PMG PETRO MANAGEMENT GROUP LTD.

Performance Evaluation of Multi-stage Fracing of Hz Wells *"MFHW"*

By: Saad Ibrahim, P. Eng.

For information:
www.petromgt.com
2015

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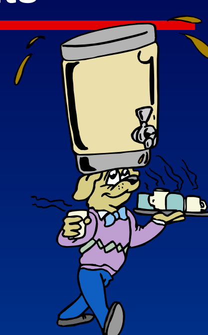
Petro Management Group

Quality Petroleum Engineering Consultants



Services:

- Reservoir Studies (Conventional/Simulation)
- Well Test Planning and Analysis
- Waterflood Design & Performance Monitoring
- Production Optimization
- Performance Evaluation of MFHW's (PTA, RTA, Numerical)
- Reserves and Economic Evaluations
- Complete frac design/optimization (Gohfer/KAPPA software)
- Government Submissions
- Customized course contents
- Expert Witness

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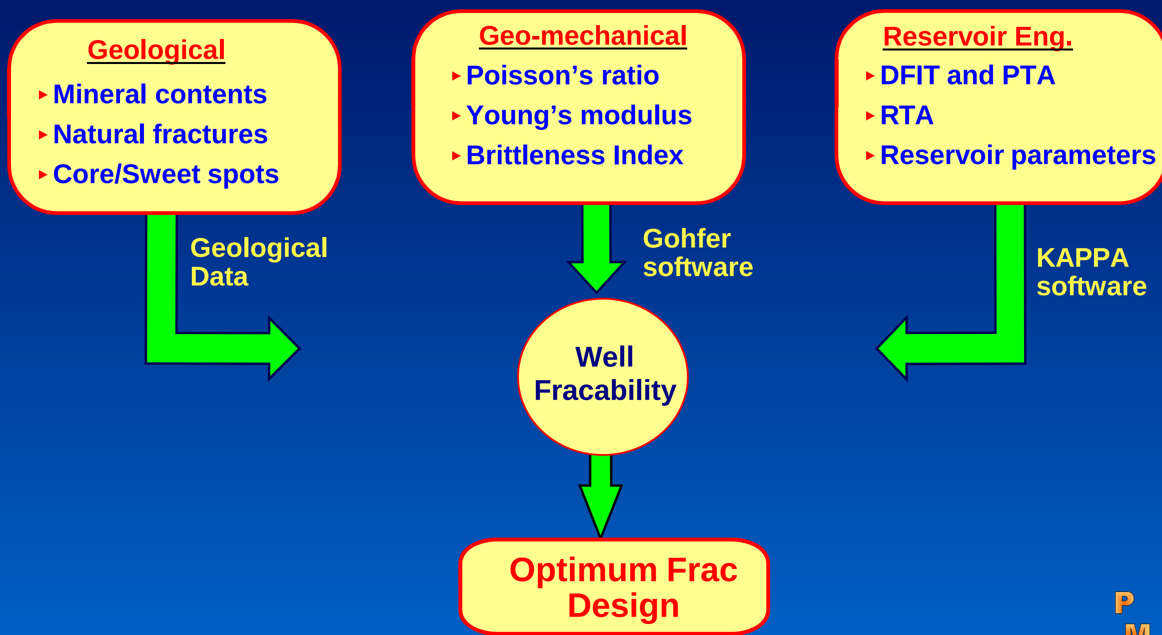
Petro Management Group - FracKnowledge

Full Well Frac Design and Optimization Services:



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Lunch and Learn Presentations

- Challenges of Reserves Estimate **(Feb. 24)**
- Waterflood Application for MFHW's **(March 25)**
- Applications of Mini Frac (DFIT) - **(May 7th)**
- Performance Evaluation of Multi-Stage fracs Hz Wells (MFHW's) - **June 18th, 2015**
- How to get the Most out of Well Testing
- Frac Databases: benefits to improve frac results
- How can we improve your frac design/performance in this poor oil price environment

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Upcoming Courses

- Well Test Analysis Non-specialists (1 day) **Sept. 3**
- Performance Evaluation of Hz Wells (2 days) **Sept. 14**
- Waterflood Management (3 days) - **Sept. 16**

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Performance Evaluation of Multi-stage Fracing of Hz Wells *"MFHW"*

Agenda:

- Introduction
- Data acquisition to improve frac design
- How to optimize the design of *MFHW*'s
  - Open hole vs cased hole
  - Number of frac stages
  - Size of frac stages
  - How to take advantage of sweet spots
- Review of case study
- What is new in performance evaluation of MFHW's

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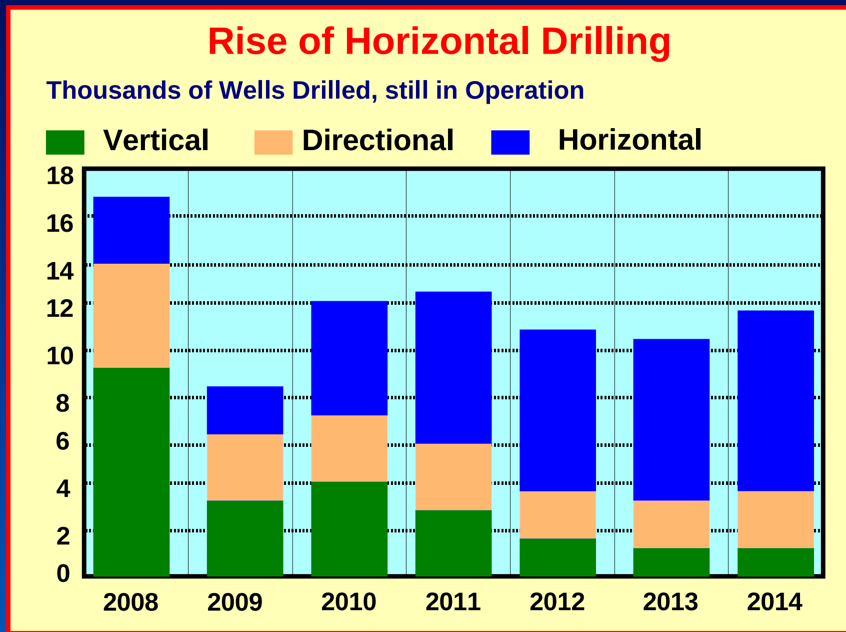
Drilling Activities in Canada



Source: Andrew Barr/National Post

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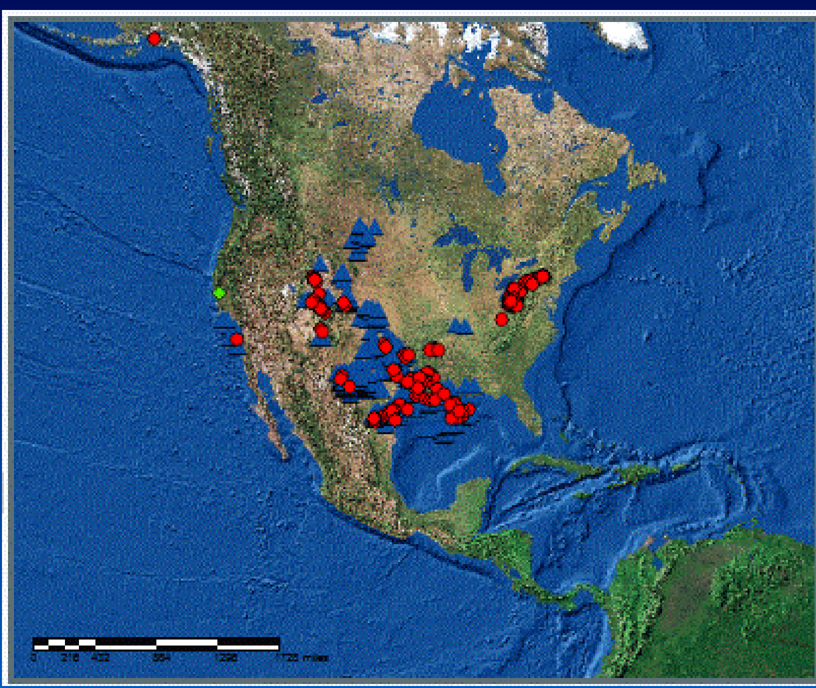
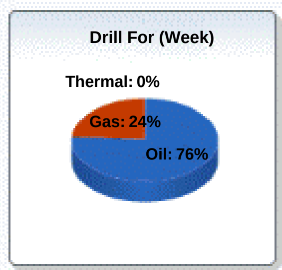
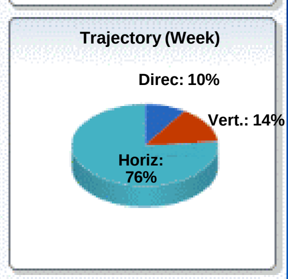
Drilling Statistics - USA (2015)



Rig Count: 884
14-Aug-2015





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How Did "MFHW" Start?

- Early 1980's **George Mitchell** drilled the first wild cat well in the Barnett Shale; with limited success
- Two decades after, he managed to make shale gas commercial by applying **"MFHW"** new technology:
  - Horizontal drilling and coiled tubing perforating
  - Multi-stage fracturing
- Devon Energy Corp (Oklahoma) bought out his technology and holdings for $3.5 Billion, making Mitchell the 139 richest American in 2002

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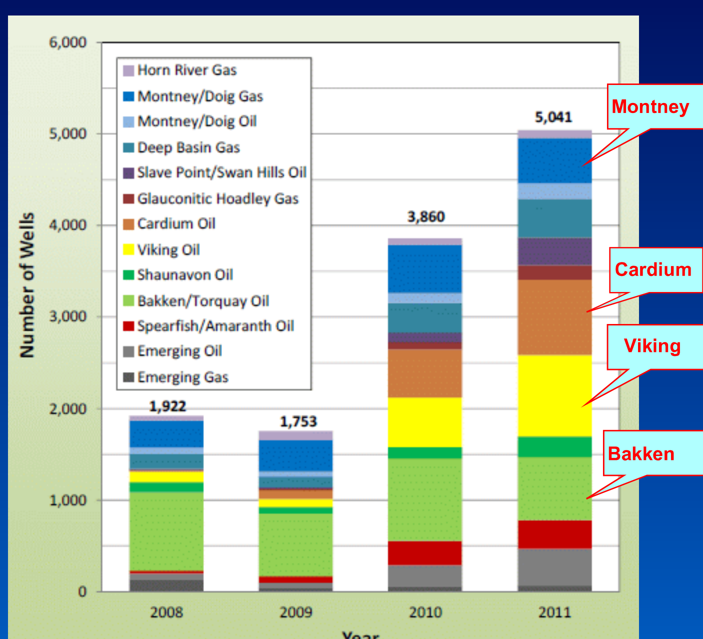
Number of MFHW's Western Canada by Resource Play



Source: Canadian Discovery Ltd.

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Hydraulic Fracturing of Hz Wells

Major efforts/money spent on mechanical aspects of the frac - "it is a matter of "***Power***"!

- **Water:** up to 1.5 M gallons/frac
- **Sands:** 100 to 200 tons/frac
- **Horsepower:** large!, depends on depth and type of rock

Limited efforts/money spent on **optimization** of MFHW

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How to Collect Meaningful Data?

Pre-fracing:

- Convention flow/buildup test; Rate Transient Analysis (RTA)
- PITA (Perforation Inflow Test Analysis)
- Mini-fracing (DFIT)
- Fracture orientation (FMI logs, wellbore Caliper)
- Injectivity fall-off tests to estimate permeability and pressure
  - Water (CBM)
  - N_2 (shale gas)

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How to Collect Meaningful Data?

Post-fracing:

- Micro-seismic
- Tilt meter surveys
- Production logging
- Tracer surveys
- Analysis of production/pressure history, using Type Curve Matching; Rate Transient Analysis (RTA)

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Optimization of Hz Well Design

Main objectives:

- Orientation of the Hz well; to intersect natural fractures
- Determine optimum spacing of Hz wells
- Open hole vs. cased hole completion/fracing
- Determine the optimum number of fracs
- Frac design; proppant, fluids, size
- Locate the sweet spots to frac; where to frac!!

