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SPE DISTINGUISHED LECTURER

Creating a Worldwide Unconventional Revolution

Through Technically Justifiable Strategies

Basak Kurtoglu, PhD
Citi Global Energy Group

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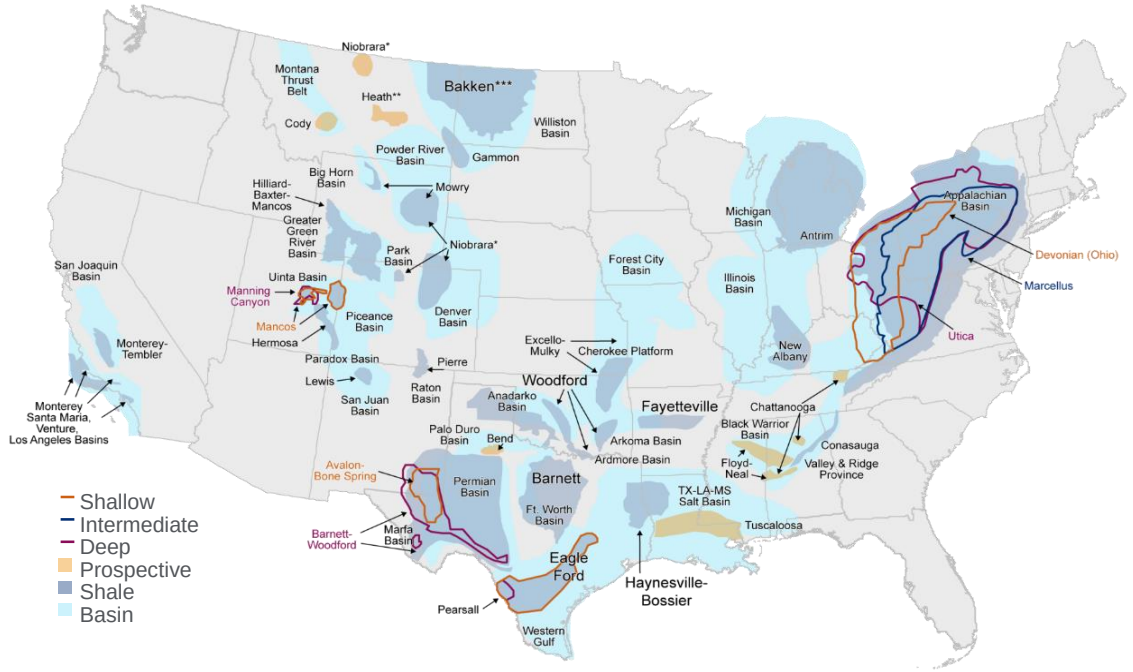
The Unconventional Resource Revolution in North America

- **Technology** enabled production from unconventional reservoirs
  - Horizontal drilling increased reservoir contact area
  - Hydraulic fracturing enhanced very low permeability

- **2000-2010 Highlights:**
  - All started with the Barnett in Texas
  - Development of Bakken in Montana shifted to North Dakota
  - The Marcellus started to develop in Pennsylvania and West Virginia
  - Activity in the Haynesville started in eastern Texas/western Louisiana

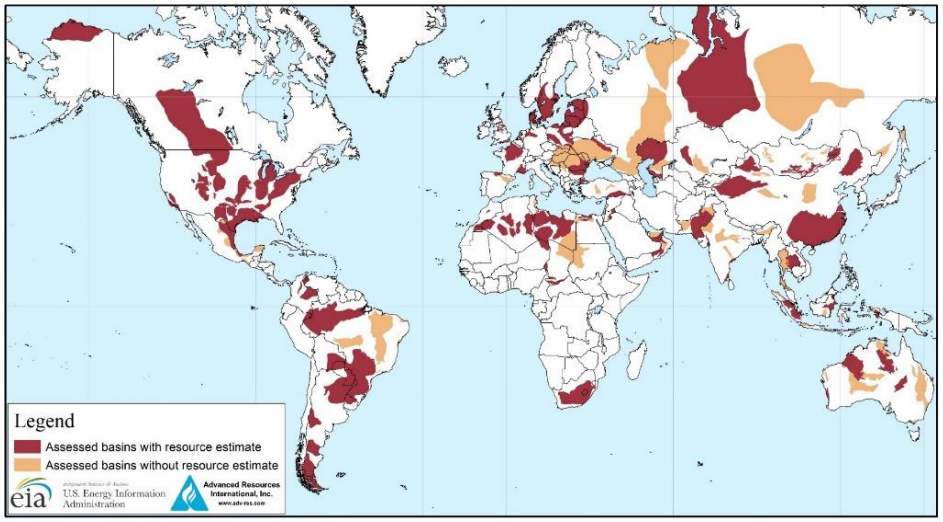
US Unconventional Play Development

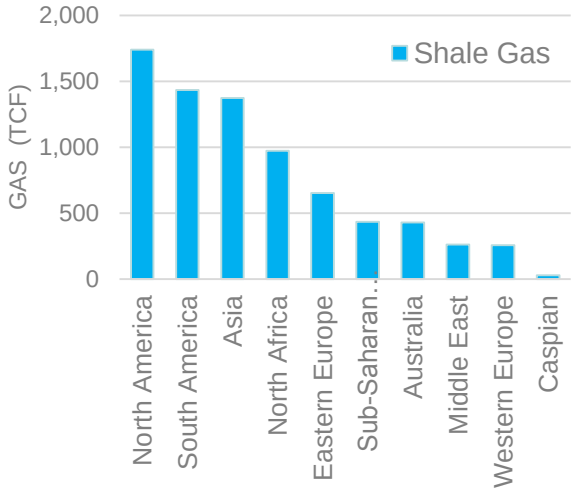


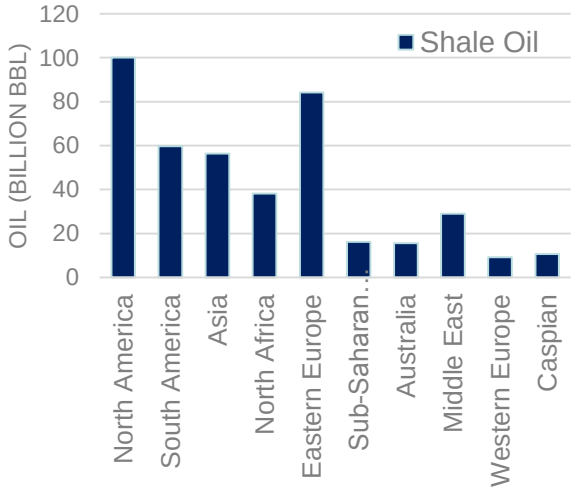
- **2010- 2015 Highlights**
  - Eagle Ford became the lead for oil production
  - Permian has received great attention with multi-horizon development opportunities
  - Unconventional development propelled the United States to produce more oil than it imports for the first time in 20 years

How to Develop Unconventionals Worldwide?

Technically Recoverable Shale Resources







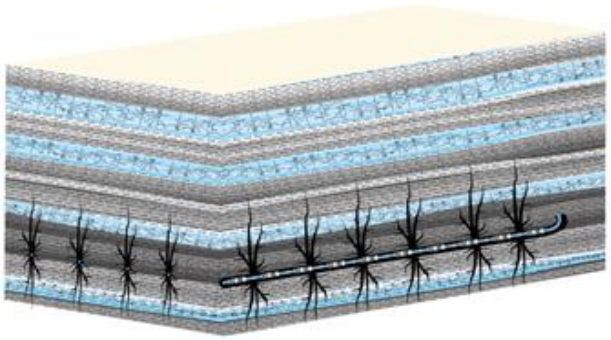
Key Factors for Success

- Operational Execution
- Technical Understanding
- Strategic Development Plan

Source: EIA, Aug 2016

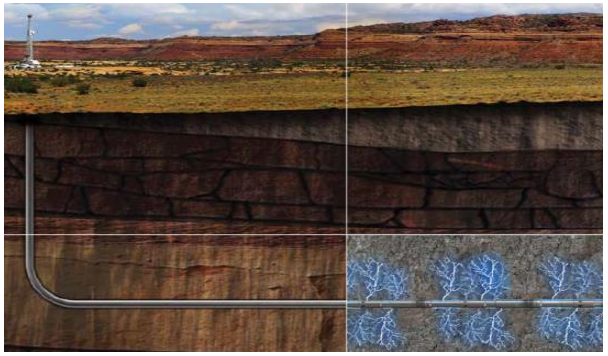
Unconventional Approach

Reservoir Characterization



+

Operational Execution



Value Creation

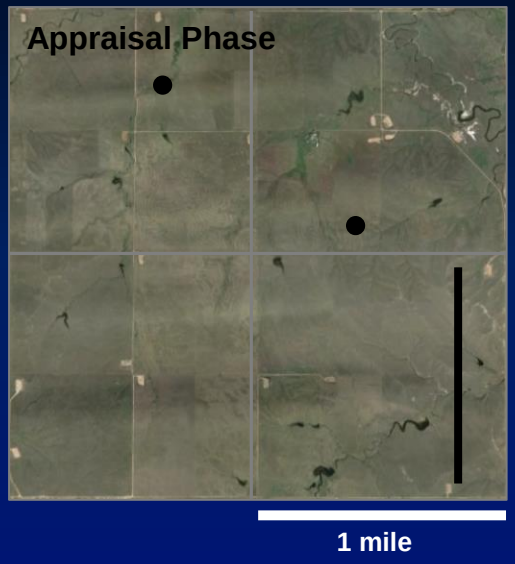
Development Strategy

Integrated Workflow

- Petroleum system
- Targeting and landing
- Multi-horizon development
- Completion design
- Well spacing
- Improved/Enhanced recovery

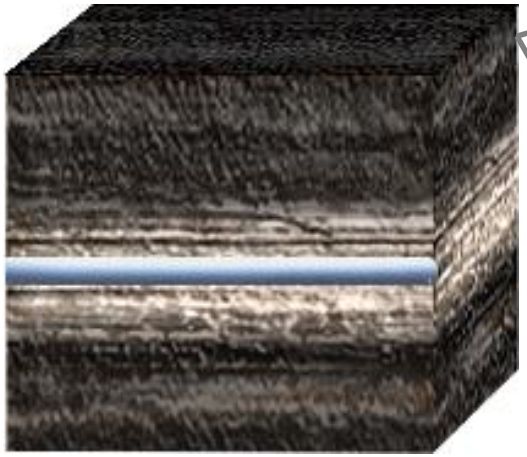
Source Rock Properties- Reservoir Characterization

Development Acreage

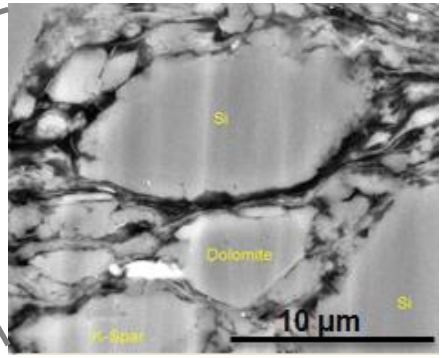


- Pore structure- Scanning Electron Microscopy (SEM)
- Maturity- Total Organic Carbon (TOC)
- Ductility
- Low permeability (k)

