OPTIMAL SHALE GAS EVALUATION METHODS

IBC 3RD ANNUAL GAS SHALE CONFERENCE, SINGAPORE

GEOFF BARKER, PARTNER

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DECISIONS WITH CONFIDENCE

RISC

DISCUSSION TOPICS

1. Shale Gas Play Concepts
2. Evaluation Methods
   - Rock Eval Methods
   - Petrophysical Methods
   - Performance
   - Analogues
3. Risking
4. Conclusions

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WHAT IS SHALE GAS?

Commercial shale gas is found in organic-rich fine grained sedimentary rocks that are:

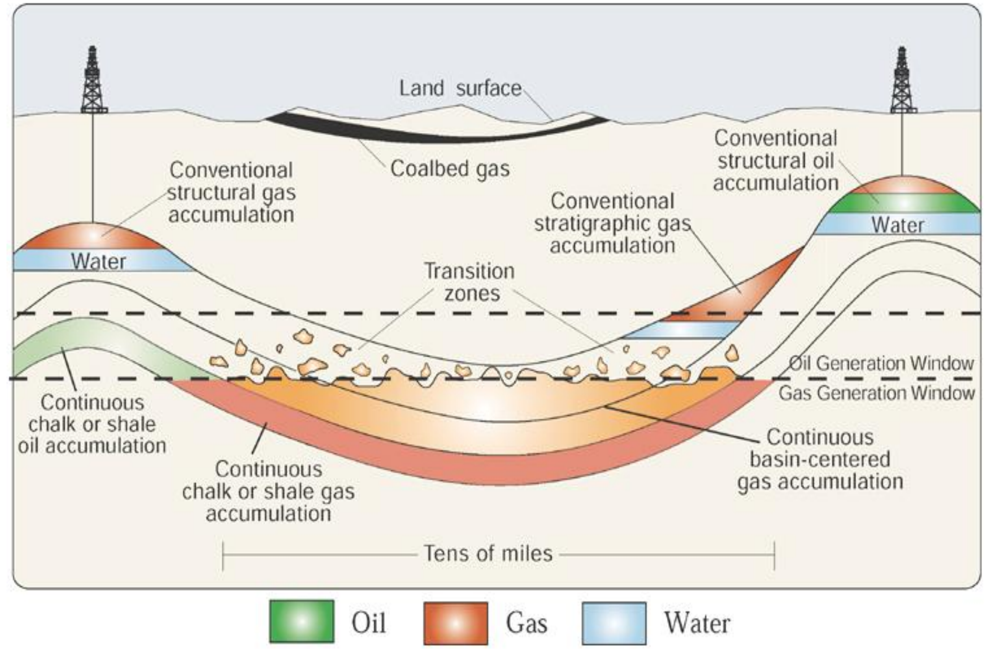
- Thick, typically over 20m
- Generally widespread in distribution
- High in TOC (total organic content), 1-20%
- Low porosity, typically 2-8%
- Low permeability, typically 100's of nano-Darcies

Gas Sources:

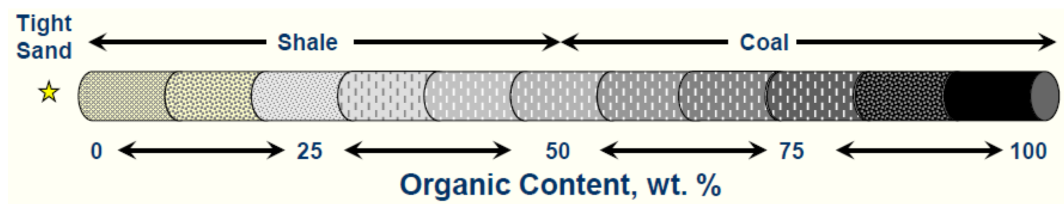
- Gas is generated from organic material in the rock
- Free Gas contained within gas filled porosity
- Adsorbed Gas within organic material
- Produced from thermogenic or biogenic sources

Gas Production:

- Enhanced by natural and/or hydraulic fractures



Pollastro et al, 2003



Source: Weatherford Laboratories 2009

SHALE GAS CLASSIFICATION SYSTEMS

Claypool (1998)

1. Biogenic Gas
2. Thermogenic Gas
3. Mixed Gas

Jarvie et al (2007)

1. High thermal maturity
2. Low thermal maturity
3. Mixed lithology intra-formational systems
4. Combination plays with conventional and unconventional gas

SHALE GAS GENERATION

Thermogenic Sources:

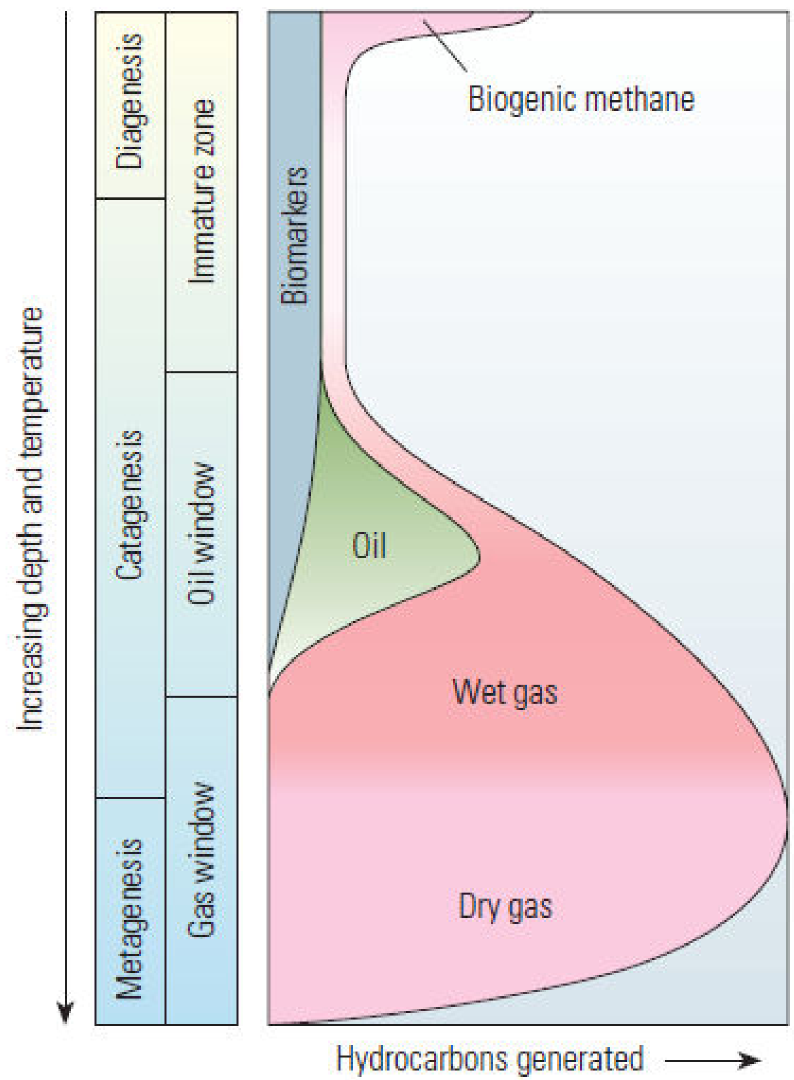
- Higher thermal maturity (Ro > 1.1)
- Higher temperatures cause gas to be generated from organic material using thermal processes
- Typically more brittle, have relatively high silica or carbonate content
- Typically low TOC as organic material converted to hydrocarbons
- eg Barnett Shale

Biogenic Sources:

- Lower thermal maturity
- Lower temperatures enables gas to be generated from organic material using biogenic (bacterial) processes
- Often less brittle
- Rely on open natural fractures
- eg Antrim Shale

Thermal Maturity:

- Determined from Vitrinite reflectance (Ro) (or Level of Maturity - LOM) or Rock –Eval pyrolysis techniques are used to estimate thermal maturity.

