origin

WHY THE WAIT? SHALE GAS EXPLORATION REVIEW AND LOOK AHEAD

David Close, Ph.D.

Exploration Manager – Shale and Tight Gas

Origin Energy

appea

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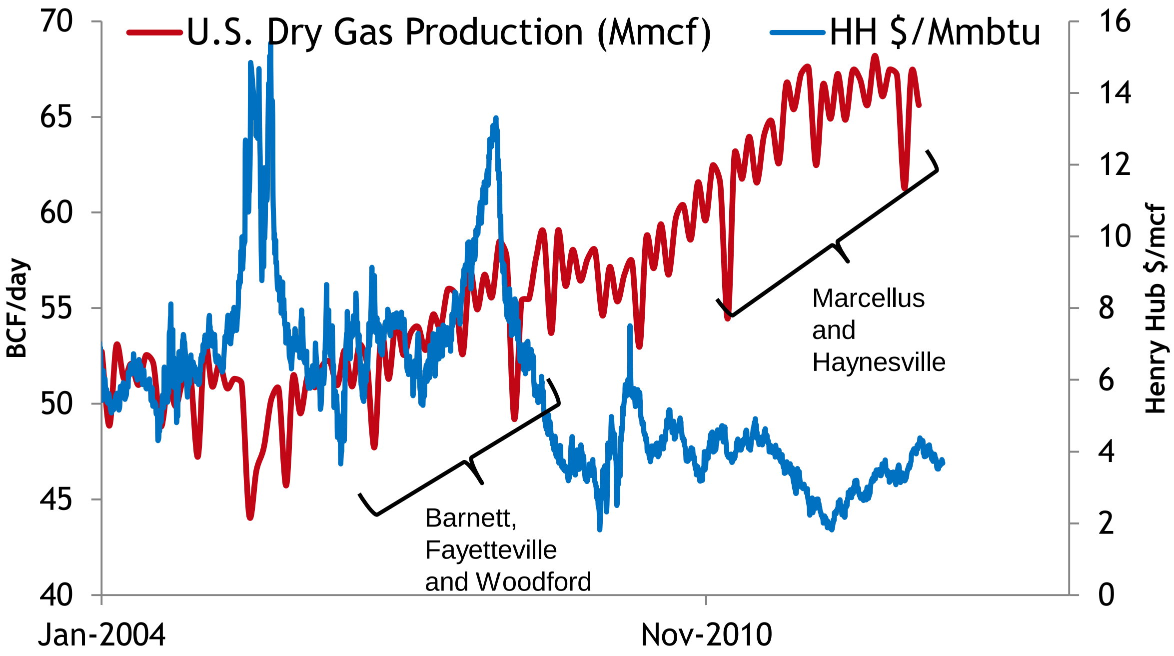
SPE International

Society of Petroleum Engineers

Outline

- Unconventional play evolution in North America
- Australian unconventional exploration review
- Technical workflow and North American case study
- External challenges present and future



Source: EIA

The unconventional exploration expectation rollercoaster

January 2013

The Telegraph

Trillions of dollars worth of oil found in Australian outback

Up to 233 billion barrels of oil has been discovered in the Australian outback that could be worth trillions of dollars, in a find that could turn the region into a new Saudi Arabia.

October 2014

The Sydney Morning Herald

BusinessDay

ConocoPhillips pulls plug on Australian onshore exploration

October 7, 2014

Read la

Angela Macdonald-Smith

March 2015

OIL&GAS JOURNAL

UNCONVENTIONAL OIL & GAS MAGAZINE PAST ISSUES

Chevron exits Cooper basin unconventional gas project

MELBOURNE, Mar. 30
03/30/2015
By Rick Wilkinson
OGJ Correspondent

May 2015

THE AUSTRALIAN

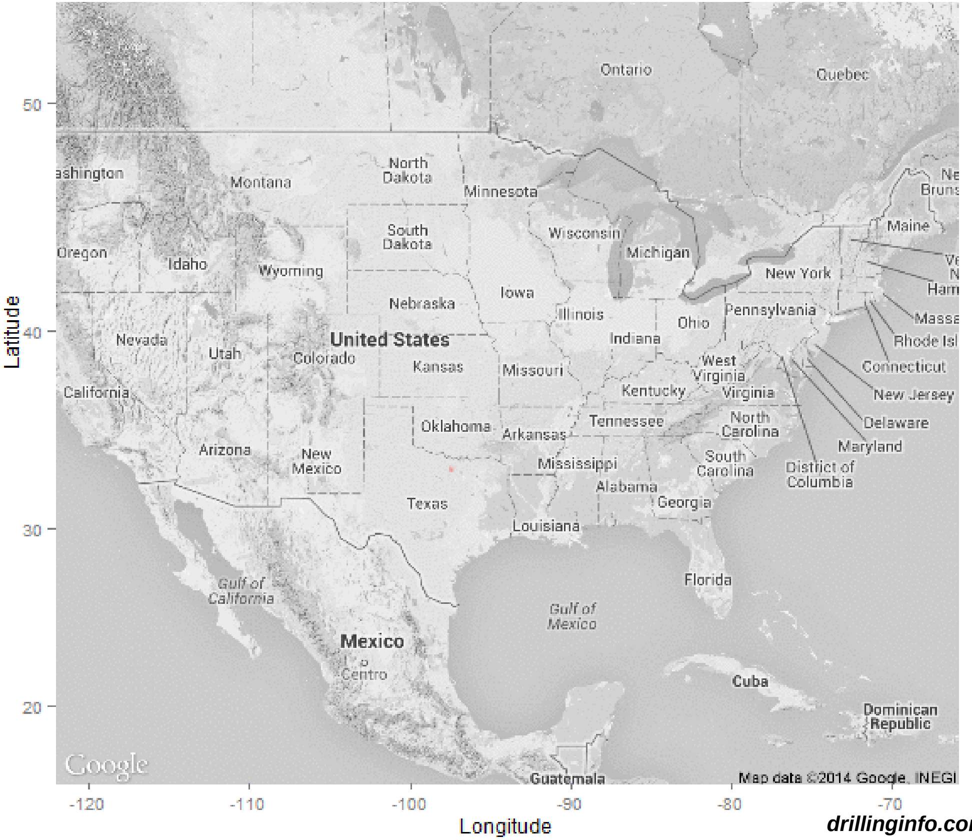
BHP shale ‘revolution’ rethink

Early exploration, appraisal and development of North American plays moved rapidly

- Measured Barnett Shale development
- Rapid subsequent play development
- Technical differences in plays but principles consistent
  - Longer wells
  - Bigger frack jobs...
  - Higher production and reserves

2000-01-01

15 years of unconventional development in the USA

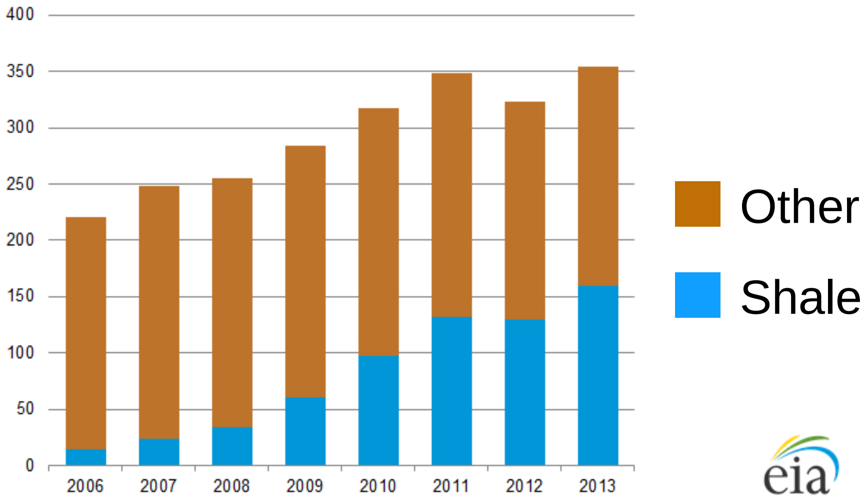


drillinginfo.com

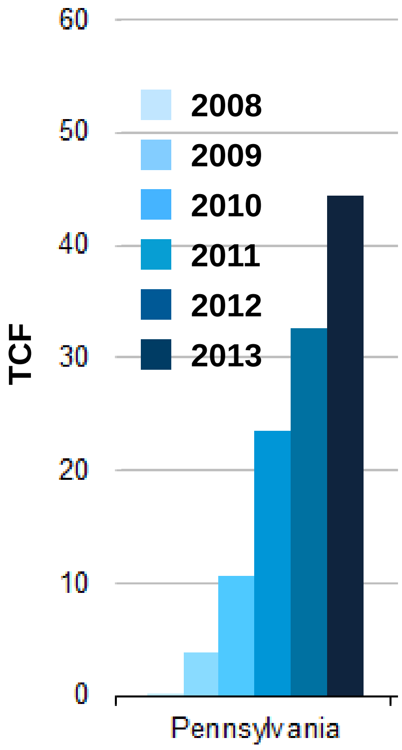
Scale of US reserves inconceivable in 2005

- Not a lot of attention from 2005-2008
- Potential of North America is untested – the penalty of success
- A revolution underpinned primarily by geology

US Total Proved Reserves (TCF)

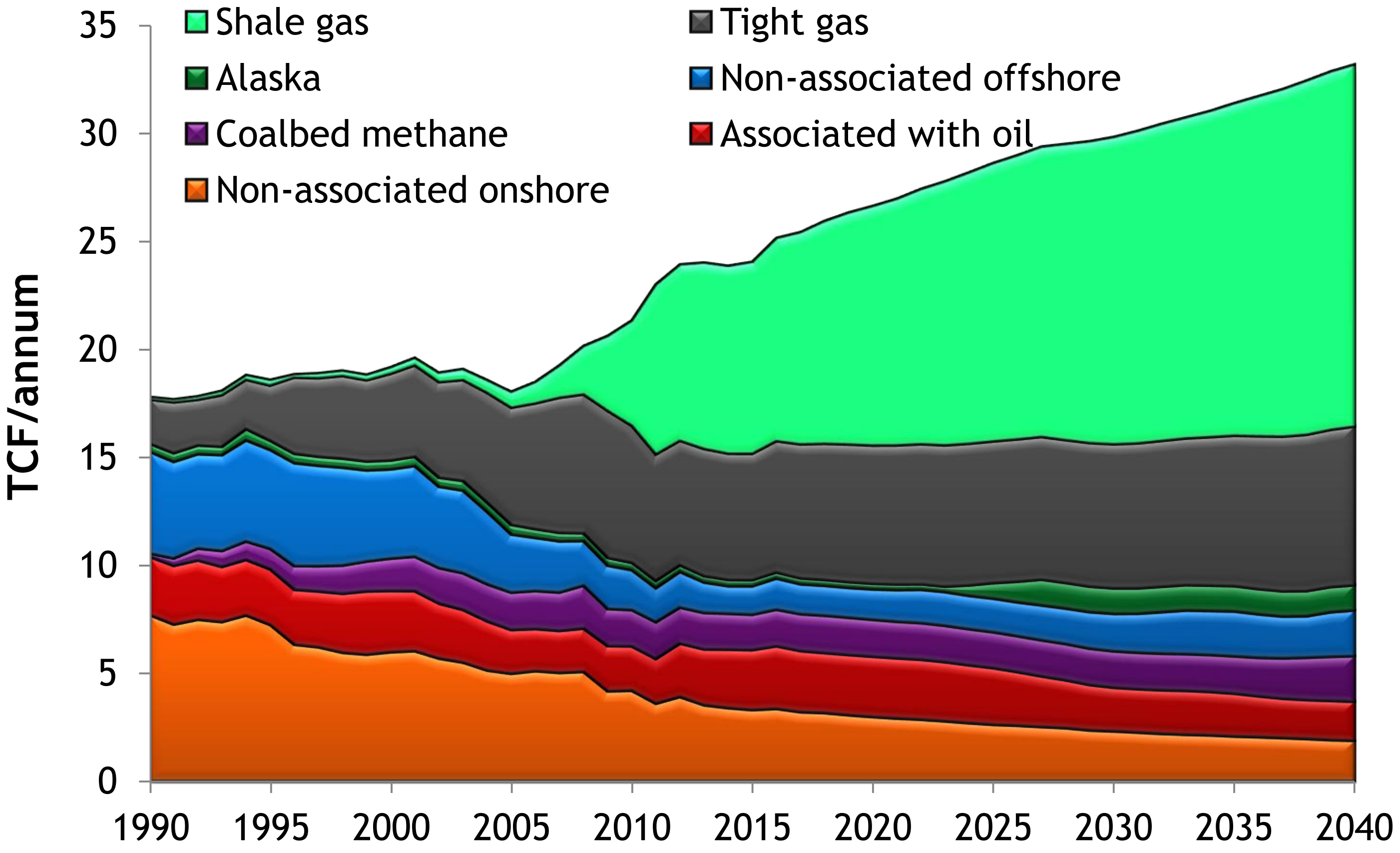


Source: U.S. Energy Information Administration, Form EIA-23L, Annual Survey of Domestic Oil and Gas Reserves, 2006-13.



