Analogizing Hybrid Reservoirs
Reservoir Engineering and Production Best Practices*

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Abstract

Production from unconventional resources is from permeability challenged reservoirs. Such reservoirs vary from conventional oil and gas trapped in ultra-tight or tight formations to the source rock plays. Tight reservoirs are an extension of the uneconomic conventional plays with the promise of economic production through hydraulic fracturing and multistage stimulation. The tight and ultra-tight reservoirs are referred to as hybrid reservoirs. The production mechanism of hybrid reservoirs is similar to that of unconventional source/shale plays but the reservoir performance differs from that of source rock plays. The success in the development and production from the tight reservoirs in the United States has been mostly through trial and error methods. During the last decade, improvement and advances in the areas of reservoir evaluation, well completion methods, hydraulic fracturing, and operational efficiencies resulted in the economic production of gas/oil from the hybrid reservoirs.

This paper addresses the popular question of using a successful hybrid reservoir production as an analog for the development and production of hybrid reservoirs in other basins of the world. Two of the tight reservoirs from North American oil and gas fields are analyzed as case studies to determine the key factors in reservoir evaluation and completions that drive success for long term production. Specific learnings from the reservoir performance and production from these fields are identified and its usefulness as analog is discussed. The learnings are expected to accelerate the understanding of a new reservoir and focus not only on similarities but also to understand the differences that play into the equation. It will also address how best to analogize hybrid reservoirs and avoid the pitfalls of transferring analog mindset that may have worked for the conventional field development.

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ANALOGIZING HYBRID RESERVOIRS

RESERVOIR ENGINEERING & PRODUCTION BEST PRACTICES

HARI P MENON & ROB HULL

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ANALOGIZING HYBRID RESERVOIRS
RESERVOIR ENGINEERING & PRODUCTION BEST PRACTICES

PRESENTING POINTS

- **What are Hybrid Reservoirs**
- **How Hybrid Reservoirs are Evaluated**
  - **Reservoir Types**
  - **Pore scale: what flows and when**
- **North American Experience & Learnings**
- **How Processes relate to Production performance**
  - **Engineered Solutions**
- **Analogizing Hybrid Reservoirs – How?**
  - **Diagnostics over Analog**

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What are Hybrid Reservoirs/Reservoir Plays ?

Permeability Challenged Reservoirs

1. Conventional System : Source- Migration- Trap - High Perm systems (> 0.1md -D)
   - Gravity/density plays the key role in migration & accumulation
   - Natural pressure driven production (Primary)

2. In SRR System: Hydrocarbons retained in the source rock .
   - Oil & Gas available to produce are the remaining oil & gas in-place: Accumulation
   - Ultra low Perm systems: (0.1 microdarcy to 100 nanodarcies)
   - Stimulation (Hydraulic Fracture) driven production

3. Between the two ends are the hybrid system: Tight Reservoir
   - Low Perms (<0.1md – 0.1 microdarcies)
   - Oil & Gas Accumulation is migratory, similar to conventional but different process
     - Relative permeability & Capillary pressure creates & maintain the accumulation
   - Stimulation (Hydraulic Fracture) driven production

Associated with Conventional or Source Rock Resources

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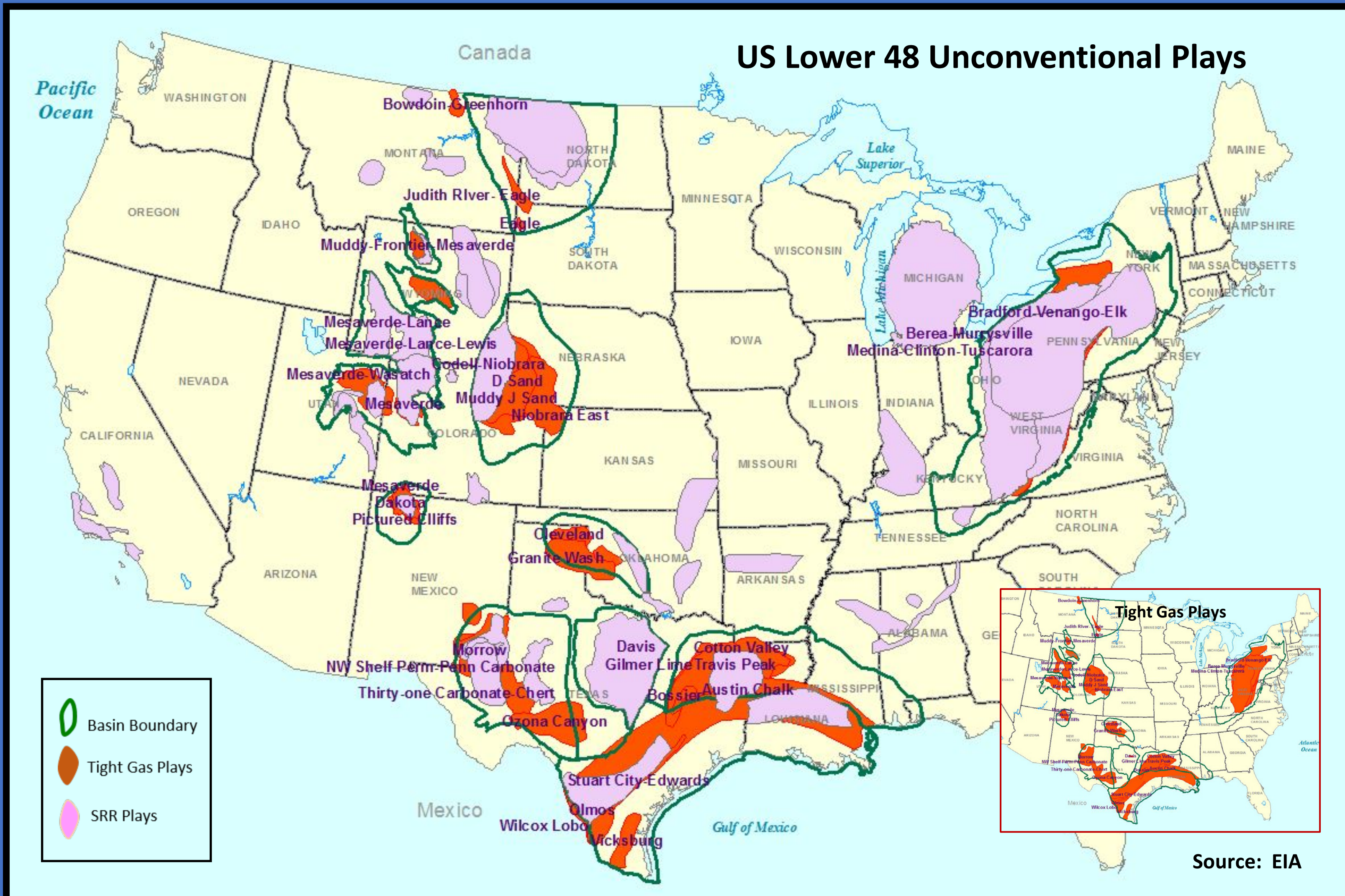
Hybrid Reservoirs are Associated with Source Rock Resource Plays



