“Sweet Spot” Identification & Optimization in Unconventional Reservoirs

June 5, 2019

Jeffrey B. Aldrich & Dr. John S. Seidle

Copyright © 2019 Sproule

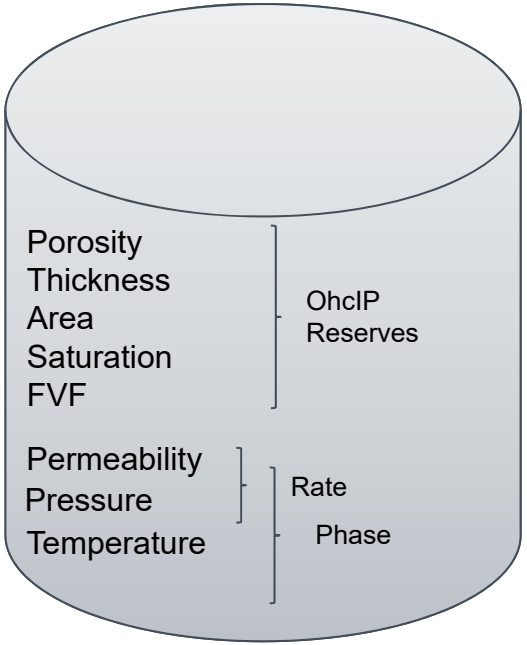
Fundamental Questions

- 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”?

Copyright © 2019 Sproule

Producing Conventional Reservoirs

Earth (what can vary)



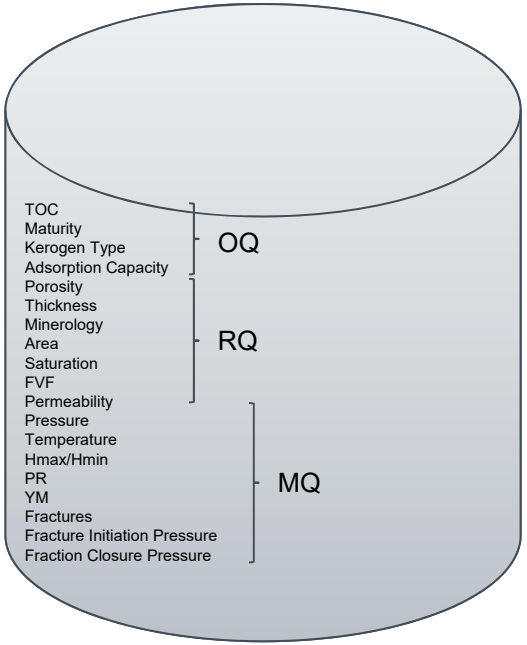
Tools (what we can vary)

Wellbore Diameter
Well Spacing
Tubing Pressures
Artificial Lift
Enhanced Recovery Mechanisms

Copyright © 2019 Sproule

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

Copyright © 2019 Sproule

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.

