Systematic Geomechanical Applications for Unconventional Reservoir Development*

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Abstract

The application of geomechanics has been recognized as a necessary process for successful exploration and development of an unconventional resource, shale gas or tight oil reservoir. This presentation summarizes geomechanical applications for unconventional gas and tight oil reservoir exploration and development. Applications discussed include wellbore stability for drilling operations by way of optimizing mud weights and well trajectory; geomechanical evaluation for the possibility of openhole completion; optimization of the horizontal wellbore azimuth for multi-stage hydraulic fracturing development; geomechanical consideration for optimization of hydraulic fracturing design, stress-dependent fracture permeability, natural fracture characterization and identification of critically stressed fractures; reservoir evaluation from a geomechanical prospective on brittleness and fracability; and production prediction with considerations towards integrated geomechanical parameters. Clear knowledge on how to apply geomechanics in a proper manner will increase exploration and development efficiency in an unconventional resource reservoir.

Selected References

Barree, R.D., S.A. Cox, J.L. Miskimins, and J.V. Gilbert, 2014, Economic Optimization of Horizontal Well Completions in Unconventional Reservoirs: Society of Petroleum Engineers Hydraulic Fracturing Technology Conference, 4-6 February, 2014, The Woodlands, Texas, USA, SPE-168612-MS.

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Hashmy, K.H., and A. Bhatnagar, 2014, Shale Reservoirs: Improved Production from Stimulation of Sweet Spots: <u>Search and Discovery Article #41355</u>.

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Hashmy, K.H., D. Tonner, S. Abueita, and J. Jonkers, 2012, Shale Reservoirs: Improved Production from Stimulation of Sweet Spots: SPE Asia Pacific Oil and Gas Conference and Exhibition, Perth, Australia, 22-24 October, 2012, SPE 158881.

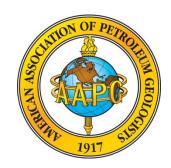
Hashmy, K.H., S. Abueita, C. Barnett, and J. Jonkers, 2011, Log Based Identification of Sweet Spots for Effective Fracs in Shale Reservoirs: Canadian Unconventional Resources Conference, Calgary, Alberta, Canada, 15-17 November, 2011, CSUG/SPE 149278.

Fulks, R.W., and S. Smythe, 2012, A New Approach to Fracturing and Completion Operations in the Eagle Ford Shale: SPE Europec/EAGE Annual Conference, 4-7 June, Copenhagen, Denmark, SPE-152874.

Singbeil, R.P., 2013, If Vertical Wells Could Talk: SPE Calgary Luncheon February 14, 2013.

Welling and Company, 2012, Hydraulic Fracturing and Fracture Mapping Survey, Outlook for Domestic Unconventional Resources: PESA Annual Meeting, Boerne, Texas.







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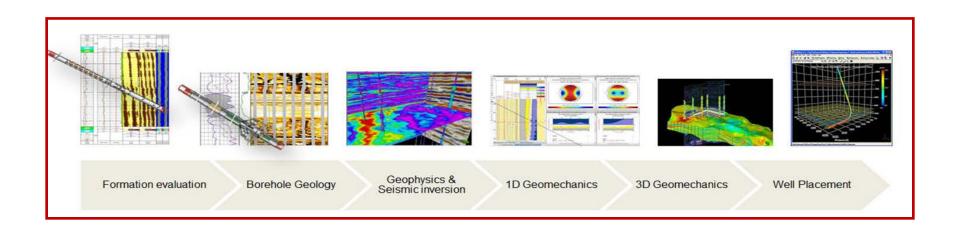
Weatherford Petroleum Consulting Services

Queena Chou, Chris Walsh, Geoff McBryan, Mehdi Noroozi, Pete R. Singbeil AAPG GTW Unconventionals Update, 4 – 5 November 2014

Agenda



- It's a Different Ball Game
- Technical Challenges
- Geomechanics: the Difference Maker
- Setting Packers in Openhole Completions
- Hydraulic Fracturing Optimization
- Systematic Reservoir Development



Play Types



- Resource Plays "The Permeability Hunter"
 - "Untapped" (RF near zero)
 - "Halo" step out from production (k Halo << k Prod)
 - "Challenged" (RF low with verticals)
- Every perm and fluid content will require design and forethought; it's not a "Farm"
- Predictive tools are even more important than ever as the "stakes are high"
- Fashionable to call everything a "shale"