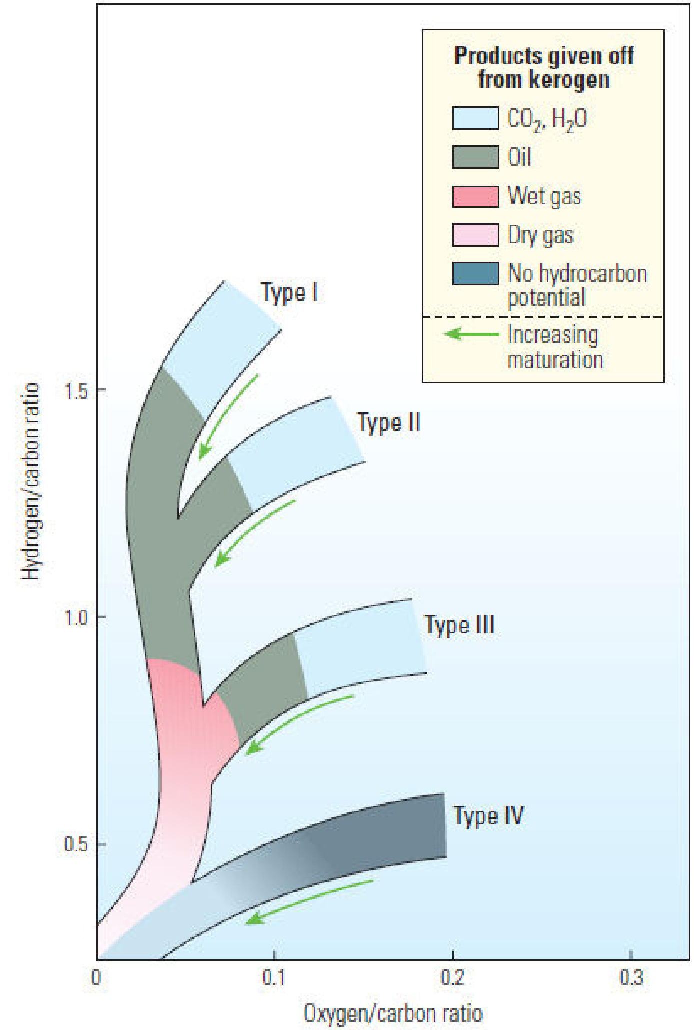


ORGANIC MATERIAL IN SHALE: KEROGEN

Kerogen is an insoluble material that is key in generating hydrocarbons. 4 main types:

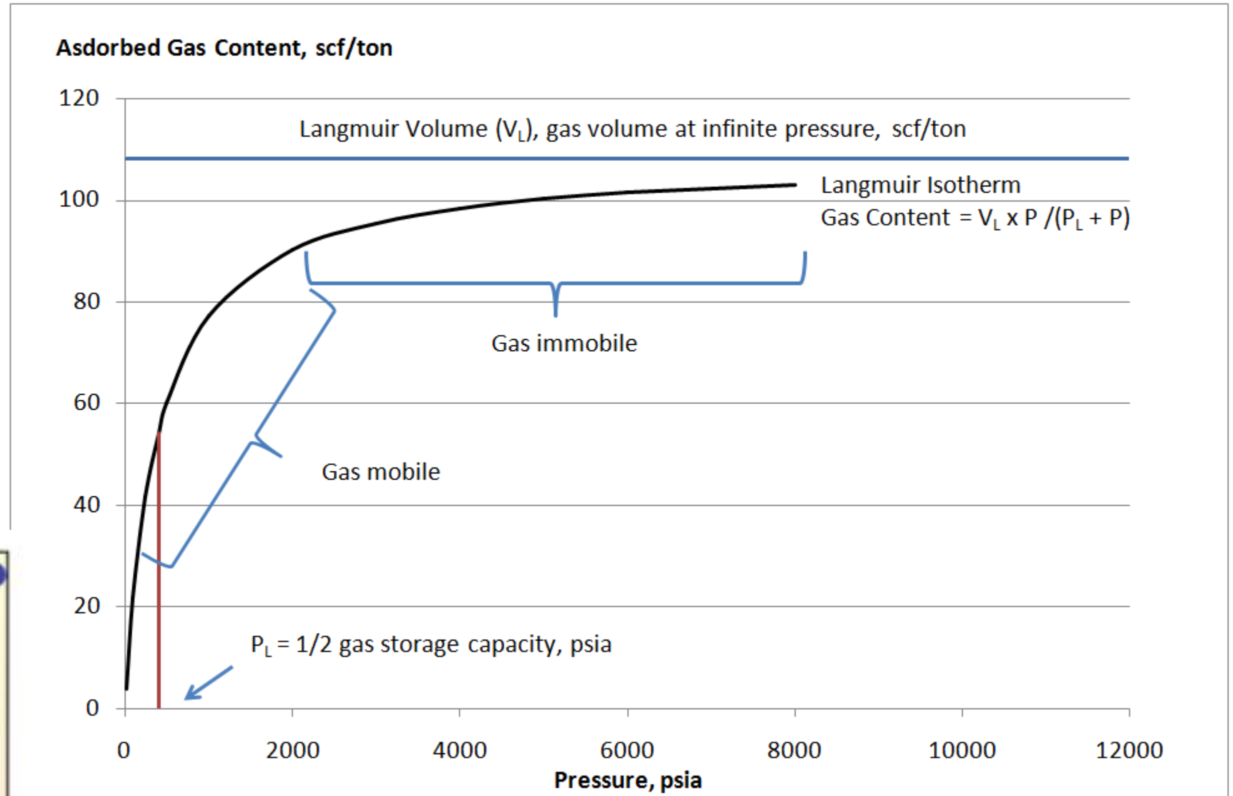
- Type I – generated from algae in lacustrine. Tends to be oil prone.
- Type II – generated from plankton, some algae. Found in marine settings. Can generate oil or gas.
- Type III – generated from plant material. Generates mostly dry gas.
- Type IV – comprised of re-worked oxidised material. Not capable of hydrocarbon generation

To determine the source rock potential the original kerogen content is required. From this, the TOC (total organic carbon) can be determined and is a key parameter in calculating adsorbed gas.