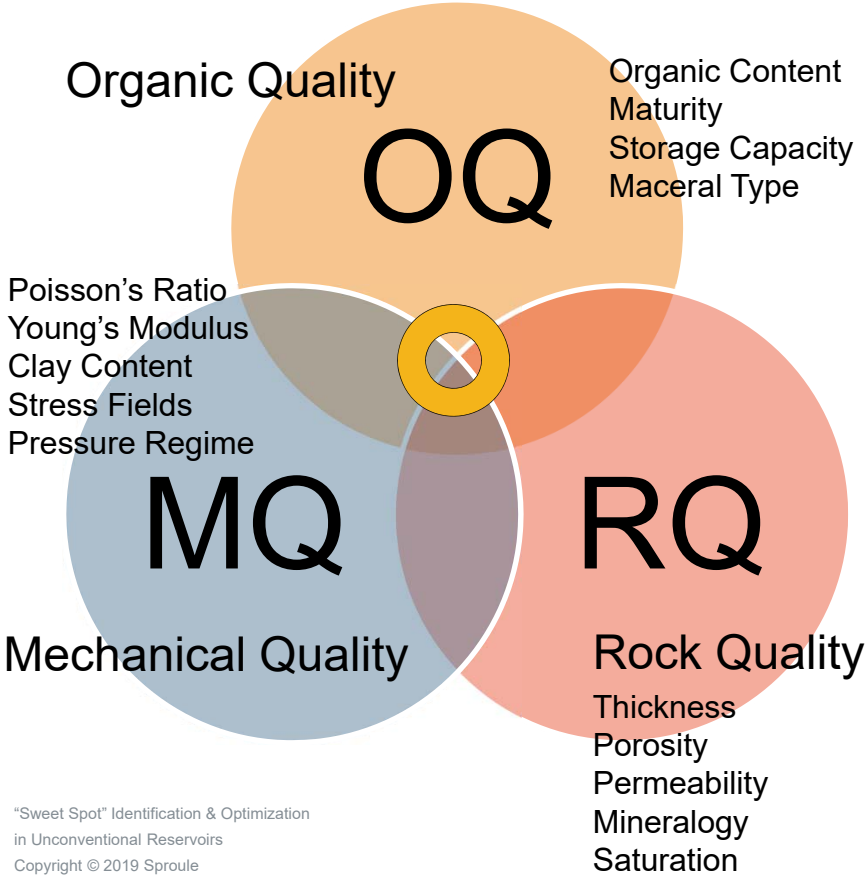
Copyright © 2019 Sproule

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

Copyright © 2019 Sproule

Factors that are needed for Sweet Spot Quantification



Fit for Purpose Operations

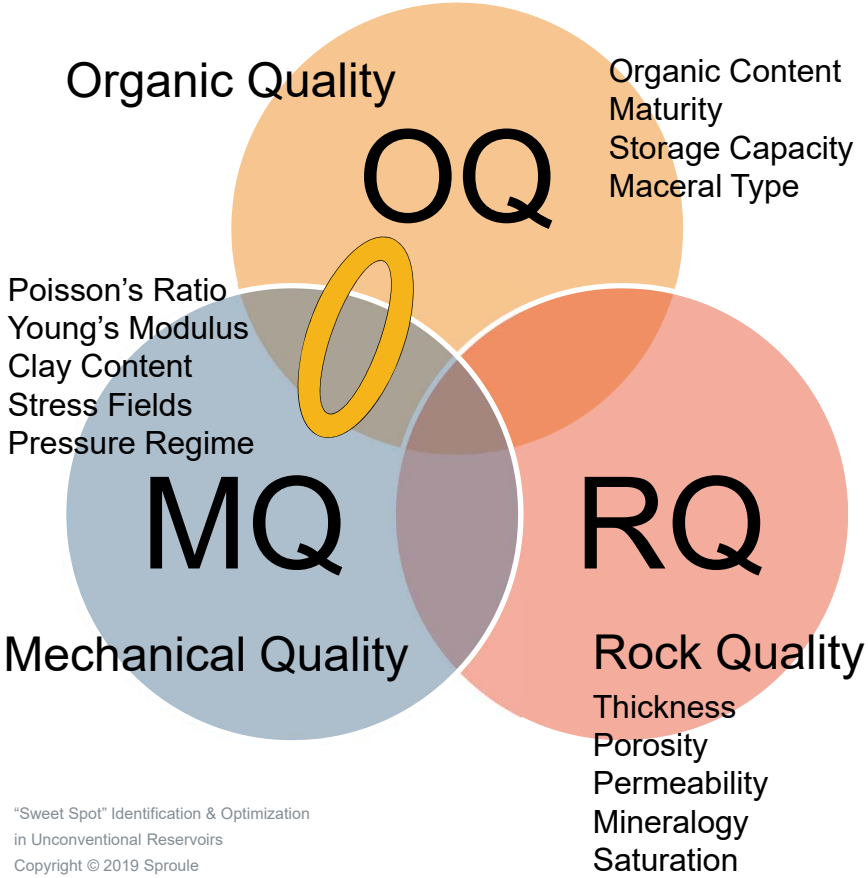
Sufficient Fiscal Environment

Proper Regulations and Environmental Management

When there are the optimum factors from all three Qualities, then the reservoirs will be in the sweet spot.

Copyright © 2019 Sproule

Factors that are needed for Sweet Spot Quantification



Fit for Purpose Operations

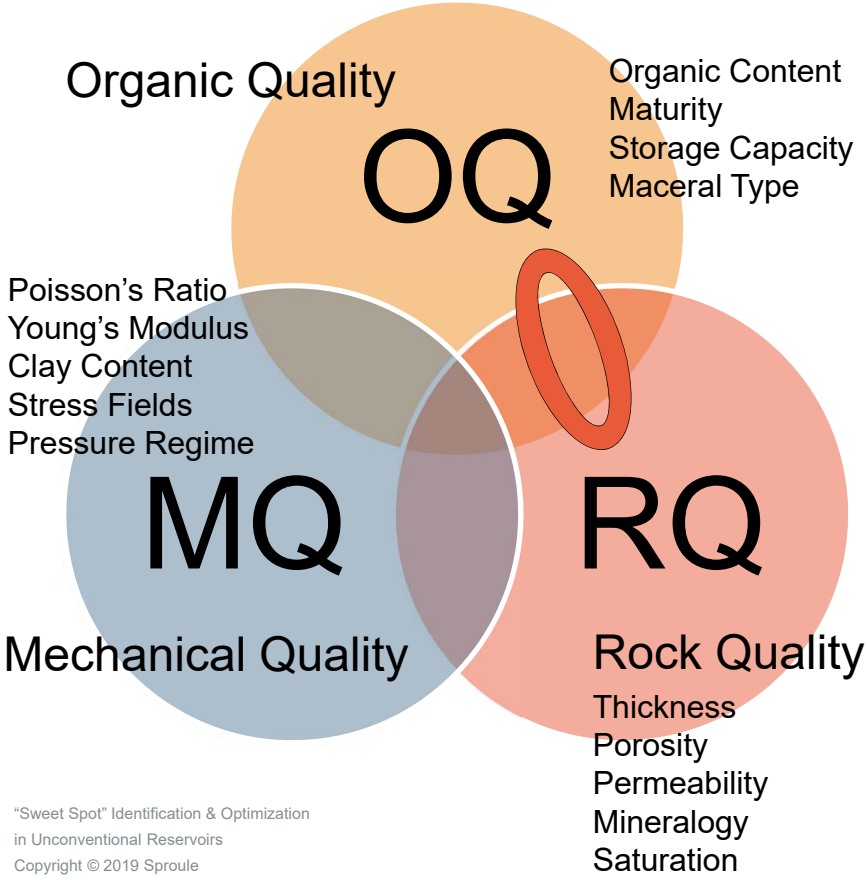
Sufficient Fiscal Environment

Proper Regulations and Environmental Management

With no "RQ" there is HC and the rock can be frac'd, but it is just a source rock