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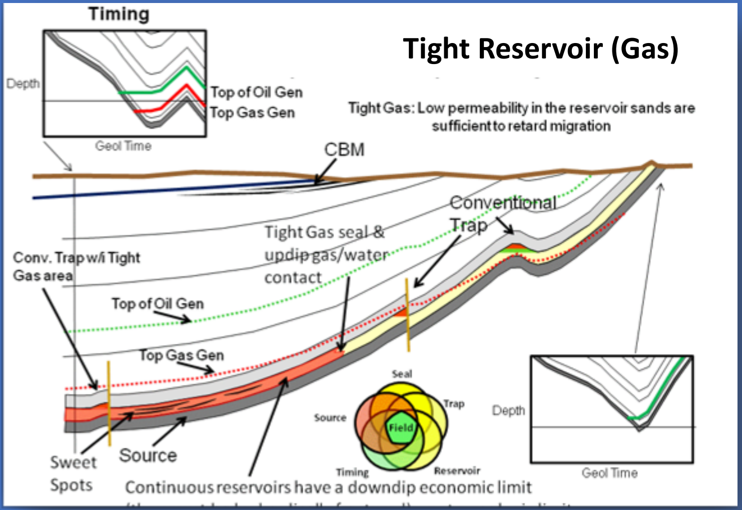
Hybrid Reservoir Types

- Depending upon the proximity of the reservoir to the source Rock:
  - **Conventional Hybrid**
  - Unconventional Hybrid

  - Conventional Hybrid: Far Source: Accumulation requires some process of migration
    - Diffusion driven/Knudson slippage
    - Matured source rock could be deeper.
    - Matrix porosity -Water wet with or without natural fracture system
    - Low Permeability– 0.1 to 0.5 millidarcies or lower
    - Sweet spots: high porosity & permeability are production drivers



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Hybrid Reservoir Types

- Depending upon the proximity of the reservoir to the source Rock:
  - Conventional Hybrid
  - **Unconventional Hybrid**

  - Unconventional Hybrid: Accumulation is in proximity to Source rock – Near Source
    - Oil or gas do not move very far – low permeability prevents movement
    - Permeability closer to microdarcies
    - Low perm reservoir may be sandwiched between organic rich layers or may be present as interbedded layers.
    - Not water wet: flows by Knudsen slip diffusion and water is not part of production delivery system
    - High TOC & Maturity of OM along with permeabilities of microdarcies are production drivers.

In Hybrid Reservoir systems relative permeability & capillary pressure create and maintain hydrocarbon accumulations

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Pore scale
what Stores - What flows - When ?

- Porosity determines the storage capacity (typically 10% or less) & fluid flow behavior
  - Main pore systems for Hybrid reservoirs
    - Inter-particle dissolution pores
    - Primary inter-particle pores
  - Pore throat diameter range from 2 to 0.03μm

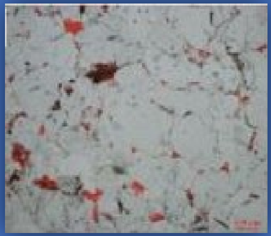
(Philip H Nelson, 2009)

  - Pore systems for Source Rock Reservoirs
    - Inter-particle & Intra-Particle dissolution pores
    - Intra-matrix dissolution pores
    - Clay interlayer micropores
    - Organic pores
  - Pore throat diameter range from 0.1 to 0.005μm

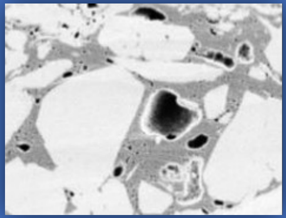
(Philip H Nelson, 2009)

- Permeability – ability to flow hydrocarbons (economically)

Dissolved Pores [1]
Tight Sandstones



Intergranular Pores[1]
Tight Sandstones



Intergranular Organic Pores[2]
Organic Rich Silty Shale

1. After Bo Jiu et al 2018; 2. Courtesy Ingrain Halliburton

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Pore scale
what Stores - What flows - When ?

- A pore throat diameter of 1 mm- 2 μm : Darcy Flow
- Pore throat diameter of < 2 μm : Diffusion flow – SRR

Deliverability

- Pore throat size & Permeability – Key parameters to flow hydrocarbons (economically)
- Hydraulic Fracture creates the plumbing system that connects the low permeability storage system

Deliverability throughout the lifecycle is the key to Hybrid reservoir development