Bakken (Locally Sourced)

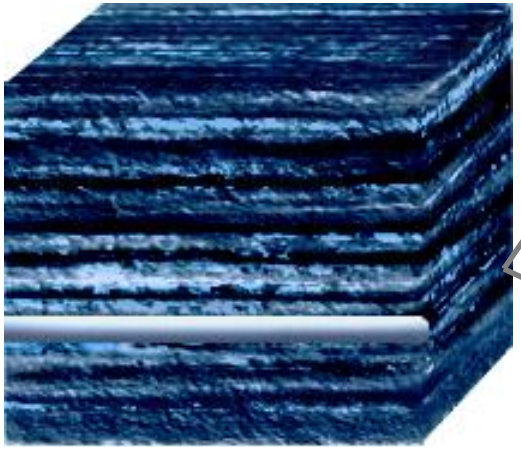


Black Shale SEM

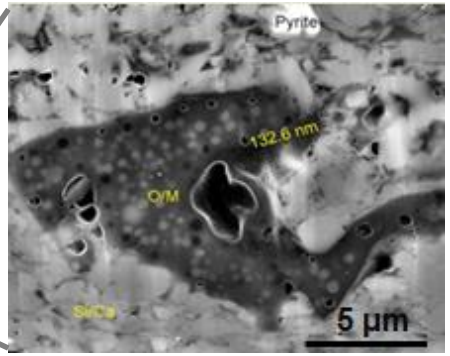


TOC: 25- 28 weight %
k_{shale}: 4.0E-08 md

Eagle Ford (Self-Sourced)



Marl SEM

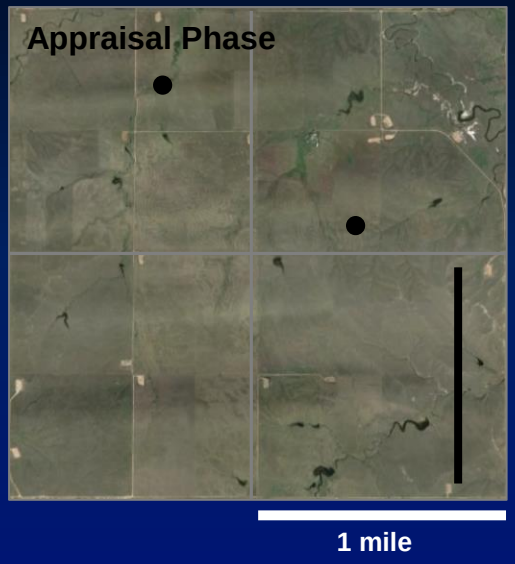


TOC: 2- 4 weight %
k_{marl}: 5.0E-07 md

Kurtoglu, 2013 & Rosen et al., 2014 (SPE 168965)

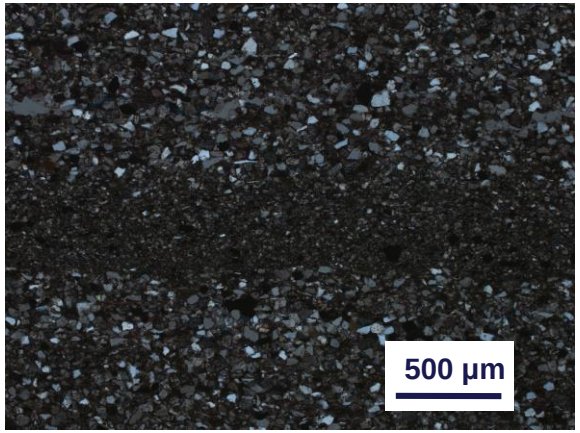
Reservoir Rock Properties- Characterization

Development Acreage

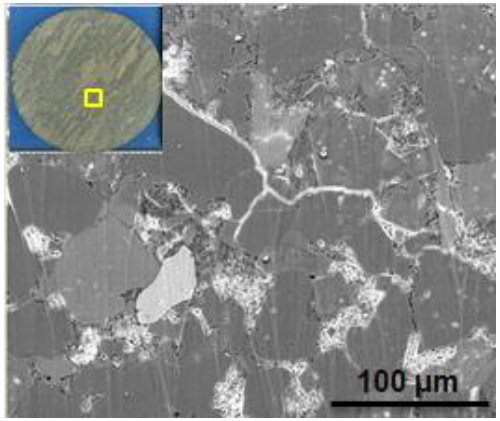


- Pore structure- Scanning Electron Microscopy (SEM)
- Micro-fractures
- Brittleness
- High permeability (k)

Bakken- Thin Section

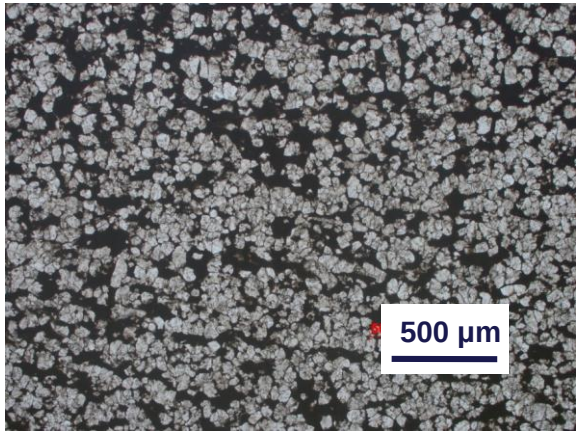


Sandstone SEM

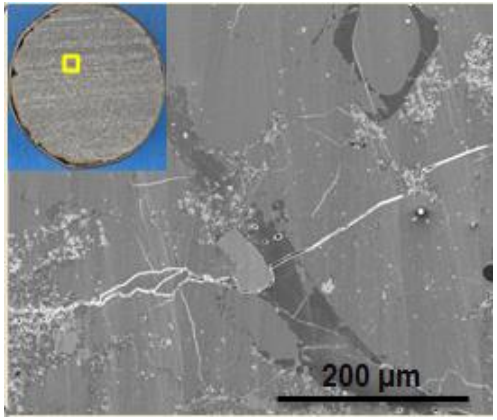


$k_{fractured-\ core}$: 0.0013 md

Eagle Ford- Thin Section



Limestone SEM



$k_{fractured-\ core}$: 0.0059 md

Kurtoglu et al., 2014 (SPE 171688) & Rosen et al., 2014 (SPE 168965)

Target Window- Reservoir Characterization

Current Conventional Strategy

Energy/Drive
Pore pressure & GOR
Burial history
Seals

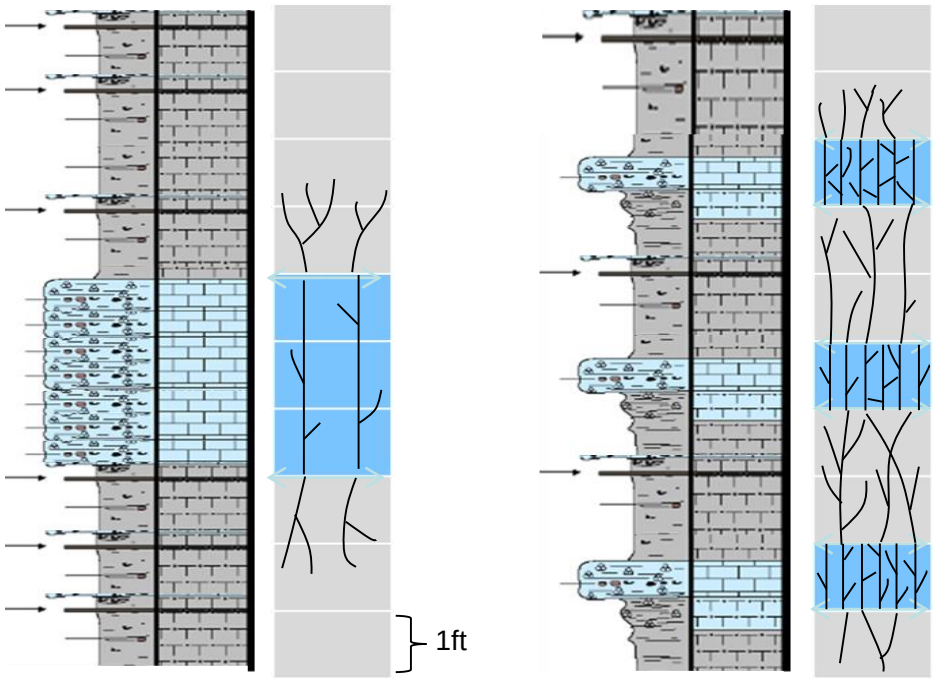
Storage Capacity
Thickness and extent
Porosity: type and amount
Fluid(s): type and amount

Unconventional Strategy

Connectivity
Brittleness of the rock
Faults and natural fractures
Type and amount of clay
Ability to induce fractures
Ability to maintain fractures

Increased Interbedding= Increased Connectivity

LOW → HIGH

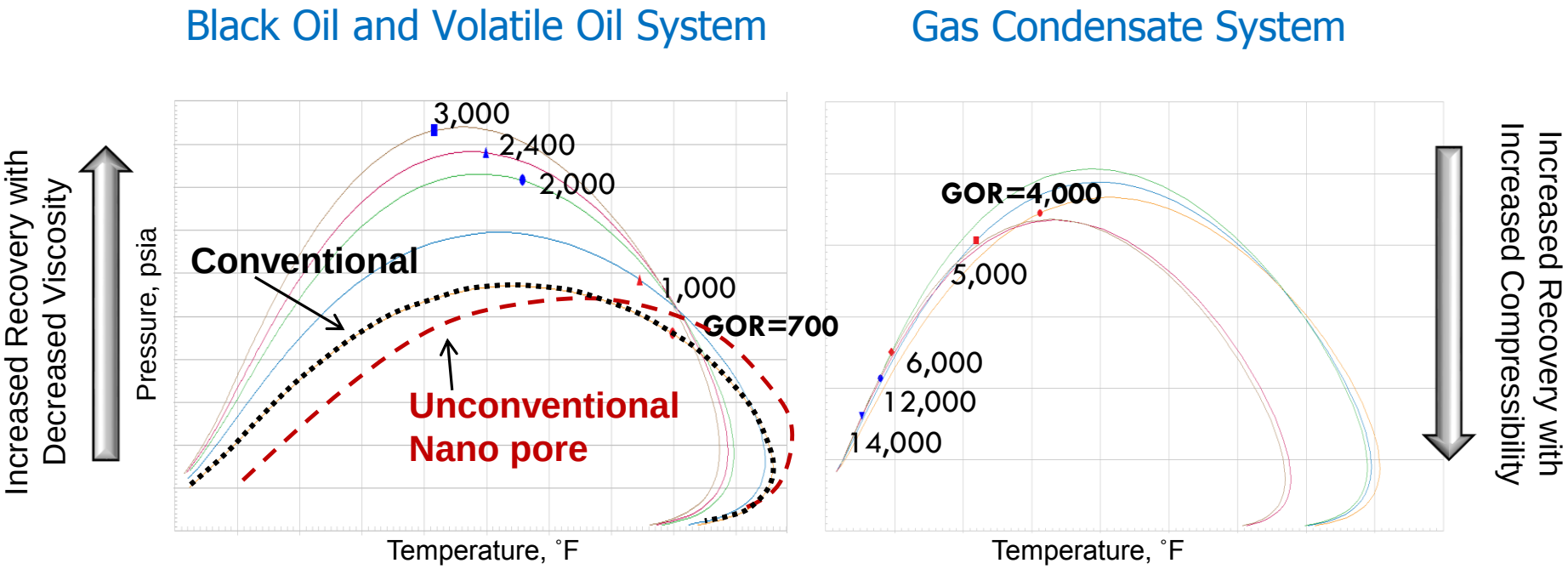


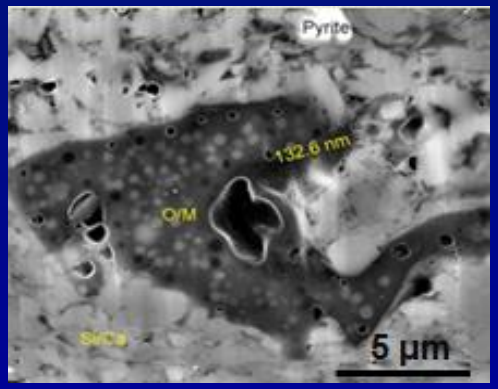
Source Rock %: 70
Reservoir Rock %: 30
Frequency: 1/10ft

