PS"Sweet Spot" Identification and Optimization in Unconventional Reservoirs*

Jeffrey B. Aldrich[1] and John P. Seidle[1]

Search and Discovery Article #80644 (2018)**
Posted August 27, 2018

*Adapted from poster presentation given at AAPG 2018 AAPG Annual Convention and Exhibition, Salt Lake City, Utah, May 20-23, 2018

[1]MHA Petroleum Consultants, Denver, CO, United States (jaldrich@mhausa.com)

Abstract

Correct identification of area or zone of maximum commercial productivity, or the "sweet spot" for unconventional reservoirs requires a thorough understanding of three different reservoir Quality factors: Organic Quality (OQ), Rock Quality (RQ), and Mechanical Quality (MQ). Each of these factors has several individual components that must be measured and quantified. OQ is comprised of the type and maturity of the organic material and the current storage capacity of the organics. RQ, the traditional properties of conventional reservoirs, is the thickness, porosity, permeability, saturation plus mineralogy. MQ is both brittleness and stiffness (which have various indices) and measurements of the stress fields and pressure regimes.

The "sweet spot" is the intersection of these Qualities for the optimum production under a set of foundational conditions. These foundational conditions are 1) Proper regulations and environmental management, 2) Sufficient fiscal environment, and 3) Fit for purpose operations.

Many previous attempts of "Sweet Spot" classification have only focused on reservoir parameters and have not included necessary economic and operational factors. Unconventional reservoirs are a complex interplay between twenty reservoir variables, fourteen completion variables, and five to ten economic and environmental variables. Proper field management requires optimization, in four dimensional space, of all variables.

References Cited

Altamar, R.P., and K.J. Marfurt, 2015, Identification of Brittle/Ductile Areas in Unconventional Reservoirs Using Seismic and Microseismic Data: Application to the Barnett Shale: SEG Interpretation, v. 3/4, p. T233-243.

Alzahabi, A., A. Algarhy, M. Soliman, R. Bateman, and G. Asquith, 2014, Shale Gas Plays Screening Criteria, "A Sweet Spot Evaluation Methodology": Fracturing Impacts and Technologies Conference, Texas Tech, Lubbock, TX. doi:10.13140/2.1.1580.8960

Anderson, D.S., J.L. Folcik, and J.H. Melby, 2015, A Short History of the “Jake” Niobrara Horizontal Oil Discovery, Weld County, Colorado: Mountain Geologist, v. 52/3, p 5-12.

Chopra, S., R.K. Sharma, H. Nemati, and J. Keay, 2017, Organically Rich Sweet Spot Determination in Utica Shale: AAPG Explorer, September, 2017, Search and Discovery Article #42137 (2017). Website accessed July 2018.

Chorn, L., J. Yarus, S. del Rosario-Davis, and J. Pitcher, 2013, Identification of Shale Sweet Spots Using Key Property Estimates from Log Analysis and Geostatistics: Unconventional Resources Technology Conference, 12-14 August 2013, Denver, CO, URTEC 1580188-MS.

Dotsey, P., no date, Logs Reveal Marcellus Sweet Spots: AOGR, 3-3M, T1, A2, 4 p.

Ghanizadeh, A., B. Rashidi, C. Clarkson, A. Vahedian, C.P. Vocke, and A.R. Ghanizadeh, 2017, Indirect Estimation of Fluid Transport and Rock Mechanical Properties from Elemental Compositions: Implications for "Sweet Spot" Identification in the Montney Formation (Canada): Unconventional resources Technology Conference, URTEC 2670893-MS.

Glaser, K.S., G.M. Johnson, B. Toelle, R.L. Kleinberg, P. Miller, and W.D. Pennington, 2014, Seeking the Sweet Spot: Reservoir and Completion Quality in Organic Shales: Oilfield Review, 2013-2014, v. 25/4, p. 16-29.

Hower, T.L., J.B. Aldrich, and J. Sipeki, 2013, Assessing and Advancing a CBM Resource Play Towards Commerciality - A Case Study from the UK: Unconventional Resources Technology Conference, 12-14 August, Denver, CO, URTEC 1581734-MS, 9 p.

Kormaksson, M., M.R. Vieira, and B. Zadrozny, 2015, A Data Driven Method for Sweet Spot Identification in Shale Plays Using Well Log Data: SPE Digital Energy Conference and Exhibition, 3-5 March 2015, The Woodlands, TX, SPE-173455-MS, 9 p.

Liao, X., A. Rolph, B. Gui, D. Mueller, S. Antipenko, and J. Zhou, 2014, Sweet Spots Identification in a BCG Play in Sichuan Basin China: International Petroleum Technology Conference, 19-22 January 2014, Doha, Qatar, IPTC-17276-MS, 14 p.

Licitra, D., F. Vittore, J.R. Quiroga, L. Monti, E. Lovrincevich, P. Oviedo, V. Montoya, and C. Shannon, 2015, Sweet Spots in Vaca Muerta: Integration of Subsurface and Production Data in Loma Campana Shale Development, Argentina: Unconventional Resources Technology Conference, San Antonio, Texas, 20-22 July 2015, URTEC 2153944-MS, p. 1953-1970.

Liu, N., and G. Wang, 2016, Shale Gas Sweet Spot Identification and Precise Geo-Steering Drilling in Weiyuan Block of Sichuan Basin, SW China: Petroleum Exploration and Development, v. 43/6, p. 1067-1075.

Petroleum Resources Management System, 2007, 47 p.

Pan, R., Q. Gong, J. Yan, and J. Jin, 2016, Elements and Gas Enrichment Laws of Sweet Spots in Shale Gas Reservoir: Case Study of the Longmaxi Formation in Changning Block, Sichuan Basin: Natural Gas Industry B, v. 3/3, p. 195-201.

