“Sweet Spot” Identification & Optimization in Unconventional Reservoirs

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Fundamental Questions

- What is an unconventional reservoir?
- How are they different from conventional reservoirs?
- What are the characteristics that we can measure?
- Which of those characteristics are really important?
- What do we mean by “sweet spot”?
The Difference Between Conventional and Unconventional Reservoirs

Producing Conventional Reservoirs

Earth (what can vary)

- Porosity
- Thickness
- Area
- Saturation
- FVF
- Permeability
- Pressure
- Temperature

Tools (what we can vary)

- Wellbore Diameter
- Well Spacing
- Tubing Pressures
- Artificial Lift
- Enhanced Recovery Mechanisms

*Sweet Spot* Identification & Optimization
in Unconventional Reservoirs
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The Difference Between Conventional and Unconventional Reservoirs

Producing Unconventional Reservoirs

Earth (what can vary)

Tools (what we can vary)

- Horizontal Lateral Length
- Perf Size
- # of Perfs/Cluster
- # of Clusters/Stage
- Stage Length
- Stage Spacing
- Frac Pressure (> FIP)
- Frac Time
- Fluid Viscosity
- Fluid Slickness
- Proppant Size
- Amount of Proppant
- Uniformity of Proppant
- Strength of Proppant
- Amount of Frac Fluid

Stimulated Rock Volume
What are the Characteristics that We can Measure?

- Many different Authors have tried to categorize the “productive” shale capabilities.
- Two primary approaches:
  - Pre-Drill:
  - Post-Drill:
  - Methods vary from using as few as two parameters to as many as fourteen parameters to define a “sweet spot”.
- We reviewed papers from most active North American shale plays as well as advanced international shale plays.
- The major papers are summarized in the handout.
The Three “Qualities”

- Organic Quality
  - TOC
  - Maturity
  - Kerogen Type
  - Storage Capacity

- Rock Quality
  - Thickness
  - Saturation
  - Porosity
  - Permeability
  - Minerology

- Mechanical Quality
  - Poisson’s Ratio
  - Young’s Modulus
  - Mineralogical Brittleness
  - Stress
  - Pressure
  - Fractures
Factors that are needed for Sweet Spot Quantification

Organic Quality (OQ)
- Organic Content
- Maturity
- Storage Capacity
- Maceral Type

Mechanical Quality (MQ)
- Poisson’s Ratio
- Young’s Modulus
- Clay Content
- Stress Fields
- Pressure Regime

Rock Quality (RQ)
- Thickness
- Porosity
- Permeability
- Mineralogy
- Saturation

When there are the optimum factors from all three Qualities, then the reservoirs will be in the sweet spot.
Factors that are needed for Sweet Spot Quantification

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Rock Quality
- Thickness
- Porosity
- Permeability
- Mineralogy
- Saturation

With no “RQ” there is HC and the rock can be frac’d, but it is just a source rock.
Factors that are needed for Sweet Spot Quantification

Organic Quality (OQ)
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Rock Quality (RQ)
- Thickness
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- Mineralogy
- Saturation

Fit for Purpose Operations

Sufficient Fiscal Environment

Proper Regulations and Environmental Management

With no “MQ” there is HC and storage, but the rock can’t be frac’d so no sustainable production
Factors that are needed for Sweet Spot Quantification

Organic Quality (OQ)
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Mechanical Quality (MQ)
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- Young’s Modulus
- Clay Content
- Stress Fields
- Pressure Regime

Rock Quality (RQ)
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- Porosity
- Permeability
- Mineralogy
- Saturation

With no “OC” there is HC and the rock can be frac’d but it is non-productive
## What Can Make a Sweet Spot “Sweet”

