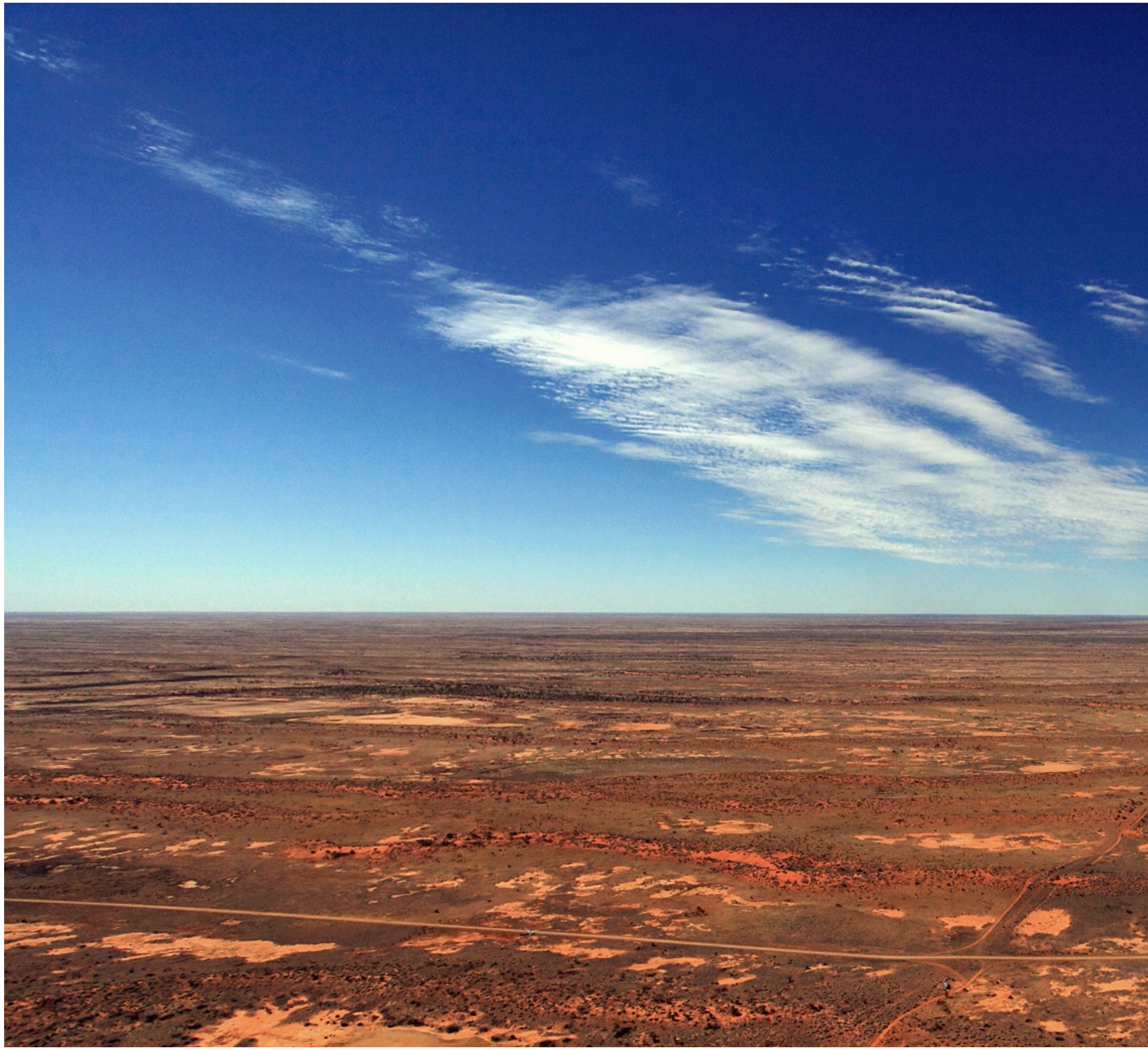

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Reservoir characterisation of the Patchawarra Formation within a deep, basin-margin gas accumulation

James Crowley and Tim Stephens

April 2014

Important notice and disclaimer

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Hornet: An off-structure gas accumulation

The Facts:

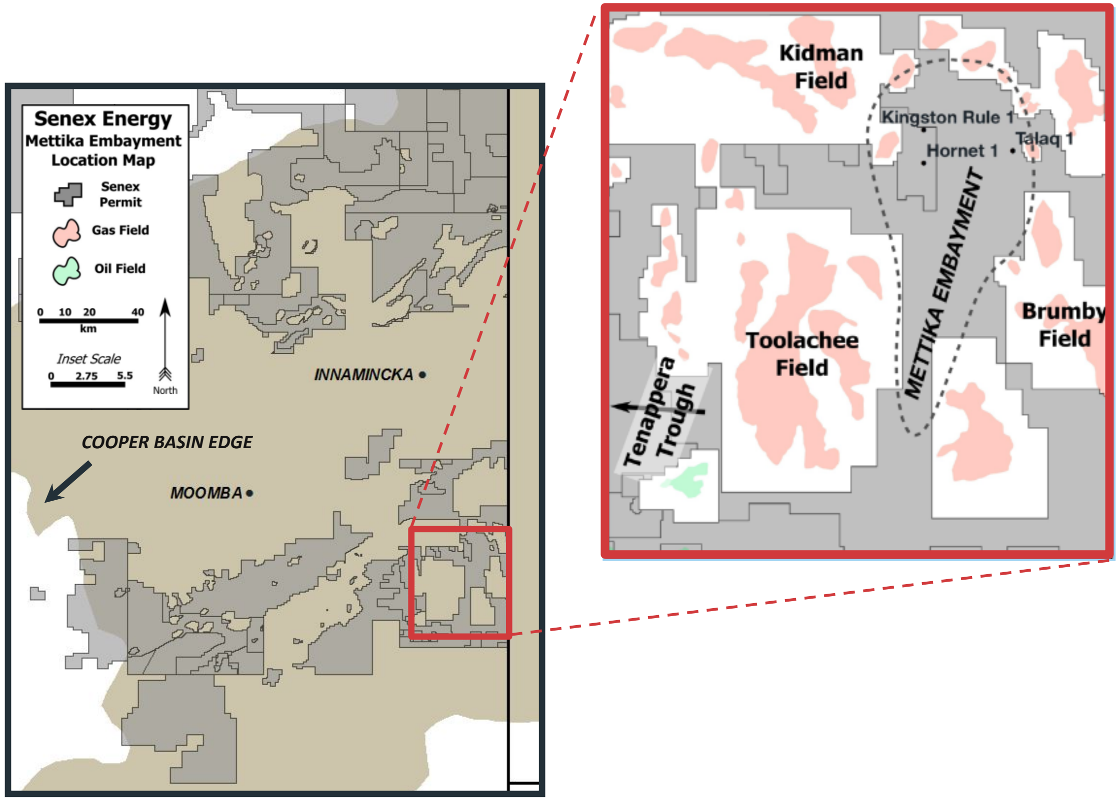
- In 2013 Hornet and Kingston Rule-1 flowed gas as a culmination of Senex's unconventional gas exploration program

The challenge:

- Is the Hornet discovery **conventional** or **unconventional?**

The result:

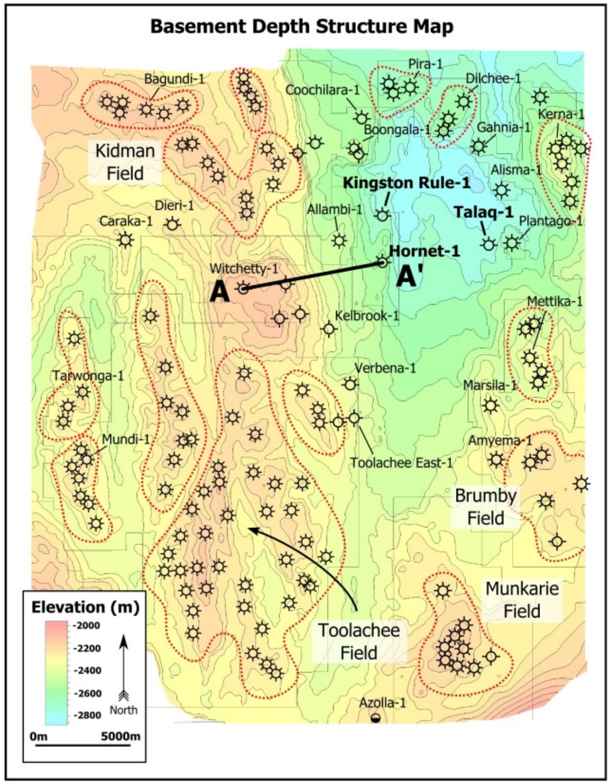
- **Conventional** stratigraphic and combination traps
- Not an **unconventional** Basin Centred Gas system (BCG)