Sahoo, A.K., D. Mukherjee, A. Mukherjee, and M. Srivastava, 2013, Reservoir Characterization of Eagle Ford Shale through Lithofacies Analysis for Identification of Sweet Spot and Best Landing Point: Unconventional Resources Technology Conference. Denver, Colorado. SPE-168677-MS.

Sena, A., G. Castillo, K. Chesser, S. Voisey, J. Estrada, J. Carcuz, E. Carmona, and P. Hodgkins, 2011, Seismic Reservoir Characterization in Resource Shale Plays: "Sweet Spot" Discrimination and Optimization of Horizontal Well Placement: SEG 2011 Annual Meeting, San Antonio, TX, 4 p.

Sharma, R.K., and S. Chopra, 2015, Identification of Thin Sweet Spots in the Duvernay Formation of North Central Alberta: 2015 SEG Annual Meeting, New Orleans, LA, p. 1802-1806.

Tahmasebi, P., F. Javadpour, and M. Sahimi, 2017, Data Mining and Machine Learning for Identifying Sweet Spots in Shale Reservoirs: Expert Systems with Applications, v. 88/C, p. 435-447.

Tinnin, B., H. Bello, and M. McChesney, 2016, Multi-Source Data Integration: Eagle Ford Shale Sweet Spot Mapping: International Conference and Exhibition, Barcelona, Spain, 3-6 April 2016, URTEC 2154534, p. 347-348.

Toelle, B., 2014, Shale Sweet Spot Detection with Surface Seismic: SPE Distinguished Lecturer Program.

Ver Hoeve, M., C. Meyer, J. Preusser, and A. Makowitz, 2013, Basinwide Delineation of Gas-Shale "Sweet Spots" Using Density and Neutron Logs: Implications for Qualitative and Quantitative Assessment of Gas-Shale Resources. American Association of Petroleum Geologists Memoir 103: Critical Assessment of Shale Resource Plays, Chapter 9, p. 151-165.

Yang, X., X. Wang, A. Aoues, and A. Ouenes, 2015, Sweet Spot Identification and Prediction of Frac Stage Performance Using Geology, Geophysics, and Geomechanics - Application to the Longmaxi Formation, China: SPE Asia Pacific Unconventional Resources Conference and Exhibition, Brisbane, Australia, 9–11 November 2015, SPE-176931-MS, 15 p.

Yu, G., Y. Zhang, X. Wang, W. Liu, R. Guo, X. Liang, U. Strecker, and M. Smith, 2017, Shale Gas Reservoir Characterization and Sweet Spot Prediction: SEG International Exposition and 87th Annual Meeting, SEG Technical Program Expanded Abstracts, p. 3174-3178.

2856955 **"Sweet Spot" Identification and Optimization in Unconventional Reservoirs**

Jeff Aldrich & John Seidle
MHA Petroleum Consultants

Abstract

The term "Sweet Spot" is often used to describe the area of a play, or a license, that will produce the highest rate of return under the currently employed technology. This definition, itself, combines the disciplines of economics, completion technology and reservoir description; disciplines that traditionally have not worked seamlessly together in oil and gas fields. We define the optimum area for field development in unconventional fields as the intersection of three clear quality factors, Organic Quality (OQ), Rock Quality (RQ) and Mechanical Quality (MQ) that each are composed of several key characteristics. As the reservoir changes and decreases in the quality of any one factor the "Sweet Spot" will shrink and changes must be made to what we identify as the "Fit for Purpose Operations". This alignment of the Operations with the Reservoir can enlarge the "Sweet Spot" thus increasing the area available for development or the profitability.

There are two additional considerations that are made to the baseline equation, that of the fiscal environment, of which the price of the product is usually not within the operators control, and the regulatory and HSE environment which must be proactively maintained. A large part of all unconventional plays, and staying in the "Sweet Spot" is correctly managing and aligning the surface issues of regulation, HSE, and fiscal environment with fit for purpose operations aligned with sub-surface heterogeneities.

The model presented here is designed to keep all disciplines aligned on both a long-term commercial goal and have the ability to rapidly adapt to changes, either in the sub-surface reservoir or in various surface conditions, all which influence the size of the "Sweet Spot".

Previous Work

Many attempts have been made by various means to identify "sweet spots" in unconventional reservoirs. This poster focuses on papers that are limited to gas and liquids production from ultra-low permeability, organic and clay rich rocks; commonly known as "shale gas" or "shale oil" reservoirs. The authors have reviewed previous work from the geoscience, reservoir engineering, data analytics and petroleum engineering disciplines. In general, two distinct approaches exist for delineation of a "sweet spot", the first being primarily a geoscience and data analytic method of sub-surface evaluation (3D seismic, well logs, cores) to identify key reservoir parameters, see below, that have a major controlling influence on production and then to use this knowledge to predict, **PRE-DRILL**, the location of better reservoir rock. The second approach focuses on interpretation of test and production data to identify the best area within the field area for optimization of hydrocarbon recovery, thus this work is primarily a **POST-DRILL** approach.

At least eighteen individual reservoir parameters have been identified in the literature as having significant control on production in at least one commercial shale basin and none of the papers attempted to quantify all of the parameters. The eighteen parameters fall into three broad categories that categorize the reservoir by: various organic rock properties (Total Organic Carbon [TOC], maturity of the organics, the type of the organics, and the storage capacity of the organics), by the various standard rock properties (thickness, porosity, permeability, hydrocarbon saturation, mineralogy), and by various mechanical rock properties (mechanical brittleness as defined by Poisson's Ratio and Young's Modulus, mineralogical brittleness as defined by %Clay, the earth's stress fields, various pressure functions (overpressure, fracture initiation pressure, fracture closure pressure), and natural fractures) Figure 1.