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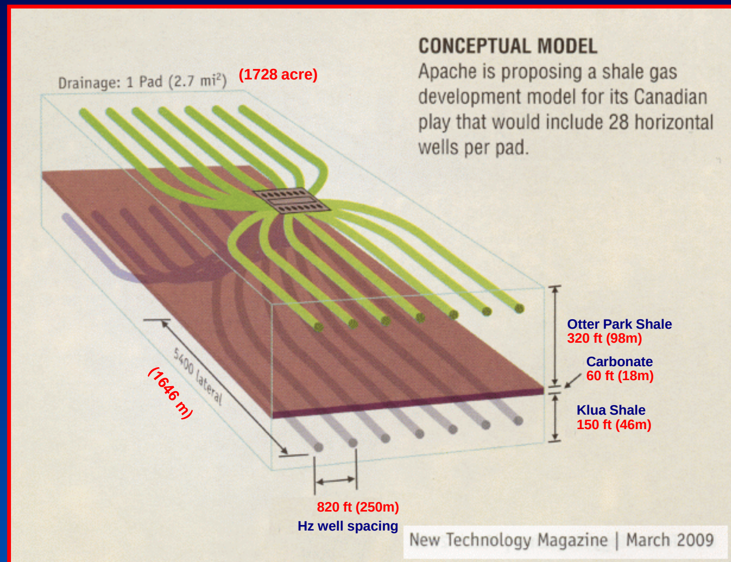
Hz Well Configurations

Apache Canada:

Spacing ≈ 124 acre/Hz well
(5.2 Hz wells/section)



EnCana (Upr Montney) at Swan:

- Hz well spacing = 200 m (8 wells/section)
- Eight fracs per well
- IP (1st month) = 10 MMscf/d

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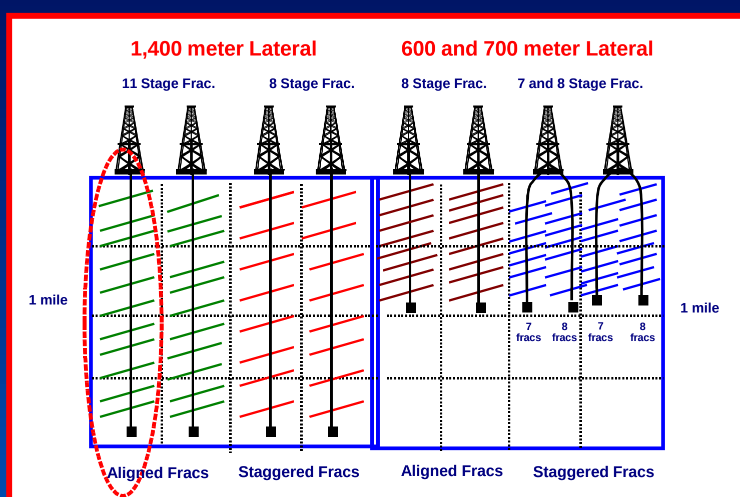
Hz Well Configuration (Bakken Play)

Improvements proposed by Lightstream (Petro Bakken):



Benefits:

- Oil recovery could increase from 12.5% to 22.5% by drilling multi-leg horizontals with shorter laterals (600 meters vs. 1,400 meters)
- Potential recoverable oil of Petrobakken's land could reach 400 MMBbl's

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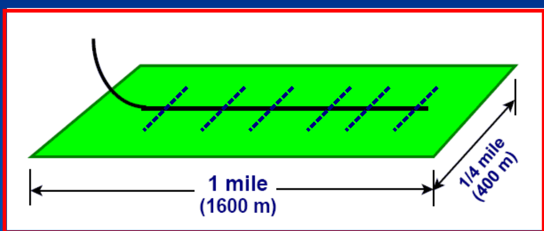
Optimization of Hz Well Spacing

Sensitivity analysis using numerical modelling (**Topaze software**) to evaluate:

- Evaluation of permeability impact on Hz **well spacing**
  - K = 0.005 md
  - K = 0.001 md



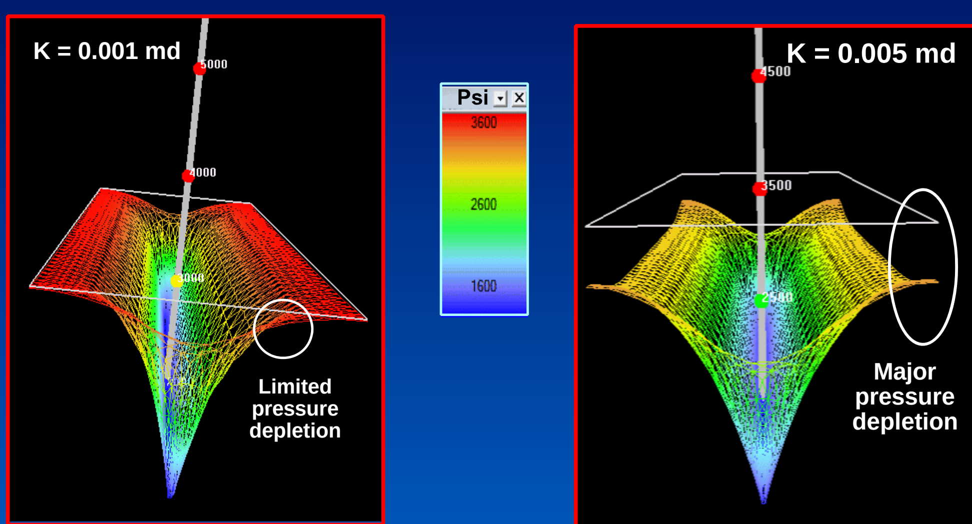
Model data:

Initial pressure	= 3500 psi
Length of Hz well	= 1500 m
Pay thickness	= 10 m
No. of fracs	= 6
Frac half-length	= 60 m
BHFP	= 1000 psi
Duration of runs	= 3 yrs

Topaze

Optimization of Hz Well Spacing

The same drainage area (1600 m x 400 m) is used to compare well spacing for two cases: **k = 0.001** md and **k = 0.005** md



Hz well spacing < 400 m is recommended

Hz well spacing > 400 m is recommended

Optimization of Hz Completion/Frac Techniques

- Evaluation of well **completion options:**
  - Cased hole completion/frac
  - Open hole completion/frac

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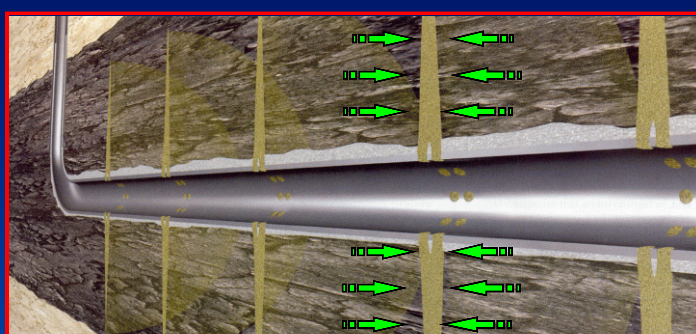
Cased Hole Completion (Perf & Plug)

Flow through fracs only:



Considerations:

- Ability to perform a large number of fracs
- Less sand production problems and good wellbore integrity
- Good hydraulic isolation between frac stages is possible, if a good casing cement bond is achieved

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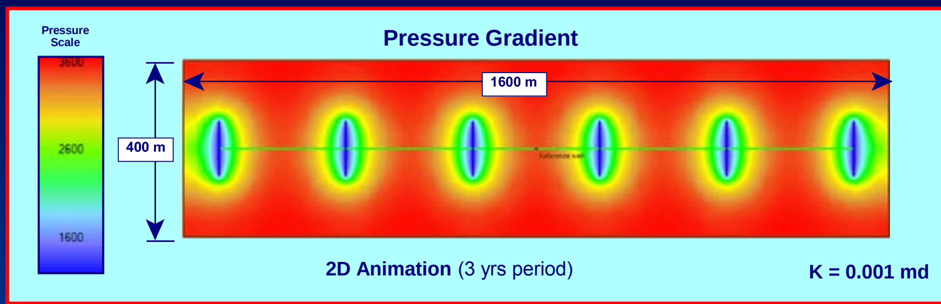
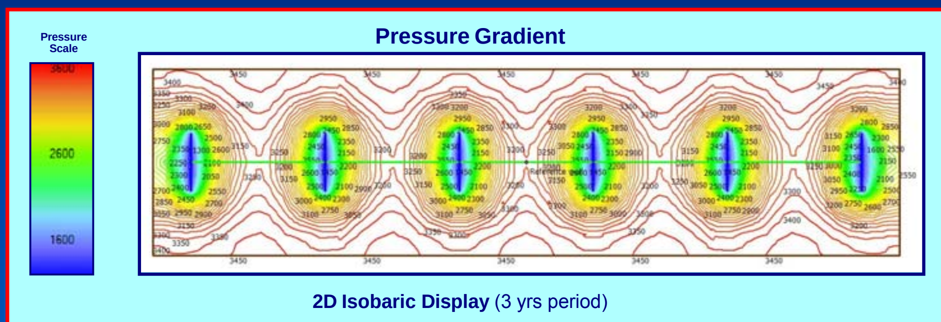
Production from Fracs Only



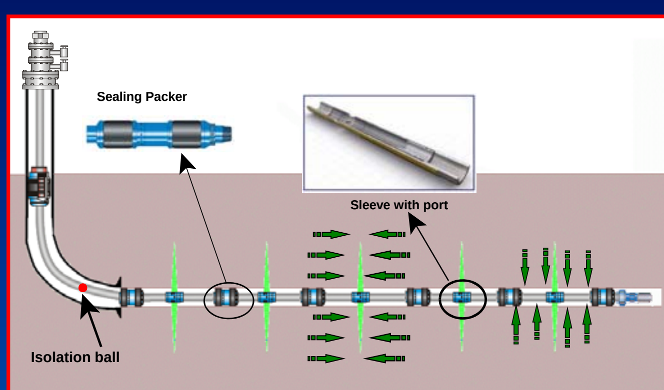


Pressure decline at the edge of drainage area is approx. **50** psi, after 3 years of production

IP = 15 MMscf/d
Cum. gas (3yrs) = **0.18 Bcf**

Open Hole Completion

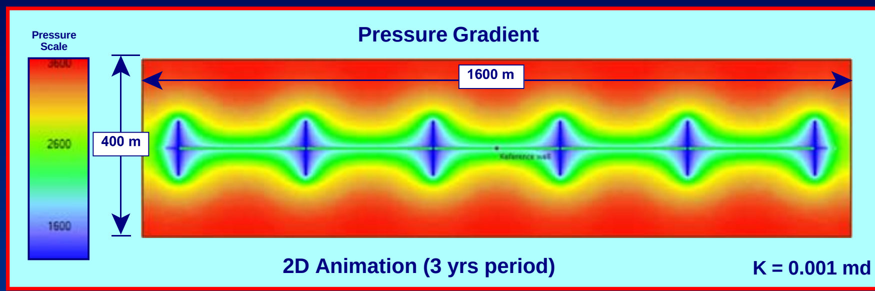
Flow through both fracs and wellbore:

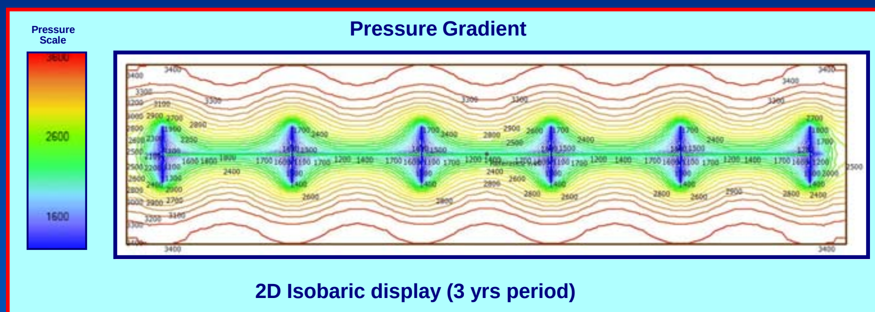


Considerations:

- Flow can occur through both the fracs and wellbore, for reasonable formation permeability
- Simple to perform; neither cement nor perforating required
- Fast to perform; well could be on production soon

Production from Both Wellbore and Fracs





Pressure decline at the edge of drainage area is approx. **150** psi, after 3 years of production

IP	= 11 MMscf/d
Cum. gas (3yrs)	= **0.275** Bcf

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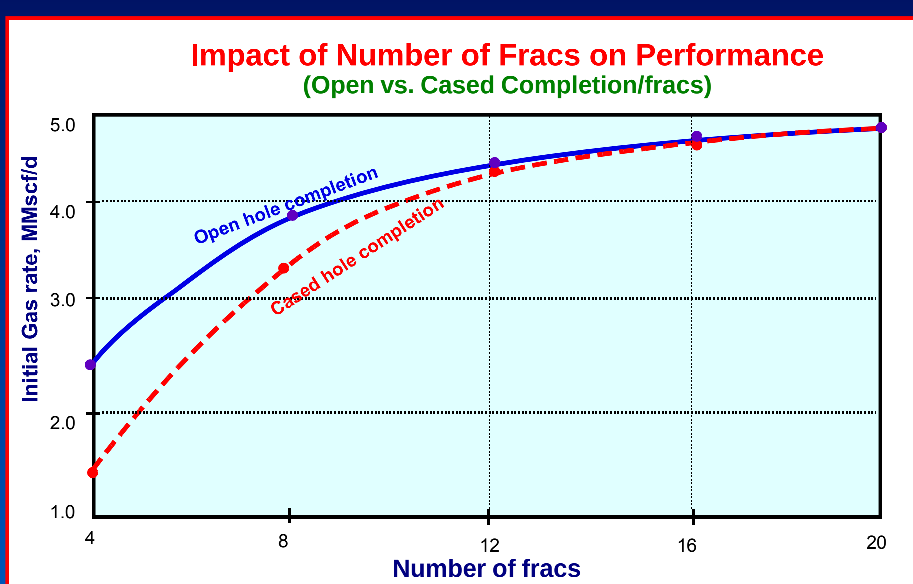
Open hole vs Cased Hole (gas)



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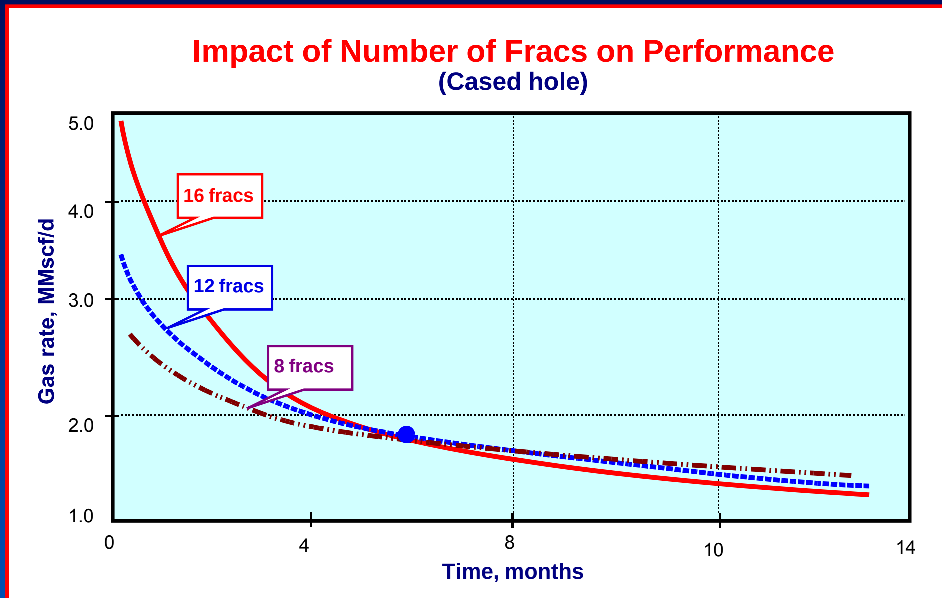
Sensitivity of No. of Fracs vs. Gas Rate



- The larger the no. of fracs, the higher the IP, but..
- Will the larger no. of fracs result in increased reserves, or it is merely a production acceleration?

