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“Reservoir Engineering While Drilling” In Horizontal Wells

Shahid Azizul Haq
Schlumberger

Society of Petroleum Engineers
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Outline

- Why Reservoir Engineering While Drilling (REWD) in Horizontal Wells?
  - » Evolution of Logging While Drilling (LWD)
  - » Evolution of Wellbore Steering
- The Concept of Productivity Steering
  - » Key Enablers

Reservoir Engineering?

Management of fluids and energy distribution in a porous medium (reservoir) over time and space

The practice (art & science) of

a. estimating recoverable reserves, and
b. maximizing (hydrocarbon) recovery, cost effectively

Why Drill Horizontal Wells?

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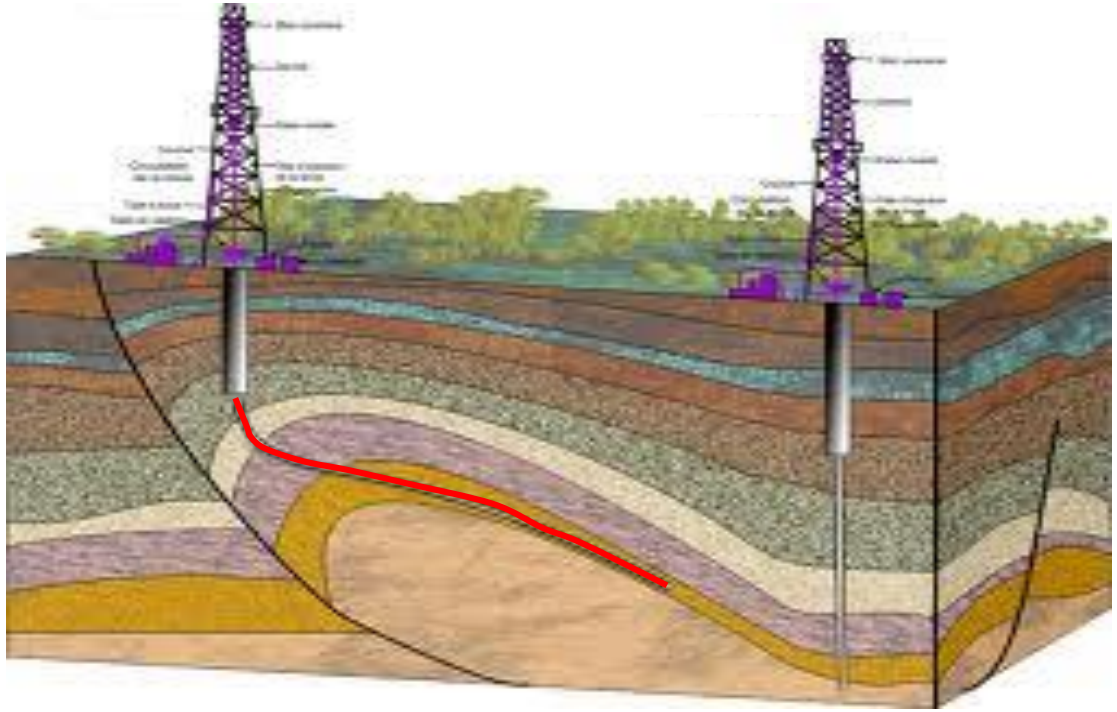
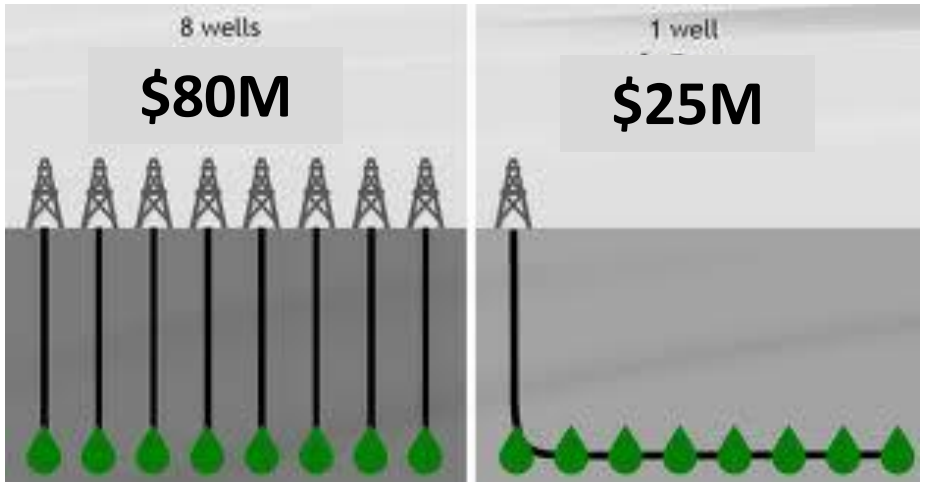
Horizontal Drilling

Vertical Drilling





Why Drill Horizontal Wells?

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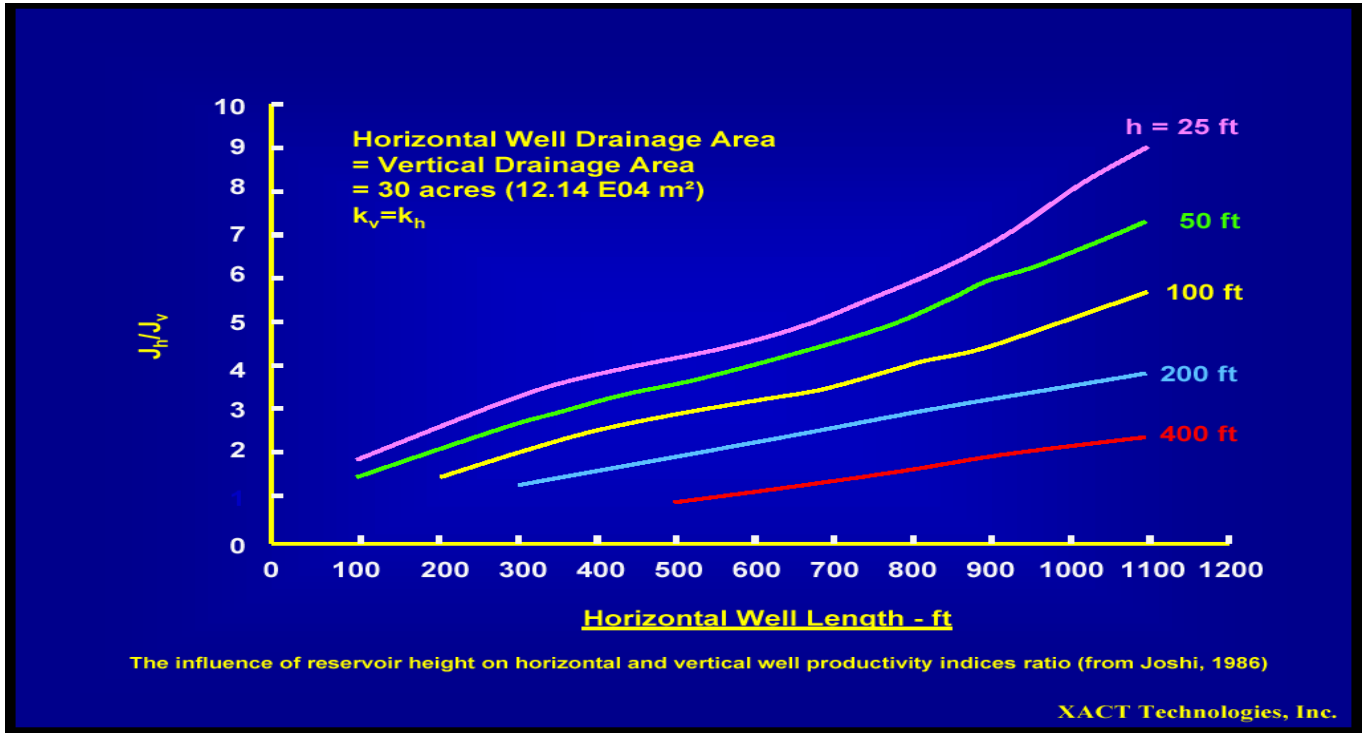
Increase Reservoir Contact

- Higher oil recovery rates



Why Drill Horizontal Wells?