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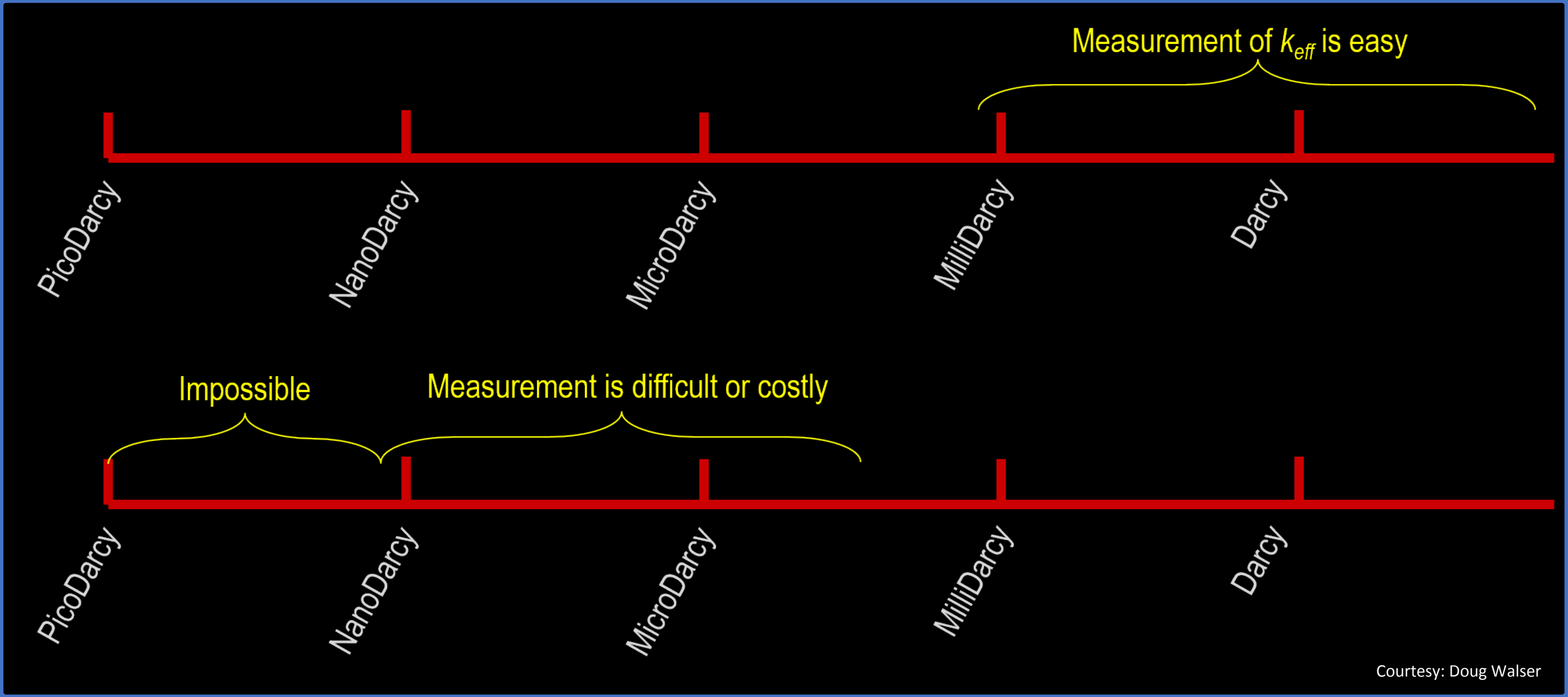
Effective Permeability Rules

$$Q = \frac{-kA\,(\Delta P)}{\mu L}$$



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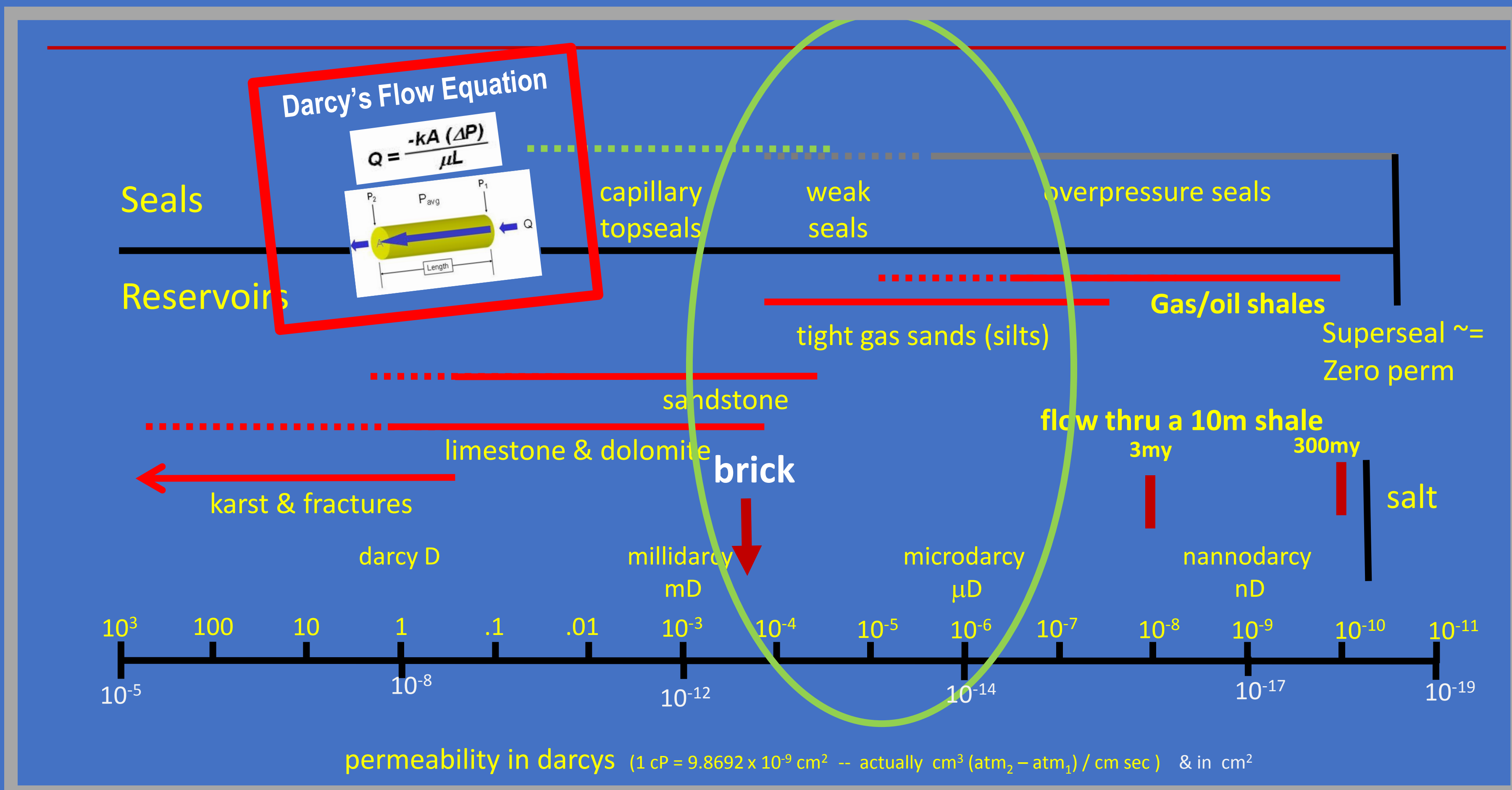
HYBRID RESERVOIRS