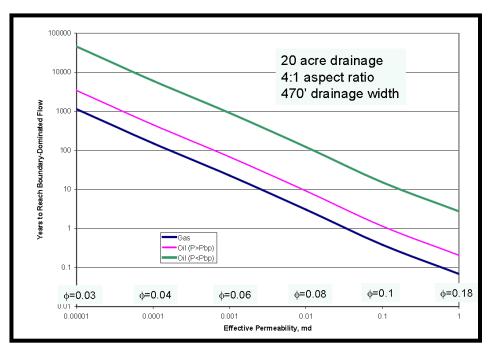


RF = Recovery Factor k = Permeability

What Is Your Field Development Plan?



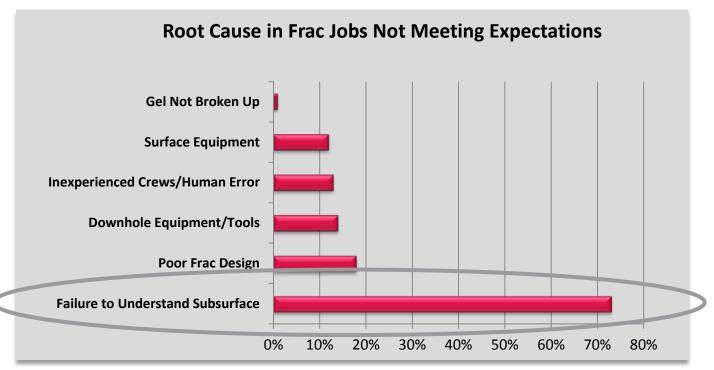
- Most don't have cash flow to develop resources without bringing in capital
- How to estimate capital requirements and opportunities in an unconventional play?
- Field trial and error?
 - Typical permeability values, well spacing, and frac spacing take a decade to see interference
 - Case Study: Montney Dawson case study presented at SPE Calgary Luncheon Singbeil Feb 14, 2013 "If Vertical Wells Could Talk"
- Drill now and continue to raise money?
 - Reservoir simulation with the right inputs can assist with the decisions



Source: SPE 168612

Industry's Formation Evaluation Challenges





Source: Welling & Co. 2012 Hydraulic Fracturing and Fracture Mapping Survey

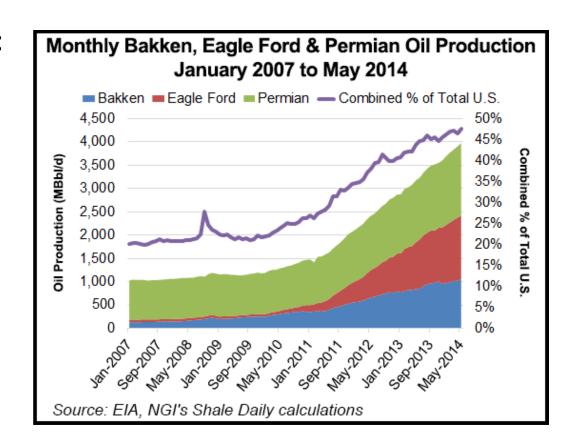
- Most common shortcoming in frac jobs not meeting expectations is from lack of good understanding of subsurface causing false expectations
- Reservoir characterization and integration of multiple reservoir attributes is the largest area to add value

What Do We Want?



We want increases in:

- accuracy of horizontal reservoir characterization
- fracability
- control of hydraulic fracture geometry
- production rate
- hydrocarbon recovery factor
- field drainage



Geomechanical Evaluation Benefits



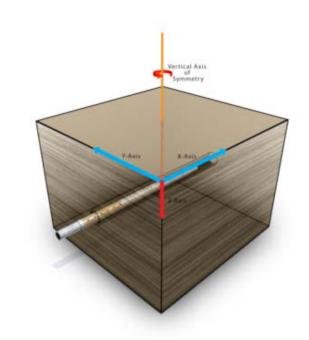
- Geomechanical evaluation gives insight to:
 - Fracability
 - Selective fracing (less stages or zones possible?)
 - Optimize production
- Geomechanical and reservoir evaluations benefit:
 - G&G: reservoir appraisal for economic feasibility
 - Drilling: geo-steer to stay in zone
 - Completions: "sweet spots" identification to increase productivity

