

Is it the Geological Environment, Engineering Skill or Luck that Differentiates the Success of Hydraulic Fracturing in Australian Coal Seam Gas Projects?*

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Abstract

Coal seam gas (CSG) pilot testing is employed to characterize the production from a particular geo-domain associated with certain perceived geological risk and uncertainty or to estimate potential project reserves to a reasonable degree of accuracy for further development planning. These pilots strive to increase the chance of success by defining optimal reservoir characterisation methods and developing the most effective stimulation strategy (e.g., cavitation, hydraulic fracturing). CSG pilots often attribute success to a combination of several factors, including favourable:

- Geologic, structural or geomechanical settings;
- Reservoir properties such as the permeability distribution or gas content; and
- Completion or stimulation strategy, most often hydraulic fracturing.

In Australia, this need to reduce uncertainty appears to be more pronounced based on the increased costs of development, tenure retention requirements, and technical risks that often remain an ongoing contingency for developmental decisions (Johnson and Mazumder, 2014). The largest technical contingency across several large basins in Australia continues to be the inability to produce economic outcomes using completions involving hydraulic fracturing. Thus, it is reasonable to believe that differences exist in the Australian and North American environments hindering widespread application of hydraulic fracturing.

In this presentation, key observations regarding several Australian CBM pilots will be presented and discussed. For each of these areas, the author will explore the questions of whether the geological/geomechanical environment, engineering skill or luck was the likely main contributor to success of hydraulic fracturing treatments in each area. Finally, the presentation will note areas for new technology implementation and experimentation to improve hydraulic fracturing success in problematic areas where high in-situ stress magnitudes or unfavourable current stress orientations exist relative to pre-existing cleats and natural fractures (formed by paleostresses).

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Is it the Geological Environment, Engineering Skill or Luck that Differentiates the Success of Hydraulic Fracturing in Australian Coal Seam Gas Projects?

Presented by:

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Principal, Unconventional Reservoir Solutions

February 13, 2015

Introduction

- CSG pilots owe their degree of success to several factors including:
 - geology;
 - structural or geomechanical settings;
 - favourable permeability distribution (cleating) or gas content; or
 - completion or stimulation strategy, sometimes involving hydraulic fracturing.
- Despite over 25 years of exploration and appraisal there remains large, unsuccessful regions, limited by the ability to successfully stimulate coals to effectively produce
- So where has it worked well and why?
- What key factors have hindered widespread application of hydraulic fracturing technology in the Australian environment and is there anything we do to fix it?

Activities to Reduce Uncertainty During CSG Project Maturation

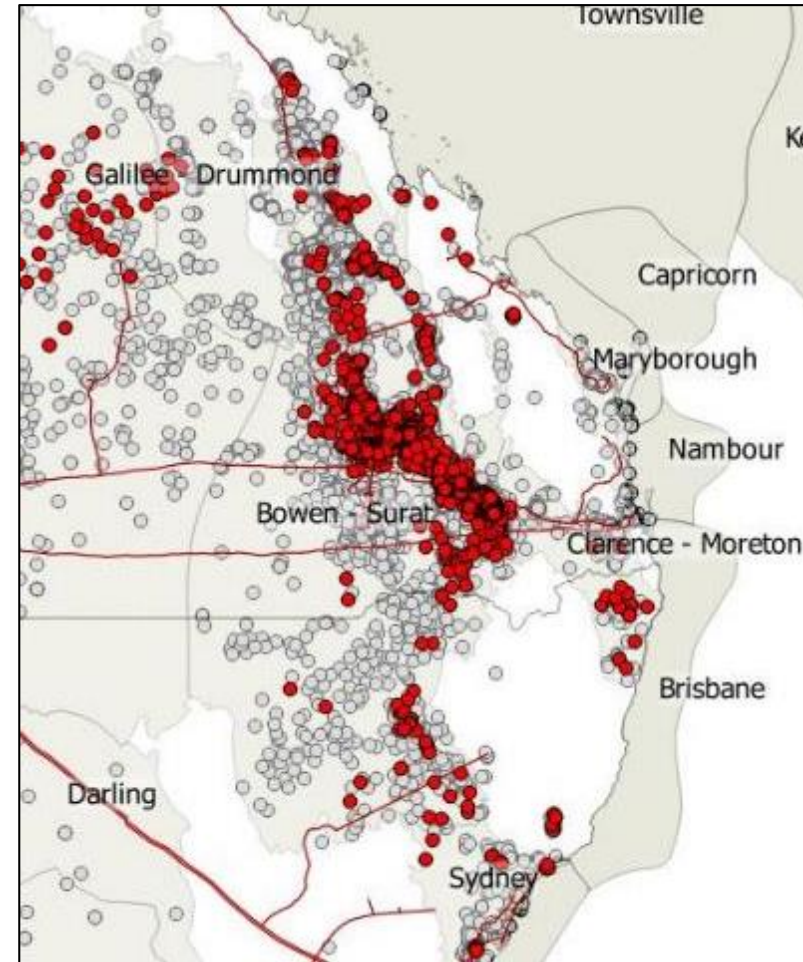
Activity	Exploration	Appraise	Development Pilot/Initial Development	Full Scale Development
Objective	Screen exploration acreage for highest potential	Confirm production potential, trial well completion methods	Characterise longer term production trends, fine tune well design and create initial development hub for larger scale development	Maximise the value of the resource through development
Data Acquired or Processed	Coal depth, thickness, gas content, saturation, reservoir pressure, permeability	Production and producibility, effectiveness of the well completion, operational performance, water quantity/quality, gas composition	Longer term gas and water rates on development scale, reservoir pressure response	Field wide production, detailed geological and reservoir data from development wells, reservoir pressure from production and observation wells
Forecasting Tools	Analogy, volume and decline estimates	Volume and decline estimates, simple single well model	Simple sector modelling with site specific reservoir parameters and simple history match of the initial pilot	Full field reservoir model with a history match of the small scale development

Eastern Queensland CSG projects have been able to successfully develop 3 LNG projects, so some have made it successfully through this hurdle.

After Johnson and Mazumder, IPTC 18108, 2014

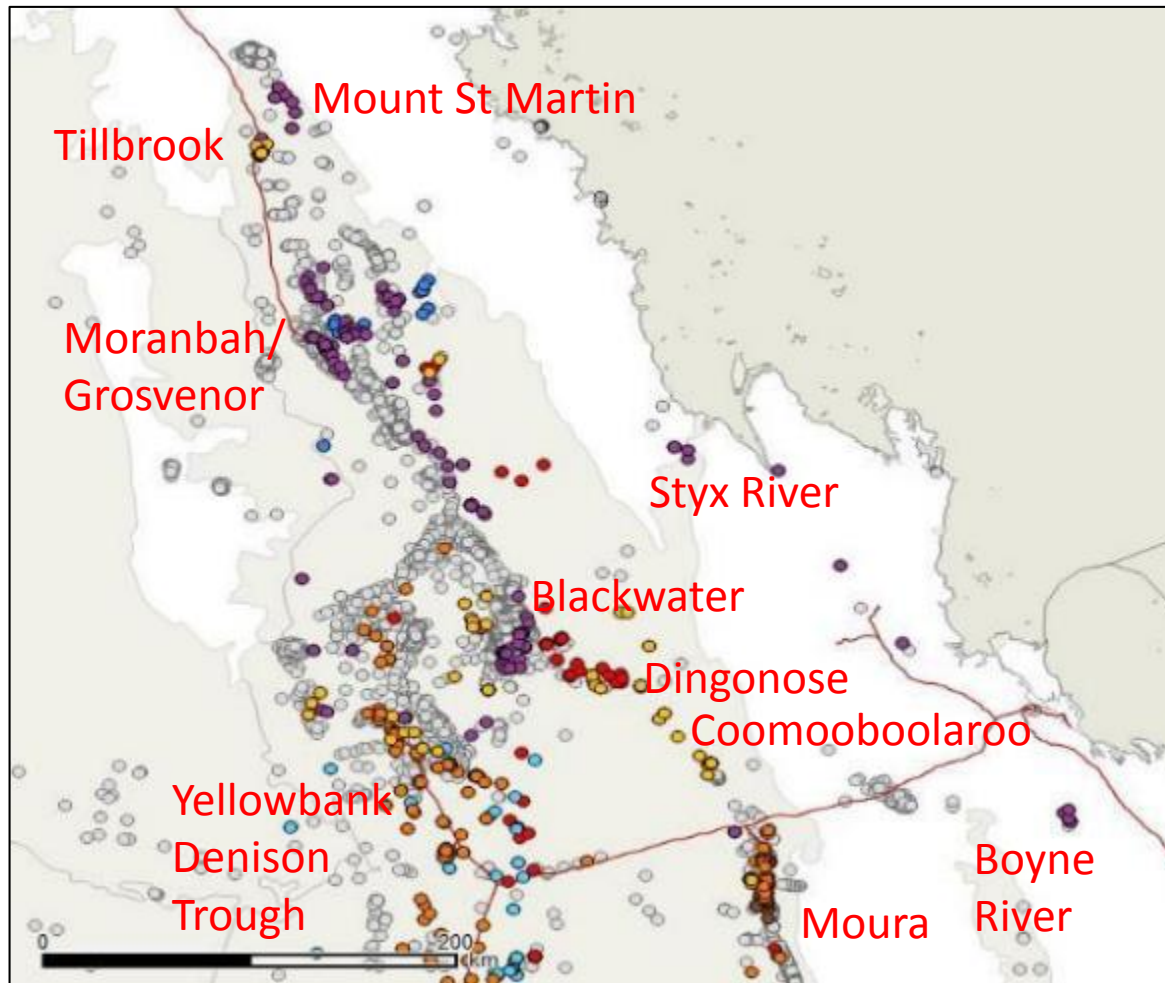
Presentation Outline

- Review some example areas
 - Northern/North Central Bowen Basin
 - Central Bowen Basin-Peat/Scotia Fields
 - Surat Basin
- Lessons learnt by project
- Track successes and challenges for each area
- Future challenges



Wells drilled in Eastern Australia since Jan 2010 - Source IHS database

Area 1, Northern/North Central Bowen Basin



Wells by operator or drilled since Jan 2010 - Source IHS database

Successes? If not, why?

- Broadmeadow project near Moranbah (Reeves and O'Neill 1989)
 - High stress
 - Lower cost to optimise frac
- Central Colliery, near Middlemount QLD (Jeffrey et al. 1992)
 - High stress
 - Significant fracture branching and multiple vertical components
- Dawson Valley area
 - High stress (Morales and Davidson 1993)
 - Frac coverage (McMillan and Palanyk, 2007)
- Observations of high treating pressure from compressive stress regimes (Jeffrey, Settari and Smith 1995, Jeffrey et al. 1998, Jeffrey and Settari 1998).