Conventional Reservoir —— Source Rock Reservoir



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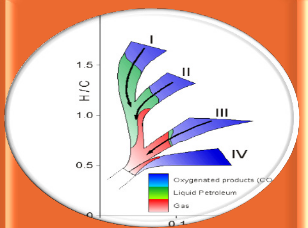
Asset Evaluation Components : Reservoir Specific Solutions

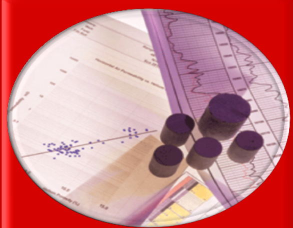
Rock Characterization to Production Workflows

Reservoir Characterization ⟷ Reservoir Fluid Properties ⟷ Geomechanics



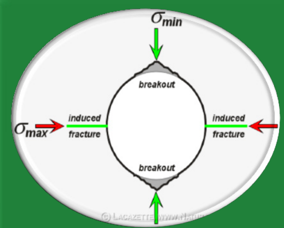
Geochemistry

- TOC,
- Kerogen,
- Maturity ..etc



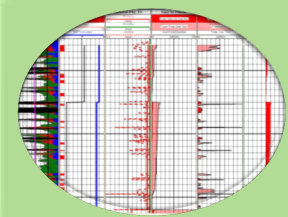
Formation Evaluation

- Mineralogy
- Porosity, Perm
- Fluid Volumes



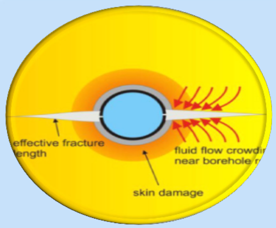
Geomechanics

- Mechanical Properties
- Stress Field
- Frac. Parameters



Net Pay

- Evaluating Reservoirs
- Net Thickness
- Estimating Reserves
- Reservoir Quality



Productivity Prediction

- Frac Drainage
- Decline Rate & Cumulative

Source Rock Reservoir Play Solution: Front End Geochemistry

Hybrid Reservoir Play Solution: Predicts Production & Potential

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SINGLE WELL ⟶ FULL FIELD OPERATIONS

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North American Experience & Learnings

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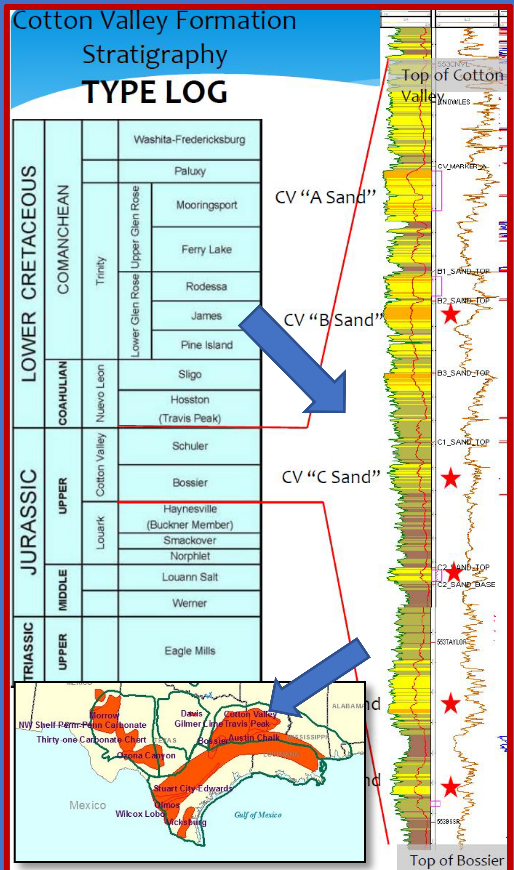

Jurassic Cotton Valley – East Texas – A Case History

- Cotton Valley Formation located above the Haynesville/Bossier Shale
- Tight reservoir: gas play with some oil
- Fluvial to wave dominated deltaic sandstone.
- Depth: 7,800' to 10,000'
- Thickness: 1100' to 1300'

Challenge:

- Conventional porosity & Saturation analysis look equivalent
- Vertical /hydraulic fracturing varied tremendously by zone – no correlation
- Needed to predict vertical well pre-frac production to identify horizontal drilling opportunities

Solution:

- Reservoir zonation & discriminate reservoir movable fluids
  - Acquired reservoir diagnostic tools
    - MRIL & Oriented Dipole sonic with Triple combo program
  - Discriminated moveable fluids with MRIL
  - Kh profiles determined by zone using MRIL texture perm
  - Anisotropic Closure stress calculated for better frac boundary discrimination

Result:

- Identified Middle Cotton Valley 'C' sand as horizontal target
- Vertical frac test confirmed pre-frac productivity prediction
- Optimized Fracture Design for Optimal Production