EIA

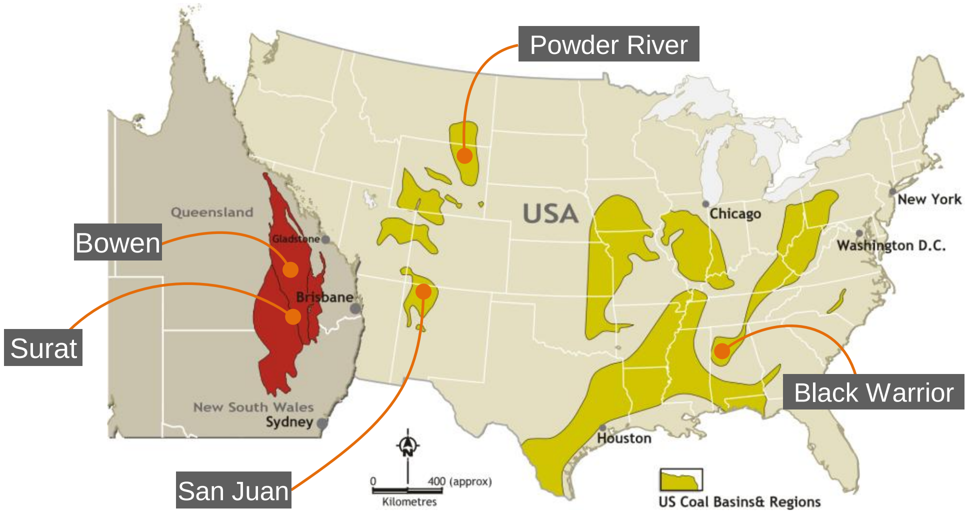
US natural gas production – underpinned by world class geology



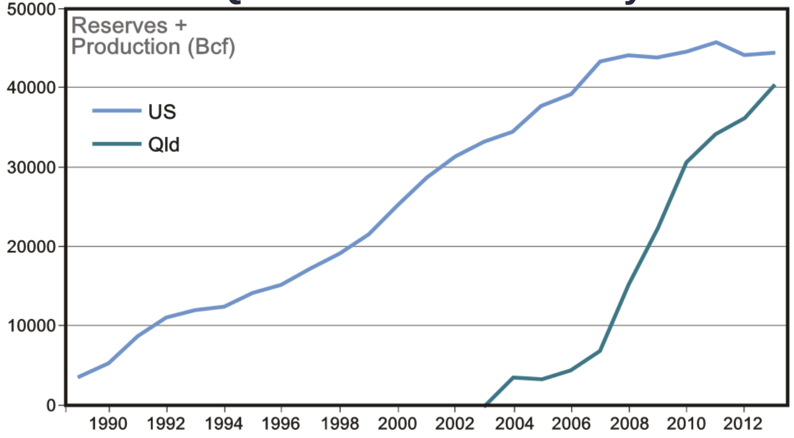
EIA

Australia's world class CSG geology

- Geology is the fundamental factor necessary for success
- World class CSG geology in Surat and Bowen Basins

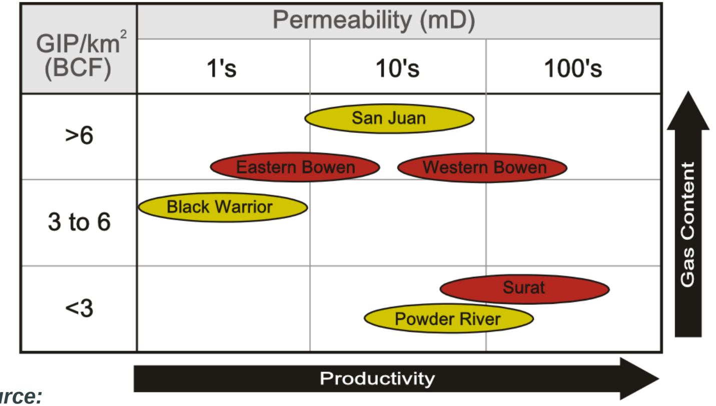


US and QLD estimated recovery



Source: Qld Dept of Natural Resources and Mines; US EIA

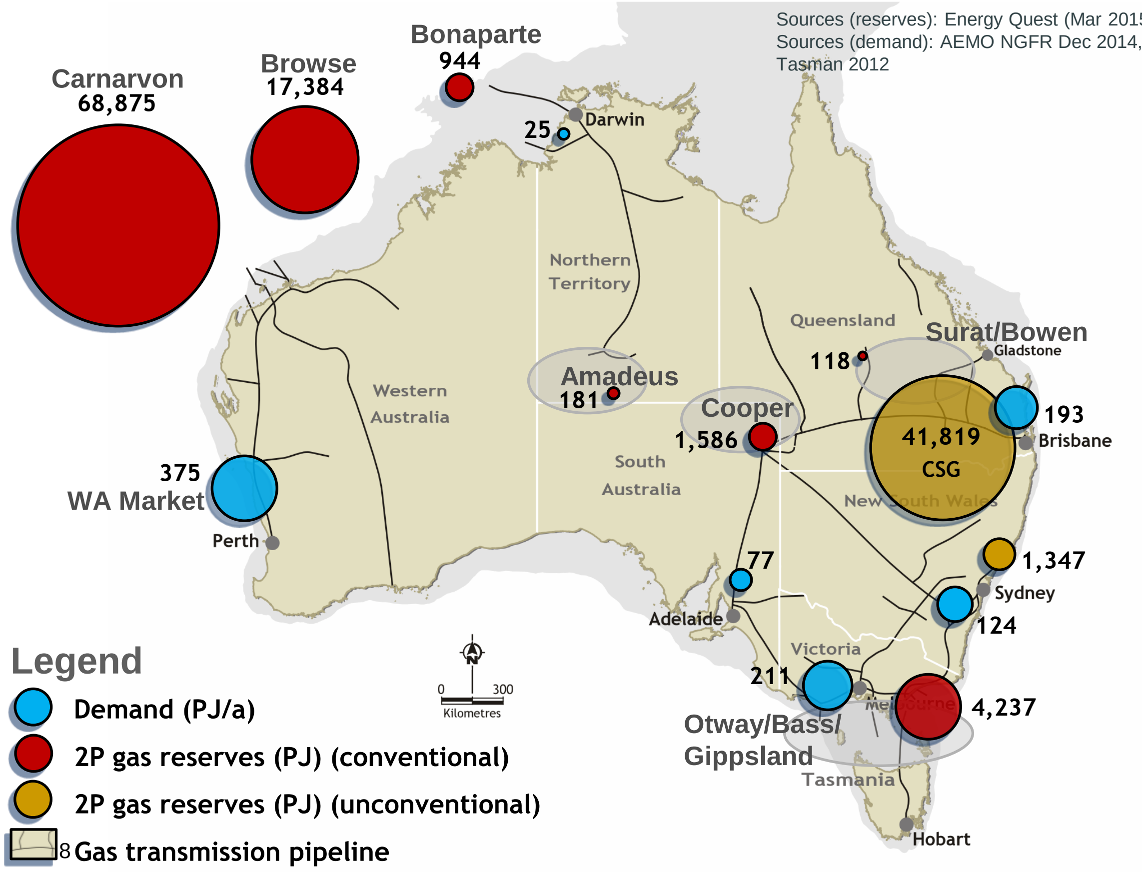
Commercial CSG Basins - permeability and resource concentration

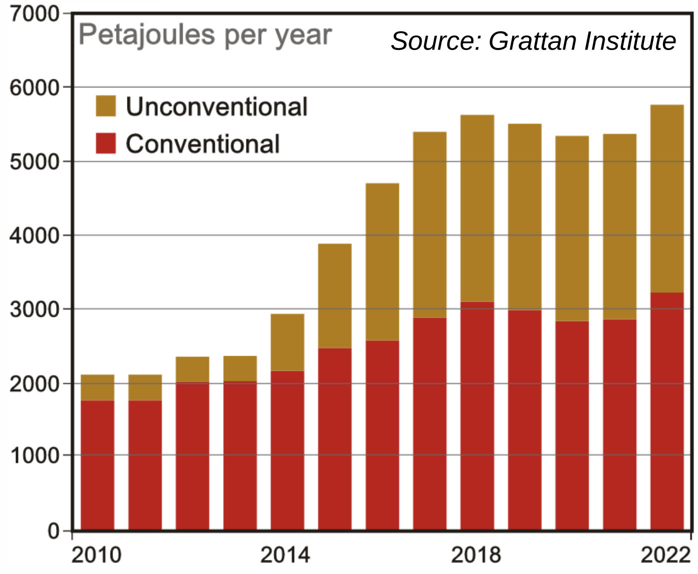


Source:
Schlumberger Business Consulting, Internal Presentation (used with permission)

Unprecedented CSG reserves and production increases

Sources (reserves): Energy Quest (Mar 2015) & QLD Dept' Nat' Resources
Sources (demand): AEMO NGFR Dec 2014, IMOWA GSOO Dec 2014, ACIL Tasman 2012





Are the USA and Queensland anomalies?

EIA unconventional hydrocarbon technical assessments

origin

- EIA studies in 2011 and 2013 – first systematic international assessment
- Results since have been mixed:
  - Good
    - Argentina – Vaca Muerte (Late Jurassic): >45,000bopd in 2015
    - Saudi Arabia – Jubaila/Hanifa/Tuwaiq Mtn (Jurassic): tested ‘like Eagleford’
  - Poor
    - Poland – Wenlock/Llandovery/Alum (Siluran-Cambrian)
    - Sweden – Alum (Cambrian-Ordivician)
  - Mixed
    - China – CNOOC Anhui Project shelved, CNPC/Shell Sichuan Basin project continuing
    - Australia – Various plays and basins

Rank	Country	TCF
1	China	1,115
2	Argentina	802
3	Algeria	707
4	U.S.	665
5	Canada	573
6	Mexico	545
7	Australia	437
8	South Africa	390
9	Russia	285
10	Brazil	245
	World Total	**7,299**

EIA (2013)

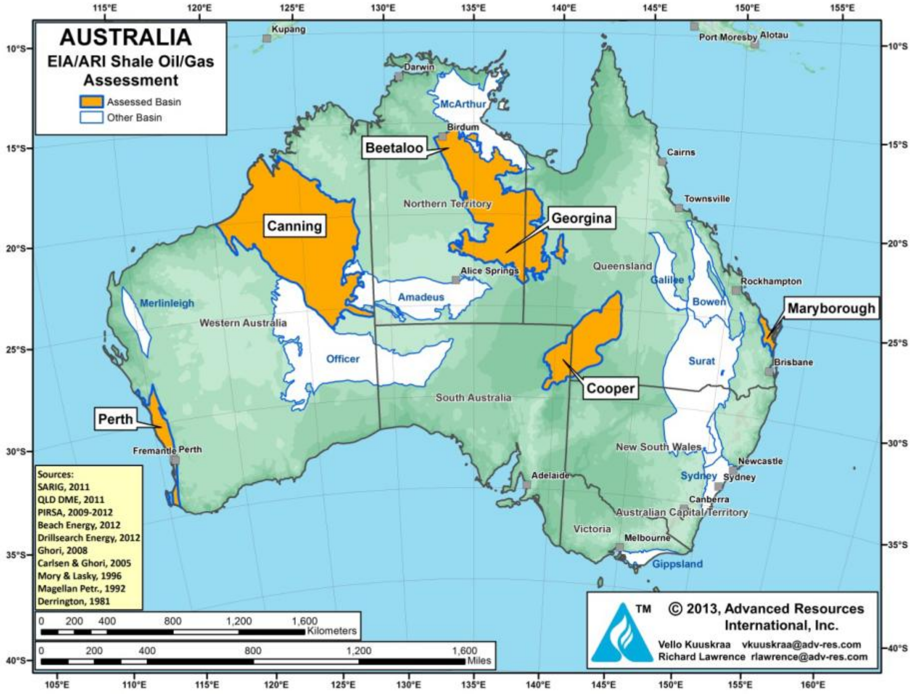
…created a surge of broad international interest from explorers, media, and regulators

EIA assessment of Australian basins

- Can these numbers be ‘real’?
- Can the resource be produced economically?

Basin	Play	Tech Rec. (Tcf)
Cooper	R.E.M.	93
Perth	Carynginia-Kockatea	33
Canning	Goldwyer	235
Georgina	Arthur Shale	13
Beetaloo	Velkerri-Kyalla	44
Maryborough	Goodwood-Cherwell	19
Total		**437**

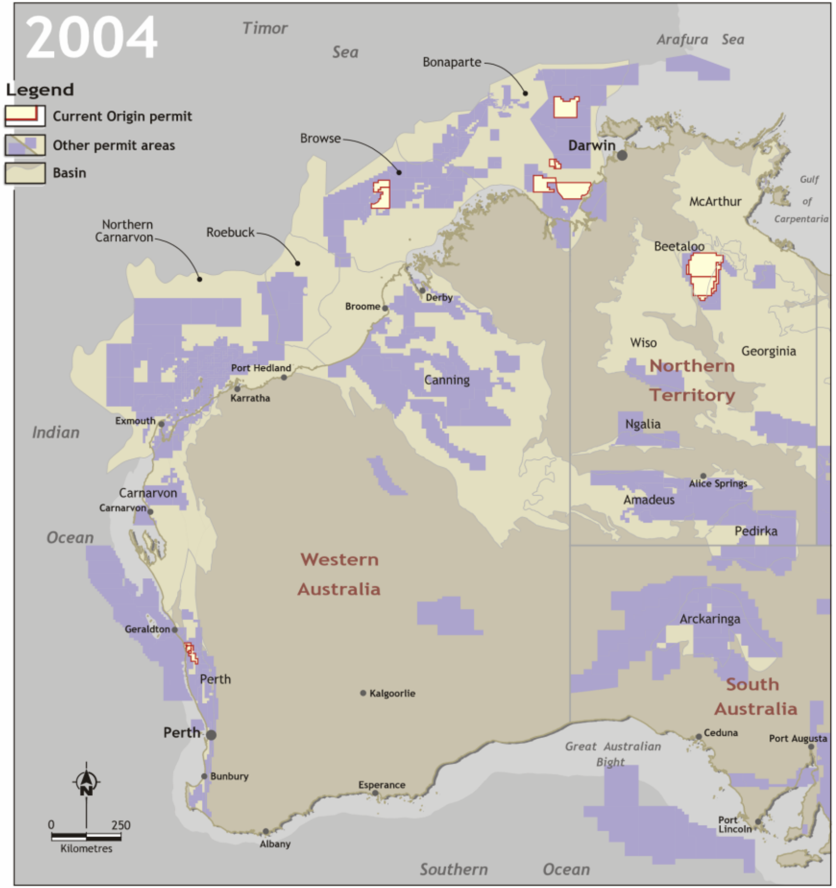
EIA (2013)



EIA (2013)

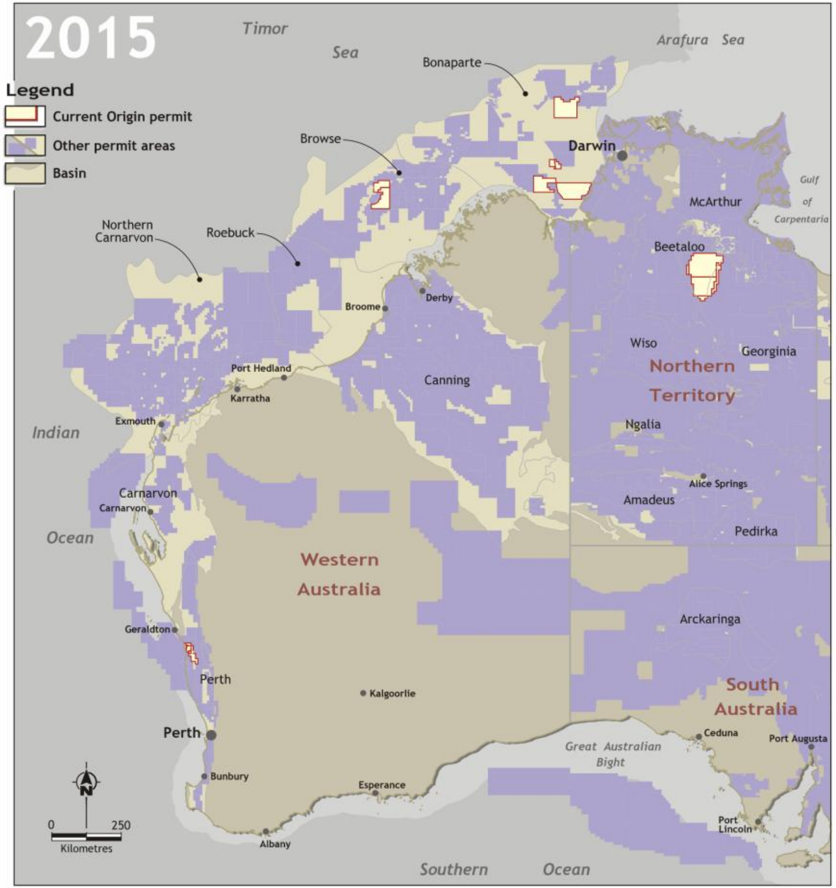
…limited subset of basins but attention grabbing estimates!