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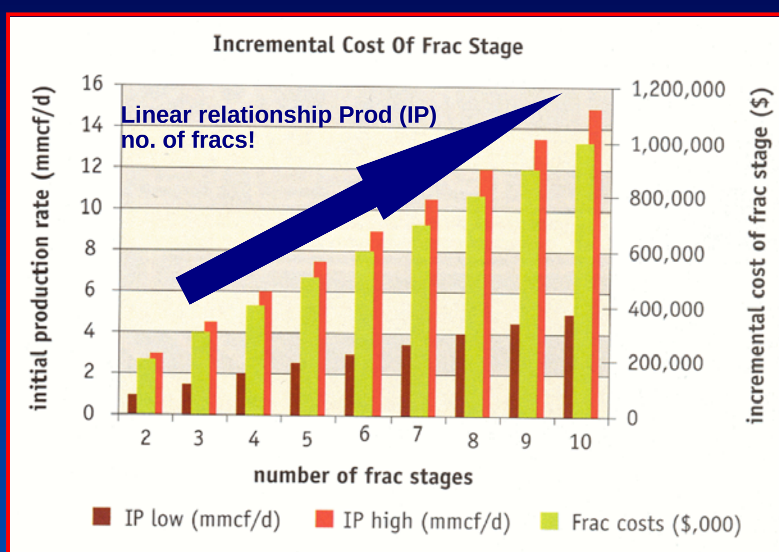
Costs/Benefits of Multi-Stage Fracing



- Each frac increases IP by 0.5 to 1.5 MMscf/d
- Cost of frac treatment and closeness to infrastructure, significantly affect the economics of shale gas in Canada

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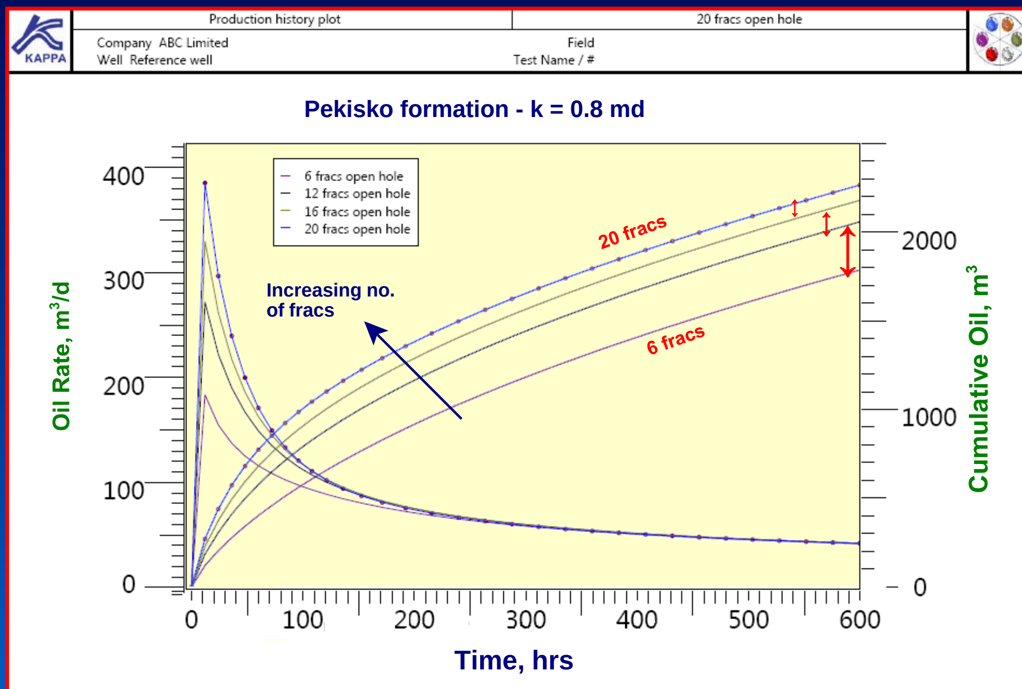
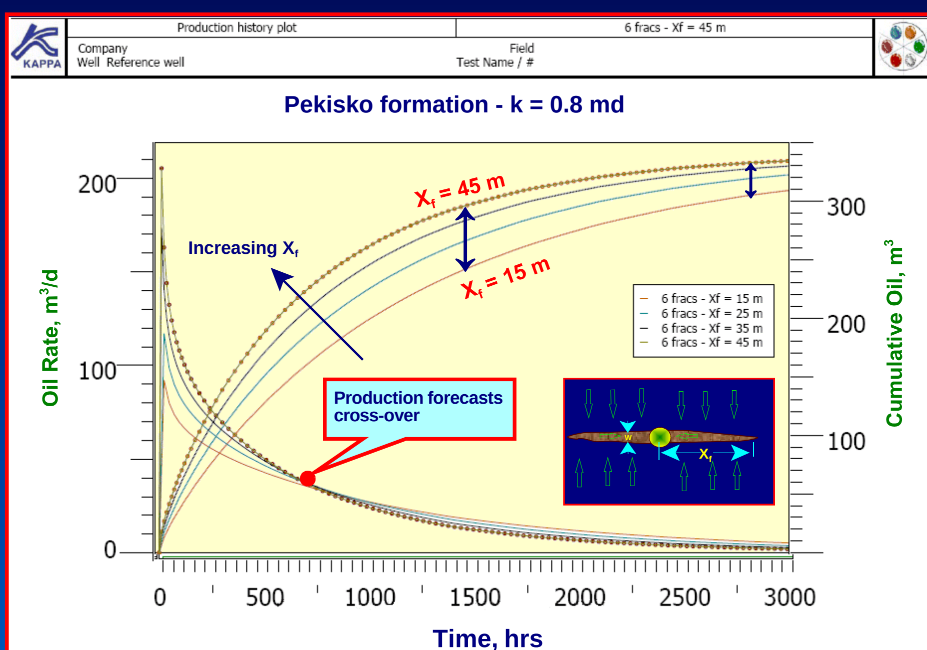
Sensitivity of Number of Fracs



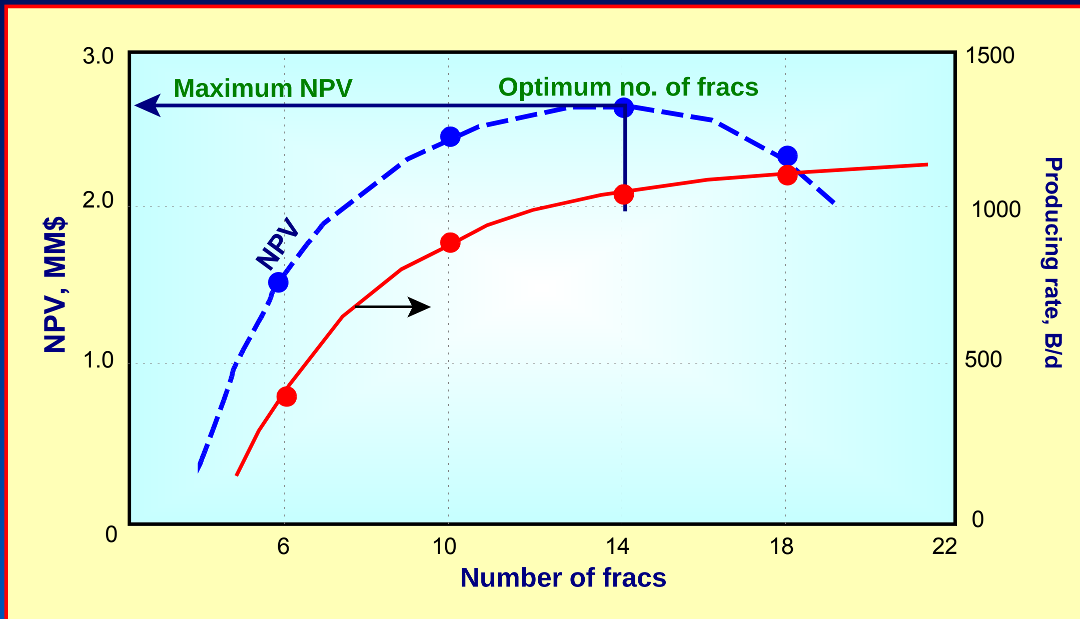
Observation: diminishing return for increasing no. of fracs

Sensitivity of Frac Half-Length, X_f



Observation: will larger fracs add more reserves? Production acceleration? or both?

Optimum Number of Fracs



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Optimization of Frac Location

How to locate the "sweet spot":

- Open hole logs
- Specialized logging tools: FMI, sonic
- Mud logging
- Advanced seismic interpretations
- Core

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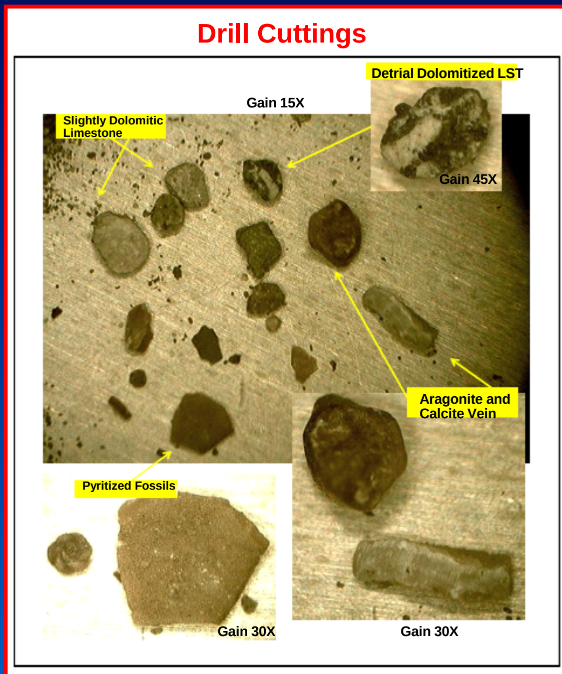
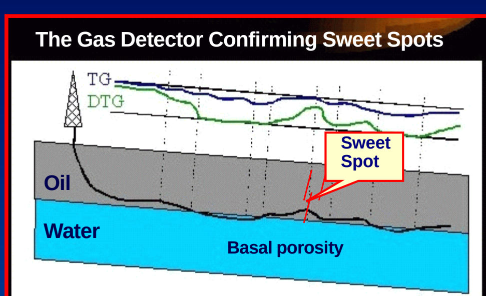
Mud Logging



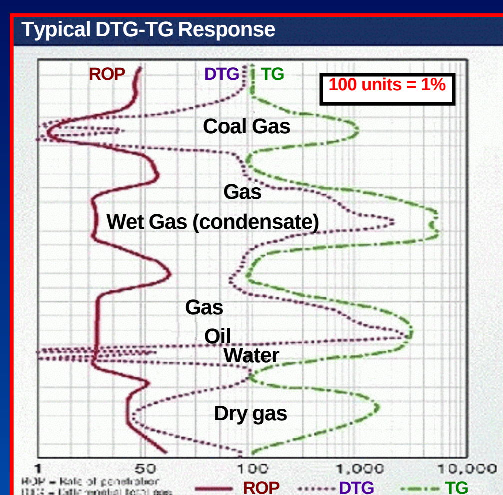
Cuttings samples are collected at the shaker, analyzed and logged (i.e gamma ray)

- Detailed lithological study
- Rock composition
- Fracture identification
- Porosity determination
- Porosity type
- Swelling clays
- Hydrocarbon indication (gas detector)

Identification of Hydrocarbon and Fracture

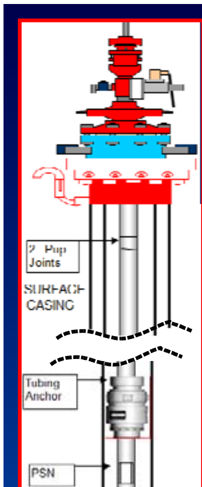


Highlighted zones for pinpoint frac stimulation



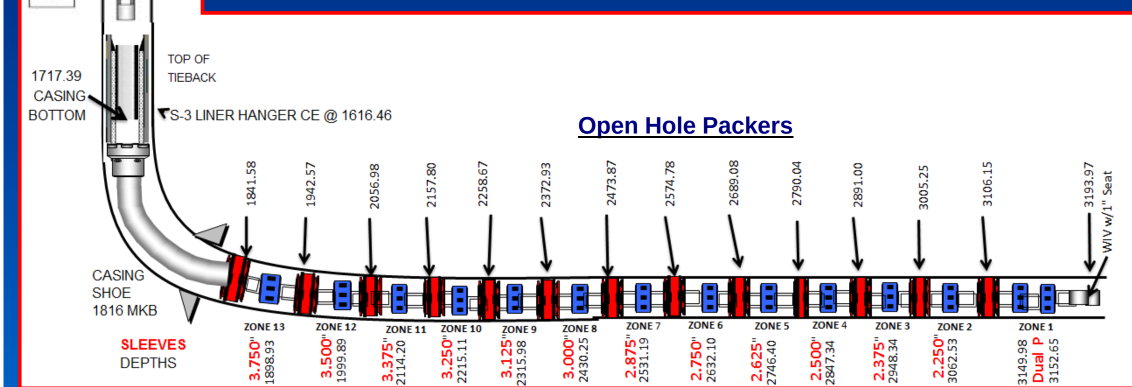
- TG: Total gas (C_1-C_5)
- DTG: Differential total gas (C_3-C_5)