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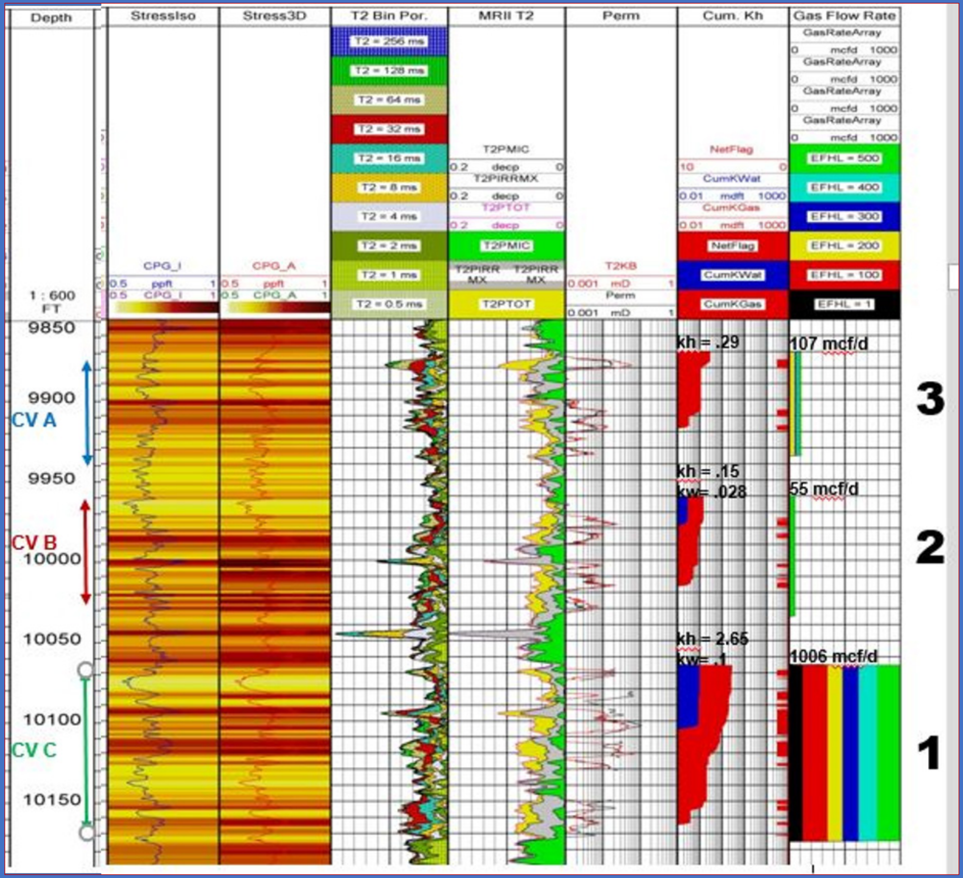
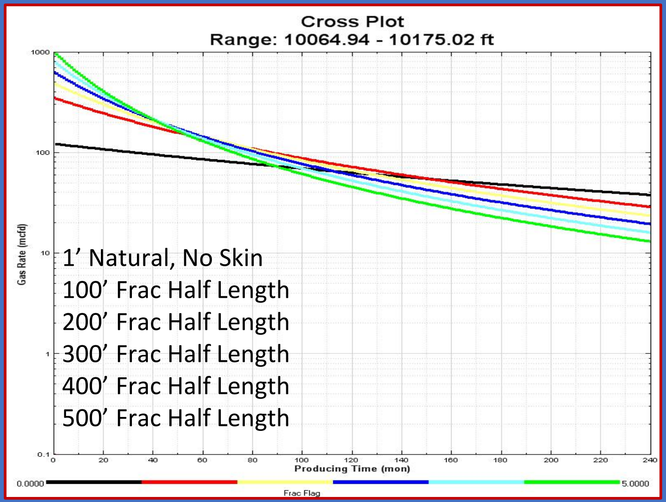
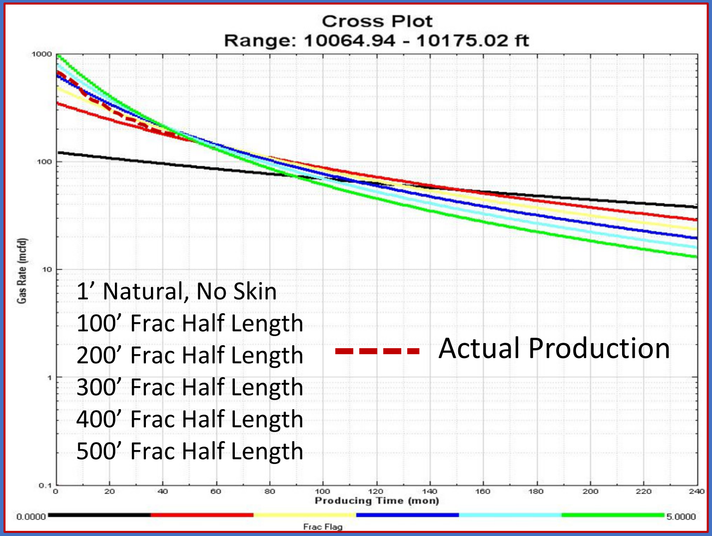
Stratigraphy column from East Texas Geological Society