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Increase Reservoir Contact

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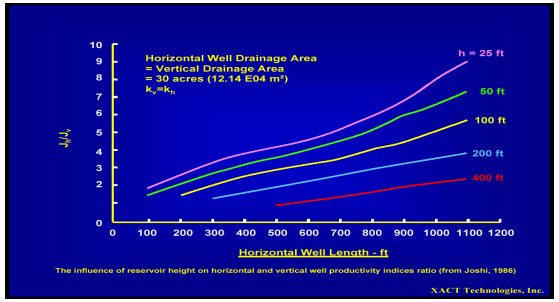
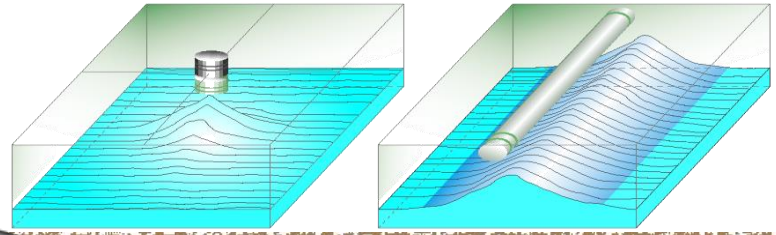


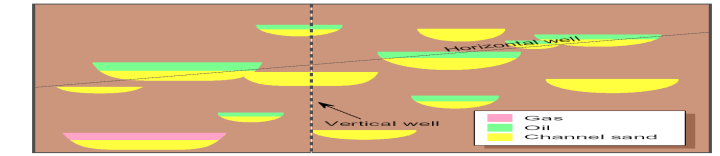
Reduce water or gas coning

- Higher sweep efficiency
- Lower production and infrastructure costs

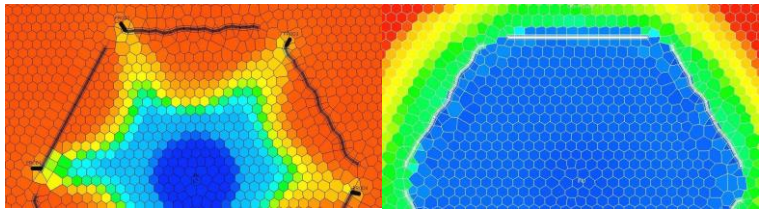


Heterogeneous Reservoirs

- Isolated channels, bypassed oil
- Fractured reservoirs



Heavy Oil



- Cyclic Steam Stimulation

Uncertainties Associated with Horizontal Drilling

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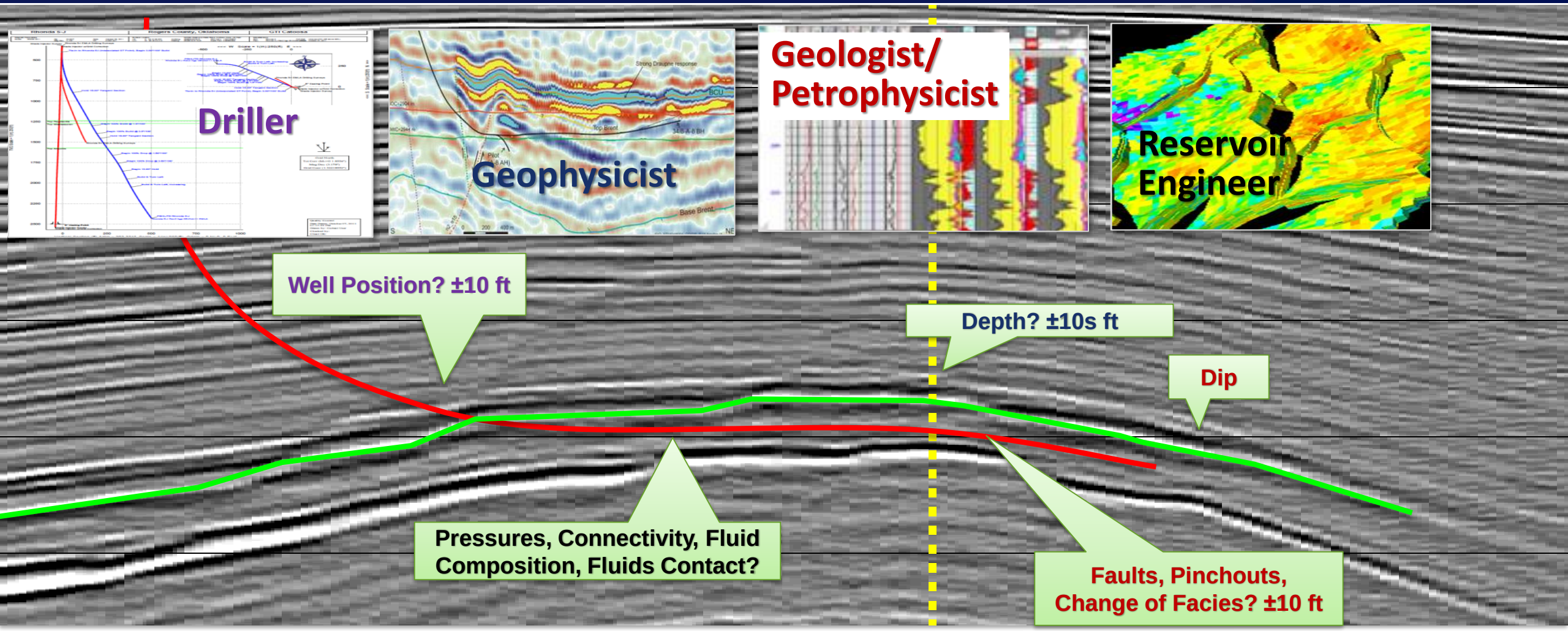

Logging While Drilling (LWD) Evolution

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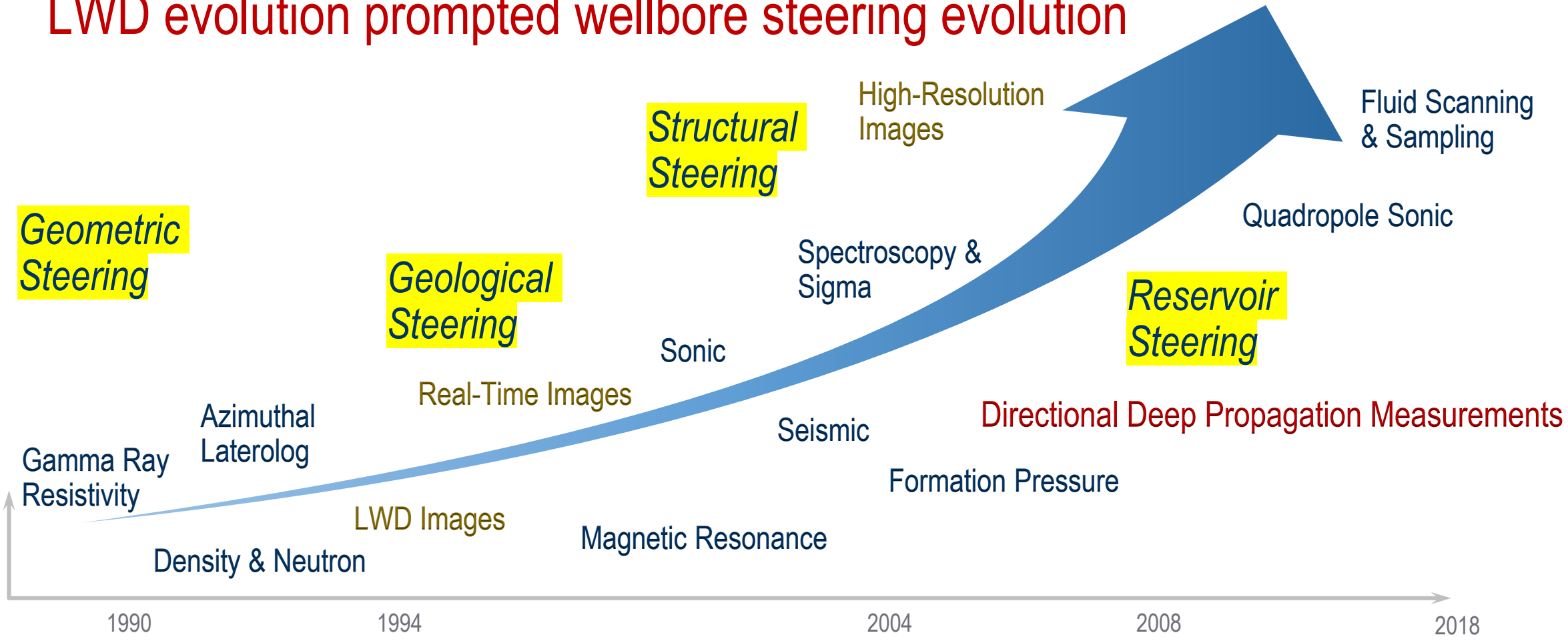
LWD evolution prompted wellbore steering evolution