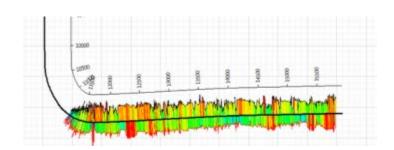
Levers in Optimization

Use Rock Properties to Full Advantage

- Stimulated fracture system influenced by extensive horizontal laminations
- Laminations strongly influence the hydraulic fracture height
- Rock mechanical properties differ normal and parallel to the bedding planes
- Anisotropy must be considered to accurately predict frac height

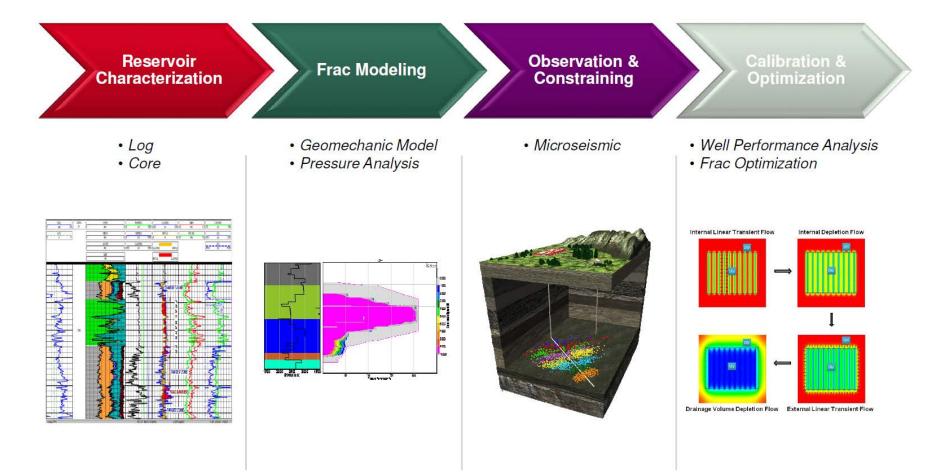






Four-Step Field Development Optimization Work Flow





Oriented Borehole Geometry



 Upper 4 caliper arms are cross-linked (hole centralization)

Lower 4 caliper arms are independently articulate (borehole contact)

Minimum hole size 3" Max hole size 19.5"

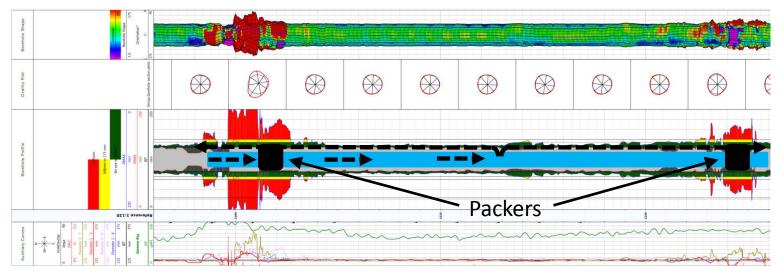
 Drill pipe (memory logged) or wireline conveyed