Jurassic Cotton Valley – East Texas

Rock Characterization + Geomechanics + Reservoir Fluid Properties







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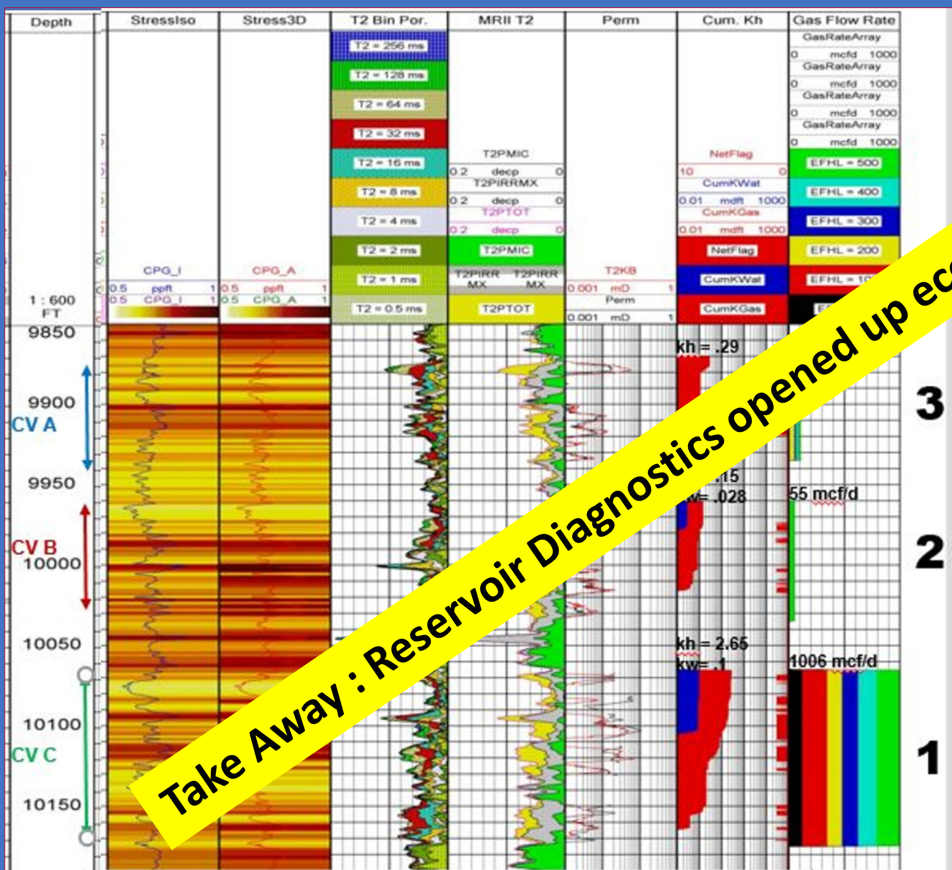
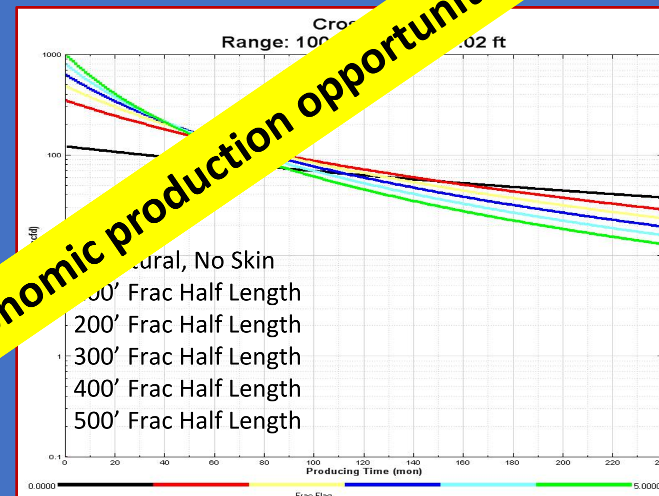
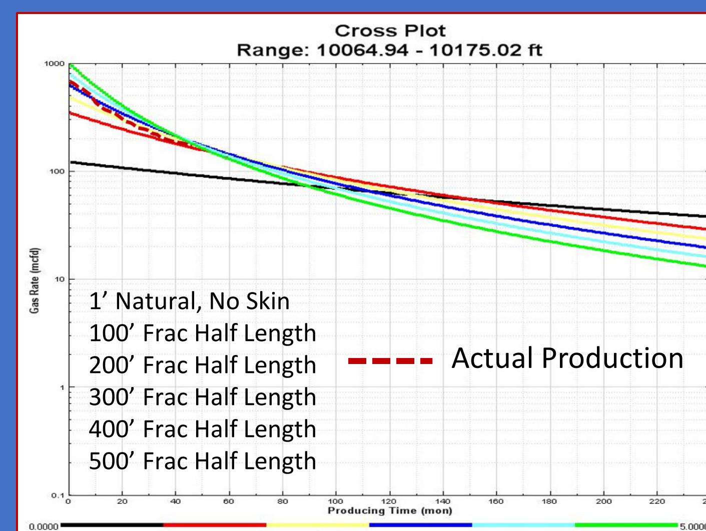
Jurassic Cotton Valley – East Texas

