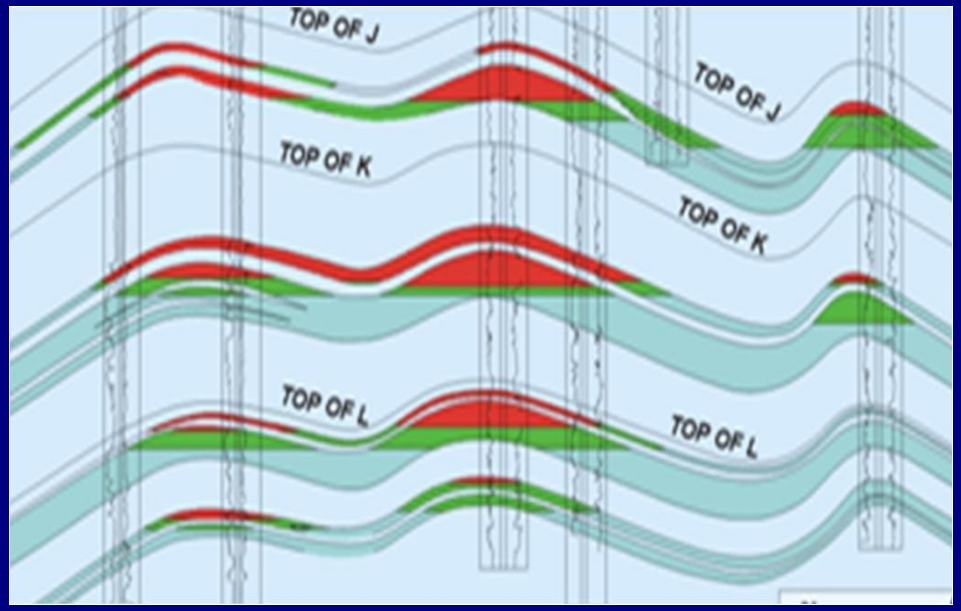
- Oil Rim definition/concept/Challenges
- Guidelines/best practices/key technologies/success factors
- Reservoir and business management and exploitation strategies
- Successful field application and examples
- Closing Remarks

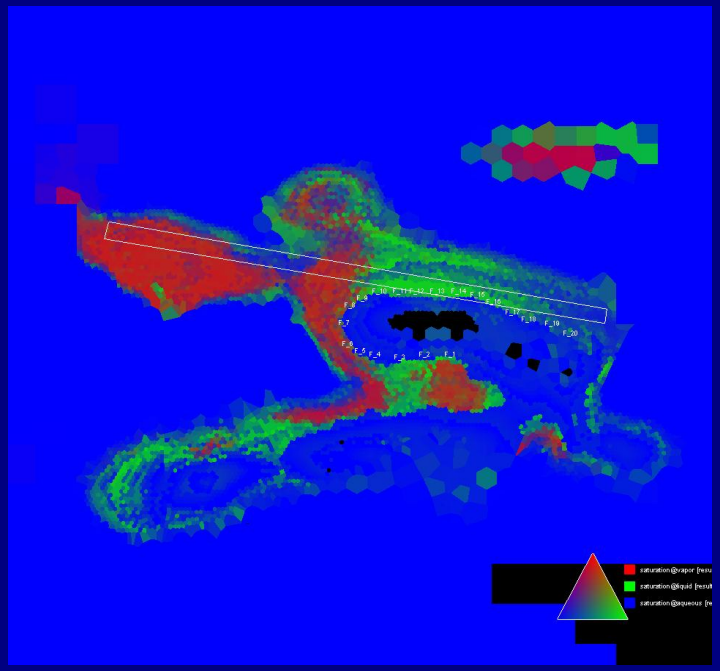
Oil Rim

Opportunity and Headache!

- Limited Thickness
- Overlain by Gas Cap
- Underlain by Aquifer

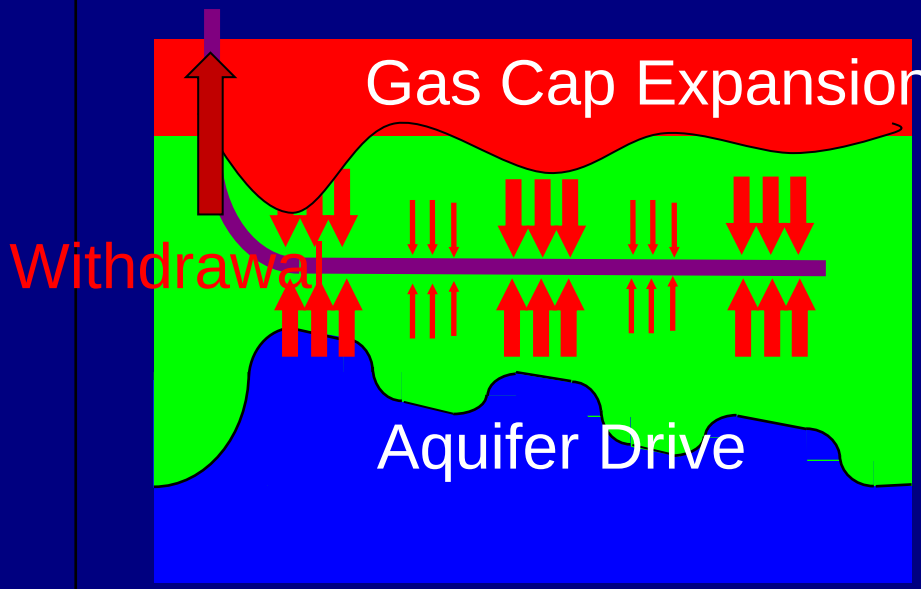


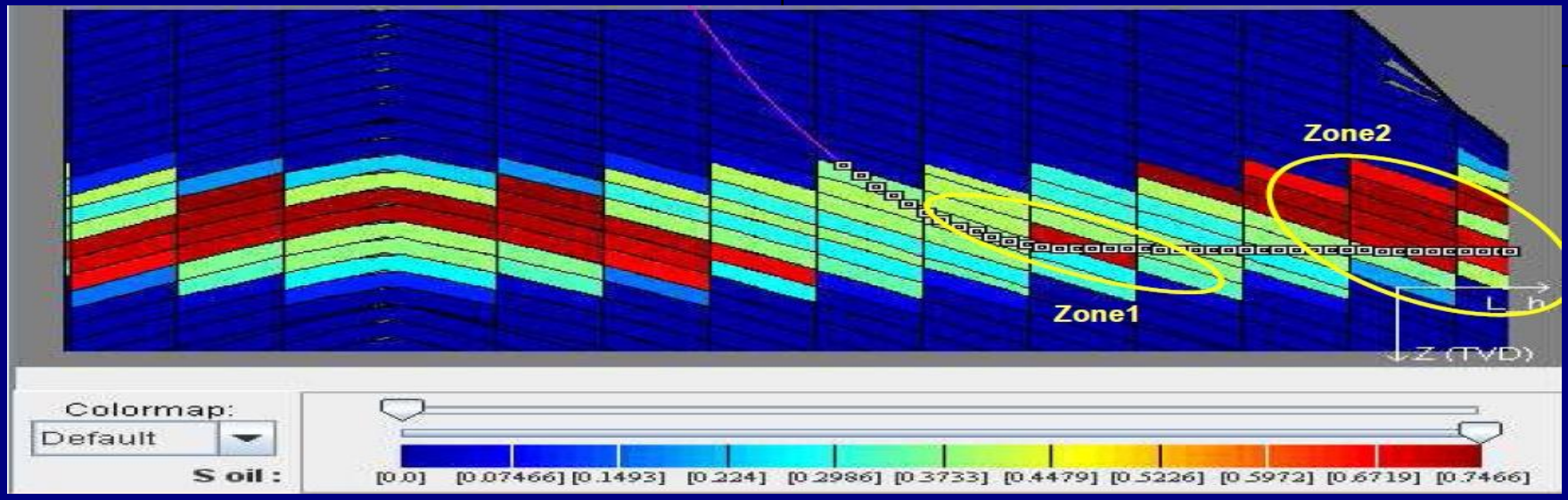




Forces Balance Mechanism:

- Preservation of Reservoir Energy
- Maximizing the hydrocarbon recovery





Technical Challenges:

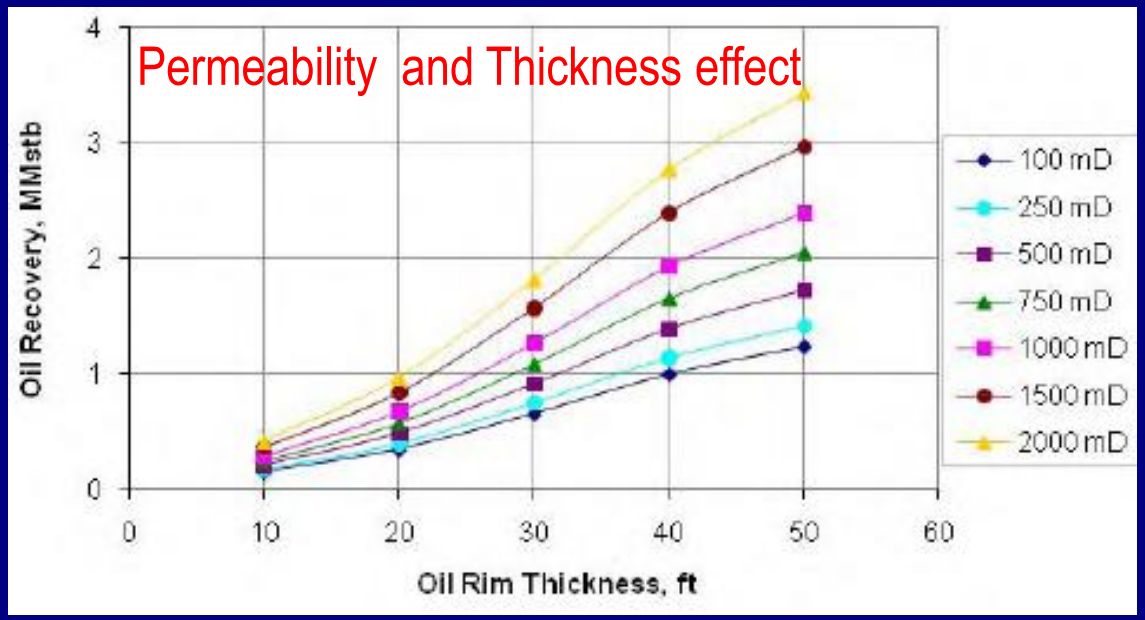
- Water/Gas Coning and Break-through
- Spread Out Resources
- Complicated Production Mechanism
- Transition and Invasion Zones
- Oil Smearing
- Low Recovery Factor (<18%)

Business Challenges:

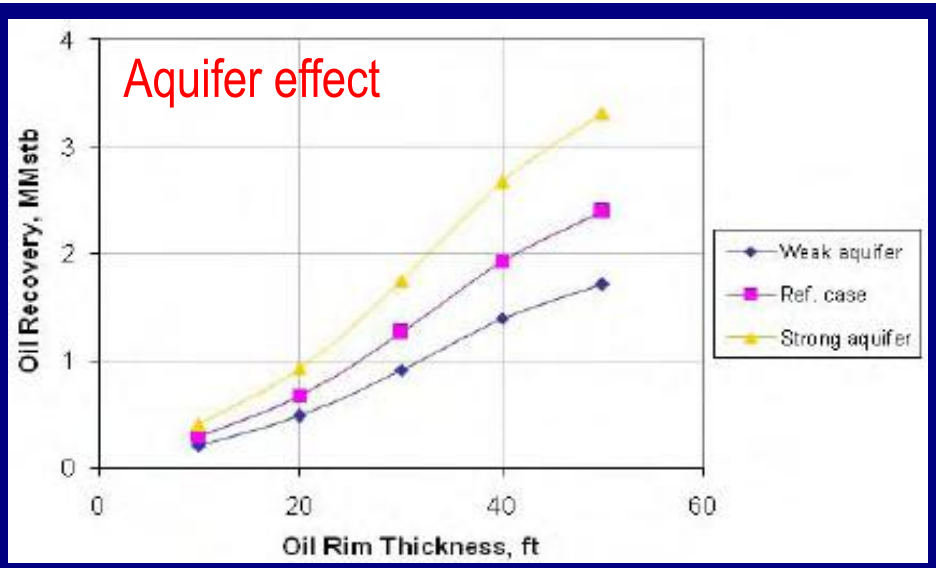
- Different focus for the host company and the operator
- Narrow window of opportunity for “Oil rim” development
- Early gas commitment vs. oil rim IOR development
- Expensive Field Development and marginal economy

Oil Recovery Factor: Main Affecting Parameters

- Oil Thickness
- Permeability
- Aquifer support
- Kv/Kh
- Gas Cap Size
- Viscosity and mobility
- Sor, Pc, Kr

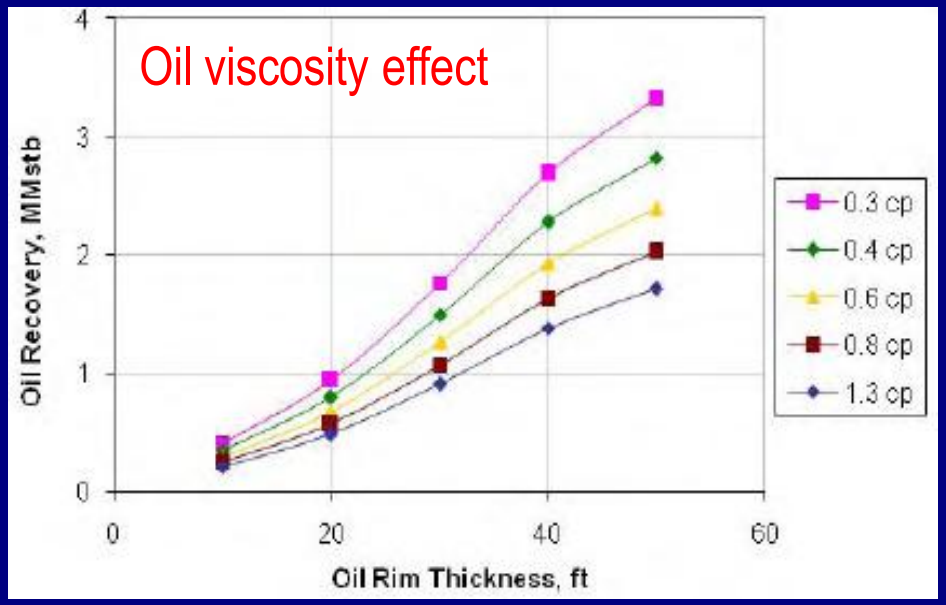


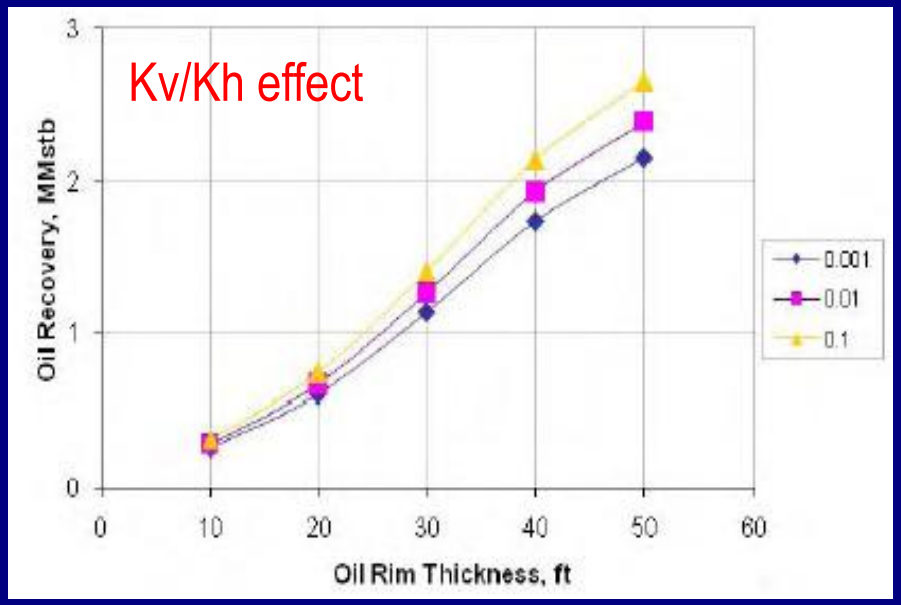
- Well Placement
- Production Strategy
- GIGP
- Reservoir well Contact
- HW vs VW

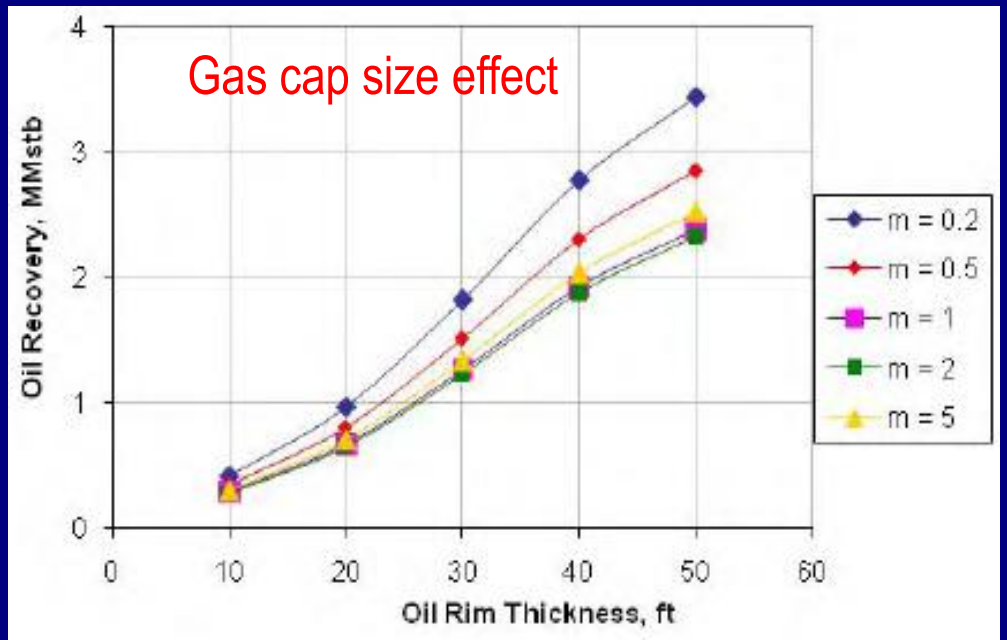


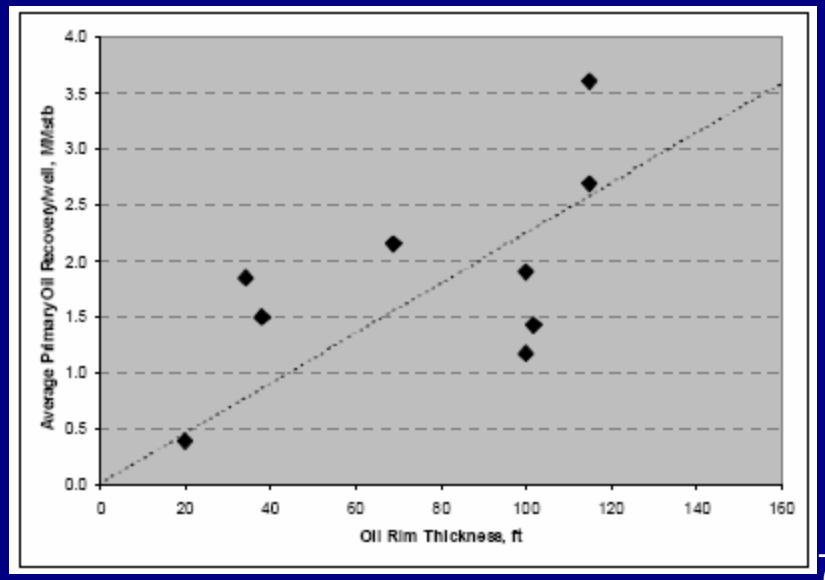
SPE 128603

Oil Recovery Factor: Main Affecting Parameters (Cont.)







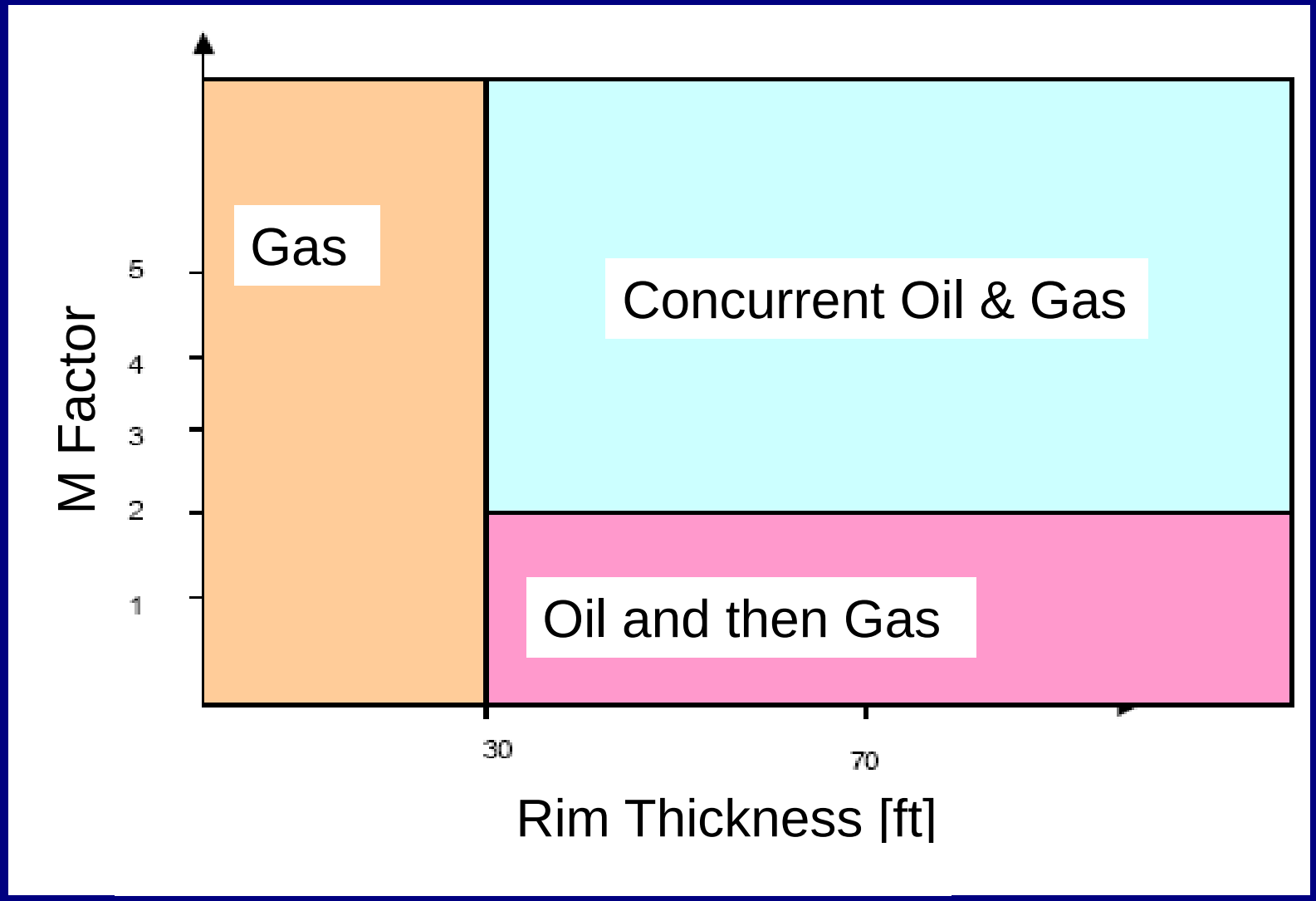


Available Screening Tools

Traffic Light Guideline

Oil Column size	***< 30 ft***	***30-70 ft***	***> 70 ft***
Gas cap size	***m>7 and/or FGIIP > 1 TSCF***	***m>2 and/or FGIIP > 200 BSCF***	***M<=2 and/or FGIIP <= 200 BSCF***
Mobility	***Perm < 500 mD Visc > 1cP***	***Perm 500-1000 mD Visc > 1cP***	***Perm > 1000 mD Visc < 1cP***
Aquifer Strength	***Weak, <25% of total drive***	***Mid, ~50% of total drive***	***Strong, >70% of total drive***
Reservoir Geometry/Dip	***Complex geometry Large dip uncertainty***	***Complex geometry Small dip uncertainty***	***Simple geometry None or small dip uncertainty***