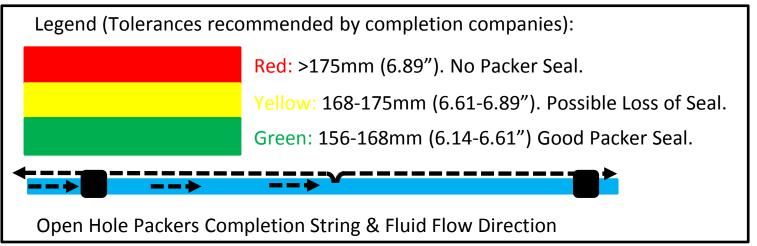




Oriented Borehole Geometry Plot

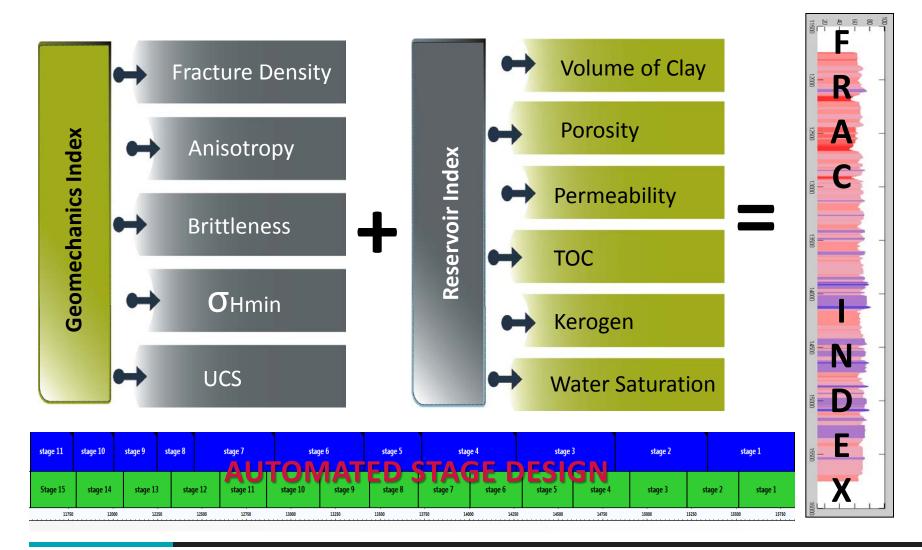






New Hydraulic Fracture Optimization Work Flow





Use Every Data Source Available for Hydraulic Fracturing Design



Lithology, Mineralogy,
Total Organic Content,
Clay Content,
Mechanical
Stratigraphy, Bedding,
Fracture Density

Natural Gas, Condensate, Liquids, Water Saturation, Porosity, Permeability

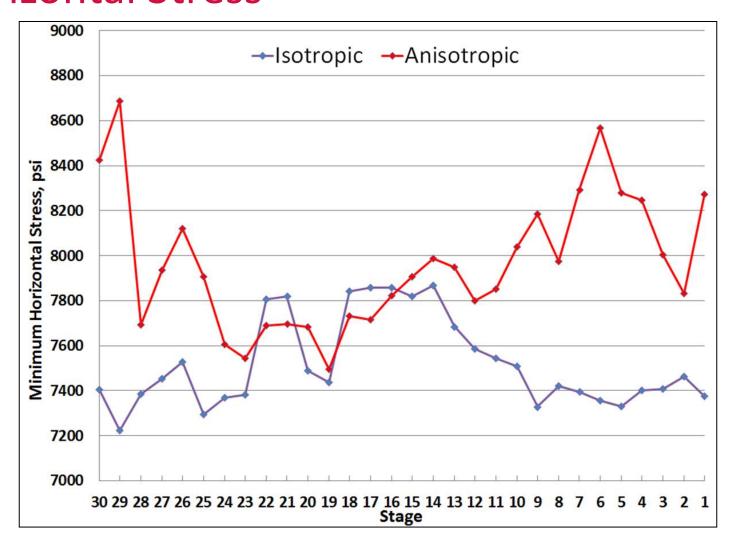
Reservoir Thickness, Area, Volume, Water Zones

In-Situ Stress Regime,
Pore Pressure,
Anisotropy, Rock
Stiffness, Strength,
Fracture Toughness

Drilling & Completions
Technologies, Lateral
Length, Fracture Fluid
Type, Proppant Type

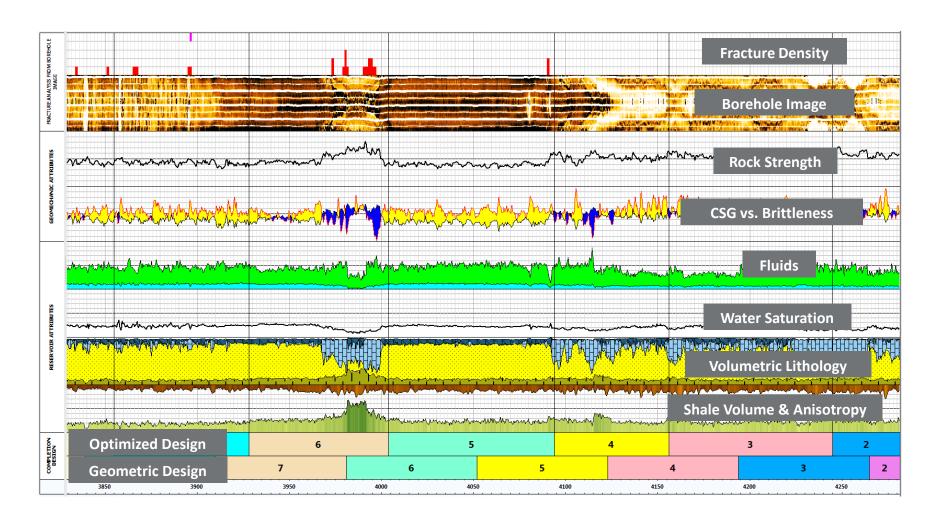
Anisotropy's Effect on Minimum Horizontal Stress