Source Rock %: 70
Reservoir Rock %: 30
Frequency: 3/10ft

Reservoir Rock: Brittle
Source Rock: Ductile

Fluid Properties- Reservoir Characterization



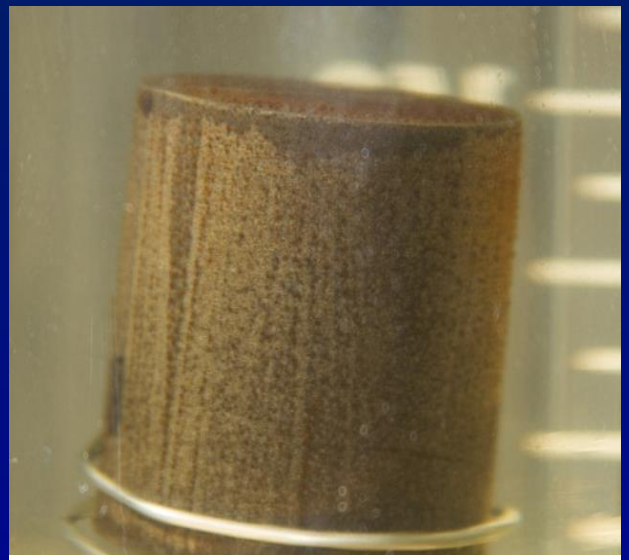
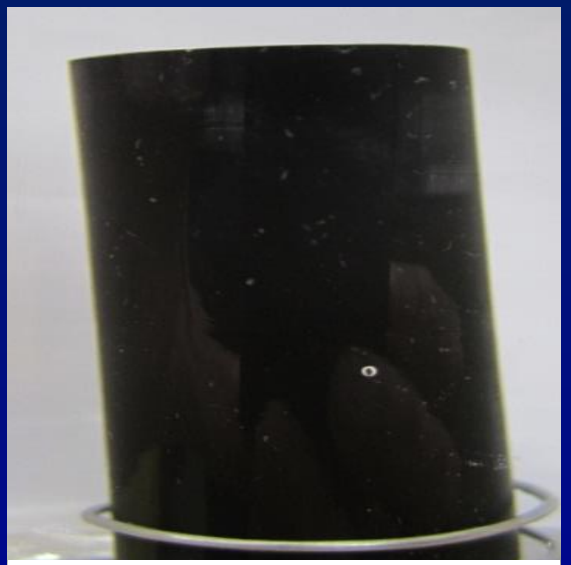


- Increased capillary pressure
- Bubble point suppression
- Delayed multi-phase production
- Longer time constant gas-oil ratio (GOR)
- Lesser volume of gas released below bubble point pressure

Rock-Fluid Interaction- Reservoir Characterization

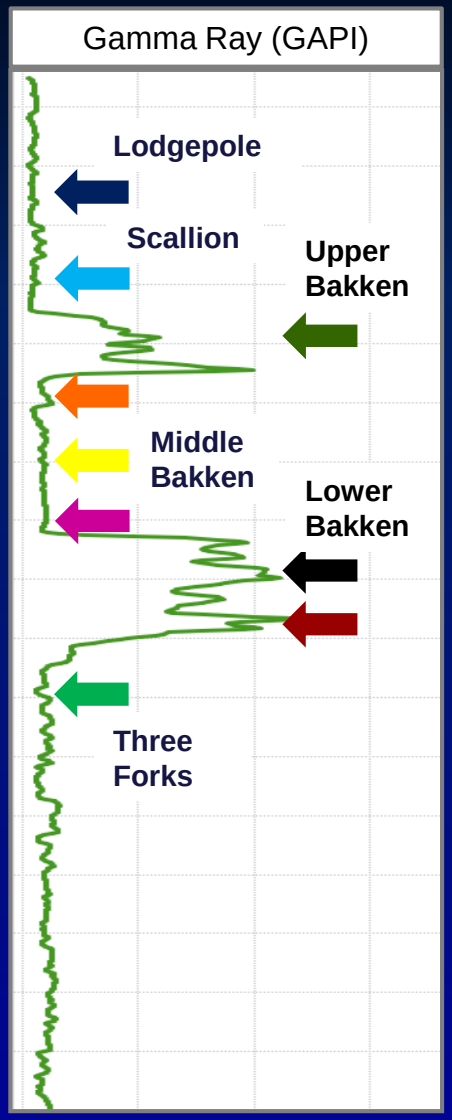
Transport Processes

- Counter-current spontaneous imbibition
  - High and Low Salinity
- Osmotic pressure
- Wettability

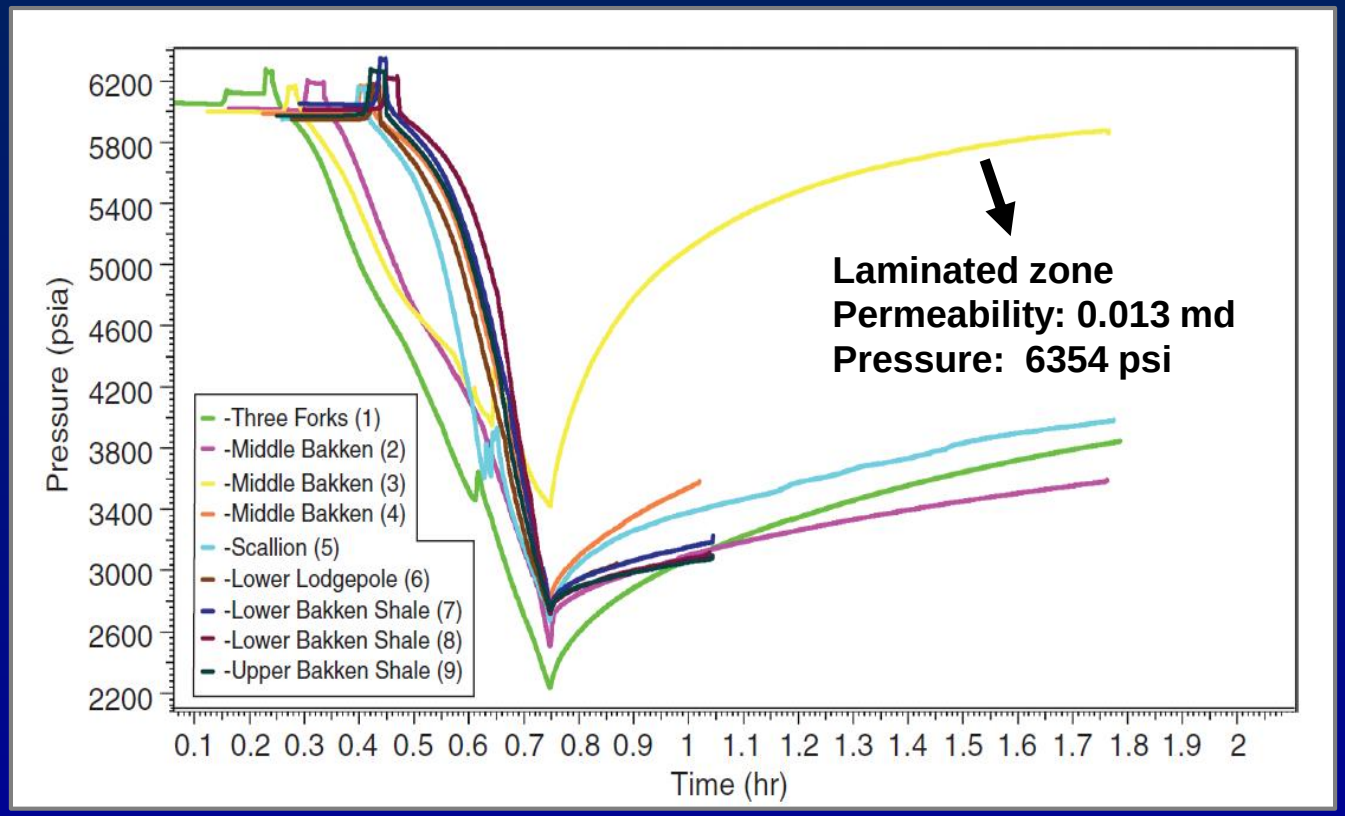
1- High Salinity Experiment	2- Low Salinity Experiment after 5 days	1- Low Salinity Experiment
		
Bakken Reservoir Rock		Eagle Ford Source Rock

Kurtoglu et al., 2014 (SPE 171688) & Fakcharoenphol et al., 2014 (SPE 168998)

Formation Deliverability- Reservoir Characterization



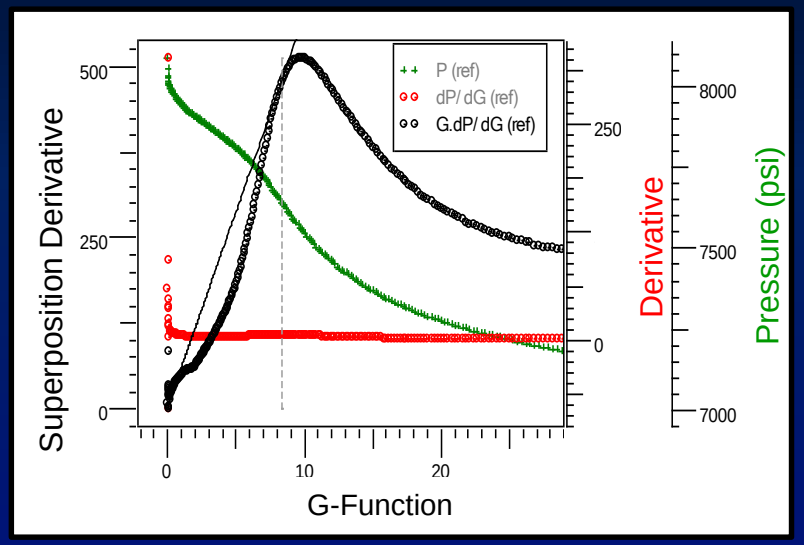
- Core to field level permeability reconciliation
- Near wellbore transient behavior:
  - Mini- Drill Stem Test (DST)
- Target zone identification
  - Formation deliverability and pressure