Available Screening Tools

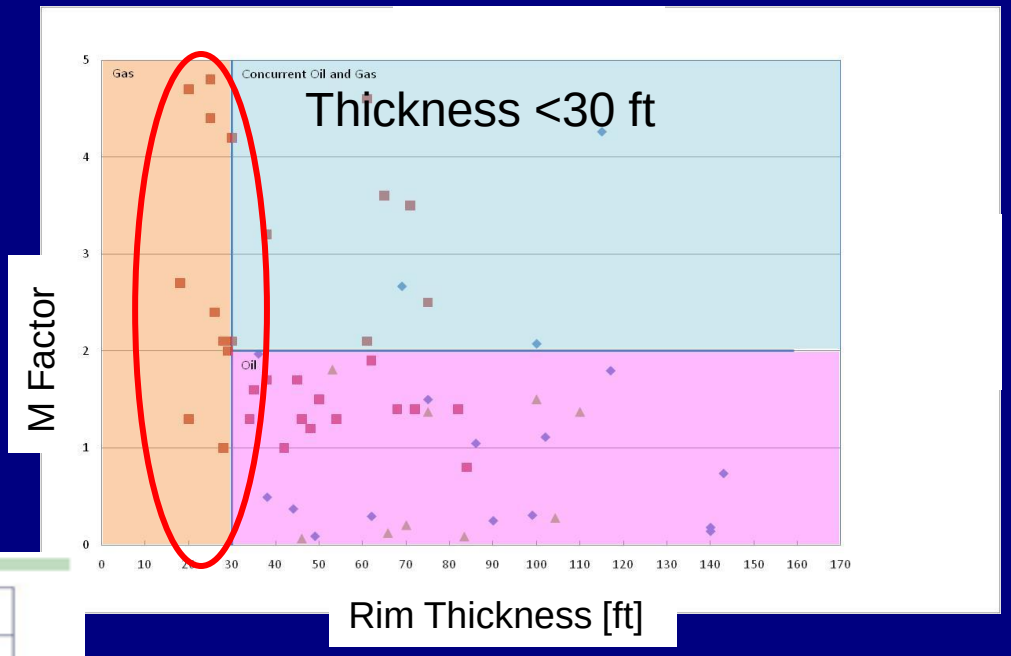


Development Strategy

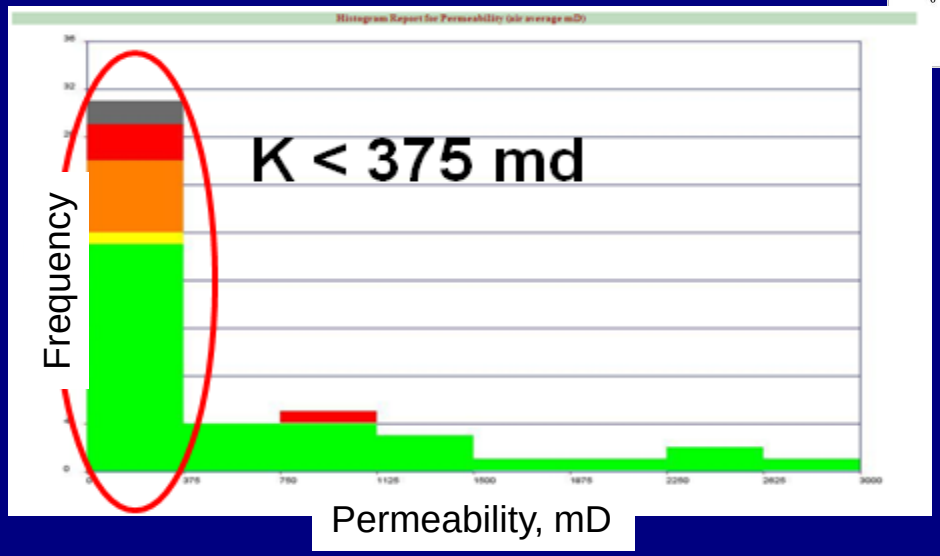
Source : SPE 128603

Available Screening Tool: Shortcomings

- Successful development in:
  - Thickness < 30 ft
  - K < 375 mD
- Not in line with the guide line
- 4 to 10 m oil column development

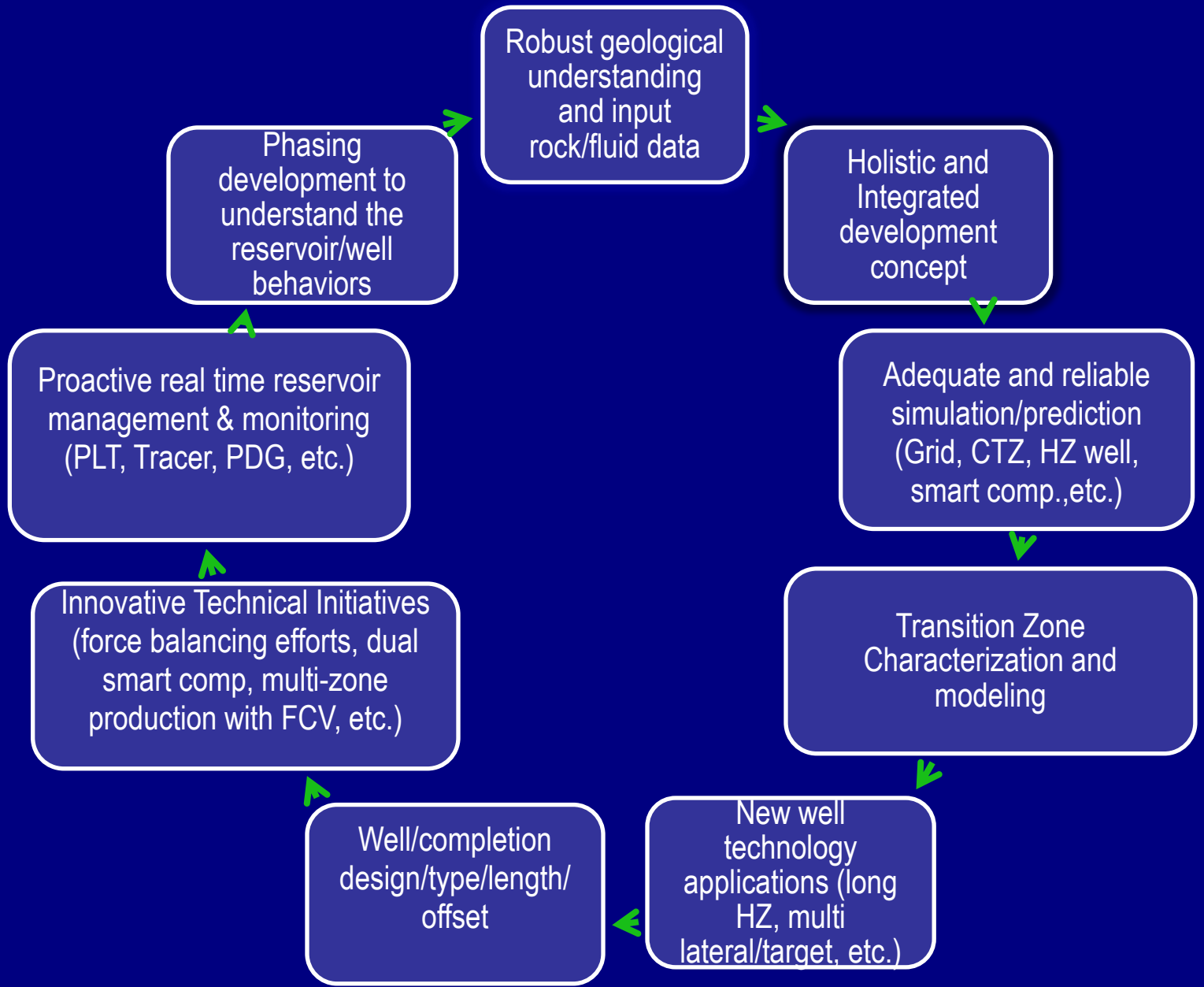


Source : C&C Reservoir and IHS Energy



- Technical Initiatives
- Technology Roles

Oil Rim Development Success Factors



Production/Depletion Strategy

Gas Cap Blowdown

- -Early Gas prod.
- -Oil prod. Ignored!
- -Oil smearing concern
- -Low oil RF

Sequential Development

- -Early oil prod.
- -Gas come later
- -Commitment concerns
- -Different contractual interest
- -Higher oil/gas RF

Concurrent Development

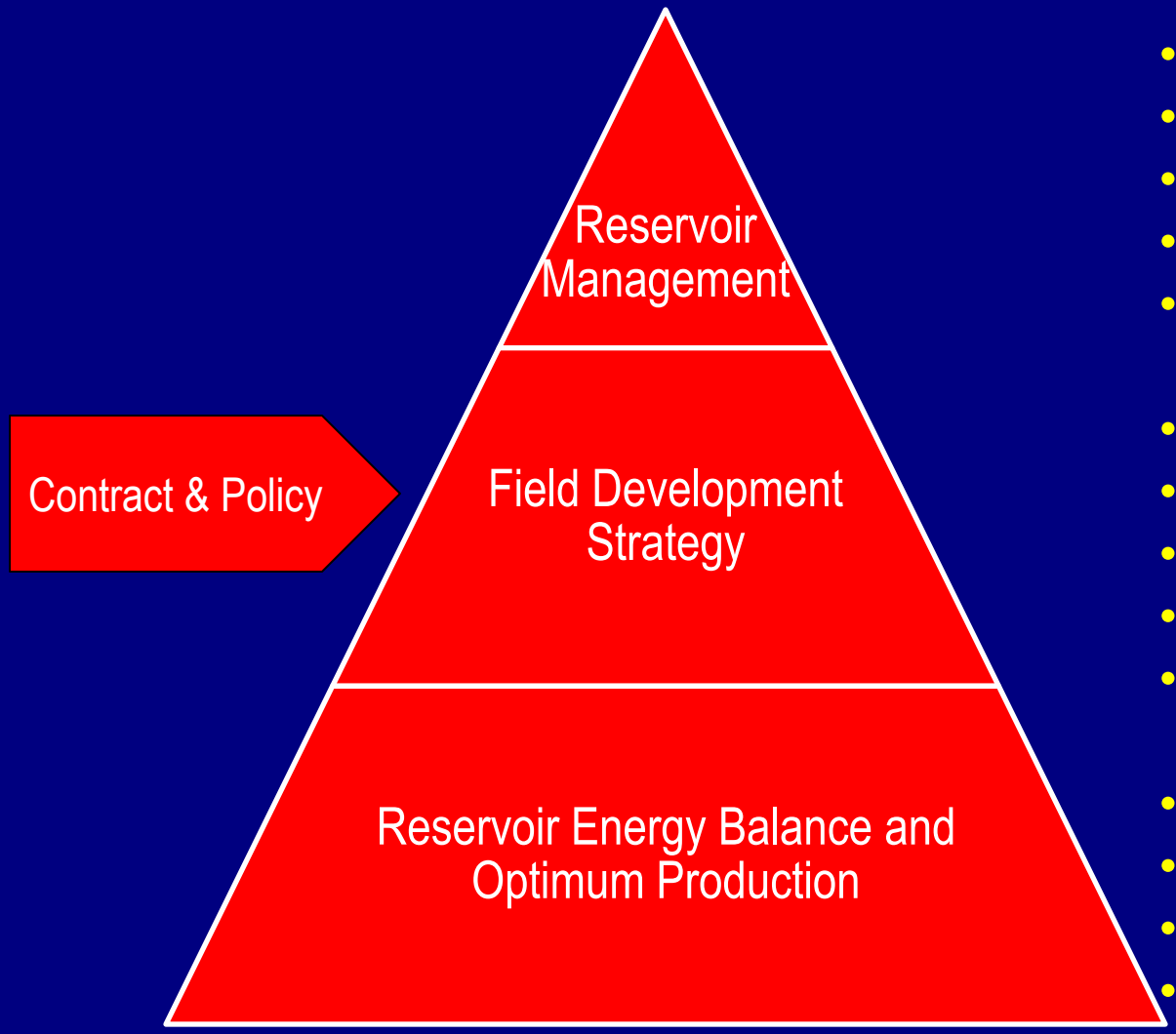
- -Early oil and gas prod.
- -Limited gas prod.
- -Up to 10% of the GIIP per annual
- -Might suit to both operator and host company interest
- -Lower oil RF

Swing Development

- -Cyclic oil and gas prod.
- -Balance the energy
- -Suitable for reservoir with big gas cap
- -Lower oil RF

•The FDP, well design and philosophy, RMP is highly dependent on selected strategy

Oil Rim Reservoir and Business Management



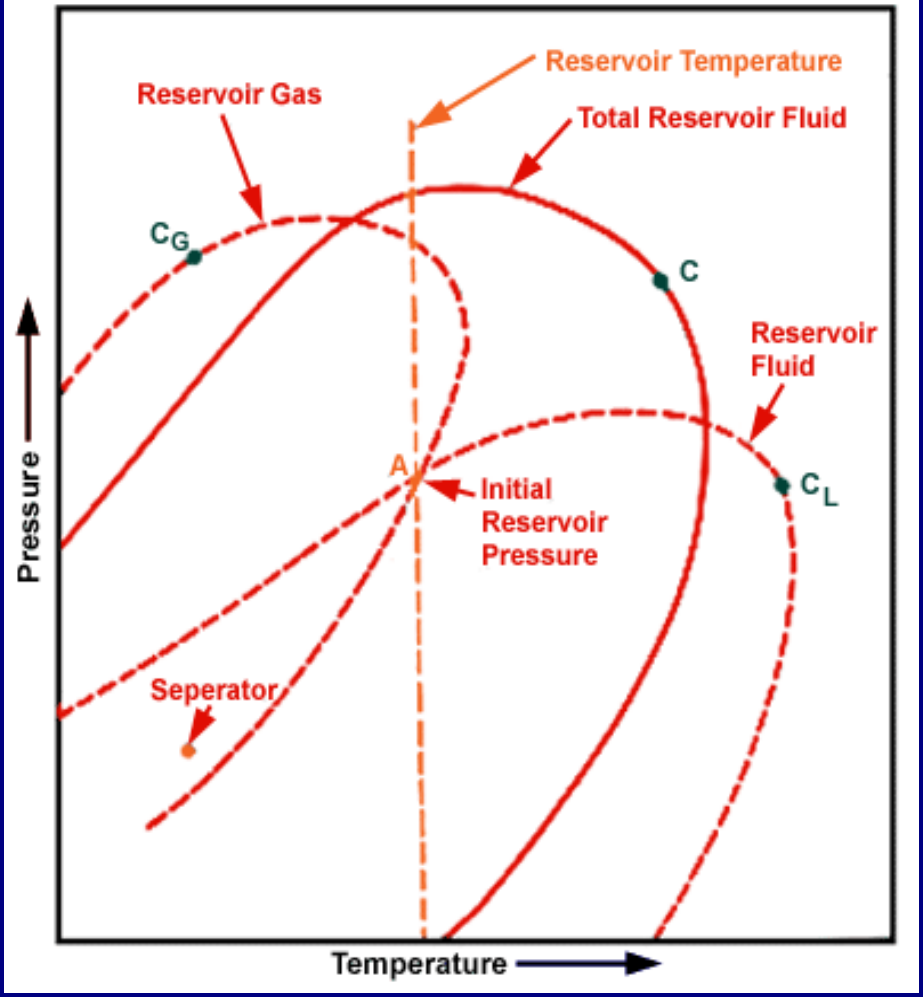
- Well type
- Well length , spacing , stand off
- Contact movements
- GOR and production constraint
- Coning, Cusping, Cresting
- IOR/EOR

- Gascap Blowdown
- Sequential
- Concurrent
- Swing
- Incorporated with IOR/EOR?

- Robust static/dynamic models
- Gas cap size
- Aquifer size and extension
- Driving mechanism contributions

Fluid Sampling, Analysis and PVT

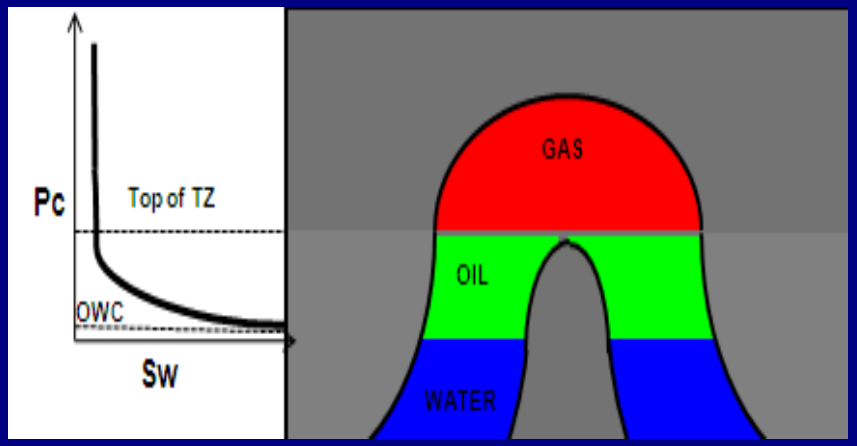
- Usually simplified!
- Surface sample can be misleading
- Both phases need to be sampled
- Recombined with the GIIP/STOIIP ratio
- Reliable fluid model is a must
- Modeling just Oil can be misleading on the RF evaluation
- Oil and Gas need to be modeled together
- Compositional grading and non-equilibrium concerns

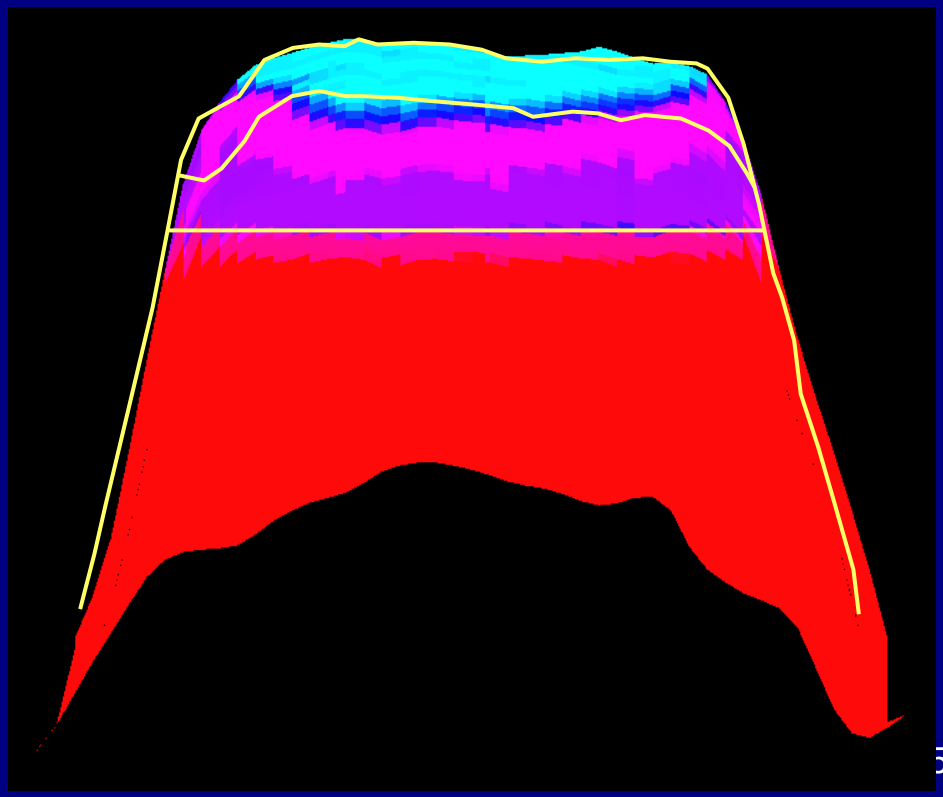


(after Amyx, Bass and Whiting, 1960; courtesy of McGraw-Hill)

Transition Zone and Oil Smearing Concerns

- Saturation modeling?
- Can oil rim move upward to the gas producing well?
- How much is the Sor? Soi/Sor relation to be considered.
- Mobile oil and displaced oil zone?
- Dry oil production! Performance better than prediction!



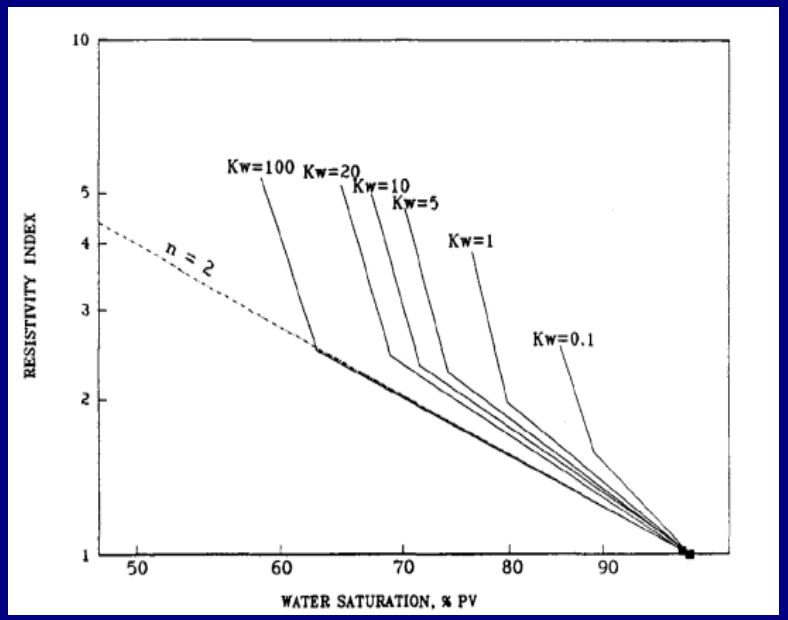


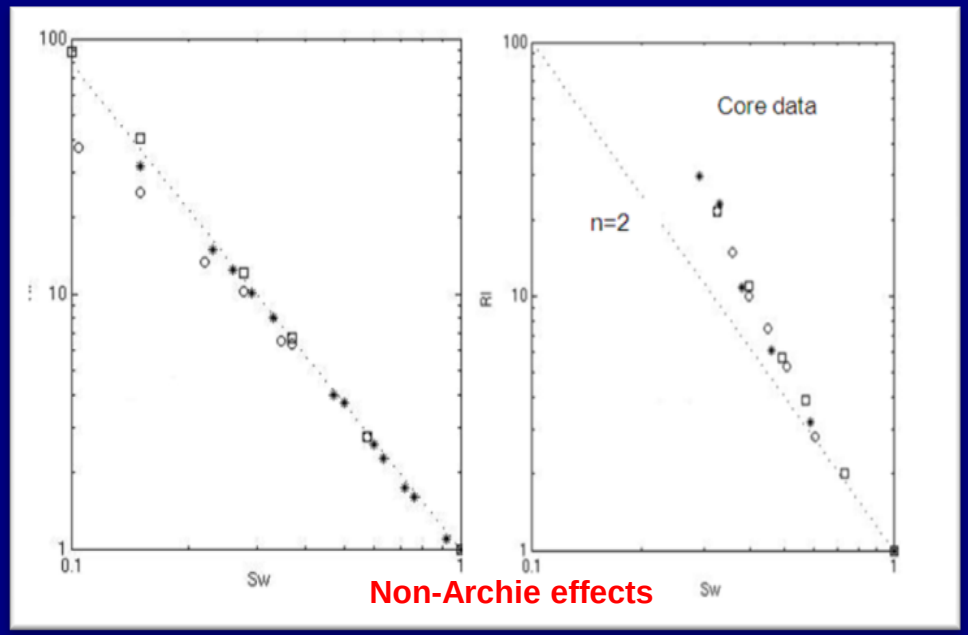
SPE 143983
SPE 145867

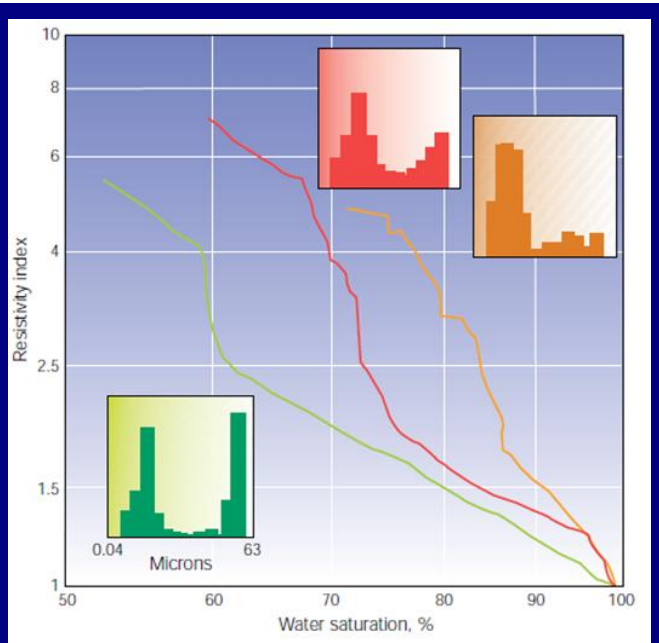
Capillary Transition Zone Flow Dynamic

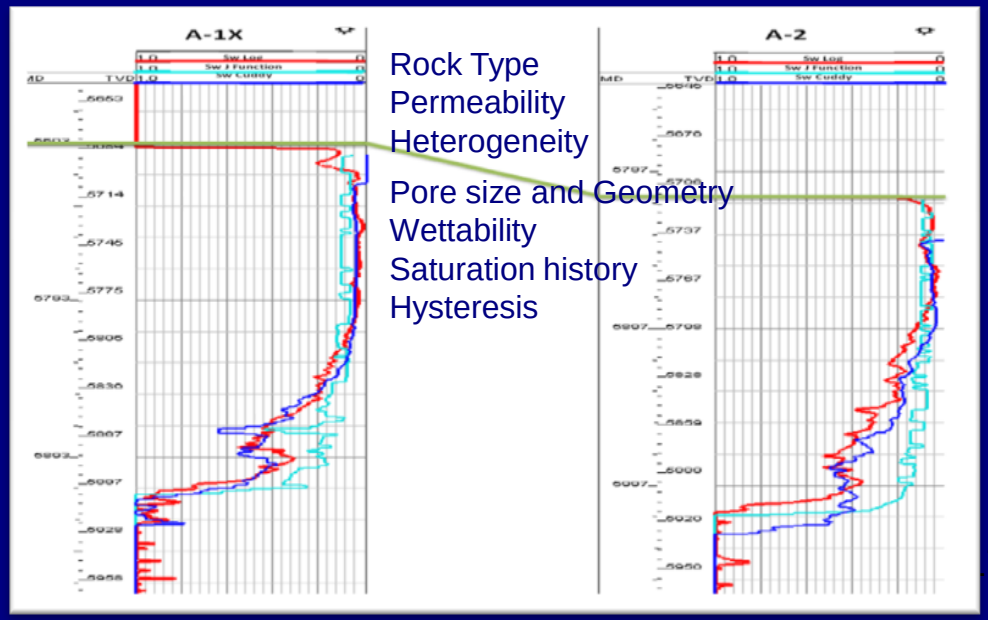
- Dry oil production! Performance better than prediction!
- Sw Modeling:
  - Resistivity index and wettability effects (esp. in carbonates)
  - SHF from resistivity log using water wet derived n exponent can be different from that derived from drainage PC curve
  - This can over estimate the HC saturation above the transition zone
  - Saturation dependent n exponent may need to be used
- Displaced Oil Zone
- Imbibition curves and hysteresis effects
- Pseudo Kr with artificial high immobile Sw may produce HM but can give poor prediction
- How much is the Sor? Soi/Sor relation to be considered.