Land rush in NT, WA and SA



…NT sparsely leased

Land rush in NT, WA and SA

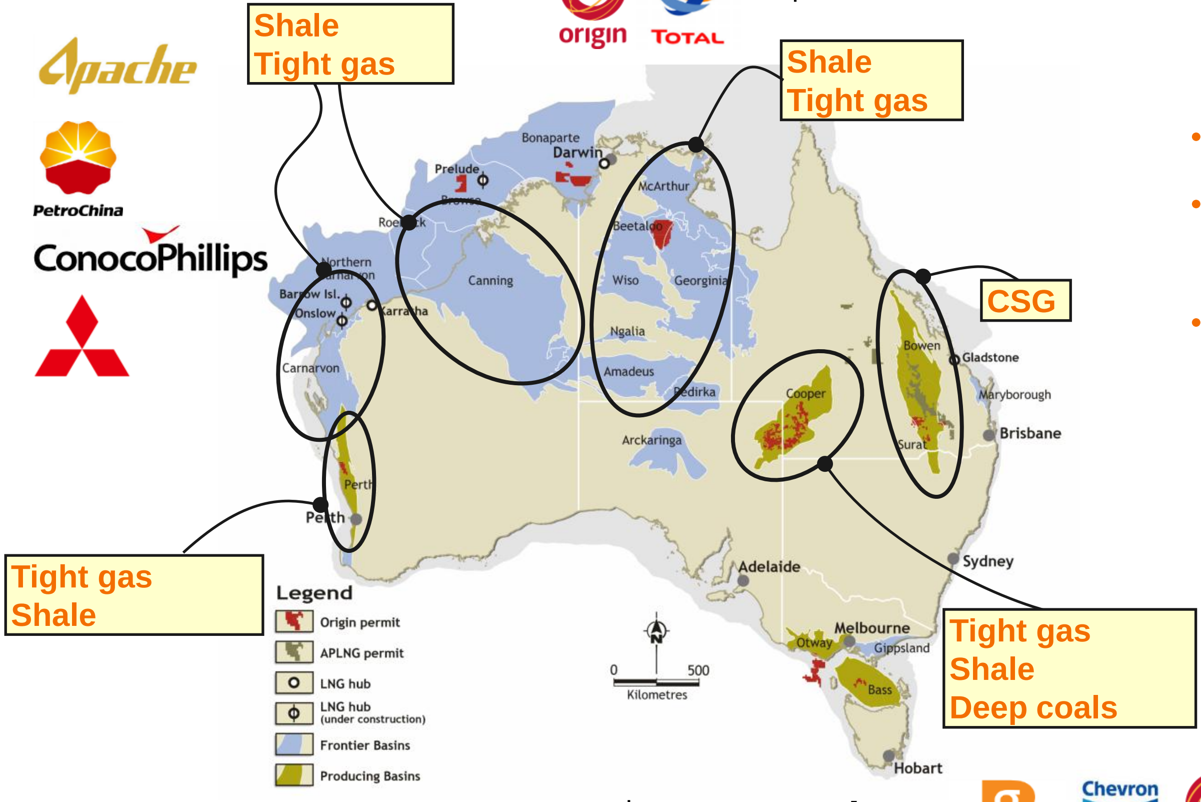


…NT >95% leased

Farm-ins to key plays followed: 2010-14

$3-15/acre

$1s-10s/acre



$10s-100s/acre

- Early movers attracted farm-ins
- International and domestic interest
- Low $/acre deals
  - $4/acre in McArthur
  - >$500/acre in Cooper

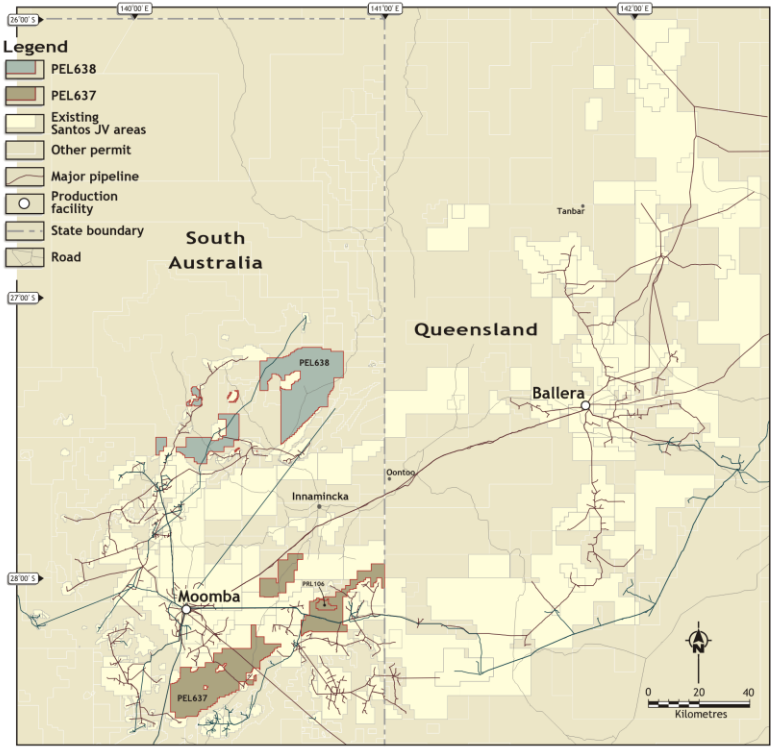
Australian unconventional exploration overview

Cooper Basin

- Focus has moved beyond REM play
- BCG play proven in the Nappamerri Trough
- Measured, focused activity in the current market conditions
- Origin remains active in pursuing Cooper Basin upside

Rank	Region	Targets	Reservoir Quality	Completion Quality
1	Patchawarra Trough	Deep Coal		
2	Nappamerri Trough	Tight Sand, Shale, Hybrid Shale, Deep Coal		
3	Moomba Big Lake	Shale, Hybrid Shale		

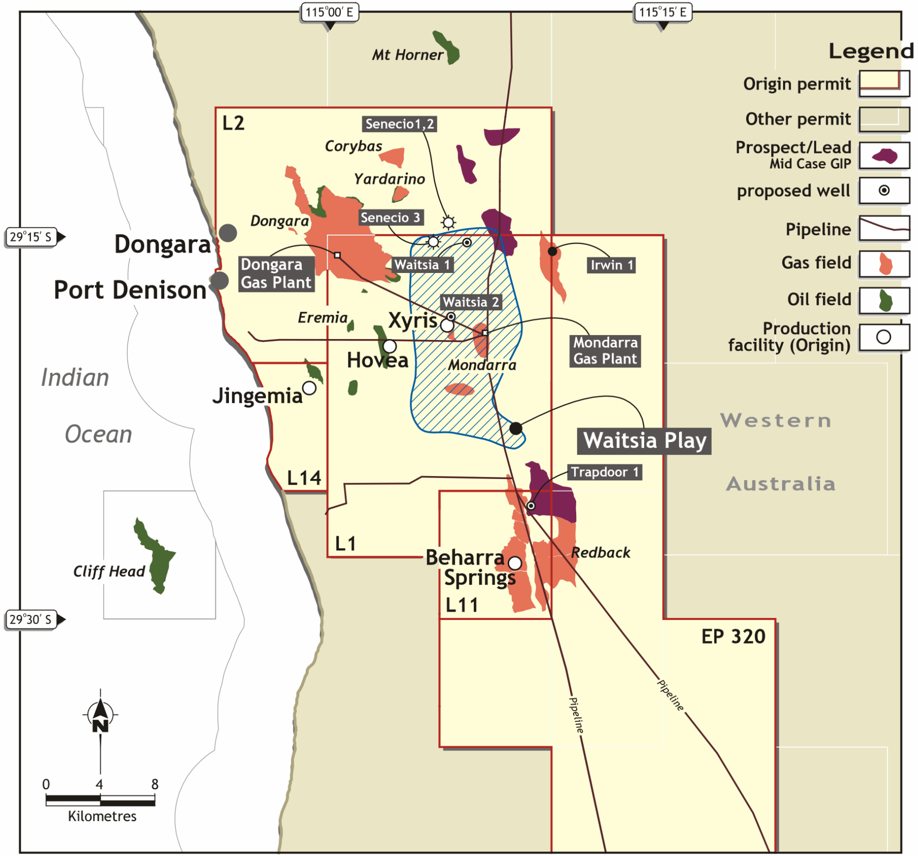
Santos (2015)



...Santos, Beach and DrillSearch Operated JVs have tested a number of plays

Perth Basin – Tight Gas

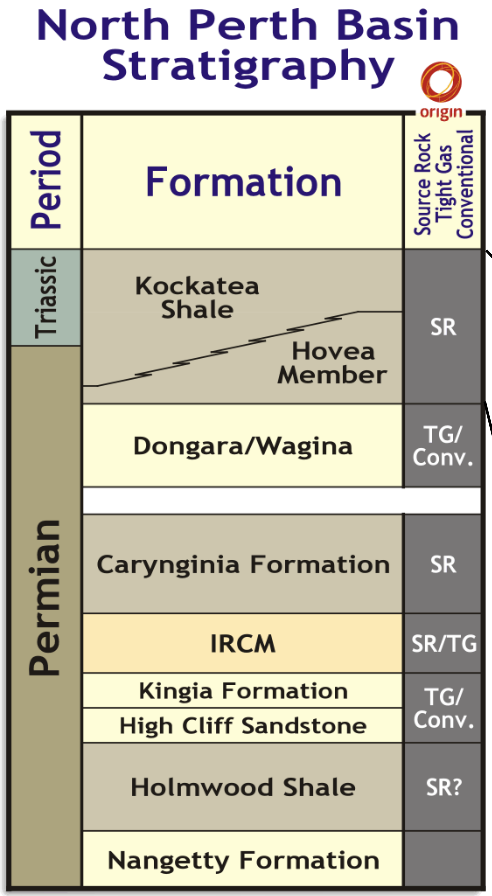
- Tight gas exploration program
  - e.g. Corybas, Senecio, Irwin
  - Large potential resource
- 'New' conventional play in the Kingia/High Cliff Formations (Waitsia Field)
  - Large resource to be appraised
  - Single zone tested at ~10 mmscf/d
- Benefit of pipeline and gas plant access



…Origin-AWE JVs hold the core of the exploration fairway in the North Perth Basin

Perth Basin – Shale Gas

- Permo-Triassic source rocks – heavily structured basin
- Kockatea Shale
  - Oil prone source rock
  - High clay
  - Thin stratigraphic sweet spot
- Carynginia Formation
  - Hybrid shale/tight gas
  - Low TOC
- Irwin River Coal Measures
  - Thin coals and tight sands



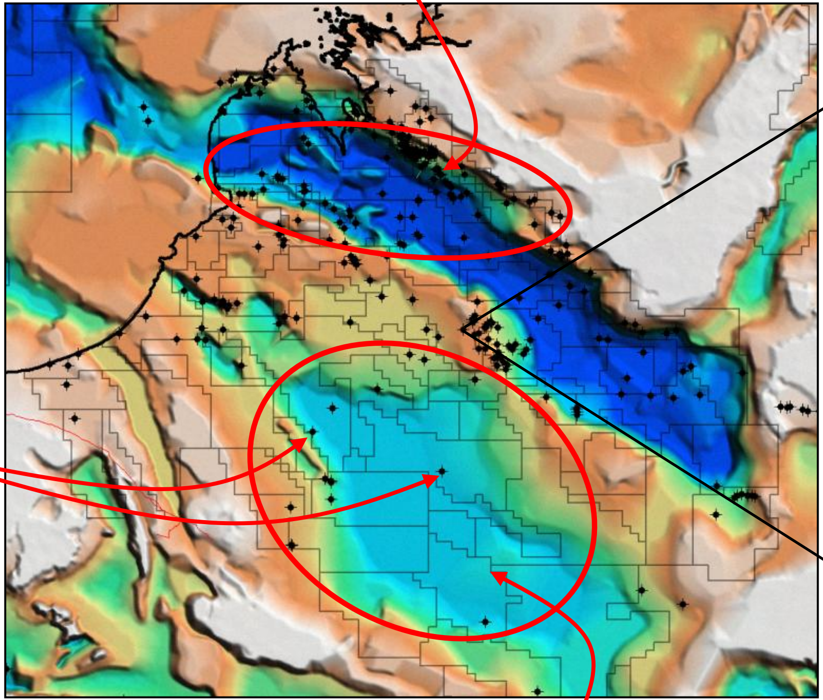
norwestenergy.com, ASX Announcements

…technical proof of concept without clear evidence of a path to commercialisation

Canning Basin

Fitzroy Trough: Laurel tight gas play (clastic play over carbonate ramp)