Copyright © 2019 Sproule

Factors that are needed for Sweet Spot Quantification



Fit for Purpose Operations

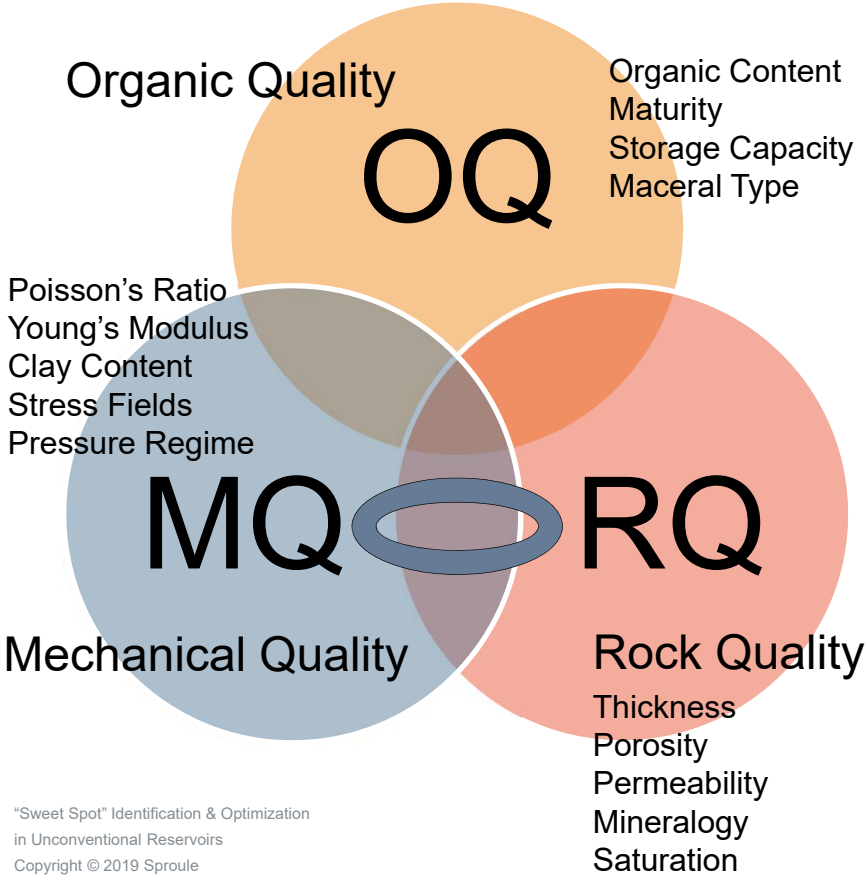
Sufficient Fiscal Environment

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

Copyright © 2019 Sproule

Factors that are needed for Sweet Spot Quantification



Fit for Purpose Operations

Sufficient Fiscal Environment

Proper Regulations and Environmental Management

With no "OC" there is HC and the rock can be frac'd but it is non-productive

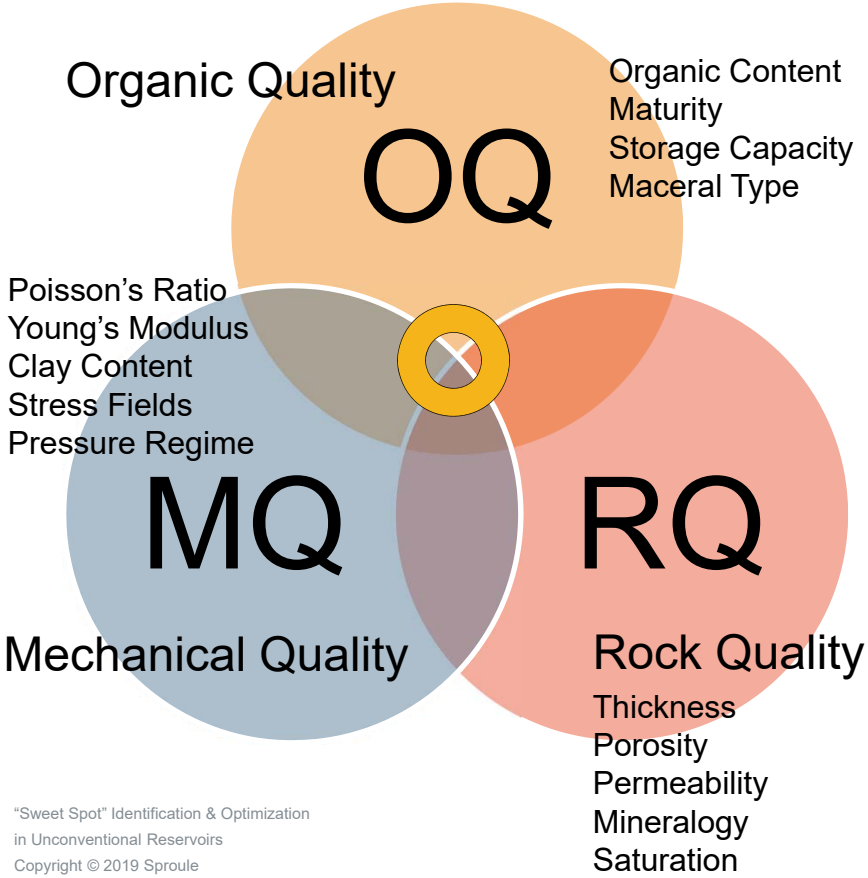
Copyright © 2019 Sproule

What Can Make a Sweet Spot "Sweet"

	Variable	Range for Commercial Shales
OQ	Organic Content	>3% and <12% of correct macerals
	Maturity (Vr_0, Tmax, $CAI_)$	Wet gas or dry gas windows
	Storage Capacity (Langmuir Isotherm, BCF/ac-ft, etc.)	Variable by shale and thickness
RQ	Thickness	>100' and bounded for Frac
	Porosity	>8% - can be much higher
	Permeability	>.001mD – not firm rule
MQ	Clay Content	<40%
	Poisson's Ratio	<.2
	Young's Modulus	>5x10e6
	Pressure	Generally – overpressure is positive

Copyright © 2019 Sproule

Factors that are needed for Sweet Spot Quantification



Fit for Purpose Operations

Sufficient Fiscal Environment

Proper Regulations and Environmental Management

Copyright © 2019 Sproule

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?

Copyright © 2019 Sproule

The Use of the PRMS

- 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.