Rock Characterization + Geomechanics + Reservoir Fluid Properties







Take Away : Reservoir Diagnostics opened up economic production opportunities

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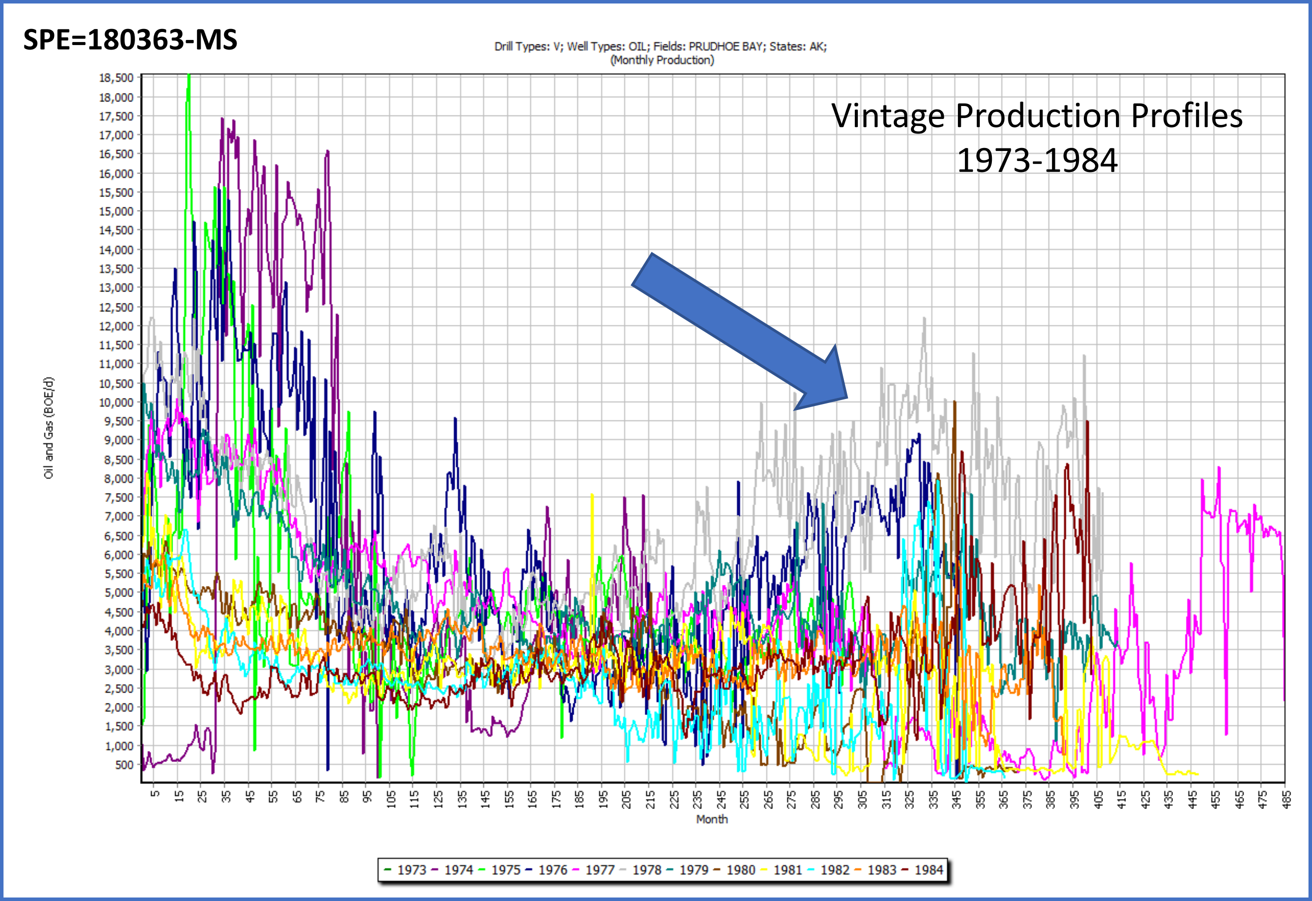
Prudhoe Bay – Alaska

- When permeability decreases (ultra low) process begins to dominate production
  - The reverse trend is due to K.
- What Contributed increase in K

- Frac Packs introduced
  - Very small ft^2

- Increase in total exposed & conductive fracture surface area



Courtesy Doug Walser

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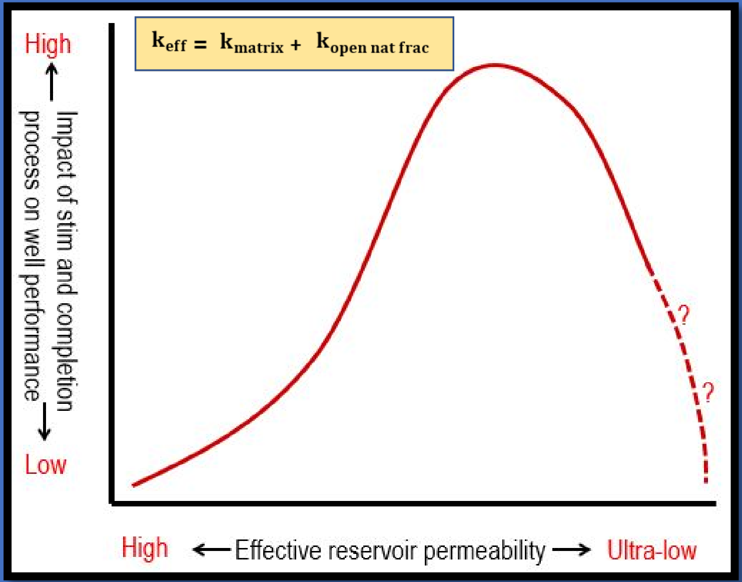
North American Experience & Learnings

- Recognize the interrelationship between Rock Characterization (mineralogy, diagenesis and pore throat size), fluid flow properties and geomechanics of the area. They are the three major categories that impact stimulation & production
- 15 years of North American experience suggest that the lower (within reasonable limit) the effective permeability of a given reservoir, the higher the impact of process on well performance.
  - Understanding the role of Keff of reservoir early on will give insights on production economics
  - Intense fracturing techniques to lessen the distance 'L"

$$Q = \frac{-kA\,(\Delta P)}{\mu L}$$

  - Decreasing the distance L in the flow equation will have a tremendous impact on production.



Courtesy Doug Walser (personal communication)

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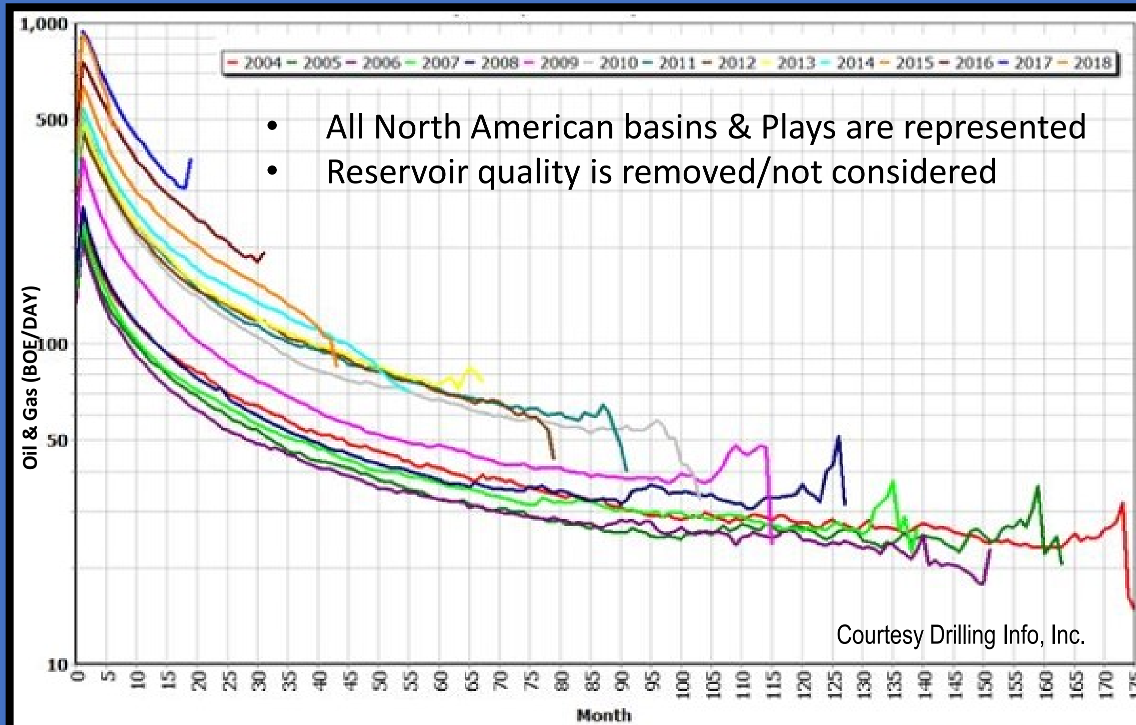
North American Learnings
Low Permeability Reservoirs
Stimulation & Completion Process and Production