Methods to quantify the "Sweet Spots" involve the use of 3D seismic data (Sena, et. al.; Toelle; Altamar & Marfurt), electric logs (Van Hoeve, et. al.; Glaser, et. al.; Dotsey; Chopram, et. al.), big data – data mining (Kormaksson, et. al.; Tahmasebi, et. al.), and integration of multiple datasets (Algarhy, et. al.; Renfang, et. al.; Liu and Wang). Methods which linked selected geoscience data to production for sweet spot prediction varied from a high of 12 parameters, (Glaser et. al.), to a low of only 2 parameters (Van Hoeve, et. al., and Tahmasebi, et. al.); although they used completely separate parameters. Shales reviewed for this study included the Barnett Shale of the Fort Worth Basin, the Eagle Ford and Haynesville of the Texas Gulf Coast Basin, the Marcellus and Utica of the Appalachian Basin, the Longmaxi of the Sichuan Basin, the Wolfcamp of the Permian Basin, the Woodford of the Arkoma Basin, the Bakken of the Williston Basin, Horn River, Montney, and Duvernay of the Western Canadian Sedimentary Basin, the Vaca Muerta of Argentina and several others mentioned in passing.

The common theme in all of the cited research is to find a methodology that will tie some limited set of sub-surface reservoir parameters to the identification of an area of the field that has the highest maximum productivity, yet this productivity is usually left unscaled or the quantification of the high productivity area is scaled relative to the whole of the reservoir. None of the papers truly define or quantify what a "sweet spot" is, they only describe methodologies to high-grade areas of the reservoir, that is find areas of the reservoir that are more likely than not to produce at a higher rate and/or for a longer time than other areas of the reservoir.

Summary of Previous Authors Productivity Factors (PF) for Sweet Spots

				Organic Quality					Rock Quality					Mechanical Quality							
Authors	Title	Shale\Basin	Refernce	TOC	Maturity	Kerogen Type	Storage Capacity	Thickness	Porosity	Permeability	Density	Saturation	Mineralogy	Mechanical Brittleness		Mineralogical Brittleness	Brittleness	UCS	Stress Fields	Pressure	Fractures
														Poisson's Ratio	Young's Modulus	Clay Content					
Algarhy, Soliman, Bateman, Asquith	Shale Gas Plays Screening Criteria, "A Sweet Spot Evaluation Methodology"	Barnett; Ohio; Antrim; New Albany; Lewis; Fayetteville; Haynesville; Egleford; Marcellus; Woodford; Bakken; Horn River	Fracturing Impacts & Technologies Conference, Texas Tech Univ, 2014	X	X		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	Barnett \ Ft. Worth	SEG Interpretation, Nov, 2015 T233									X				X	X				X
Brian Toelle	Shale Sweet Spot Detection with Surface Seismic	Marcellus - Utica\ Appalachian	SPE Distingushed Lecturer Program (2014?)	X	X				X												X
Chopram Sharma, Nemati and Keay	Organically Rich Sweet Spot Determination in Utica Shale	Utica	Search and Discovery, Article #42137, 2017	X					X								X				
Chorn, et. al.	Indentification of Shale Sweet Spots Using Key Property Esimates from Log Analysis and Geostatistics	Barnett \ Ft. Worth	URTeC: 1580188	X	X			X				X			X					X	
Dotsey	Logs Reveal Marcellus Sweet Spots	Marcellus \ Appalachian	AOGR, 3-3M, T1, A2	X				X	X												
Ghanizadeh, et. al.	Indirect Estimation of Fluid Transport and Rock Mechanical Properties from Eleemental Compositions: Implications for "Sweet Spot" Identification in the Montney Formation (Canada)	Montney	URTeC:2670893		X				X	X	X		X	X	X			X			
Glaser, et. Al.	Seeking the Sweet Spot: Reservoir and Completion Quality in Organic Shales	Woodford,; Bakken; Haynesville; Wolfcamp; Eagle Ford	Olfield Review, Winter 2013/2014 pp16-29	X	X			X	X			X	X	X	X	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
Licitra, et. al.	Sweet Spots in Vaca Muerta: Integration of Subsurface and Production Data in Loma Campana Shale Development, Argentina	Vaca Muerta	URTeC:2153944	x	x			x					x				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	Longmaxi\ Sichuan	Petroleum Exploration and Development V43, Is 6, Dec 2016	X				X	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	Longmaxi\ Sichuan	Natural Gas Industry, B3, 2016, pp 196-201	X	X	X	X	X	X	X			X				X			X	X
Sahoo, et. al.	Reservoir Characterization of Eagle Ford Shale through Lithofacies Analysis for Identifcation of Sweet Spot and Best Landing Point	Eagle Ford	SPE 168677	X					X				X			X				X	
Sena, et.al.	Seismic Reservoir Characterization in Resource Shale Plays: "Sweet Spot" Discrimination and Optimization of Horizontal Well Placement	Haynesville	SEG 2011 Annual Meeting, San Antonio						X			X	X	X	X				X	X	
Sharma & Chopra	Indentification of Thin Sweet Spots in the Duvernay Formation of North Central Alberta	Duvernay\Western Cananadian Basin	2015 SEG Annual Meeting	X	X		X	X		X	X	X	X	X	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				
Tinnin, et.al.	Multi-Source Data Integration: Eagle Ford Shale Sweet Spot Mapping	Eagle Ford	URTeC:2154534	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	Haynesville; Eagle Ford; Marcellus	AAPG Memoir 103: Critical Assessment of Shale Resource Plays, Chapter 9, PP 151-165, 2013					X	X												
Yang, et. al.	Sweet Spot Indentification and Prediction of Frac Stage Performance Using Geology, Geophysics and Geomechanics - Application to the Longmaxi Formation, China	Longmaxi\ Sichuan	SPE-176931-MS						X						X						X

Figure 1:Work by previous authors can be subdivided into Shale Productivity Factors (PF) that affect hydrocarbon generation capacity (Organic Quality or OQ), hydrocarbon storage capacity (Rock Quality or RQ) and the ability to place and sustain stimulation (Mechanical Quality or MQ). This work covers multiple USA and International basins and there is not a consistent agreement on what factors or methods should be used.