Sw Determination and Modeling in Carbonates (IPTC 14588)









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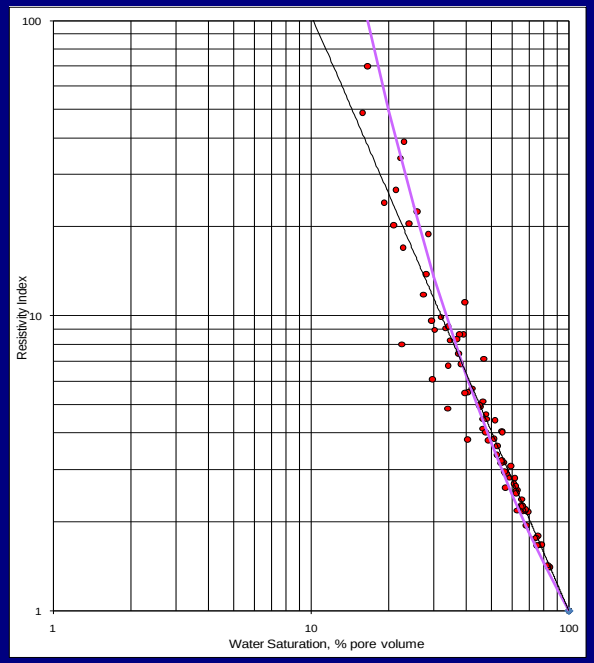

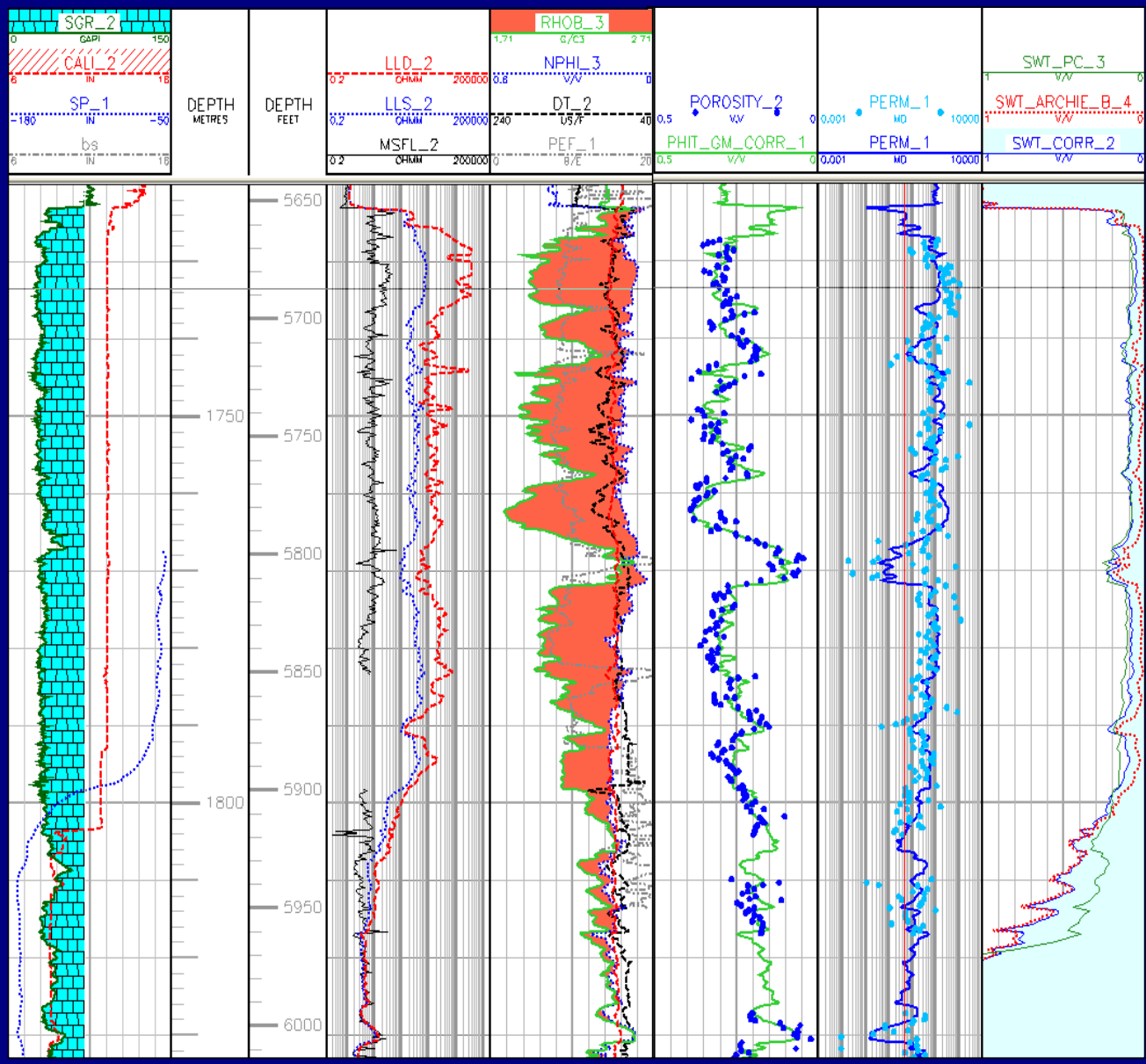

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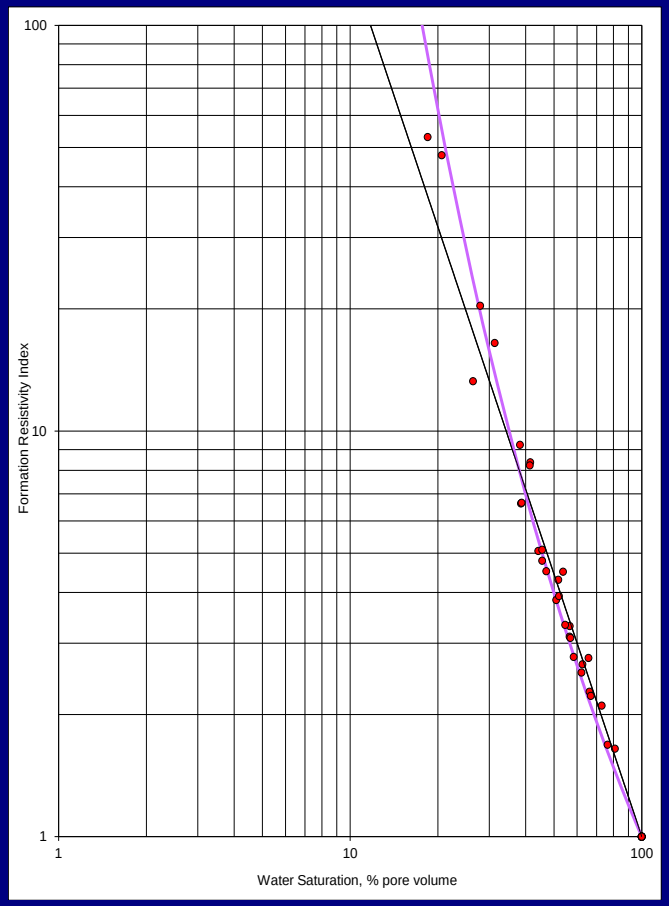
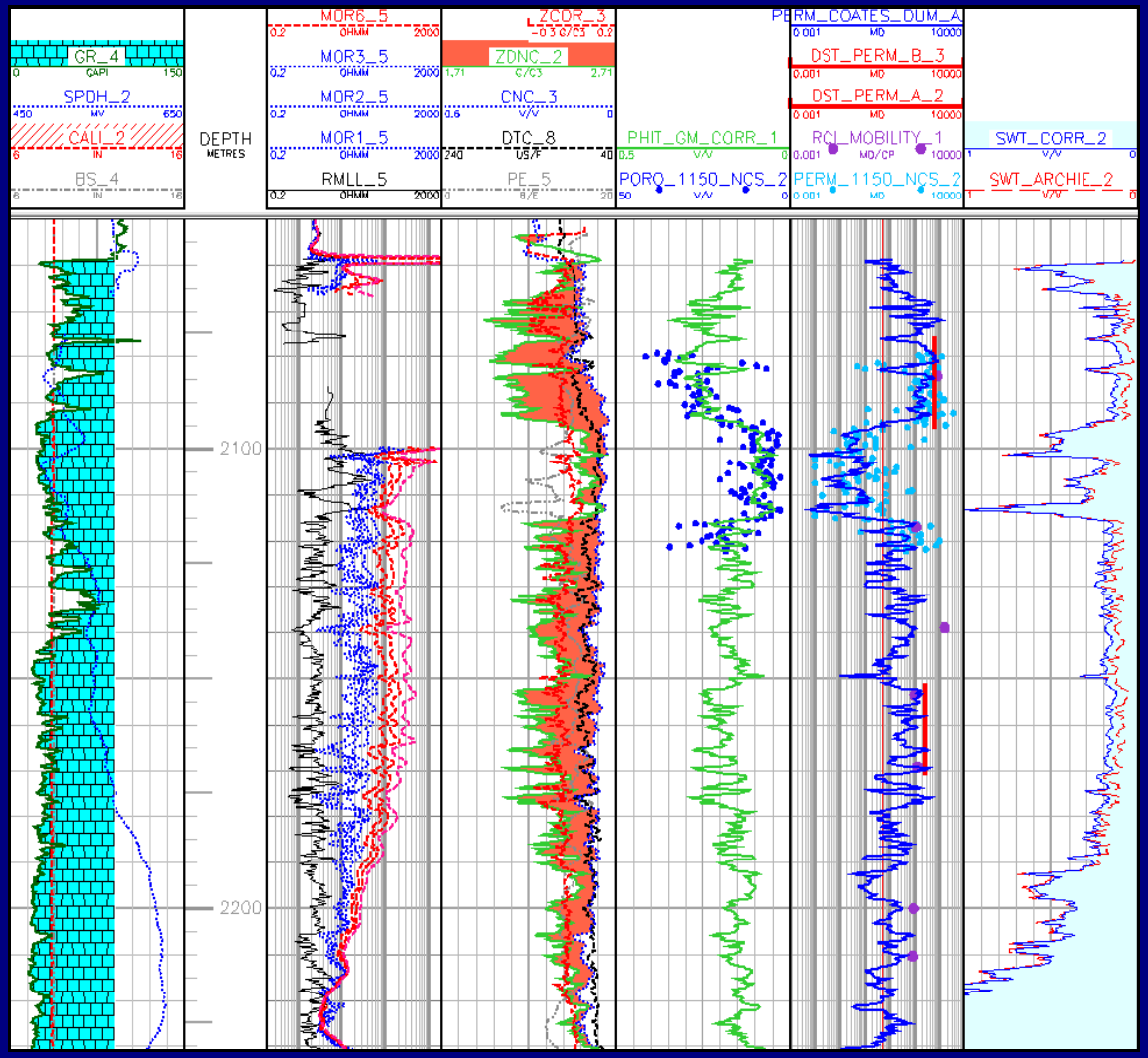
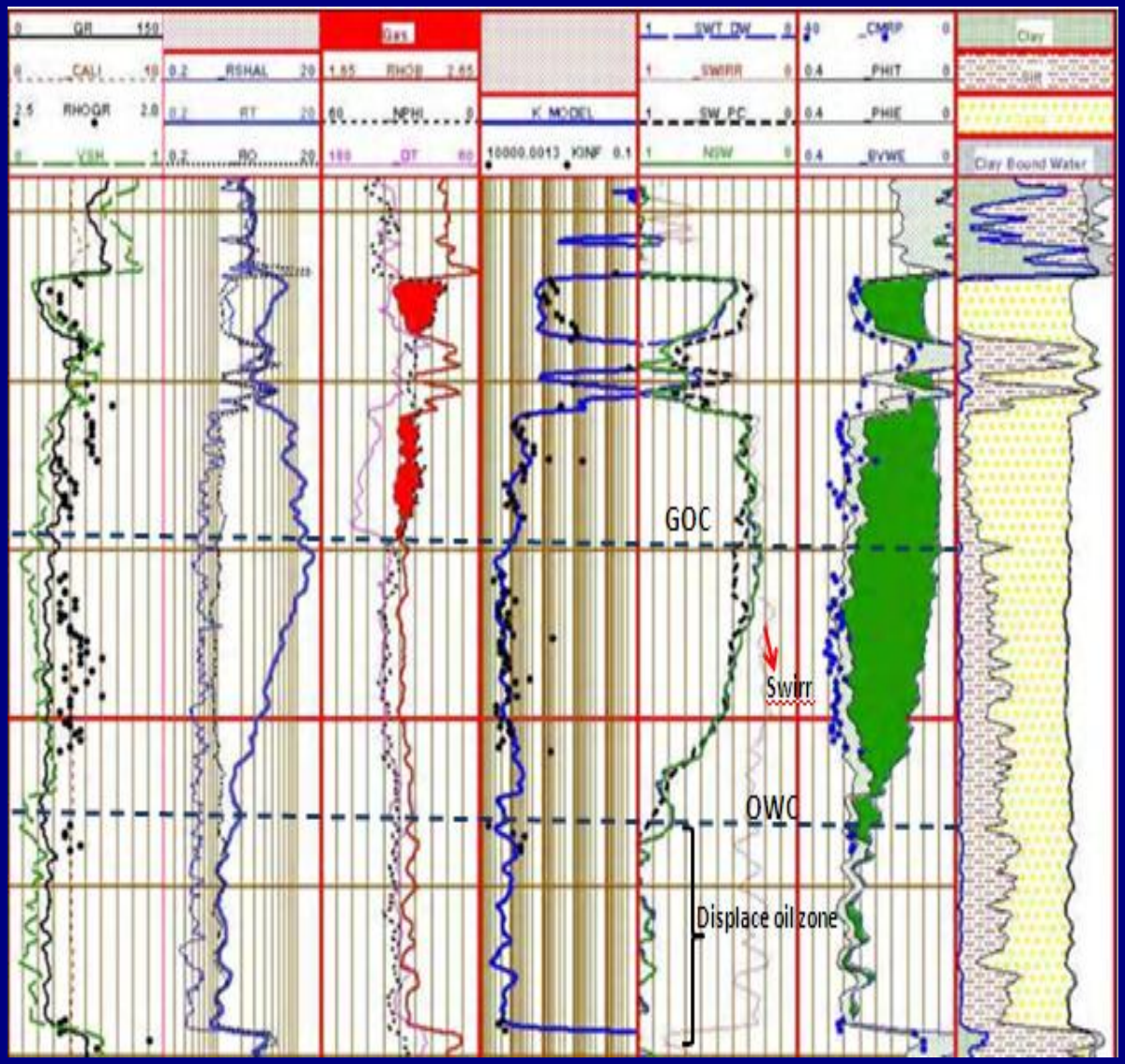
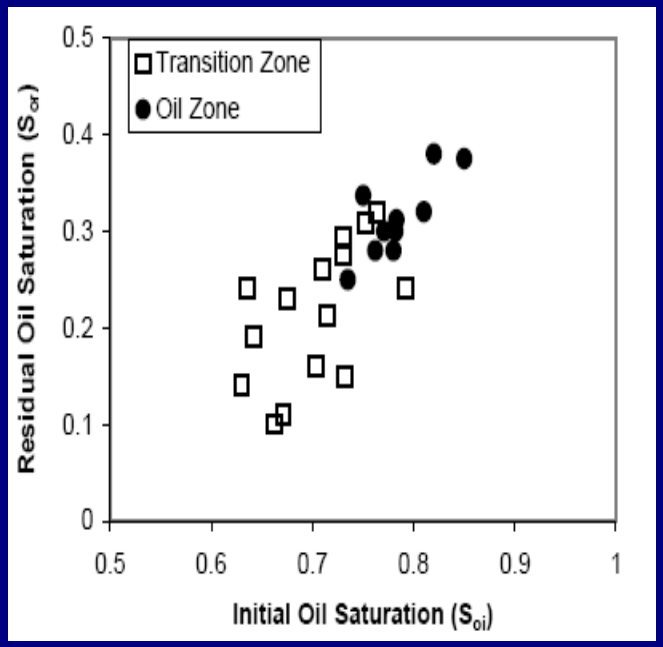




Capillary Transition Zone Flow Dynamic (1)

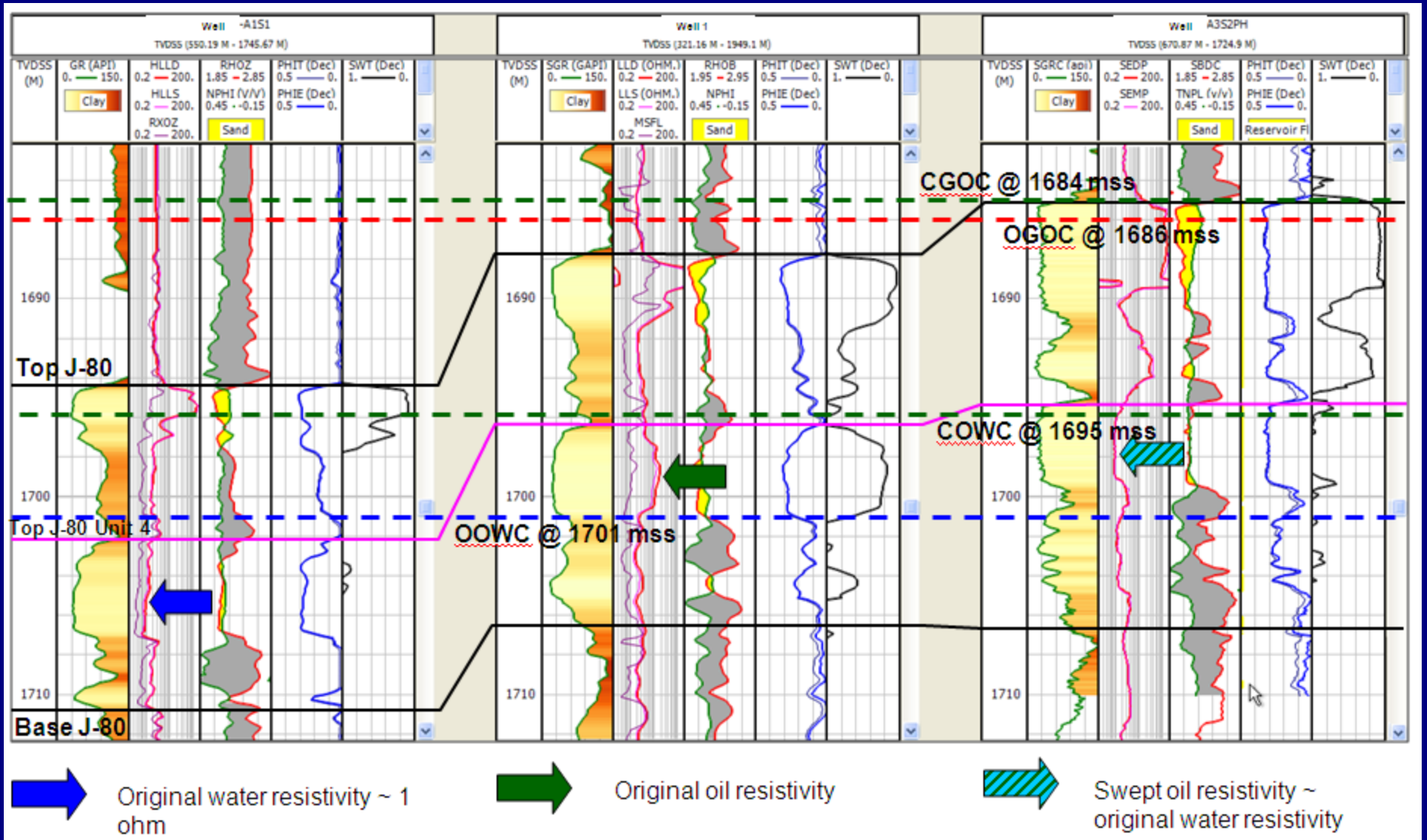


SPE 143983



SPE 77545
IPTC 10238

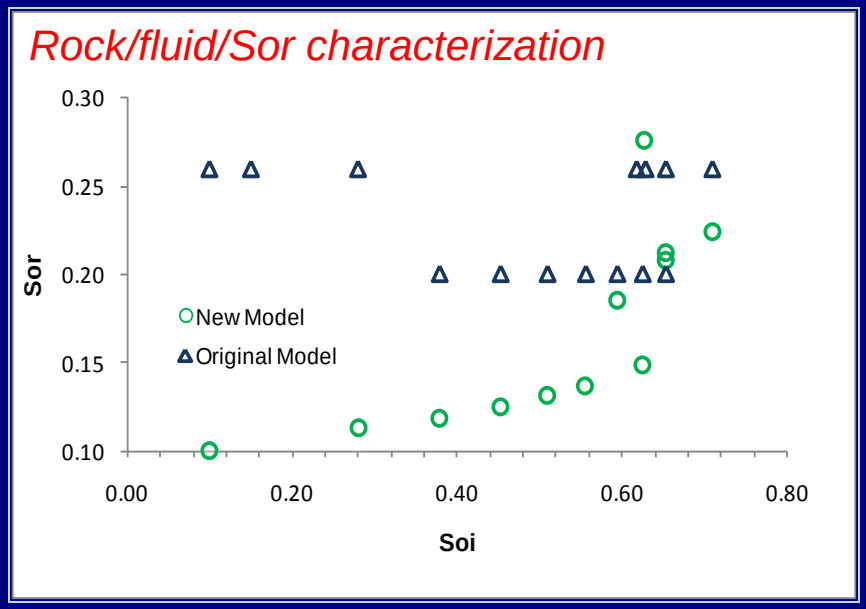
Capillary Transition Zone Flow Dynamic (2)

