WHY THE WAIT? SHALE GAS EXPLORATION REVIEW AND LOOK AHEAD

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Origin Energy
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

The Telegraph

January 2013

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.

The Sydney Morning Herald

October 2014

Business Day

ConocoPhillips pulls plug on Australian onshore exploration

October 7, 2014

Angela Macdonald-Smith

March 2015

Chevron exits Cooper basin unconventional gas project

MELBOURNE, Mar. 30 09/30/2015
By Nick Wilkinson O&G 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
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 natural gas production – underpinned by world class geology

- Shale gas
- Tight gas
- Alaska
- Non-associated offshore
- Coalbed methane
- Associated with oil
- Non-associated onshore

EIA
Australia’s world class CSG geology

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

Sources (reserves): Energy Quest (Mar 2015) & QLD Dept’ Nat’ Resources

Legend
- **Demand (PJ/a)**
- **2P gas reserves (PJ) (conventional)**
- **2P gas reserves (PJ) (unconventional)**
- **Gas transmission pipeline**

Are the USA and Queensland anomalies?
EIA unconventional hydrocarbon technical assessments

- 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-Ordovician)
  - Mixed
    - China – CNOOC Anhui Project shelved, CNPC/Shell Sichuan Basin project continuing
    - Australia – Various plays and basins

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<tr>
<th>Rank</th>
<th>Country</th>
<th>TCF</th>
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<tr>
<td>1</td>
<td>China</td>
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<td>8</td>
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<td>390</td>
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<td>9</td>
<td>Russia</td>
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<tr>
<td>10</td>
<td>Brazil</td>
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<td>World Total</td>
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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?

<table>
<thead>
<tr>
<th>Basin</th>
<th>Play</th>
<th>Tech Rec. (Tcf)</th>
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<tr>
<td>Cooper</td>
<td>R.E.M.</td>
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<td>Perth</td>
<td>Carynginia-Kockatea</td>
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<td>Canning</td>
<td>Goldwyer</td>
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<td>Arthur Shale</td>
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<td>Beetaloo</td>
<td>Velkerri-Kyalla</td>
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<td>Maryborough</td>
<td>Goodwood-Cherwell</td>
<td>19</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>437</strong></td>
</tr>
</tbody>
</table>

...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

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

$3-15/acre

- Tight gas
- Shale

$1s-10s/acre

- Tight gas
- Shale

$10s-100s/acre

- Tight gas
- Shale
- Deep coals

Legend:
- Origin permit
- APLNG permit
- LNG hub
- LNG hub (under construction)
- Frontier Basins
- Producing Basins
Australian unconventional exploration overview
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

...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

...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)

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

...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

...a vast, underexplored basin with numerous dissimilar provinces
Beetaloo Sub-Basin

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

...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

[Graph showing XRD mineralogy with bars for TOTAL CLAY, NON-CLAY, and QUARTZ, labeled A, B, C, D.]

SEM image

[Image with a scale bar of 2 mm and a red arrow pointing to Organics (bitumen).]
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

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

Curtis et al. (2010)
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

\[
\nu = \frac{\varepsilon_{xx}}{\varepsilon_{zz}}
\]

Low Poisson’s ratio

\[
\nu = \frac{\varepsilon_{xx}}{\varepsilon_{zz}}
\]

High Poisson’s ratio

Perez and Close (2011)
Lambda-Mu-Rho (LMR) is a relatively widely known but often poorly understood ‘domain’

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

\[
V_p = \sqrt{\frac{\lambda + 2\mu}{\rho}}
\]

\[
V_S = \sqrt{\frac{\mu}{\rho}}
\]

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)

$\begin{align*}
K_1, \mu_1 \\
K_2, \mu_2 \\
K_3, \mu_3
\end{align*}$

$\begin{align*}
\text{Volume} & \quad \text{Moduli} & \quad \text{Geometry} & \quad \text{Mix} \\
\text{Voigt} & \quad \text{(isostrain)} & \quad \text{Reuss} & \quad \text{(isostress)} \\
\text{Hill} & \quad \text{(average)}
\end{align*}$

$\begin{align*}
K_1 & \quad \text{Upper bound} \\
K_2 & \quad \text{Soft} \\
2 \quad \text{Stiffer} \\
\text{Volume fraction of material 2} & \quad \text{Lower bound}
\end{align*}$

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.

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

- 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...

\[ Y = mX + c \]

\[ m = \frac{\lambda}{\lambda + 2\mu} \]
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
Unconventional Case Study: Horn River Basin, BC, Canada

Looks as good as conventional pay
Schematic integrated QI appraisal and development workflow

1. Acquisition and processing

2. Interpretation and wavelet extraction

3. Inversion and interpretation

4. Velocity modelling

5. Inversion calibration: Core and logs

5a. Petrophysical processing

6. Pad selection and well design

7. Drilling and geosteering

8. Inversion calibration: Completion and stimulation data, microseismic and SRV

9. Interpretation calibration: Production by stage (PLs), well, half-pad and pad

10. Geocellular model

Close et al. (2012)
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
  - ...

...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