Kurtoglu et al., 2013 (SPE 162921)

Geomechanical Properties- Reservoir Characterization

Diagnostic Fracture Injection Test
Fracture Properties

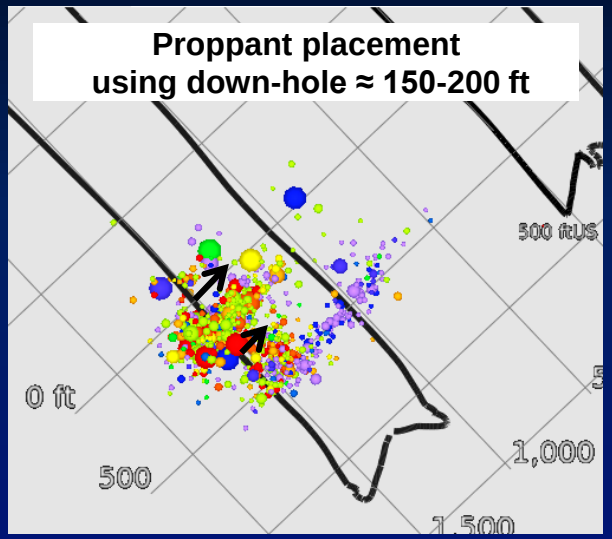


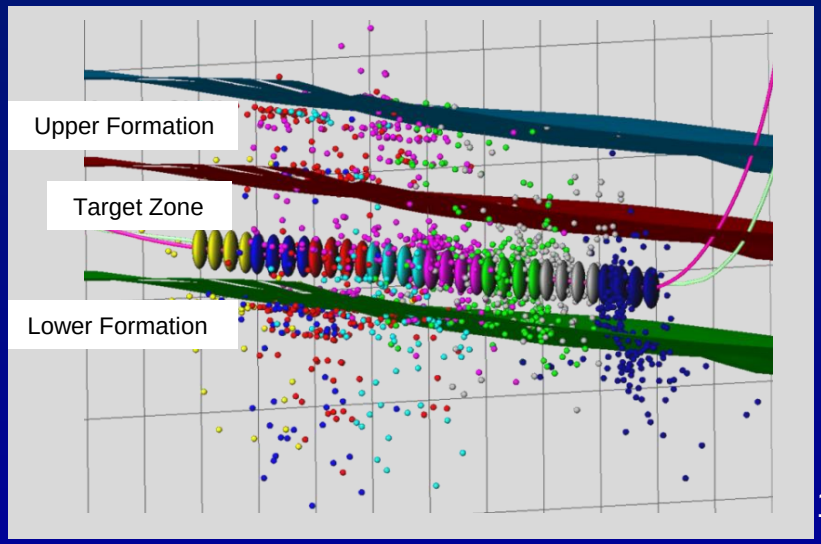
- Formation leak-off mechanism
- Fracture closure pressure
- Pore pressure
- Vertical and horizontal connectivity

Horizontal Connectivity

Vertical Connectivity

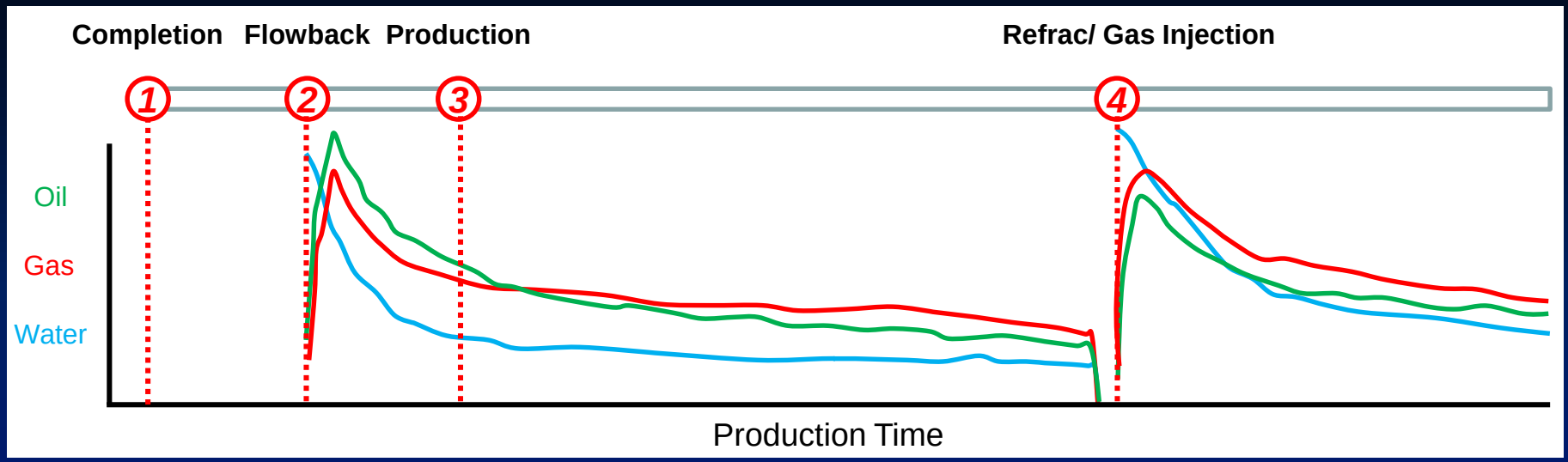
Microseismic
Reservoir Connectivity

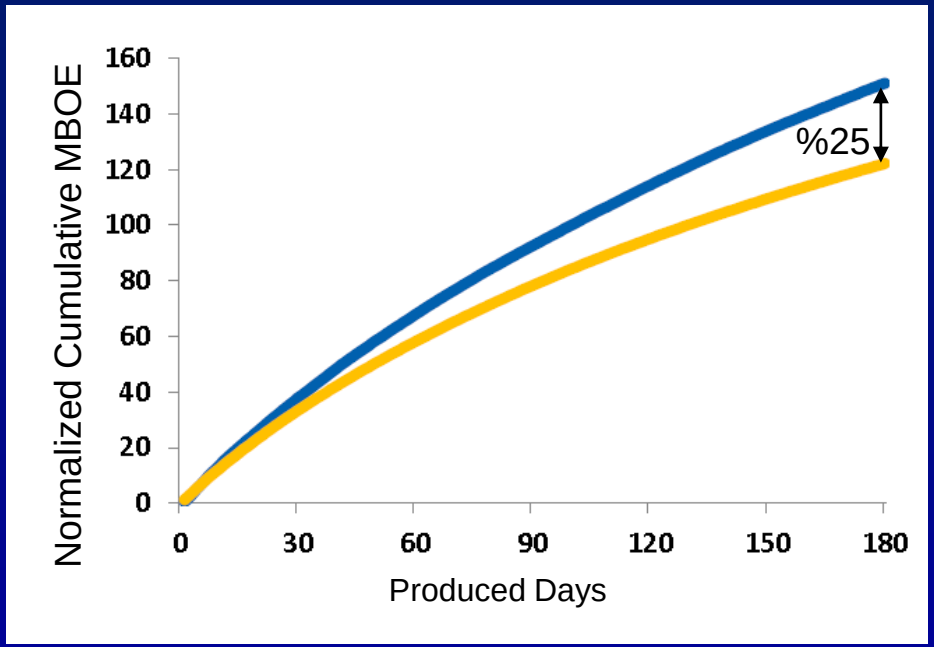




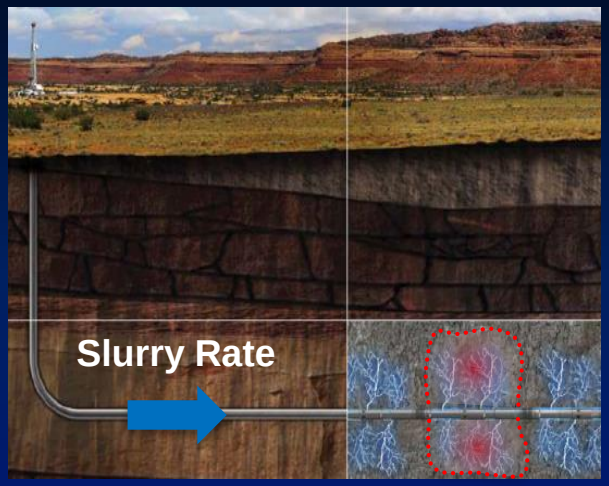
Kurtoglu et al., 2012 (SPE 162473)