Typical *“MFHW”* Wellbore Diagram



Equally spaced fracs is commonly used; regardless of varying formation characteristics, such as:

- Natural fractures
- High permeability intervals
- Non-reservoir rock
- Wellbore outside target formation



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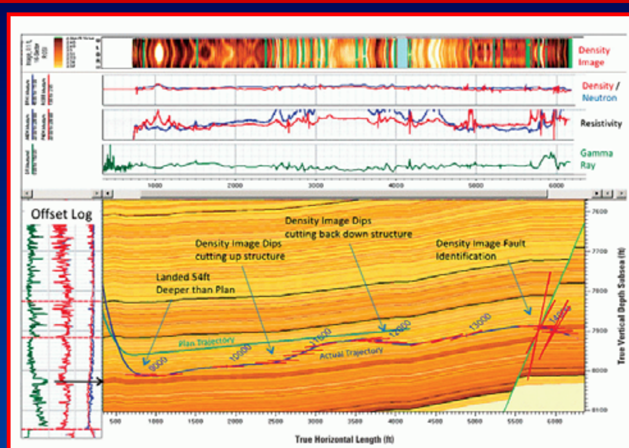
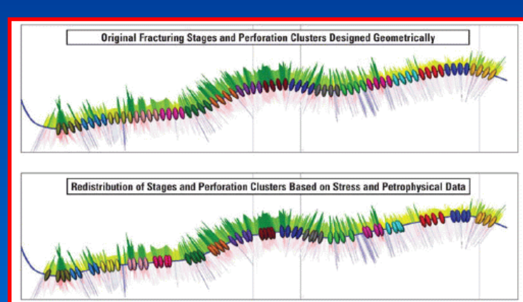
Use of Open Logs to Optimize Frac Locations



Eagle Ford Shale, USA

EcoScope and sonicVISION data revealed dip changes



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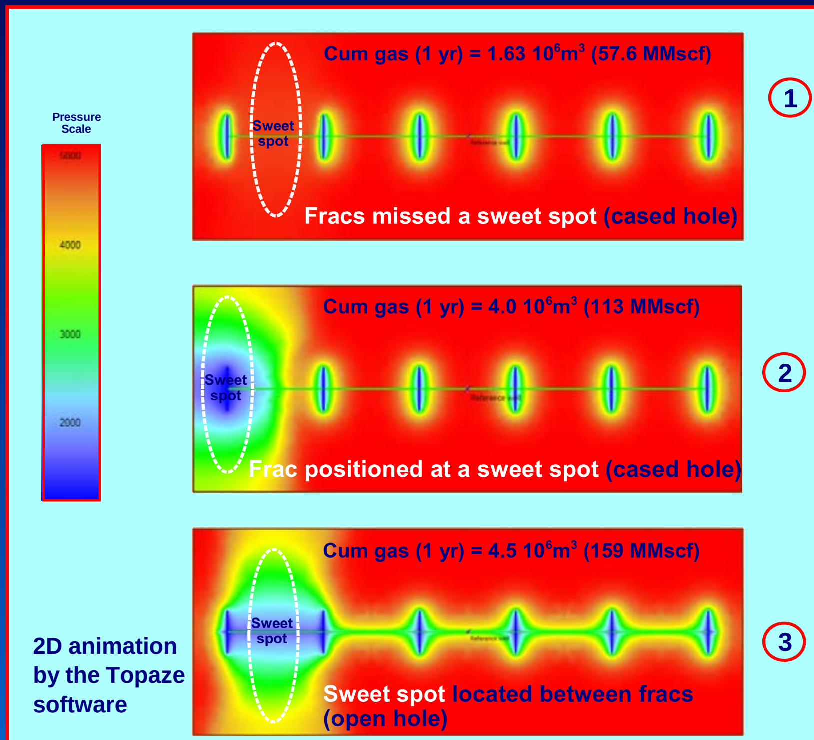
Selection of Frac Location Impact of Sweet Spot

Reservoir model:

- K = 0.1 md
- $K_{(sweet\ spot)}$ = 2 md
- H = 10 m
- X_f = 60 m
- P_i = 5000 kPa
- BHFP = 1000 kPa
- L = 1400 m
- Area = 1600 x 600 m



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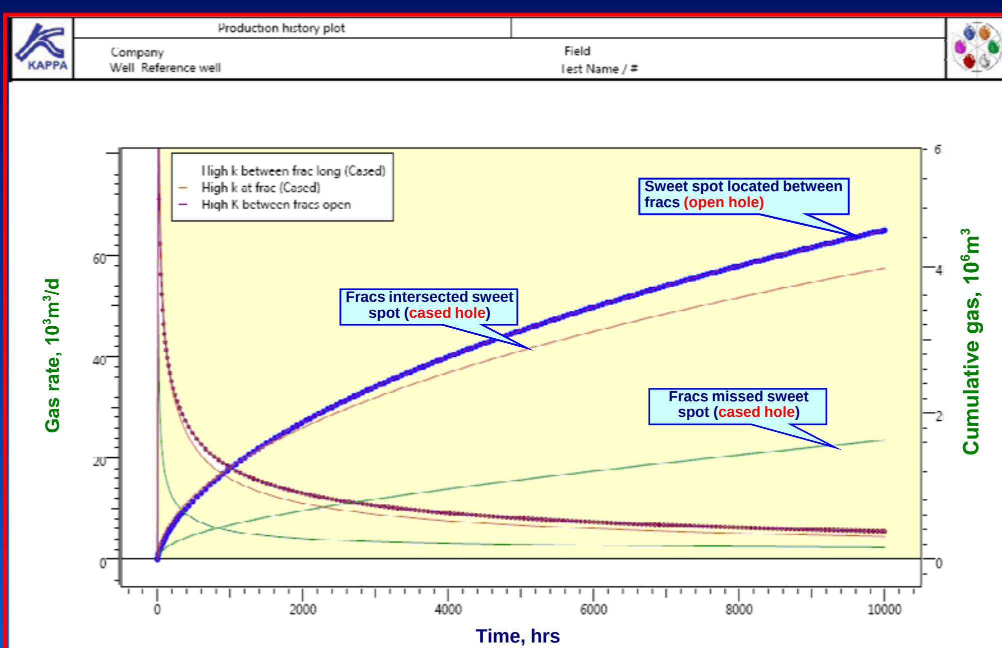
Impact of Frac. Location and Completion Technique on Performance



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Evolution of *“MFHW”*s Well Test Analysis Techniques

- Do not test or evaluate !!
- A vertical well model with a negative model !!
- A horizontal well model with a skin factor
- Use of appropriate model (MFHW) - **Saphir** software
  - Analytical model
  - Numerical model

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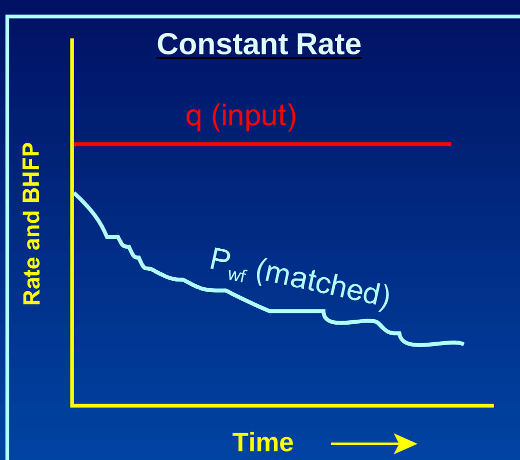
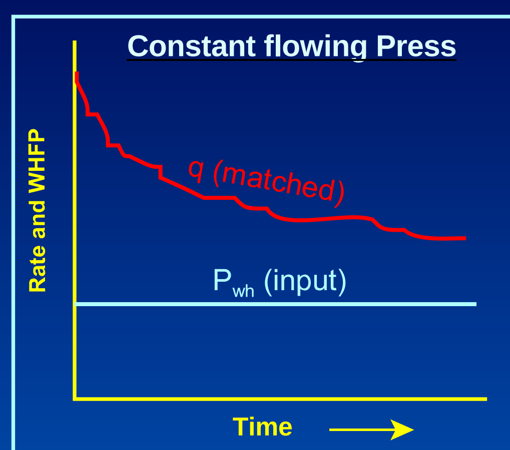
Analysis Techniques

Well Testing (PTA)



Rate Transient Analysis (RTA)



- Constant production rate
- Declining BHFP
- Accurate and frequent measurements
- Short test duration

- Constant BHFP
- Declining production rate
- Sparse and inaccurate/noisy pressure data; usually WHFP
- Long period of flow data

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Case Study - Shale Gas

Horn River Basin (HRB)
B.C - Canada

Use of production analysis (PA) to estimate:

- Reservoir parameters; k, s, P*
- Evaluate frac parameters
- Production forecast and reserves

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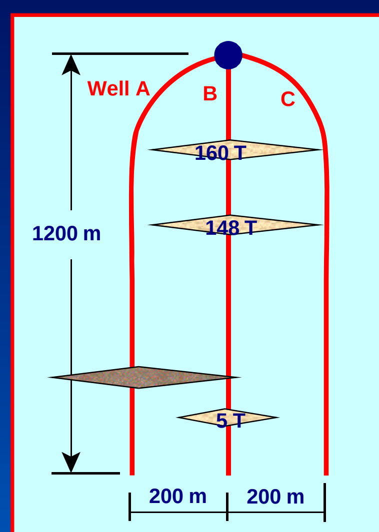
Background Information (Well B)

Three-well pad development:

- Six frac stages were attempted; only 3 were successful.
- Sand was not pumped in 3 stages due to unexpected high break-down pressure
- During the frac operation of well “A”, the frac broke-through into well “B”
- Production history of well “B” after the frac break-through was excluded from the analysis



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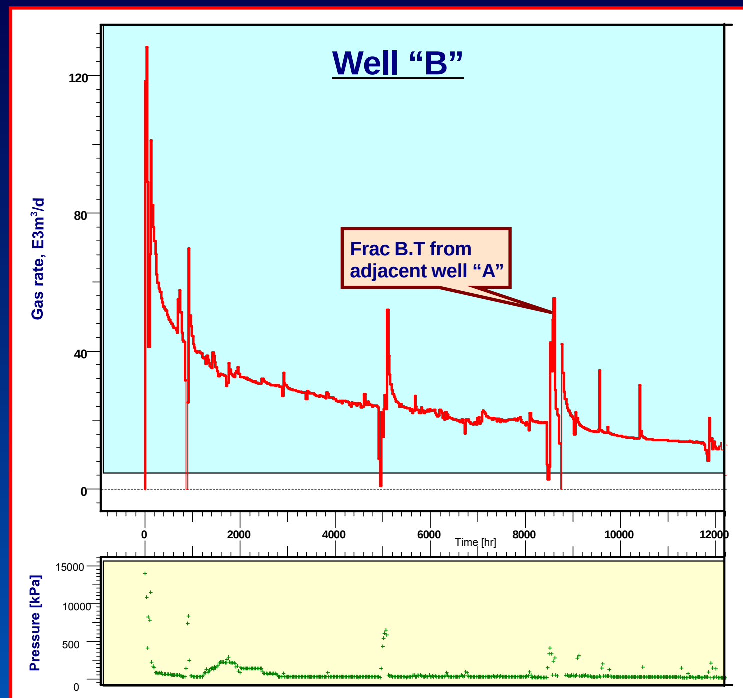
Frac Break-through (hit)

- H = 120 m
- ϕ = 4.8%
- S_w = 10%
- mPP = 2450 mTVD
- R_w = 0.114 m
- WGR = 0.08 $m^3/E3m^3$



Production history of well "B" after break-through was excluded from the analysis

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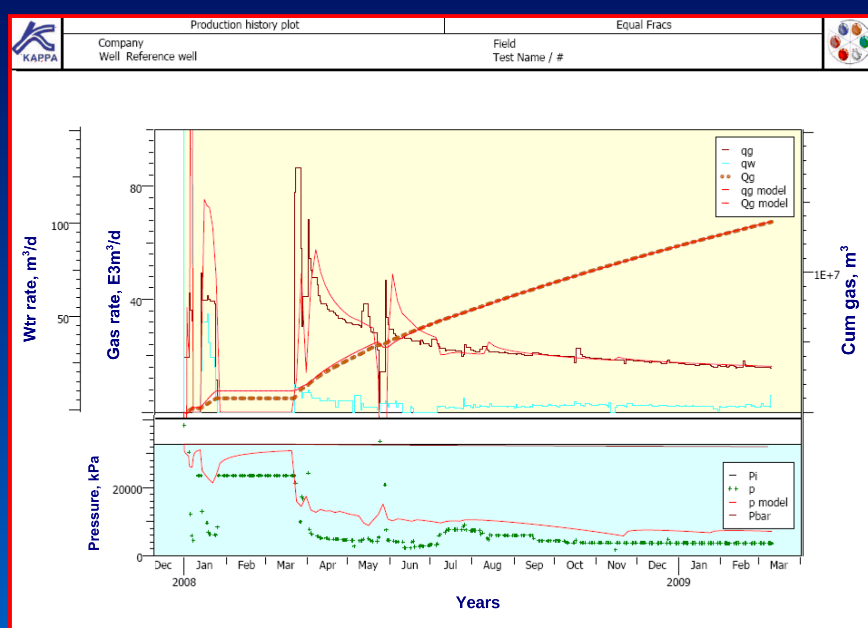
History Matching Results
Model: Equal Frac Parameters