“Sweet Spot” Identification and Optimization in Unconventional Reservoirs

Jeff Aldrich & John Seidle
MHA Petroleum Consultants

The Difference Between Conventional and Unconventional Reservoirs

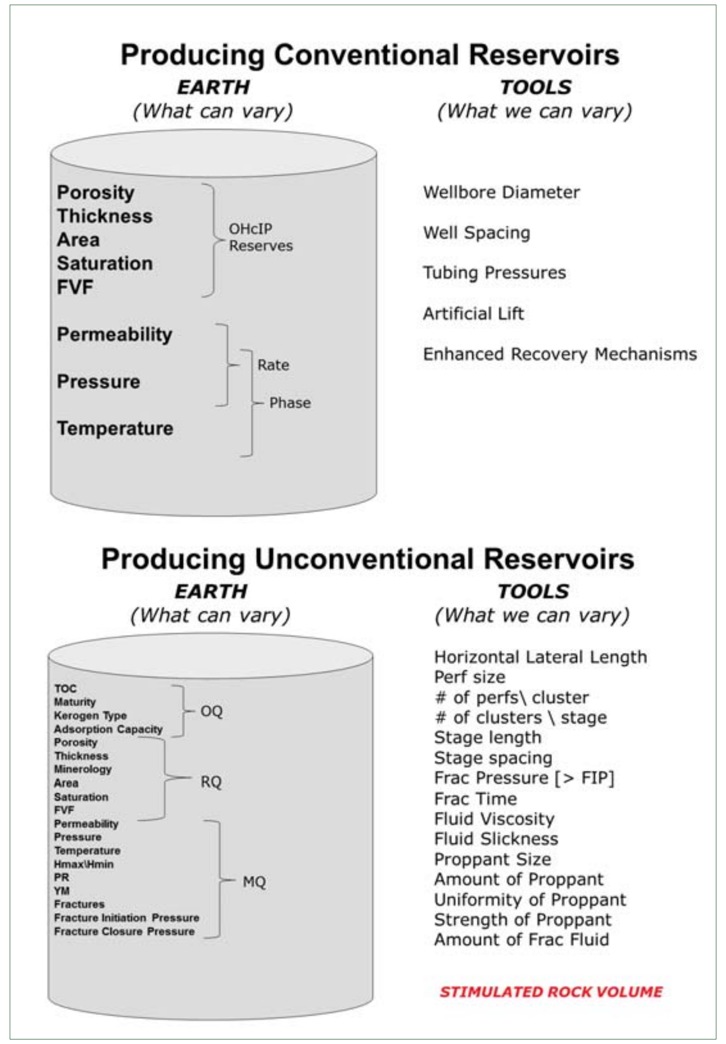


Figure 2

What Can Make a Sweet Spot “Sweet”?

Not Hard Rules – But Guidelines

	Variable	Range for Commercial Shales
OQ	Organic Content	>3% and <12% of correct macerals
	Maturity (Vr_o, 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

Figure 3

Sub-surface Factors that are needed for Sweet Spot Quantification

As shown by the work of the previous authors there are multiple methods attempted to quantify sweet spots and not all methods appear to work in all basins or reservoirs. It is important to recognize that the sub-surface factors can be grouped into classes that define the ability to generate the hydrocarbons (Organic Quality or OQ), to store the hydrocarbons (Rock Quality or RQ) and to be able to take and sustain stimulation (Mechanical Quality or MQ). Often one or two factors from each of these three Quality Classes will end up controlling production and methods that can quantify those parameters, in that basin are often successful in creating a relative productivity factor (PF) or sweet spot indicator.