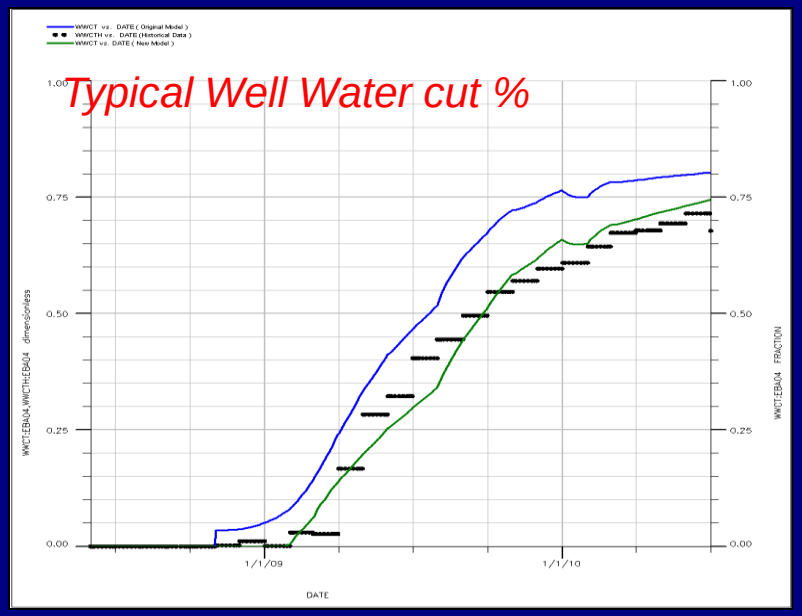


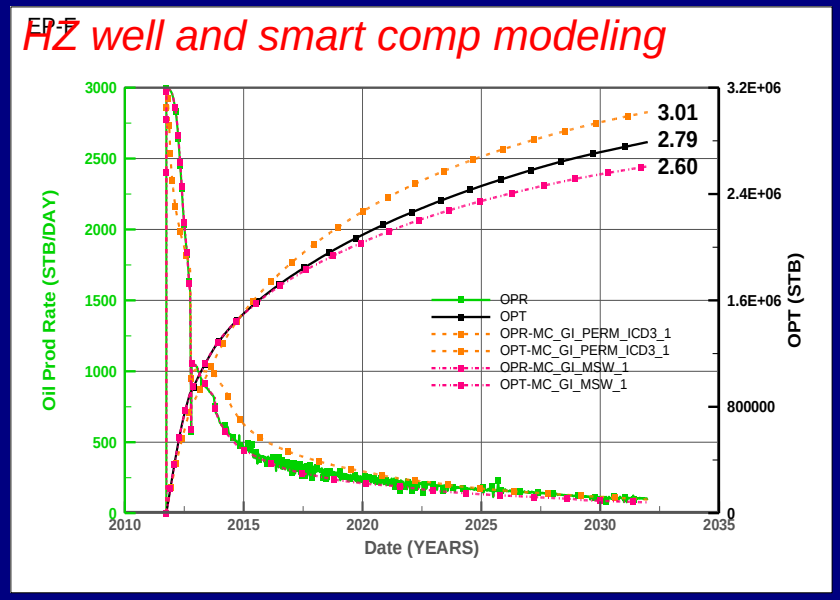
SPE 143983

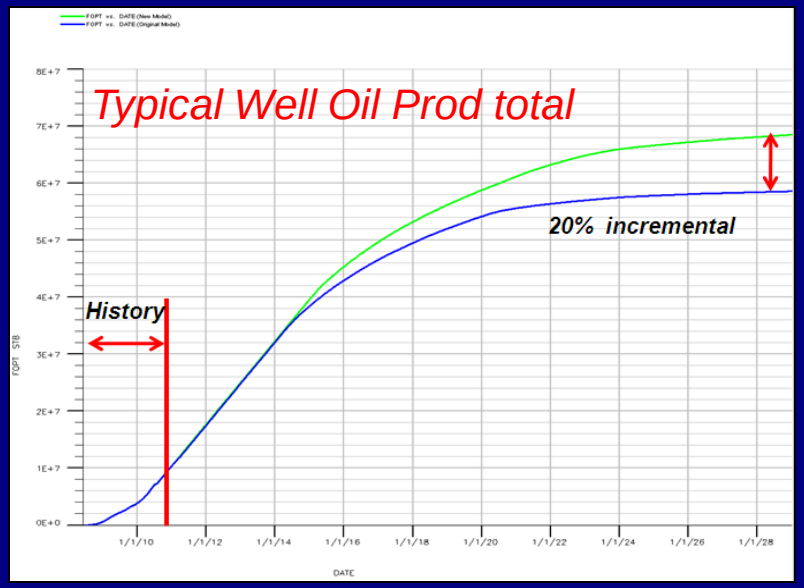
Capillary Transition Zone Flow Dynamic (3)

SPE 143983



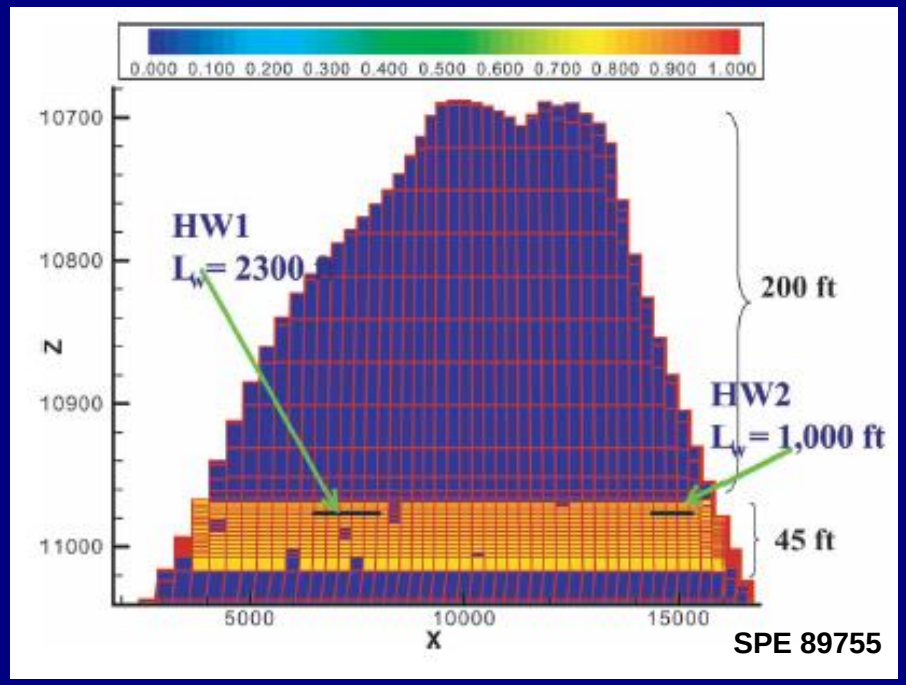




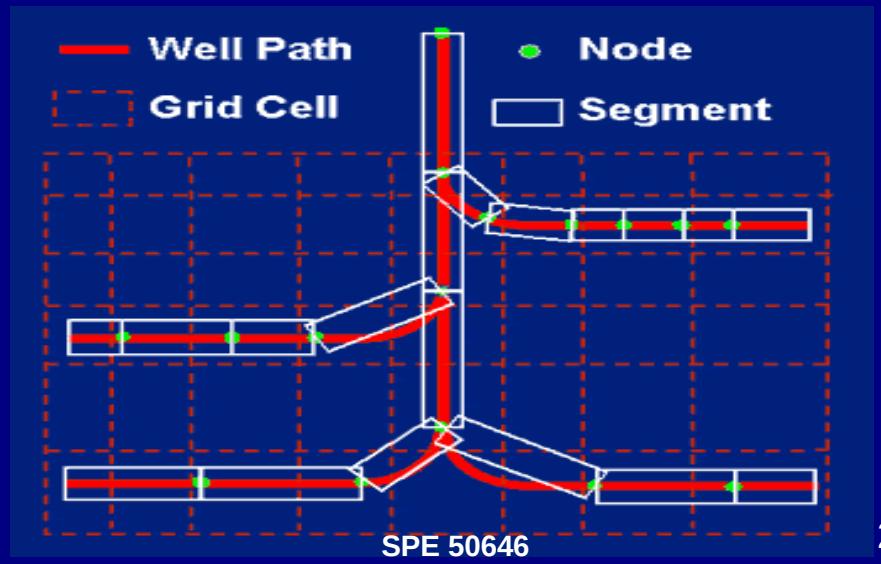


Reservoir Modeling and Simulation

- Girding scheme
- Horizontal or non-horizontal corner point geometry grids
- Horizontal grids capture the contact movement more accurately (SPE 39548)
- Local grid refinement (LGR)
- Finer layering scheme (SPE 93137)
- Multi Segmented Well (MSW) approach



SPE 89755

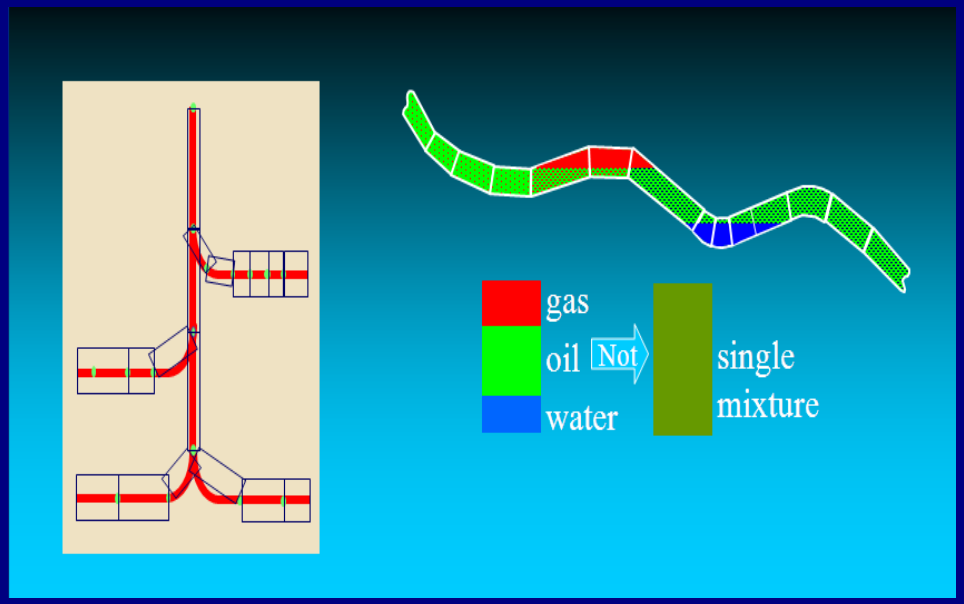


SPE 50646

Modeling of Horizontal wells with smart completion

<u>Conventional modeling</u>

- Hydrostatic only
- No slip and friction along the well
- Uniform mixture density
- Excessive oil production in early stages



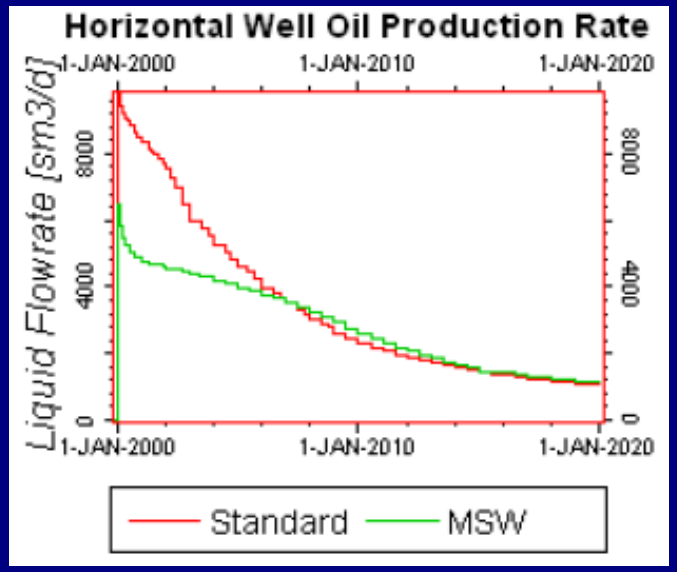
<u>Proposed Technique</u>

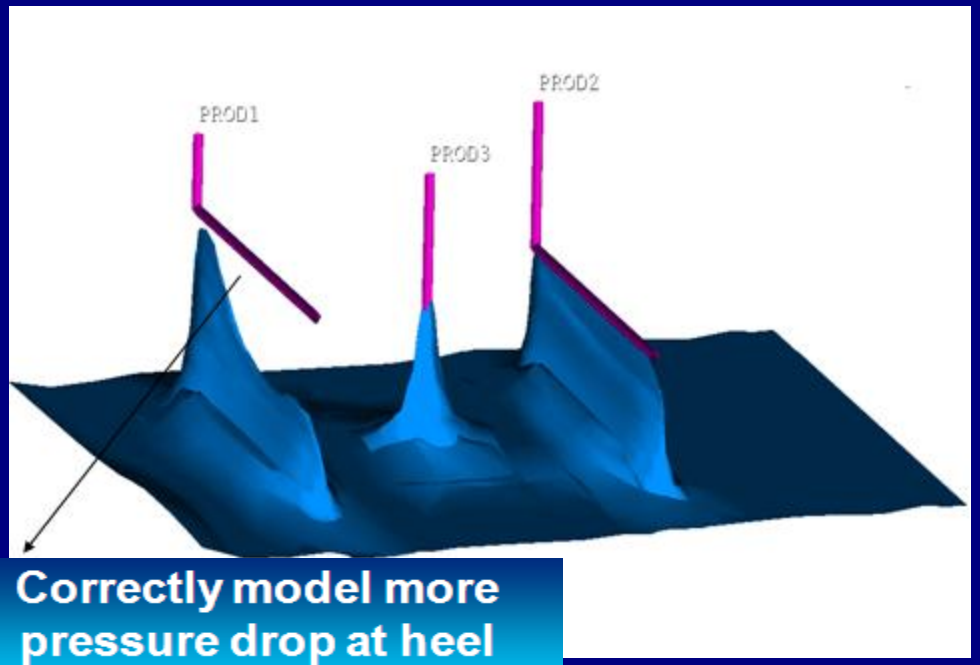
- Multi segmented well (MSW) model
- Segment topology to honor the well path
- Coupled to the reservoir model

Modeling of Horizontal wells with smart completion (cont.)

MSW Capability

- Reliable wellbore pressure gradient and fluid mixture properties
- Proper representation of the well trajectory.
- Ability to model smart completions (ICD, Inflow Control Device, ICV, Inflow Control Valve)
- Coupled to the reservoir simulation equations

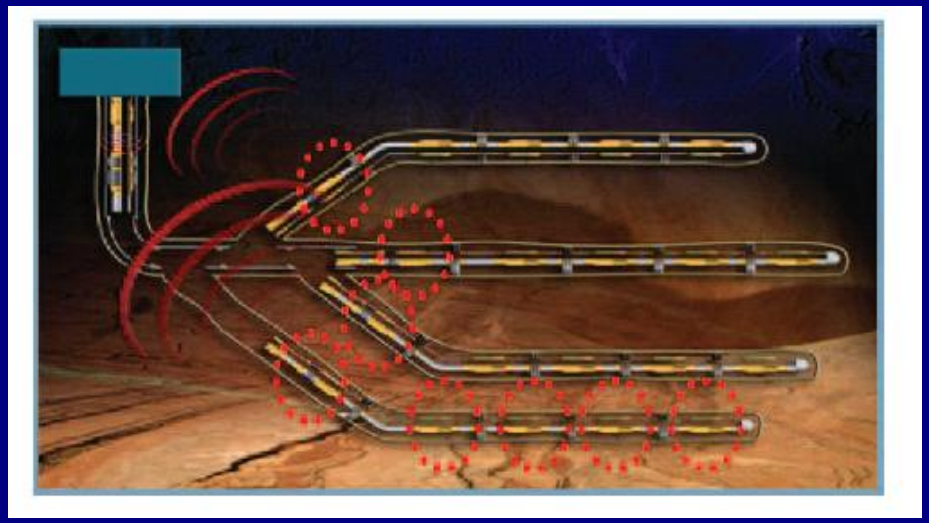




Correctly model more pressure drop at heel with MSW

Key Technologies/ Methodologies

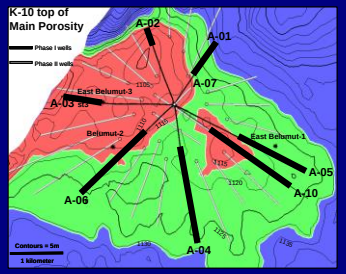
- Horizontal and Lateral Wells
- Thin Column Drilling
- Inflow Control Well Design
- Smart Completion Design
- Modeling New Technologies
- Real-Time Reservoir Management
- Real Time Reservoir Modeling
- Improved Sweep



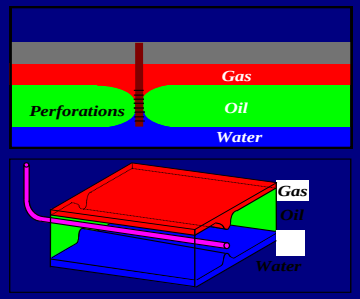
Horizontal Well Basis of Design

Basis of Design

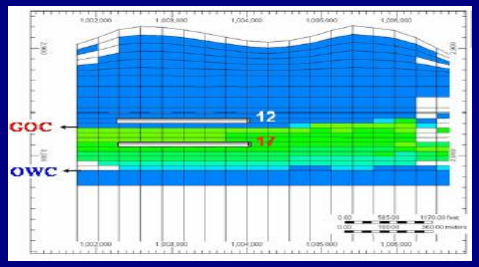
Well Spacing



Optimum Fluid Rate

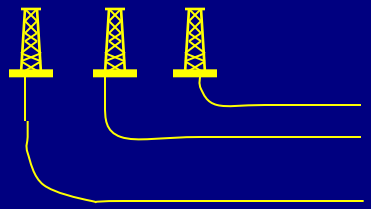


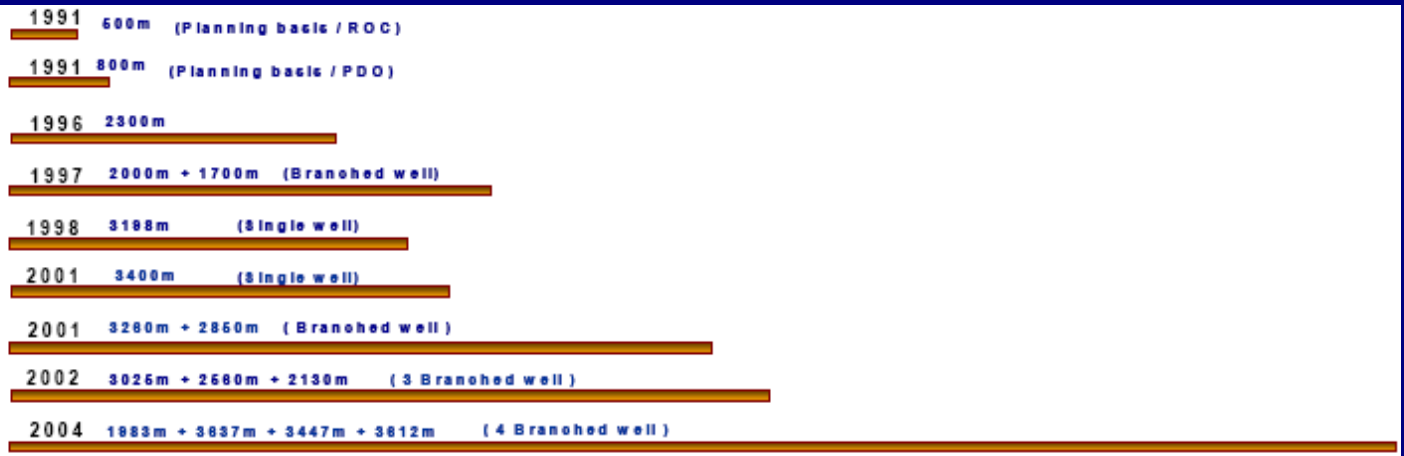
Distance to GOC/WOC



Lateral/perforation length

Smart Completion





(Madsen and Abtahi- 2005)

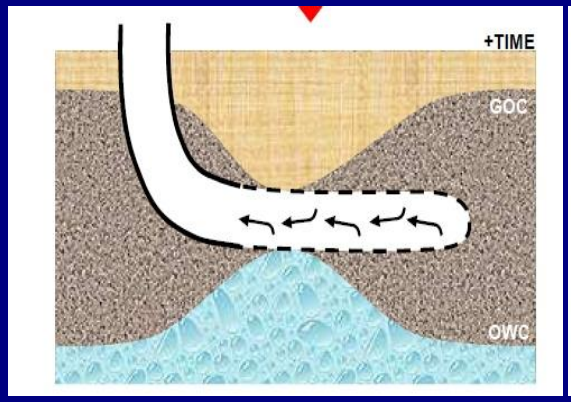
Long Well Length

Horizontal Well with Smart Completion

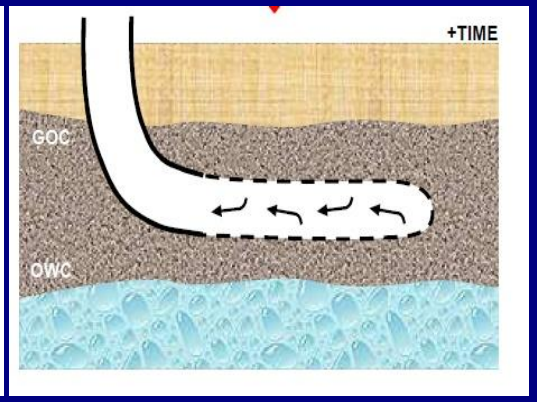
Smart Completion (ICD, ICV):

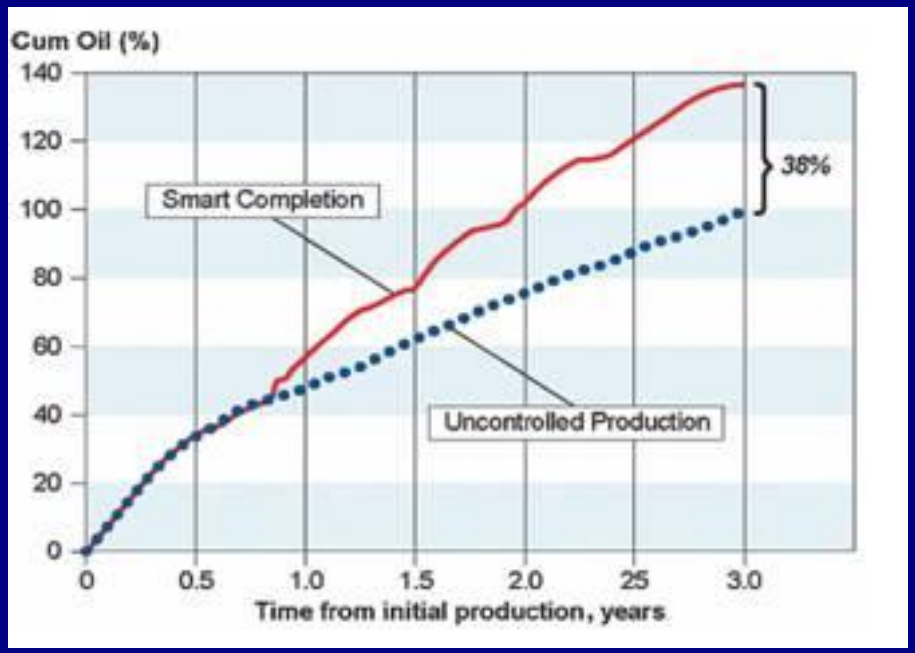
- Transmit delta-P along well
- Heel-to-Toe effect reduction
- Higher well PI.
- Better sweep efficiency.