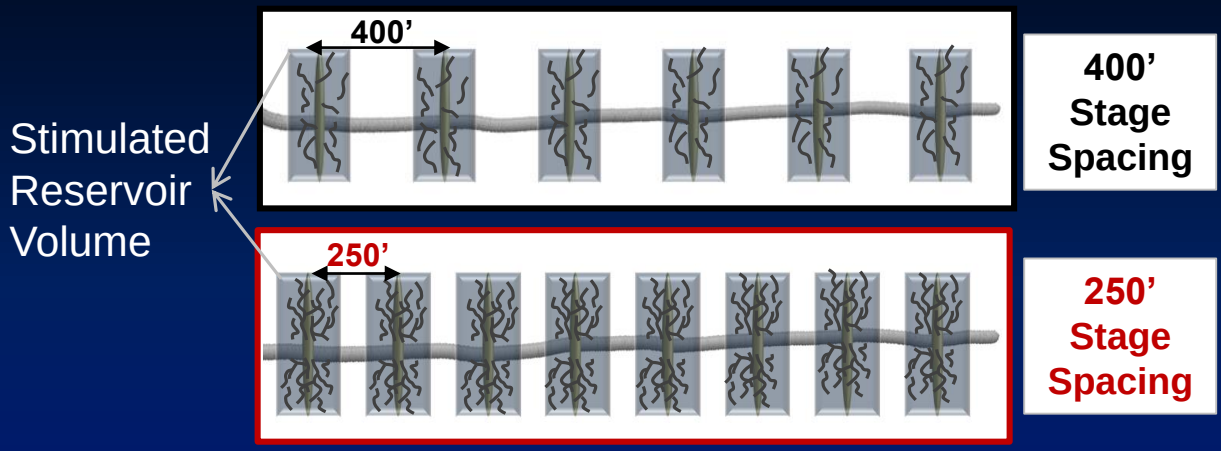
Well Life Cycle- Operational Execution





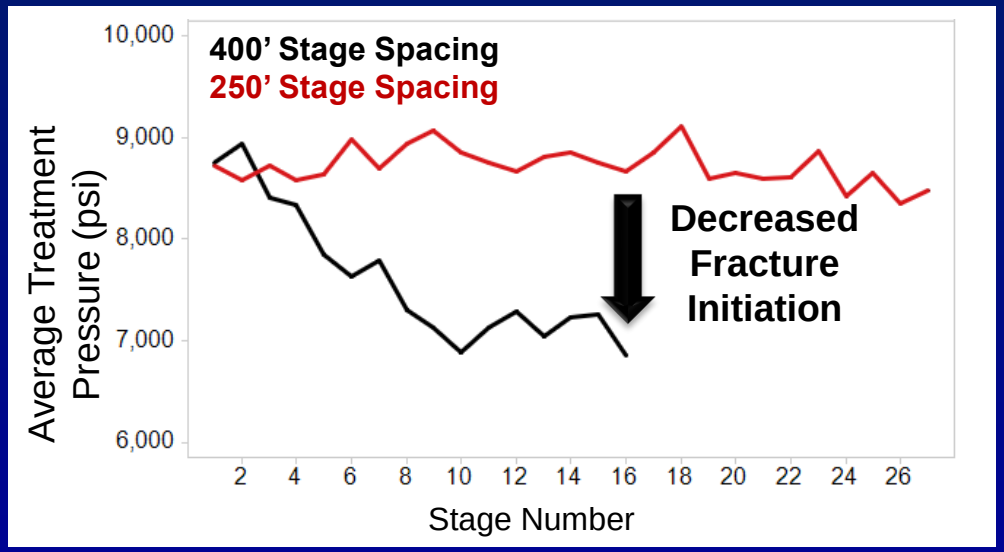
Completion Efficiency- Operational Execution





- Design parameters
  - Stage/cluster spacing
  - Proppant type/volume
  - Frac fluid type/volume
  - Injection rate/pressure
- Creation of stimulated reservoir volume
- Fracture network complexity and propagation

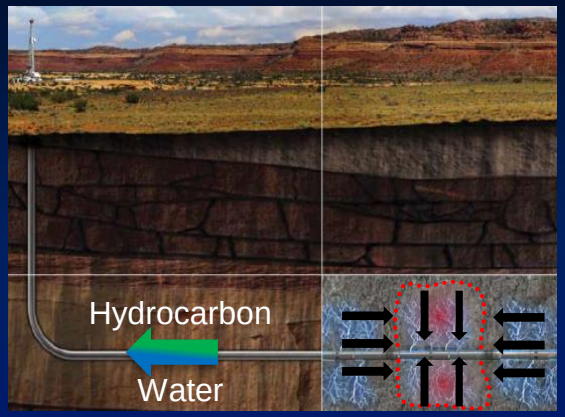
Fracture Treatment Pressure along the Lateral



Kurtoglu et al., 2015 (SPE 172922)

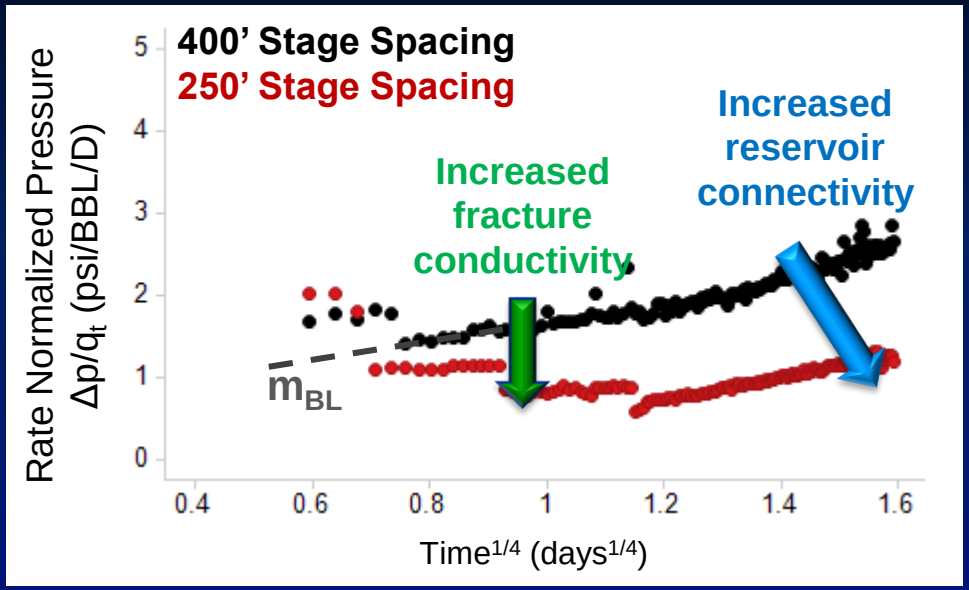
Hourly Flowback- Operational Execution

Multi-Phase Flowback



Bilinear Flow: One linear flow within fracture towards well and one within the formation towards the fracture

Bilinear Flow Analysis



$$m_{BL} = \frac{44.102\lambda_t^{-1}}{hn_f\sqrt{k_f w_f}}\left(\frac{\lambda_t}{\varphi c_t k_{eff}}\right)^{1/4}$$

Bilinear Slope

Hydraulic Fracture Conductivity

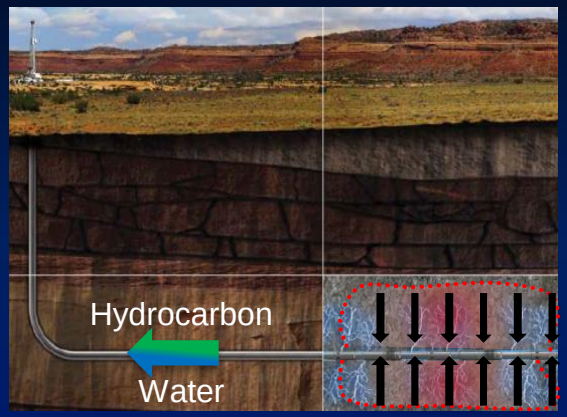
Reservoir Effective Permeability

$h = thickness$ - ft
$n_f = number\ of$ stages
$k_f = hydraulic\ fracture\ permeability$ - md
$w_f = hydraulic\ fracture\ width$ - ft
$k_{eff} = effective\ permeability$ - md
$\varphi = porosity$
$c_t = total\ compressibility$ - 1/psi
$\lambda_t = total\ mobility$ - md/cp

Kurtoglu et al., 2015 (SPE 172922)

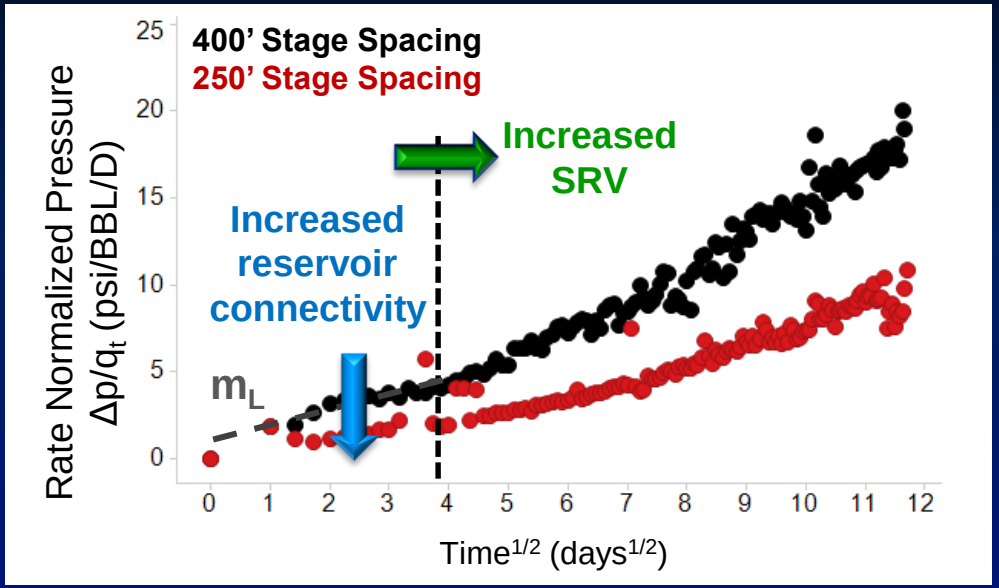
Daily Production- Operational Execution

Multi-Phase Production



Linear Flow: Linear flow within stimulated reservoir volume (SRV) towards well

Linear Flow Analysis



$$m_L = \frac{19.91}{h n_f x_f \sqrt{k_{eff} \lambda_t}} \left(\frac{1}{\varphi c_t} \right)$$

Linear Slope

Fracture Half-Length

Reservoir Effective Permeability

$h = thickness$ - ft

$n_f = number\ of$ stages

$x_f = fracture\ half\text{-}length$ - ft

$k_{eff} = effective\ permeability$ - md

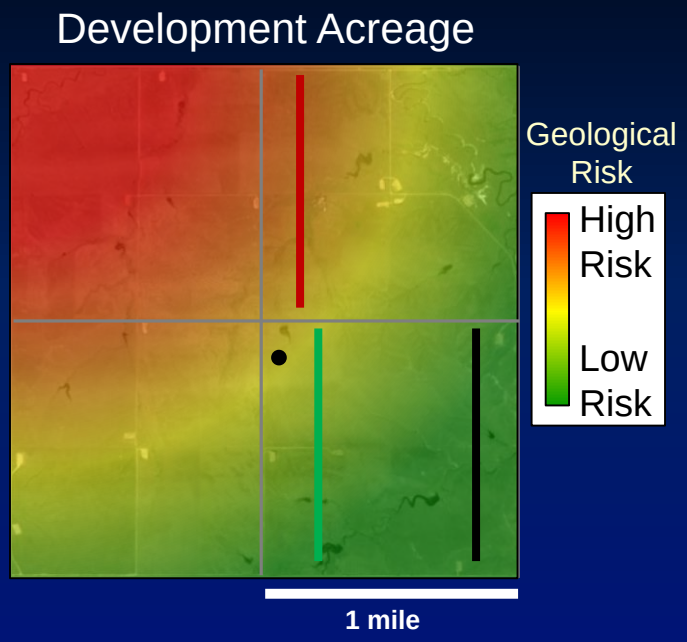
$\varphi = porosity$

$c_t = total\ compressibility$ -1/psi

$\lambda_t = total\ mobility$ - md/cp

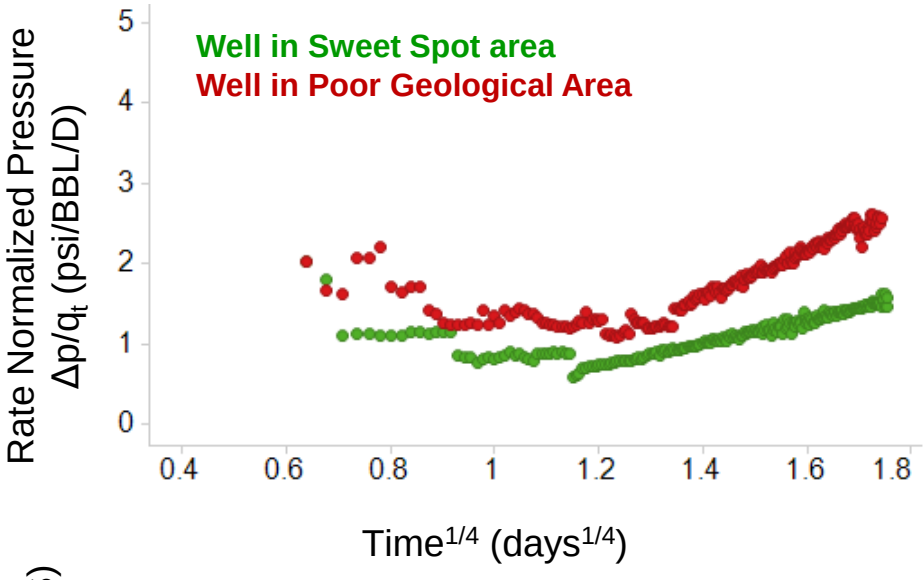
Kurtoglu et al., 2015 (SPE 172922)