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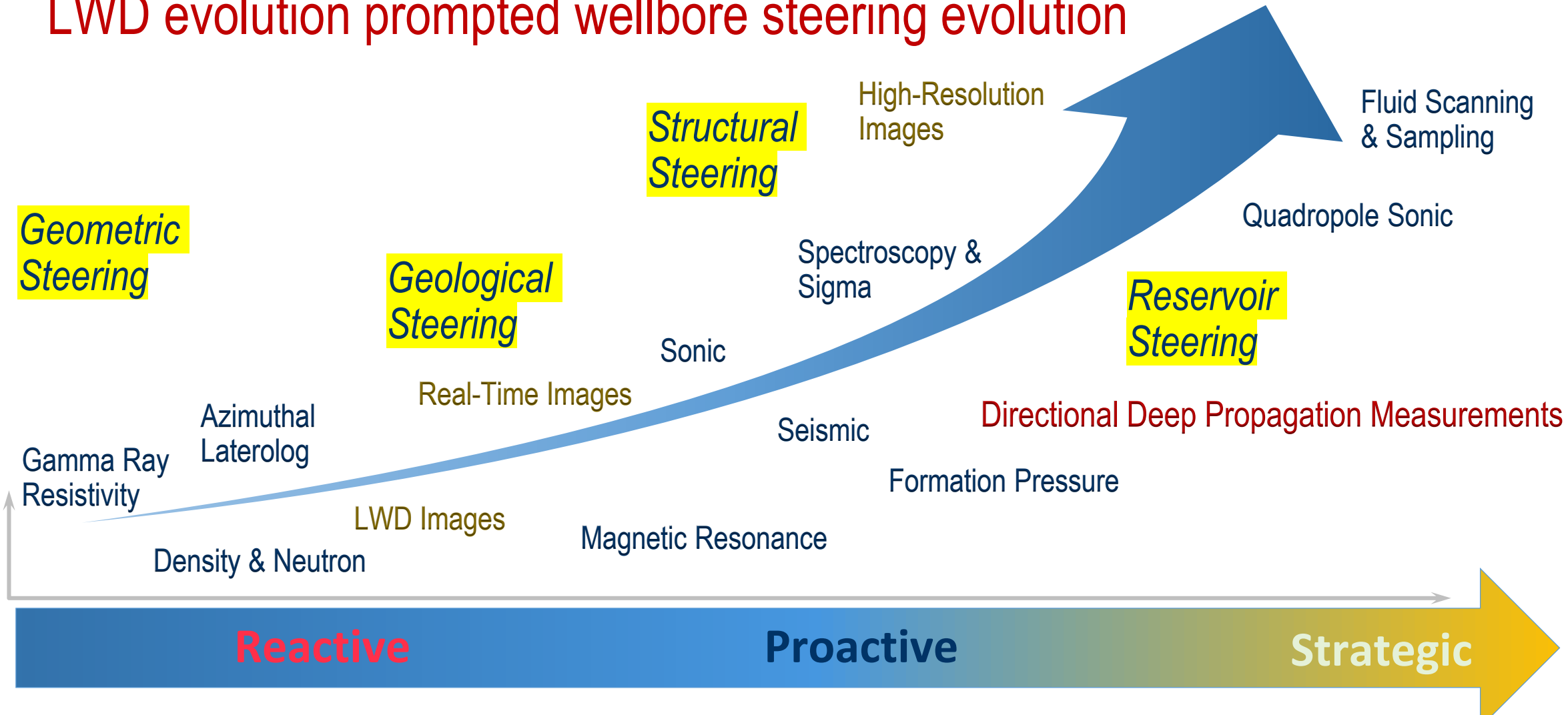
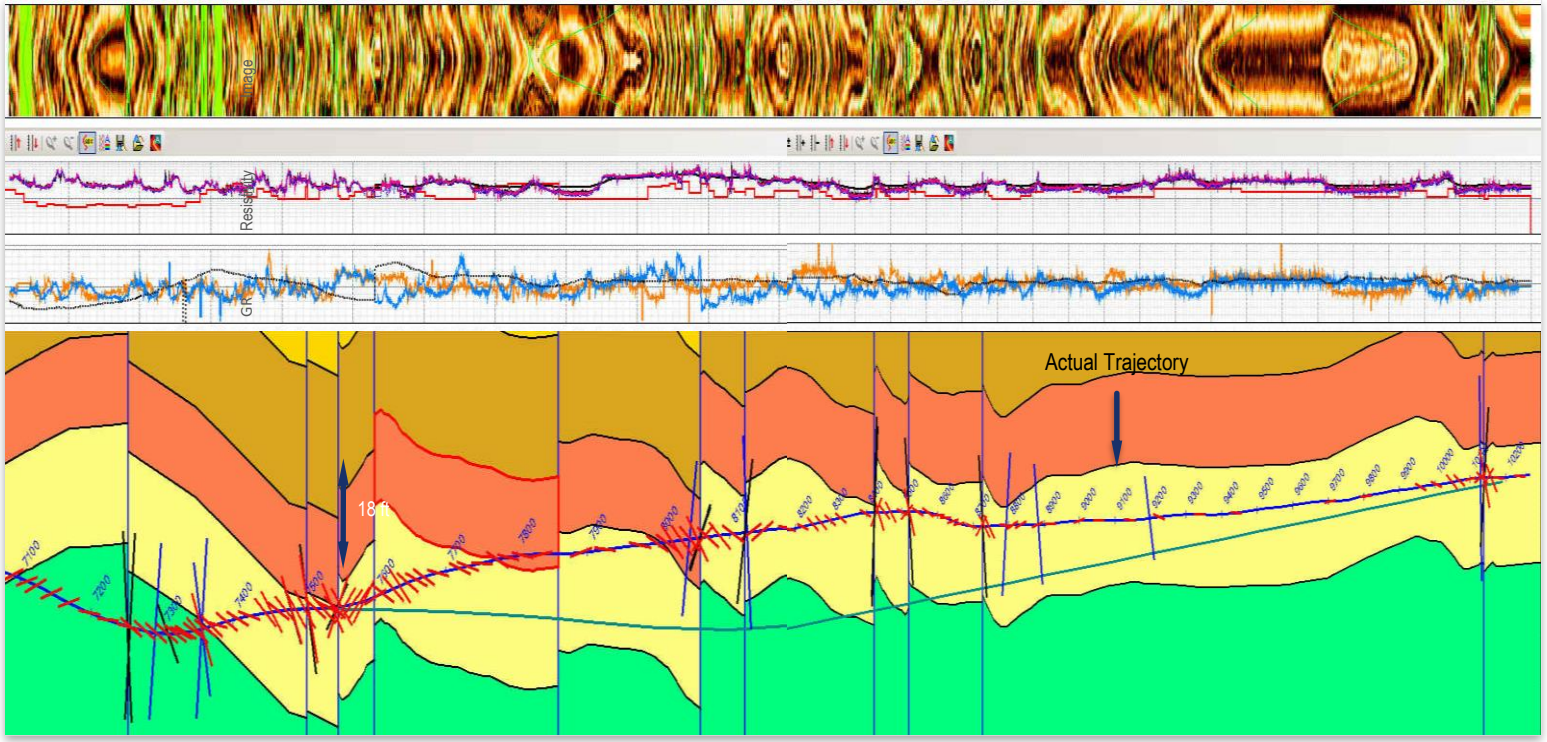


Real-time Images Identify the Structure



Ref: Petrophysics, Vol. 53, No. 3 (June 2012); Page 197-207
Luca Ortenzi et al.

Real-time Images Identify the Structure

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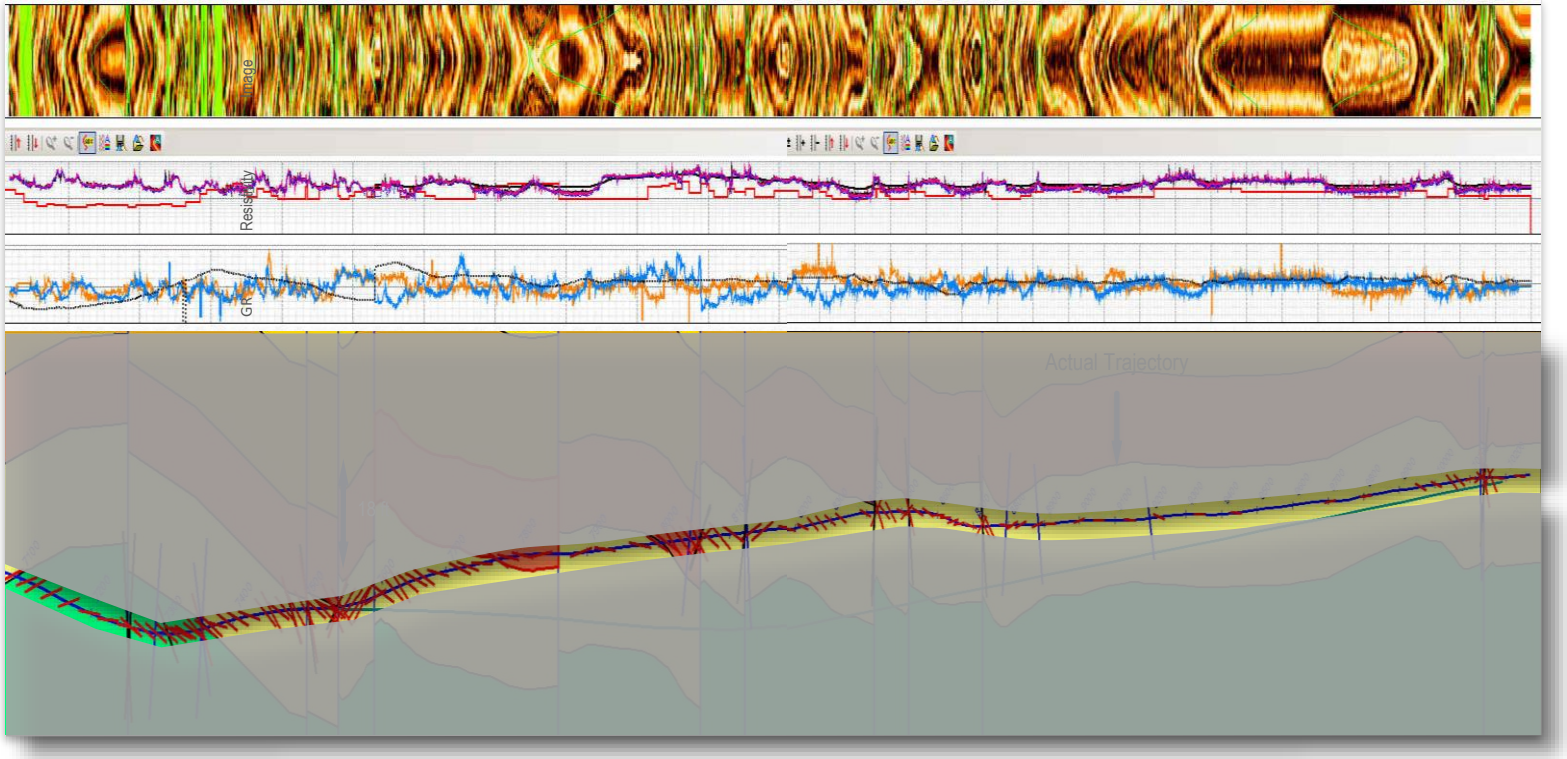
Fractures and the first concept of Productivity

Fractures; Open or Closed?