Multi-stage Frac Hz Well (MFHW)

Model Parameters
Reservoir & Boundary parameters

Pi	32800 kPa
k.h	0.0789 md.m
k	6.57E-4 md
Lw	697.82 m
Well Skin (Lw)	0.0980468
No of Fractures	3
Xf of Fractures	66.944 m
hf of Fractures	120 m
Fc of Fractures	3.18156 md.m
Zw	60 m
kz/kr	0.1
S - No flow	200 m
E - No flow	800 m
N - No flow	200 m
W - No flow	800 m



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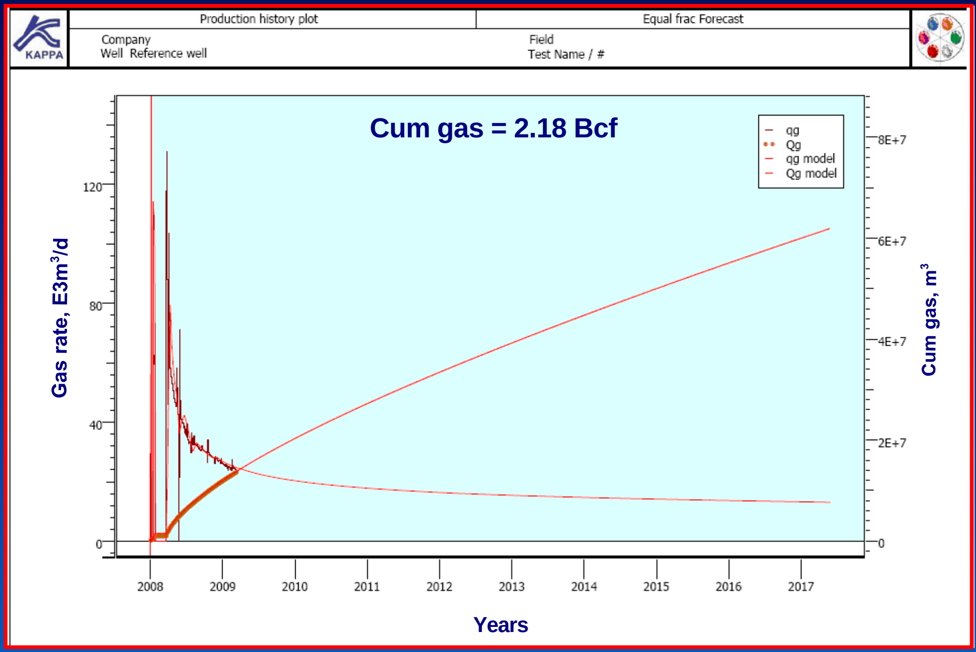
Production Forecast - Equal Frac Model



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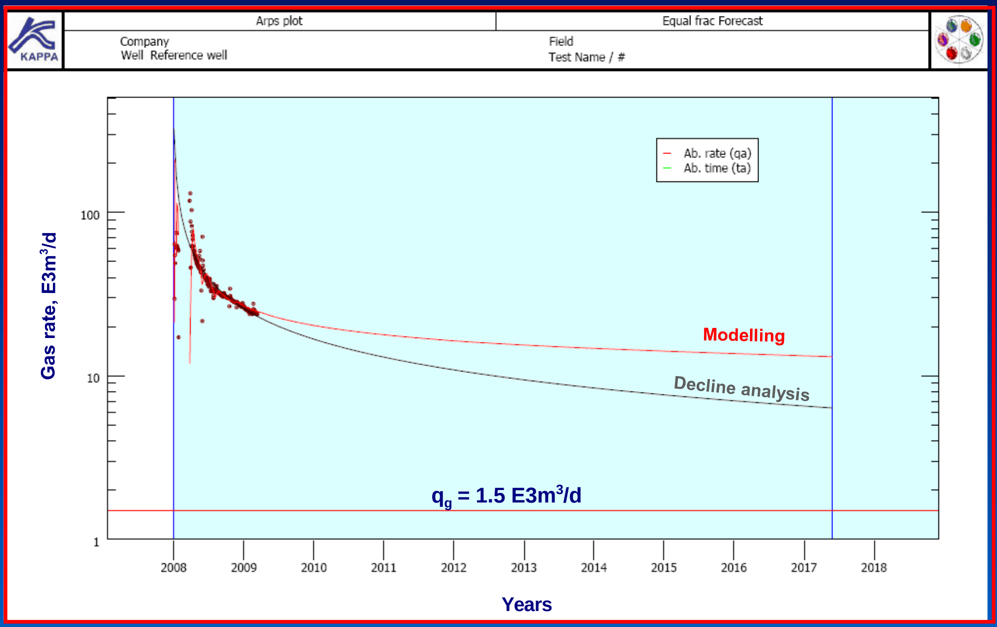
ARPS vs. Modelling
(b = 1.58)



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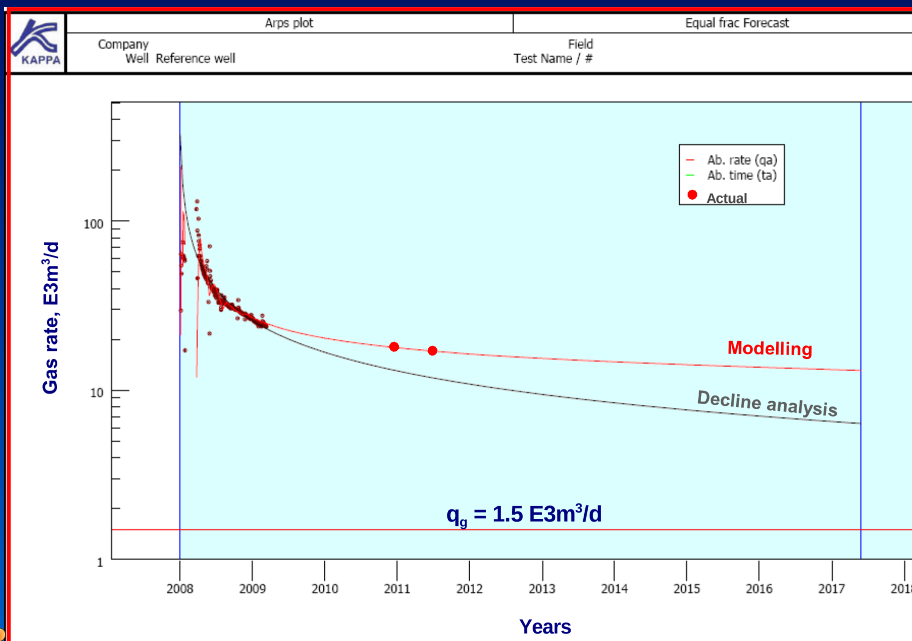
Which Production Forecast Matches Actual History?



Well ID	200/d-070-J 094-O-08/02			
Date	Monthly Production			Daily
	Gas E3m3	Wtr m3	Hrs Hrs	Gas E3m3
2007-04	941.6	0.0	597.6	37.82
2007-05	1131.9	0.0	698.4	38.90
2007-06	938.9	0.0	720.0	31.30
2007-07	999.2	44.3	744.0	32.23
2007-08	817.7	32.7	657.6	29.84
2007-09	931.4	29.0	691.2	32.34
2007-10	762.9	29.2	667.2	27.44
2007-11	449.1	11.0	403.2	26.73
2007-12	694.5	86.5	516.0	32.30
2008-01	703.8	30.0	657.6	25.69
2008-02	181.0	0.6	165.6	26.23
2008-03	0.0	0.0	0.0	0.00
2008-04	0.0	0.0	0.0	0.00
2008-05	0.0	0.0	0.0	0.00
2008-06	279.6	0.0	549.6	12.21
2008-07	358.9	0.0	744.0	11.58
2008-08	327.7	0.0	744.0	10.57
2008-09	230.1	0.0	720.0	7.67
2008-10	247.6	0.0	588.0	10.11
2008-11	264.8	0.0	626.4	10.15
2008-12	249.3	0.0	744.0	8.04
2009-01	224.3	0.0	679.2	7.93
2009-02	182.1	0.0	448.8	9.74
2009-03	242.8	0.0	472.8	12.32
2009-04	221.5	0.0	720.0	7.38
2009-05	223.1	0.0	744.0	7.20
2009-06	182.8	0.0	273.6	16.04
2009-07	207.0	0.0	372.0	13.35
2009-08	189.1	0.0	302.4	15.01
2009-09	165.6	0.0	295.2	13.46
2009-10	162.6	0.0	266.4	14.65
2009-11	173.7	0.0	300.0	13.90
2009-12	135.3	0.0	232.8	13.95
2010-01	137.1	0.0	230.4	14.28
2010-02	79.3	8.0	134.4	14.16
2010-03	158.1	12.0	273.6	13.87
2010-04	148.6	11.0	240.0	14.86
2010-05	144.4	20.0	223.2	15.53
2010-06	111.9	8.0	168.0	15.99
2010-07	75.9	6.0	124.8	14.60
2010-08	0.0	0.0	0.0	0.00
2010-09	361.2	11.0	292.8	29.61
2010-10	266.9	3.0	252.0	25.42
2010-11	401.2	17.0	564.0	17.07
2010-12	279.7	22.0	218.4	30.74
2011-01	174.0	13.0	187.2	22.31
2011-02	138.7	2.0	180.0	18.49
2011-03	173.9	3.0	175.2	23.82
2011-04	151.3	0.0	216.0	16.81
2011-05	141.4	0.0	194.4	17.46
2011-06	133.5	0.0	168.0	19.07
2011-07	124.9	0.0	163.2	18.37
2011-08	122.4	0.0	151.2	19.43
2011-09	117.9	0.0	148.8	19.02

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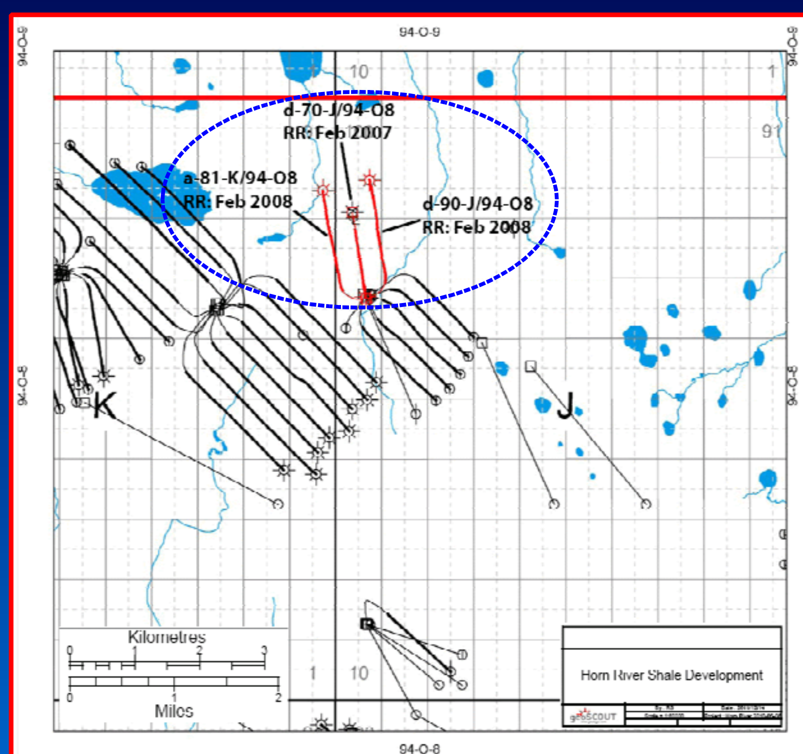
Horn River Field Development

Orientation of subsequent Hz wells is revised



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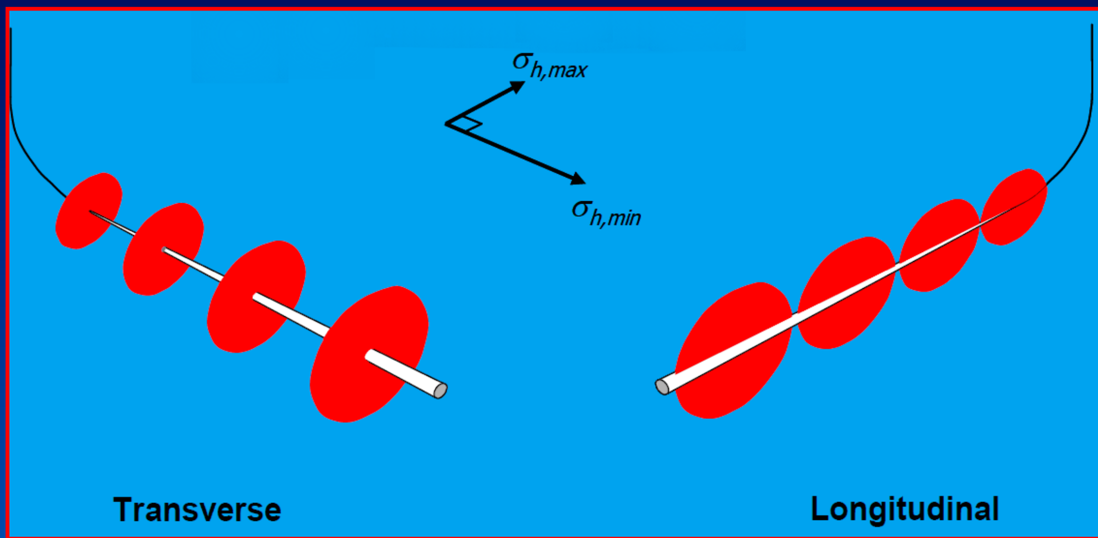
Transverse vs Longitudinal Frac