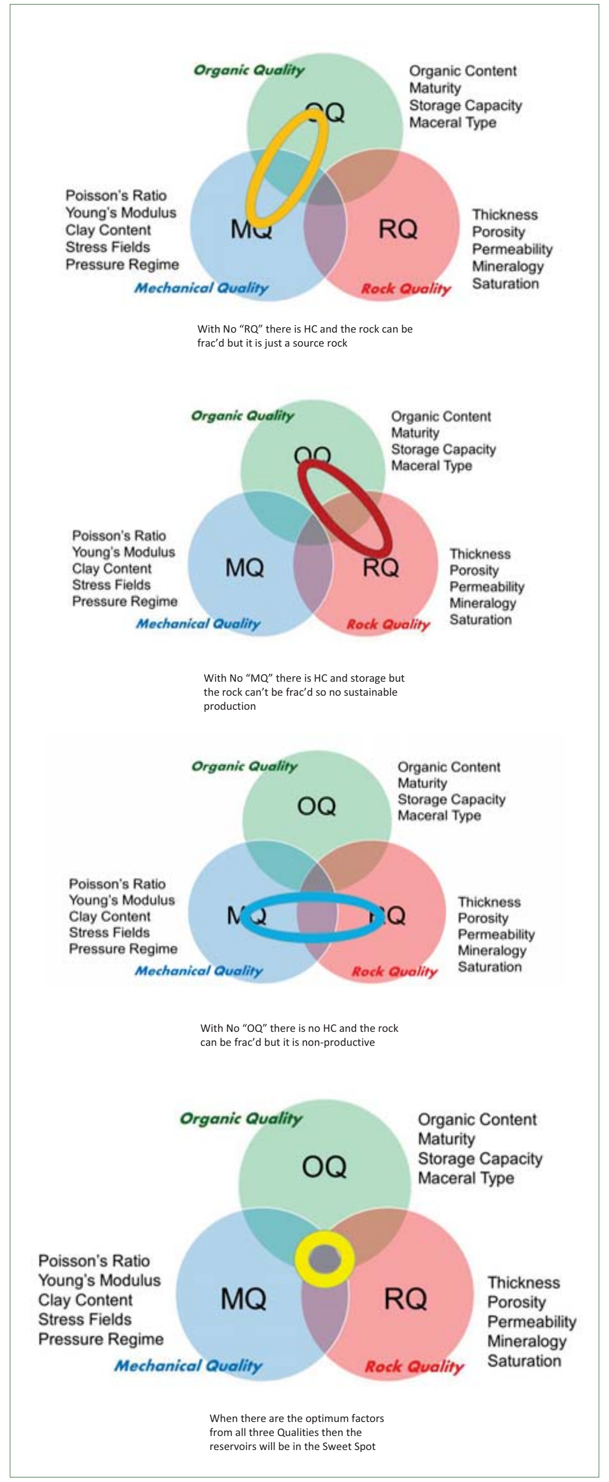


Figure 4

“Sweet Spot” Identification and Optimization in Unconventional Reservoirs

In addition to the sub-surface performance factors (PF), an operator must also properly design and execute the drilling and completion program in an economical manner. Therefore there are both operational and commercial factors that must be taken into consideration when defining a sweet spot; it is not just an academic sub-surface exercise. Further, the operator must conduct all activities in both a regulatory and a social space; meeting or exceeding all expectations if the operator is to continue developing the field. Thus all three layers, Fit for Purpose Operations, Sufficient Fiscal Environment for Commerciality, and Proper Management of all HSE Matters are all critical to the definition and execution of a Sweet Spot.

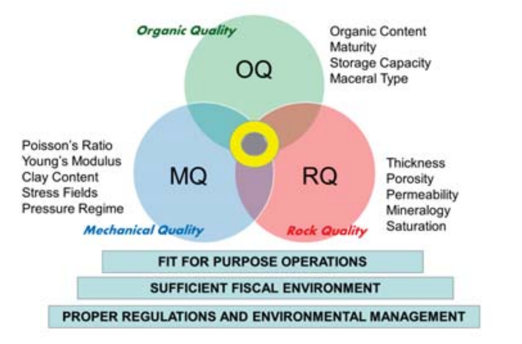


Figure 5

Any definition of “Sweet Spot” must include the critical element of commerciality and the risk that a field will stay within the commercial parameters that have been defined for it. The PRMS has built into its framework an accepted standard for a “Proved Sweet Spot”: it is that volume of a reservoir that contains proven reserves (P90) such that current understanding of completion practices, prices, surface constraints and all permitting will allow development of the hydrocarbon within the next five years. As efficiencies are gained in completions and surface facilities or as commodity prices increase the volume of the sweet spot may increase accordingly. If commodity prices decrease or there is a degradation in access to surface locations resulting in delays or more expensive operations the sweet spot volumes may decrease accordingly, however if the reserves are done correctly the Proved (P90) should not decrease. Thus “Sweet Spots” have Geological (rock properties), Reservoir Engineering (fluid properties), Drilling and Completion (stimulation and cost), Facilities (production), Land and HSE (permitting and regulations, and Economic factors that permit an evaluation of Proved Reserves and can be stress tested against a drop in commodity prices.