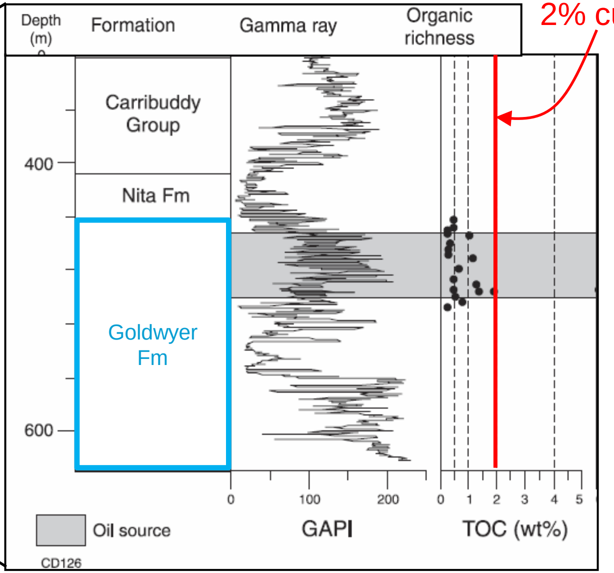
COP 2012



GPInfo

Santalum-1

2% cutoff



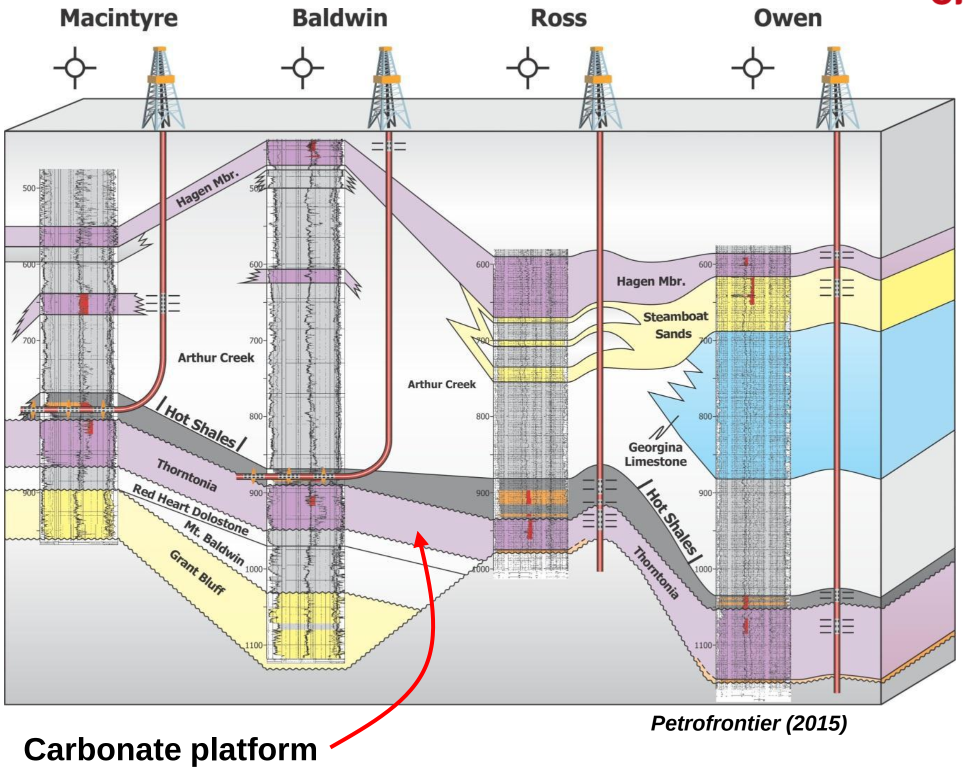
D'Ercole et al. (GSWA Record 2003/14)

Kidson Sub-Basin: Goldwyer play (organic mudstones, salt, carbonates)

…an underexplored frontier basin with some positive technical fundamentals

Southern Georgina Basin

- Cambrian Arthur Creek Hot Shale
  - Oil mature
- 2013 – three stimulated horizontal well campaign
  - Owen-3H flowed back over ~20 days without recovering measurable hydrocarbons
- 2014 – seven vertical wells with two fracture stimulations
  - No measurable hydrocarbons

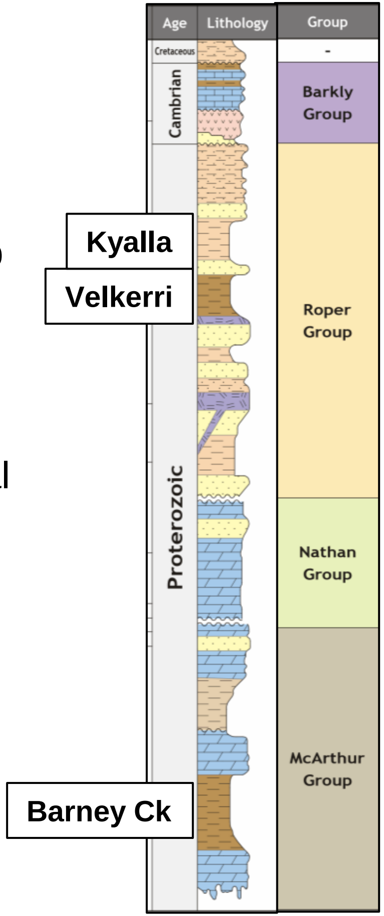


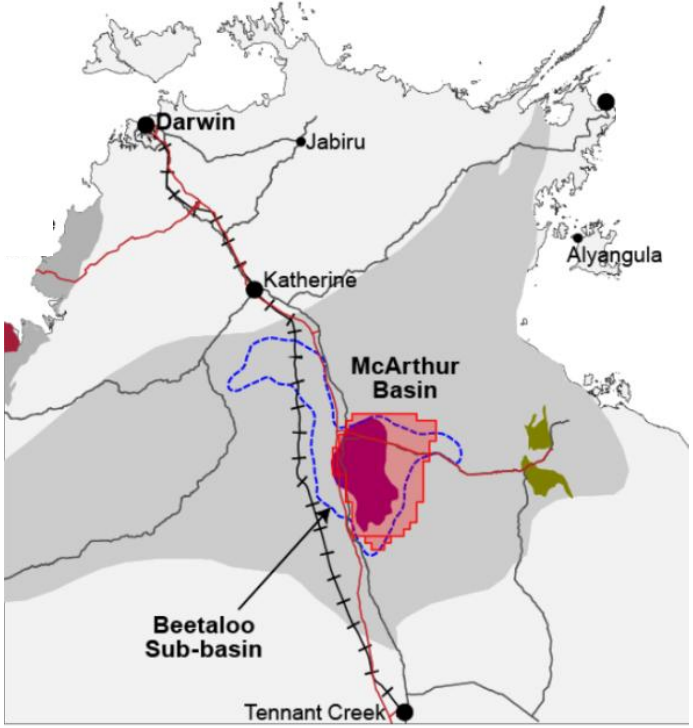
Petrofrontier (2015)

...good technical fundamentals but results from Statoil drilling are discouraging

McArthur Basin

- Proterozoic source rocks – no unconventional analogues
- Primary target is the Barney Creek Fm
    - Type I-II algal organic material
    - High carbonate, low clay content
    - Heavily thrusted/structured in east
    - Untested in west

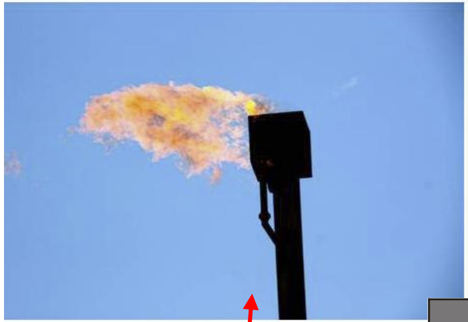




Close/NTGS (2015)

...a vast, underexplored basin with numerous dissimilar provinces

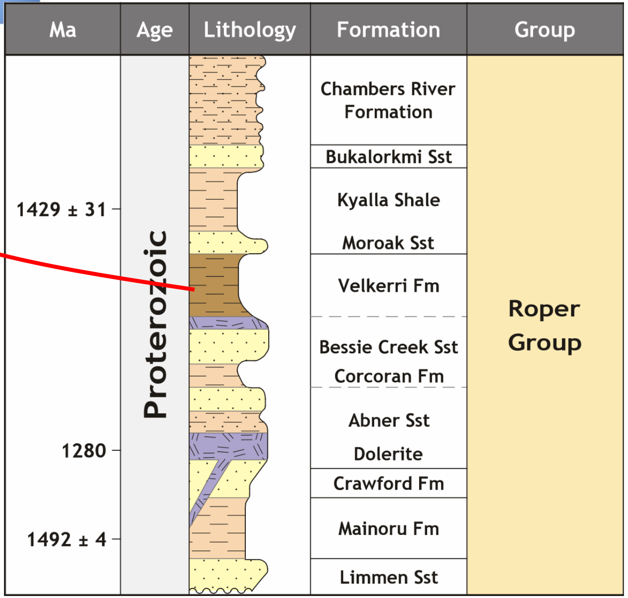
Beetaloo Sub-Basin



Shenandoah-1A, Falcon Oil & Gas, 2011

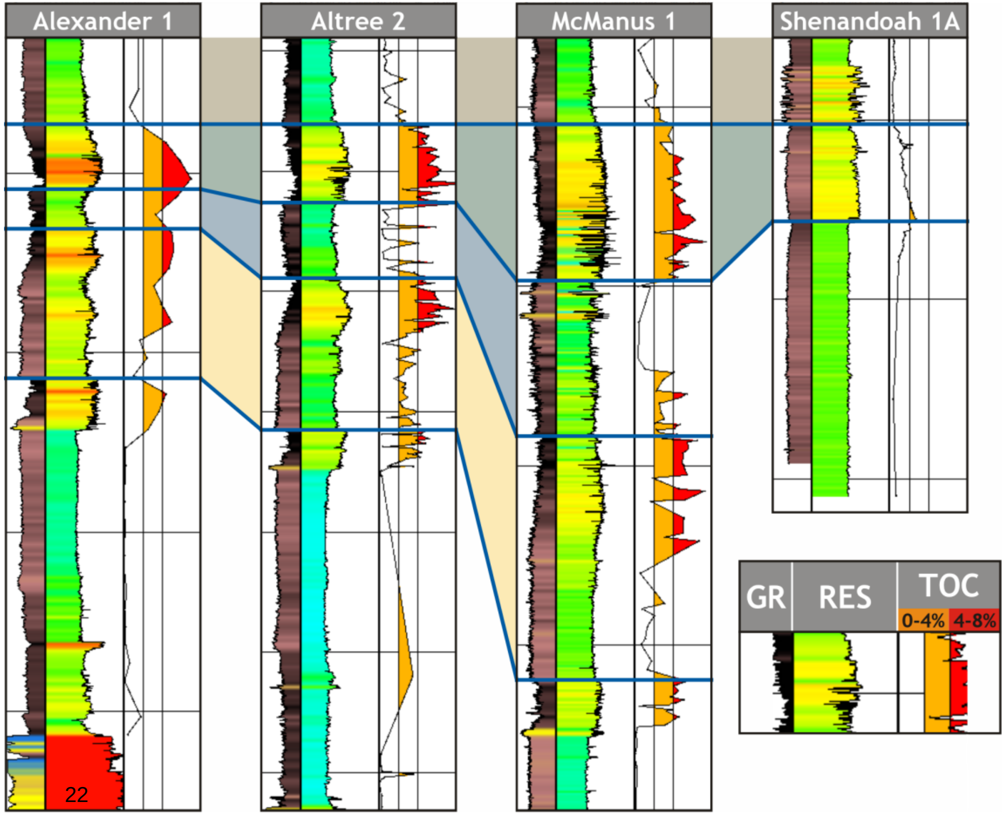
- *"Multiple thick intervals of organic-rich rock...accompanied by significant mud gas shows"* (santos.com)

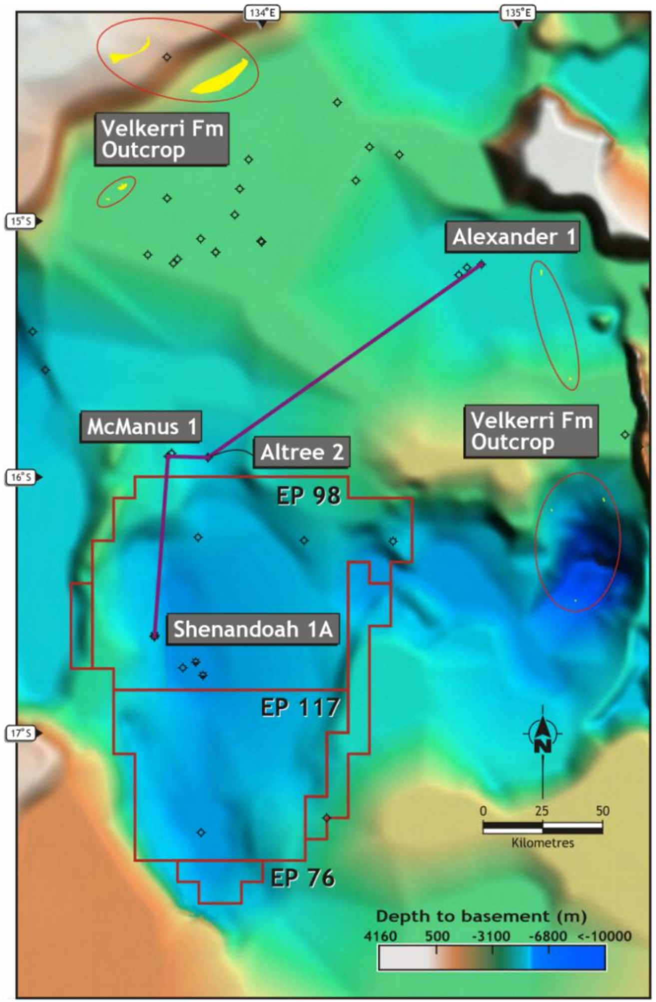
	Middle Velkerri Fm
TOC	1.5 – 6 %
Kerogen	Type I-II
Maturity	Mature for Gas>>Oil
Mineralogy	32% Clay, 8% Feldspar, 45% Quartz
Porosity	2 – 8%



...a long lived, deep basin that has preserved the prospective Roper Group sequence