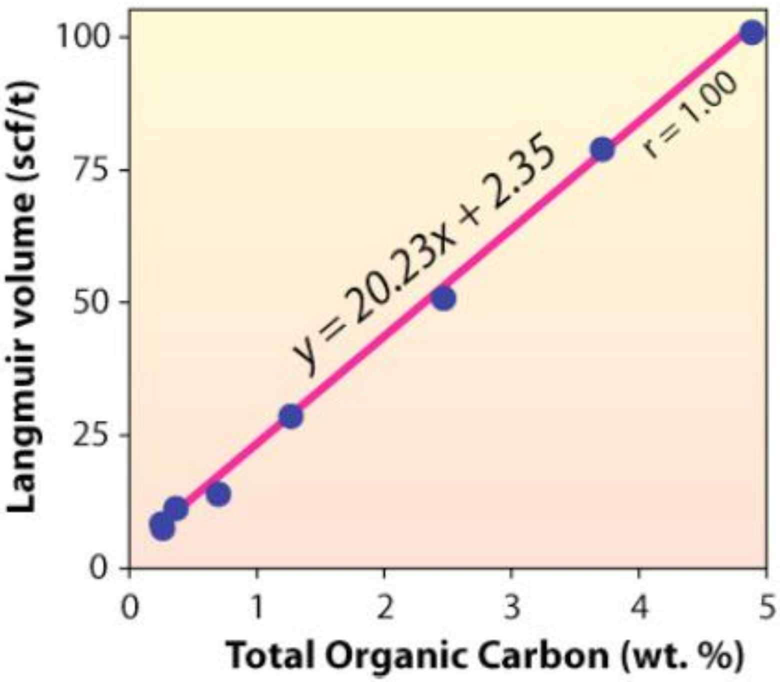


ADSORBED GAS CONTENT

- Gas is adsorbed onto to the surface of the organic material in the shale
- The relationship between adsorbed gas and pressure can be described by the Langmuir Isotherm



Source: RISC analysis

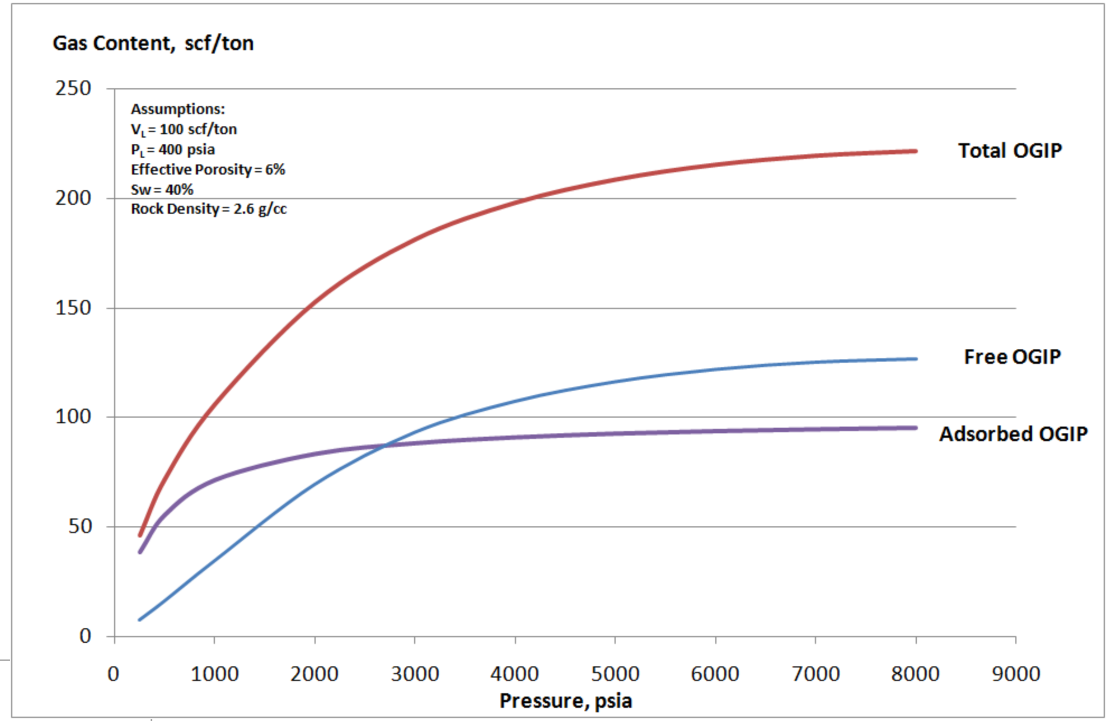


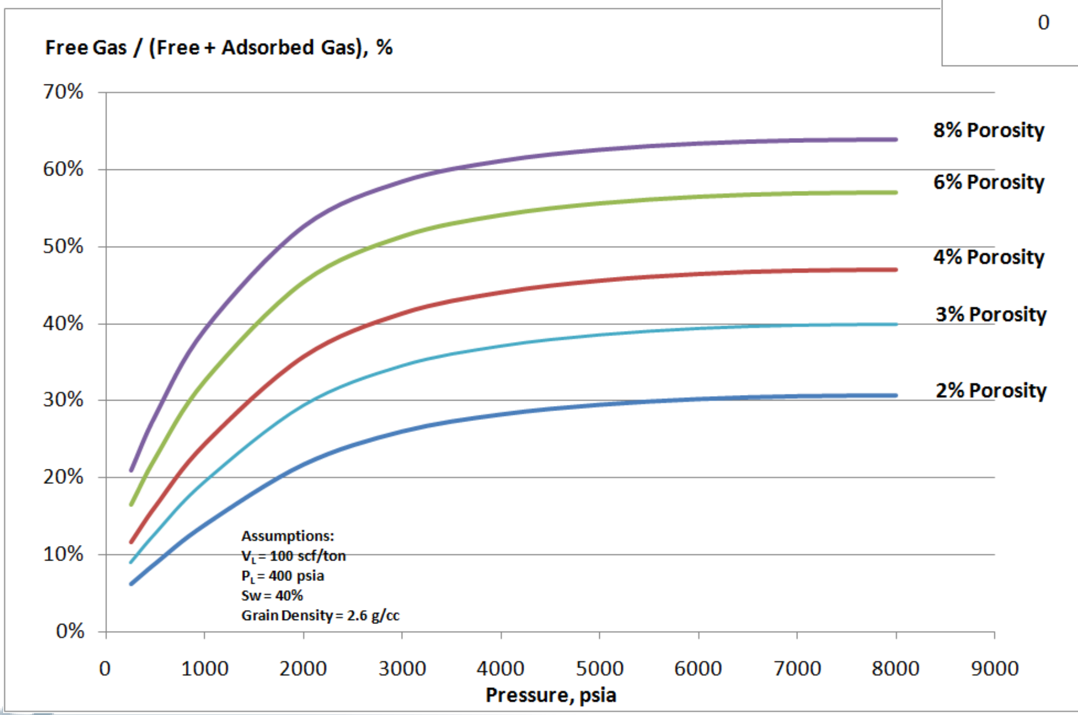
- Adsorbed gas is a function of
  - Total Organic Carbon (TOC)
  - Pressure and temperature
  - Measured in scf/ton (or m3/tonne)

Source: Pashin et al, 2010 Coalbed and Shale Gas Symposium

TOTAL GAS CONTENT

- At higher pressures, depending on the porosity, free gas in the pore space dominates the total gas in place
- The free gas is much more mobile and dominates the commercial production