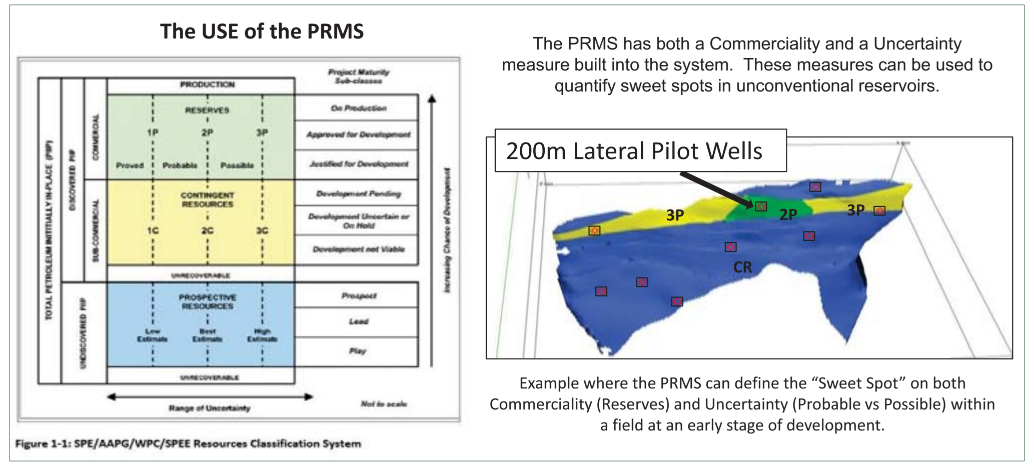
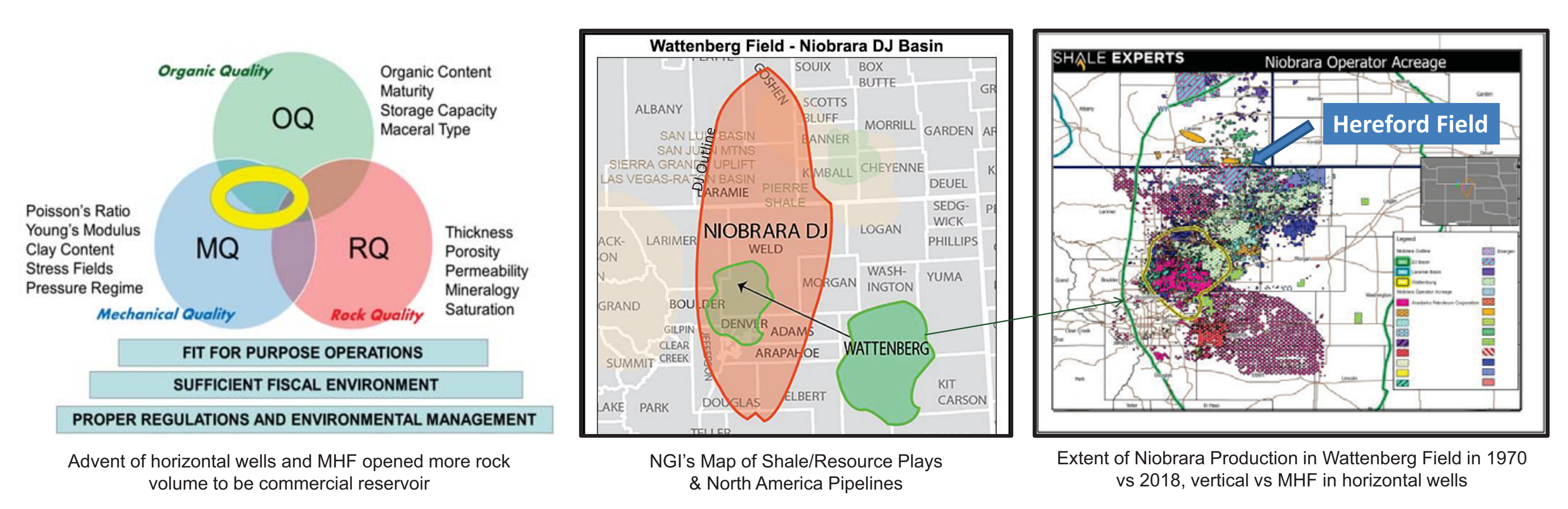


Figure 6

The term “Sweet Spot” is often used to describe the area of a play, or a license, that will produce the highest rate of return under the currently employed technology. This definition, itself, combines the disciplines of economics, completion technology and reservoir description; disciplines that traditionally have not worked seamlessly together in oil and gas fields. We define the optimum area for field development in unconventional fields as the intersection of three clear quality factors, Organic Quality (OQ), Rock Quality (RQ) and Mechanical Quality (MQ) that each are composed of several key characteristics. As the reservoir changes and decreases in the quality of any one factor the “Sweet Spot” will shrink and changes must be made to what we identify as the “Fit for Purpose Operations”. This alignment of the Operations with the Reservoir can enlarge the “Sweet Spot” thus increasing the area available for development or the profitability (**Figure 7**). There are two additional considerations that are made to the baseline equation, that of the fiscal environment, of which the price of the product is usually not within the operators control, and the regulatory and HSE environment which must be proactively maintained. (**Figure 8**) A large part of all unconventional plays, and staying in the “Sweet Spot”, is correctly managing and aligning the surface issues of regulation, HSE, and fiscal environment with fit-for-purpose operations aligned with sub-surface heterogeneities. The model presented here is designed to keep all disciplines aligned on both a long-term commercial goal and have the ability to rapidly adapt to changes, either in the sub-surface reservoir or in various surface conditions, all which influence the size of the “Sweet Spot”.

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

Effect of Technology



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

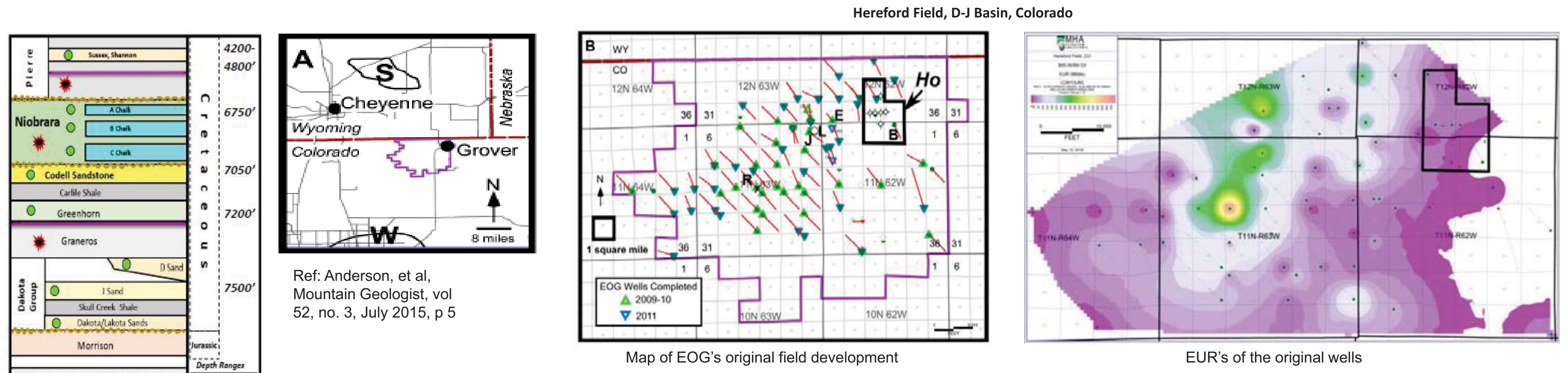
NGI’s Map of Shale/Resource Plays & North America Pipelines