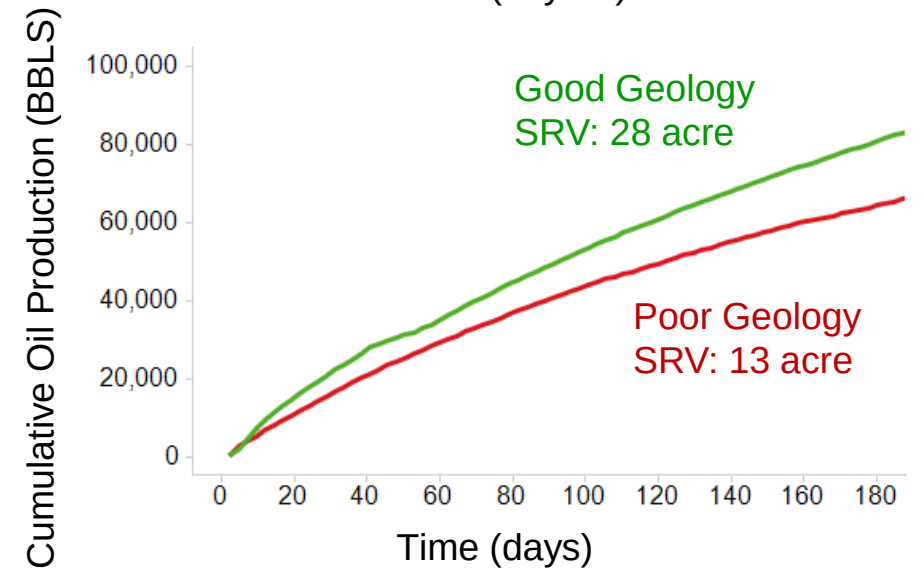
Geological Impact- Operational Execution



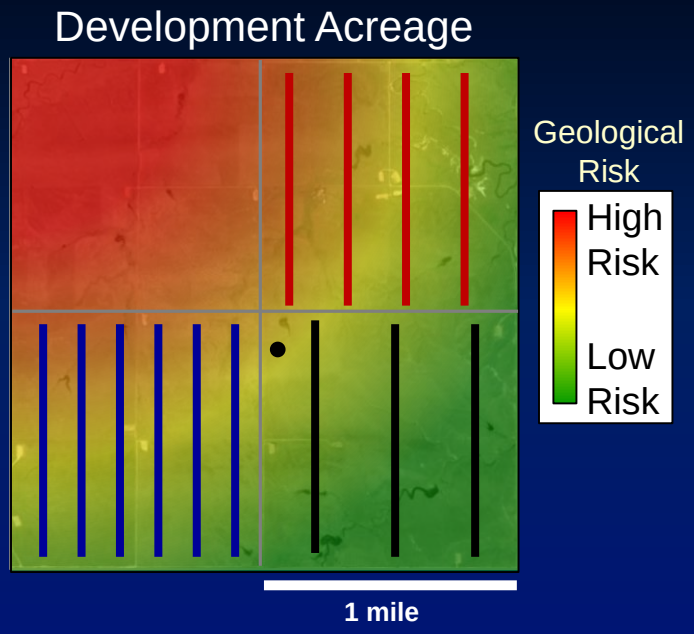
Key Attributes

- Pore Pressure
- Thickness
- Porosity
- Water Saturation
- Fault/Structure
- Fracture Intensity



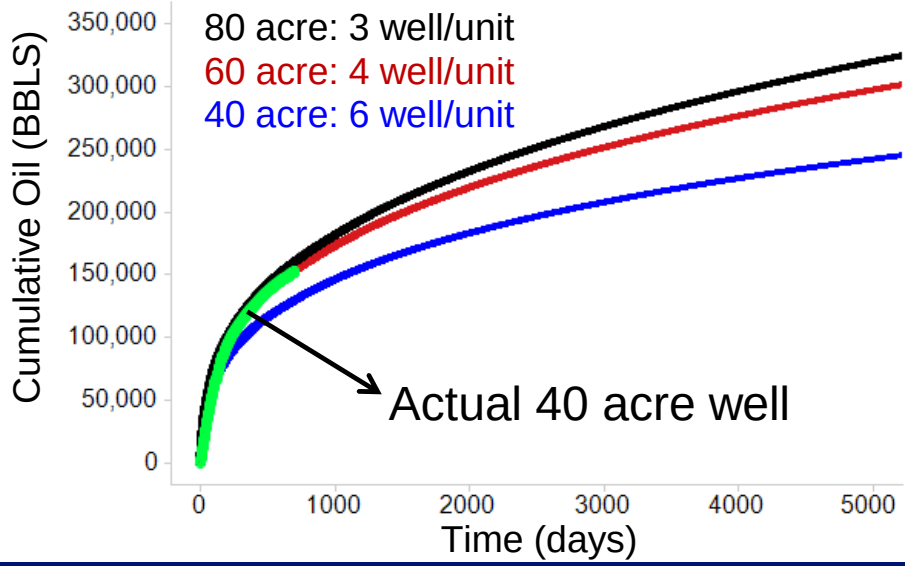


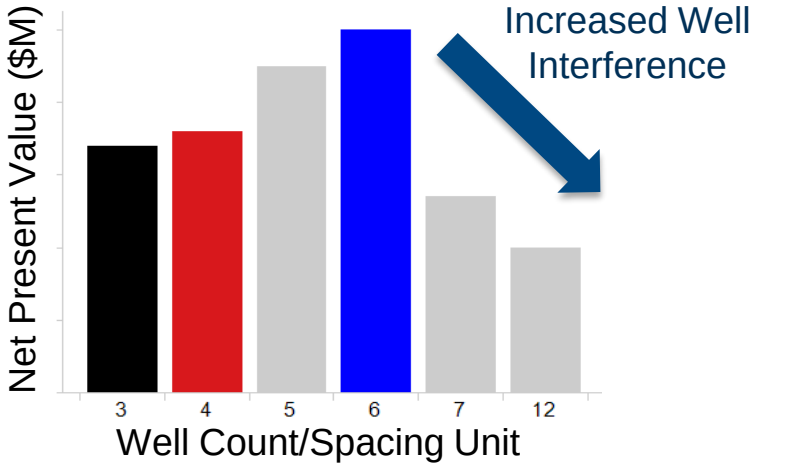
Well Spacing- Value Creation



- Defining boundaries of reservoir both vertically and horizontally
- Simulation of scenarios
- Determine point of diminishing return
- Validation with field results