"Longitudinal" fracs could produce 50% less than "Transverse" fracs

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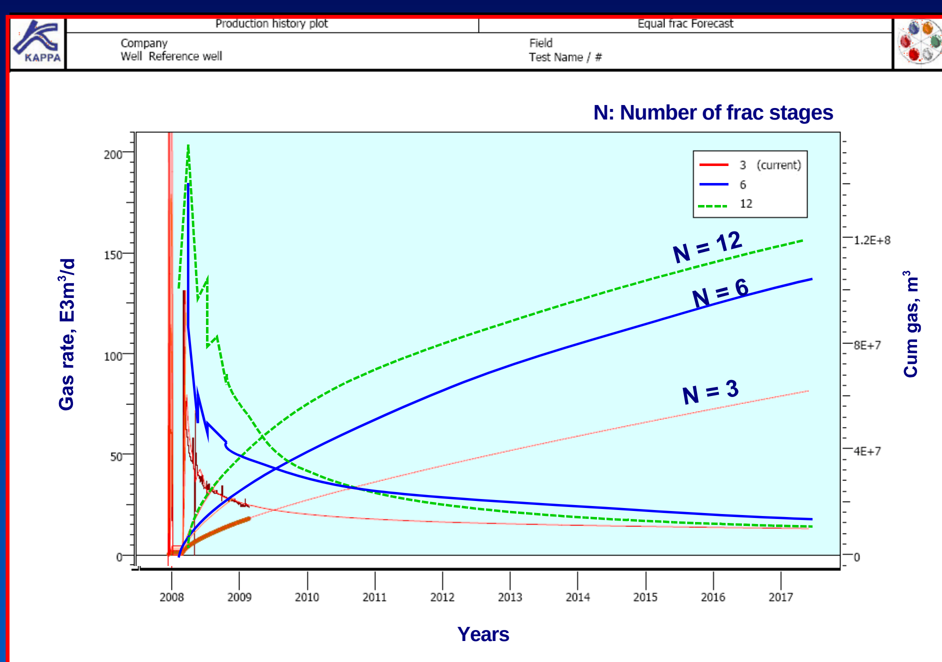
Sensitivity Analysis - No. of Frac Stages



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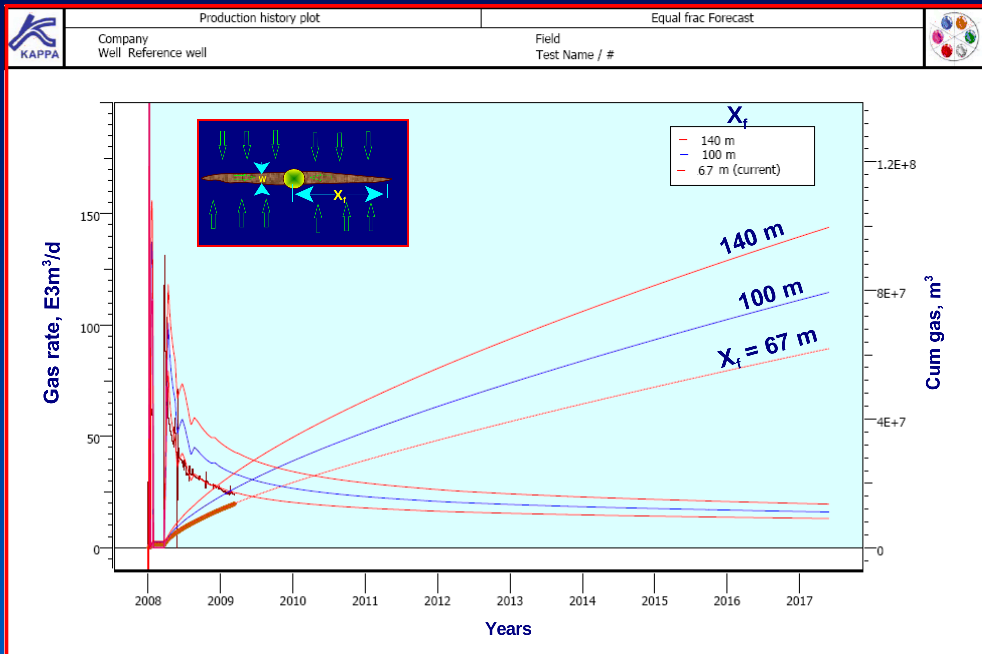
Sensitivity Analysis - Size of Fracs (X_f)



X_f: Frac half-length

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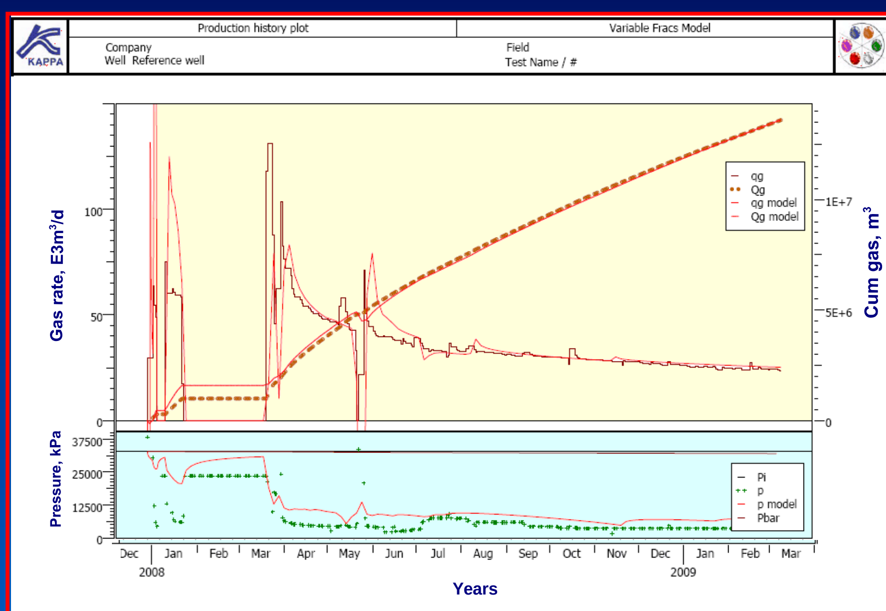
History Matching Results
Model: Variable Frac Parameters

Multi-stage Frac Hz Well (MFHW)

Model Parameters
Reservoir & Boundary parameters

Pi	32800 kPa
k.h	0.094 md.m
k	7.84E-4 md
Lw	604.487 m
Well Skin (Lw)	0.01
Zw	60 m
kz/kr	0.1
No. of Fractures	3
Fracture 1	
Distance	200 m
Xf	5.26635 m
hf	120 m
Fc	1524 md.m
Frac Skin (Lw)	0.0100473
Fracture 2	
Distance	200 m
Xf	103.038 m
hf	120 m
Fc	1523.99 md.m
Frac Skin (Lw)	0.871168
Fracture 3	
Distance	200 m
Xf	77.3087 m
hf	120 m
Fc	1524.06 md.m
Frac Skin (Lw)	0
S - No flow	200 m
E - No flow	800 m
N - No flow	200 m
W - No flow	800 m
Well Intake	
Gauge Depth	N/A m
Bottomhole Depth	2450 m



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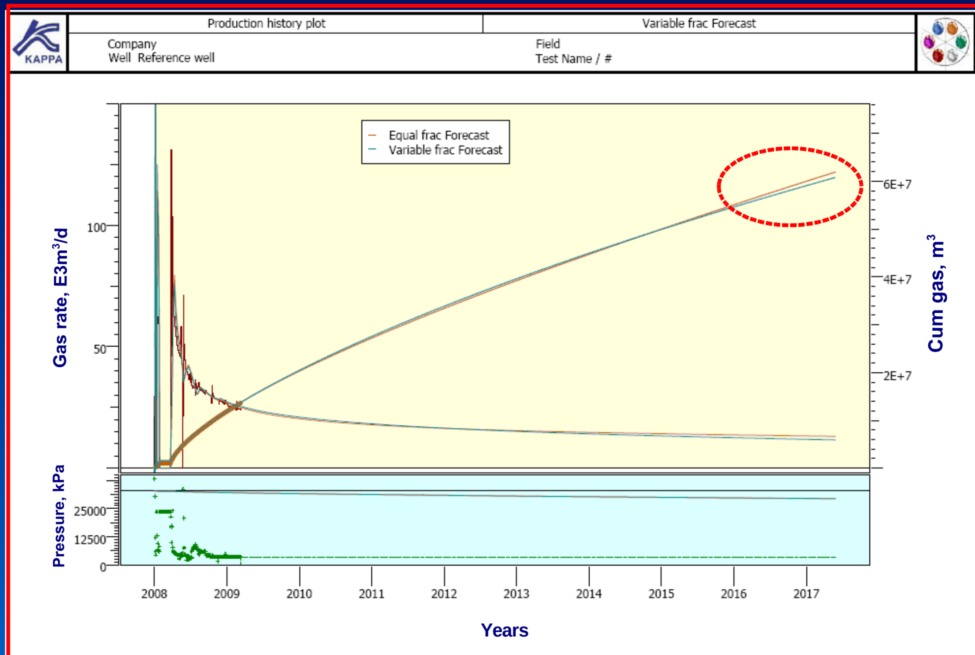
Comparison of Prod Forecasts
Fixed and Variable Fracture Parameters



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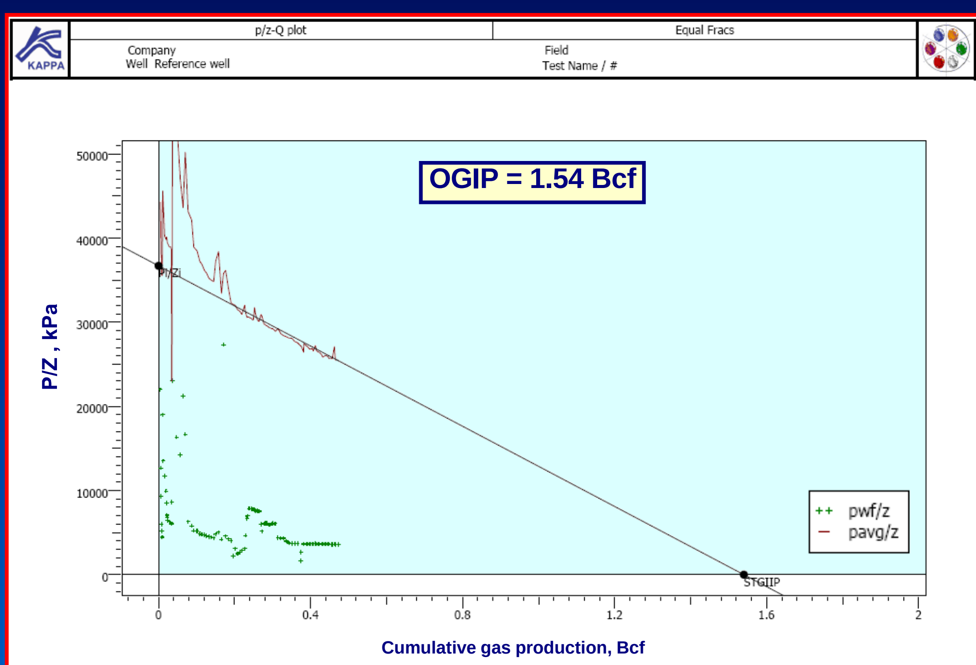
Flowing Material Balance (no desorption)



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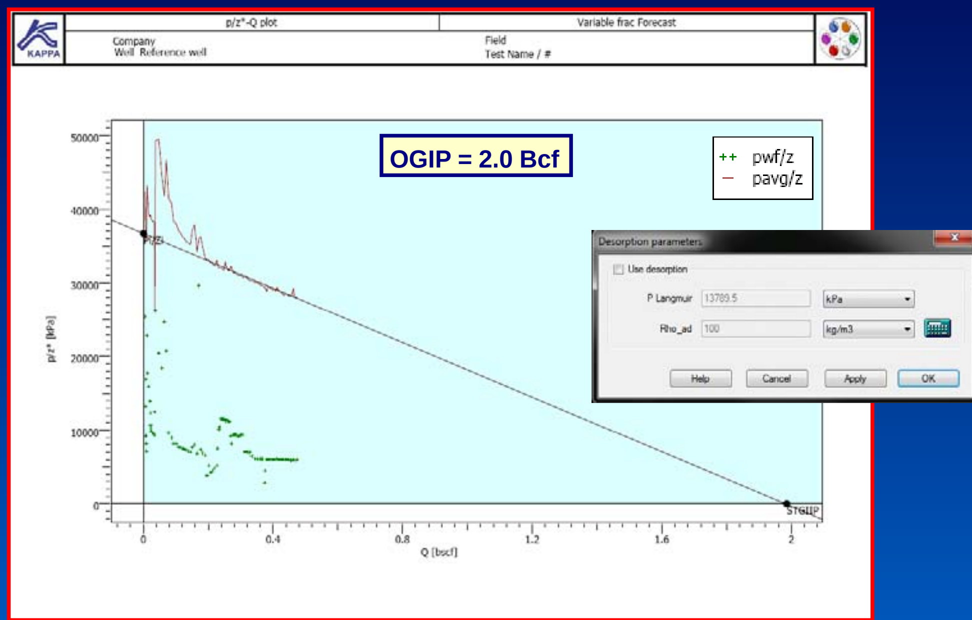
Flowing Material Balance (with desorption)



Z*: Corrected z factor, by King

Well Fracability

Well fracability describes the ability to initiate and create a desired frac extension with good conductivity. The main factors that affect well fracability are:

- Formation mechanical properties
- Rock mineralogy
- Presence of natural fractures
- Pre-existing local stresses
- Formation permeability
- Pore pressure vs treating pressure

Rock Mechanical Properties

The formation geo-mechanical Characteristics should be included in the frac design optimization to maximize well performance, by utilizing the formation geo-mechanical parameters below:

- Brittle vs ductile
- Brittleness Index
- Rock mineral contents
- Poisson's ratio
- Young's modulus
- Lame's Elastic Moduli

Open holes & Dipole Sonic

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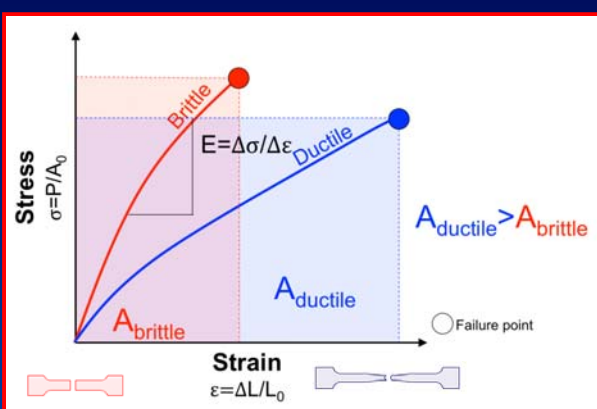
Brittle vs. Ductile



Ductile material

$$E = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{\sigma}{\varepsilon}$$

E: Young's modulus, the higher "E" the more brittle the rock

A material is **brittle** if, when subjected to stress, it breaks without significant deformation (strain). Brittle materials absorb relatively little energy prior to fracture, even those of high strength. Breaking is often accompanied by a snapping sound.