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range for Commercial Shales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Content</td>
<td>&gt;3% and &lt;12% of correct macerals</td>
</tr>
<tr>
<td>Maturity ((Vr_0, T_{max}, CAI))</td>
<td>Wet gas or dry gas windows</td>
</tr>
<tr>
<td>Storage Capacity (Langmuir Isotherm, BCF/ac-ft, etc.)</td>
<td>Variable by shale and thickness</td>
</tr>
<tr>
<td>Thickness</td>
<td>&gt;100’ and bounded for Frac</td>
</tr>
<tr>
<td>Porosity</td>
<td>&gt;8% - can be much higher</td>
</tr>
<tr>
<td>Permeability</td>
<td>&gt;.001mD – not firm rule</td>
</tr>
<tr>
<td>Clay Content</td>
<td>&lt;40%</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>&lt;.2</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>&gt;5x10e6</td>
</tr>
<tr>
<td>Pressure</td>
<td>Generally – overpressure is positive</td>
</tr>
</tbody>
</table>
Factors that are needed for Sweet Spot Quantification

**Organic Quality (OQ)**
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**Fit for Purpose Operations**

**Sufficient Fiscal Environment**

**Proper Regulations and Environmental Management**
How do We Quantify these Surface Factors?

• If proper operations, fiscal environment, regulations are also critical, how do we measure or quantify them?
• Is there a single system?
  • Organic Quality
  • Operations
  • Rock Quality
  • Fiscal
  • Mechanical Quality
  • Regulations
• Can we get to commerciality? Economics?
The PRMS has both a commerciality and an uncertainty measure built into the system. These measures can be used to quantify sweet spots in unconventional reservoirs.

Figure 2.1 – Sub-classes based on project maturity
Reserve Definitions for Shales

- Normally by decline curve analysis plus economic analysis to meet threshold values.
  - Commercial Rate
  - Commercial Gas Composition
  - Developable Gas Volume
  - Feasible Development Plan
  - Reasonable Time Frame
  - Viable Market
  - Existing or Imminent Approvals

(Facilities and Volumes and Rate Align)

Notice that for Conventional – normally a well test will suffice.
Example where the PRMS can define the “sweet spot” on both commerciality (reserves) and uncertainty (probable vs. possible) within a field at an early stage of development.
Examples of External Impacts on Sweet Spot Area from the Niobrara in the DJ Basin, Colorado
Effect of Technology

Organic Quality (OQ)
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Fit for Purpose Operations
Sufficient Fiscal Environment
Proper Regulations and Environmental Management

Advent of horizontal wells and MHF opened more rock volume to be a commercial reservoir
Effect of Technology


Extent of Niobrara Production in Wattenberg Field in 1970 vs. 2018, vertical vs. MHF in horizontal wells.
Effect of Price

Map of EOG’s original field development
Effect of Price

EUR's of the original wells

Sweet Spot based on EUR
Increase in $$ Increases Sweet Spot

Sweet Spot based on $100/Bbl

• NPV of the wells at $100/Bbl WTI Price
Sweet Spot based on $69.36/Bbl

• NPV of the wells at $100/Bbl WTI Price

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• Key Take Away #1
  • Sub-Surface Productivity Factors (PF) can vary by basin, shale or field, but can be subdivided into:
    • Organic Quality Factors (OQ);
    • Rock Quality Factors (RQ); and
    • Mechanical Quality Factors (MQ).
Key Take Aways

• Key Take Away #2
  • Sweet Spot quantification needs to include commercial terms:
    • Operations
    • Fiscal
    • Regulations
  • The AAPG-SPE PRMS has the built-in tools for quantification of both commerciality and uncertainty.
Key Take Aways

• Key Take Away #3
  • Due to above ground factors of:
    • Commodity Price
    • Drilling and Completion Efficiency
    • Regulations
    • Societal Challenges

“Sweet Spots” are not static but change over time.
<table>
<thead>
<tr>
<th>Literature Review</th>
</tr>
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<tbody>
<tr>
<td><strong>Organic Quality</strong></td>
</tr>
<tr>
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<tr>
<td>Greer, W.R.</td>
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<tr>
<td>Van Heerden, Meyer, &amp; Pretorius</td>
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<td>Baliga, S., &amp; Supratman, A.</td>
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<td>Ivan, T.</td>
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<td>Komissarova, Y. &amp; Savchuk, V.</td>
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<td>Chappo, D., &amp; Suzuki, Y.</td>
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