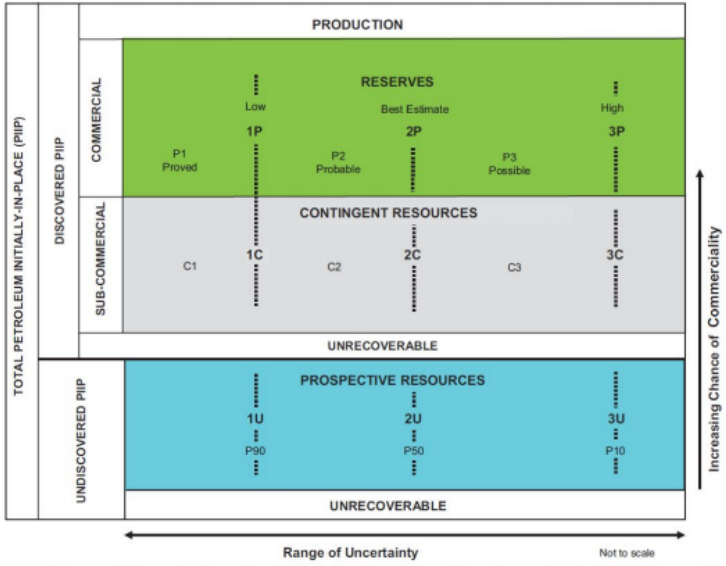


Figure 1.1—Resources classification framework

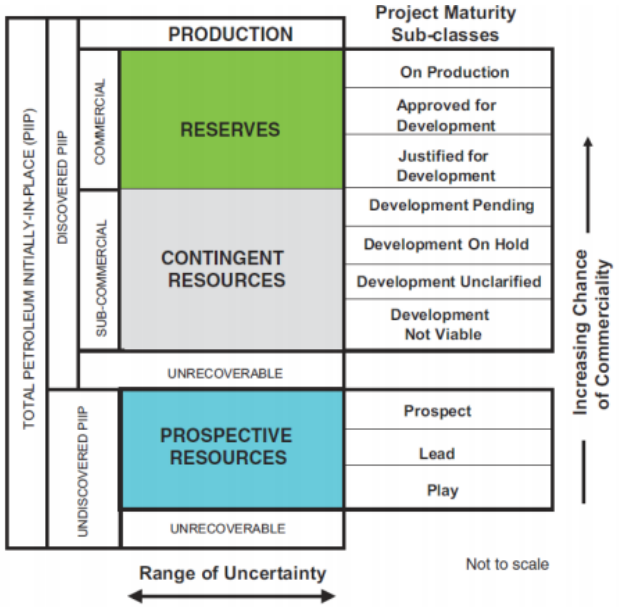


Figure 2.1 – Sub-classes based on project maturity

Copyright © 2019 Sproule

Reserve Definitions for Shales

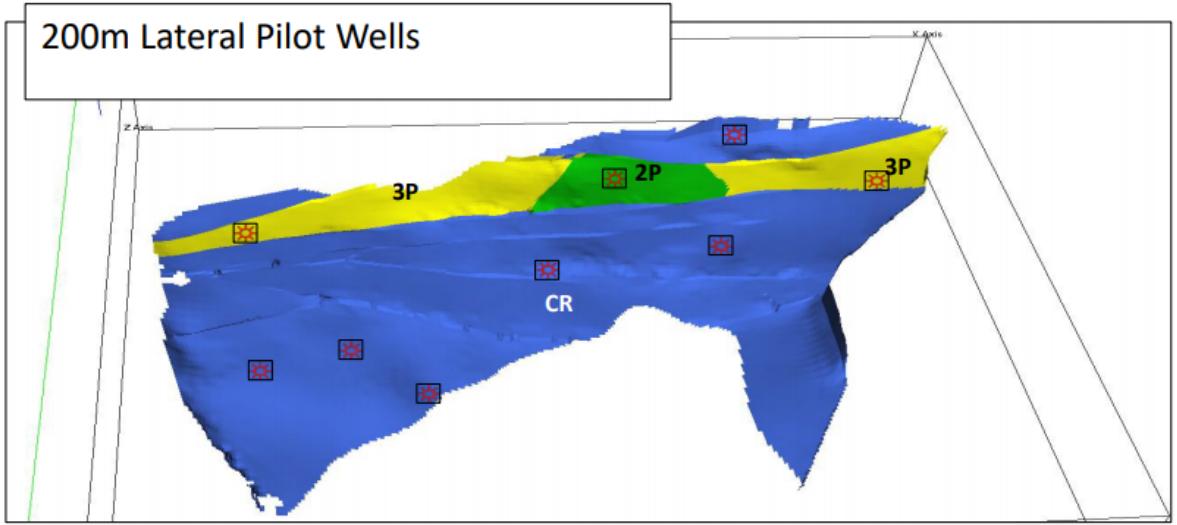
- Normally by decline curve analysis plus economic analysis to meet threshold values.
  - Commercial Rate
  - Commercial Gas Composition
  - Developable Gas Volume
  - Feasible Development Plan (Facilities and Volumes and Rate Align)
  - Reasonable Time Frame
  - Viable Market
  - Existing or Imminent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

Notice that for Conventional – normally a well test will suffice.

Copyright © 2019 Sproule

Using the PRMS

- 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.



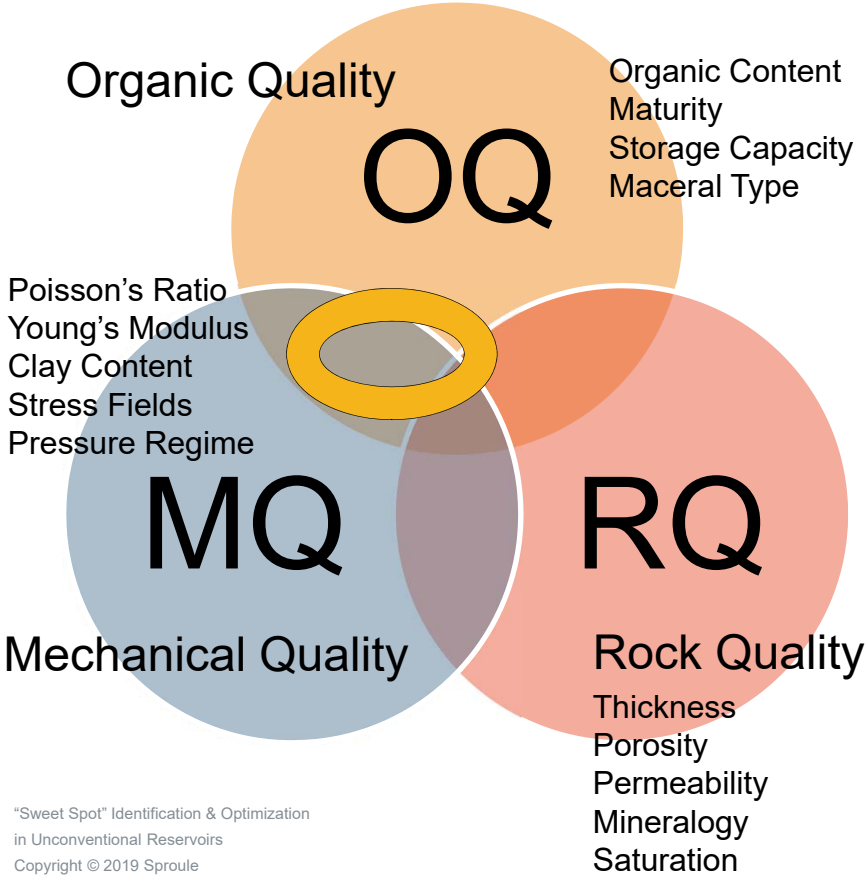
Timothy L. Hower, Jeffrey B. Aldrich, Julianna Sipeki. SPE 168809/URTeC 1581734

Copyright © 2019 Sproule

Examples of External Impacts on Sweet Spot Area from the Niobrara in the DJ Basin, Colorado