- The proportion of free gas vs adsorbed gas depends on the porosity and pressure
- Adsorbed gas is only economically important at low pressures and/or low porosity

Source: RISC analysis

SHALE GAS RESOURCE EVALUATION METHODS

1. Exploration/Pilot Testing Phase

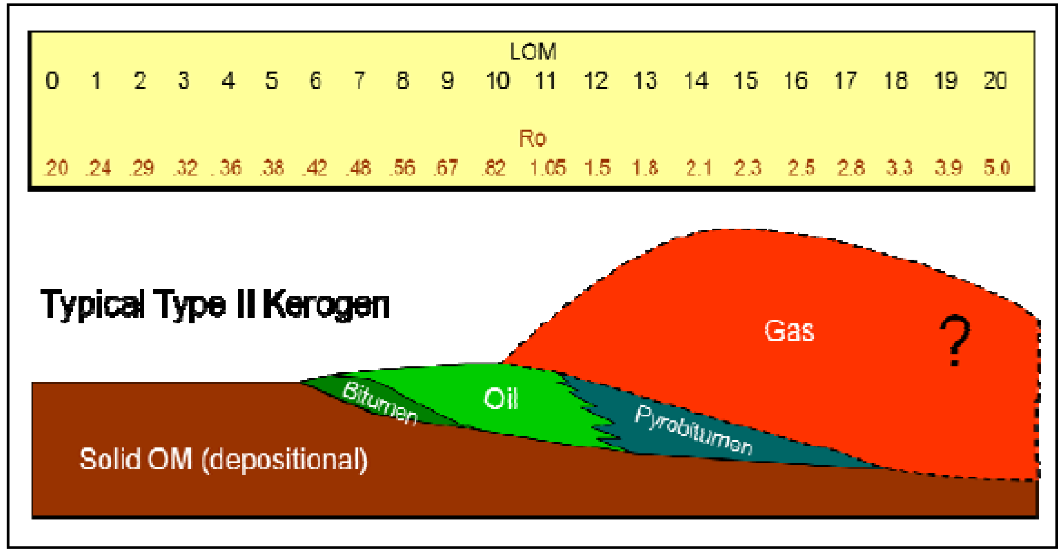
- **Rock Eval Method**
  - Based on geochemical method reported by Jarvie, 2007
  - Suitable for exploration phase. Can be used with limited data sets and regional information
- **Petrophysical Method**
  - Based on parameters derived from well logs, core and tight rock analysis (TRA)
  - Suitable for exploration and development phase
  - Provides richer information about reservoir characterisation, but requires modern well data
  - Independent to Rock Eval approach
- **Gas Density Factors**
  - Based on analogue data
  - bcf/km2, bcf/sq.mi, Mcf/section, scf/ton etc
  - Needs care in selecting and modifying analogues (often misused and abused)

2. Development/Production Phase

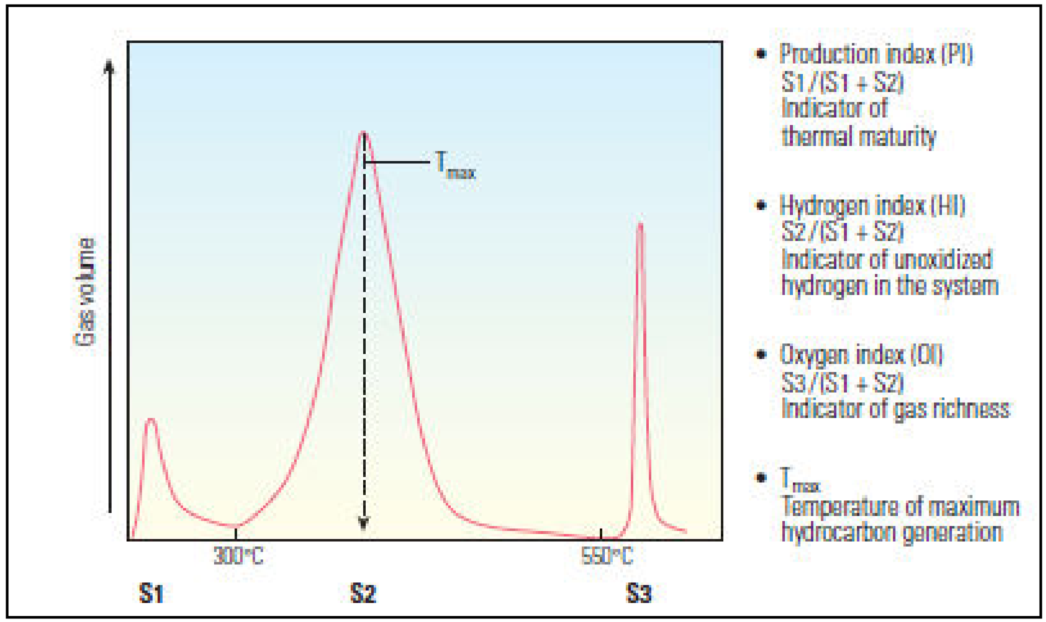
- Well IP's and decline analysis
- EUR/well, EUR/frac stage
- Well spacing / Infill opportunities
- Typically takes lots of wells (>100)and years (5-10) to get enough statistics to get a good handle on this

ROCK EVAL METHODS

- Thermal maturity determined from Vitrinite Reflectance (Ro)
- Rock-eval pyrolysis evaluates the type and maturity of the organic matter along with the hydrocarbon potential. Key parameters determined include:
  - Hydrogen Index (HI) – indicates un-oxidised hydrogen in the system
  - Oxygen Index (OI) – indicates gas richness
  - Free hydrocarbons (S1)
  - Hydrocarbons generated by thermal cracking (S2)
  - CO_2 released by kerogen (S3)
  - Temperatures at which maximum release of hydrocarbons occurs (Tmax)
  - Production Index (PI) – indicates thermal maturity



Passey, 2010



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ROCK-EVAL VOLUMETRICS

- Based on method reported by Jarvie, 2007
- Geochemical method
- Independent to petrophysical approach
- Suitable for exploration phase

Inputs

- Total Organic Carbon (TOC)
- Original Hydrocarbon Potential, S2
- Source Rock Thickness
- Expulsion and retention efficiency
- Secondary oil cracking efficiency
- Porosity
- Reservoir pressure
- Recovery efficiency

Outputs

- Oil and gas generated from shale
- Adsorbed gas retained in shale
- Free gas retained in shale
- Total gas retained in shale