Without ICD



With ICD

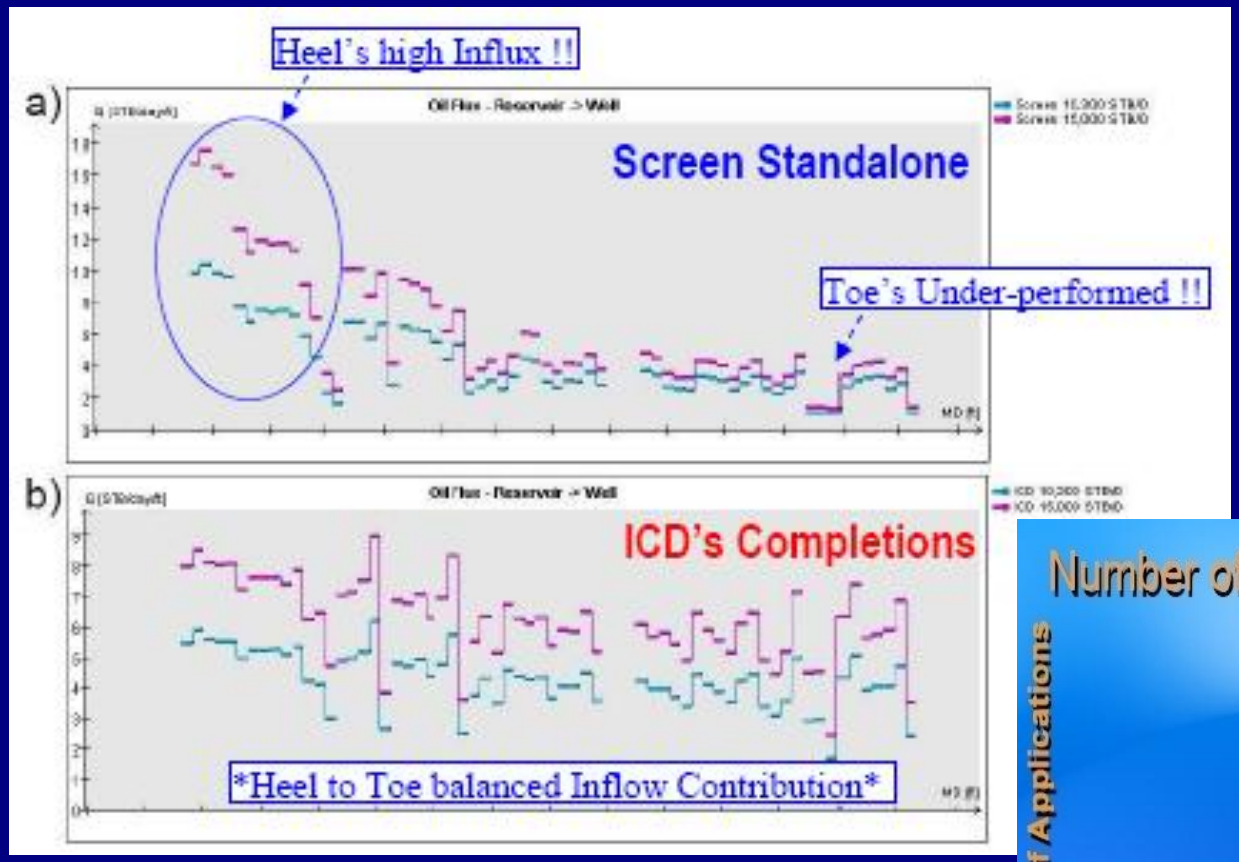




Iron Duke Field (SPE 81107)

(OTC-19172)

ICD Minimizes Toe-Heel Effect (OTC-19172)

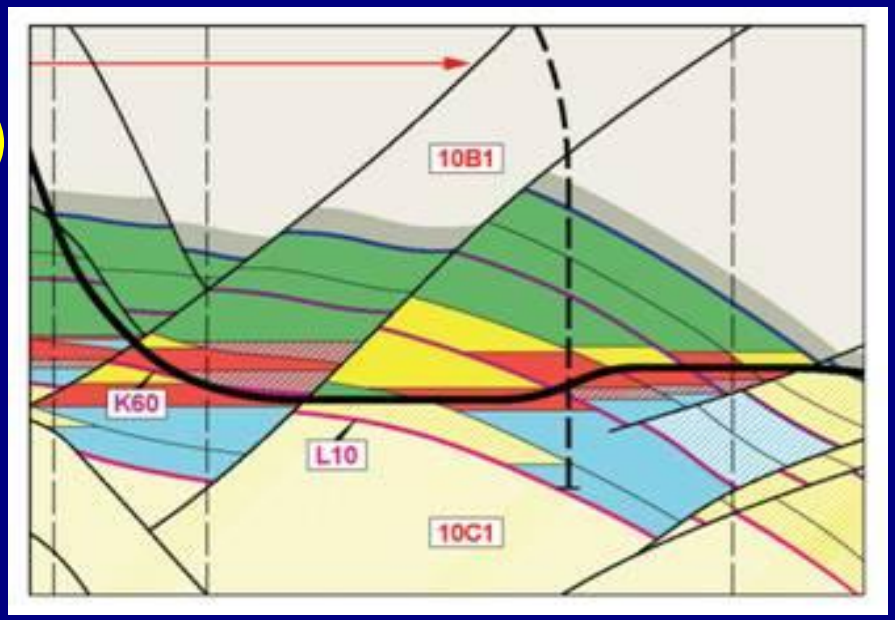


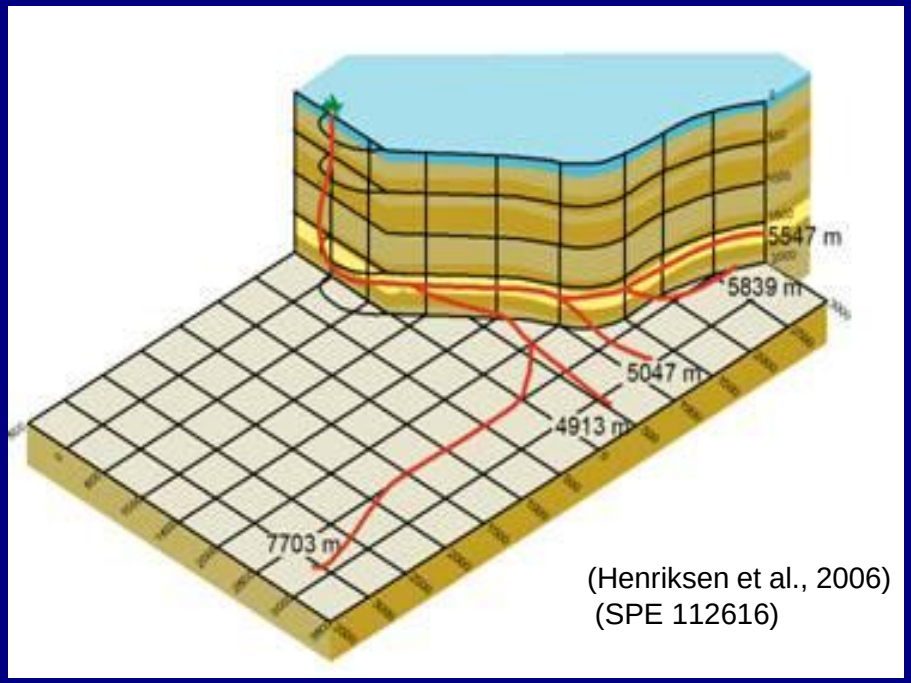
Uniform Drawdown along the well

World wide
Installation Forecast!

Improve the well contact with the reservoir-1!

- Brunei Shell Iron Duke Field (SPE 81107)
- One H well with smart completion
- Five zones in two blocks with different reservoir characteristics

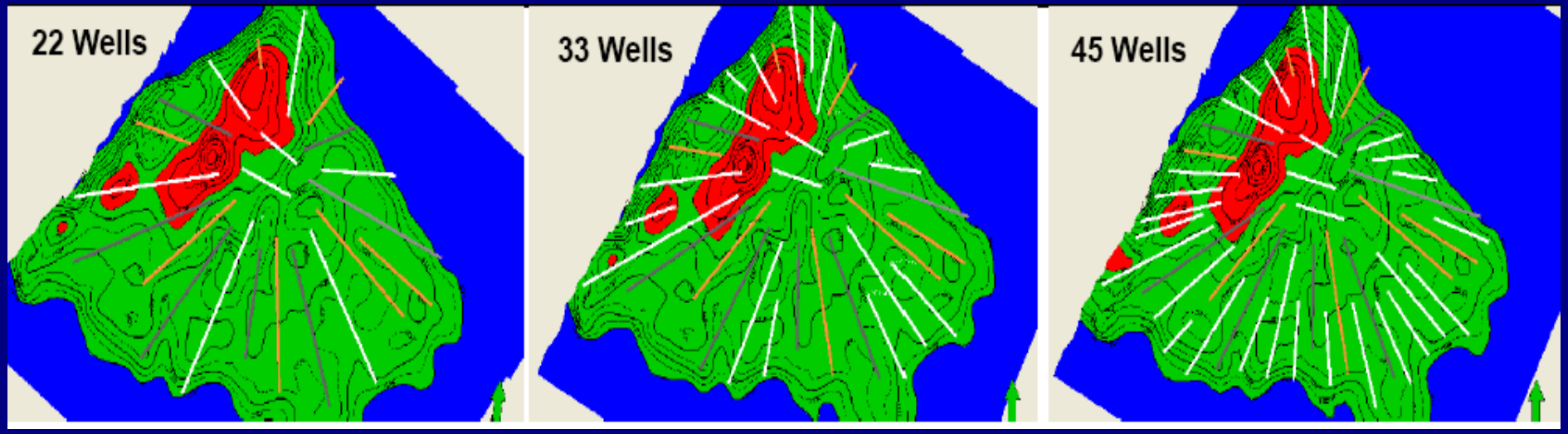


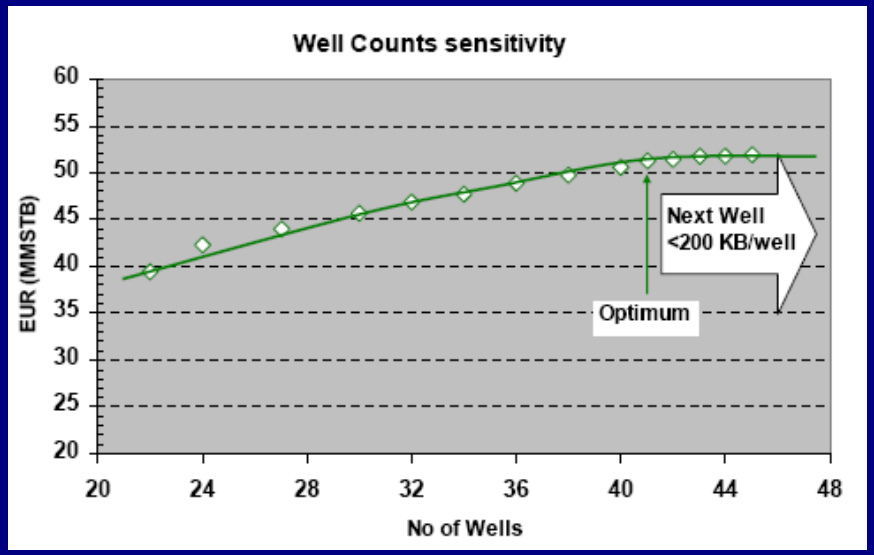


(Henriksen et al., 2006)
(SPE 112616)

- StatoilHydro Troll Field (SPE 112616)
- Known as gas field!
- 110 HZ sub sea wells with 53 MLT wells
- Over 13 km well contact
- Up to 7 HZ branches in different zones

Improve the well contact with the reservoir-2!

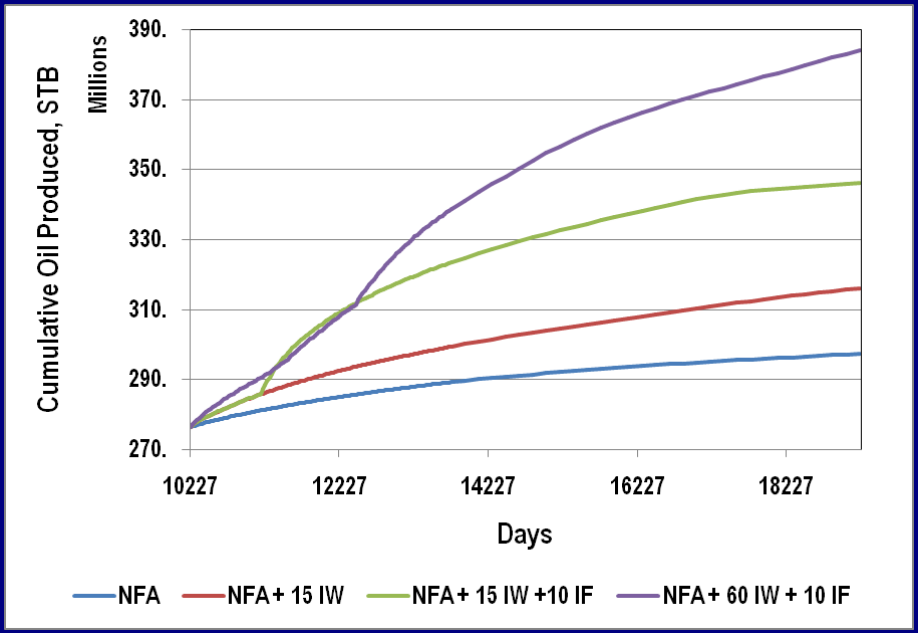


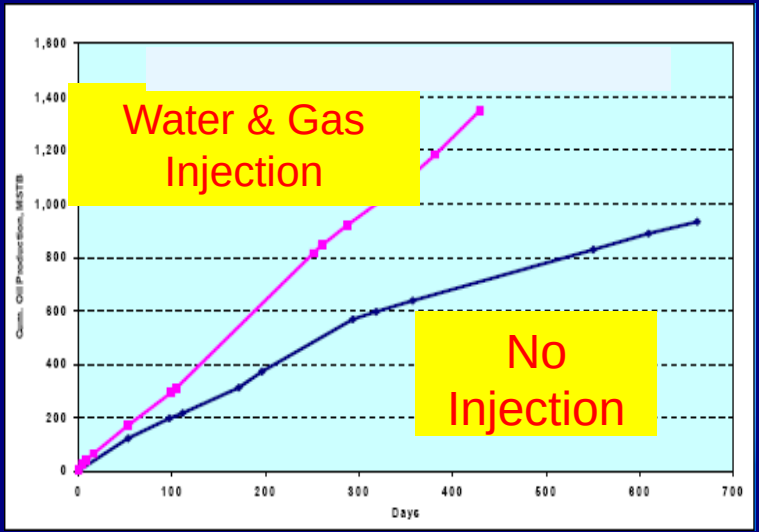


- Total of 41 wells in 3 phases
- Optimal well off set from contacts
- 250 m average well distance
- EUR increases with well No.

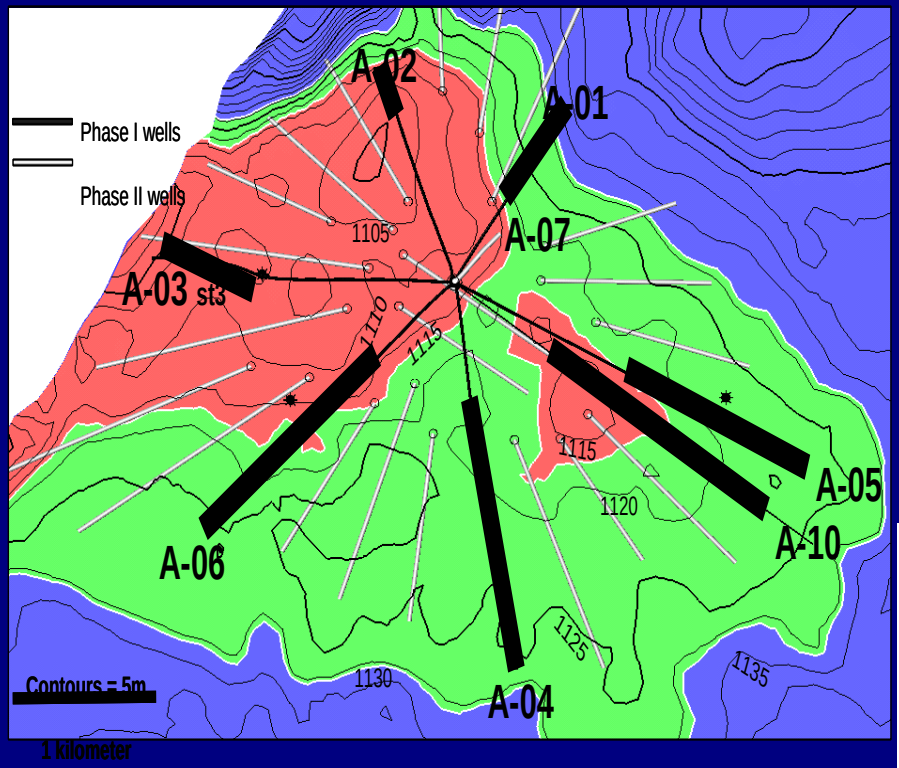
IOR/EOR Considerations

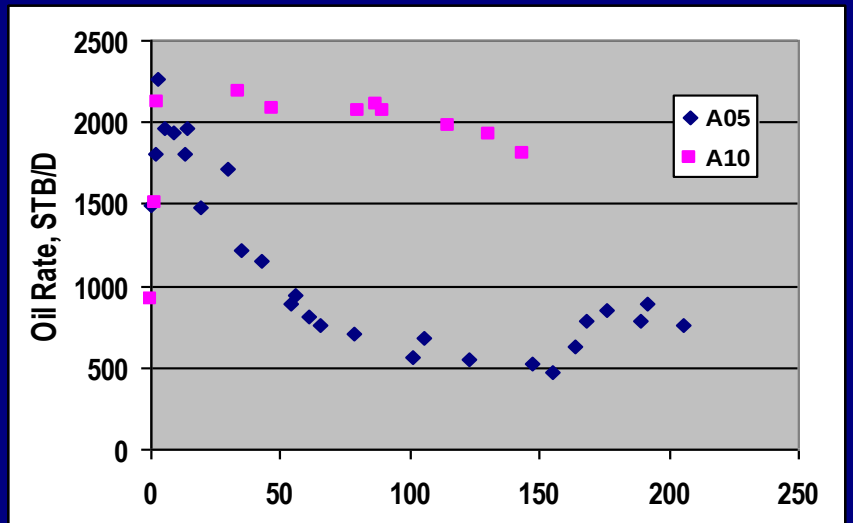
- EOR plan integrated in FDP
- Improve IOR through force balance
  - Minimize coning, cresting and cusping
  - Control fluid contact movement
- Produced Gas Injection
  - GIGP Ratio
- Water Injection
  - Injection at GOC (water fencing scheme)
  - Injection at WOC
- Water Alternative Gas Injection
  - Gravity Assisted Simultaneous WAG
  - Lowering residual HC
- Surfactant augmented water flood

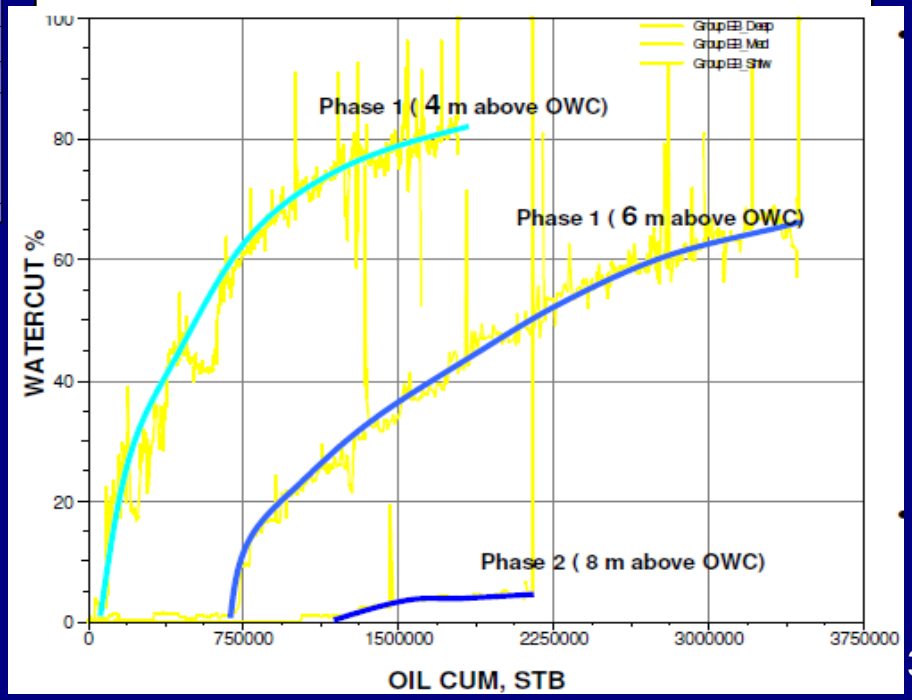




Field A: Real Time RMS in a Field in Malaysia



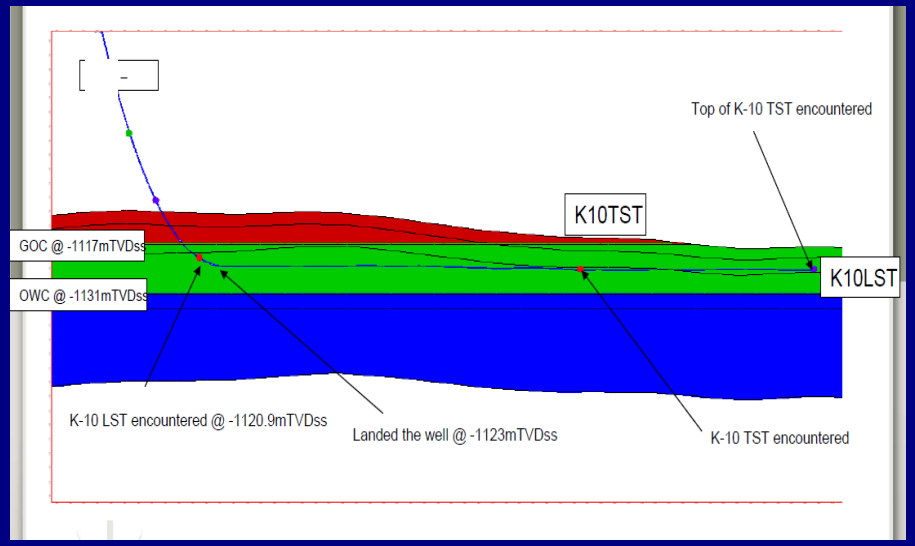


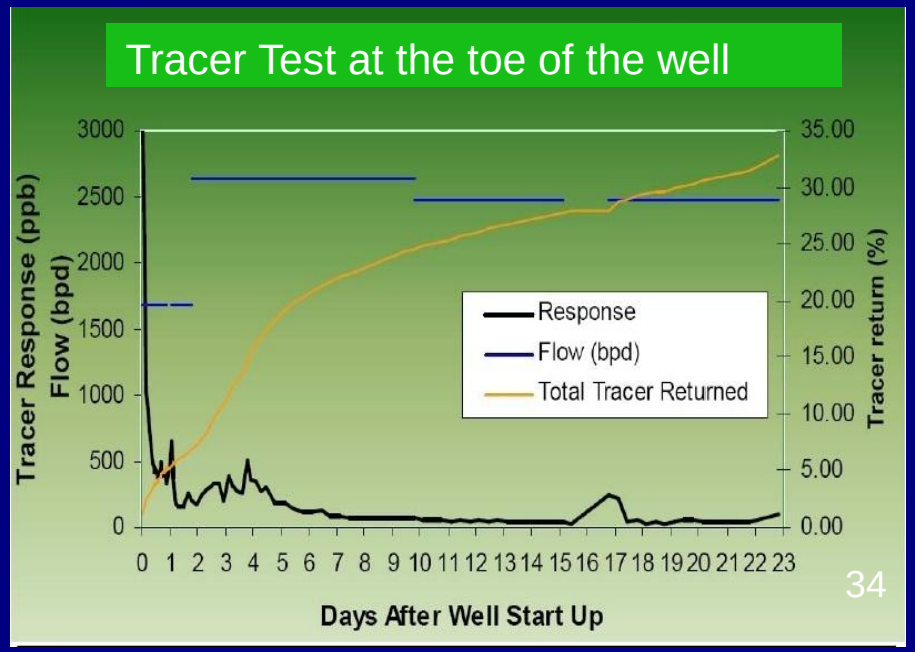


- 14 m oil column
- Known as non-commercial asset!
- Optimization of well spacing and landing
- 200 m lateral spacing for Well A05 & A10
- 4 m, 6 m and 8 m above WOC
- More oil production and delay WBT

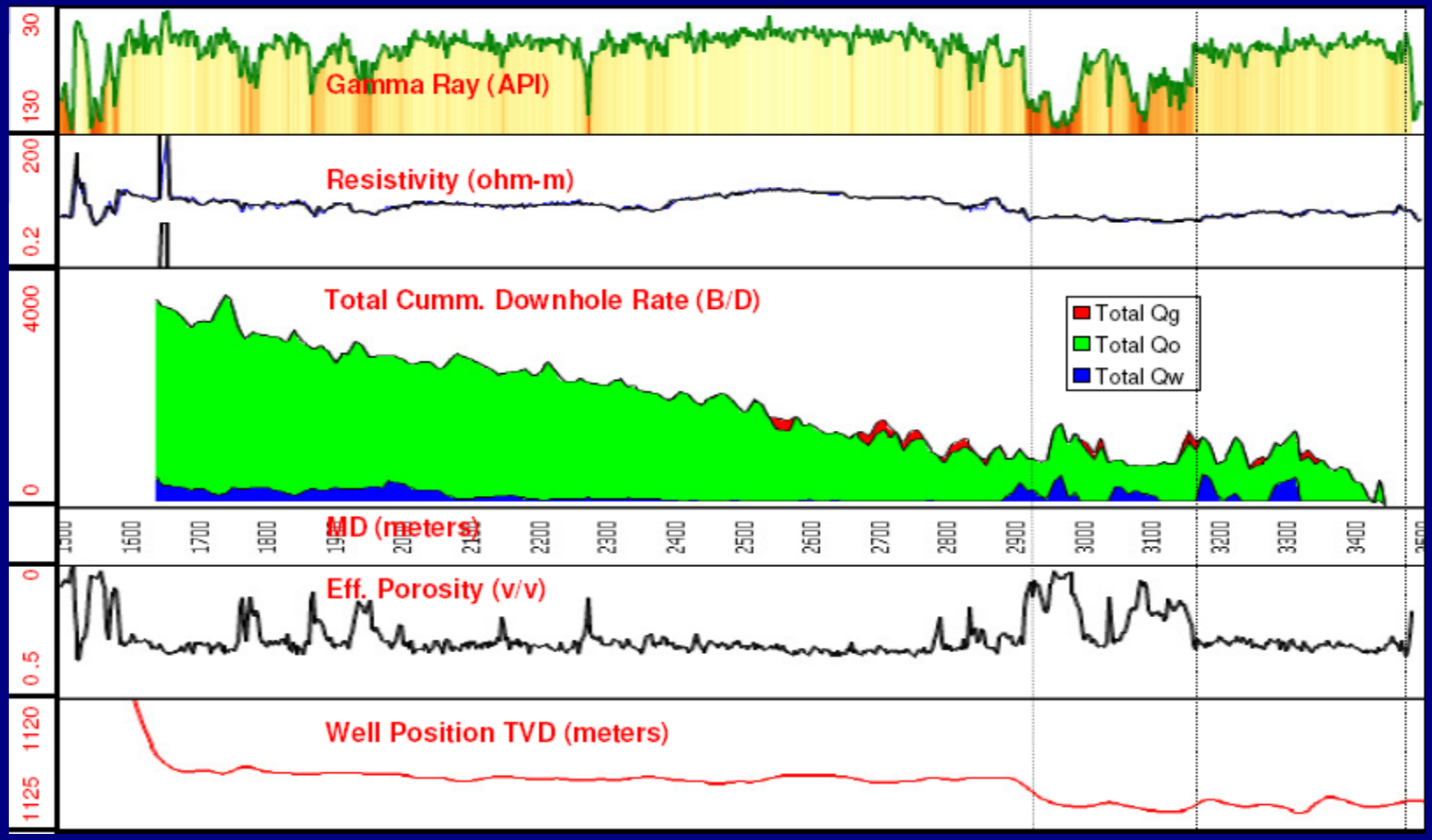
Field A: Horizontal well length optimization and tracer application

- 1.6 km horizontal well with ICD completion
- Toe section contribution
- Tracer application in the toe section
- Toe flow contribution in the early stage
- Smart completion allows longer HZ wells
- PLT is planned post WBT.