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

Figure 7

Effect of Price

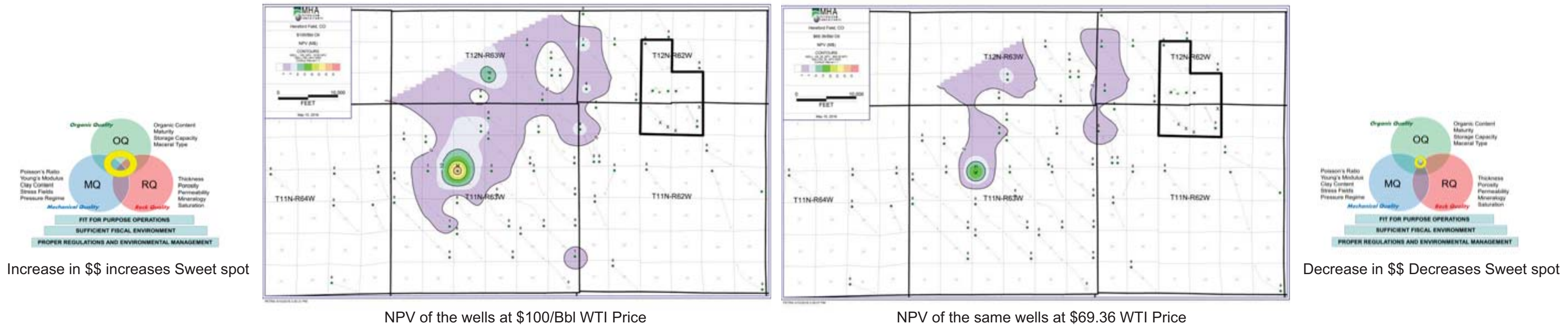
Hereford Field, D-J Basin, Colorado



Map of EOG’s original field development

EUR’s of the original wells

The field can be ‘stress tested’ using economic criteria, such as NPV, to evaluate areas that are the best performers and which areas are subject to not being commercial wells during periods of low commodity prices.



Increase in $$ increases Sweet spot

NPV of the wells at $100/Bbl WTI Price

NPV of the same wells at $69.36 WTI Price

Decrease in $$ Decreases Sweet spot

It is important to note that this ‘Stress Test’ is for demonstration purposes, on existing wells and production and does not reflect current operating practices nor wells in Hereford Field

Figure 8

"Sweet Spot" Identification and Optimization in Unconventional Reservoirs

Jeff Aldrich & John Seidle

MHA Petroleum Consultants

Conclusions

Many different authors have made attempts to identify and quantify "Sweet Spots" in Unconventional Reservoirs, either by looking for a combination of sub-surface characteristics that can be identified PRE-DRILL to narrow the play area to a more limited area of enhanced productivity or by looking to optimize production on a POST-DRILL basis to optimize hydrocarbon recovery. The key characteristics that authors identify vary by both basin and by technique focus (seismic, log, core, production, data analytics) but the factors can be subdivided into three principle "Quality Factors": A) those that describe the Organic Quality or the factors that describe the components that will affect the generation of the hydrocarbons; B) those factors that describe the Rock Quality that will affect the storage capacity of the hydrocarbons (and this includes the organic porosity); and C) those factors that describe the Mechanical Quality that will affect the ability to place and sustain a stimulation (Schlumberger calls this Completion Quality). Contrasting different basins and different methods, various combinations of these factors can be successfully correlated to production to give a predictive tool, specific to that basin, which once calibrated, can be used to map out areas or zones of higher productivity as defined by a Productivity Factor or PF.

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).

This PF, however is not an indicator of commerciality, it is typically just a relative scale used to rank areas or zones of the reservoir that are expected to have better production, or to be able to sustain stimulation better than other zones or areas. A true "Sweet Spot" must have a scalable, testable standard that can be used to compare one play or field against another and must have some economic standard within it. Fortunately the AAPG-SPE Petroleum Resource Management System (PRMS) has by design a commerciality basis for all volumes of hydrocarbons in the RESERVE category. Further there is a standard range of uncertainty for the reserves category from 90% certain of at least this volume or higher down to 10% or higher volumes will be recovered over the life of the field built into the assessment system. Thus an operator can "stress-test" the field under a variety of scenarios, price, operations, HSE regulations, etc., to understand what areas of a field can withstand expected challenges over the life of the operations. Both the SEC and the PRMS Guidance's are now requiring that operators drill planned Proved Reserve locations (PUDs) within 5 years of first disclosure on the stated corporate reserve books. These PROVED RESERVES, whether already drilled and uncompleted (DUCs), or PUDs by definition meet all of the requirements for being included in the "Sweet Spot" of an Unconventional Reservoir. Wells that are in the PROVED CATEGORY have a 90% confidence that actual recoveries will equal or exceed reported estimated ultimate recoverable hydrocarbon (EUR). Sweet Spot identification and assessment should include price variations in commodities and services as well as any pertinent changes to regulations. The OQ-RQ-MQ sub-surface factors identify areas of sufficient quality to sustain commercial production even during periods of lower commodity prices and challenging regulatory environments. The PRMS allows both the scientist and a company to evaluate new plays, existing fields, and developed production and place them in context with each other. Combining these technical parameters with internal business metrics preferred by the company, whether it be NPV, ROI, ROC, or any of a range of economic yardsticks, assets can be evaluated both for identification of areas of best productivity and classification as either reserves or resource (based on commerciality) and by the quality of the reservoir, the "sweetness" or PF, by the use of the uncertainty measurements P90 to P10 and the categories PROVED, PROBABLE, and POSSIBLE. The PRMS is as useful a tool for unconventional reservoirs as for conventional reservoirs however different sub-surface factors must be evaluated for proper reservoir characterization.