Usually expressed as bcf/km2, bcf/section, Mcf/acre-ft

At this stage, resources are unrisked

PETROPHYSICAL VOLUMETRIC METHODS

Outputs

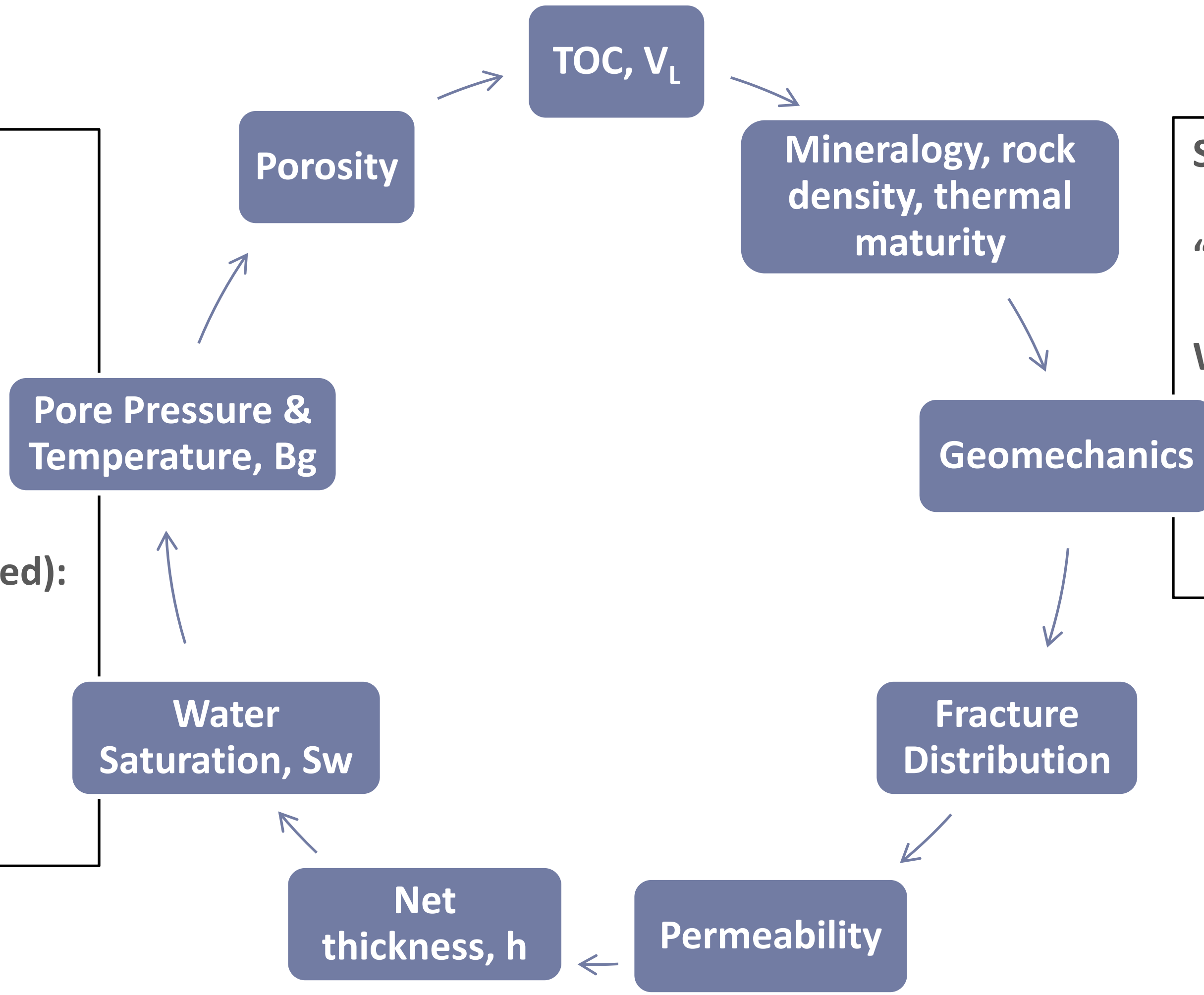
Adsorbed Gas:

$$\frac{V_L \times P}{(P_L + P) \times \text{Density}}$$

Free gas:

$$\frac{A \times h \times \text{Poro} \times (1-\text{Swi})}{\text{Bg}}$$

Total Gas In Place (unrisked):
Adsorbed Gas + Free Gas



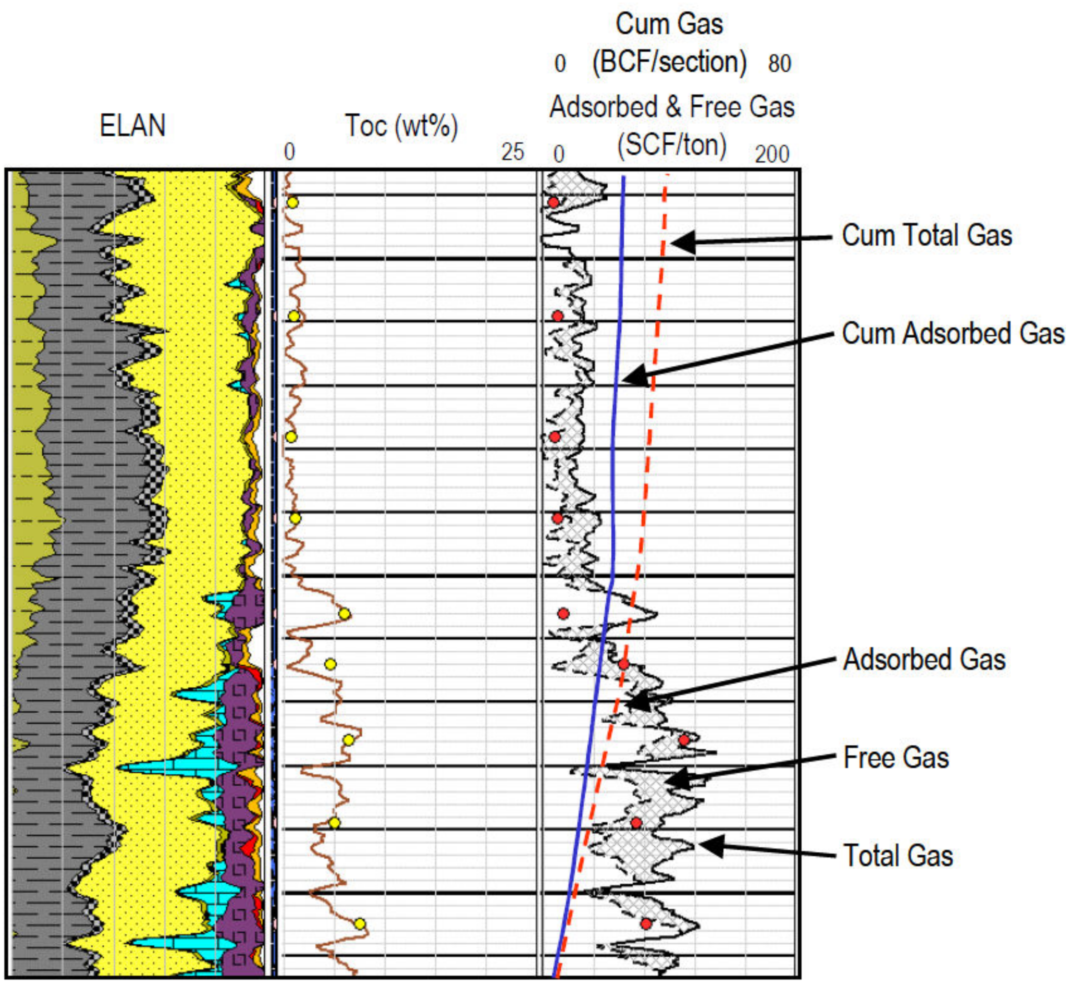
Outputs

Source potential

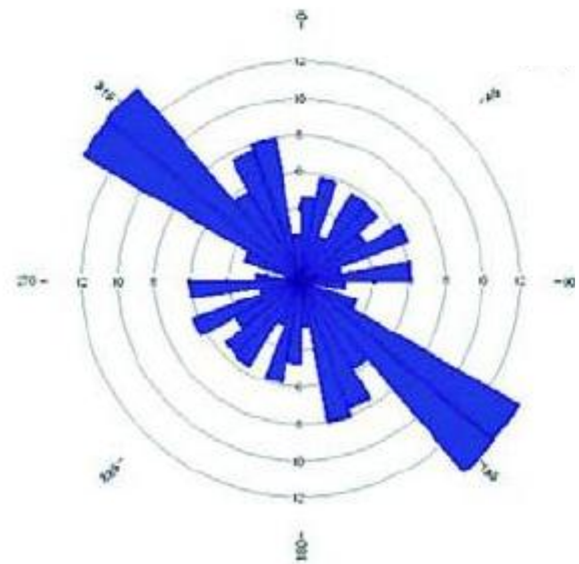
"Fracability"

Well Productivity

GAS AND FRACTURES FROM LOGS



Source: Schlumberger Reservoir Symposium 2004



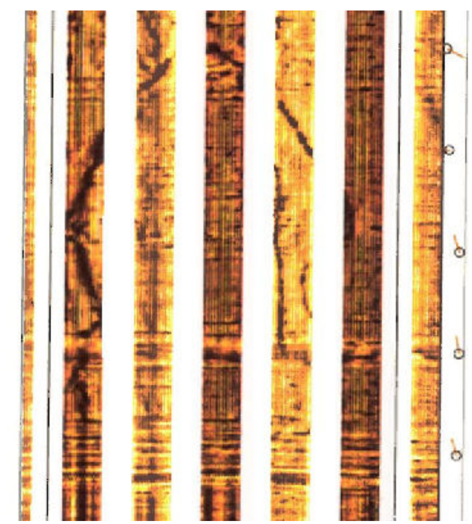
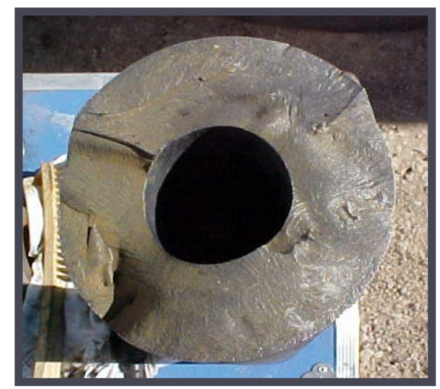


Image log showing natural fractures orentation

IMPORTANCE OF GEOMECHANICS

- Knowledge of the in-situ stress and geomechanical properties of rocks is essential for successful drilling and fracturing
  - Well bore stability
  - Fracture stimulation difficult in reverse or high stress regimes
  - Low mean stress regimes support open and conductive natural fracture
  - Stress intensity affects production
- Wells will perform better if they are targeted in areas of low mean stress with fracture systems that are conductive in the *in-situ* stress regime
- Stress can vary vertically and laterally depending upon rock strength and structural history
- Information on geomechanical properties and stresses can be obtained from well logs, frac/leak-off tests, core and seismic data

Drill Collars Bent Uni-Directionally



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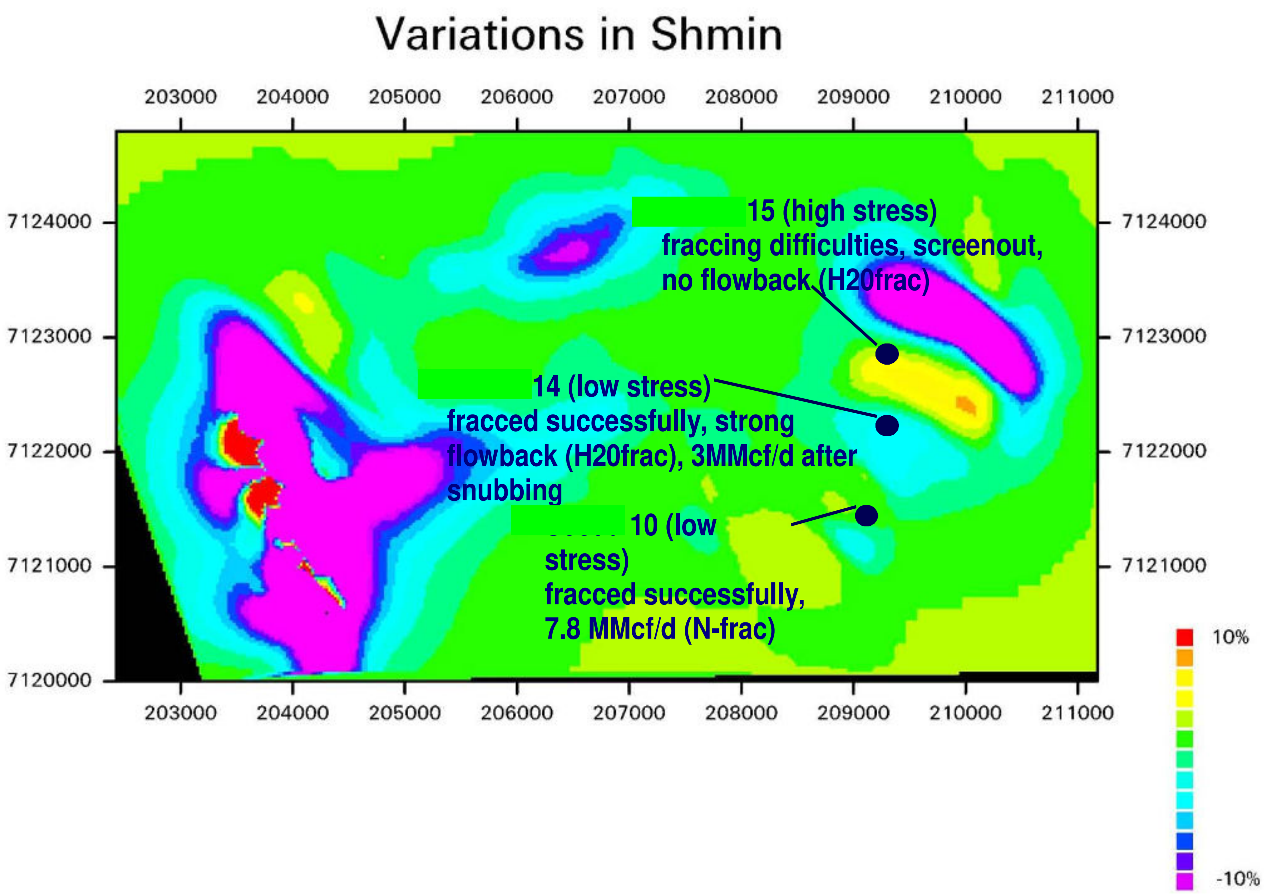
STRESS MODELLING