- Increase in total exposed and propped fracture surface area
  - Increasing Volume of fluid and/or proppant
  - Decreasing average diameter of proppant
  - Increasing the magnitude of the in-situ σ_{hmax} normal to and away from well bore –
    - promotes far field complexity
  - Technology to divert fluids within a given stage
  - Increased surface efficiency



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North American Learnings
Low Permeability Reservoirs
Stimulation & Completion Process and Production

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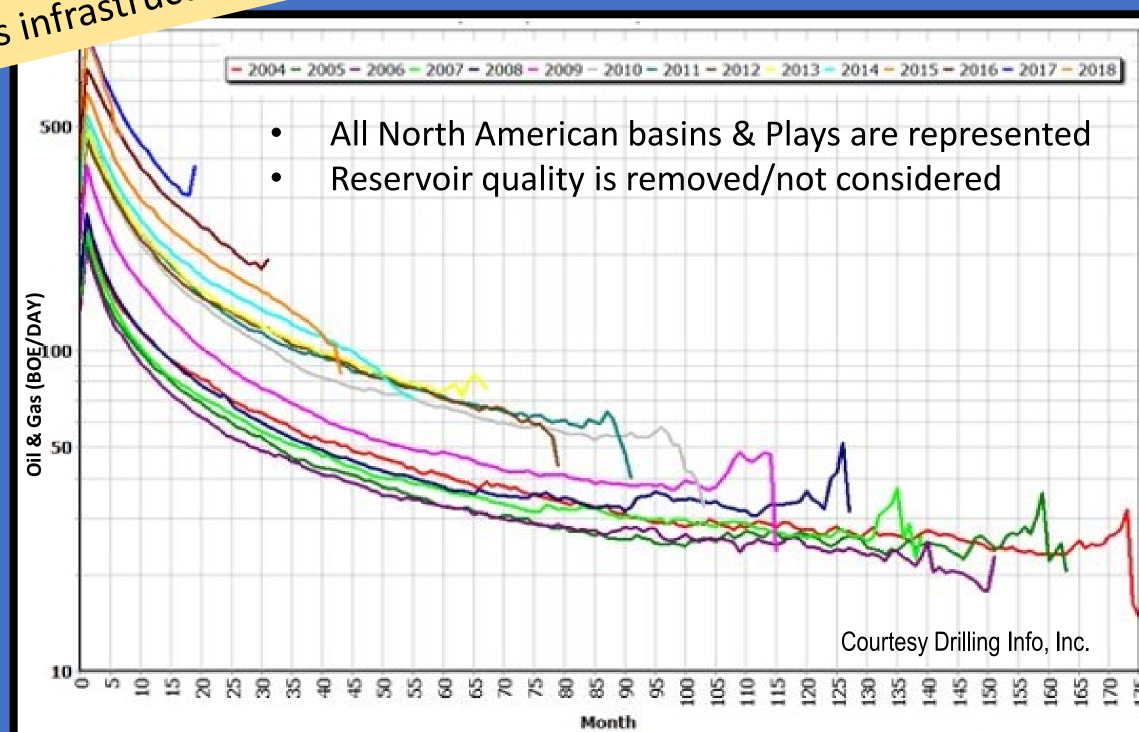
  - ...eased surface efficiency

Key Take Away on NA Learnings

Establishing Drilling & Completions infrastructure is critical for commerciality when Di > 90%



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ANALOGIZING – HYBRID RESERVOIR

1. Acknowledge that there are no perfect analog for any existing plays.
   - Both similarities and differences in play types are to be considered (for analog).

2. For low permeability reservoirs, in particular hybrid reservoirs similarities between plays can be useful in three critical areas:
   - Rock Characterization: Depositional sedimentology & Pore throat sizes
   - Geomechanics: Stress regime & Tensile strength of the rock
   - Flow properties: Effective Permeability & Role of Natural Fractures – Assist or Resist

3. Instead of drilling wells based on analogs, upfront measurements will shorten (or steepen) the learning curves (Diagnostics over Analogs)
   - NA experience : From Trial & Error to Engineered Solutions
   - Consider each well as portfolio of assets rather than targeting a single interval or formation (Hybrid Reservoirs are almost always associated with Source Rock Reservoirs)

4. Analog Scenario: Data Analytics
   - Using the database of thousands of fracturing stages in dozens of plays and accelerate the process of turning data into insight.

5. Resource & Reserve Evaluation
   - USGS uses analog/single well reserve estimation method.

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We are also thankful to several colleagues within Halliburton, for sharing their experience, opinions and insights on the North American basins. Their ideas are imbedded in the presentation and are absorbed into my own thinking that I cannot distinguish them as separate any more.

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