Ref: Petrophysics, Vol. 53, No. 3 (June 2012); Page 197-207
Luca Ortenzi et al.

Bed Boundary Mapping Workflow

Positioning the Drain Within the Layer

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Effect of undulations?

The bridge between Geosteering and hydrocarbon **reserves** (via **M**aximum **R**eservoir **E**xposure and **N**et-**t**o-**G**ross)

Well Placement Fundamentals
ISBN: 978-097885304-4 (2013)

Wellbore Steering - The Changing Workflows

From "Staying in the sand" to "positioning in the layer"

Geometric Steering

From "landing in the sand" to "staying in the sand"

Geological Steering

Where is my reservoir?

From "reservoir positioning" to "reservoir model positioning"

Reservoir Steering

Structural Steering

From "positioning in the layer" to "reservoir positioning"

Wellbore Steering - The Changing Workflows

Geometric Steering

Geological Steering

How is my reservoir?

Productivity Steering

Reservoir Steering

Structural Steering

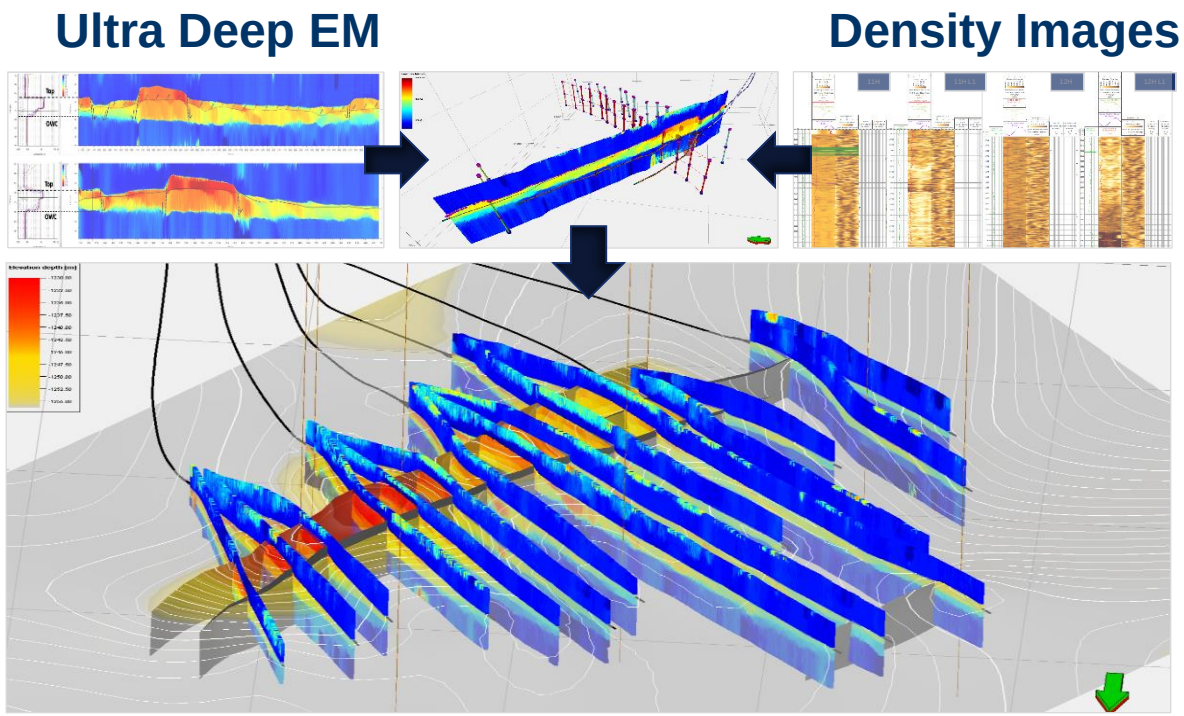
Productivity Steering – Key Enablers

- Reservoir Mapping While Drilling
- Fluid Mapping While Drilling
- Simulation While Drilling
  - Single Well Predictive Modeling (SWPM)
  - Productivity Index While Drilling (PIWD)
  - Real Time Productivity Steering (RTPS)

Ref: SPE-185312 The Quest for Productivity Steering
Haq et al. (2016)

Reservoir Mapping Workflow

OBJECTIVE: Maximize oil recovery in a 6-well (15 multilaterals) offshore field



Ref: SPE-176109 3D Reservoir Mapping While Drilling (RMWD)
Mauro Viandante et al.

CHALLENGES

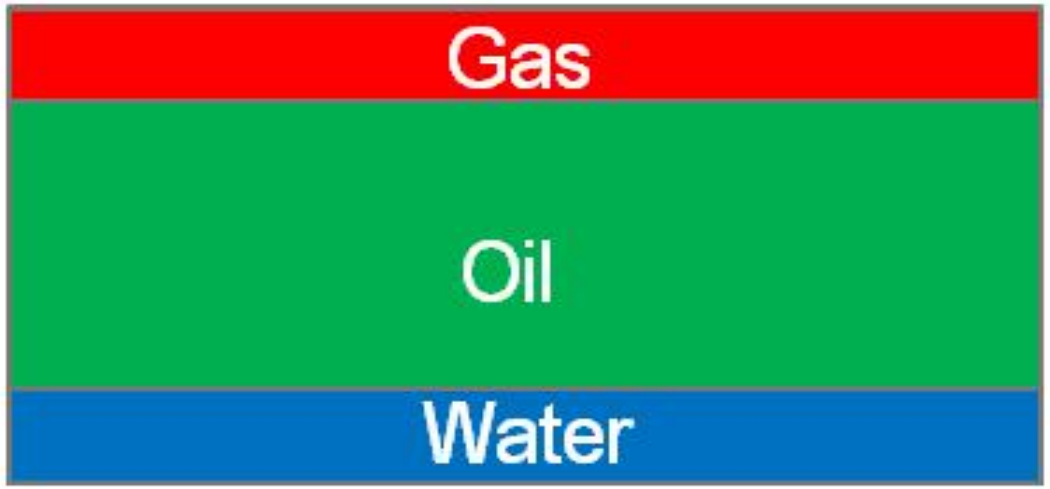
- Oil underlain by aquifer
- Discontinuous sand bodies
- Highly faulted sections

RESULTS

- ✓ RMWD mapped Top of Sands and OWC in all 15 MLs
- ✓ 83,660 ft MD mapped
- ✓ 11,150 ft MD of lateral section extended
- ✓ 11% increase in expected reserves

Recoverable Reserves?

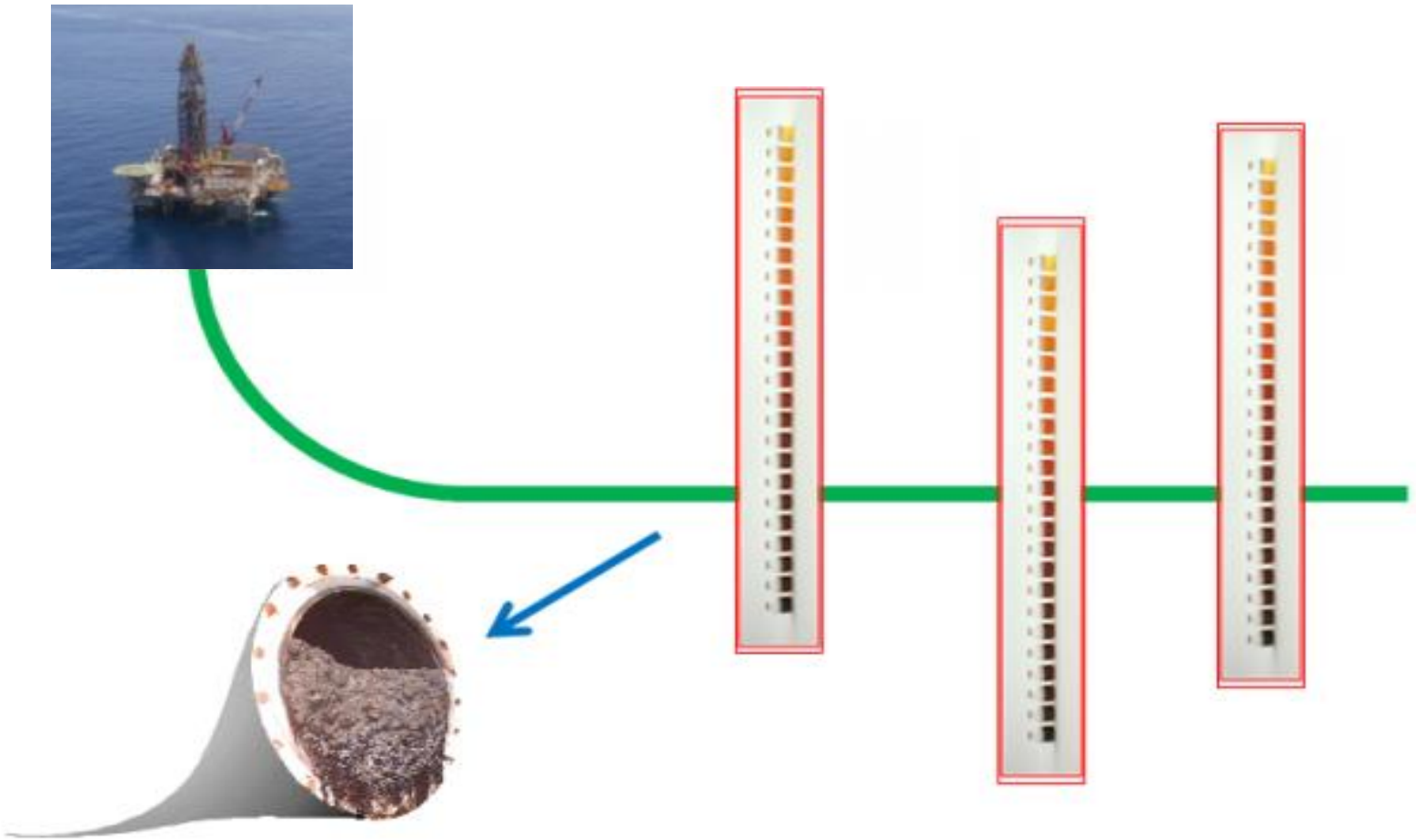
Fluid Mapping While Drilling



Less Likely

More Likely

Fluid Mapping While Drilling



Ref: SPE-177402 Formation Sampling While Drilling in Productivity Steering Process
Makhmotov et al. (2015)