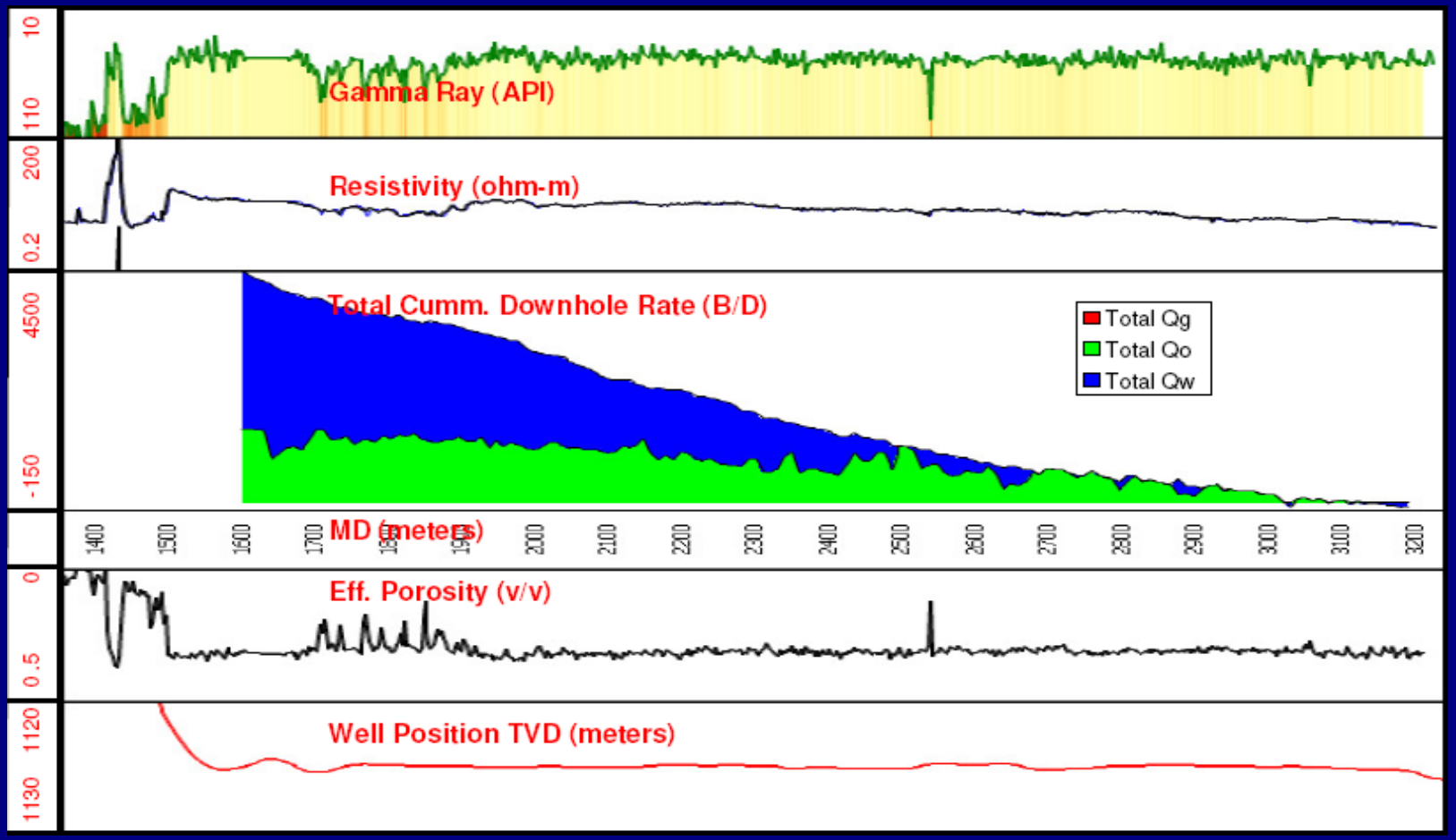


Field A: Horizontal well A performance with ICD post WBT



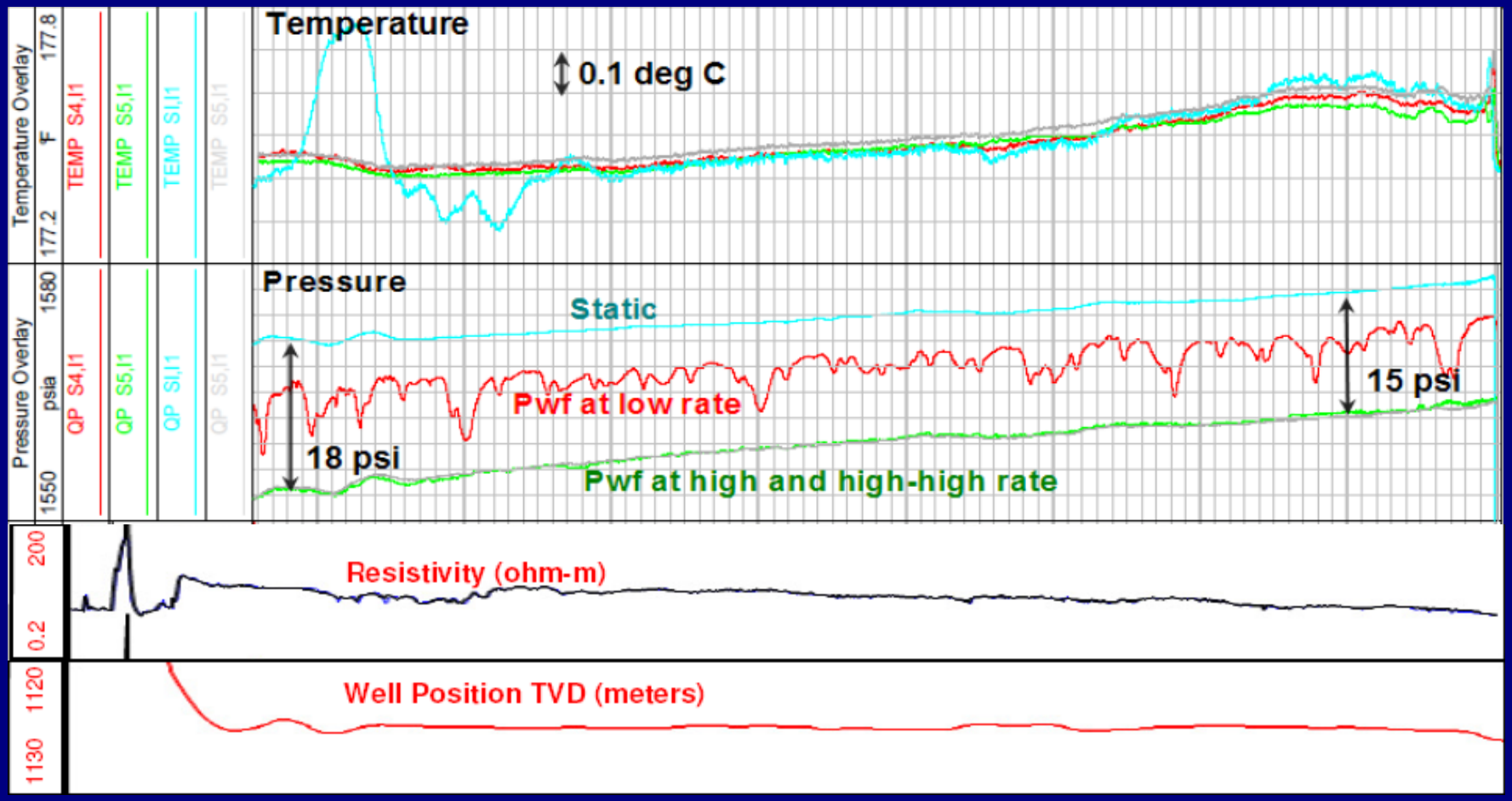
- Well-A with 1.9 km length, 4000 BPD, 5% W-cut, Np of 750 MSTB
- Coil Tubing Unit clean out and PLT
- Low (2.5 KBPD) and high (4.5 KBPD) rate flowing condition tested
- Flow contribution from the entire wellbore

Horizontal well04 performance with ICD post WBT- Field A



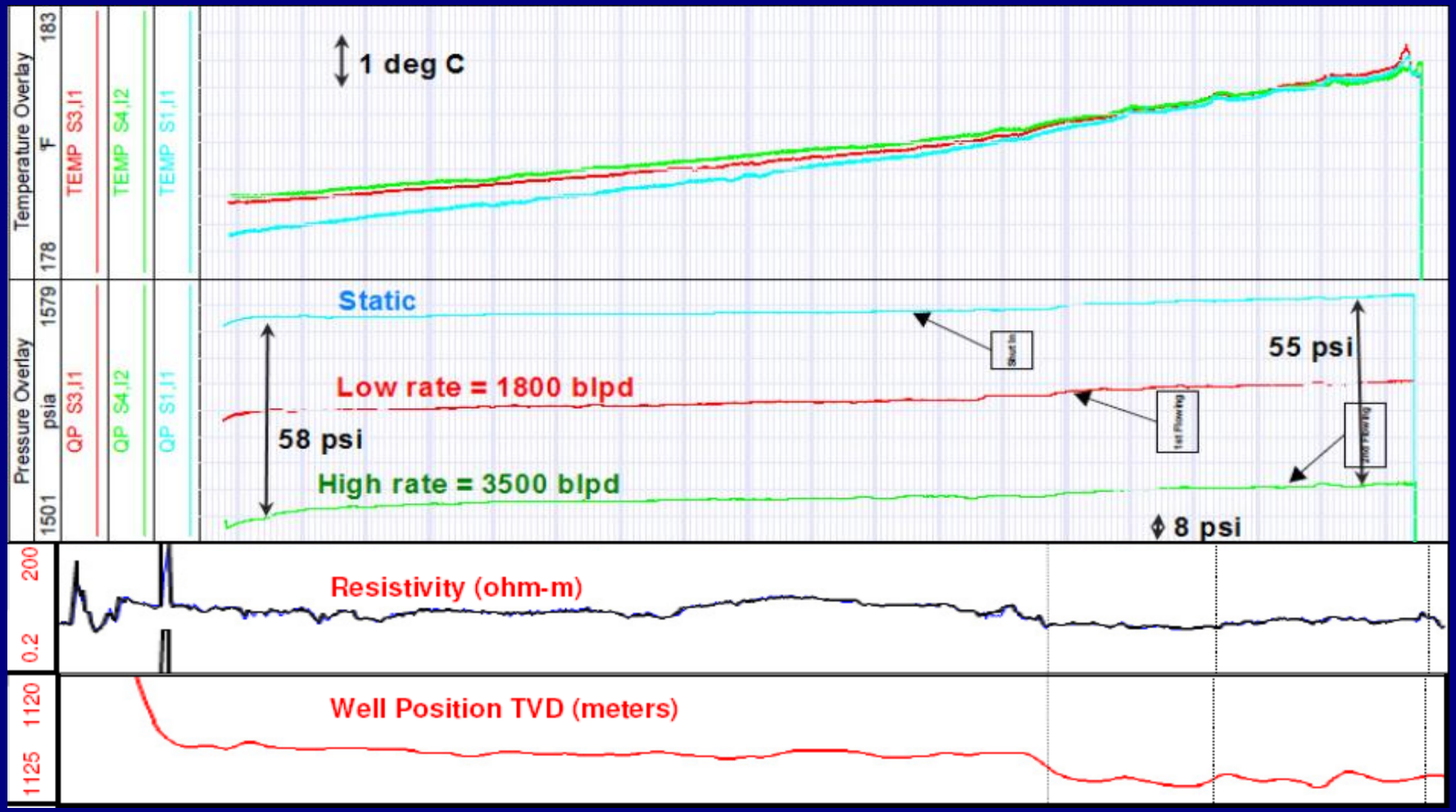
- Well-04 with 1.6 km length, 4500 BPD, 70% W-cut, Np of 1.5 MMSTB
- Coil Tubing Unit clean out and PLT
- Low (2.5 KBPD) and high (4.5 KBPD) rate flowing condition tested
- Flow contribution from the entire wellbore
- Even with ICD, there are more water from the heel

Pressure and Temperature Proifile- Well04



- Although claimed horizontal by drilling contractor, the static pressure/temp/resistivity shows downward deviation
- Big ICD pore size (4/32 Inch in this case) create small drawdown and it is a challenge to have uniform drawdown along the well (15 psi vs 18 psi, 17% different)

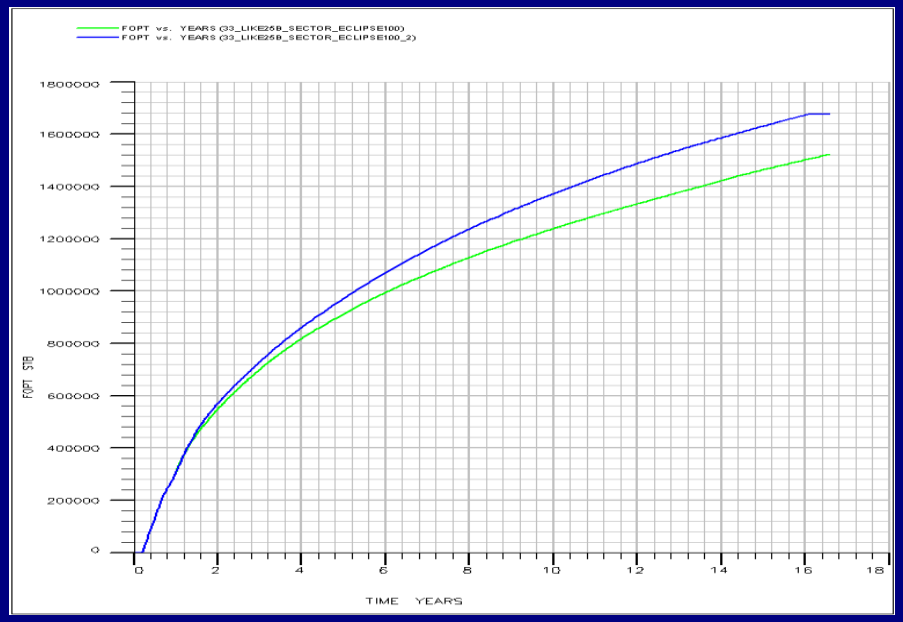
Pressure and Temperature Profile- Well08

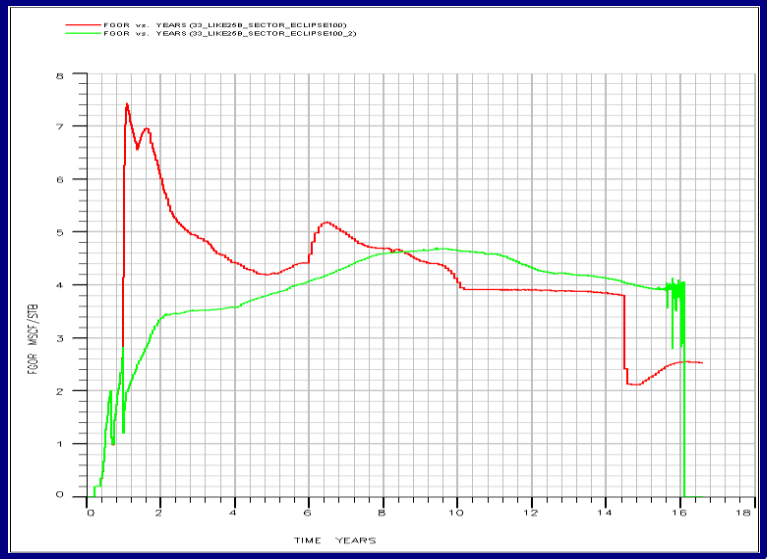


- Although claimed horizontal by drilling contractor, the static pressure/temp/resistivity shows downward deviation
- Smaller ICD pore size (3/30 Inch in this case) create bigger drawdown and it is better for having uniform drawdown along the well (58 psi vs 55 psi, 5% different)

Field A: Improving the hydrocarbon recovery

- Horizontal wells with ICD completion
- MSW approach for well modeling
- 11% RF increase on “No ICD” case.
- This happened through:
  - Draw down management
  - Gas suppression
  - WBT control
- ICD pore size can be further optimized!
- Reservoir heterogeneity along the well





Field A: Journey of recovery factor improvement

- Water injection
- Mobility control
- Idle well re-activation

- 42 Wells
- Phase 3 prospect

- Long HZ Well
- 6-8 m offset from OWC
- Project Phasing

>34%

32%

23%

20

16%

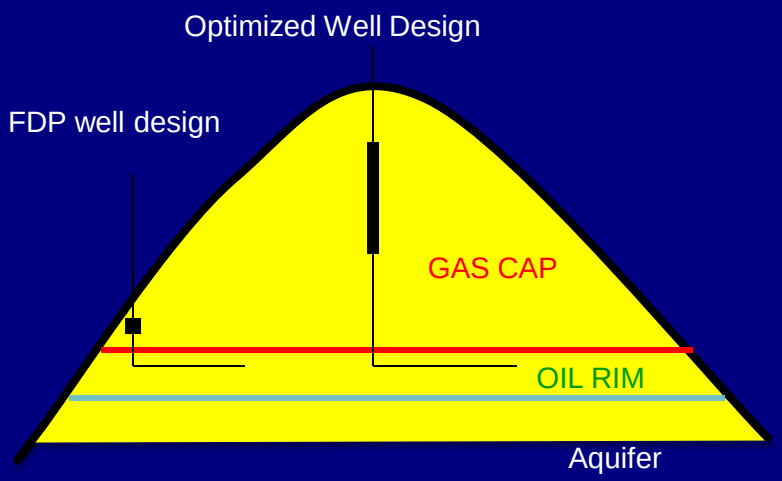
- Accurate TZ characterization
- Proper HZ and smart well modeling
- Economical phase 3
- Optimizing the number of wells

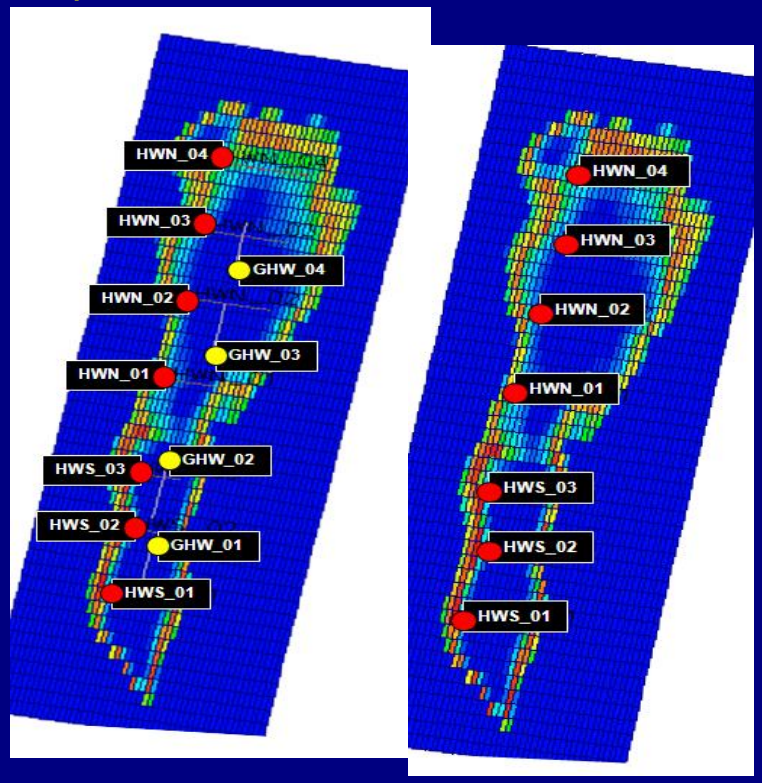
- 27 Wells
- Horizontal wells + ICD
- Gas cap gas reinjection
- 4 m offset from OWC

Field B: Optimized Production Strategy in a Malaysian Carbonate Oil Rim

Cases	Oil Recovery (MMSTB)	GAS Recovery (BSCF)	Well No.
Original FDP	41	375.4	7 + 4
Opt. attempt (1)	38.3	383.1	7