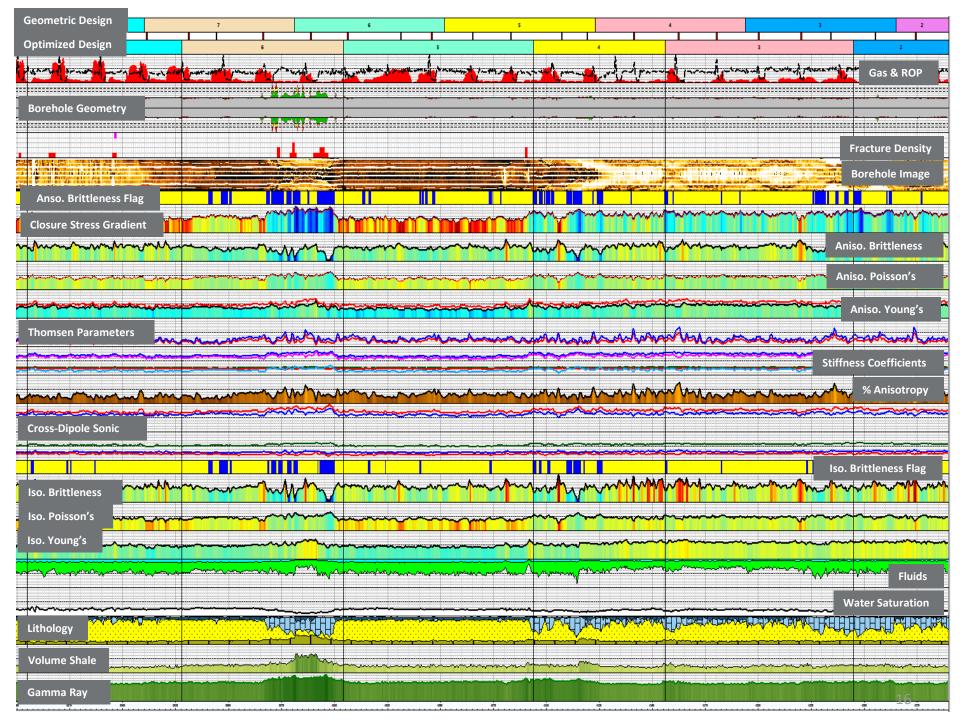




Horizontal Well Hydraulic Fracture Optimization Design – Montney Case Study





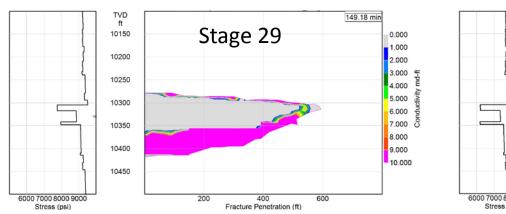


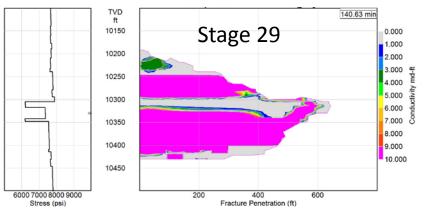
Modelled Fracture Height and Conductivity Comparison