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

There are more factors for unconventional reservoirs and operators have more variability in the manner that they complete the reservoir which makes reservoir optimization more difficult. The basic philosophy still applies in that to optimize commerciality the prudent operator must complete wells in the best locations, with the best technology, using the best HSE practices and follow all regulatory rules and permits. The "Sweet Spot" is that area or zone of the play where, over the life of the field and the variations in price and technology, the play is and remains commercial. As price and technology allow the "Sweet Spot" can expand into areas not previously commercial but if commodity prices rapidly fall, as in 2014, or regulations suddenly change (as in a ban on stimulation), the "Sweet Spot" area can swiftly contract; the area is not static through time.

Key Take Away #3: Due to above ground factors of commodity price, D&C efficiency, regulation and societal challenges "Sweet Spots" are not static but change over time.

Prudent operators 'stress-test' their fields against challenges to developing their field plans. Nothing in the future is certain however proper management of the uncertainties, be they the sub-surface uncertainties, uncertainties in commodity prices, uncertainties in technology trends or regulations, can certainly assist operators in maximizing their returns out of these demanding assets.

Acknowledgements

The authors wish to thank MHA Petroleum Consultants for permission to publish this work. All ideas are the authors and intended for the sole purpose of discussion during the 2018 AAPG Annual Convention and Exhibition. The authors would like to offer special thanks to Mrs. Shawna Harrison, Jessica Davey, and Traci Paine for their hard work in helping us prepare this presentation.

Bibliography

Algarhy, Soliman, Bateman, and Asquith. *Shale Gas Plays Screening Criteria, "A Sweet Spot Evaluation Methodology".* Fracturing Impacts & Technologies Conference, Texas Tech, 2014.

Altamar, and Marfurt. *Identification of Brittle/Ductile Areas in Unconventional Reservoirs using Seismic and Microseismic Data: Application to the Barnett Shale.* SEG Interpretation T233, 2015.

Anderson, et al. *A Short History of the "Jake" Niobrara Horizontal Oil Discovery, Weld County, Colorado.* Mountain Geologist, vol 52, no. 3, p 5. 2015.

Chopram, Sharma, Nemati, and Keay. *Organically Rich Sweet Spot Determination in Utica Shale.* Search and Discovery, Article #42137, n.d.

Chorn, et. al. *Indentification of Shale Sweet Spots Using Key Property Esimates from Log Analysis and Geostatistics.* URTeC: 1580188, n.d.

Dotsey. *Logs Reveal Marcellus Sweet Spots.* AOGR, 3-3M, T1, A2, n.d.

Gang, Yu, et al. *Shale gas reservoir characterization and sweet spot prediction.* SEG International Exposition and 87th Annual Meeting, 2017.

Ghanizadeh, et. al. *Indirect Estimation of Fluid Transport and Rock Mechanical Properties from Eleemental Compositions: Implications for "Sweet Spot" Identification in the Montney Formation (Canada).* URTeC:2670893, n.d.

Glaser, et. al. *Seeking the Sweet Spot: Reservoir and Completion Quality in Organic Shales.* Olfield Review, 2015-2016.

Hower, Tim; Aldrich, Jeffrey; Sipeki, Julianna. *Assessing and Advancing a CBM Resource Play Towards Commerciality - A Case Study from the UK.* SPE 168809-MS. 2013.

Jinying, Zhou, Gui Biwen, Xi Liao, Dietmar Mueller, Sergey Antipenko, and Alan Rolph. *Sweet Spots Identification in a BCG Play in Sichuan Basin China.* International Petroleum Technology Conference, 2014.

Kormaksson, Vieira, and Zadrozny. *A Data Driven Method for Sweet Spot Identification in Shale Plays using Well Log Data.* SPE-173455-MS, 2015.

Licitra, et. al. *Sweet Spots in Vaca Muerta: Integration of Subsurface and Production Data in Loma Campana Shale Development, Argentina.* URTeC:2153944, n.d.

Naizehen, Liu, and Wang Guoyang. *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, 2016.

Petroleum Resources Management System . 2007.

Renfang, Qin, Jie, and 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.

Sahoo, et. al. *Reservoir Characterization of Eagle Ford Shale through Lithofacies Analysis for Identifcation of Sweet Spot and Best Landing Point.* SPE 168677, n.d.

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, 2011.

Sharma, and Chopra. *Indentification of Thin Sweet Spots in the Duvernay Formation of North Central Alberta.* 2015 SEG Annual Meeting, 2015.

Tahmasebi, Javadpour, and Sahimi. *Data Mining and Machine Learning for Identifying Sweet Spots in Shale Reservoirs.* Expert Systems with Applications, Vol 88, Issue C, , 2017.

Tinnin, et. al. *Multi-Source Data Integration: Eagle Ford Shale Sweet Spot Mapping.* URTeC:2154534, n.d.

Toelle, Brian. *Shale Sweet Spot Detection with Surface Seismic.* SPE Distingushed Lecturer Program, 2014.

Van Hoeve, Meyer, Preusser, and 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.

Yang, et.al. *Sweet Spot Indentification and Prediction of Frac Stage Performance Using Geology, Geophysics and Geomechanics - Application to the Longmaxi Formation, China.* SPE-176931-MS, n.d.