Moura Area

- Study from Moura area, Baralaba CM
- Started foam fracturing but primarily ball-baffle, multi-stage water fracs
- Production log using spinner showed that not all zones were contributing
- However continuous flow was not achieved based on lag time between flowing and logging periods
- Further studies with current CT conveyed logging or concurrent lifting above the interval and addition of oxygen activation log technologies may show flow from some non-producing intervals

Seam	Number	Flowing
V	6	1
X	9	4
Y	10	3
A	10	10
B	9	8
C	10	6
DL & Du	10	4

Comparison of number of seams completed versus flowing based on the logging technique used

Number of Seams per stage	All seams	Fracs with near or total screen-outs	Fracs- trouble free
	Percentage of Seams that flowed (%)	All Seams in each stage that flowed (%)	All Seams in each stage that flowed (%)
one seam	100	100	100
two seams	55	71	25
three seams	25	50	0

Comparison of number of seams completed versus flowing and based on degree of “proppant packing”. **Certainly a screenout doesn’t appear to be negative and maybe a lucky rather than unlucky thing!**

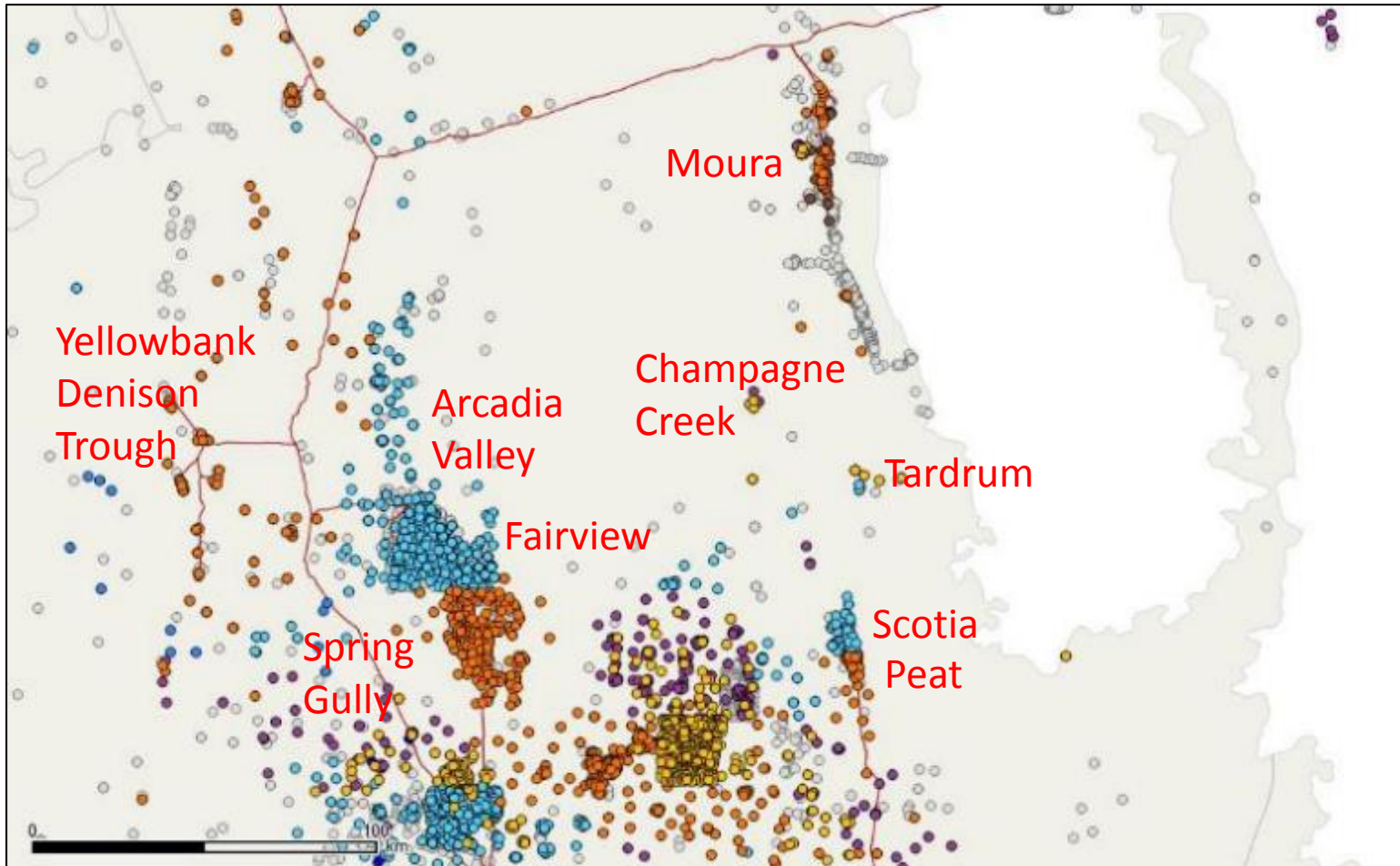
After McMillan and Palanyk, SPE 110137, 2007

Scorecard 1: Northern Bowen Basin

Area	Geology or gas content	Structural or geomechanical settings	Favourable permeability distribution (cleating)	Completion or stimulation strategy
Moranbah, Broadmeadow	✓	±	±	✗
Central Colliery	✓	✓	±	✗
Moura	✓	±	±	±
Other Dawson Valley	✓	±	±	±
Blackwater,	✓	✗	±	✗
Dingonose	✓	✗	✗	✗
Coomooboolaroo	✓	✗	✗	✗

After Johnson and Mazumder, IPTC 18108, 2014

Area 2, Central Bowen Basin



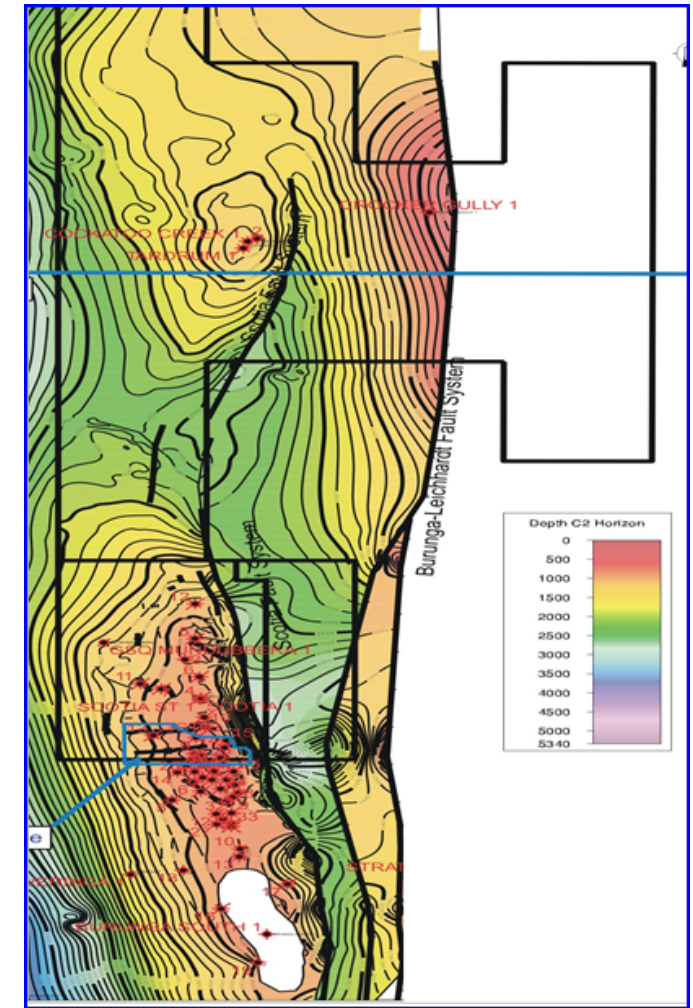
Wells by operator or drilled since Jan 2010 - Source IHS database

Successes? If not, why?

- Fairview/Spring Gully
 - High perm
 - Manageable stress
- Peat/Scotia (Badri et al. 2000, Johnson et al. 2003)
 - High stress areas
 - Good perm
 - Lots of pressure dependent behaviour
- Arcadia Valley
 - Q1 2013 reported 70m of net coal then.....?
- Tardrum
 - High stress
 - Lower perm
 - Lots of pressure dependent behaviour

Peat/Scotia Fields

- History
 - First pilots by Pacific Oil & Gas in early 1990s based on cavitation
 - Oil Company of Australia developed Peat Field with first gas in 2001
 - Scotia Field developed in 2001-2002 with first gas to CS Energy
- Key success factors in area
 - Well developed cleat and overlaying natural fracture system – good fracture porosity and high permeability
 - High gas contents
 - Extensional stress regime on structure
 - Good response to stimulation
 - Low maintenance and minimal infield compression or artificial lift to maintain production



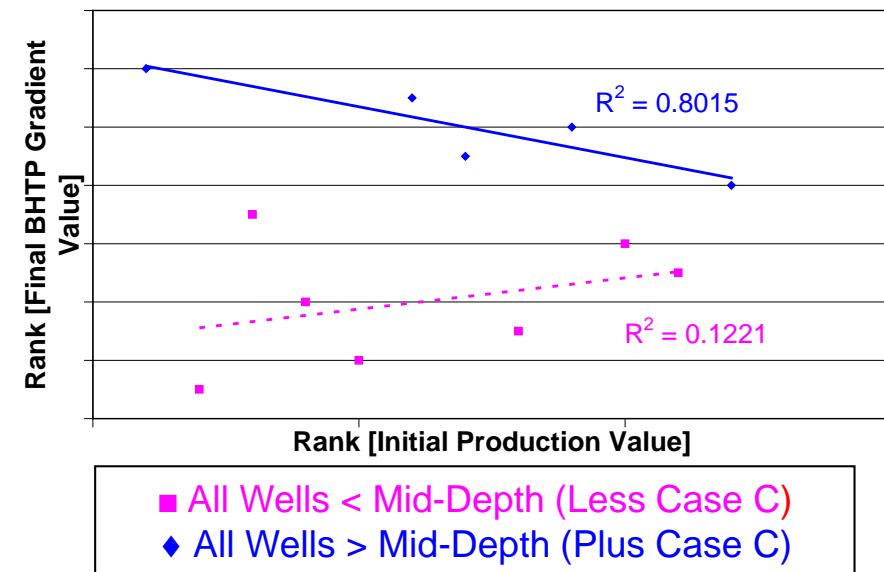
Geology of Burunga Anticline
(After Johnson et al., SPE 77824 2002)