Anisotropic

Isotropic



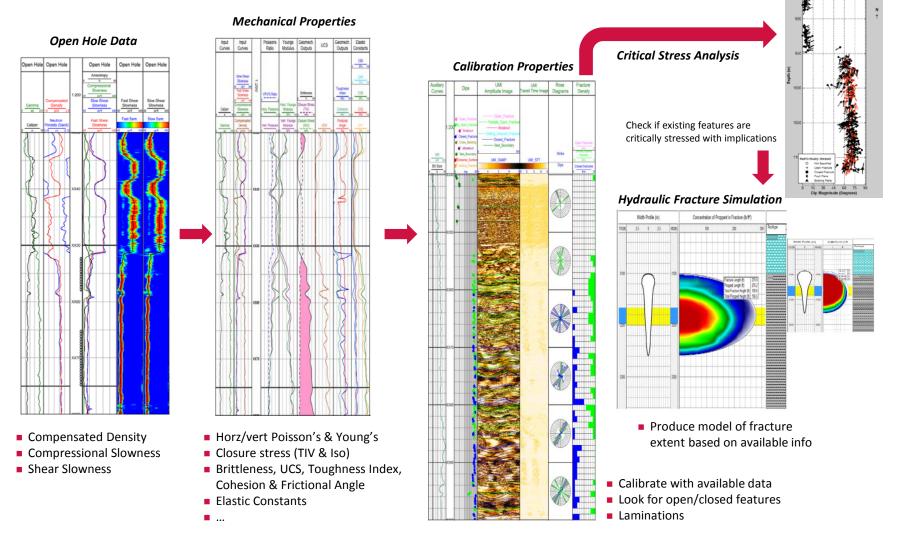


20% Closure Stress Change

No Closure Stress Change

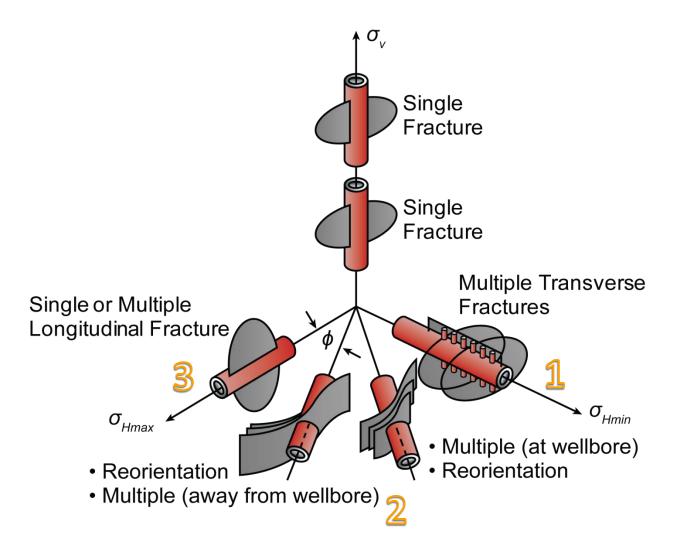
Geomechanical Hydraulic Fracture Simulation





Horizontal Well Orientation





(source: EPT International)

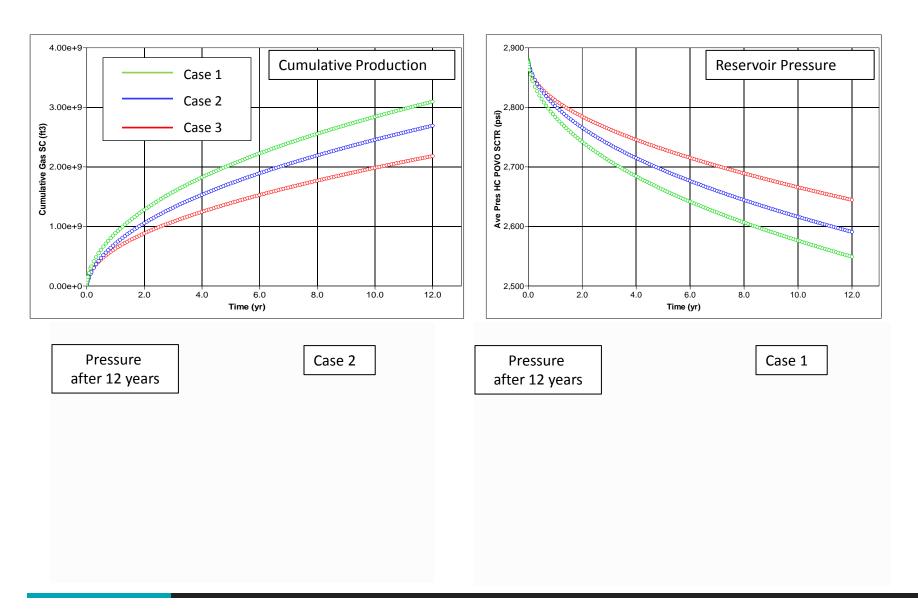
Gas Reservoir Parameter Values



Average Porosity	Reservoir thickness	Sector model size (ft)	Horizontal well section	Average Permeability (md)		Average water saturation		content msft³)
(%)	(ft)		(ft)	K _x =K _y	K _z	(%)	Free	Adsorbed
4.7	108	5250 by 5250	3937	2.45E-03	2.45E-05	32.2	24720	4238