Copyright © 2019 Sproule

Effect of Technology



Fit for Purpose Operations

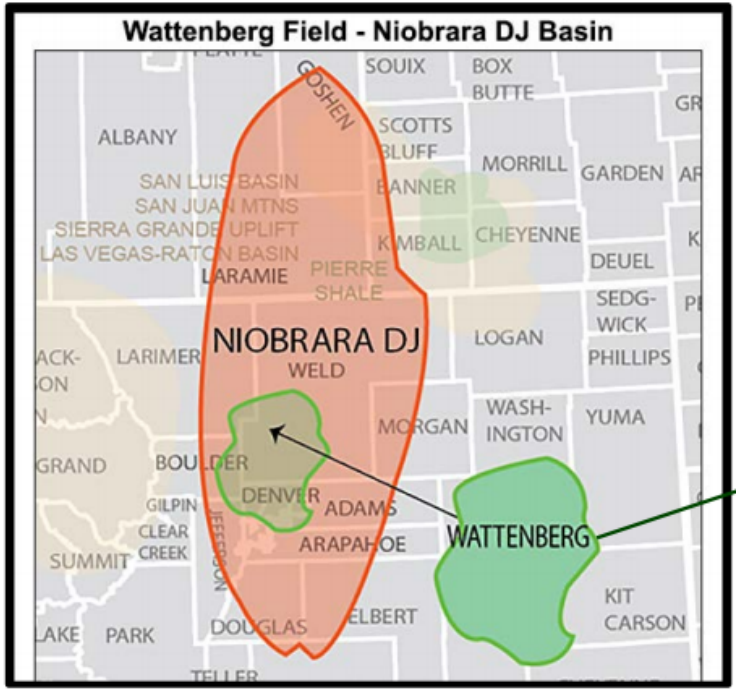
Sufficient Fiscal Environment

Proper Regulations and Environmental Management

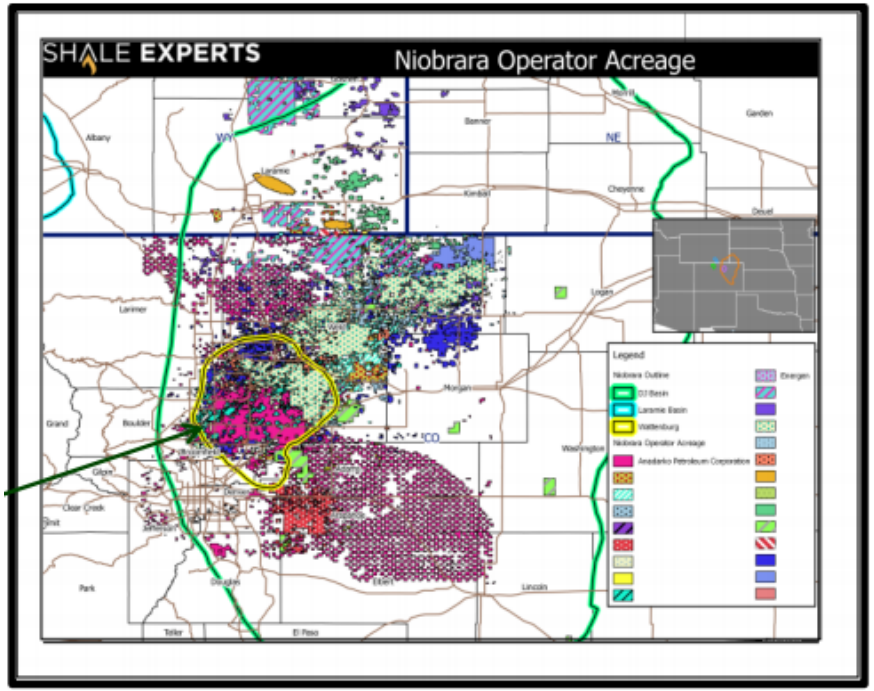
Advent of horizontal wells and MHF opened more rock volume to be a commercial reservoir

Copyright © 2019 Sproule

Effect of Technology



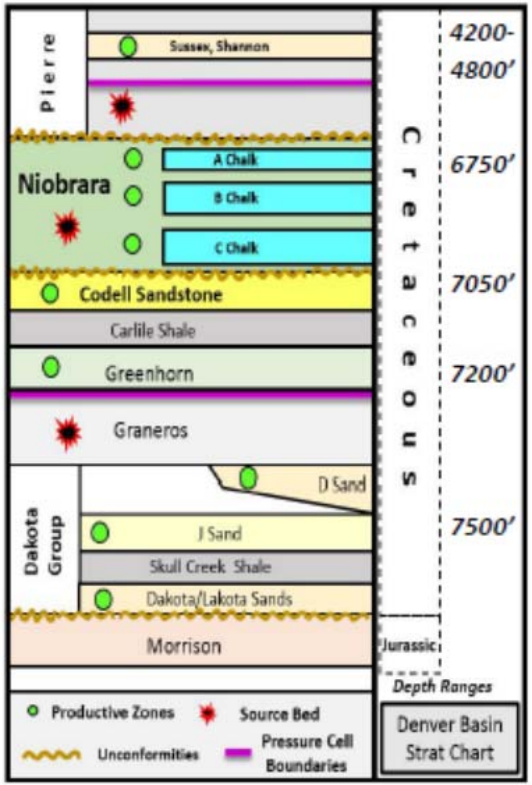
NGI's Map of Shale Resource Plays & North America Pipelines.

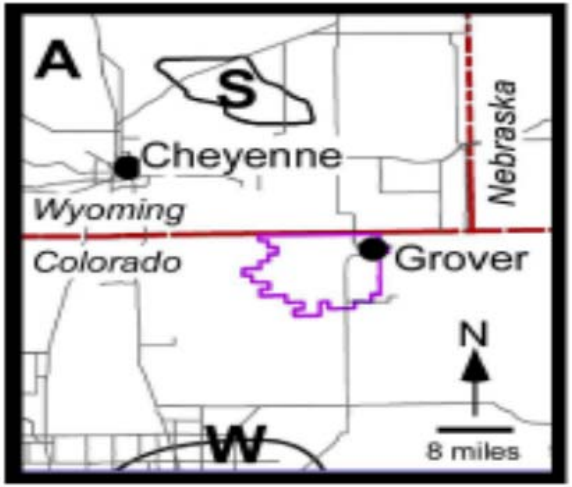


Extent of Niobrara Production in Wattenberg Field in 1970 vs. 2018, vertical vs. MHF in horizontal wells.