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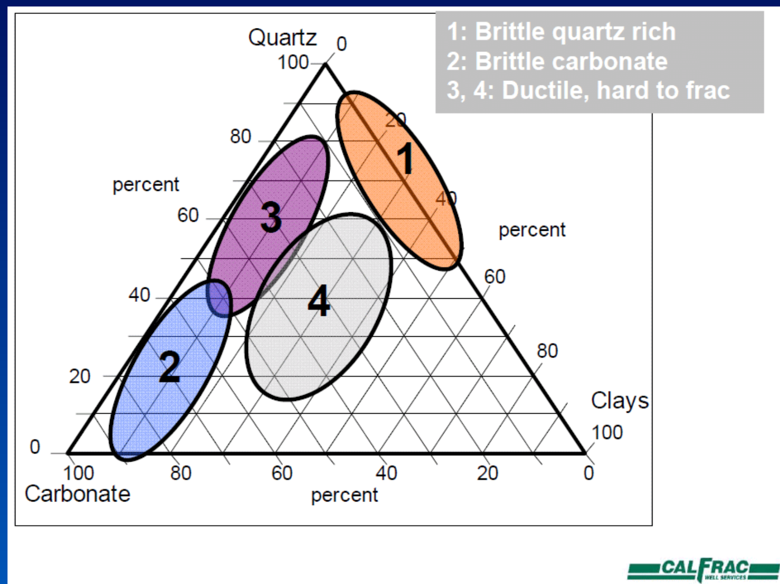
Influence of Mineralogy on Shale Characteristics



Ternary Diagram

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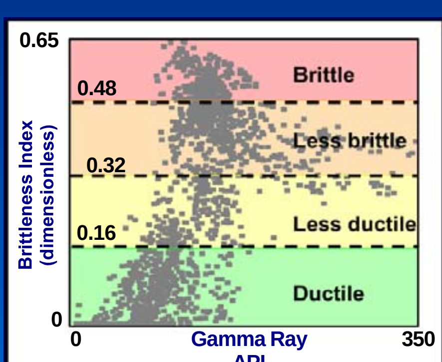
Brittleness Index (BI)

Javie (2007):

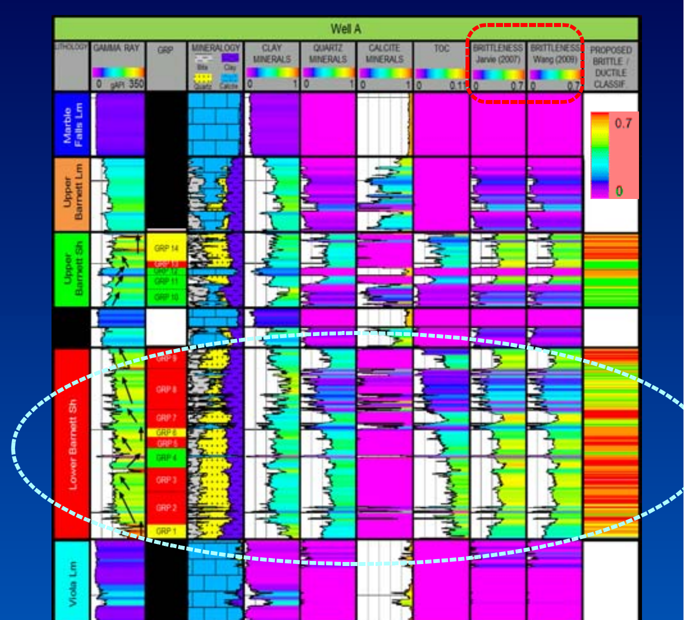
$$BI = \frac{Q_z}{Q_z + Ca + Cly}$$

Wang (2009):

$$BI = \frac{Q_z + Dol}{Q_z + Dol + Ca + Cly + TOC}$$



High BI is desirable



Lower Barrnett

Where:

Q_z = Quartz
Ca = Calcite
Cly = Clay
Dol = Dolomite
TOC = Total Organic Carbon

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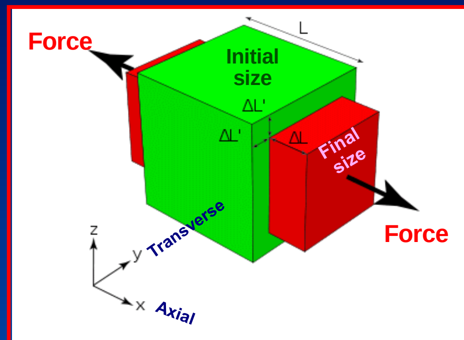
Poisson's Ratio (ν)

Poisson's ratio is the ratio of transverse contraction strain to longitudinal extension strain in the direction of stretching force



$$\nu = \frac{d\varepsilon_{trans}}{d\varepsilon_{axial}}$$

Use of (ν):

To convert the effective vertical stress component into an effective horizontal stress component. The effective stress is defined as the total stress minus the pore pressure.

Where:

ν : Poisson's ratio

ε_{trans}: Transverse strain (negative for tension or stretching), positive for axial compression

ε_{axial}: Axial strain (positive for axial tension), negative for axial compression .

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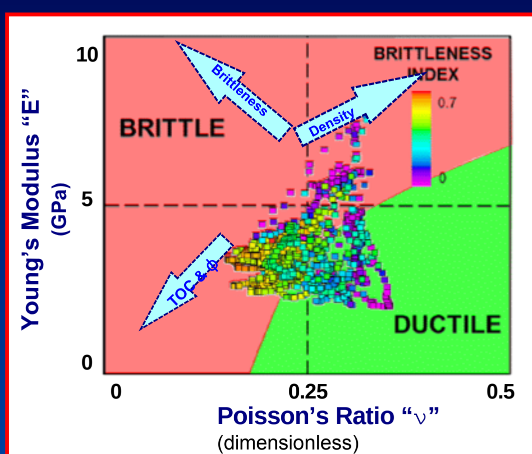
Geo-mechanical Property



Young's Modulus (E)	
Soft clay	1-3 MPa
Hard clay	6-14 MPa
Loose sand	10-28 MPa
Dense sand	35-69 MPa
Granite	10-70 GPa
Sandstone	1-20 GPa
Shale	1-70 GPa
Limestone	15-55 GPa

Poisson's ratio (ν)	
Sandy Soil	0.25-0.4
Gravel soil	0.15-0.35
Granite	0.1-0.3
Sandstone	0.21-0.38
Shale	0.2-0.4
Limestone	0.18-0.33
Chalk	0.35

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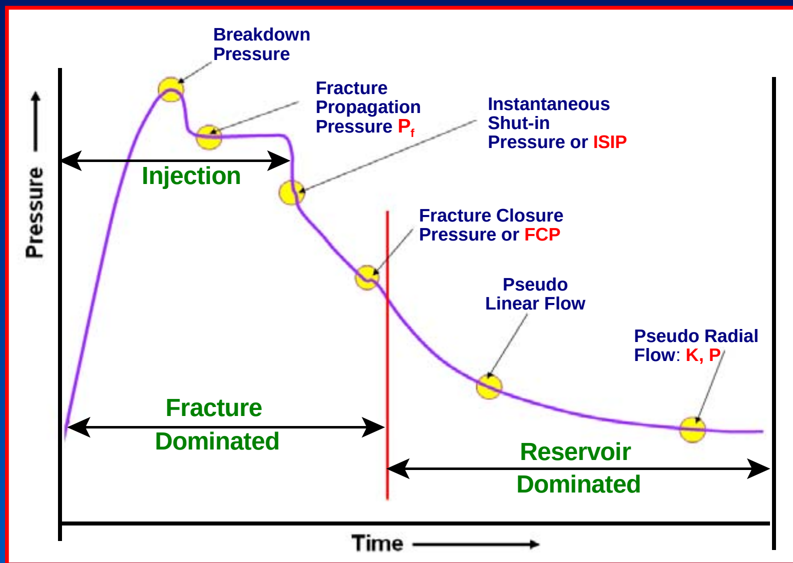
Mini Frac Test (DFIT)

Information obtained from DFIT: K, P_R, FCP, ...



ISIP: the minimum pressure required to hold open a fracture

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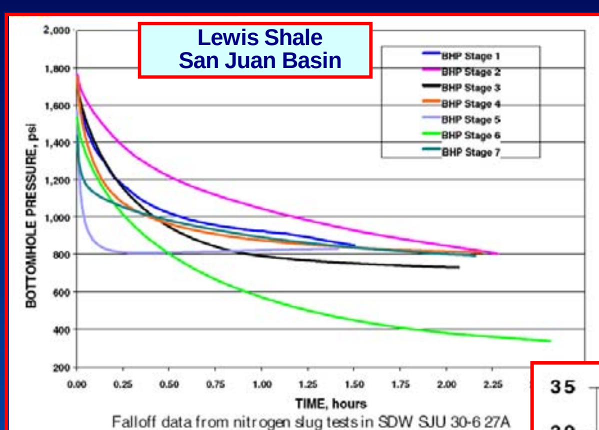
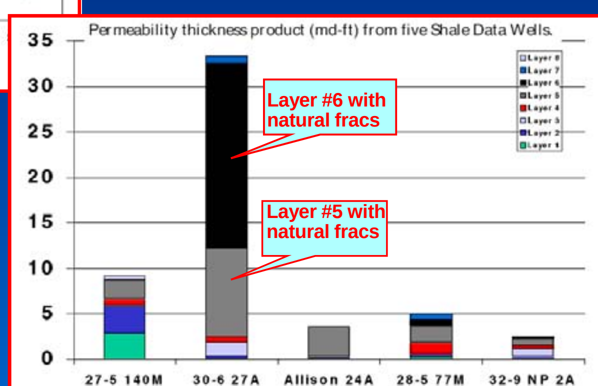
Permeability Estimate in Shale Gas



Why N_2 injectivity/fall-off Test?

- Well can not flow
- Flow/build requires long tests
- Expensive to test many intervals for CBM/shale



Ref: SPE: 63091

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What is New in Performance Evaluation of MFHW's

- **Segmented decline curve analysis**
- PLT and Tracer surveys

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Performance Evaluation Tools Besides RTA

Facts:

RTA tools are reliable, but it take a long time to perform and requires pressure data.....

Reality:

My boss wants me to finish my reserves evaluation for 200 wells in one week, how about decline curve analysis (DCA)?