Peat/Scotia Fields

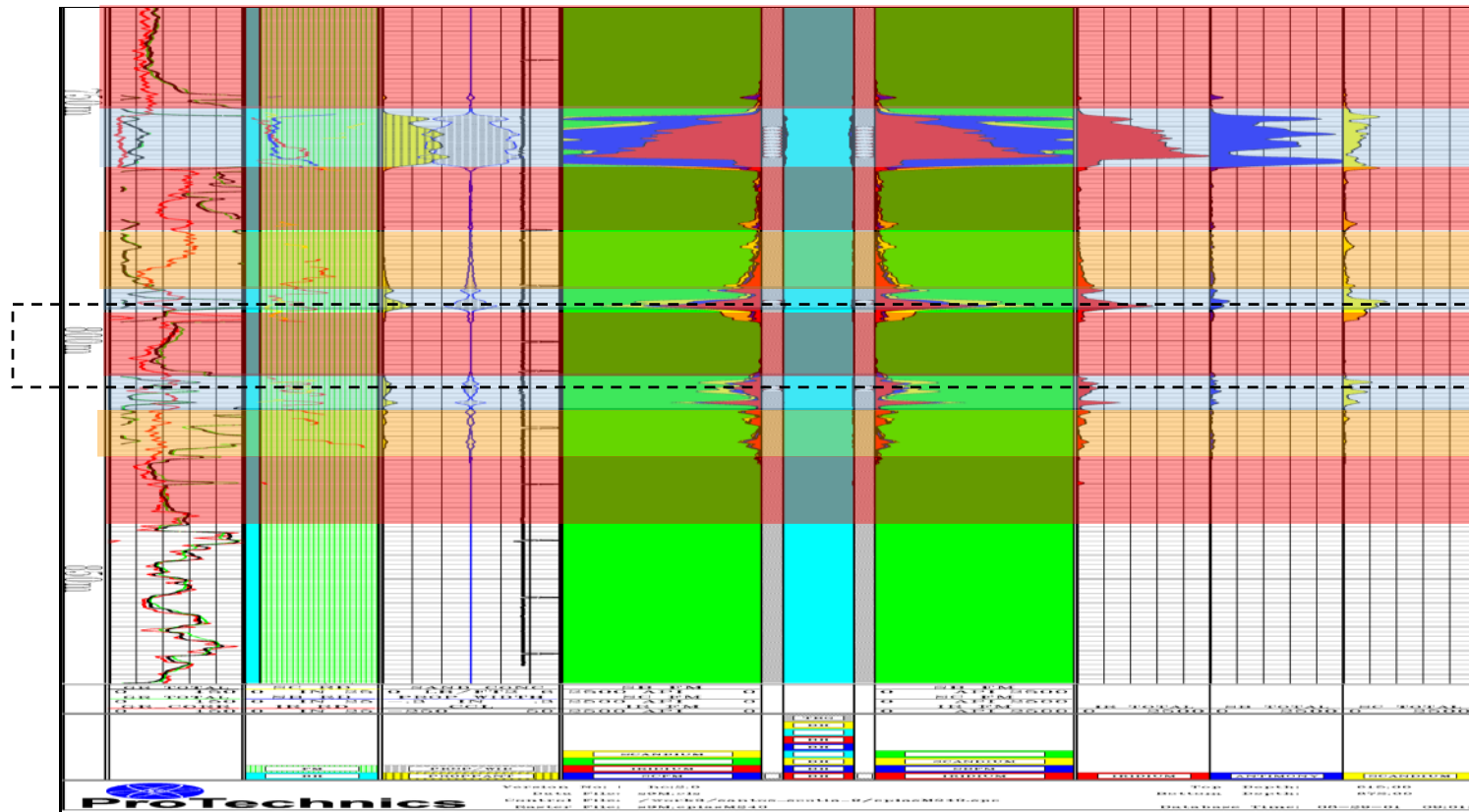
- Challenges
 - Enclaves of high compressive-stress associated with Leichardt-Burunga fault system
 - Frac treatment pressure dependent leakoff behaviour and bedding plane reactivation
 - Wellbore failures in both Peat and Scotia fields post-frac
- Successes
 - Both Peat and Scotia initial stimulation treatments were successful delivering the projects from high productivity areas
 - Infill developments have maintained production



Wellbore failure in Scotia Field (After Johnson et al., SPE 77824, 2002)



In the context of tracer logs on Scotia Case “A” containment could reflect geology



Likely vertical and well contained fracture



Likely upward contained with horizontal components



Likely downward contained with horizontal components

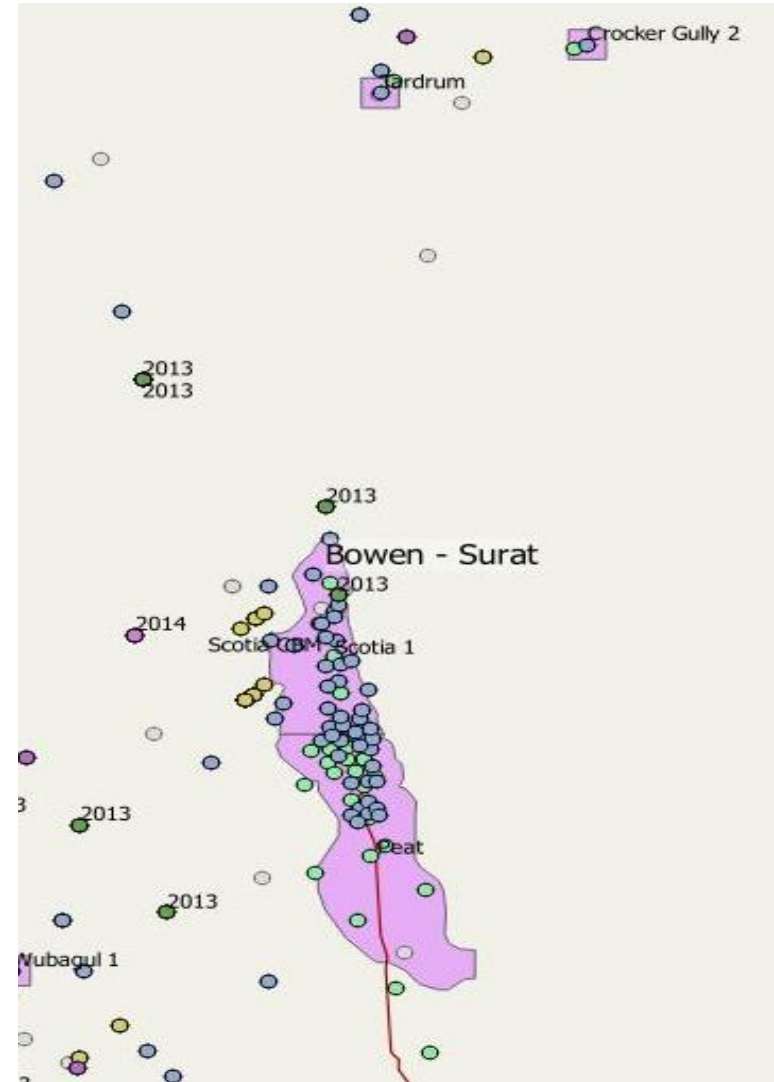


If fully decoupled, this layer could represent a region of instability for shear failure

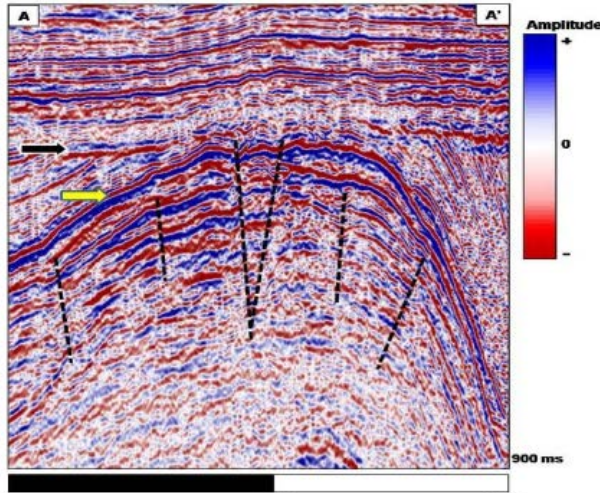
After Johnson et al., SPE 77824 2002

Peat/Scotia Fields

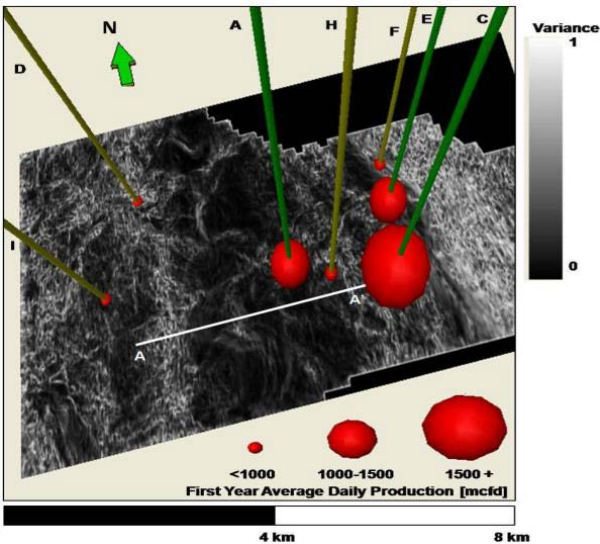
- Development wells in both Peat and Scotia have slowed over time
- Future challenges
 - Further infill development or improving production from smaller under-producing seams
 - Developing flank areas of higher stress, lower permeability
 - Developing smaller, deeper nearby structures of thick, lower permeability and higher stress coals (i.e. Tardrum)



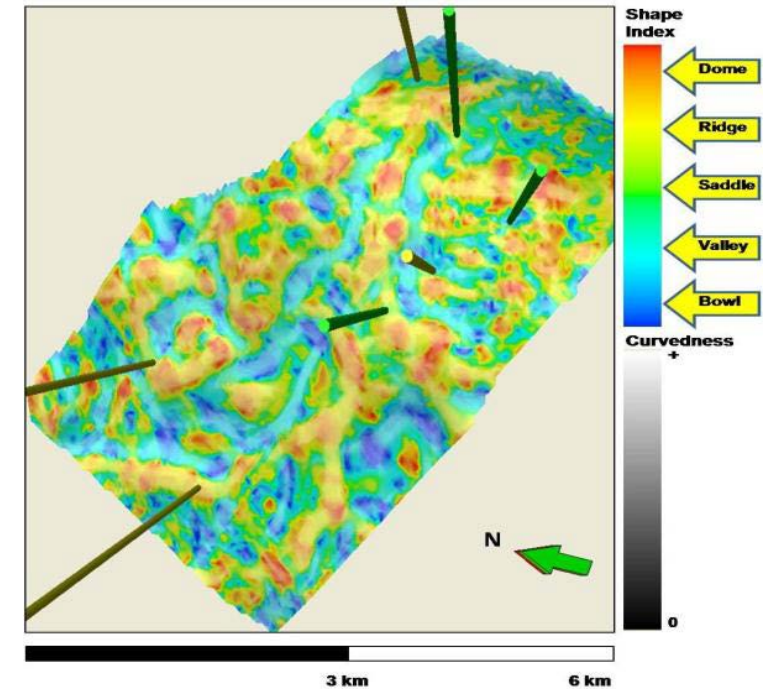
Scotia Field Geophysical Curvature Modelling



The black block arrow points to the visible unconformity that separates the Triassic and Jurassic time periods. The black dashed lines are interpreted faults formed as a result of the folding in this area.



A time slice of the variance cube depicting the wells in the study area.



This figure shows areas of high curvedness and intense structural deformation that correspond with different shapes, most notably ridge features associated with compressive stress regimes.

After Fisk, J. C., Marfurt, K. J., and Cooke, D. (2010).