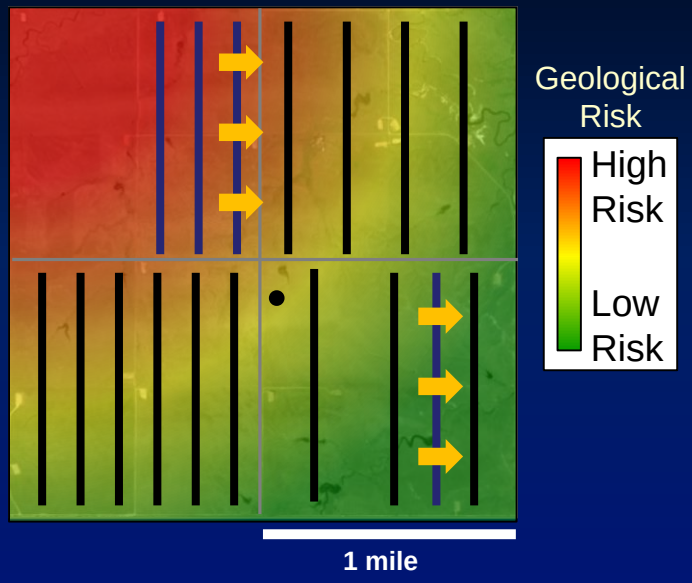
Reservoir Modeling for Well Spacing





Well-to-Well Interaction- Value Creation

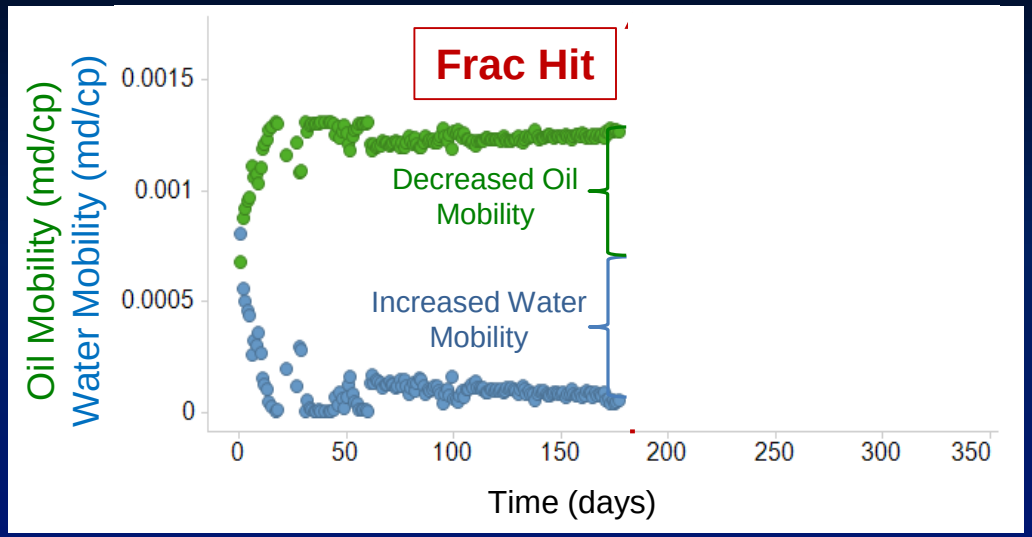
Development Acreage

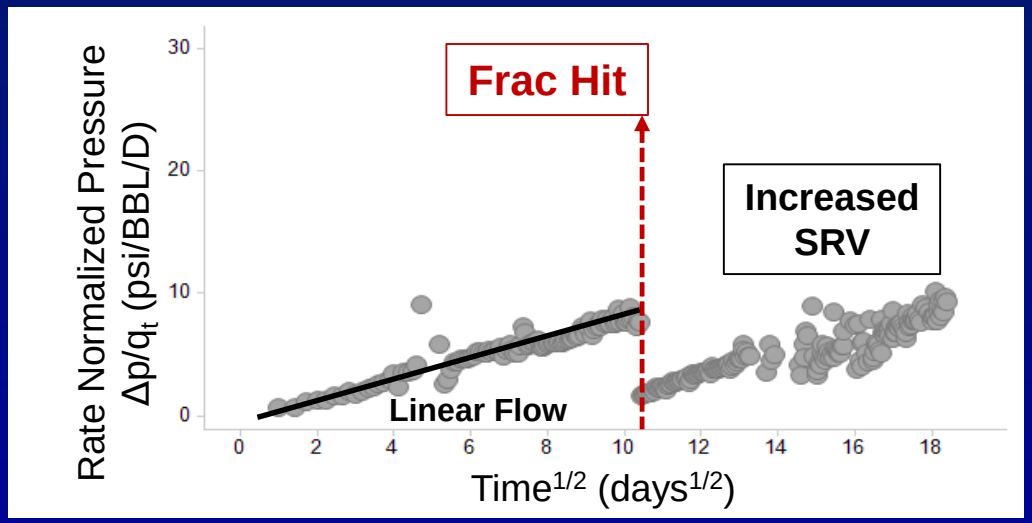


Hydraulic Fracture Interference

- Overlooked risk during infill development
- Awareness of dynamic alteration of reservoir
- Positive or negative impact on existing production
- Incorporate into plan of development

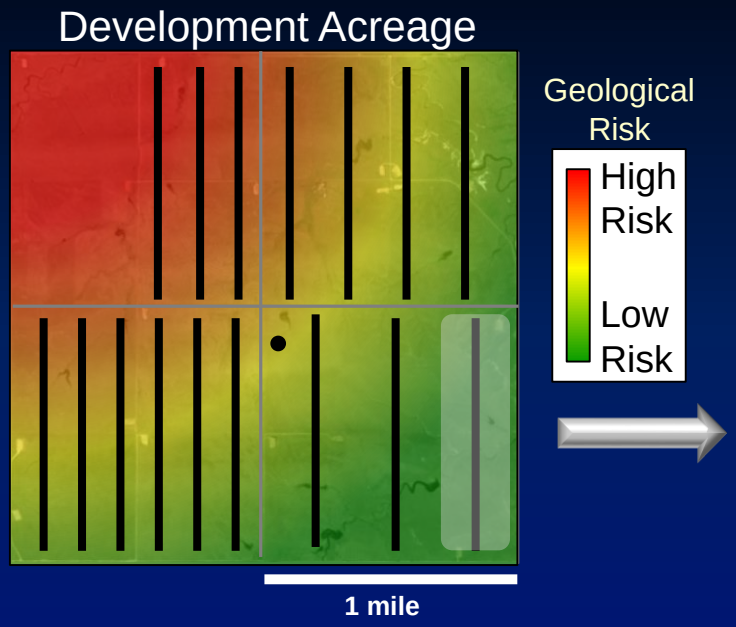
Impact to Offset Producing Wells

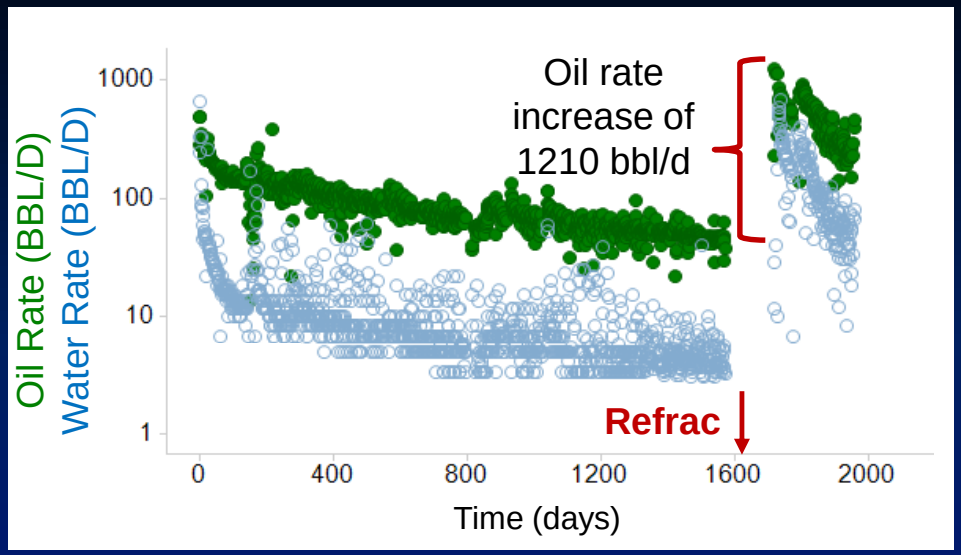




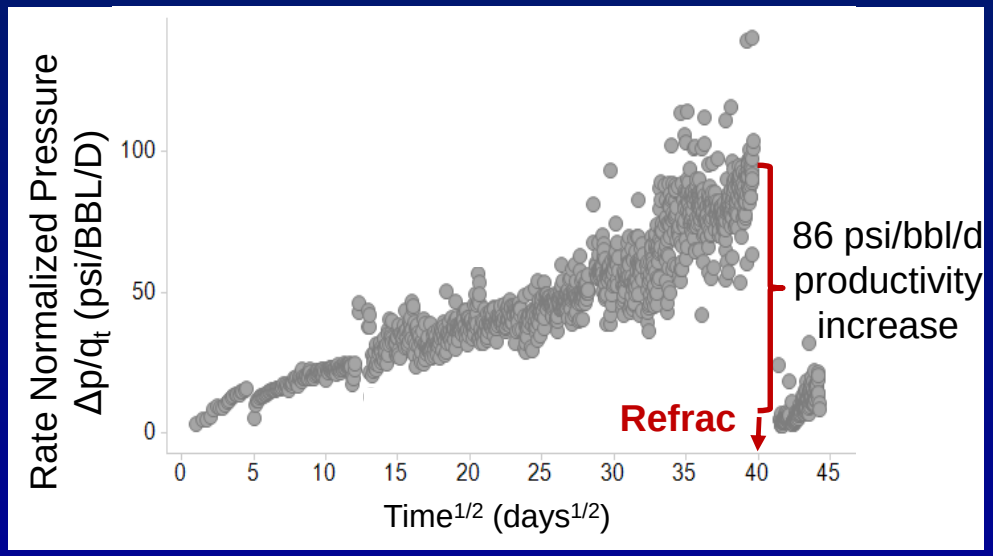
Kurtoglu et al., 2015 (SPE 172922)

Refrac- Value Creation





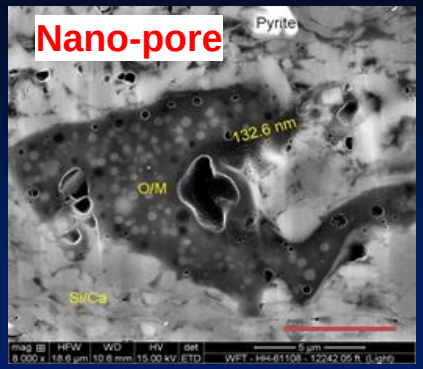
- Application of learnings from frac interference
- Classifying opportunities for refrac based on:
  - Increased productivity
  - Altered fluid mobility
  - Poor initial completion



Kurtoglu et al., 2015 (SPE 172922)

Enhanced Recovery- Value Creation

Rock Properties

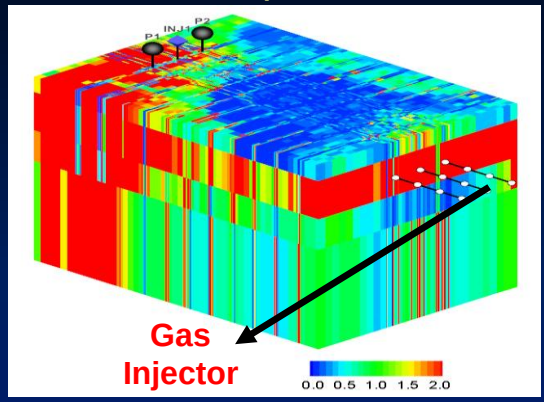


Characterize Nano-Pore Rock and Fluid Properties

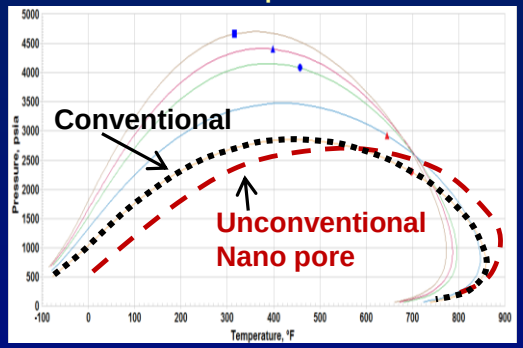
Build Integrated Reservoir Model to Understand Physics

Select the Best Location & Design Field Application

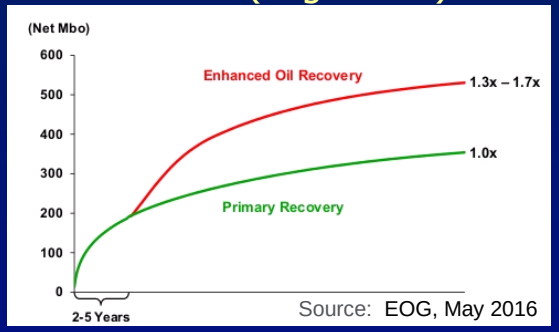
Permeability Distribution



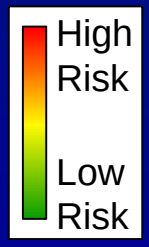
Fluid Properties

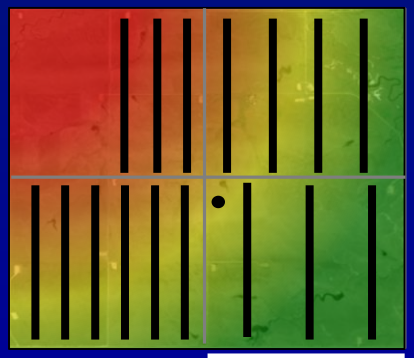


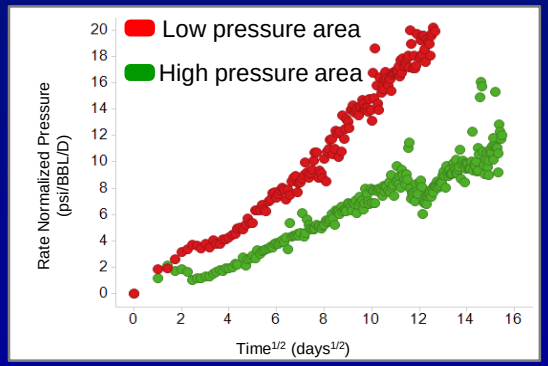
Oil Rate (Eagle Ford)