Copyright © 2019 Sproule

Effect of Price

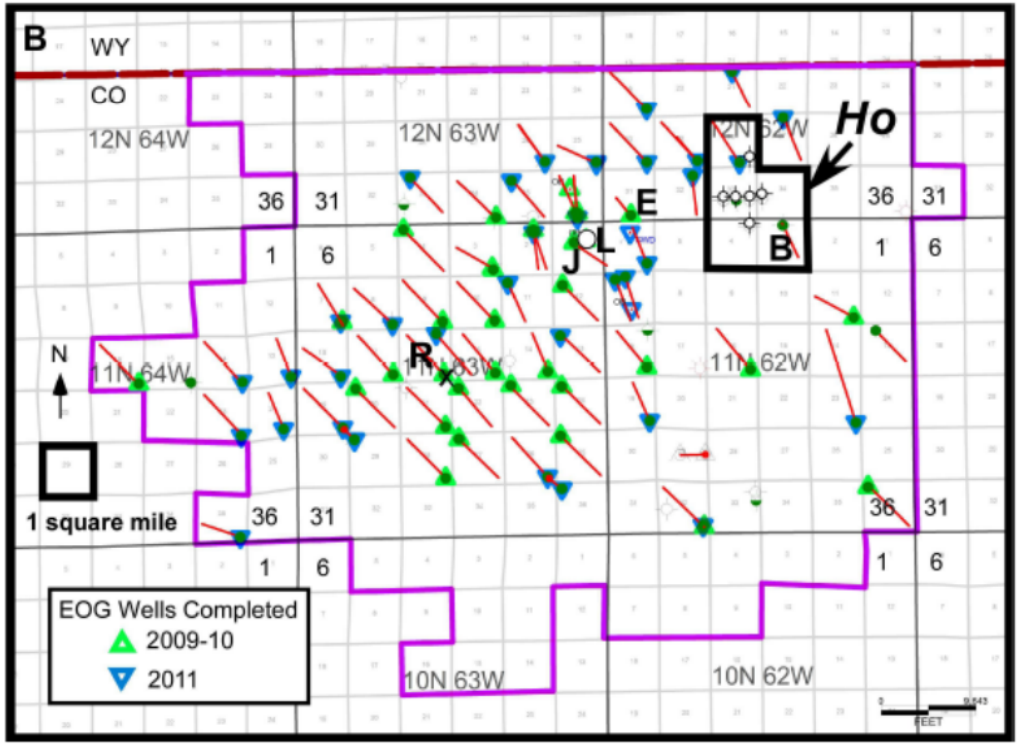




Ref: Anderson, et al, Mountain Geologist, vol. 52, no. 3, July 2015, p 5

Copyright © 2019 Sproule

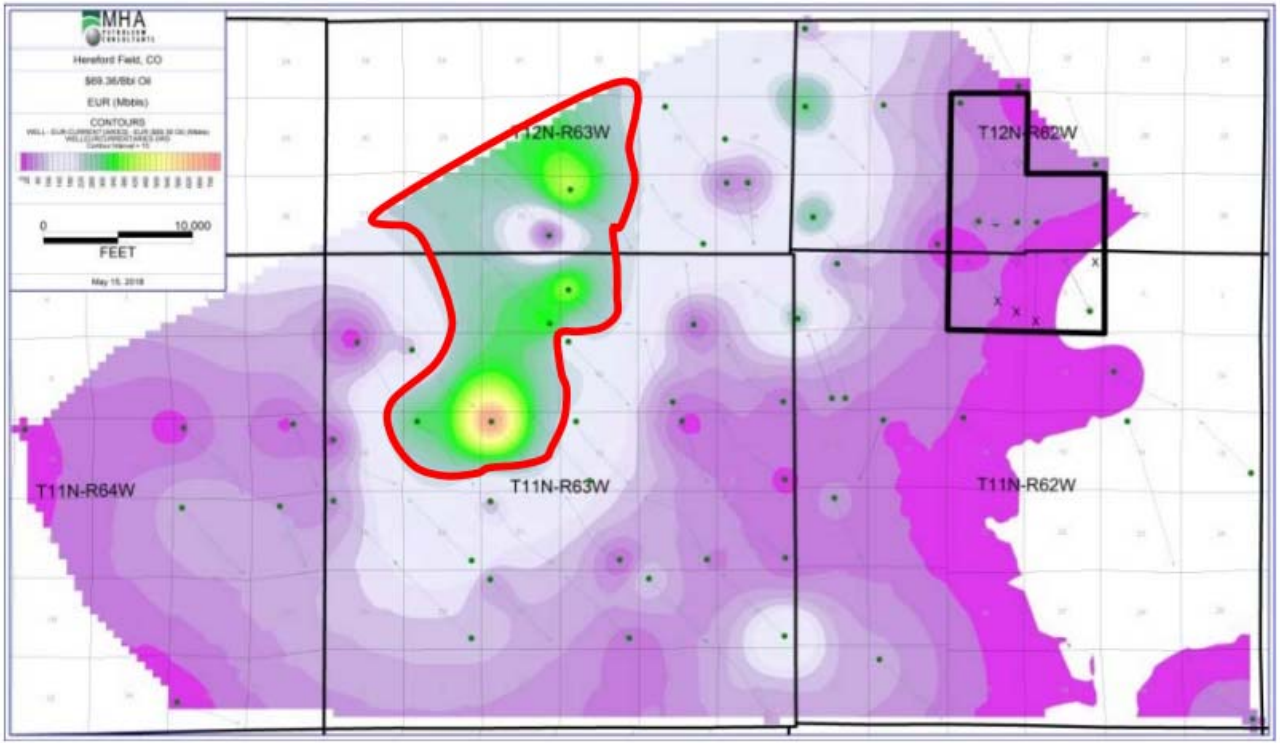
Effect of Price



Map of EOG's original field development

Copyright © 2019 Sproule

Effect of Price

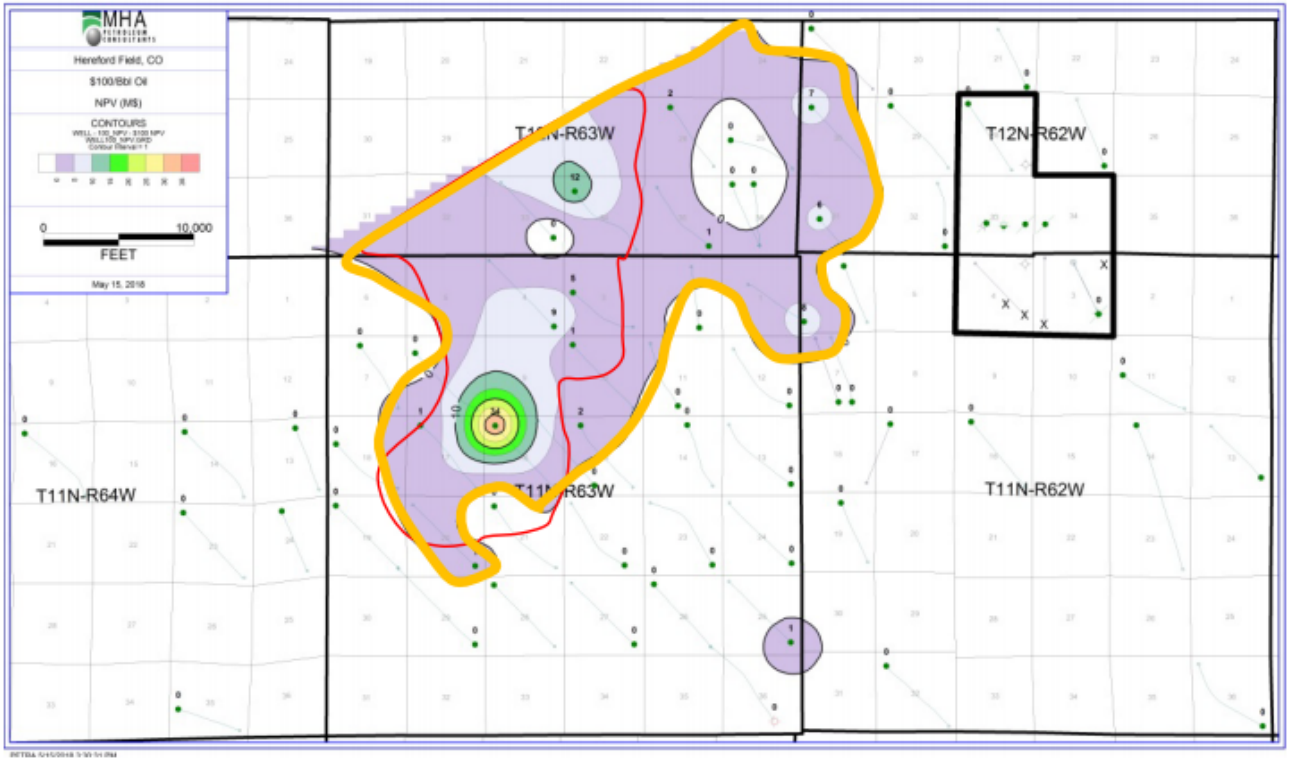


EUR's of the original wells

Sweet Spot based on EUR

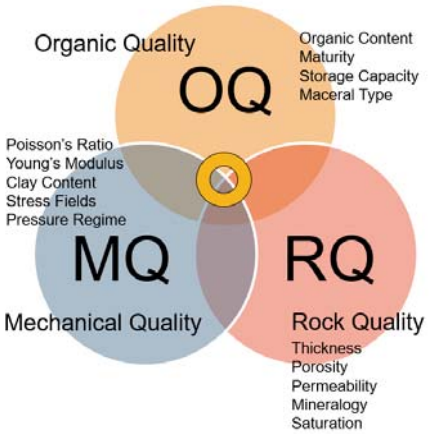
Copyright © 2019 Sproule

Increase in $$ Increases Sweet Spot



Sweet Spot based on $100/Bbl