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Limitations of DCA

- The decline curve analysis by **Arps**, should only be applied when production is stabilized; when **P.S.S** is reached
- Arps assumes that the values **"b" and "D" are constants** for the full production history, which might not be appropriate for tight formations
- Bottom hole flowing pressure is assumed constant
- No change in operating conditions
- Fetkovich (1990) indicated that a value of **b > 1** should not be used for reserves determination (SPE 116731)

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DCA Parameters ("D" and "b")

$$D(t) = -\frac{1}{dq(t)} \cdot \frac{q(t)}{dt}$$

Decline constant

$$\frac{1}{D(t)} = -\frac{q(t)}{dq(t)/dt}$$

Loss-ratio

$$b(t) = \frac{d}{dt}\left[\frac{1}{D(t)}\right] = -\frac{d}{dt}\left[\frac{q(t)}{dq(t)/dt}\right]$$

Derivative of loss-ratio

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Different DCA Tools

DCA is an empirical tool, using different curve/line fitting to match production history and extrapolate to predict future performance

- Arps in 1945 (fixed decline constant)
- Modified hyperbolic
- Power Law Loss-Ratio by Ilk in 2008 (variable decline constant) - SPE # 116731
- Stretched exponential - Valko (SPE 134231)
- Duong linear model - (SPE 137748)
- Segmented decline model (KAPPA/Topaze)

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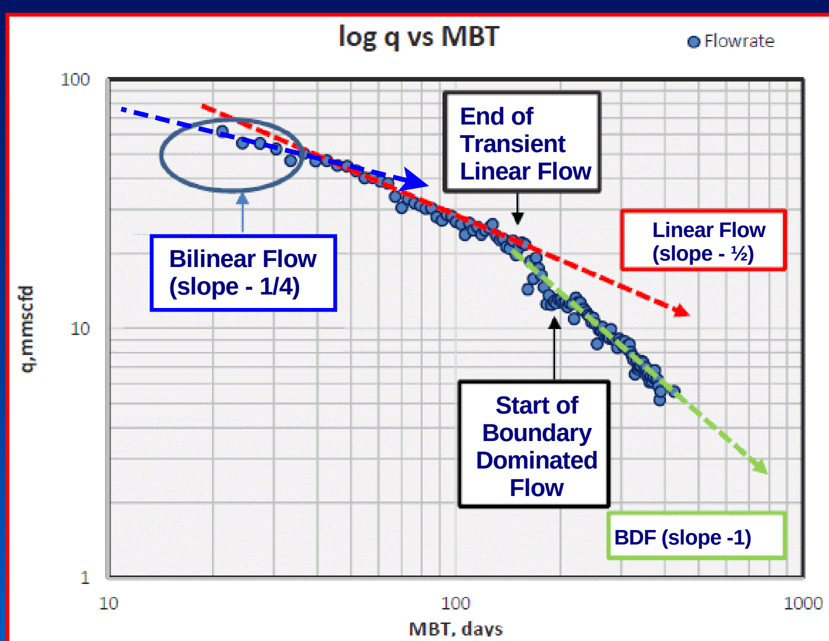
Identification of Flow Regimes
(production data only)



Source: John Lee

MBT: Material balance time - $\mathbf{N_p/q}$ = Bbl/(Bbl/day) = time

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DCA Parameters ("D" and "b")

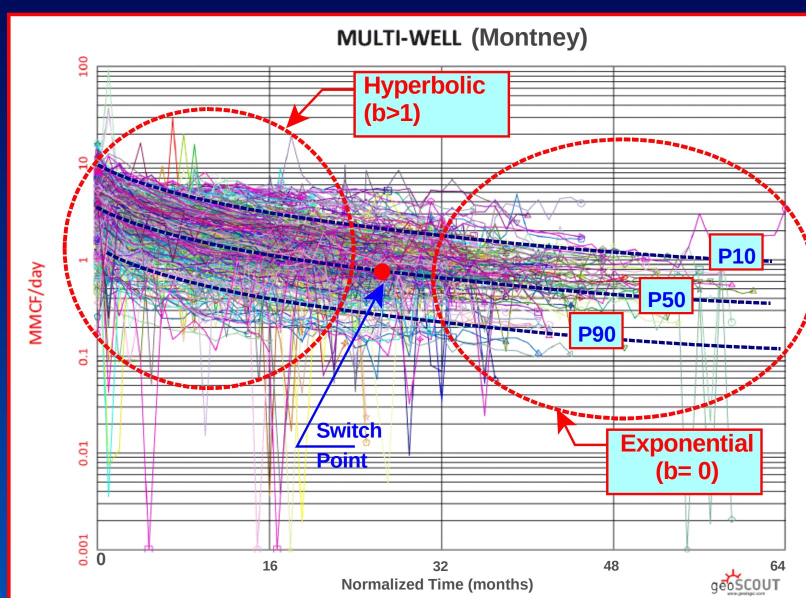
- **For conventional reservoirs,** Arps DCA is used:
  - Good for wells at P.S.S (stabilized)
  - Constant values of (D & b)
- **For tight formations**, the values of "b" are approximately the inverse of the slope of the diagnostic straight lines (rate vs time plot):
  - **Bilinear flow:** Corresponds to a slope of -1/4 ⟶ b ≈ 4
  - **Linear flow:** Corresponds to a slope of -1/2 ⟶ b ≈ 2
  - **BDF:** Corresponds to a slope of -1 ⟶ b ≤ 1

Remember, we can not use b>1 to estimate reserves

Reserve Estimates by Well Type

Commercial software:

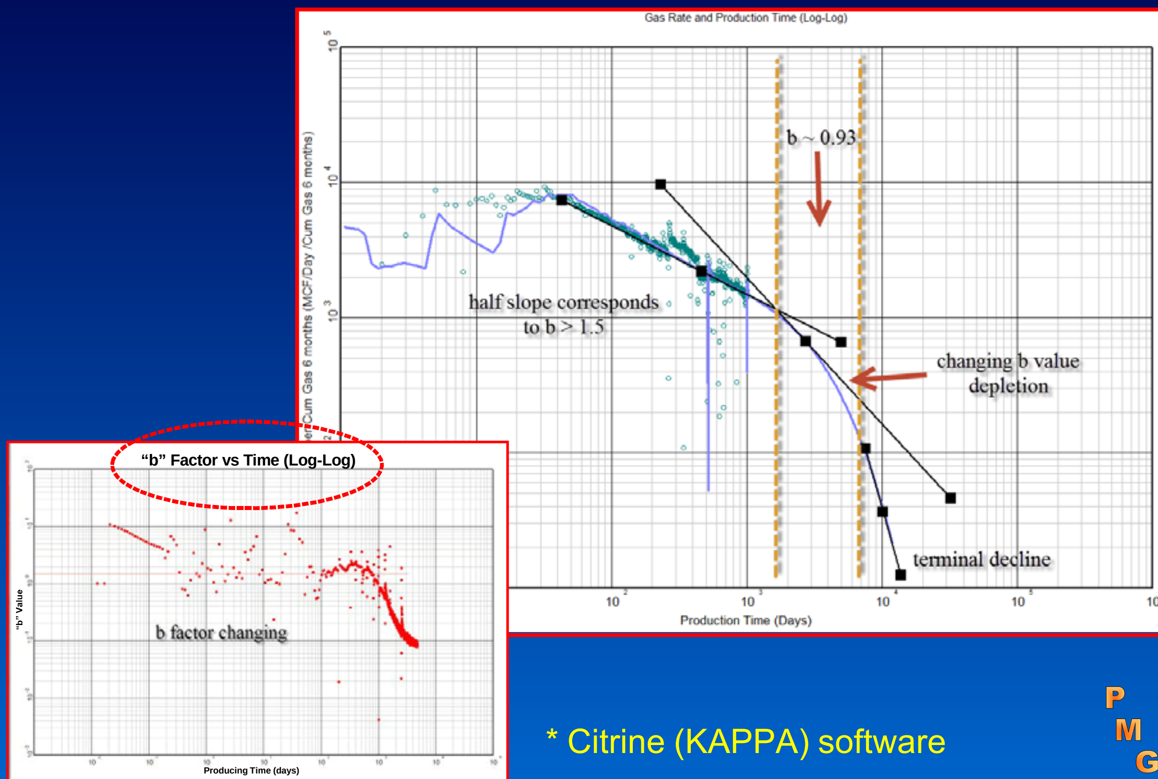
- Harmony (Fekete)
- Citrine (KAPPA)



Literature suggests the early hyperbolic decline (b>1) be switch, when the annual decline rate reaches ≈ 5%, to the following:

- Exponential decline (b=0) - **Modified exponential**
- Hyperbolic decline (b ≈0.4 to 0.5) - **Modified hyperbolic**

Use of "Segmented" Decline Analysis



* Citrine (KAPPA) software

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What is New in Performance Evaluation of MFHW's

- PLT and Tracer surveys
- Segmented decline curve analysis

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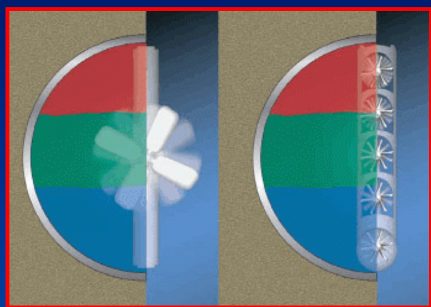
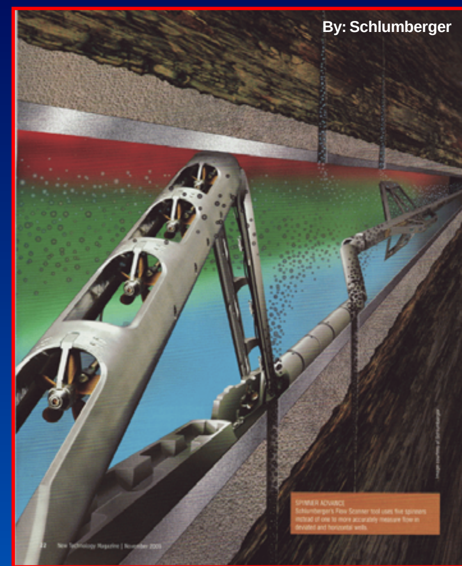
Production Logging Tools (PLT)

To identify production contribution from each frac stage



Issues of concerns:

- Is not cheap
- Yield a one-time (instantaneous) production data profile
- Well intervention could create operational problems.



A manoeuvrable arm to deploy 5 sensors along the vertical axis for non-vertical wells to obtain velocity measurements in mixed and segregated flow regimes.

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Conventional Tracer Survey

Typical operation:

- Tracers; chemical or radio-active, are injected with the frac fluids.
- Different type of tracers are injected in each frac stage
- The well is placed on flow back, after completion of the frac job. Based on the concentration and type of tracers recovered, production is allocated to each frac stage

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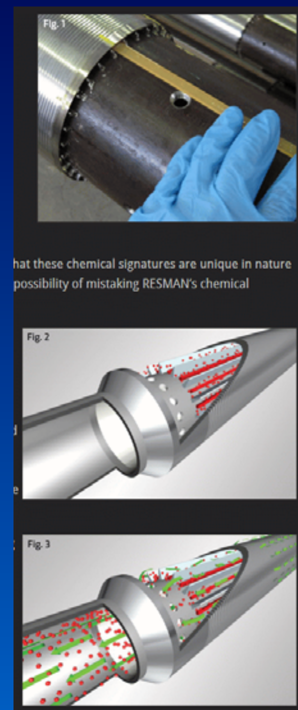
Controlled Release Tracer Surveys*

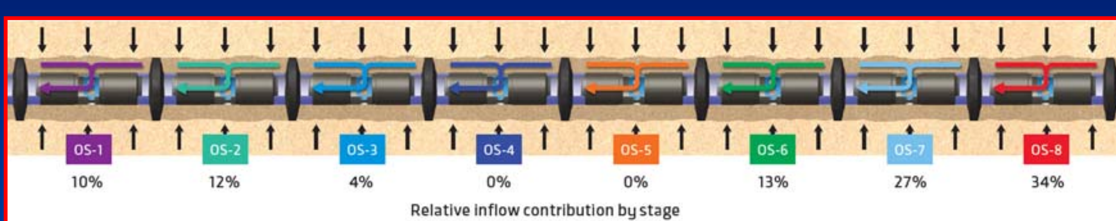
- Risk-free: no cables, no connections, no intervention, and no major changes to completion design.
- Long-term: oil Intelligent Tracers (RES•OIL) can achieve up to 5 years of life. The water Intelligent Tracers (RES•H2O) can have longer life-spans because they are dormant until activated by contact with water.
- Cost-efficient: no additional rig time, no expensive completion hardware, and no extra personnel required at the well site.
- HSE-friendly: RESMAN chemicals are used in extremely low concentrations (down to parts per trillion) and are compatible for water discharge. No radiation is used.

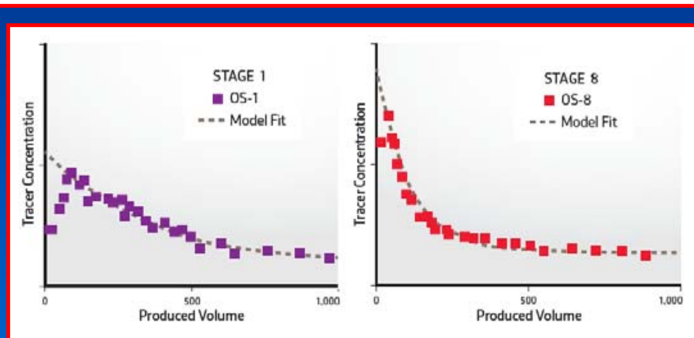


* By: Resman - Norway

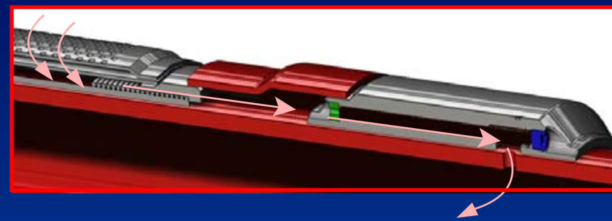
Results of Tracer Survey

The RES•OIL systems were placed in the annular space, adjacent to the frac valves from each stage via pup-joint carriers. The equipment was run in-hole without deviating from normal procedures and with no additional rig time or extra personnel at site.





Installation of controlled Release Tracers



A number of ICD's were opened by the ICD contractor, controlled release tracer was wrapped around the base pipe of the ICD and secured in place. ICD was sealed trapping the tracer within. Results in 145 days confirmed flow from Toe

By: Tracerco (London/UK)

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Closing Comments

- It is essential to evaluate the **design options** of MFHW's to maximize the NPV.
- The PTA and RTA analysis of MFHW's is still a challenge; additional information can improve interpretations, such as:
  - FMI logging
  - Micro-seismic
  - Tracer and PLT surveys
  - Advanced software with features suitable for the unconventional
- Explore the costs and benefits of the application of **new technology** to maximize the economic benefits

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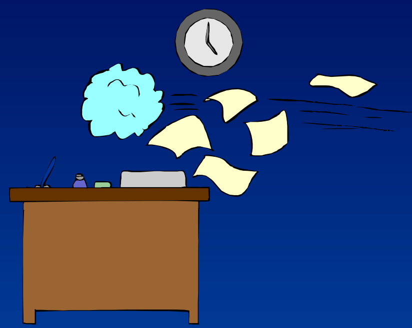
Thank You



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