Primary Development







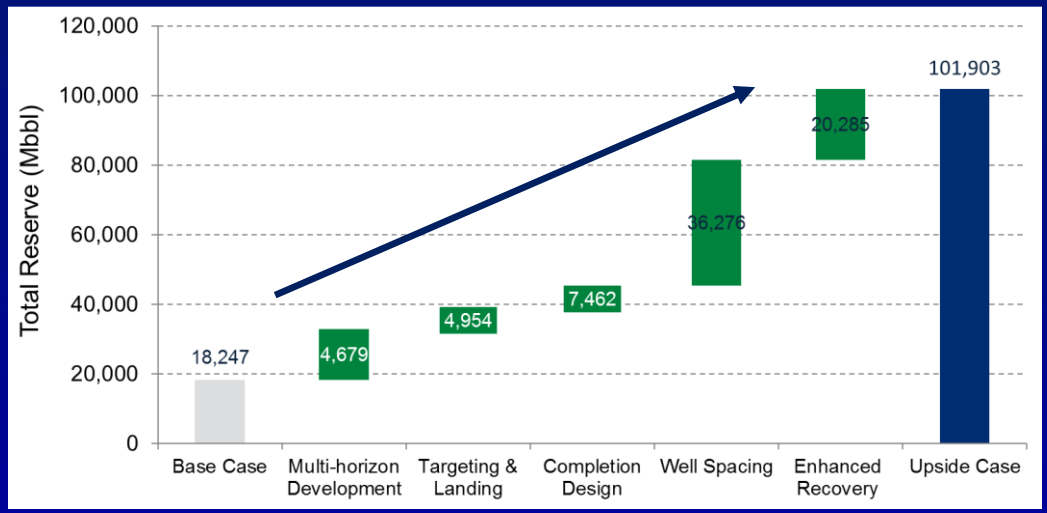
Enhanced Recovery

Value Realization

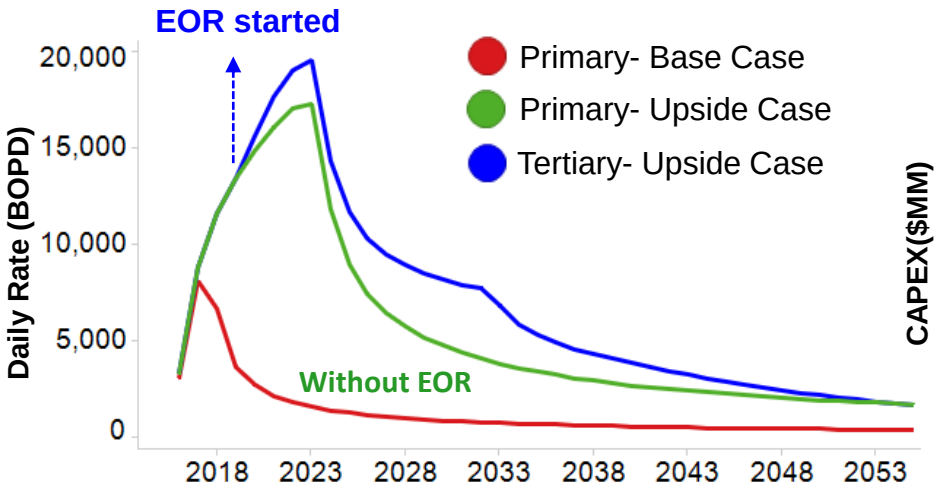
Development Scenarios	Well Count	EUR/Well (Mbbl)	Reserve (Mmbbl)
Base Case	40	456	18
Upside Case	160	637	102

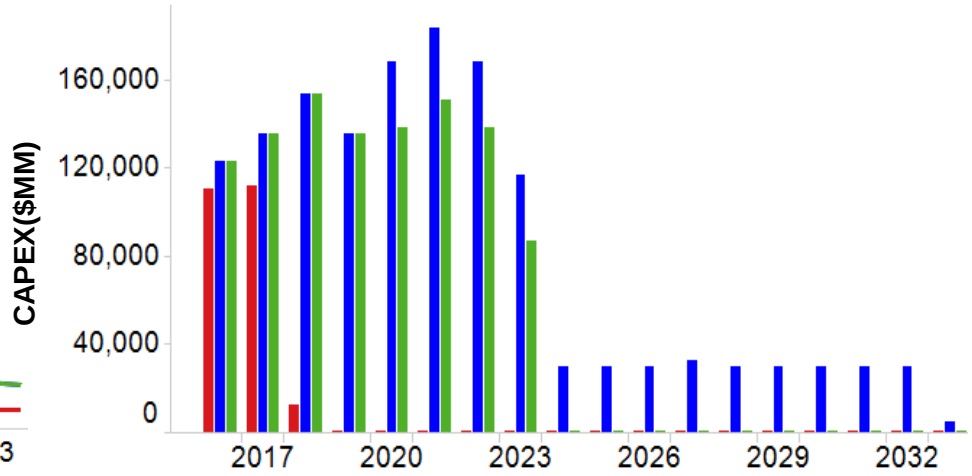
EUR Evolution

Reserve Add



Business Impact

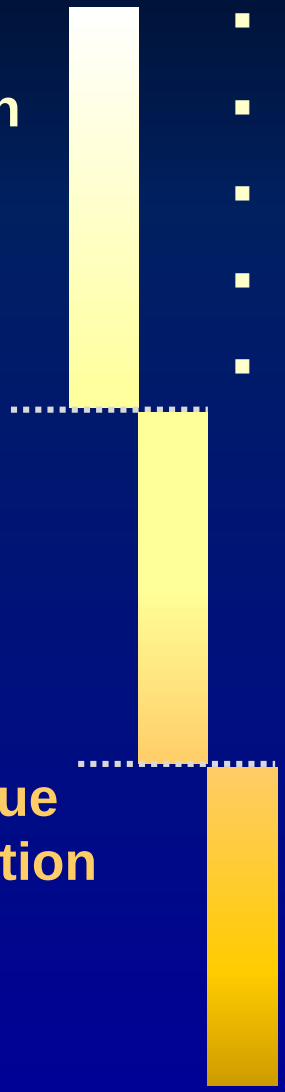




Project Review	Base Case Primary Development	Upside Case Tertiary Development
Completion		
Stage spacing (ft)	350	250
Proppant loading (lb/ft)	600	1,500+
Well spacing	80	40
Well Count	40	160
Net CAPEX ($MM)	243	1,496
Net Reserves (MMBOE)	16	90
NPV10 ($MM)	83	357
ROR (%)	28	30
Discounted NPV10/I	0.42	0.42
NPV10/Acre ($/acre)	**26,000**	**111,000**

Conclusions

Creating a Worldwide Unconventional Revolution



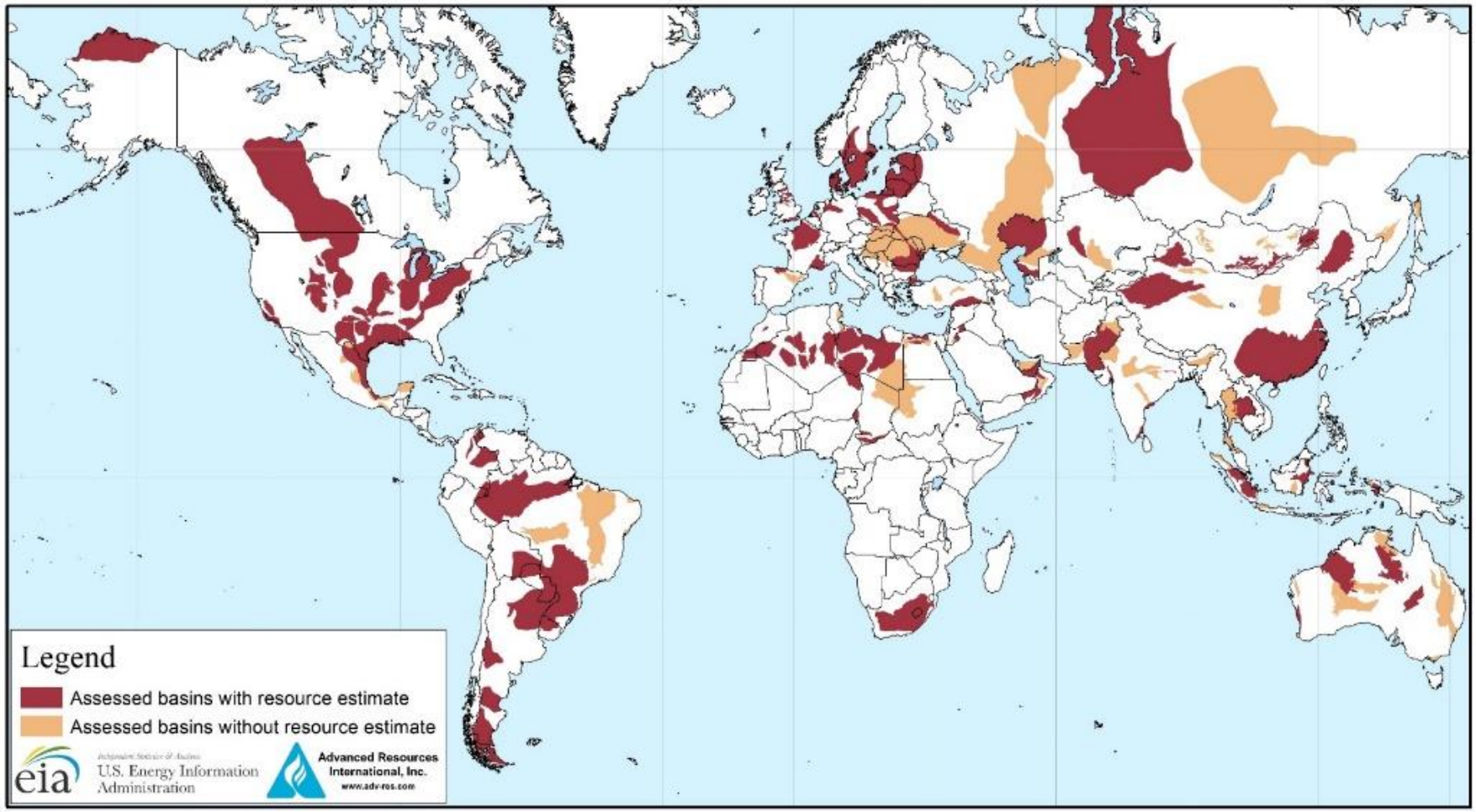
Reservoir Characterization

Operational Execution

Value Creation

- Petroleum System
- Stratigraphic Variations
- Fluid Properties
- Formation Deliverability
- Geomechanical Properties
  - Completion
  - Flowback
  - Production
  - Geology
    - Well Spacing
    - Well to Well Interaction
    - Refrac
    - Enhanced Oil Recovery

Developing Unconventionals Worldwide



Source: EIA

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