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



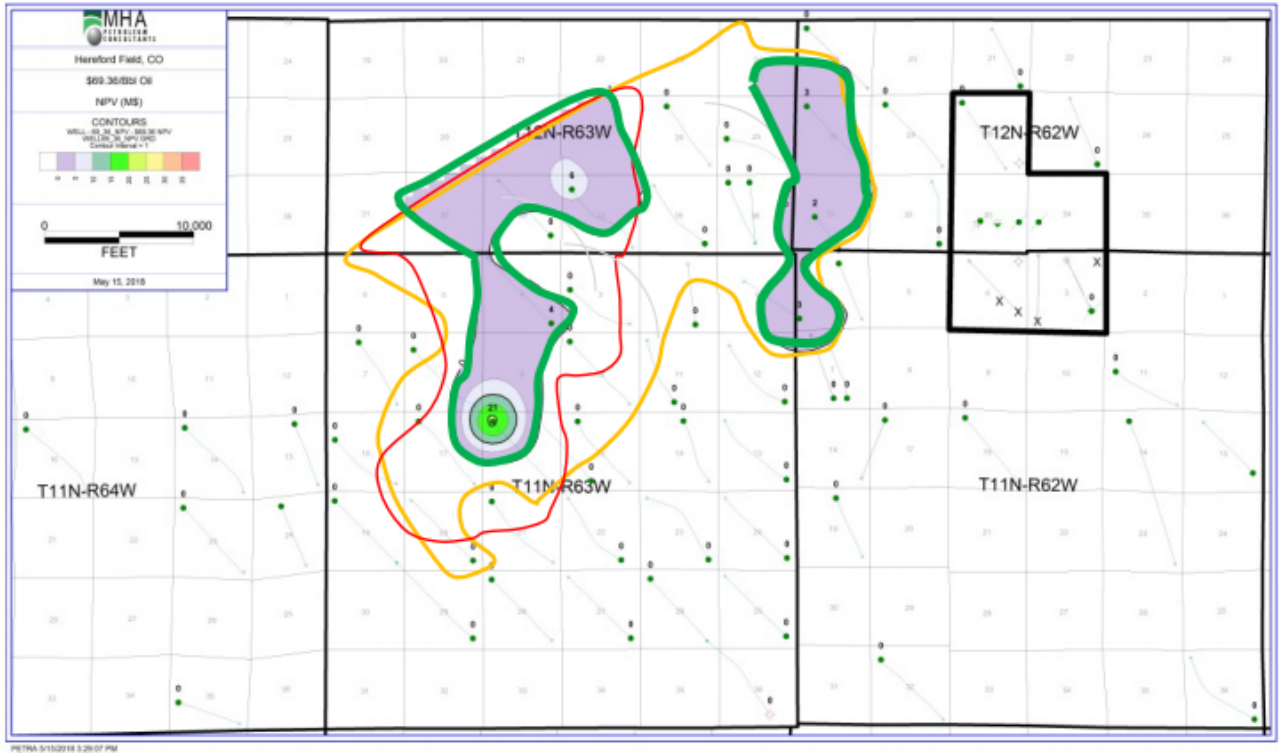
Fit for Purpose Operations

Sufficient Fiscal Environment

Proper Regulations and Environmental Management

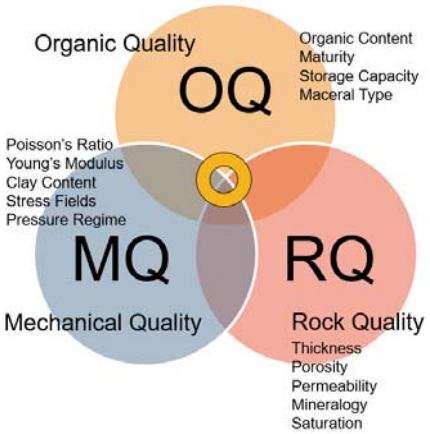
Copyright © 2019 Sproule

Decrease in $$ Decreases Sweet Spot



Sweet Spot based on $69.36/Bbl

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



Fit for Purpose Operations

Sufficient Fiscal Environment

Proper Regulations and Environmental Management

Copyright © 2019 Sproule

Key Take Aways

- 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).