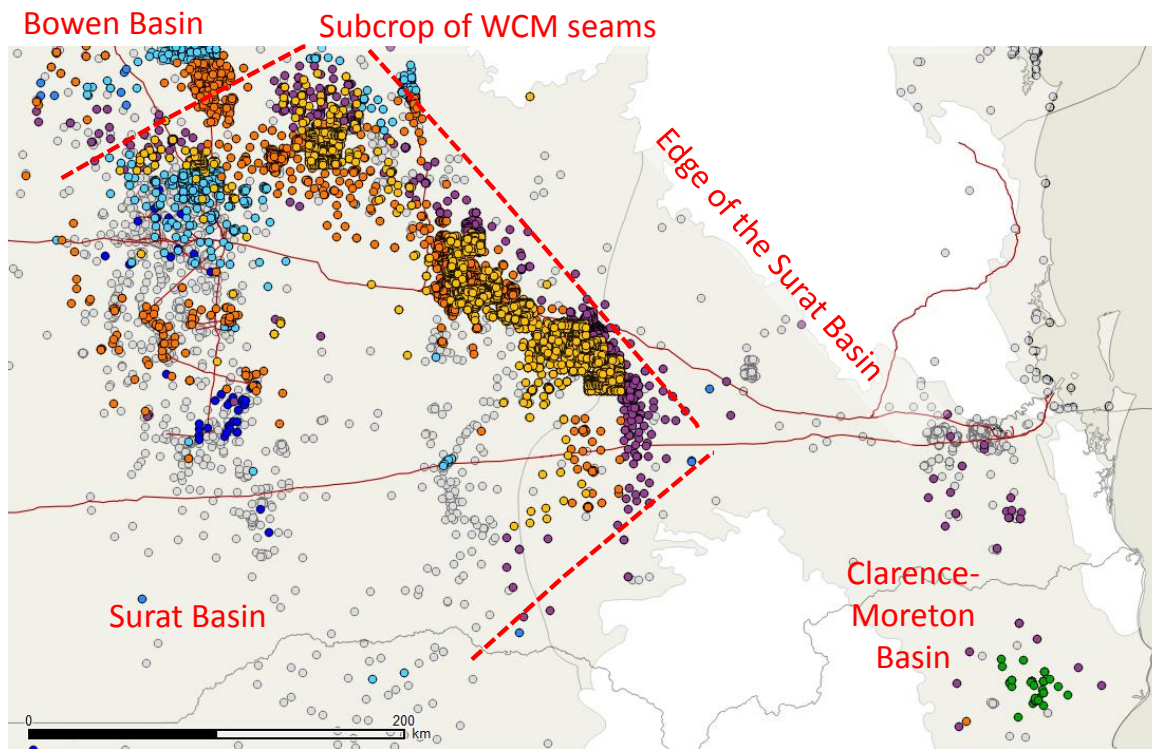
Scorecard 2: Central Bowen Basin

Area	Geology or gas content	Structural or geomechanical settings	Favourable permeability distribution (cleating)	Completion or stimulation strategy
Fairview	✓	±	±	±
Spring Gully	✓	±	±	±
Scotia/Peat	✓	±	±	±
Arcadia Valley	✓	?	?	?
Tardrum	✓	X	X	X

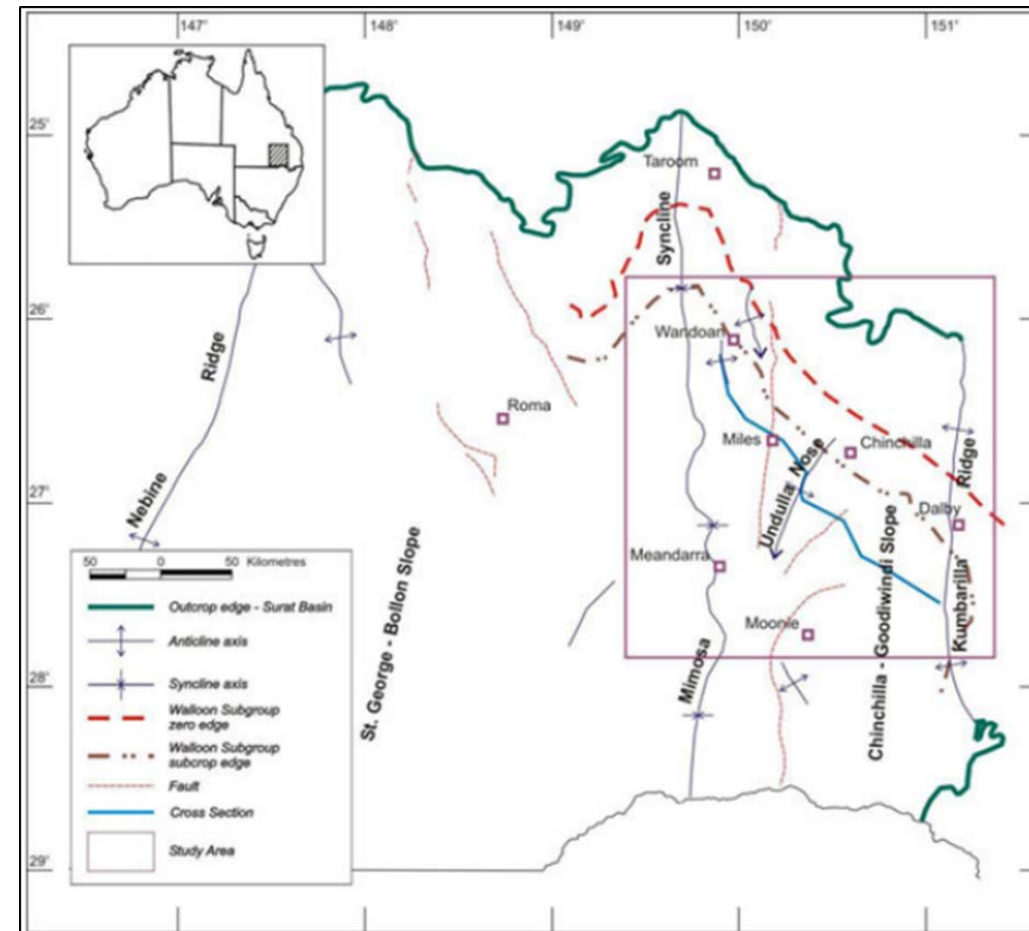
The equation for success in most of these areas has been:

- Skill and experience factors in to ability to execute efficiently but hydraulic fracture optimisation does not always equal cost optimisation
- Good geology and luck prevails except in the cases of catastrophic well failure and casing shear...bad luck!

Area 3: Surat Basin

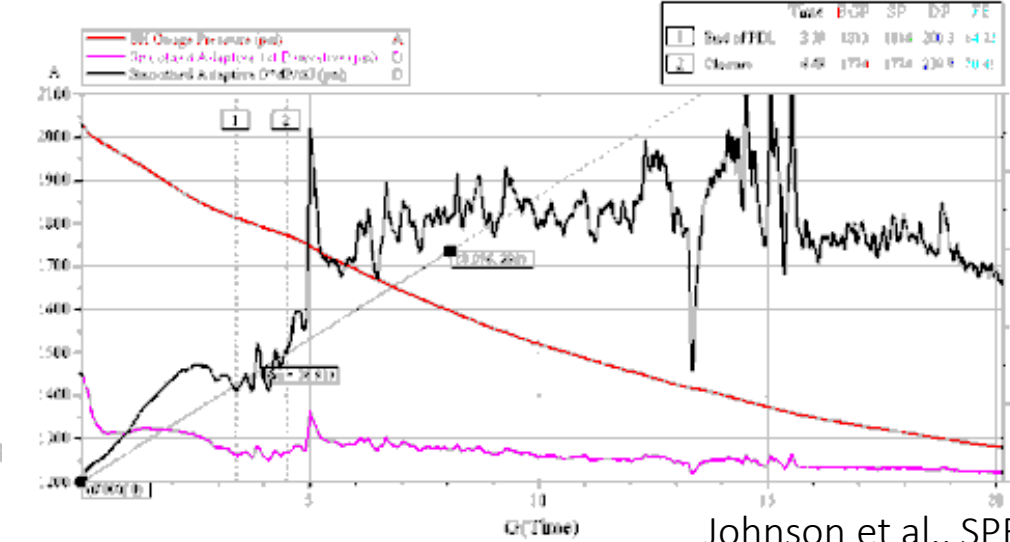
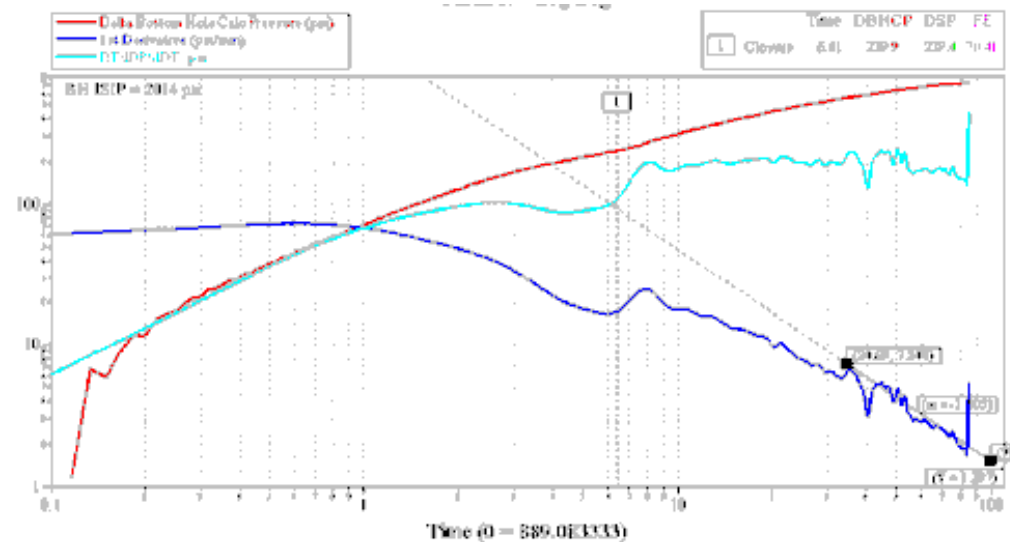
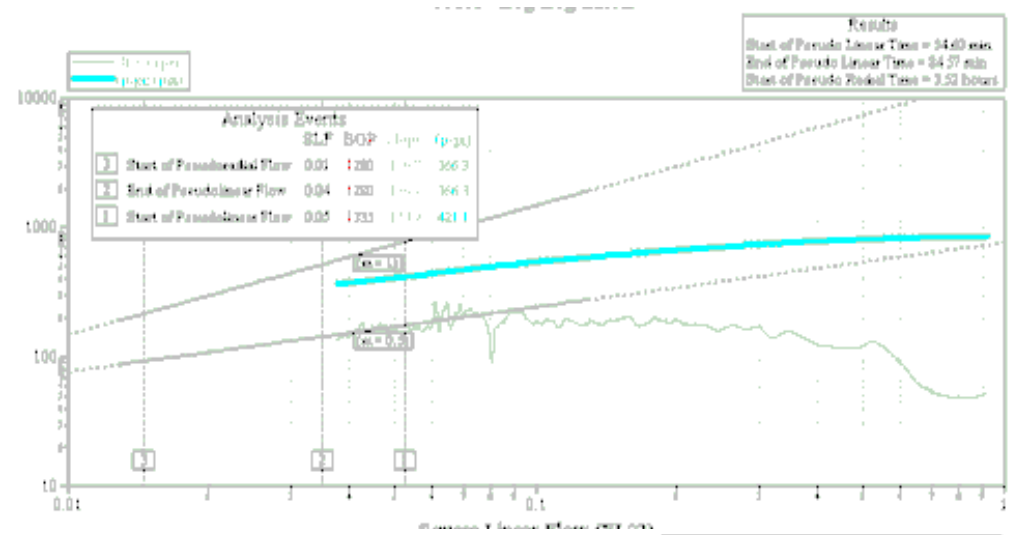
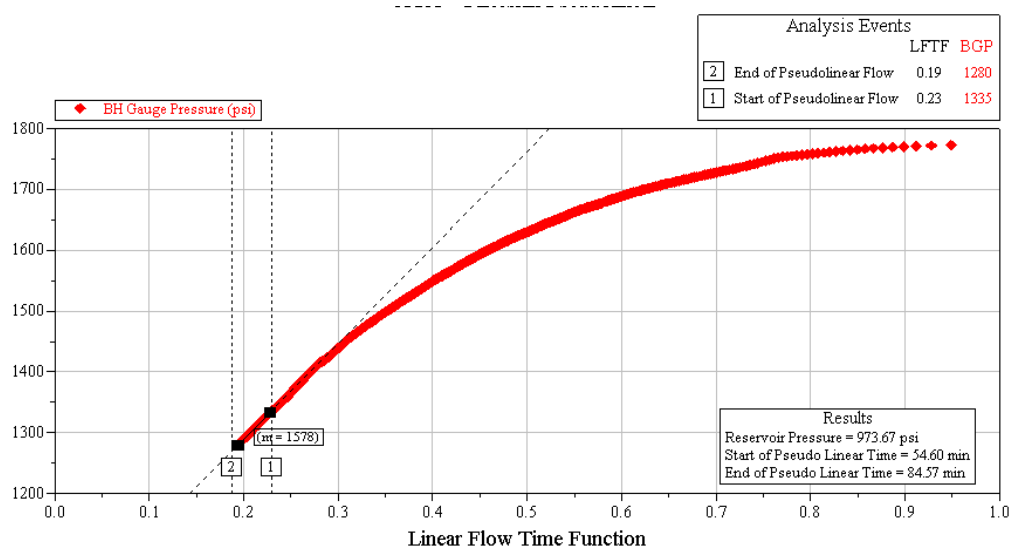