Fluid Mapping While Drilling

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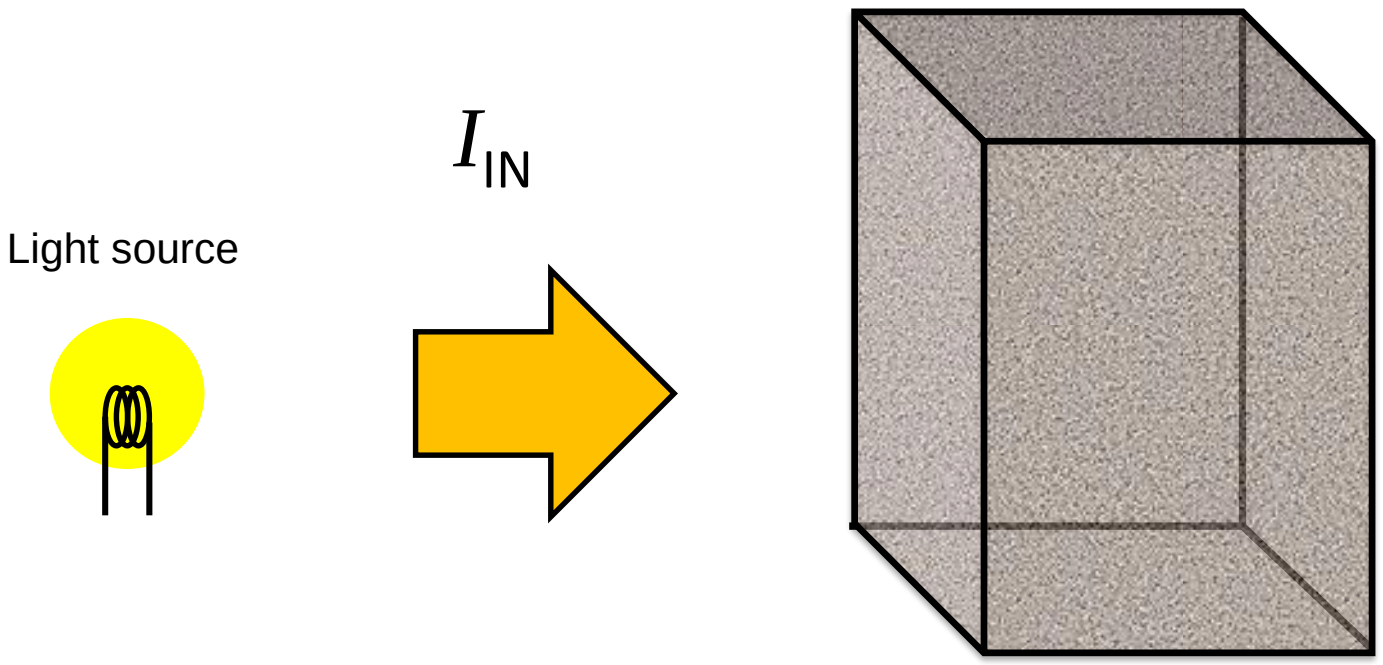
The Physics of Reservoir Fluids - Optical Spectrometry



OD=0 100%

OD=1 10%

OD=2 1%

OD=3 0.1%

Optical Density

$$\Omega_\lambda = \log_{10}\left(\frac{I_{in}(\lambda)}{I_{out}(\lambda)}\right)$$

Fluid Mapping While Drilling

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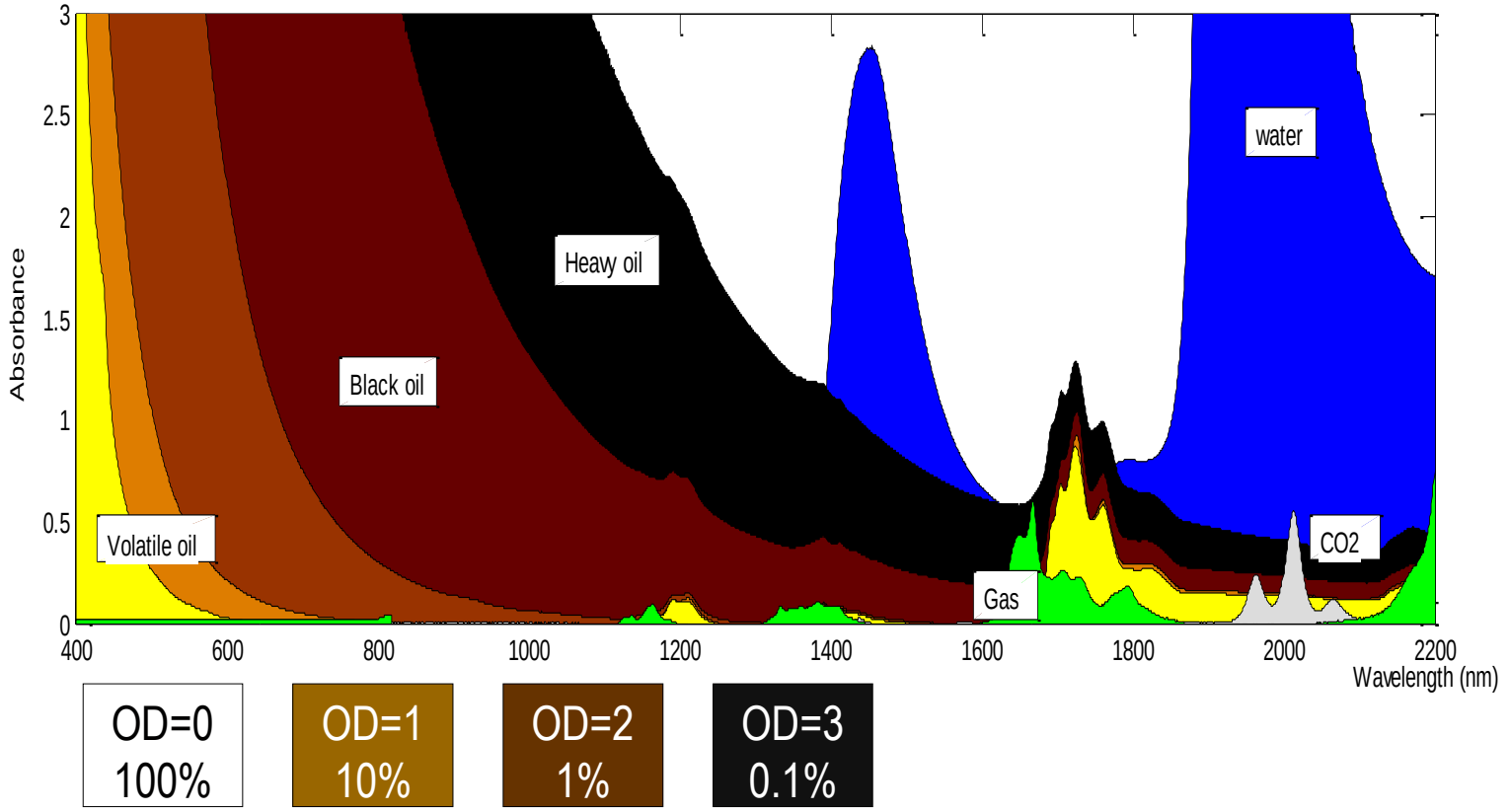
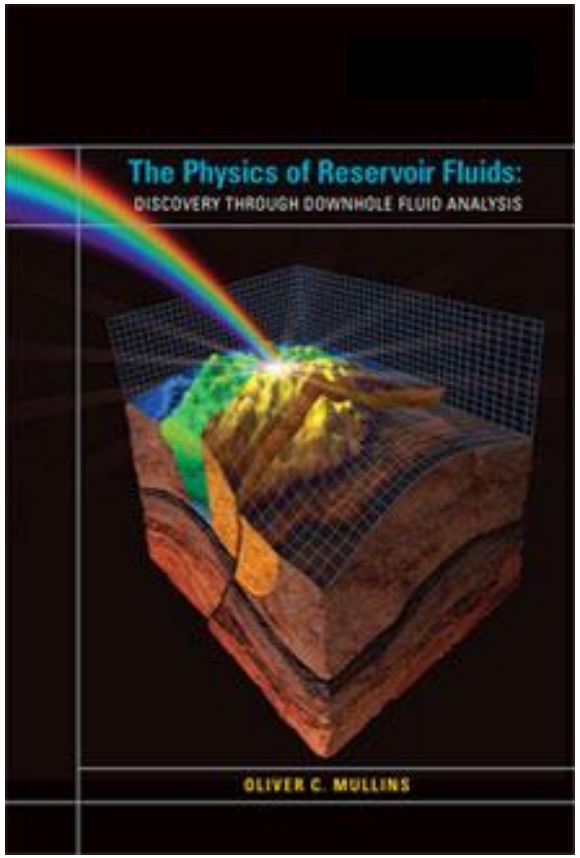
Fluid Properties From Downhole Fluid Analysis (DFA)