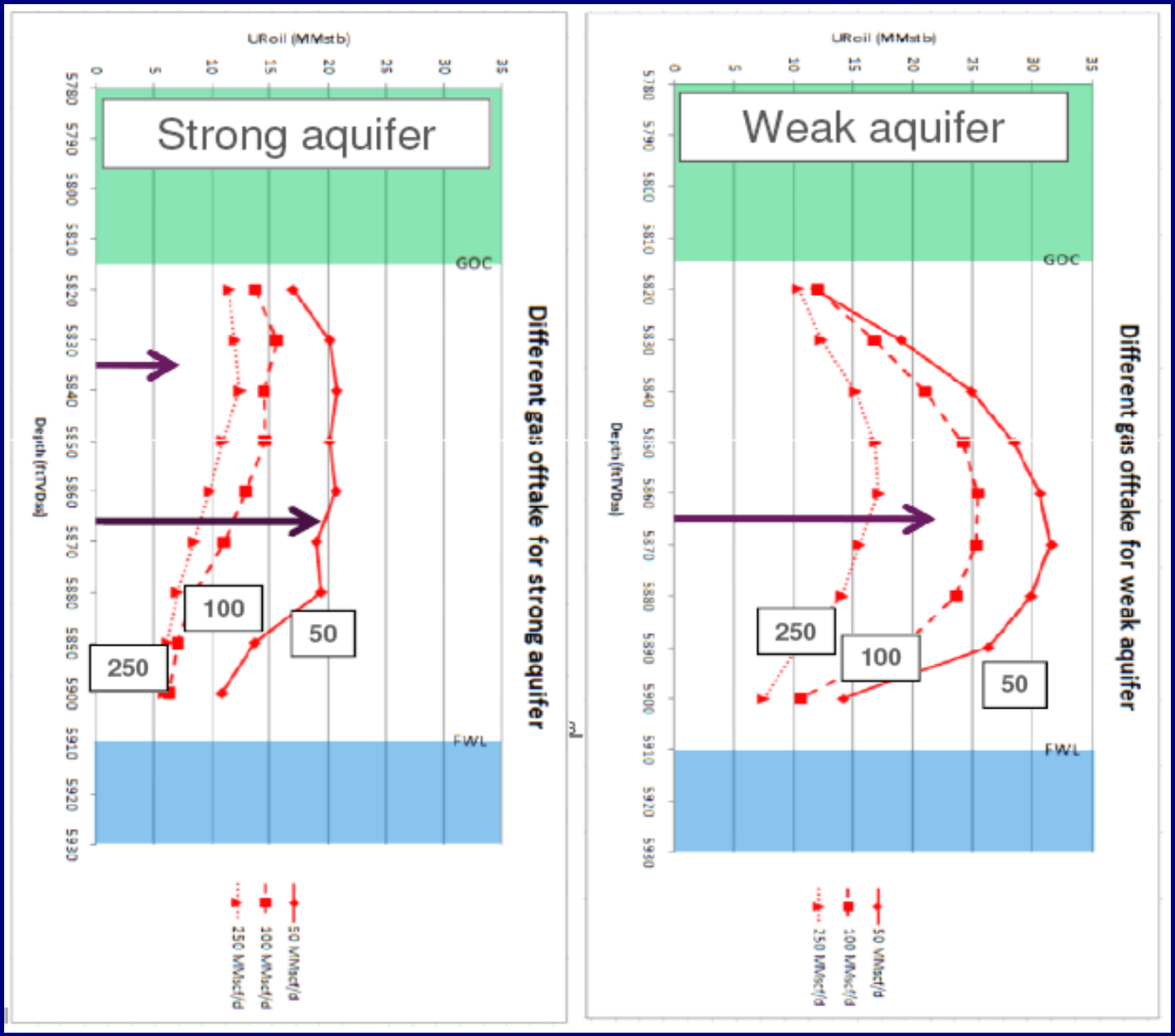
- Known as gas field!
- Concurrent Oil and Gas development
- Oil and gas production through the same well
- Dual smart completion with ICV
- Development cost reduction



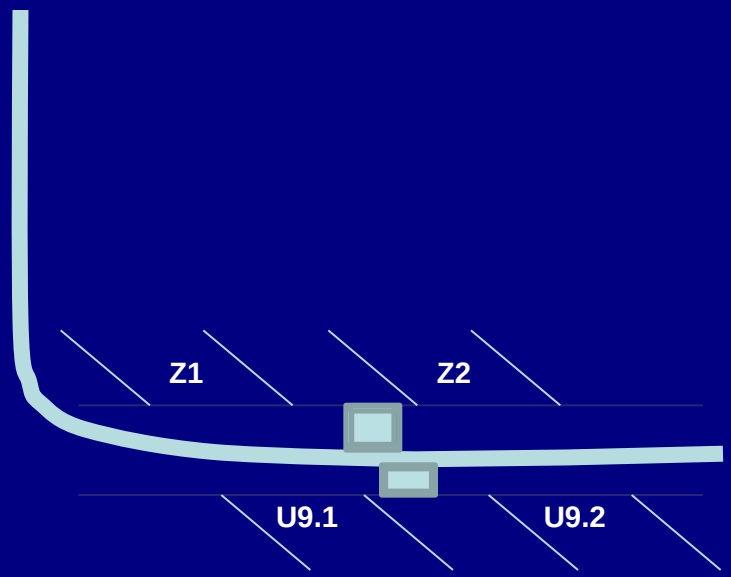


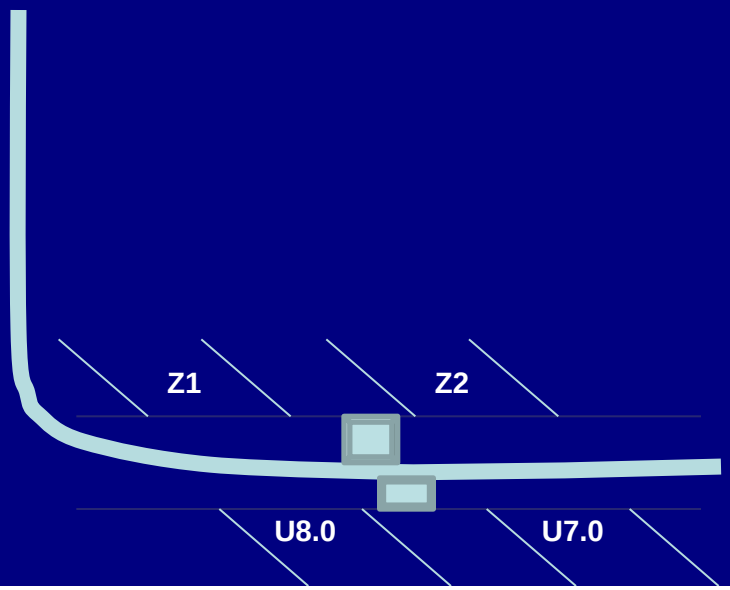
Well Position vs EUR in Field B

- 2 km HZ well
- Gas offtake effect
- Aquifer effect
- ICD vs SSD

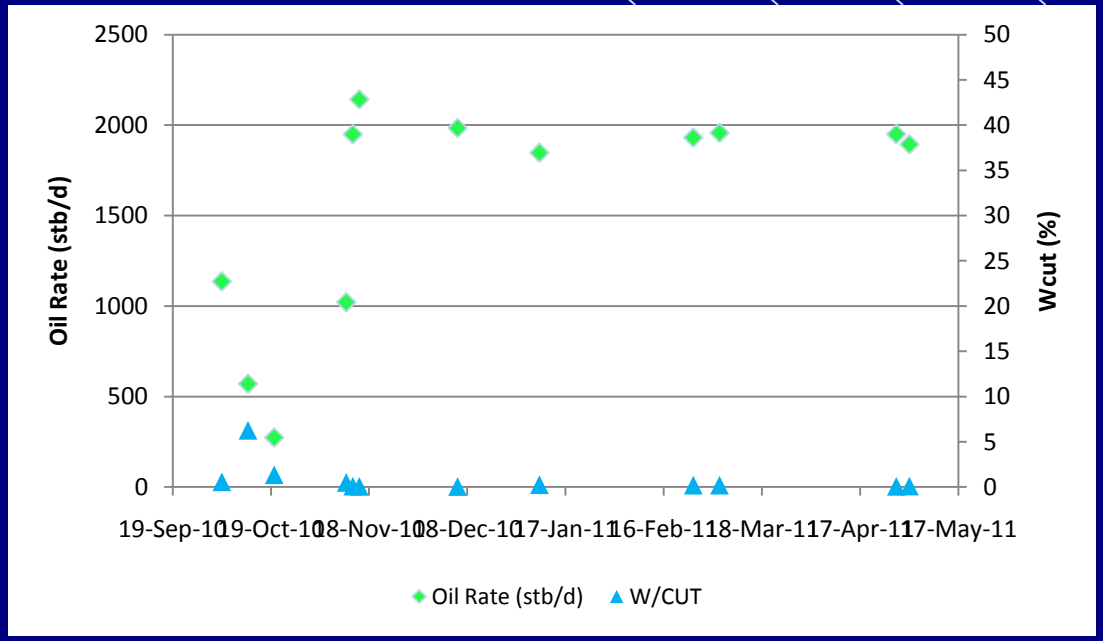


Field C: Withdrawal control from different zones



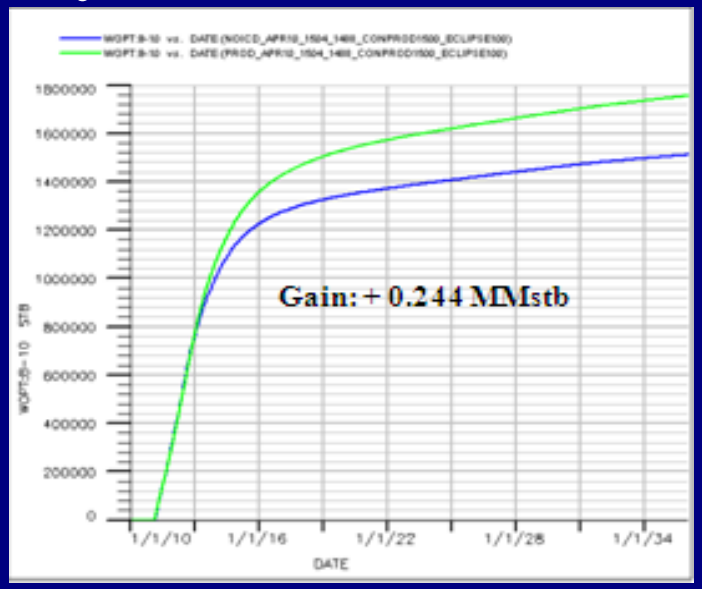


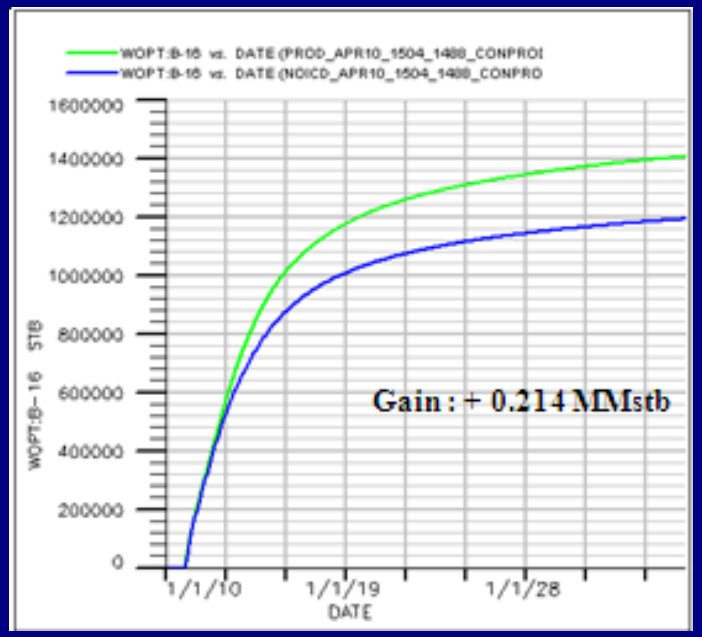
- 10 m oil column
- FCV with PDG application
- Close performance monitoring
- Valve optimization
- PBU survey

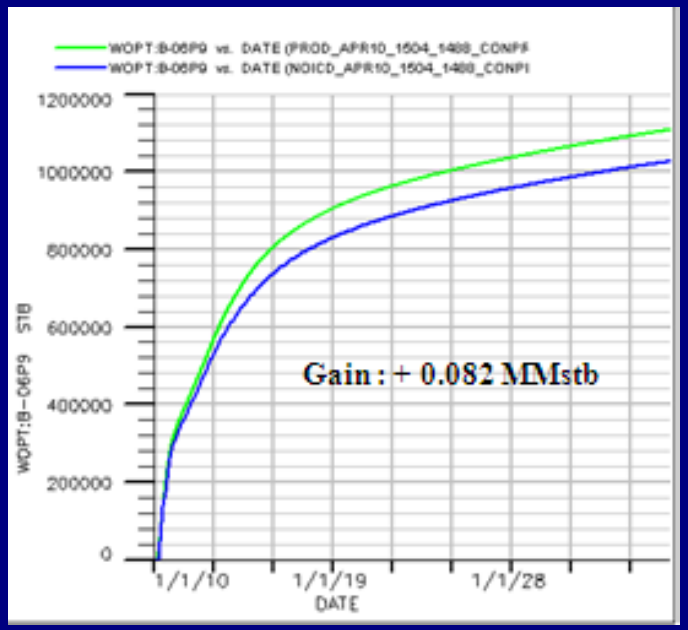


Improving the hydrocarbon recovery in Field C

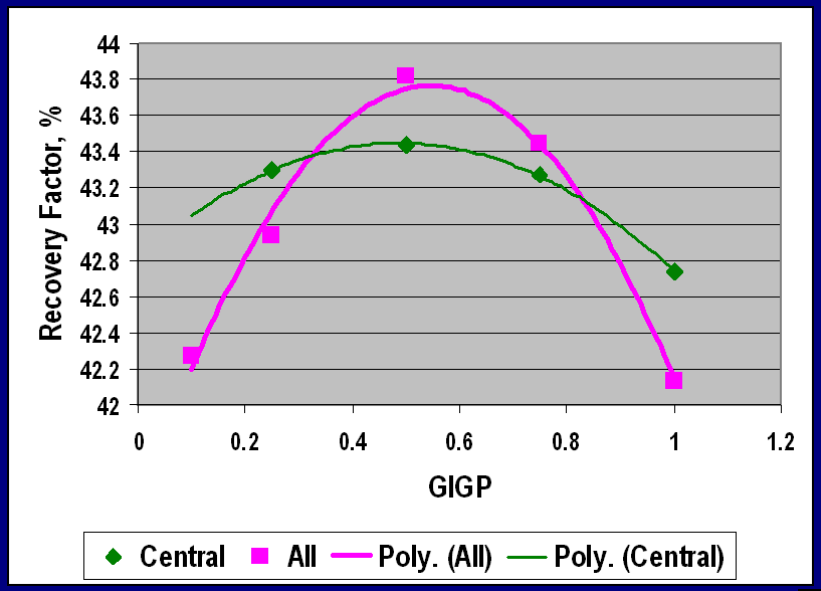
- Horizontal wells with ICD completion
- Multi zone production with Flow Control Valve
- HZ well and smart completion modeling
- 6% RF increase upon “No ICD” case.
- Recommend longer HZ well, PDG, optimum well placement, pilot hole and contact monitoring
- Recommend static/dynamic model revisit





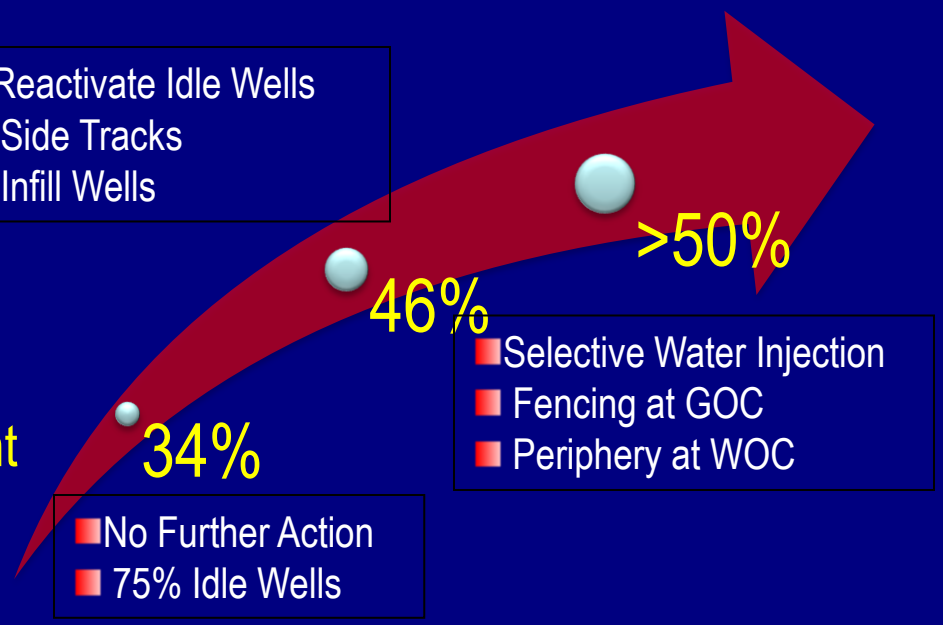


Field D: Improving the hydrocarbon recovery



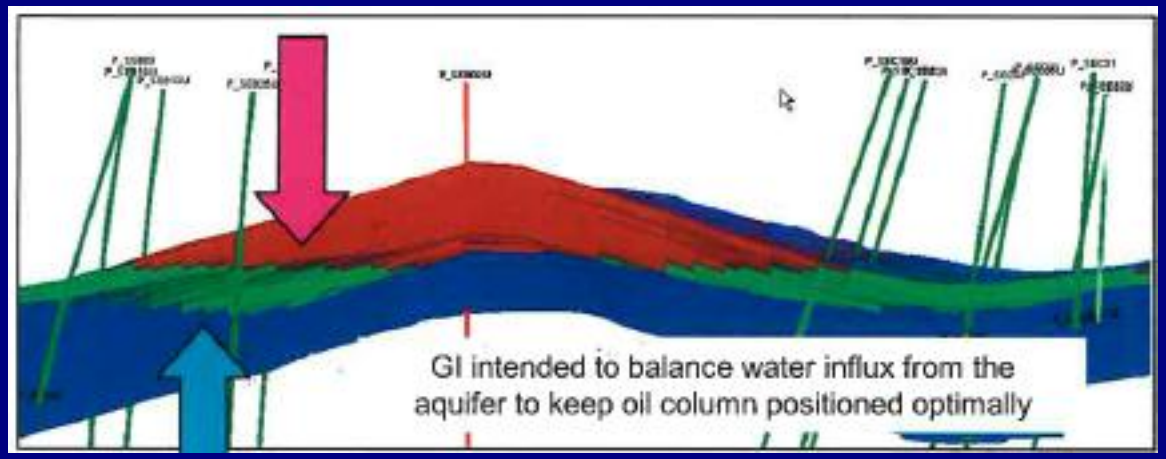
- Recovery factor vs GI/GP

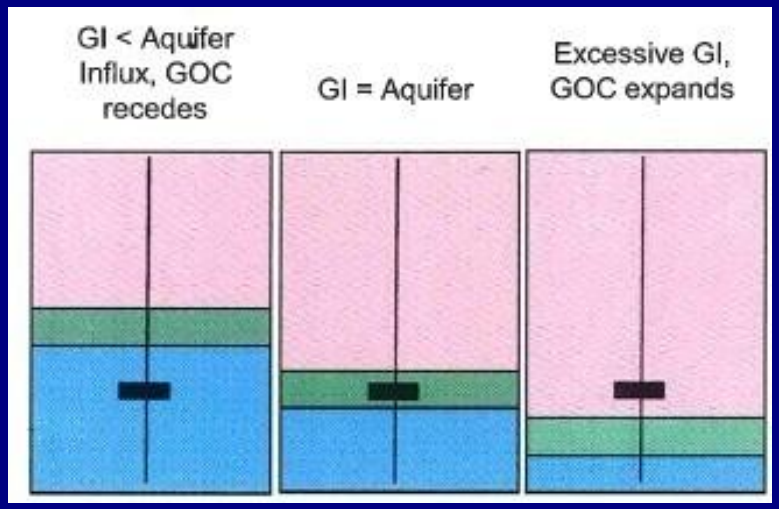
- Journey of recovery factor improvement

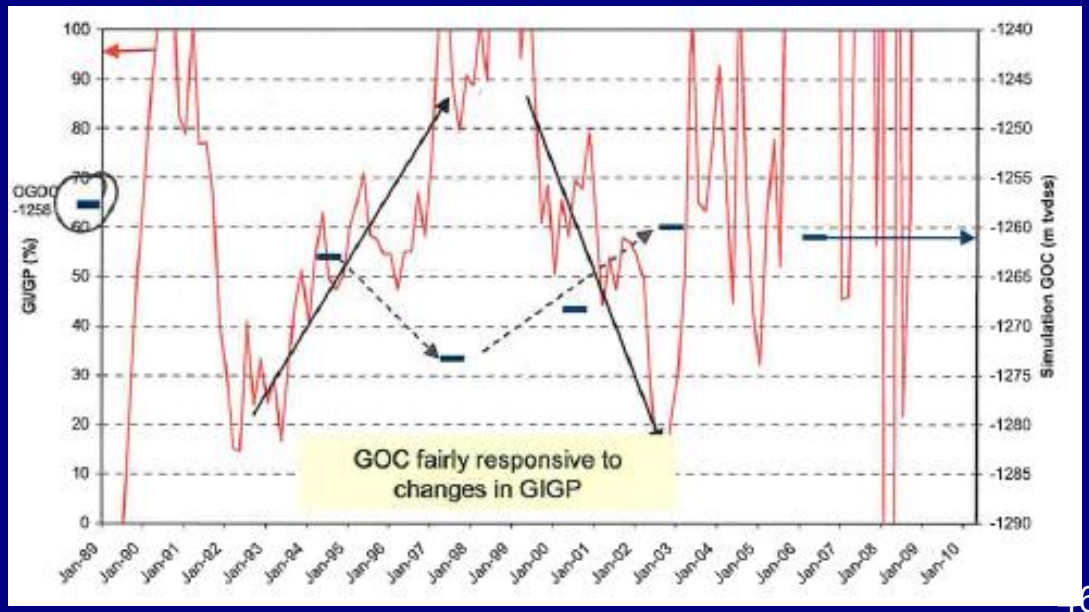


RF Sensitivity to GI/GP in Field D

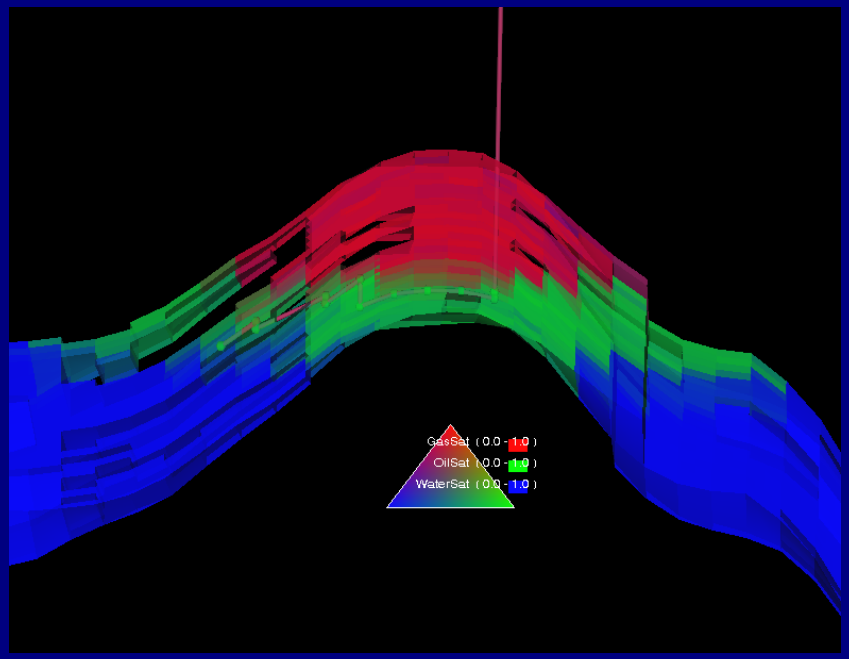
- GI/GP Management
- Recovery factor vs GI/GP