Velkerri Formation – ‘classic’ shale gas petrophysical character

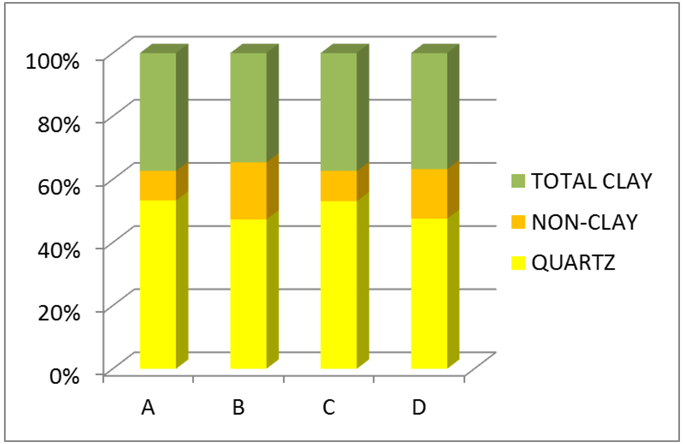


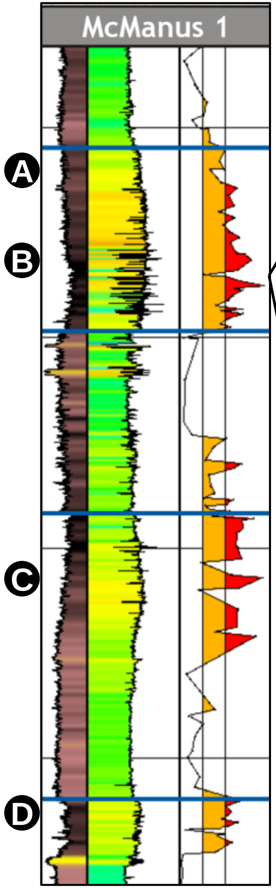


OZ SEEBASE™ (FROGTECH, 2006)

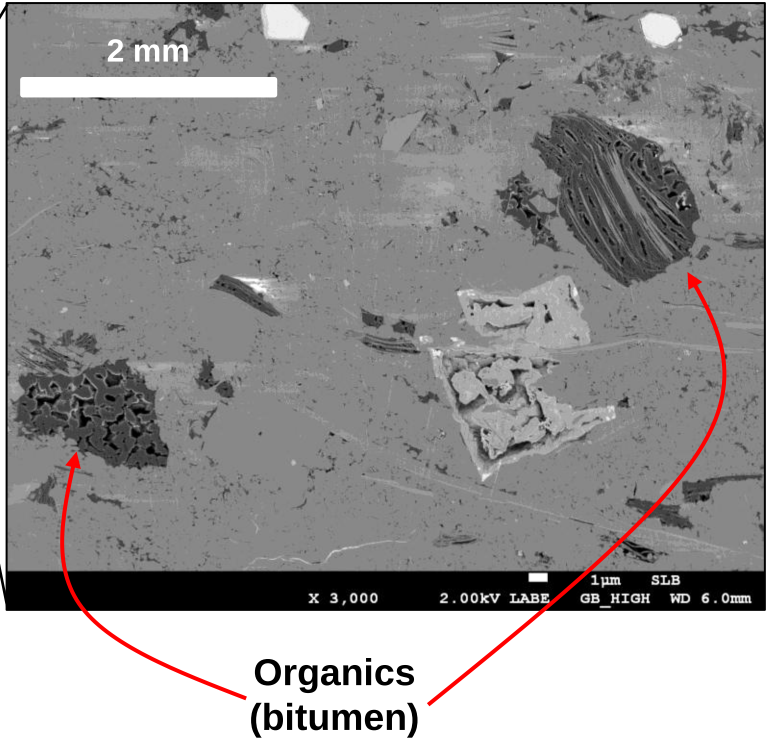
Velkerri Formation – porosity developed in gas mature organics in a quartz rich matrix

XRD Mineralogy





SEM image



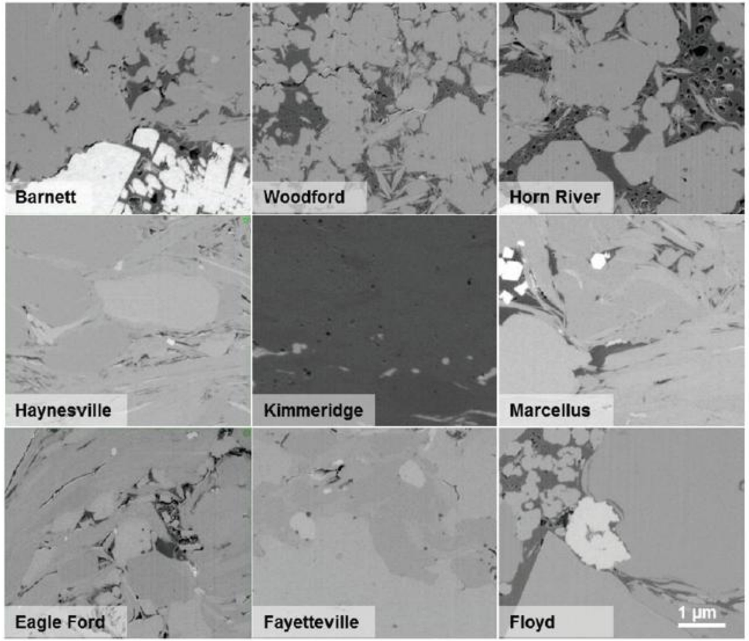
The Beetaloo JV – Origin, Sasol and Falcon Oil & Gas

- The JV permits cover the basin core – first mover advantage
- Excellent transport and pipeline access
- Transaction fundamentals
  - Nine well program
  - Compelling $/acre metrics
  - Large resource upside – high technical risk
- 2015: two-three vertical exploration wells
- 2016: first horizontal production test
- 2017-18: four horizontal production tests

Proposed wells - 2015

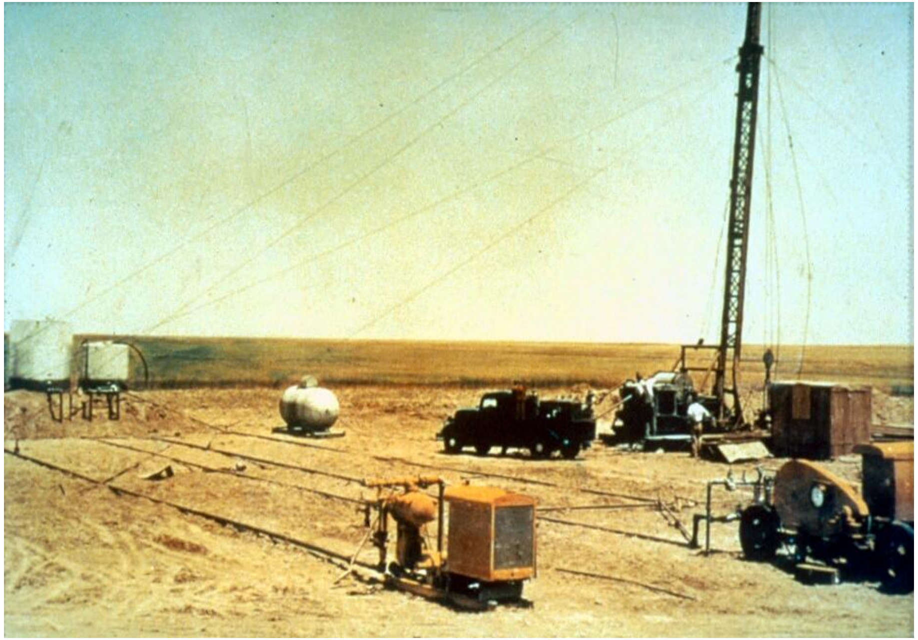
Unconventional exploration workflow and Canadian case study

Heterogeneity and a geophysical understanding of hydraulic fracture stimulation



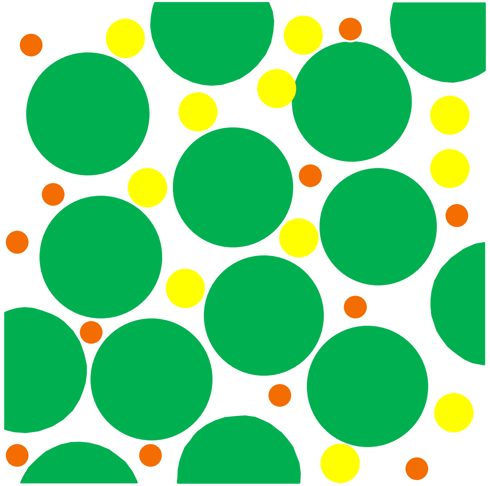
Curtis et al. (2010)

Hydraulic fracturing of oil and gas bearing sandstone formations to enhance recovery is still being done today without any means of determining the actual types, lengths, or directions of fractures induced away from the wellbore. *Shuck (1974) – SPE 5160*

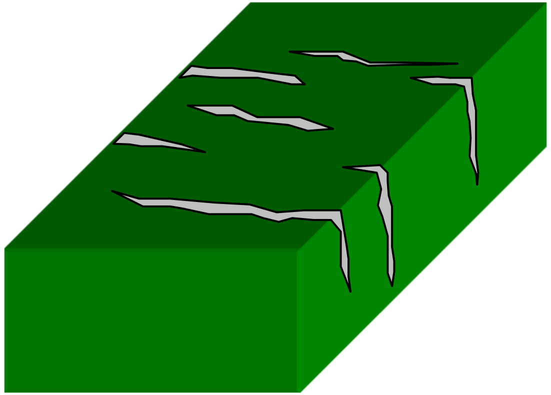


Geophysics and unconventional reservoir evaluation – mapping structures and hunting closure is no longer the imperative

- Geophysics can still add substantial value in reservoir characterisation studies of unconventional reservoirs to understand *heterogeneity*
  - Original gas in place (OGIP)
  - Fracture stimulation efficacy to maximize recovery factor (Rf)



The higher the effective porosity, the higher the OGIP



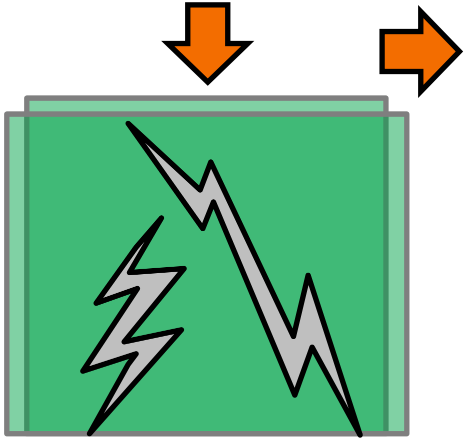
The more effective the hydraulic fracture, the greater the Rf

Perez and Close (2011)

Effective fracture stimulation requires formation breakdown and the complex propagation of the fracture

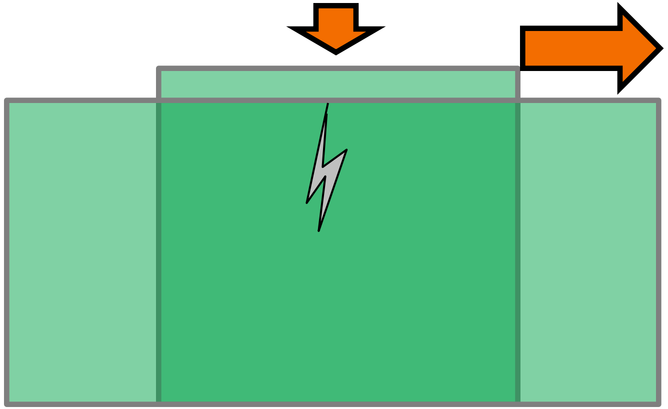
- Brittle failure: minimal strain, relatively little plastic deformation before failure
- Ductile failure: large amount of strain, extensive plastic deformation before failure
- Poisson's Ratio is meaningful in this 'lab style' schematic where rocks are not bound...but it has limitations as a 'meaningful' geophysical parameter...LMR provides an alternative domain for understanding and interpretation

$$\upsilon = \frac{\varepsilon_{xx}}{\varepsilon_{zz}}$$



Low Poisson's ratio

$$\upsilon = \frac{\varepsilon_{xx}}{\varepsilon_{zz}}$$



High Poisson's ratio

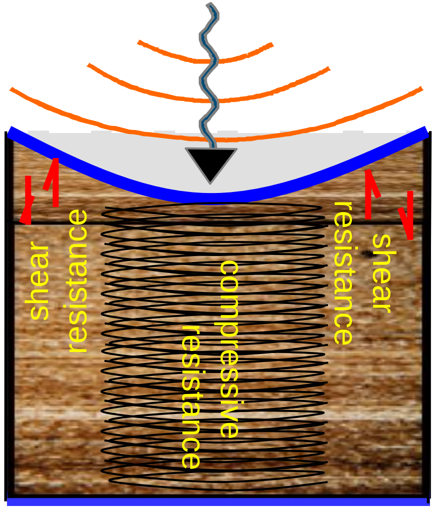
Perez and Close (2011)

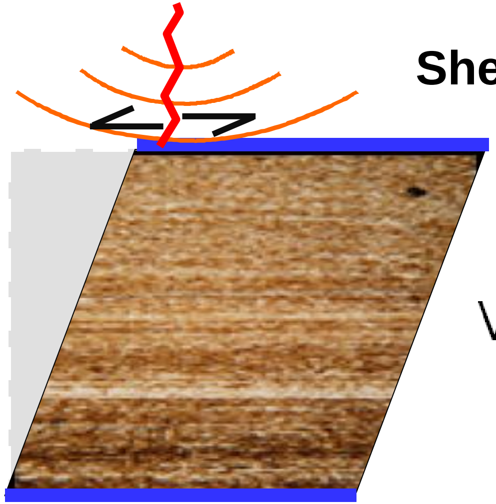
Lambda-Mu-Rho (LMR) is a relatively widely known but often poorly understood ‘domain’

- Lambda (λ) and Mu (μ) are the Lamé parameters of incompressibility (λ) rigidity (μ) in Hooke’s Law
- Rock physics can help understand and predict seismic response and fracture stimulation behaviour

Compressional P-Wave

$$Vp = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$





Shear S-Wave

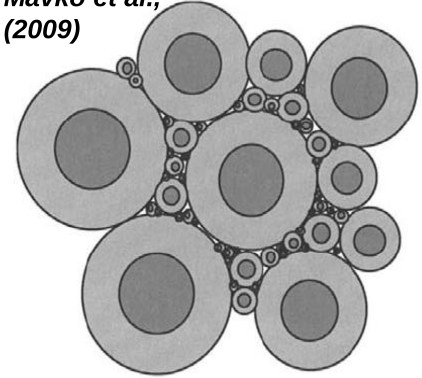
$$Vs = \sqrt{\frac{\mu}{\rho}}$$

Goodway (pers. Comm.)