ISBN: 978-0978853020 (2008)

Fluid Mapping While Drilling

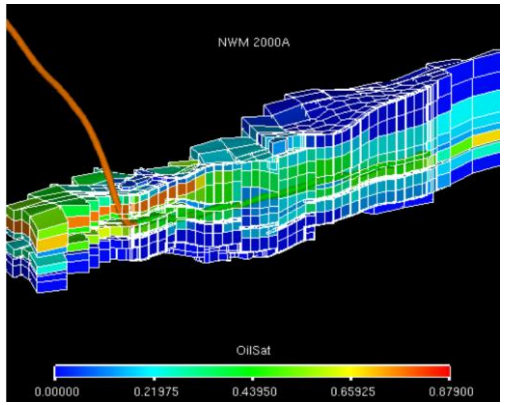
Derived Fluid Properties from downhole optical spectrometer

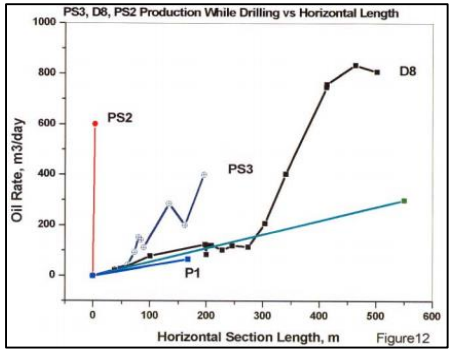
- Gas-Oil Ratio (GOR)
- Hydrocarbon Properties
  - Composition – C1, C2, C3, C4, C5, C6+ plus CO2 (wt%)
  - Formation Volume Factor
  - Asphaltene Content (wt%)

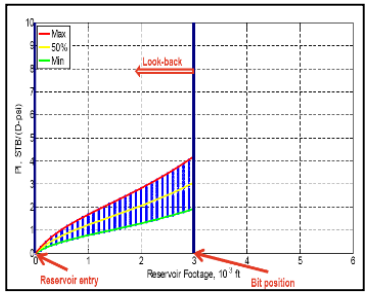
Ref: Indo et al. (SPE 166464, 173152, 178837)

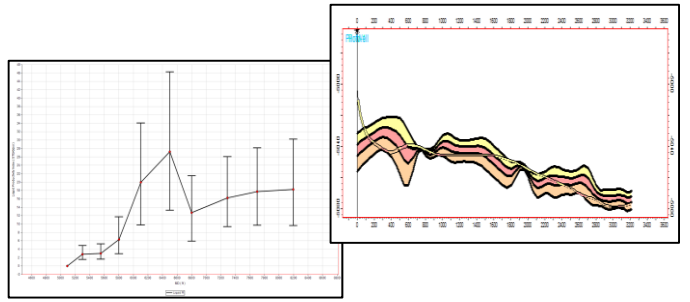
Integration with Bulk Fluid Properties (Density, Viscosity), Advanced Mud Gas Log, Geochemistry

Simulation While Drilling Evolution









Near Wellbore Modeling

Underbalanced Productivity Index While Drilling

Productivity Estimation during Drilling

Real-Time Productivity Steering

Numerical *(NWM, 2000)*

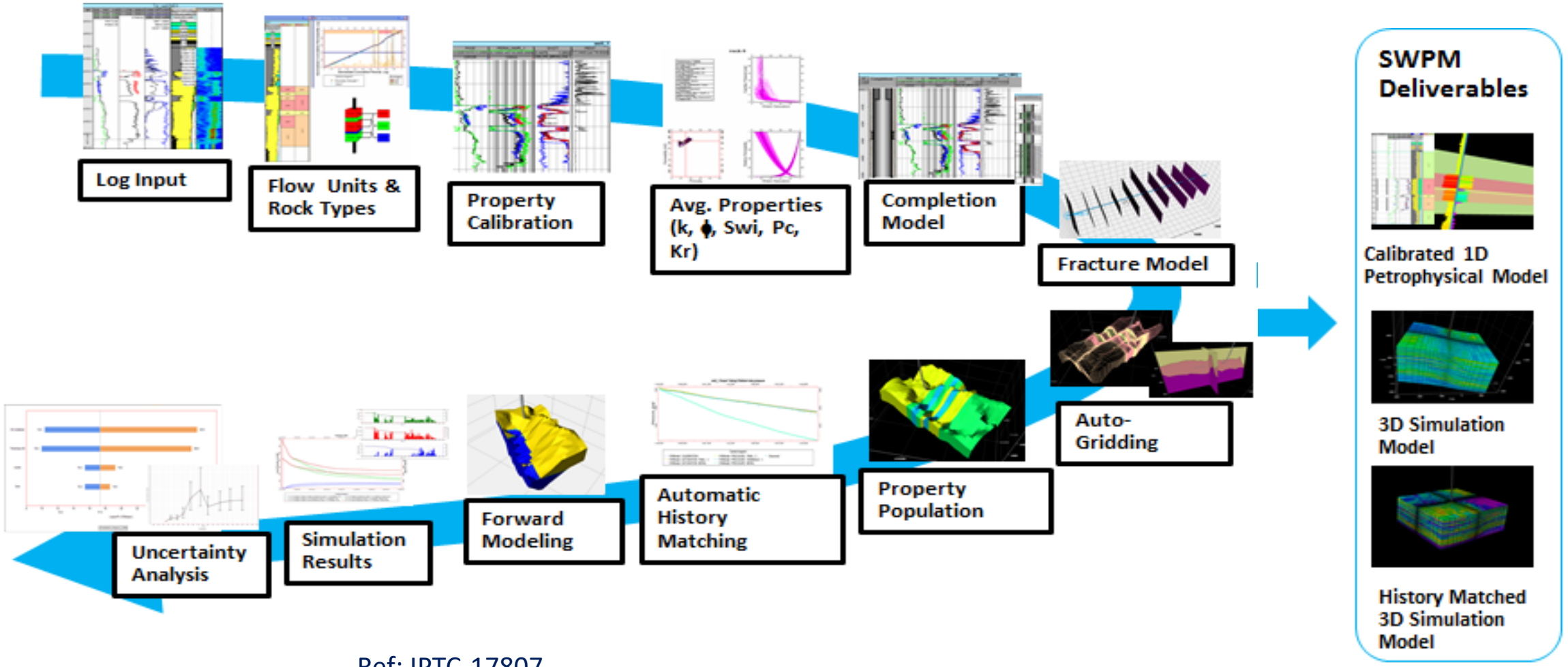
Operation *(2002)*

Analytical *(2010)*

Integrated solutions (SWPM, RTPS)

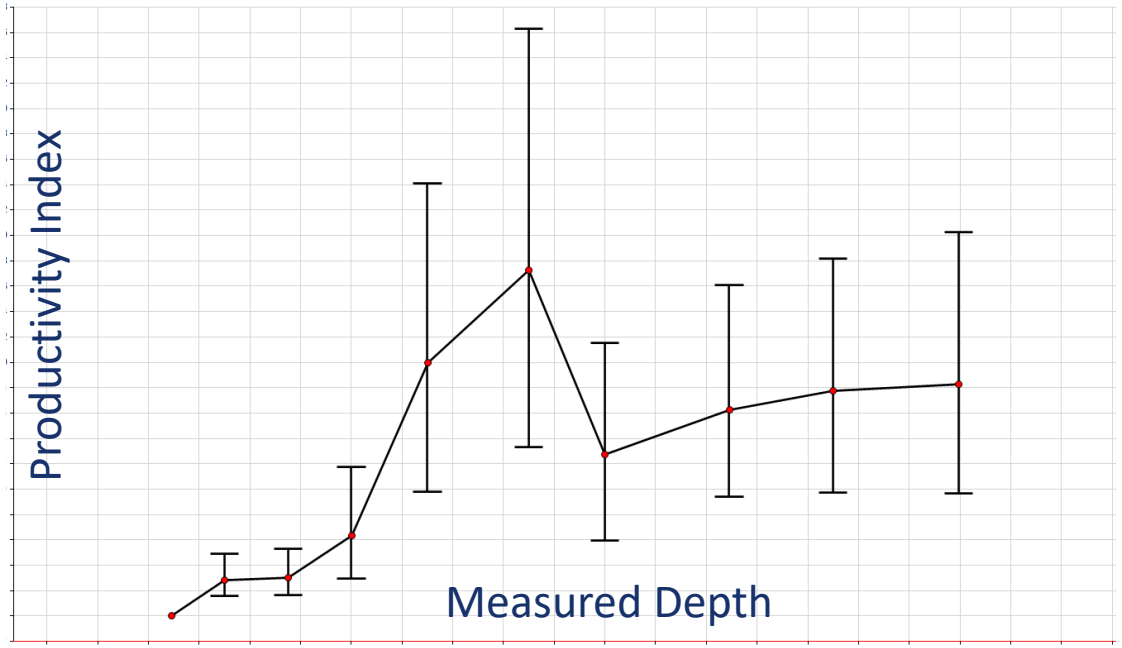
Ref: SPE-65149 (2000), SPE-77529 (2002), SPE-99945 (2006), Pages 20-29 Oilfield Review 2006, SPE-130811 (2010), SPE-175671 (2015)