Wells by operator or drilled since Jan 2010 -
Source IHS database



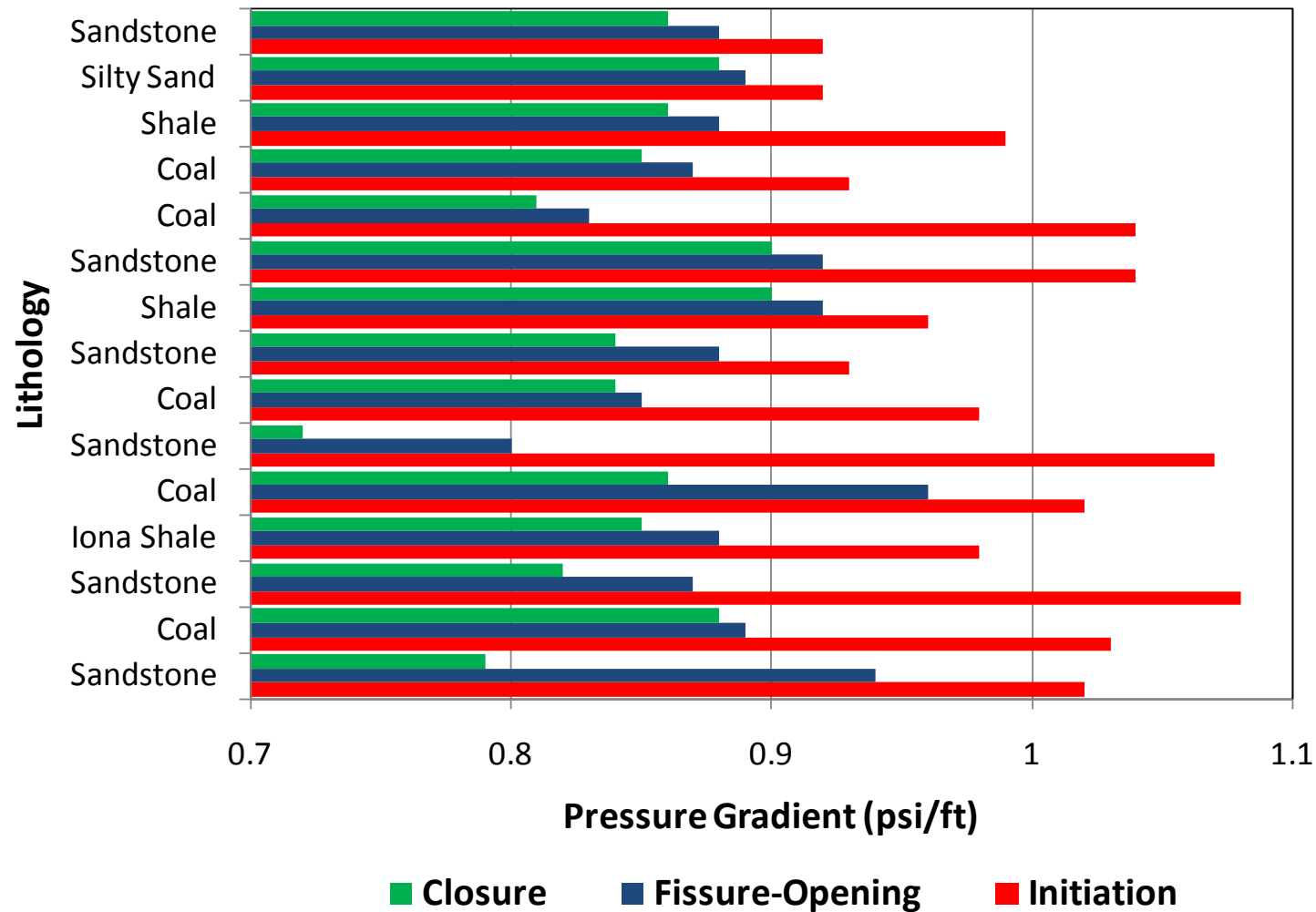
Structural Setting of the Walloon Coals, Surat Basin
(After Scott, 2008)