Production Forecast





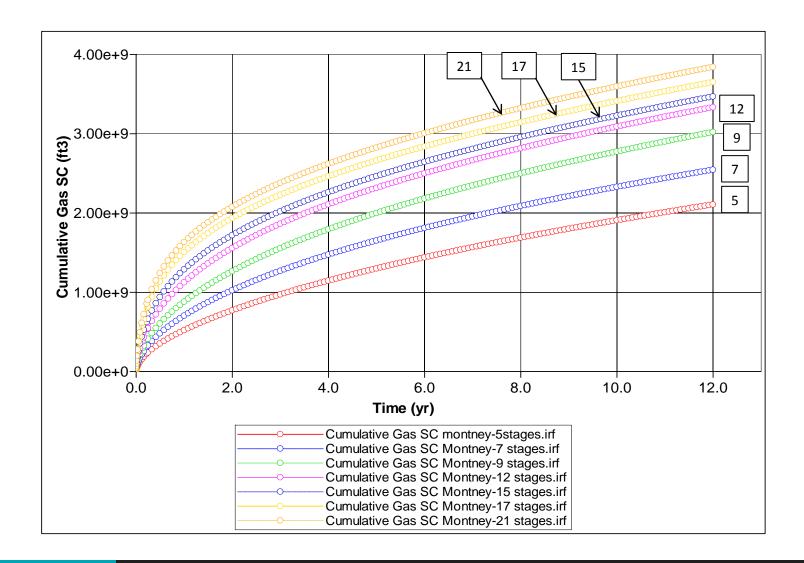
Production Forecast Comparison



Case No.	Horizontal well orientation	Hydraulic Fracture Orientation	Hydraulic Fracture Conductivity (md x ft)	Frac half length (ft)	Frac Half height (ft)	No. of H.F.	Stimulated Rock Volume (ft³)	Cum. Gas Production 12 years (mmsft ³)	Decrease Cum. Gas Production 12 years (%)
1	parallel to O Hmin	perpendicular to horizontal well	40	148	52	9	1.8E+08	3108	Base Case
2	45° to O Hmin	45° to horizontal well	32	148	52	9	1.8E+08	2684	16%
3	parallel to O Hmax	parallel to horizontal well	40	3937	52	1	6.4E+07	2190	42%

Number of Stages Sensitivity Analysis





Return on Investment



Stages	Conductivity (md x ft)	Fracture Half Length (ft)	Cumulative Gas Production 12 Years (mmsft³)	Increase Cumulative Gas Production / additional Stage 12 Years (%)	Increase Cumulative Gas Production / additional Stage 8 Years (%)	Increase Cumulative Gas Production / additional Stage 4 Years (%)
5	40	148	2119	-	-	-
7	40	148	2543	10	12	14
9	40	148	3108	12	13	15
12	40	148	3320	8	10	12
15	40	148	3461	7	8	10
17	40	148	3637	6	7	9
21	40	148	3849	5	6	8

Associate Presentations



- Shale Reservoirs: Improved Production from Stimulation of Sweet Spots – Presentation in AAPG Geosciences Technology Workshops – 2014: Khaled Hashmy and Ashok Bhatnagar
- Shale Reservoirs: Improved Production from Stimulation of Sweet Spots: Khaled Hashmy, David Tonner, Jos Jonkers(WFT) and Samir Abueita (Anadarko) – SPE 2012 (SPE 158881)
- Log Based Identification of Sweet Spots for Effective Frac in Shale Reservoirs: Khaled Hashmy, Craig Barnett, Jos Jonkers(WFT) and Samir Abueita (Anadarko) – CSUG 2011 (SPE 149278)
- A New Approach to Fracturing and Completion Operations in the Eagle Ford Shale: Rob Fulks and Steve Smythe (WFT) – SPE 2012 (SPE 152874)

Review Questions



- Do conventional reservoir formation evaluation techniques fit unconventional plays?
- Are we designing for reservoir anisotropy?
- Are we doing enough to understand well and frac spacing requirements?
- Are we logging enough wells?