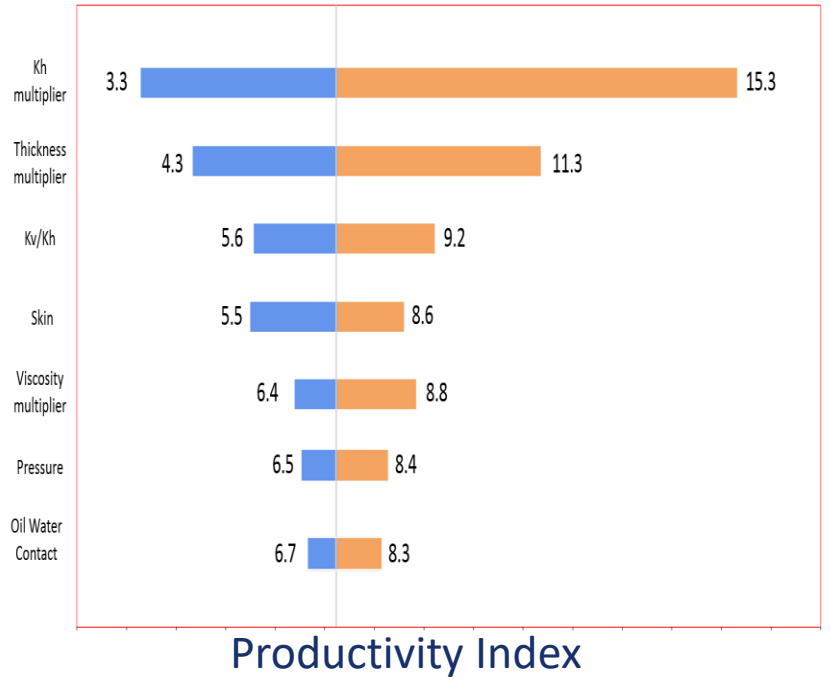
Single Well Predictive Modeling (SWPM)



Ref: IPTC-17807

SWPM - Uncertainty Analysis



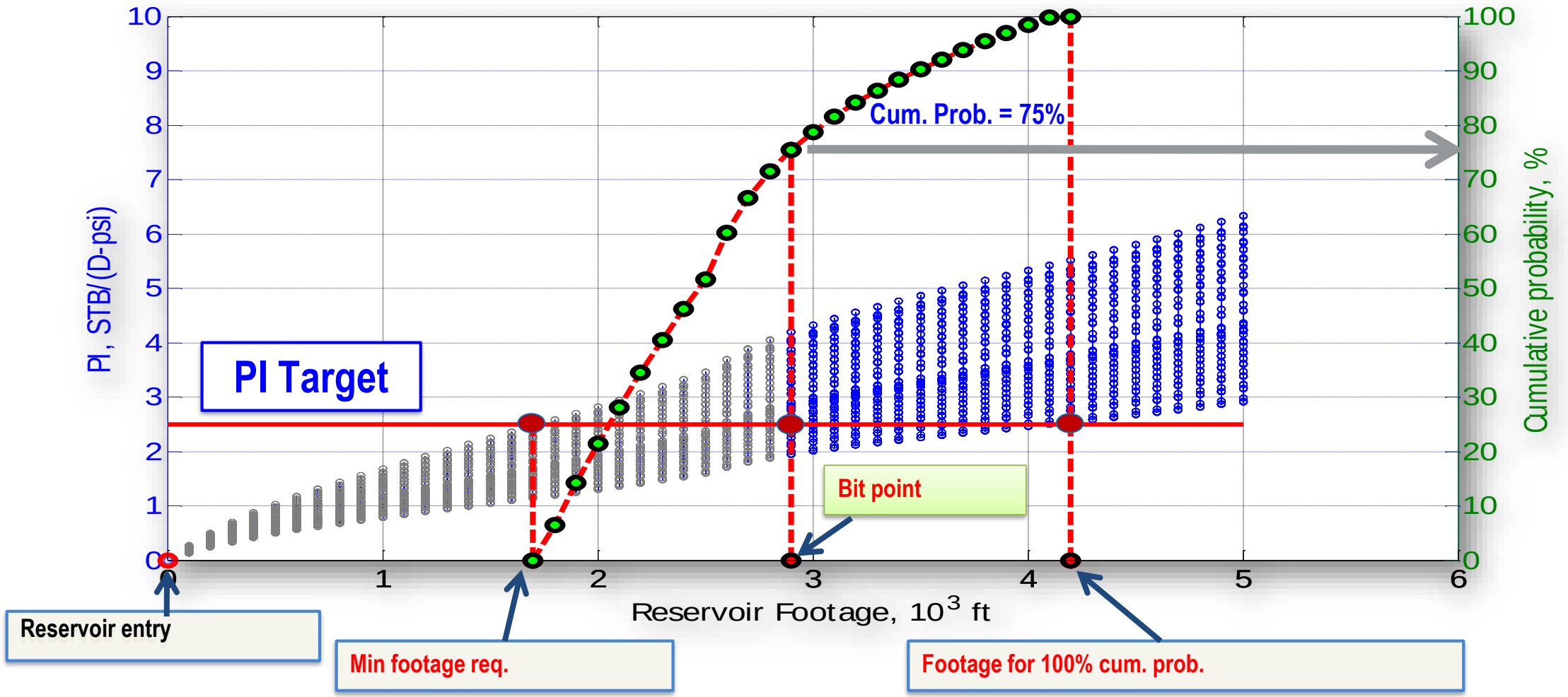


Productivity Index (PI) = Flow Rate / Pressure Drawdown (STB/d/psi)

Ref: IPTC-17807

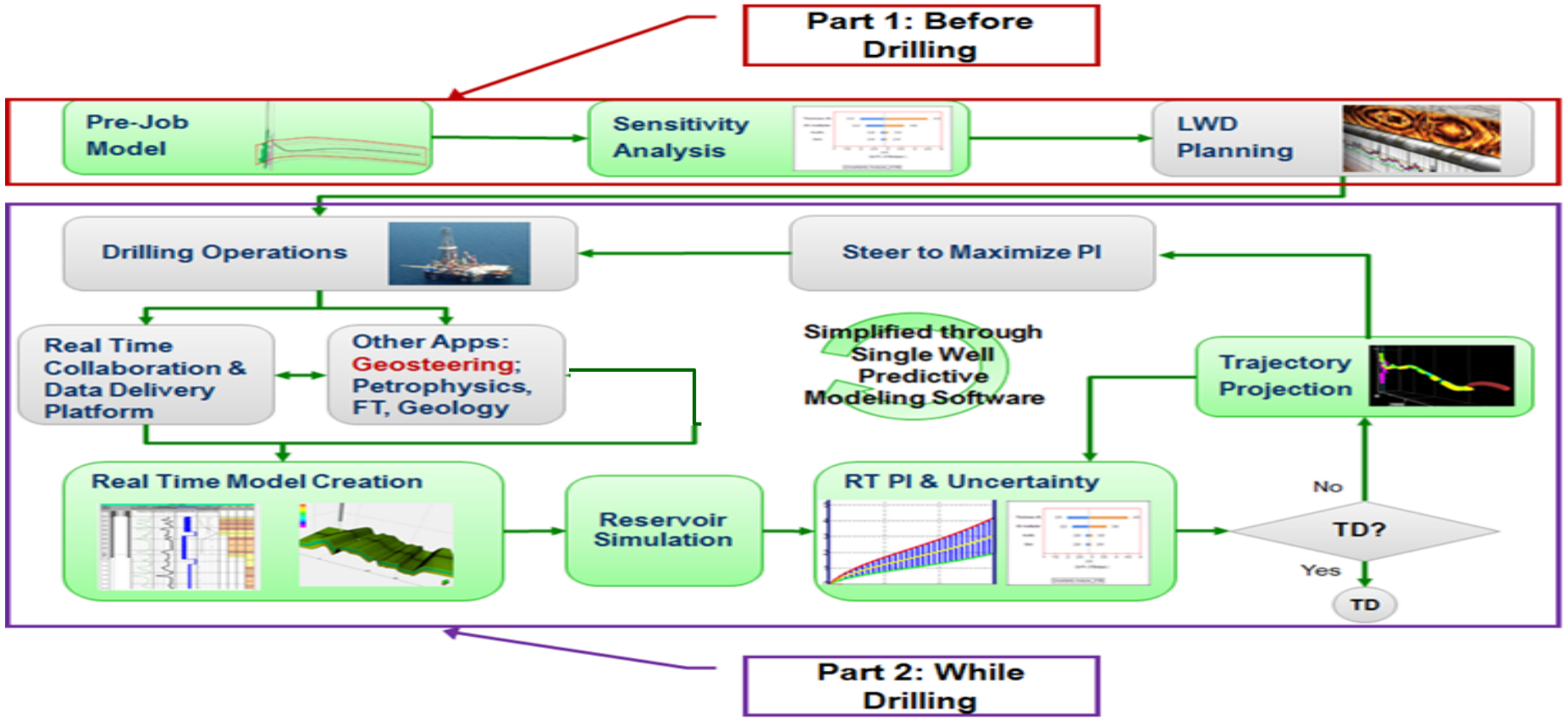
Parameters
Anisotropy
Aquifer strength / properties
Asphaltene onset pressure
Drainage radius
Fault transmissibility
Fluid contact
GOR / CGR
Horizontal permeability
Landing section
Oil density
Pressure drawdown / rate
Reservoir pressure
Rock type
Saturation pressure
Skin
Thickness
Viscosity
Water saturation
Well length