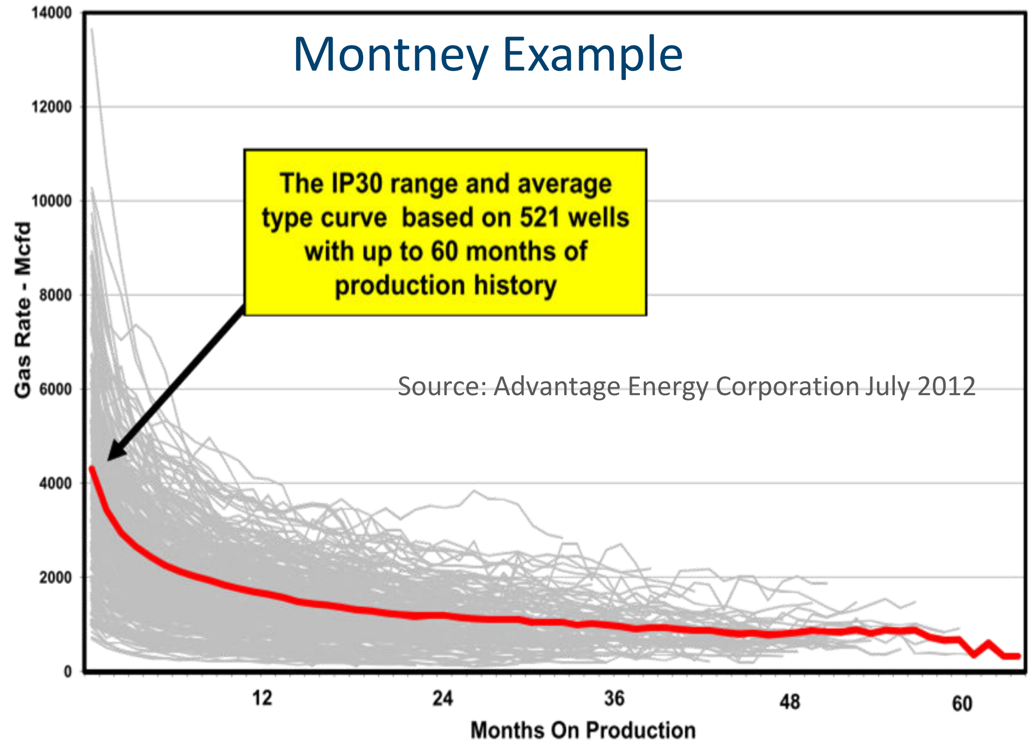
3D stress geometry modelled using a boundary element algorithm

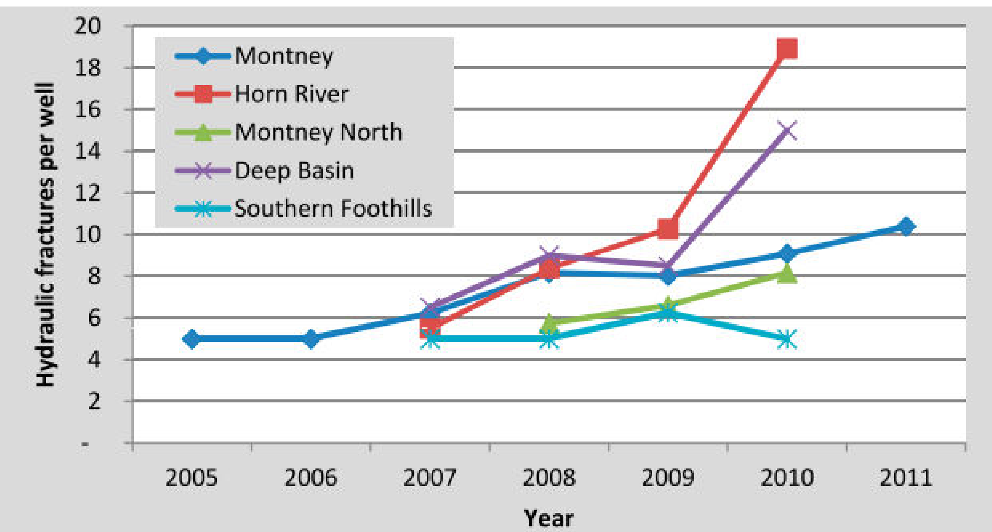


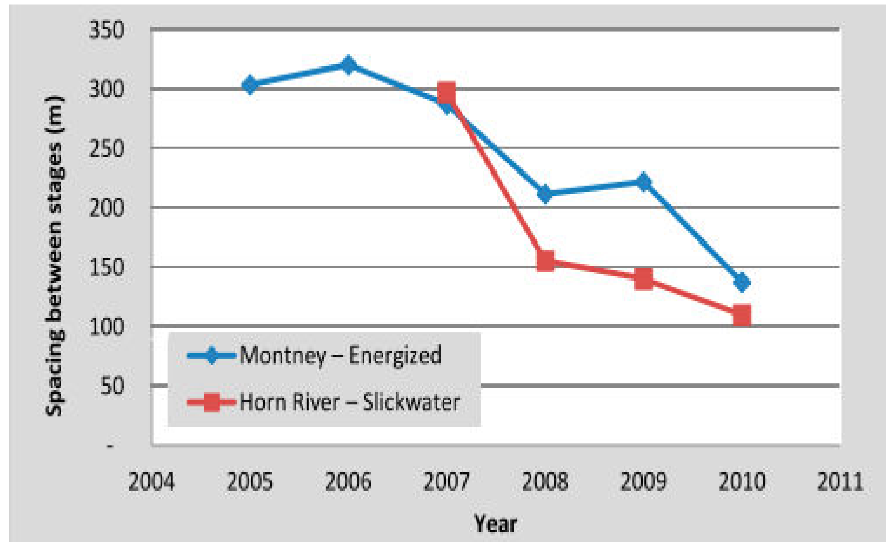
Source: RISC Analysis

WELL PERFORMANCE

- Shales are typically heterogeneous and performance varies significantly from area to area
- Significant numbers of wells required for reliable analysis, typically over 100 and 5 years or more
- Improvements / learning curve in drilling and completion practices will also need to be factored in







Source: Elizabeth G. Johnson and Laura A. Johnson, BC Ministry of Energy and Mines, 2012