RW5 and 6 Study Pre-frac DFIT program



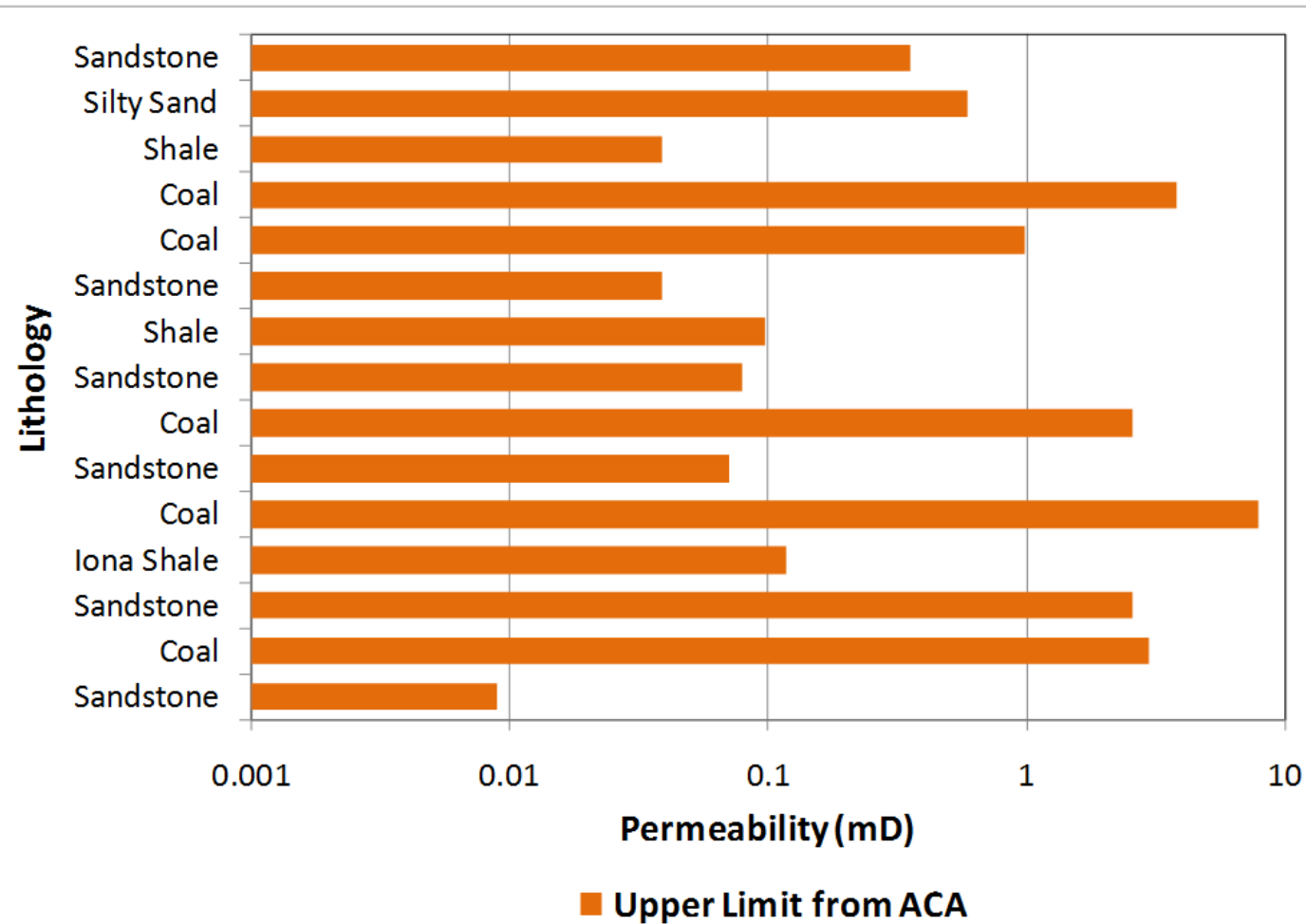
Johnson et al., SPE 133066, 2010

QGC Ridgewood 5 & 6 Study Area Stress Testing Results



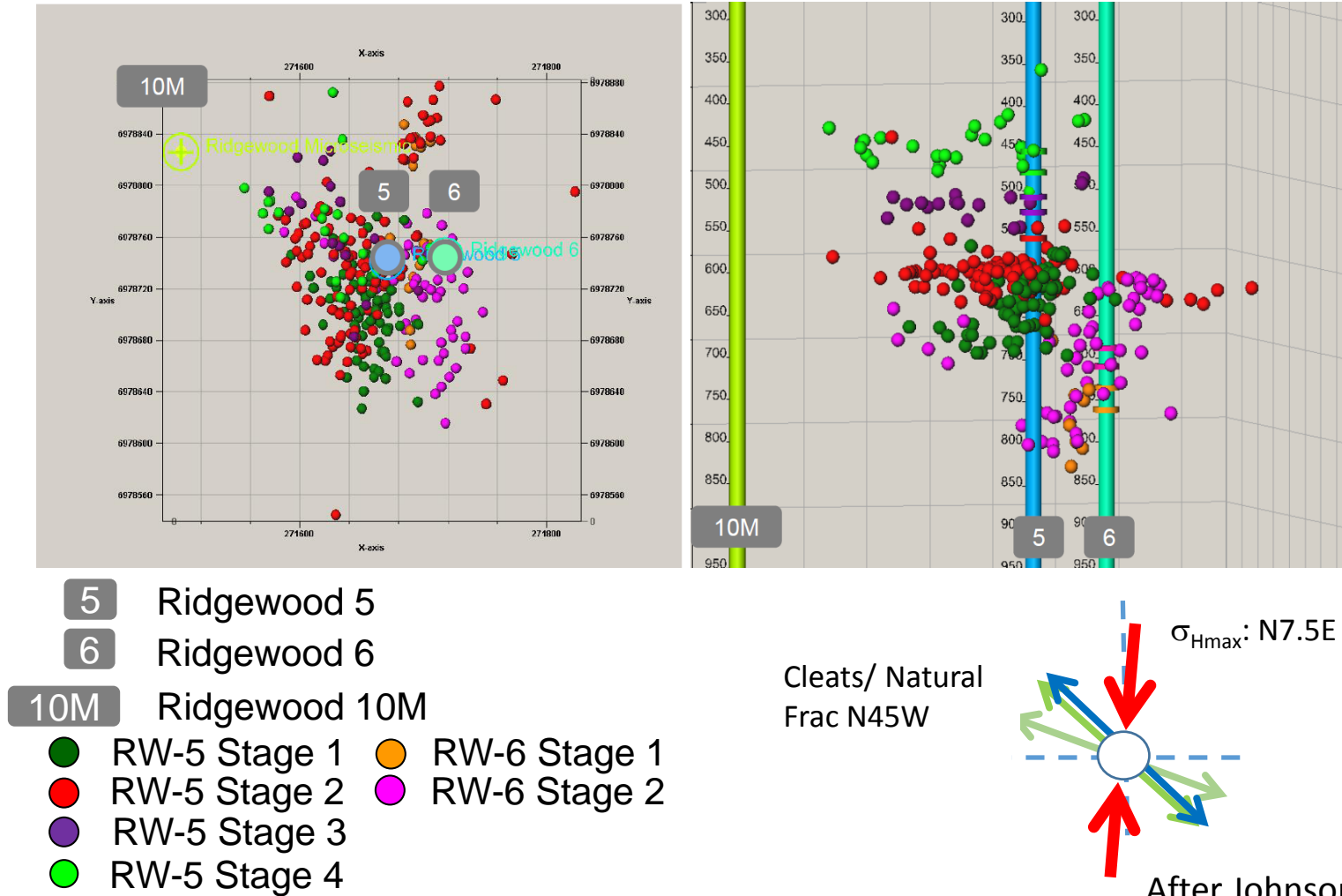
After Johnson et al, SPE 133066, 2010

QGC Ridgewood 5 & 6 After Closure Analysis Results



After Johnson et al, SPE 133066, 2010

Overall Trends in All Microseismic Data at QGC Ridgewood 5 & 6 Study Area



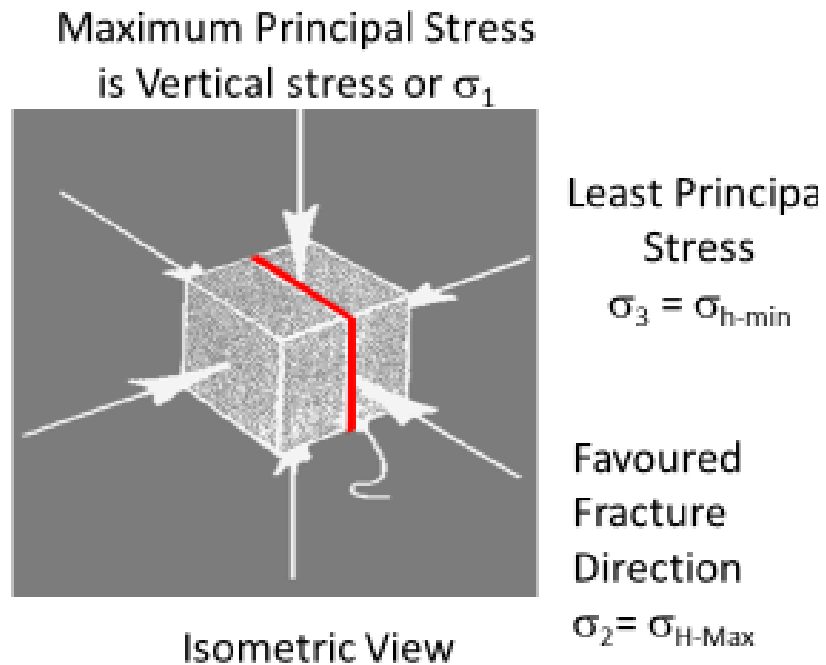
Scorecard 3: Walloon Coal Measures, Surat Basin

Area	Geology or gas content	Structural or geomechanical settings	Favourable permeability distribution (cleating)	Completion or stimulation strategy
Chinchilla Goondiwindi Slope	✓	✗	±	✗
Roma Shelf	✓	±	±	±

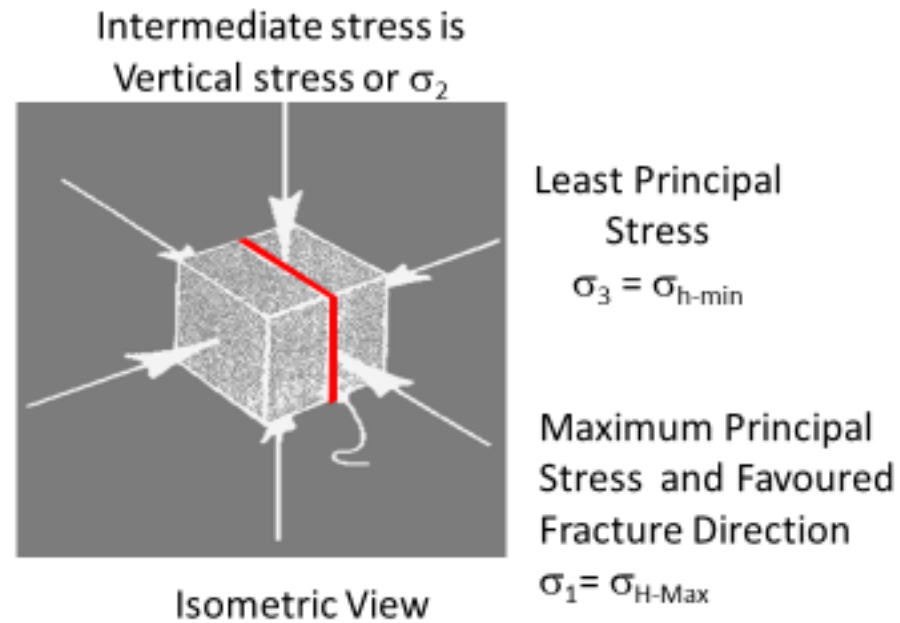
The equation for success in most of these areas has been:

- Skill and experience factors in to ability to execute efficiently but efficiency and cost optimisation does not always equal hydraulic fracture optimisation
- Not much luck outside of high perm areas, with good geology, and lowered stress
- So luck prevails except in the cases of catastrophic well failure and casing shear...bad luck!

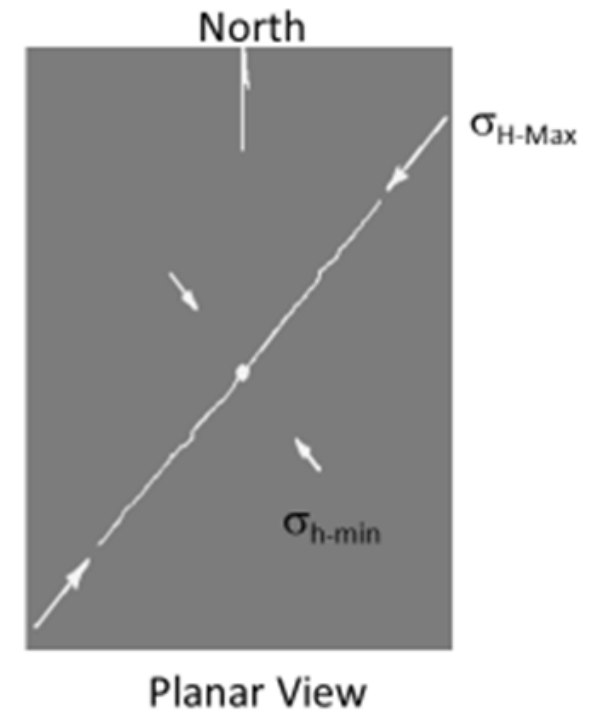
So what's going on?