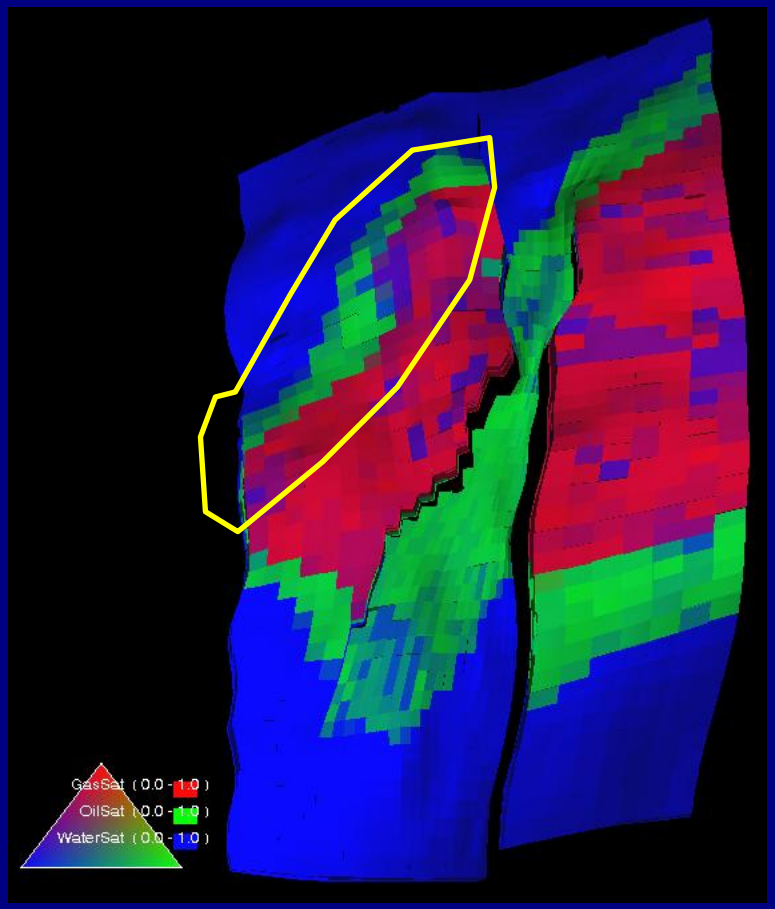






Field E: Smart HZ Well Application in Small Oil Pocket



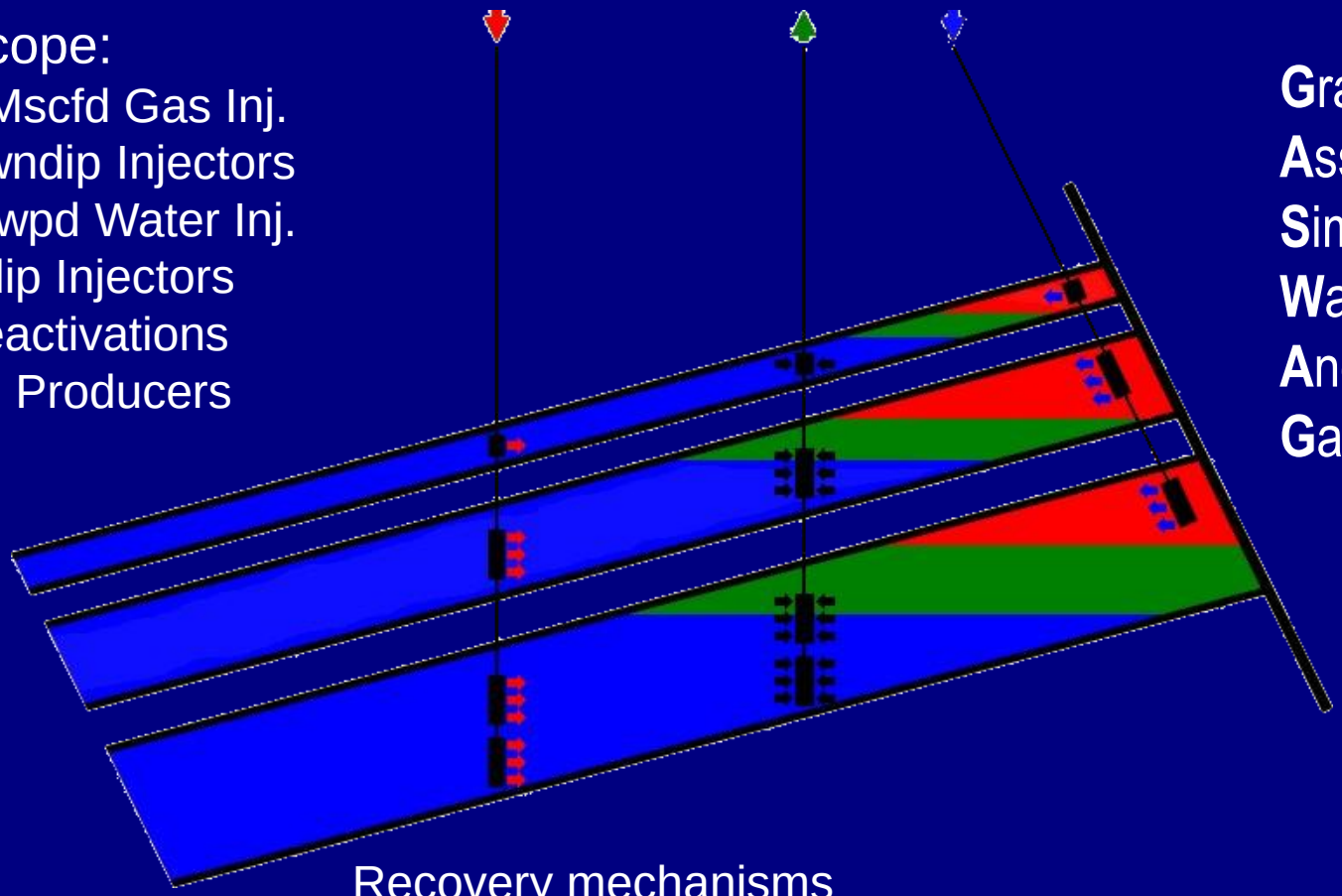


- 4 MMSTB STOIIP
- 8 m oil column
- Gas cap size M ratio=1.7
- Vertical well EUR=0.17 MMSTB
- 500 m Smart HZ Well EUR=0.9 MMSTB
- UDC= USD 18/bbl
- Oil column thickness as low as 5 m with HZ well with ICD

Field G: New EOR Scheme

EOR Scope:

- 50 MMscfd Gas Inj.
- 4 Downdip Injectors
- 50 kbwpd Water Inj.
- 5 Updip Injectors
- 22 Reactivations
- 4 Infill Producers



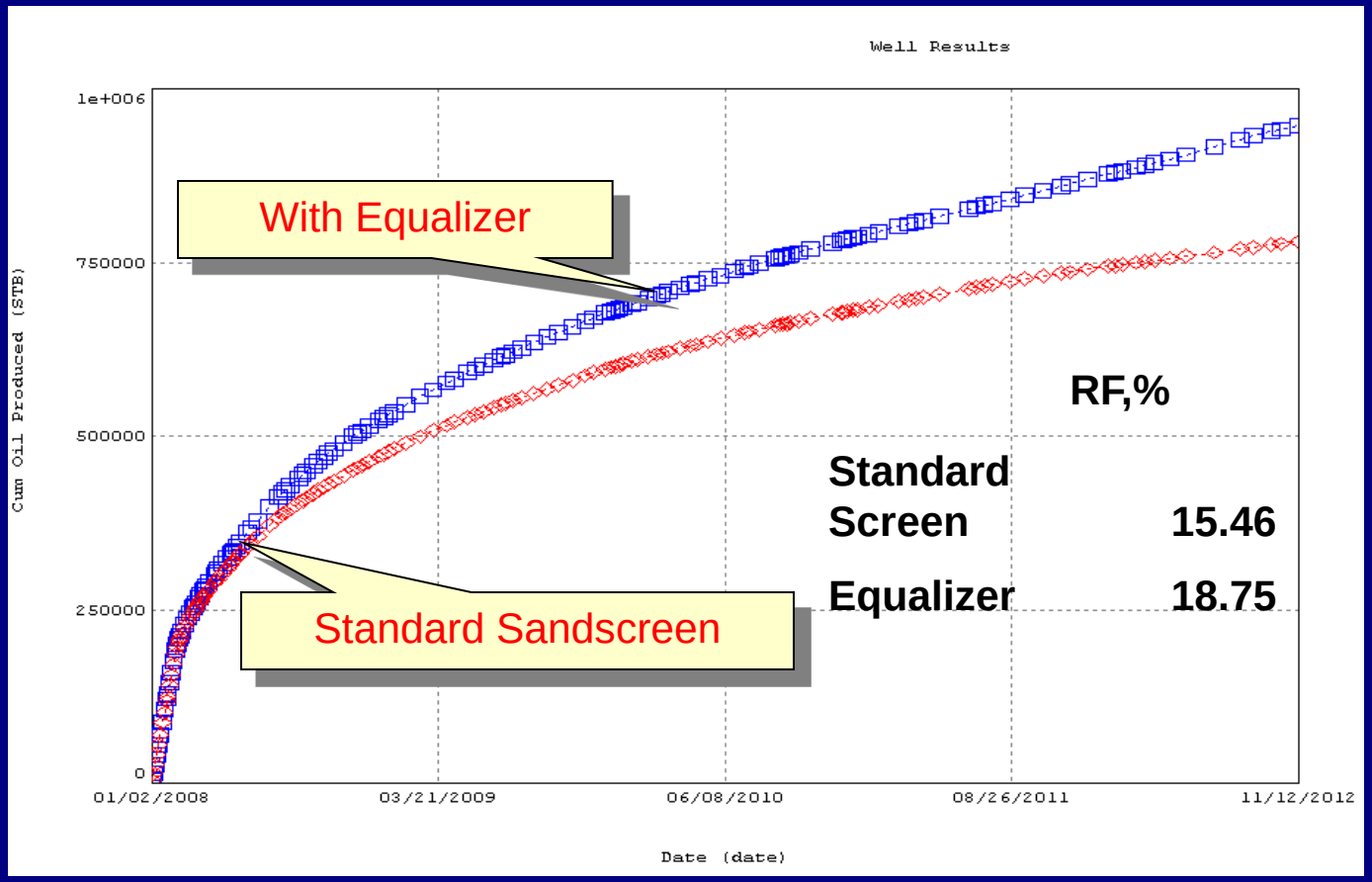
Gravity
Assisted
Simultaneous
Water
And
Gas Injection

Recovery mechanisms

- Re-pressurizing reservoir
- Sweeping remaining oil towards new wells
- Improved vertical sweep using gravity assistance
- Pushing attic oil back down to producers
- Reduced S_{or} with respect to gas in water swept layers

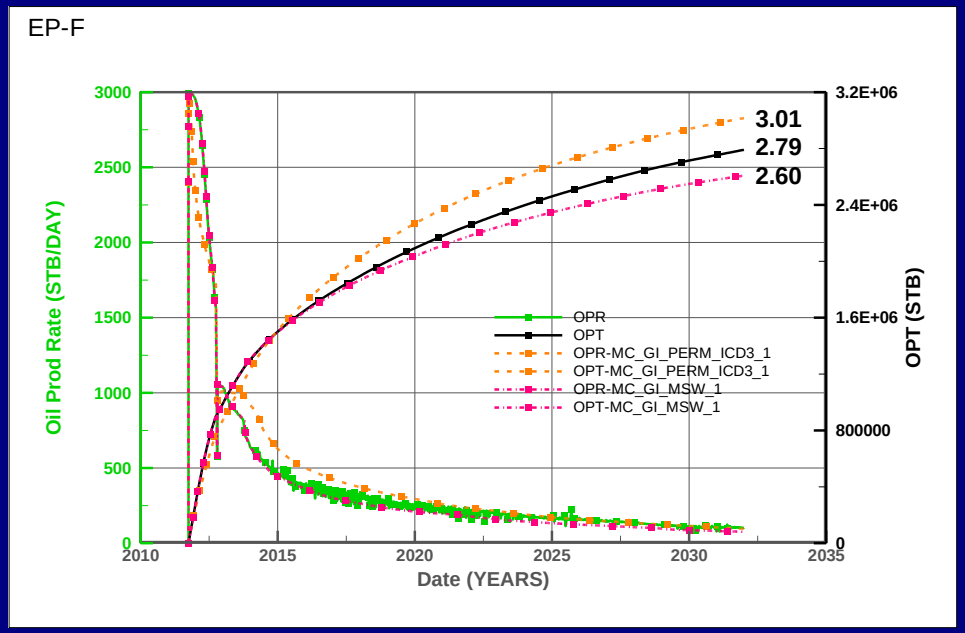
Field K: Do we need HZ well with ICD?

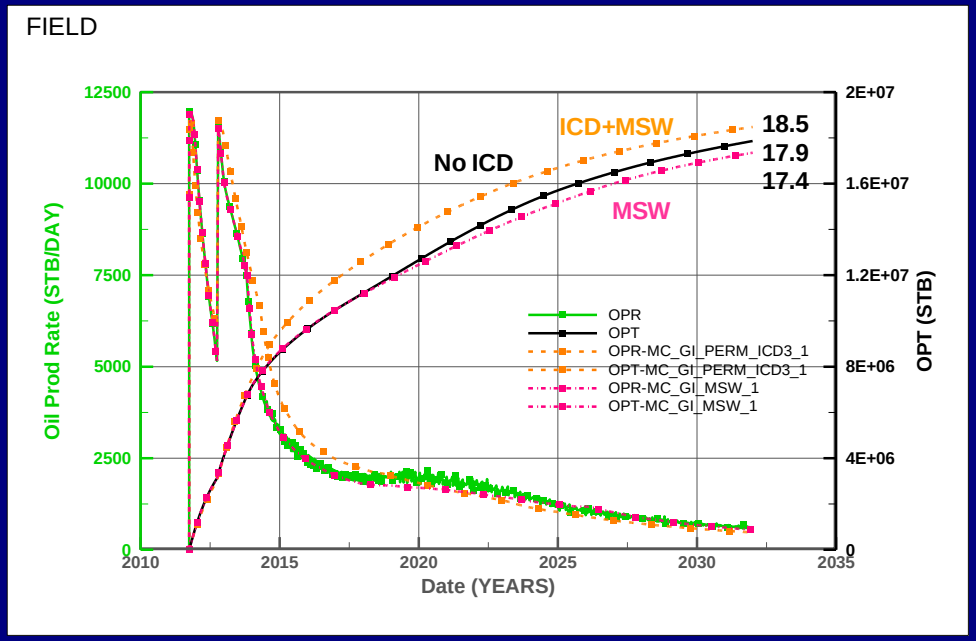
- Oil column = 6 m
- m = 2.0
- Phi avg = 25 %, k avg = 500 md
- Pini = 2100 psia, Tres = 226 deg F
- Strong aquifer



Case 9: Smart Horizontal Well modeling in a Malaysian Oil Rim

- 7% error over conventional methods
- 16% gain with ICD in well level
- 6% gain with ICD in field level

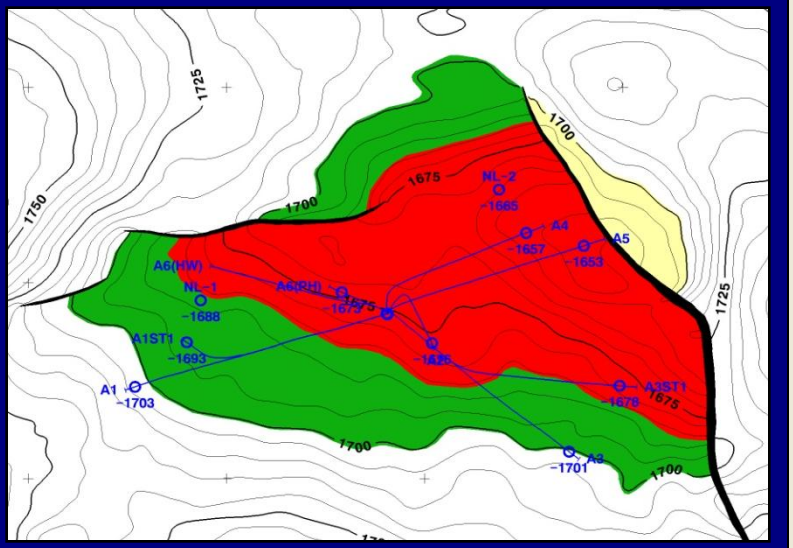


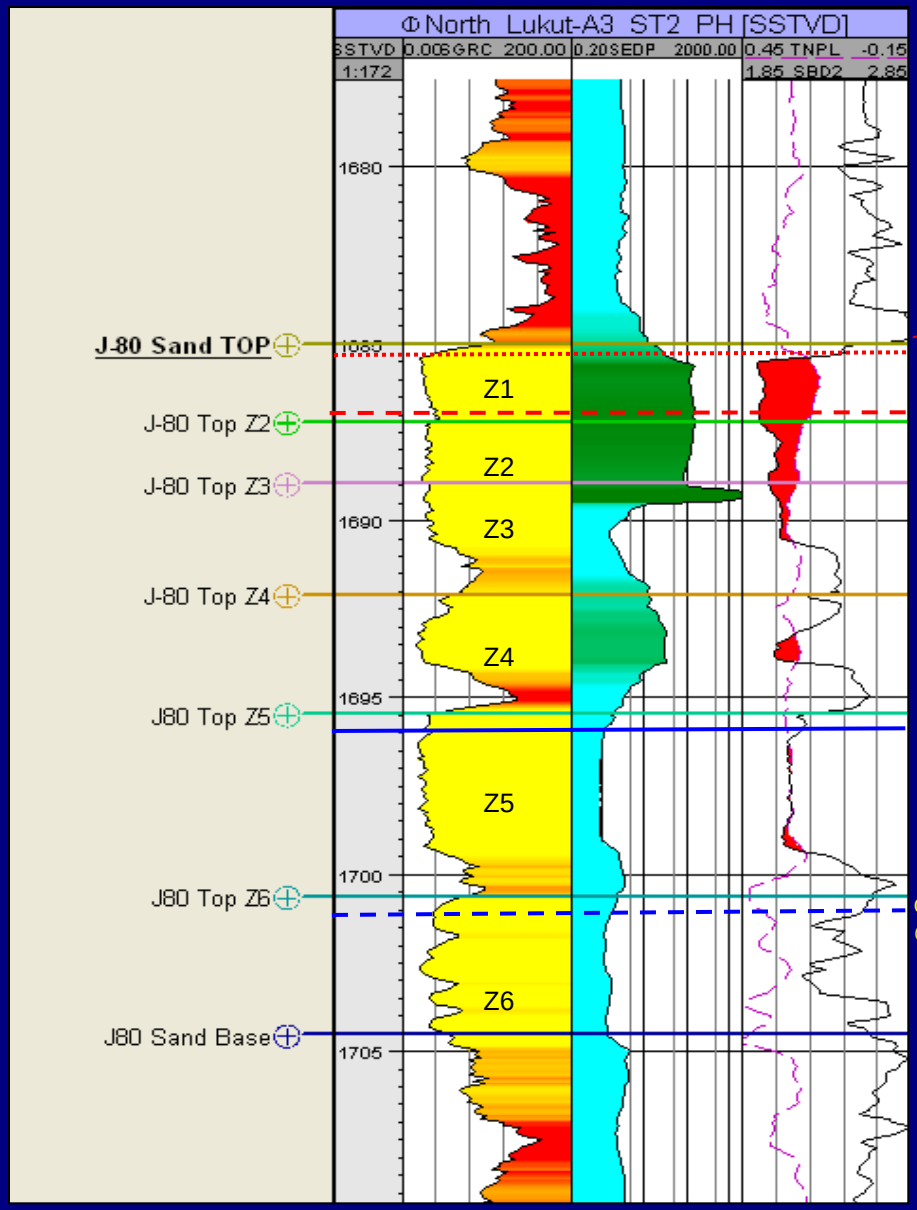


ICD Design
- Tubing OD 5.5”, ID 4.892”
- ICD port size 3/32”
- ICD interval 11m

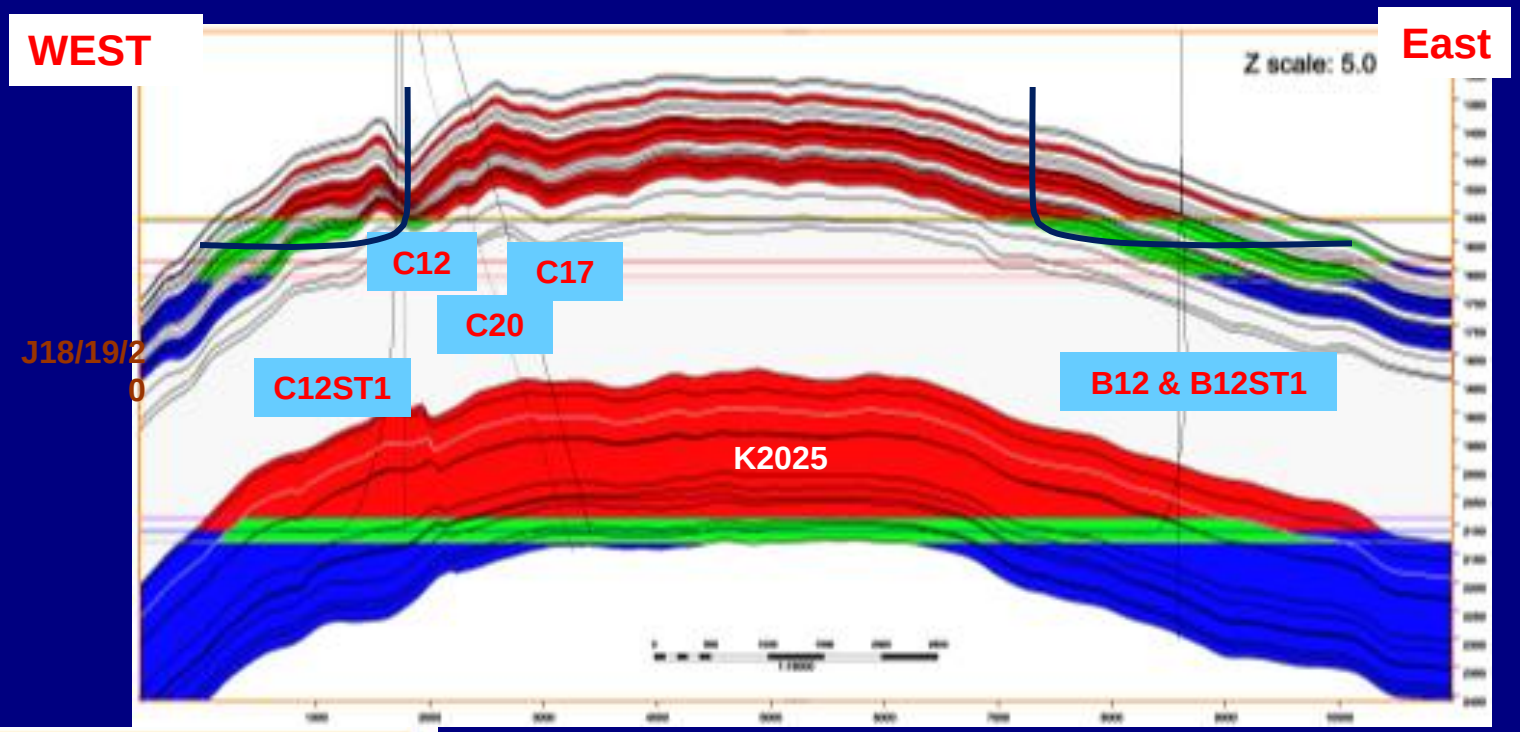
Case 5: Withdrawal Mis-Management in Field F

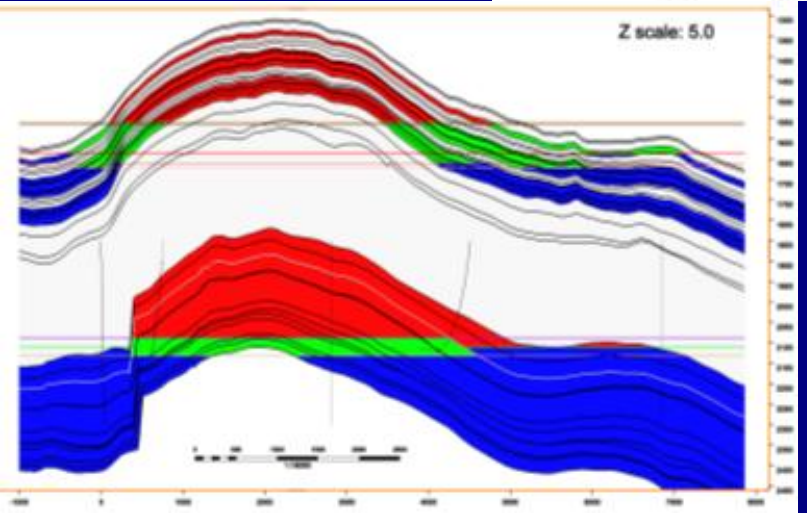
- Gas Cap production
- Oil loss to the gas cap
- Lower RF





Innovative Well Design and Off take Strategy





Closing Remarks:

- Oil rim: good business opportunity with sweet headaches!
- Integration of innovative technical initiatives and new technologies
- Real time/integrated reservoir management, monitoring and surveillances
- Several gas fields and un-commercial assets turned in to attractive oil rim developments
- Success cases on oil column thickness as low as 3 m and STOIIP as low as 3 MMSTB
- Time to change our culture/mindset! Lets follow all the success factors

Oil rim development can be reality now!

Lets move toward breaking the hydrocarbon recovery limit with lower cost!

Thank You!

Question?

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