Rock physics models can be used to build interpretation templates

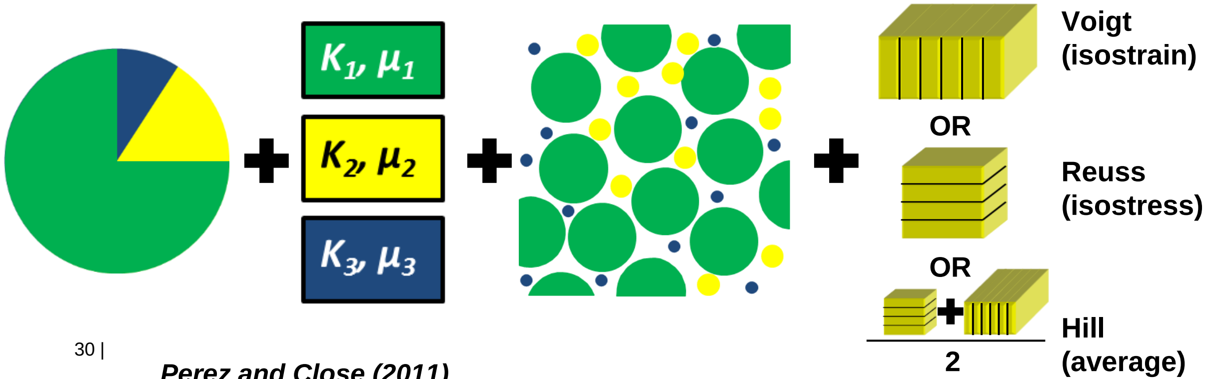
- Consider the limits of material mixtures, e.g. Hashin-Shtrikman bounds
  - Upper bound and lower bounds
  - Bounds converge at mineral (and fluid points)
- To predict moduli of grains and pores, one must specify:
  - Volume fractions and elastic moduli of the various phases
  - Geometric details of how phases are arranged (typically an unknown in practice)

Mavko et al., (2009)

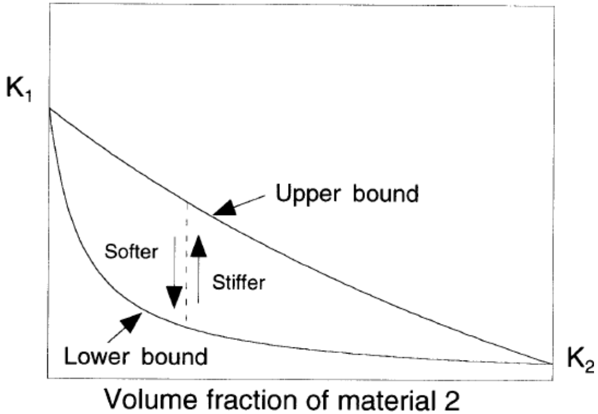


Soft/Hard or Hard/Soft

Volume **Moduli** **Geometry** **Mix**

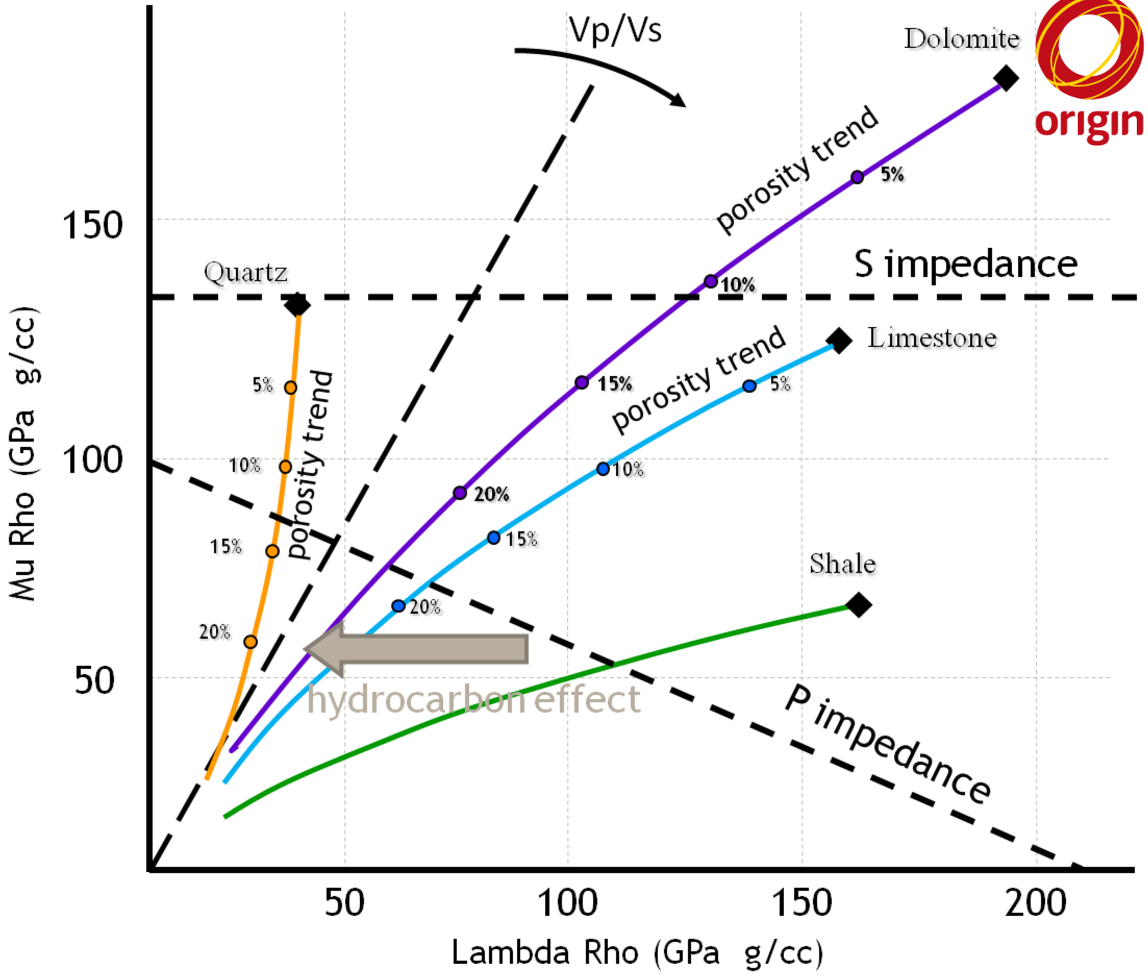


Perez and Close (2011)



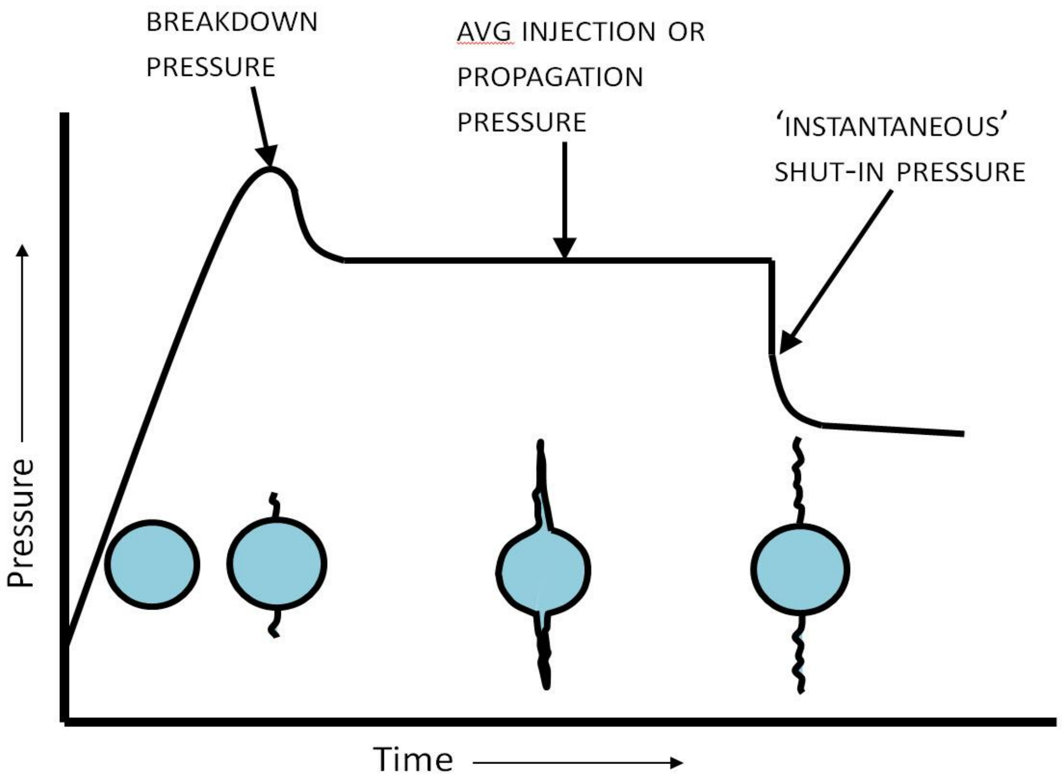
Rock physics model (RPM) based LMR template

- Rock physics: elastic properties and geology
- To predict effective elastic moduli of a mixture of grains and pores, we must specify:
  - Volume fractions
  - Elastic moduli
  - Geometric detail
- How to relate this specifically to unconventional exploration and development?

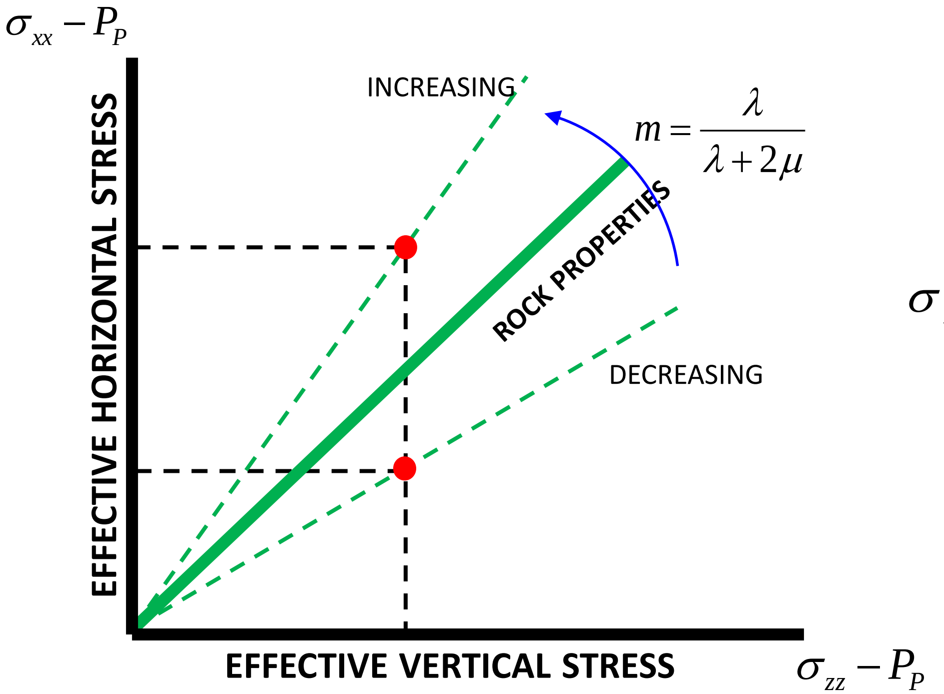


The life journey of a fracture from breakdown to closure or shut-in …according to a geophysicist

- *The minimum horizontal closure stress, defined as the minimum pressure required to open a pre-existing fracture or plane of weakness, must be exceeded by the slurry to continue to propagate fractures away from the wellbore after a fracture is initiated (typically at some higher pressure – the breakdown pressure)* (McLennan and Roegiers, 1982).



The Closure Stress Scalar (CSS) is a rock properties term that helps tie the geoscience and engineering domains



Perez (2011)

Y = m X + c

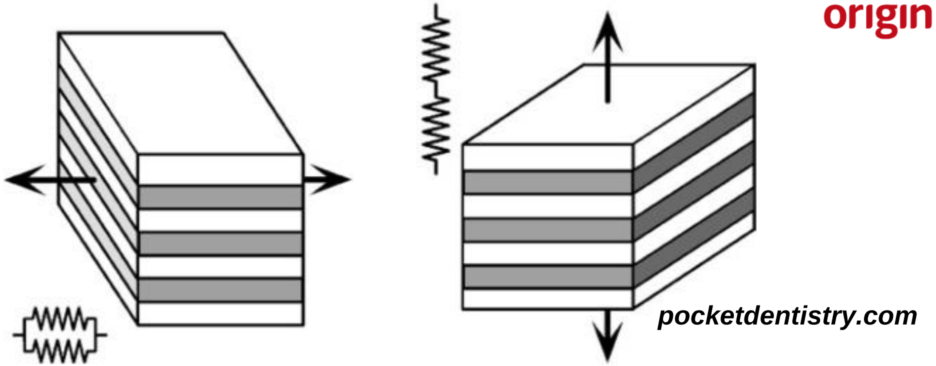
$$\sigma_{xx}-P_P=\frac{\lambda}{\lambda+2\mu}[\sigma_{zz}-P_P]+\frac{\lambda}{\lambda+2\mu}\left(\frac{\varepsilon_{yy}^2-\varepsilon_{xx}^2}{\varepsilon_{yy}}\right)$$

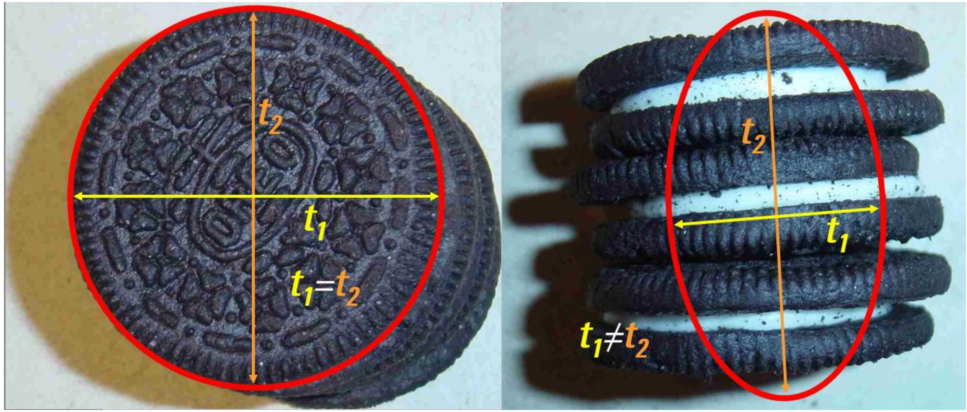
Goodway (2009)

- In a normal stress regime the CSS equation simplifies substantially
- In a strike-slip stress regime this simplification is not valid...the intercept value is non-zero and increases closure stress...but...