Normal stress regime



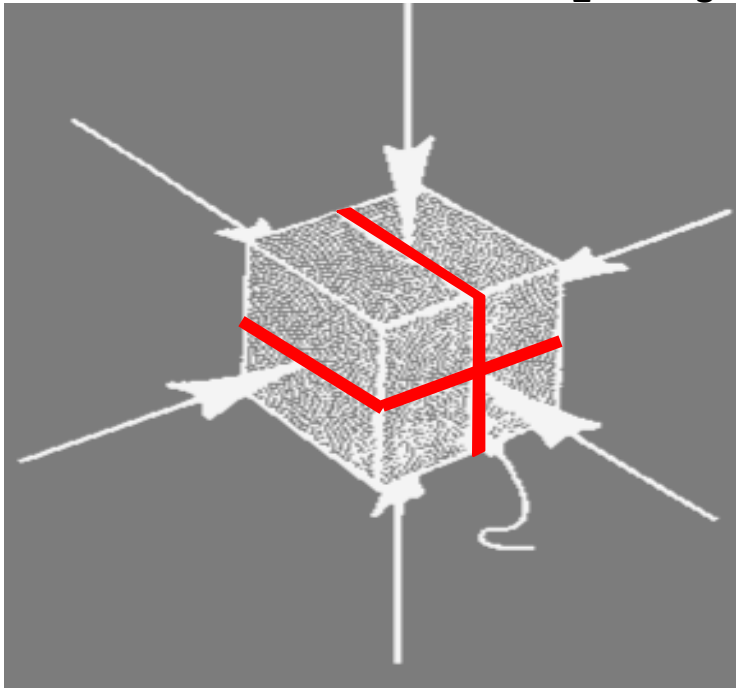
Strike-slip stress regime



Results are roughly the same

Minimum stress controls fracture azimuth – strike slip to reverse stress regime

Intermediate stress is
Vertical stress or $\sigma_2 \cong \sigma_3$



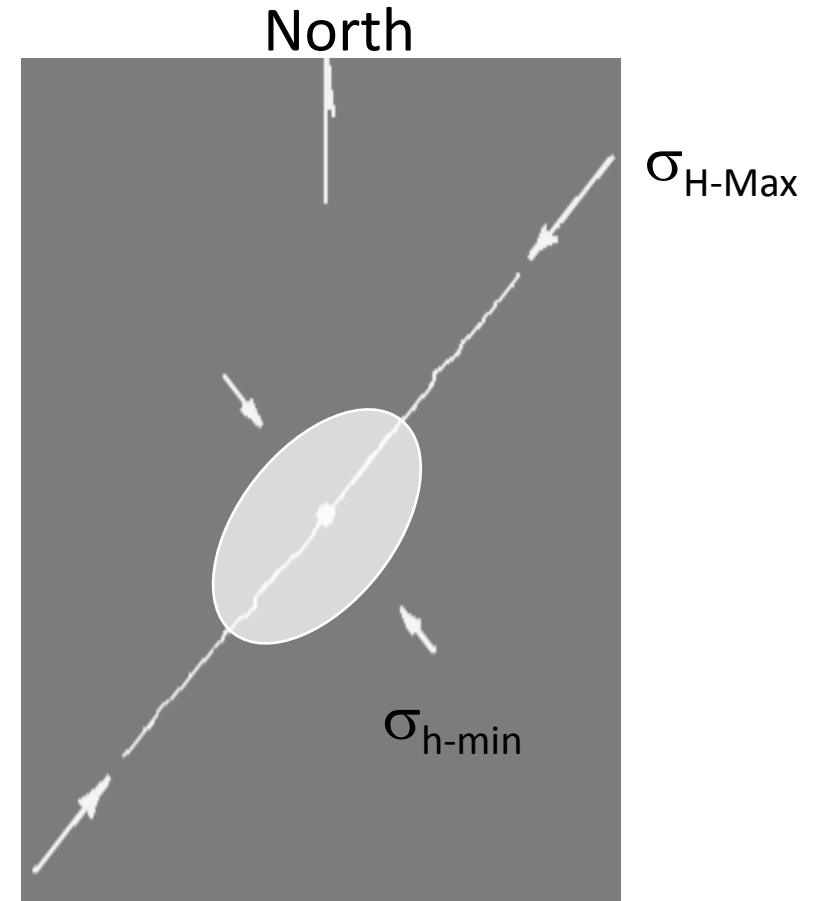
Isometric View

Least Principal
Stress

$$\sigma_3 = \sigma_{h-min}$$

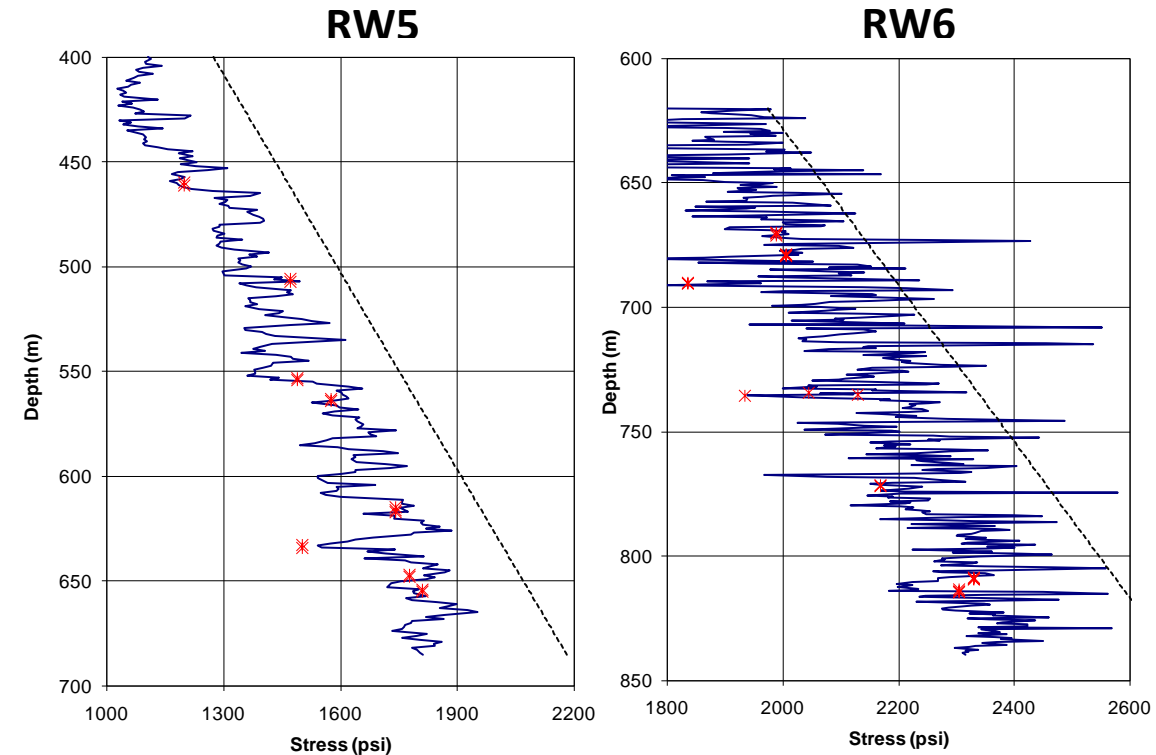
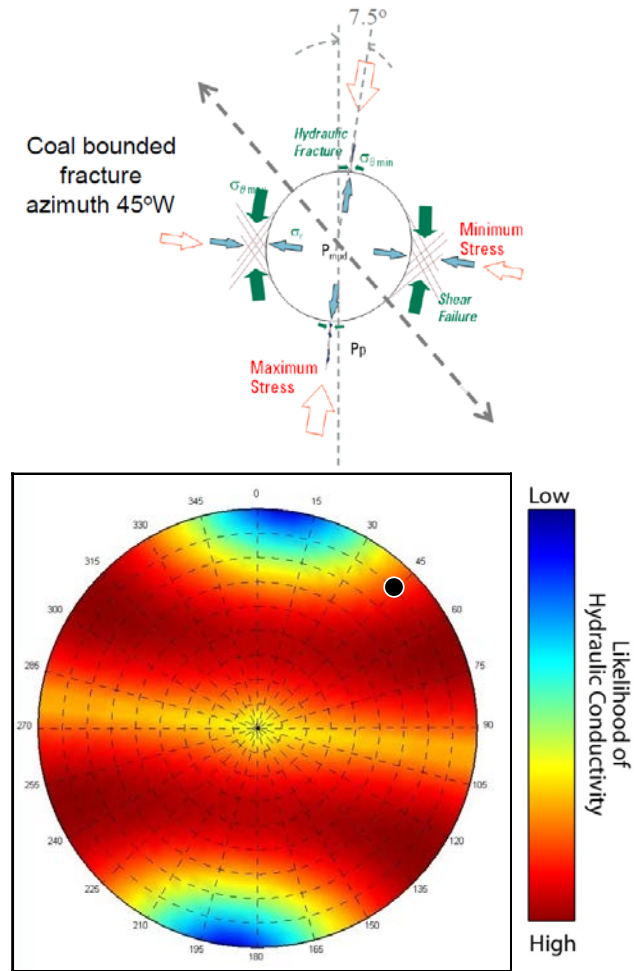
Maximum Principal
Stress and Favoured
Fracture Direction

$$\sigma_1 = \sigma_{H-Max}$$



Planar View

Key is Stress Azimuths, Stress Magnitude, and Natural Fracture Azimuths

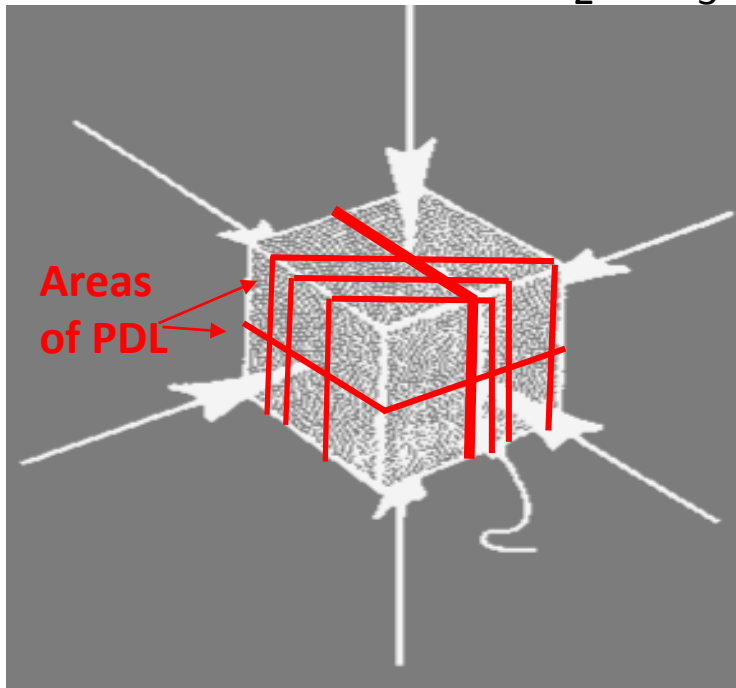


Detailed stress profiling done from cased hole dynamic rock properties and stress testing in both coal and clastic intervals

After Johnson, et al., 2010, SPE 133066

Minimum stress controls fracture azimuth – strike slip to reverse stress regime (SPE 133066)