USE AND ABUSE OF ANALOGUES

- Analogues are useful, but can easily be misleading if used inappropriately

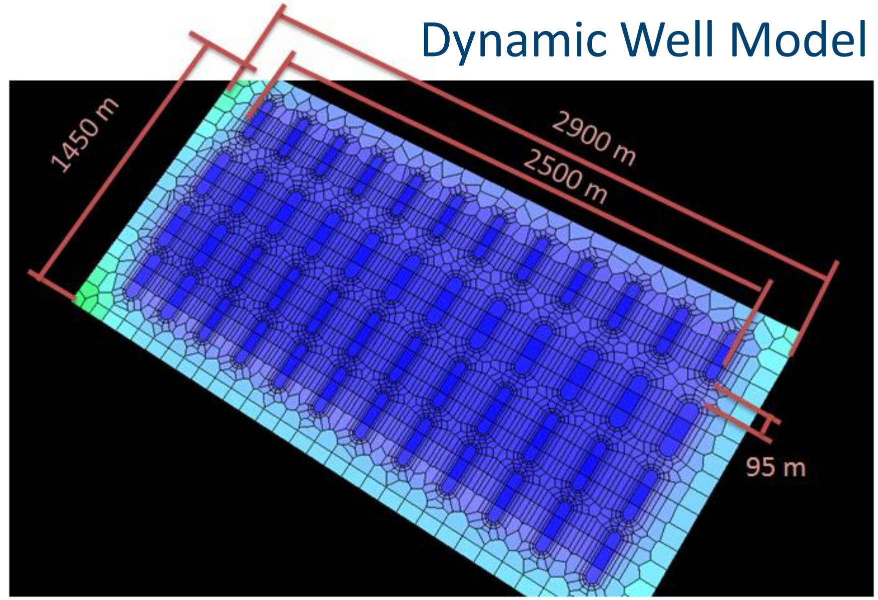
Analogue Check List

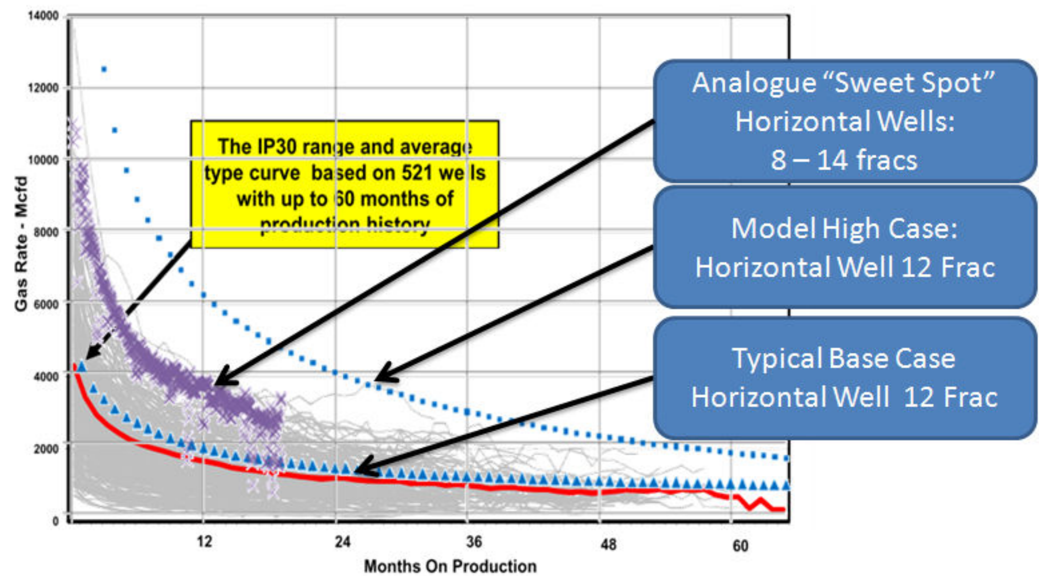
- Lithology
- TOC, thermal maturity
- Pressure, depth
- Stress regimes
- OGIP density
- Well completion types, frac type
- Well spacing

- Assumptions can be tested and adjustments can be made using simple dynamic models

Source: RISC Analysis

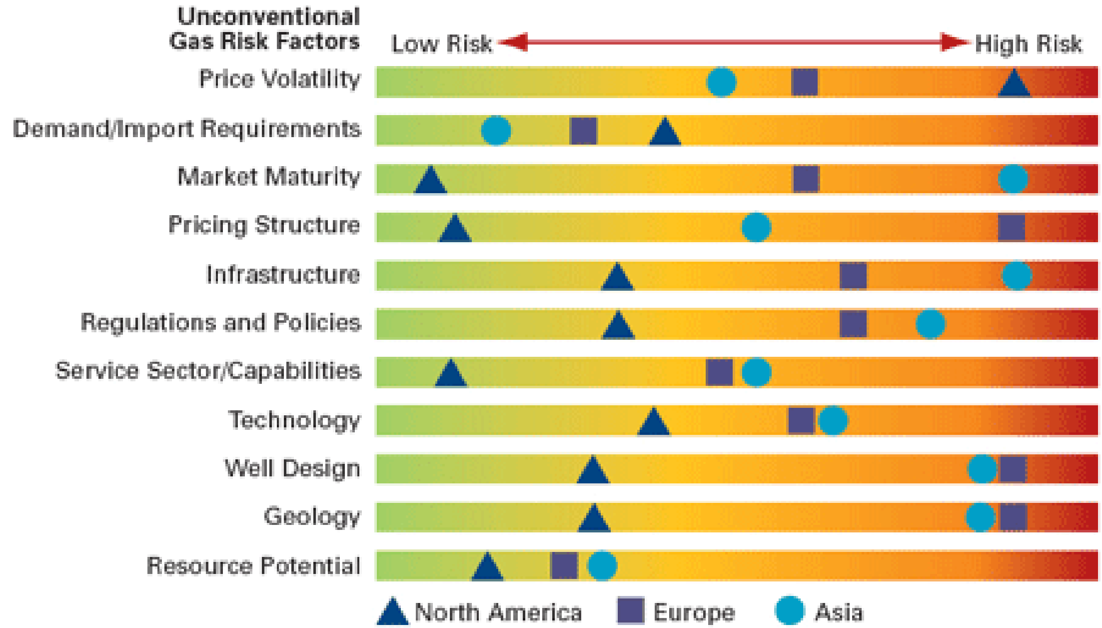
Dynamic Well Model





RISKING SHALE GAS PLAYS

- Shale gas play risks encompass both technical and non-technical factors
- Risking process is less well understood compared to conventional petroleum
- USGS has developed criteria for assessing shale gas plays



Source: Schlumberger

USGS Resource Assessment Criteria

- TOC > 2%
- Thickness >20m
- Kerogen: Hydrogen Index > 250
- Thermal Maturity: 1.2% < Ro > 3.5%

- As more knowledge is gained, these criteria will alter

Risk Factors

- Typically, once a play is established only 10-25% may be in the “sweet spot”
- 20-40% of the “sweet spot” may be recoverable
- Total recovery may be 2%-10% of the total resource

CONCLUSIONS

- Outside of N America, all shale gas is frontier exploration (an even inside N America too in some places)!!!

Methodology

- Often, the Rock Eval method is the only method available due to data availability
- Petrophysical method requires modern well data and can be used once drilling commences
- Well performance data will replace these methods, but this will take 5-10 years of drilling and 100's of wells
- Sanity check analogues

Risking

- The risks are high, typically 2-10% of a play may be recoverable
- But the areas and volumes are large to start with
- Drilling, well completion and costs are just as important as the rocks

L3 / 1138 Hay Street
WEST PERTH WA 6005
P. +61 8 9420 6660
F. +61 8 9420 6690
E. admin@riscadvisory.com

L2 / 147 Coronation Drive
MILTON QLD 4064
P. +61 7 3025 3369
F. +61 7 3025 3300
E. admin@riscadvisory.com

53 Chandos Place, Covent Garden
LONDON WC2N 4HS
P. +44 20 7484 8740
F. +44 20 7812 6677
E. riscuk@riscadvisory.com

www.riscadvisory.com

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