Footage Decision Based on PI Analysis



Ref: SPE-130811 Method and Utility of Well Productivity Estimation During Drilling
Zhang and Jalali (2010)

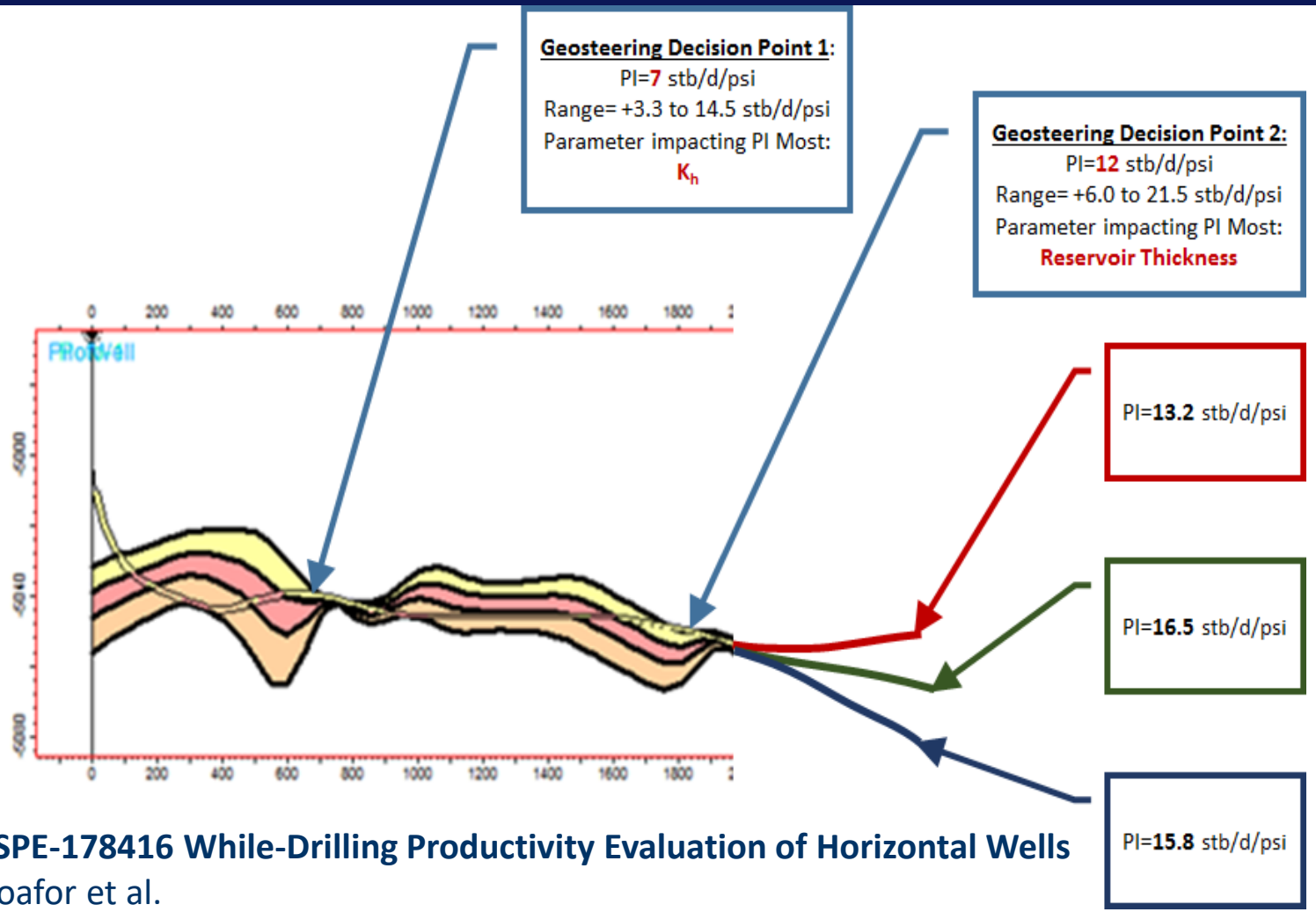
Real Time Productivity Steering Workflow



SWPM

Ref: SPE-178416 While-Drilling Productivity Evaluation of Horizontal Wells
Okoroafor et al.

Real Time Productivity Steering (RTPS)



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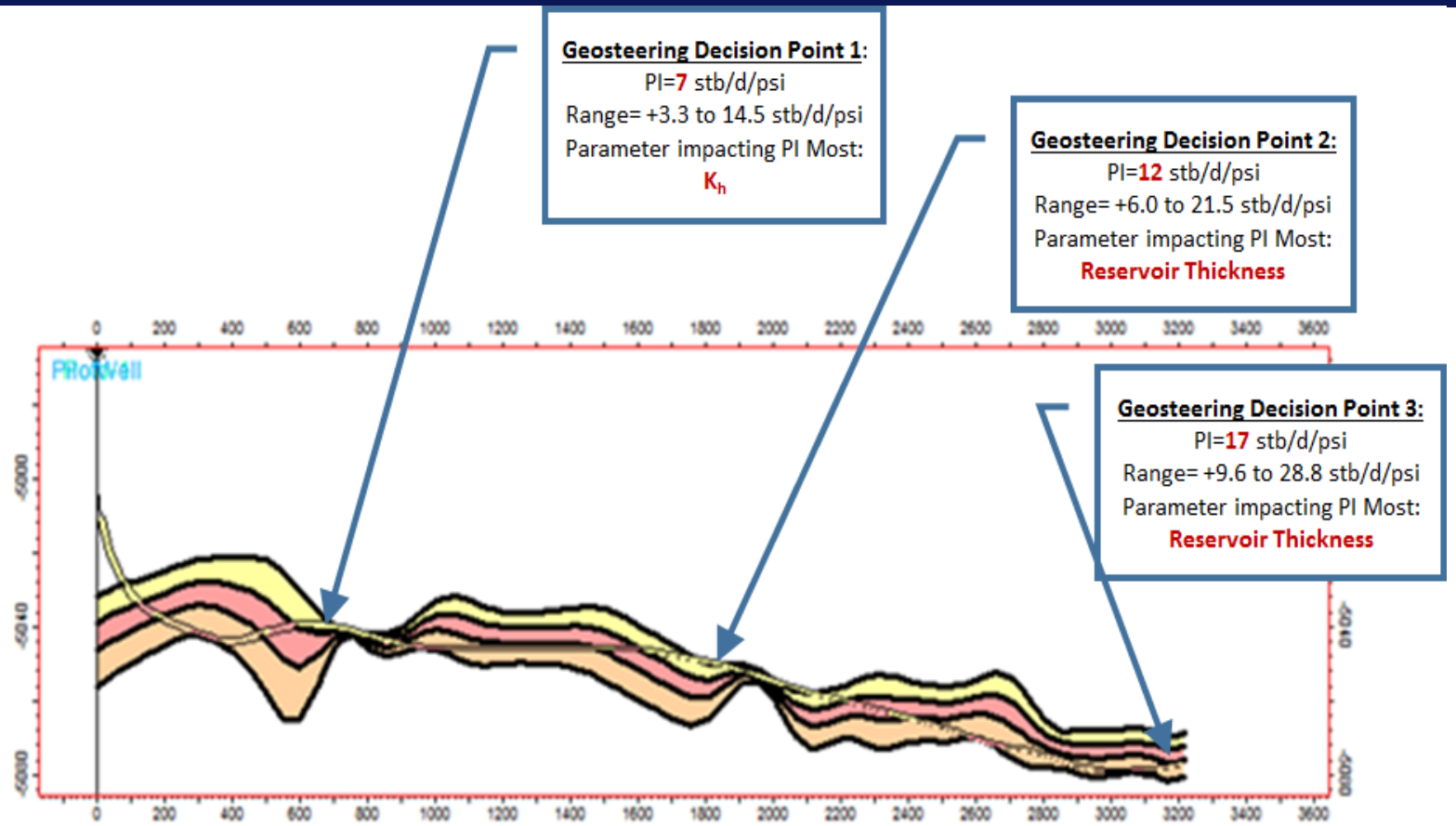

- Complement Geosteering with quantitative productivity estimation
- Minimize productivity uncertainty with LWD data
  - LWD Planner
  - Bring out Value of Information (VOI) of LWD measurements
- Determine the impact of well trajectory on productivity
- Optimize drain length

Ref: SPE-178416 While-Drilling Productivity Evaluation of Horizontal Wells
Rita Okoroafor et al.

In Conclusion

- Reservoir Engineering While Drilling (REWD) in Horizontal Wells is now possible due to
  - » Evolution of Logging While Drilling
  - » Evolution of Wellbore Steering
  - » The Workflow of Real Time Productivity Steering

- REWD is the collaboration platform for asset team

Acknowledgments

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  - Hani Elshahawi
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- SPE and yourselves for this opportunity

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