Intermediate stress is
Vertical stress or $\sigma_2 \cong \sigma_3$



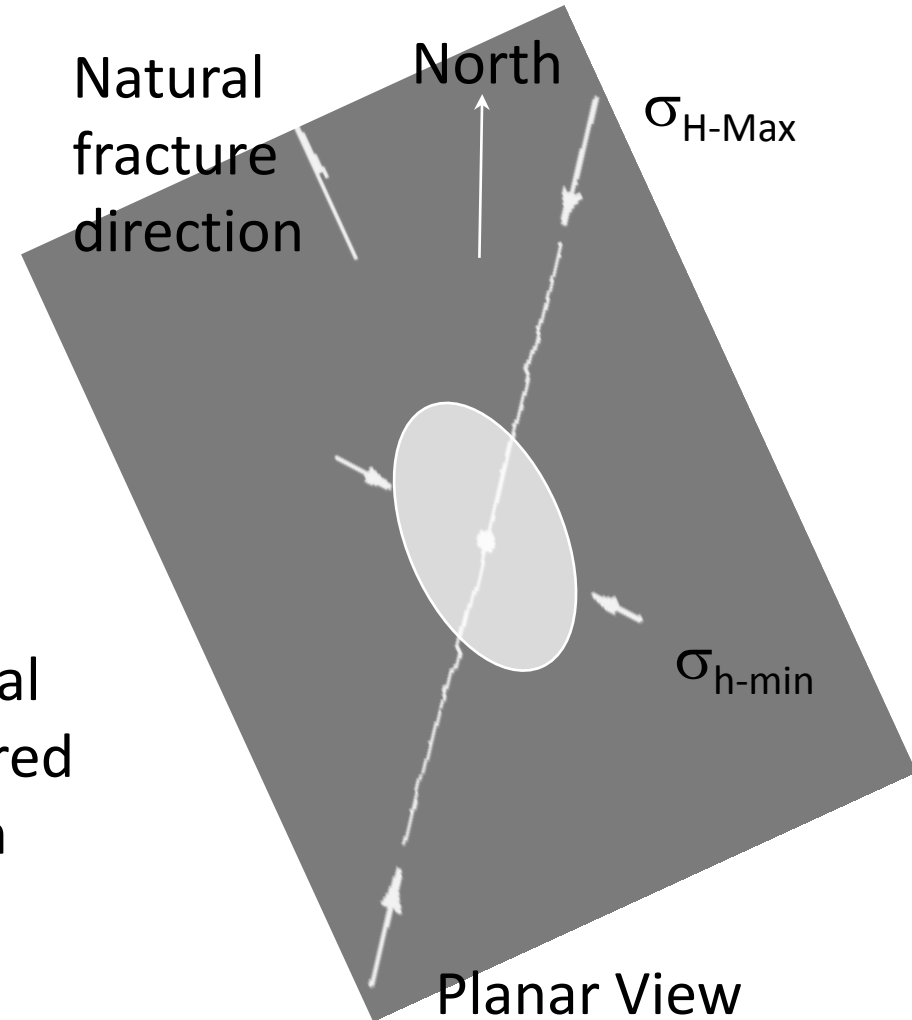
Isometric View

Least Principal
Stress

$$\sigma_3 = \sigma_{h-min}$$

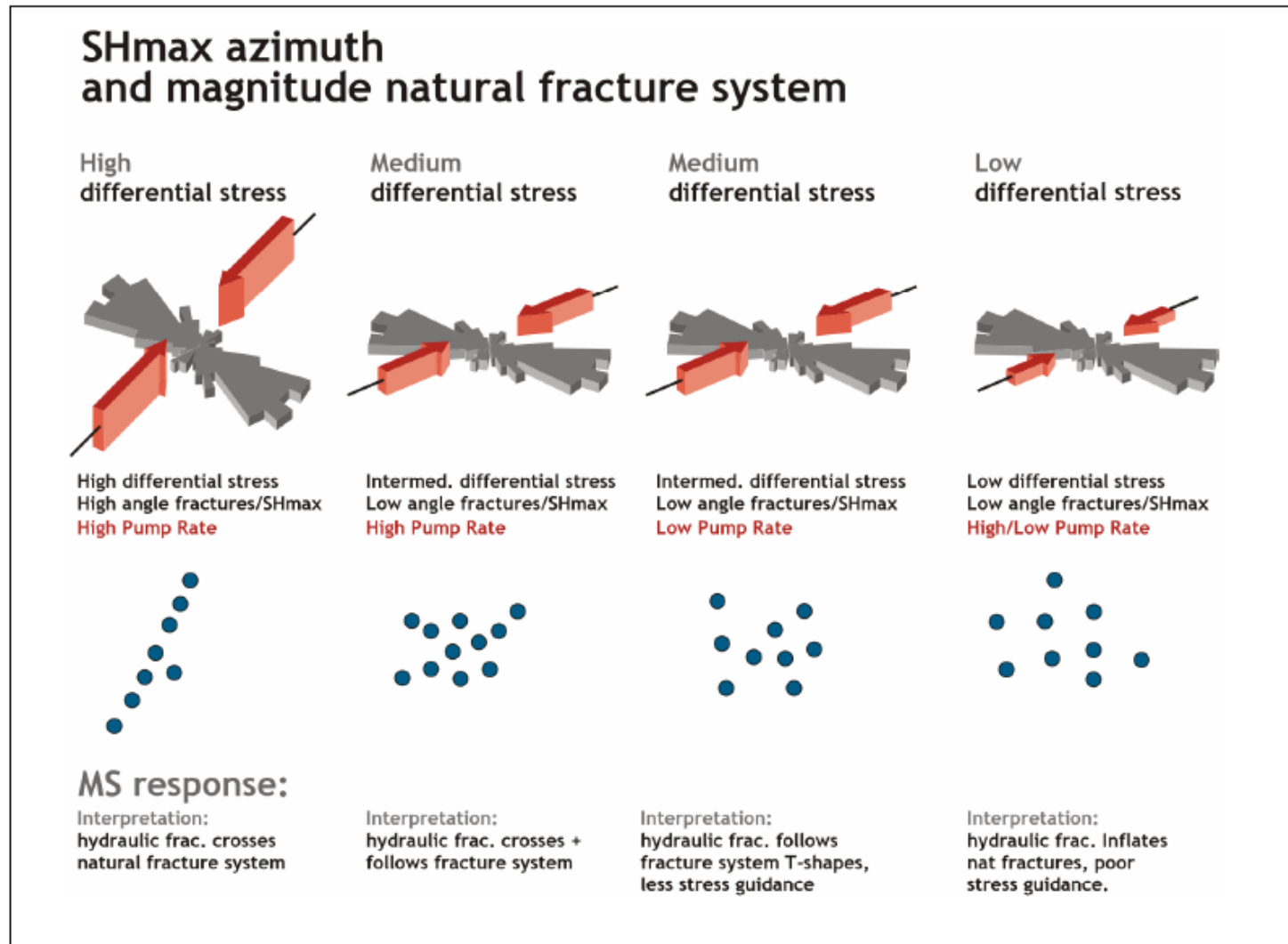
Maximum Principal
Stress and Favoured
Fracture Direction

$$\sigma_1 = \sigma_{H-Max}$$



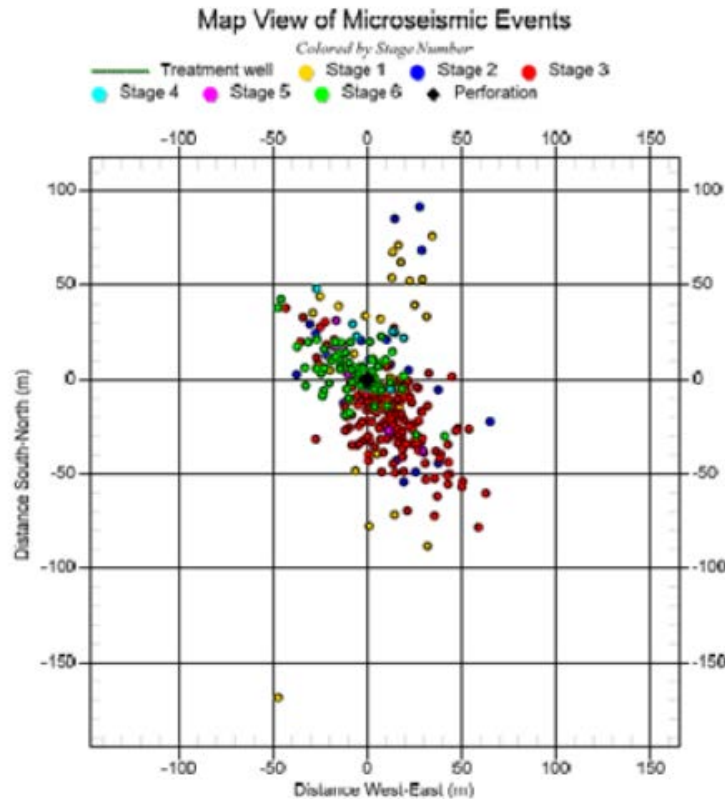
Planar View

Similar Experiences at Origin/APLNG Fracture Treatments

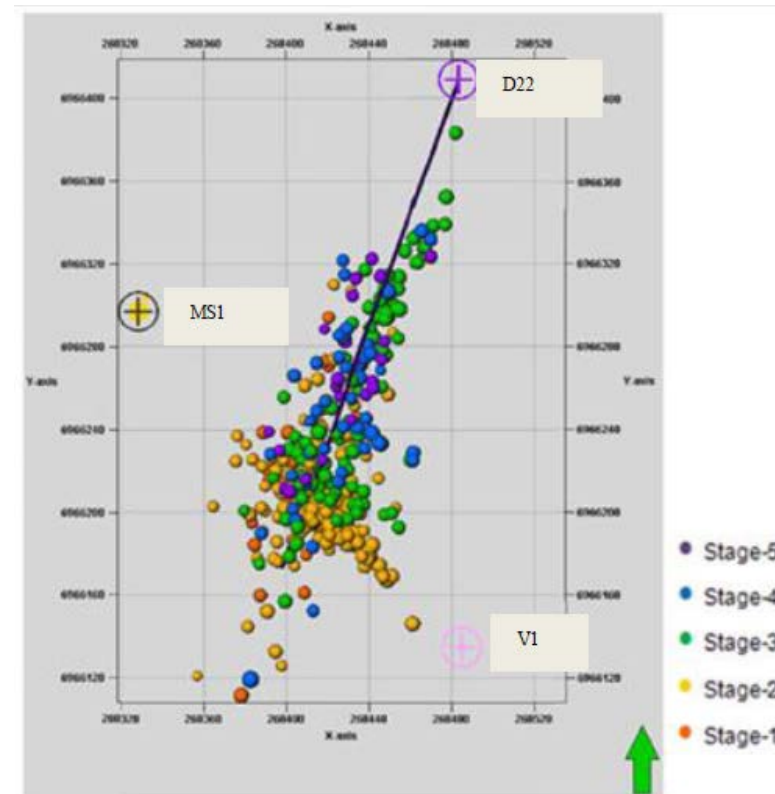


After Flottman et al, SPE
167064, 2013

Deviated Wells in s_{H-Max} Azimuth the Answer?



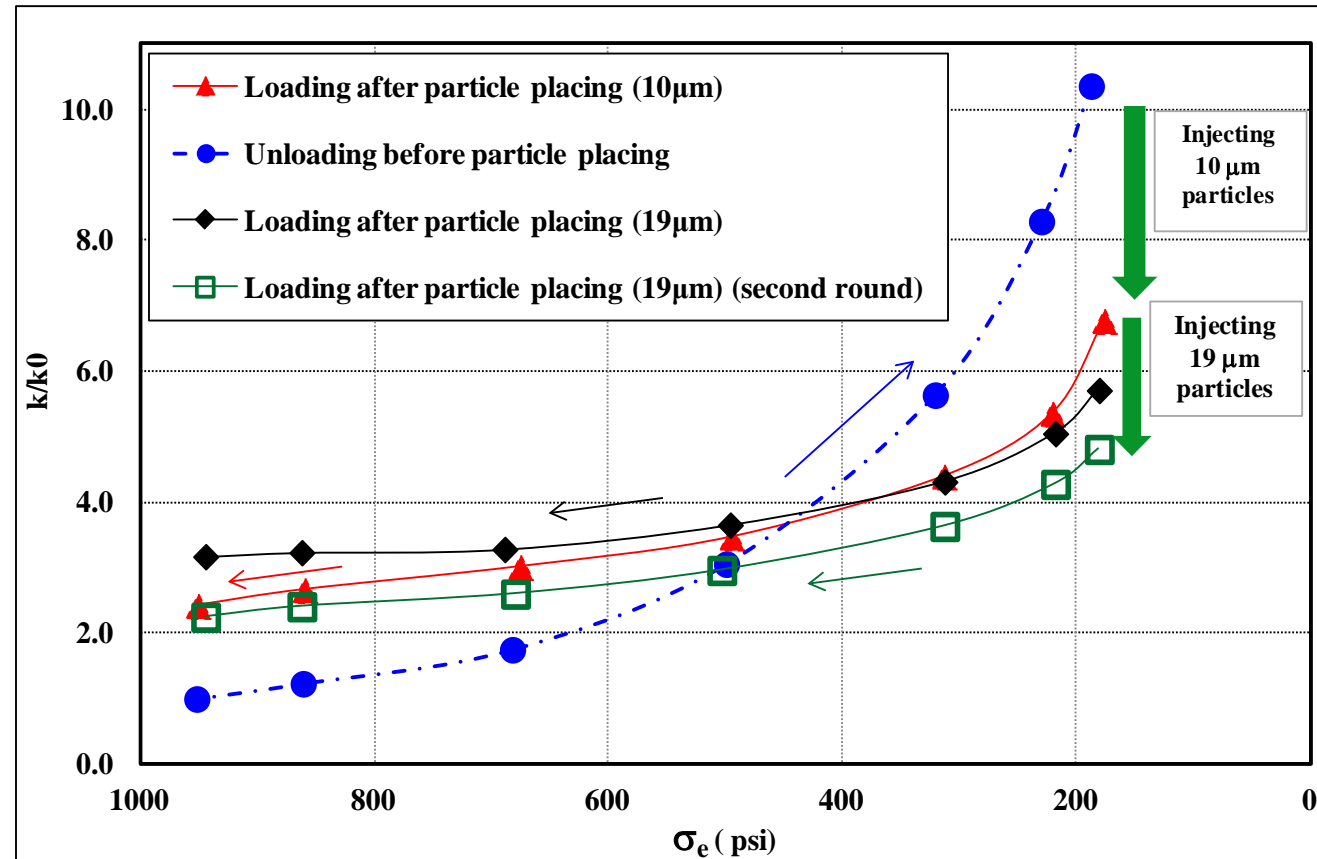
2009 Vertical frac treatments indicated frac propagation in natural fracture direction



~27.5 deg Deviated well in s_{H-Max} direction appears to orient frac in s_{H-Max} rather than natural fracture direction

After Megorden et al, SPE 167053, 2013

Normalized Coal Permeability vs. Effective Stress after Sized Particle Injection



Sample # U-2 Salinity=0.1 M

After Keshavarz et al, SPE 167757, 2014

So is it Geology, Skill or Luck?

- More geology and luck than skill in most successful Bowen and Surat Basin fracs...though experience and efficiency help!
- More 3D geophysical data to perform curvature analysis and 3D mechanical earth models might better define optimal targets for stimulation
- Remember current σ_{Hmax} azimuth does not equal those in the past!
- Develop an effective completion strategy for both Surat and Bowen Basin off-structure, higher-stress, lower permeability areas with deeper but thick coals
 - Implementation of stimulated SIS wells to improve drawdown and water lifting in lower-permeability, highly-dipping areas
 - Deviated boreholes in σ_{Hmax} direction (Megorden, et al., SPE 167053, 2013) for hydraulic fracturing
 - Oriented σ_{Hmax} multi-well pad sites with intercept drainage wells
- Fine-meshed particles to stimulate stress sensitive cleats and fractures in the SRV (Keshavarz et al, SPE 167757)

Thanks for your attention
Any questions?



Unconventional Reservoir Solutions