Copyright © 2019 Sproule

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.

Copyright © 2019 Sproule

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.

Copyright © 2019 Sproule

Literature Review

			Organic Quality					Rock Quality				Mechanical Quality						
			TOC	Maturity	Kerogen Type	Storage Capacity	Height	Porosity	Permeability	Saturation	Mineralogy	Mechanical Brittleness		Mineralogical Brittleness	Brittleness	Stress Fields	Pressure	Fractures
												Poisson's Ratio	Young's Modulus	Clay Content				
Sena, et.al.	Seismic Reservoir Characterization in Resource Shale Plays: "Sweet Spot" Discrimination and Optimization of Horizontal Well Placement	SEG 2011 Annual Meeting, San Antonio						X		X	X	X	X			X	X	
Van Hoeve, Meyer, Preusser, Makowitz	Basinwide Delineation of Gas-shale "Sweet Spots" Using Density and Neutron Logs: Implications for Qualitative and Quantitative Assessment of Gas-shale Resources	AAPG Memoir 103: Critical Assessment of Shale Resource Plays, Chapter 9, PP 151-165, 2013					X	X										
Glaser, et. Al.	Seeking the Sweet Spot: Reservoir and Completion Quality in Organic Shales	Olfield Review, Winter 2013/2014 pp16-29	X	X			X	X		X	X	X	X	X	X	X		X
Algarhy, Soliman, Bateman, Asquith	Shale Gas Plays Screening Criteria, "A Sweet Spot Evaluation Methodology"	Fracturing Impacts & Technologies Conference, Texas Tech Univ, 2014	X	X		X	X	X									X	
Brian Toelle	Shale Sweet Spot Detection with Surface Seismic	SPE Distingushed Lecturer Program (2014?)	X	X				X										X
Kormaksson, Vieira, Zadrozny	A Data Driven Method for Sweet Spot Identification in Shale Plays using Well Log Data	SPE-173455-MS, 2015										X	X			X		X
Altamar and Marfurt	Identification of Brittle/Ductile Areas in Unconventional Reservoirs using Seismic and Microseismic Data: Application to the Barnett Shale	SEG Interpretation, Nov, 2015 T233								X				X	X			X
Renfang, Qin, Jie, Jineng	Elements and Gas Enrichment Laws of Sweet Spots in Shale Gas Reservoir: Case Study of the Longmaxi Fm in Changning Block, Sichuan Basin	Natural Gas Industry, B3, 2016, pp 196-201	X	X	X	X	X	X	X		X				X		X	X
Dotsey	Logs Reveal Marcellus Sweet Spots	AOGR, 3-3M, T1, A2	X				X	X										
Naizehen Liu, Guoyang Wang	Shale Gas Sweet Spot Identification and Precise Geo-steering drilling in Weiyuan Block of Sichuan Basin, SW China	Petroleum Exploration and Development V43, Is 6, Dec 2016	X				X	X	X						X			X
Chopram Sharma, Nemati and Keay	Organically Rich Sweet Spot Determination in Utica Shale	Search and Discovery, Article #42137, 2017	X					X							X			
Tahmasebi, Javadpour, Sahimi	Data Mining and Machine Learning for Identifying Sweet Spots in Shale Reservoirs	Expert Systems with Applications, Vol 88, Issue C, Dec 2017, pp 435-447.	X												X			

Contact us

Jeffrey B. Aldrich
jaldrich@mhausa.com

Dr. John Seidle
jseidle@mhausa.com

Corporate Headquarters
140 Fourth Avenue SW, Suite 900
Calgary, AB, Canada T2P 3N3

T +1 403 294 5500
TF +1 877 777 6135

Brazil
Rio de Janeiro, RJ, Brazil
T+55 212 014 5134

Netherlands
The Hague, Netherlands
T +31 6 4862 6450

Denver
730 Seventeenth Street, Suite 410
Denver, CO, USA 80202
T +1 303 277 0270

Bakersfield
4700 Stockdale Highway, Suite 110
Bakersfield, CA, USA 93309
T +1 661 325 0038

Mexico
Mexico City, Mexico
T +52 55 5202 3600

Copyright © 2019 Sproule

Disclaimer

This material is private. It does not take into account any specific business objectives of the recipient. The information herein does not constitute advice, nor an offer to buy or sell instruments, products or services. Dealing in commodities, financial instruments, derivatives or other products involves risk. The recipient of this material should not deal in these products unless it understands their nature and its exposure. It should seek independent advice before making any investment or other decision. While every effort has been made to ensure the information herein is accurate, its accuracy cannot be guaranteed. The author accepts no liability for any damages (including, but not limited to, lost profits) arising from reliance upon this material. Unauthorized copying of this material is strictly prohibited without the prior written consent of the author

This presentation contains forward-looking information and statements (collectively, "forward-looking statements") within the meaning of applicable Canadian securities legislation, concerning the outlook of commodity prices and the potential impact these could have on industry netbacks. Forward-looking statements include, but are not limited to, statements with respect to the estimation of commodity prices, permitting time lines, currency exchange rate fluctuations, government regulation of oil and gas exploration and development activities, environmental risks, and judicial ruling. Generally, these forward-looking statements can be identified by the use of forward-looking terminology such as "plans", "expects" or "does not expect", "is expected", "budget", "scheduled", "estimates", "forecasts", "intends", "anticipates" or "does not anticipate", or "believes", or variations of such words and phrases or state that certain actions, events or results "may", "could", "would", "might" or "will be taken", "occur" or "be achieved" or the negative connotations thereof. All such forward-looking statements are based on the opinions and estimates of the relevant management as of the date such statements are made and are subject to important risk factors and uncertainties, many of which are beyond the Corporation's ability to control or predict.

Copyright © 2019 Sproule