Nothing is as easy in Australia – a passive basin assumption is not typically valid

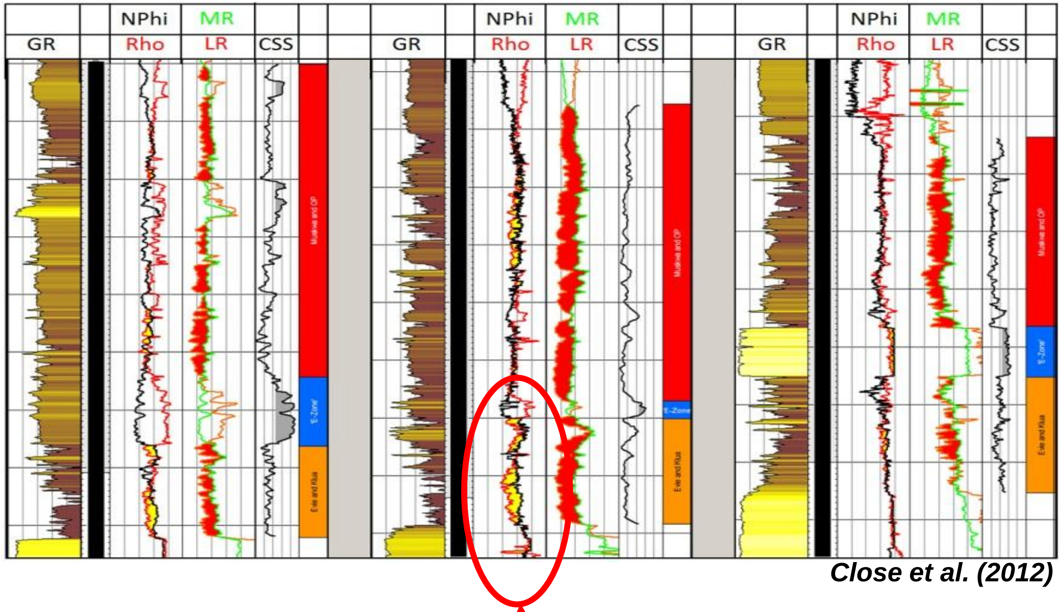
- Cooper Basin: a strike-slip basin where ductile layers are ‘understressed’ in an isostrain system
  - Reverse at depth
- Quantifying the tectonic terms in the closure stress equation is not trivial...
- We can attempt to quantitatively analyse the horizontal anisotropy using amplitude or velocity variations with azimuth





The old Oreo cookie VVAZ story

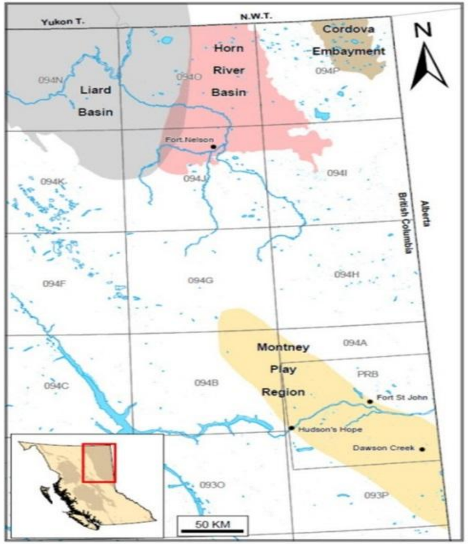
Unconventional Case Study: Horn River Basin, BC, Canada

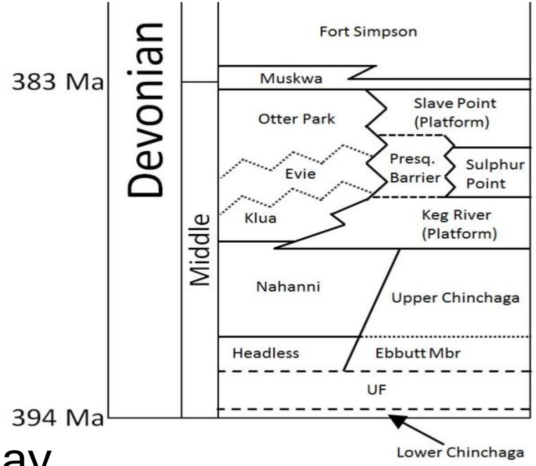


Close et al. (2012)

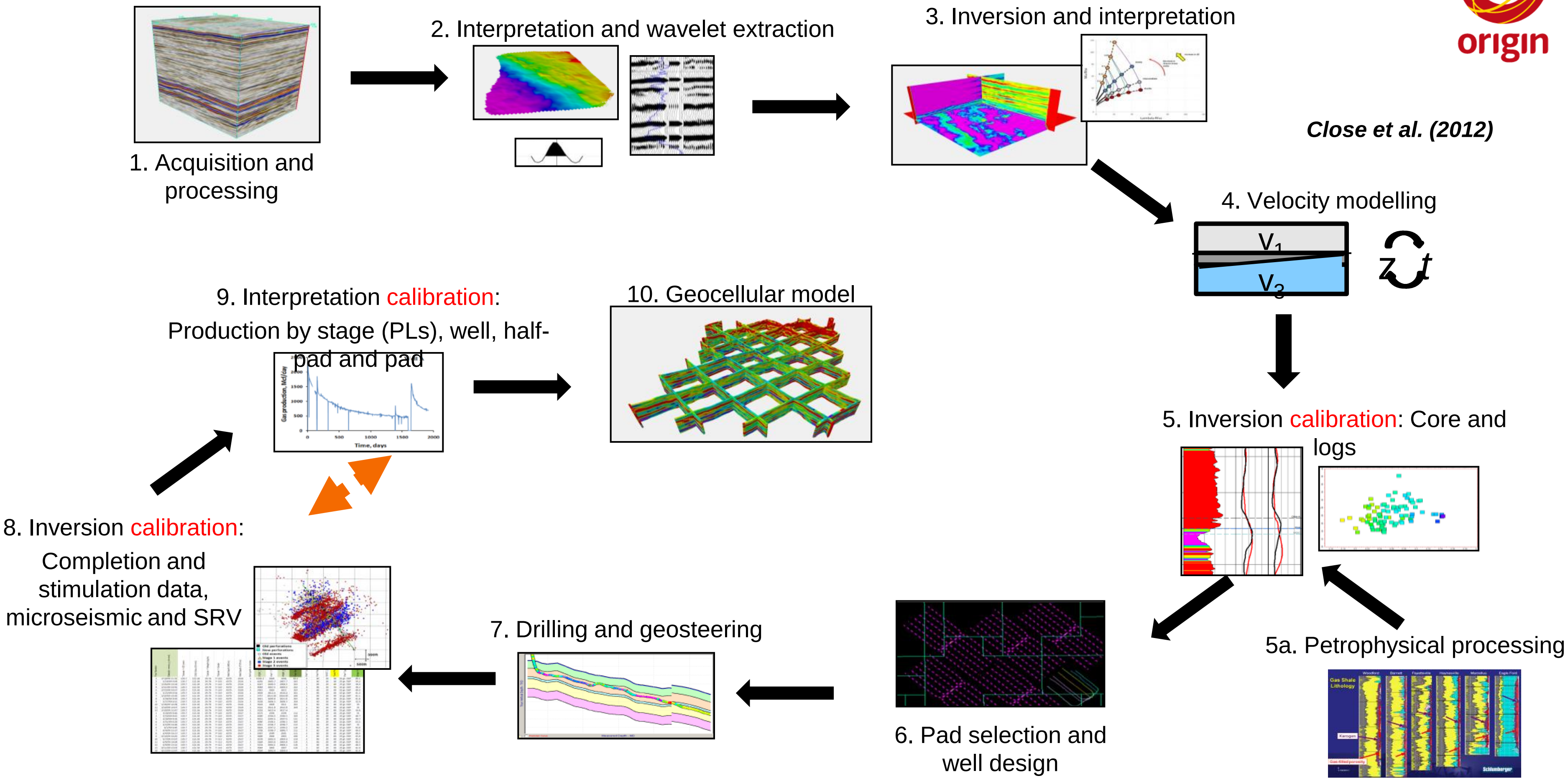
Looks as good as conventional pay

BC Min. Of Energy, Mines and Petroleum Resources



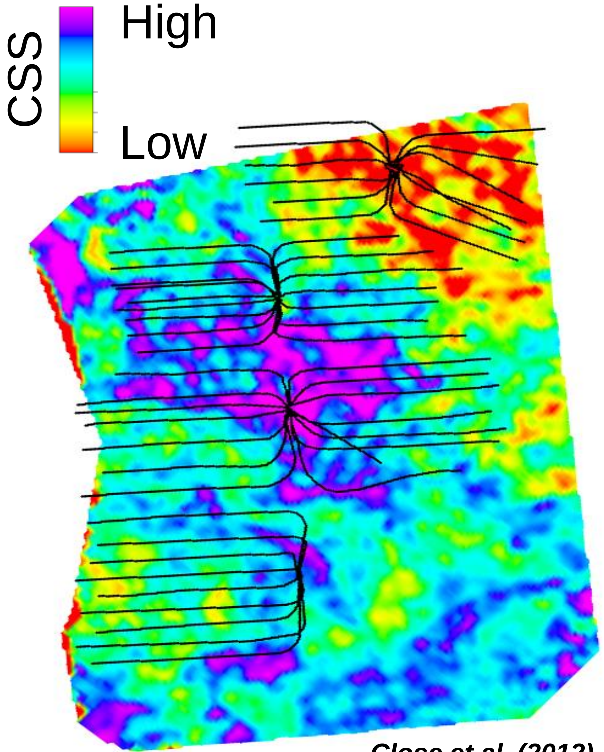


Schematic integrated QI appraisal and development workflow

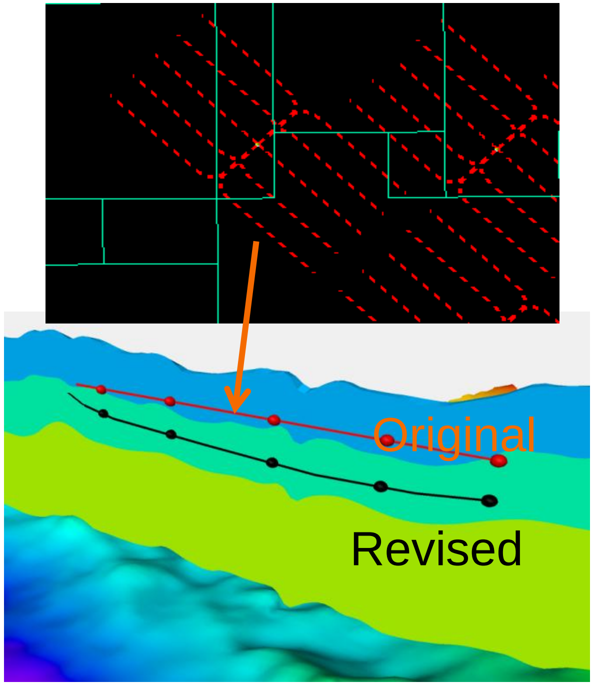


6. Pad selection and well planning: optimal development plan with no sterilised acreage

- Maps of inversion properties (e.g. closure stress scalar) illustrate heterogeneity
  - Mean? Max? Min? Threshold thickness?
- Combined with integrated pad design tool
  - Efficient pad layouts for multiple spacing scenarios
  - Optimal spacing a function of many variables (NPV vs ROR focus)



Close et al. (2012)



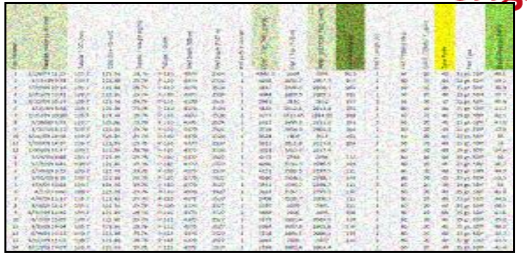
Close et al. (2011)

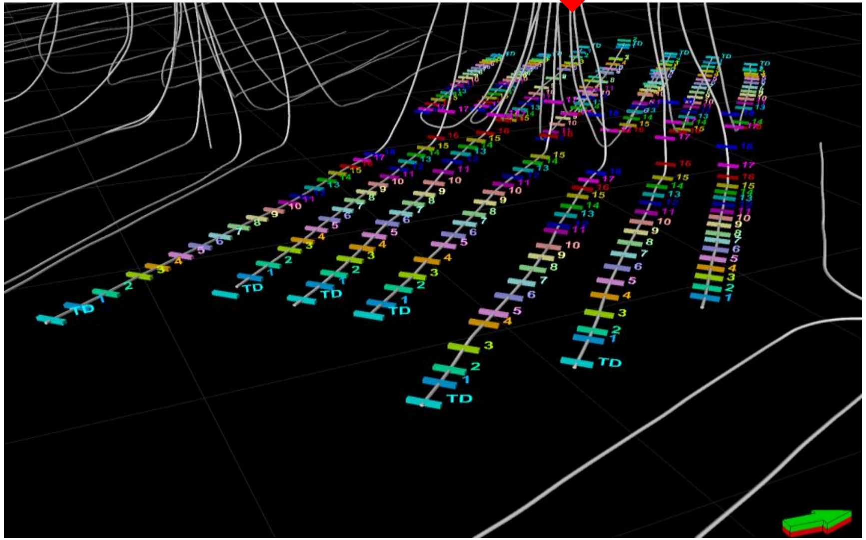
7. Real time geosteering and modelling are critical to maintaining reservoir contact – critical for stimulation success

- Efficient completions are assisted by minimum tortuosity in horizontal
- Landing the lateral is critical to frack efficacy and production outcomes
- Utilize independent data where possible:
  - ROP, gas shows, seismic-scale faults, engineering data

8. Inversion calibration using stimulation data: although lacking traditional log data the wells are rich with ‘engineering’ data

- Well by well and stage by stage: lots of data…
- Which data?
  - Breakdown pressure, ISIP: Instantaneous Shut-In Pressure
- These are the only data available to calibrate AVO inversion volumes as horizontals will rarely be logged and pilot wells will be limited
- Extracting representative data from AVO volumes is also a non-trivial process…
- Fortunately – a frack is a bit like a wavelet it averages the formation over a finite volume

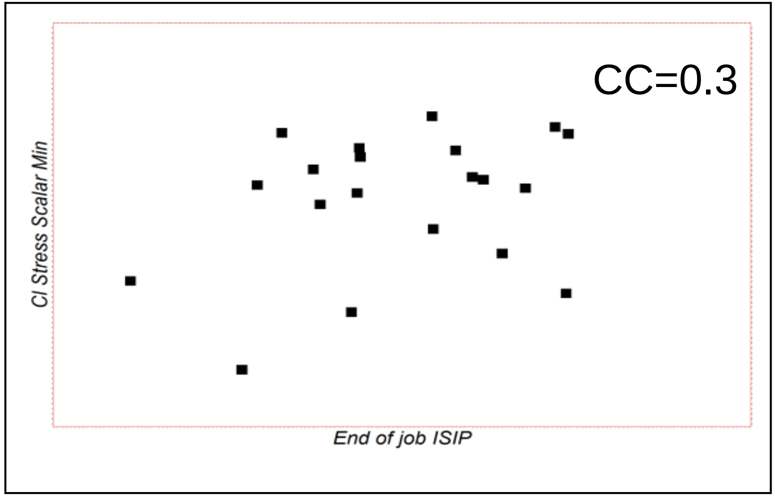


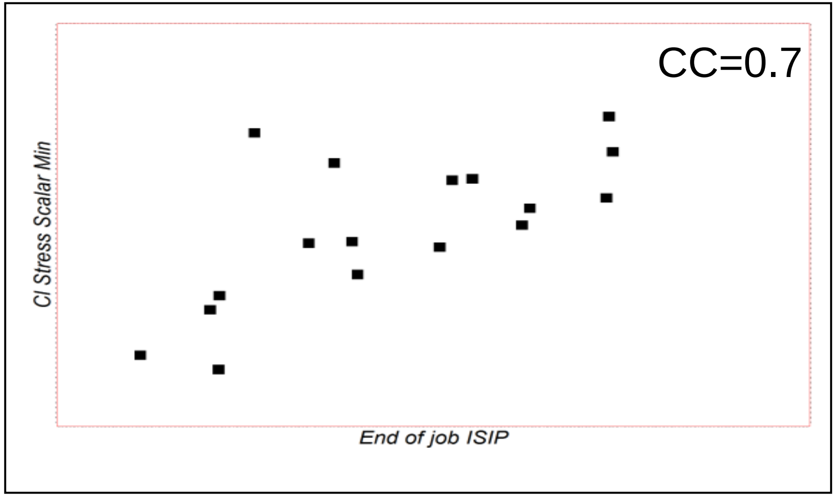


Close et al. (2011)

8. Calibration using stimulation data and reservoir properties predicted from AVO: a very challenging experiment but 'proves' the predictive power of seismic

- Data quantities sufficient for this analysis probably not available until development phase of a project
- Extracted seismic property vs stimulation data
    - By stage, geologic zone, lateral, half-pad, full-pad…





Close et al. (2012)

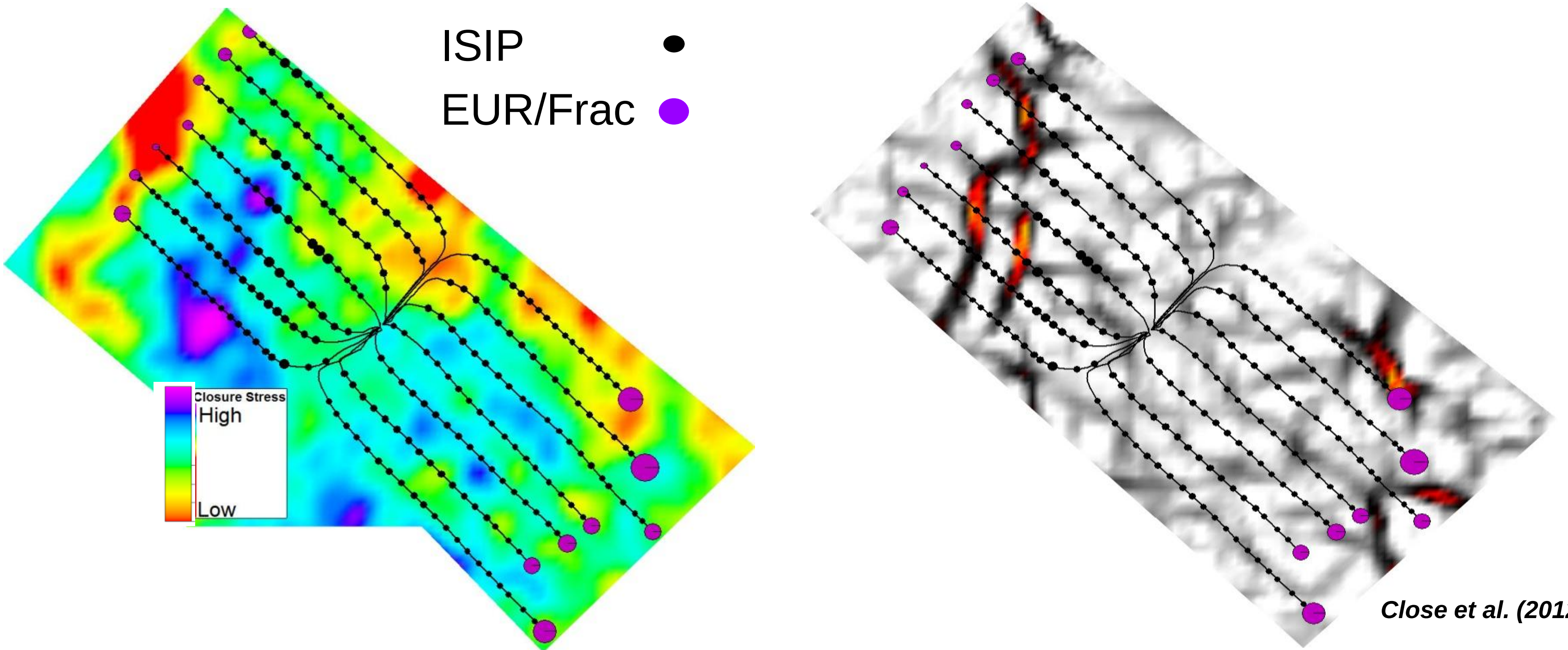
9. Interpretation calibration using production data: complicated for horizontal and stimulated wells

- Simple at a high level – conventional bubble plot analogue
- Complex in the detail
  - It is difficult to consistently get access to wellbores over time to run production logs
  - Hence it is likely that total production from a well (that is likely 1500-2500m in length) must be plotted against a single property from that well
  - The production likely also needs to be normalized by length, number of fracs, size of frac jobs, etc.

- Choosing appropriate production proxies (IP, 30 day average, etc.)

9. Integrated calibration using production data - qualitative

- Qualitative calibration and interpretation possible at this point
- Note the variability (heterogeneity) in production

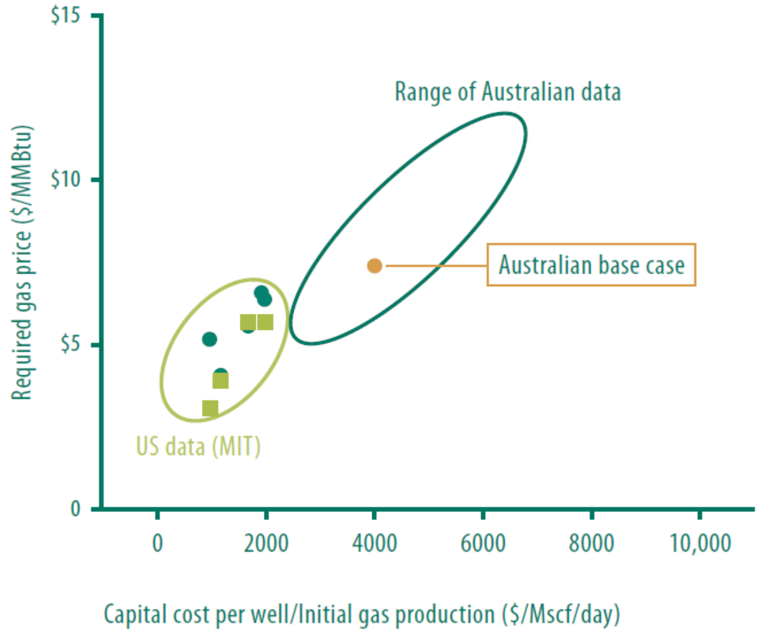


Close et al. (2012)

External challenges to unconventional exploration and development

Non-technical challenges

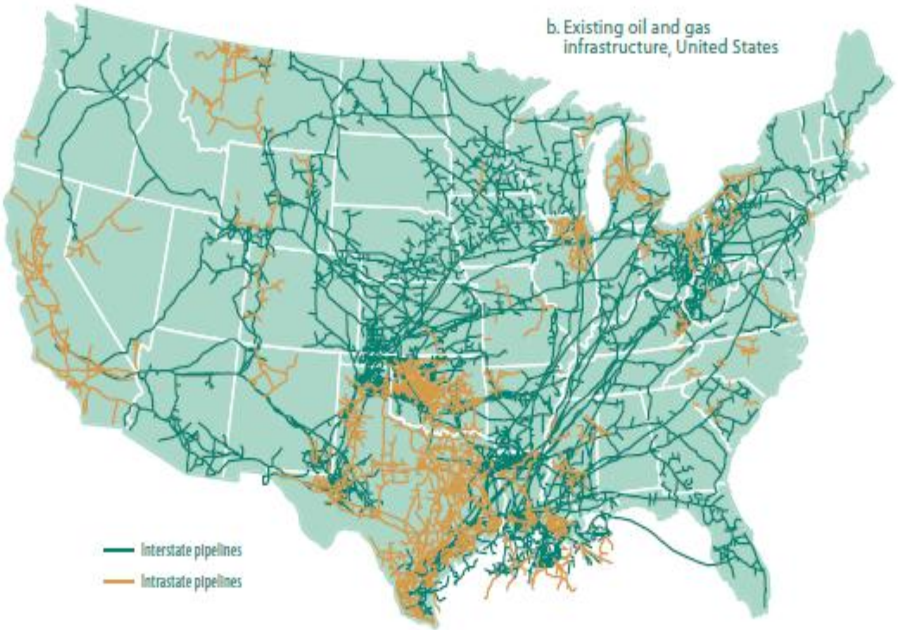
- Cost of drilling and fracture stimulation
- Regulatory compliance costs
- Partisan politics and fracture stimulation leveraged as a political wedge issue
- Reactive policy that ignores advice from repeated inquiries and commissions by respected scientific organisations in Australia and internationally
- Anti-gas activism using skilled ENGO campaign tactics
  - .

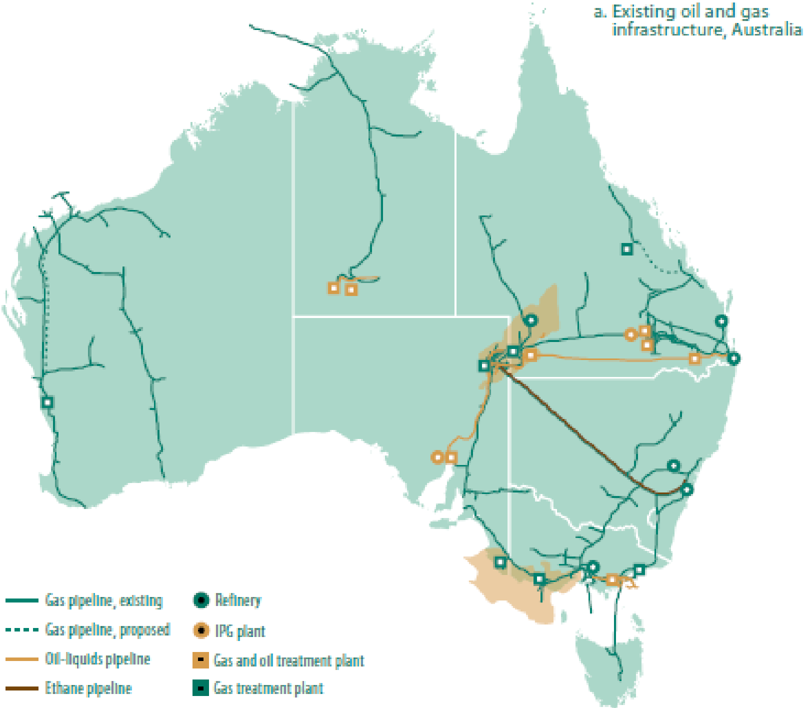


ACOLA (2013)

...vary by state/territory and basin – but there are some consistent themes

Infrastructure and market maturity

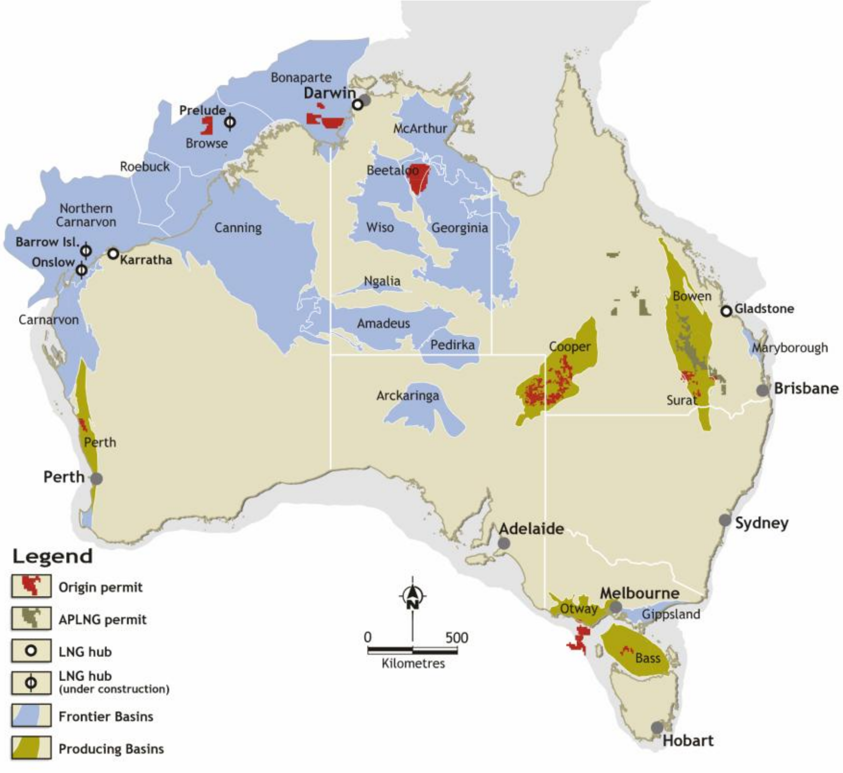




ACOLA (2013)

Summary and conclusions

- Technical challenges primary cause of delays
  - No easy wins
- No 'Eureka' moments...yet
  - Australian basins remain underexplored
- Highly prospective Beetaloo Sub-Basin to be tested in the coming 1-3 years
- One successful play will potentially change the onshore gas market
- Commercial, regulatory and community challenges to a nascent and poorly understood industry
  - Sovereign risk in Australia?



THANK YOU

References

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