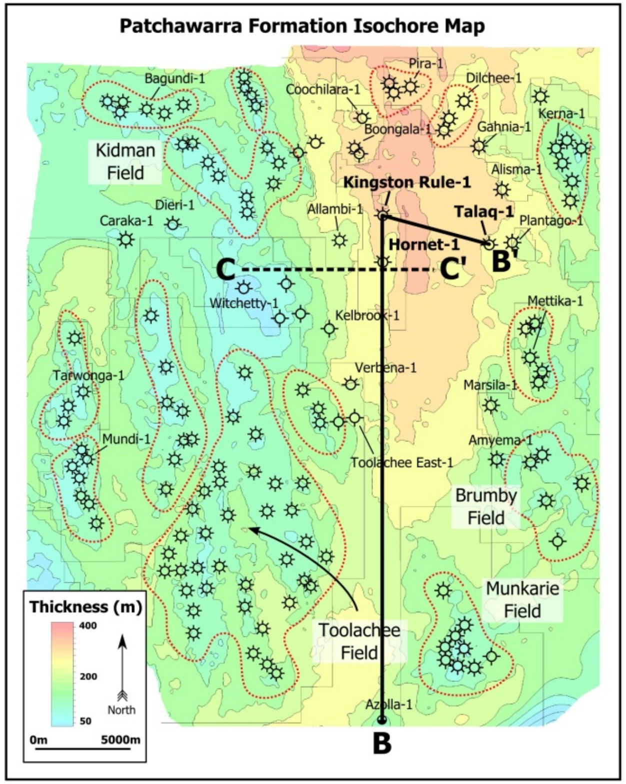


Geology and regional setting

Structure and isochore

- The Mettika Embayment is a north-south striking Permian depocentre
- The Hornet gas field is located on the eastern flank of the Toolachee-Kidman paleo-high
- Surrounded by proven and prolific gas accumulations hosted in structural and combination stratigraphic traps





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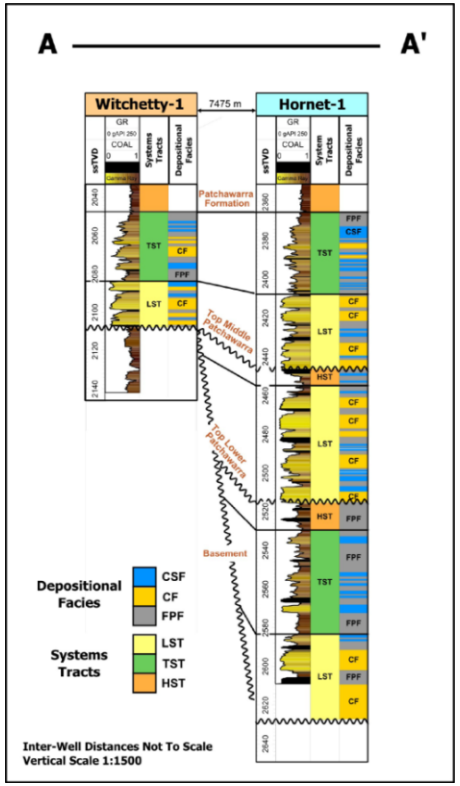
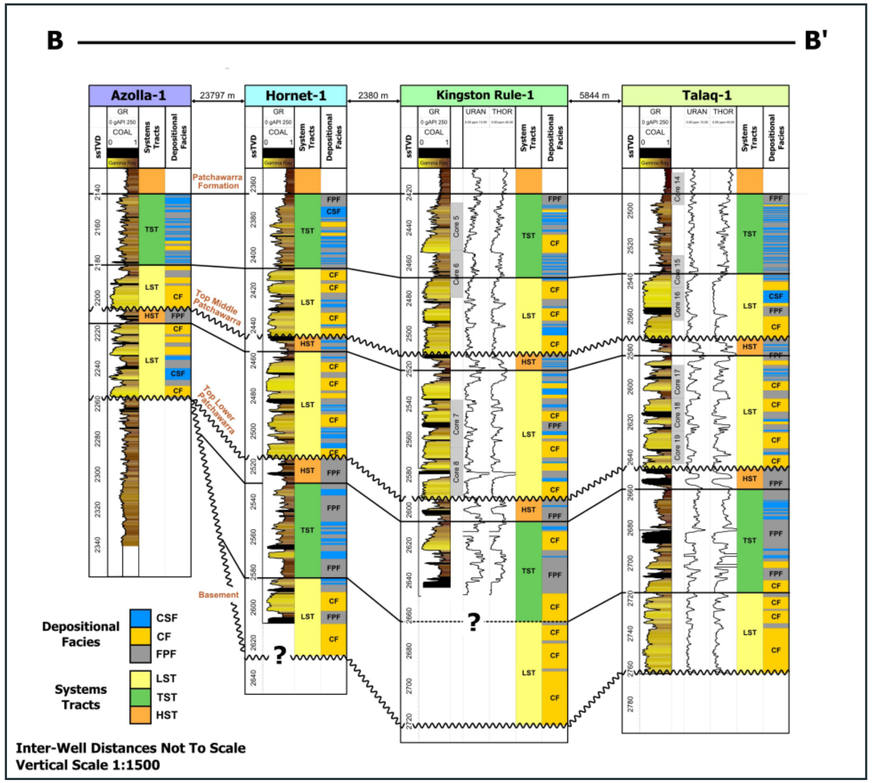
Geology

Depositional architecture and stratigraphy

- Good lateral continuity of major packages
- “Systems tracts” reflect major changes in base-level
- Poor lateral continuity of individual sandstone bodies reflecting depositional environment





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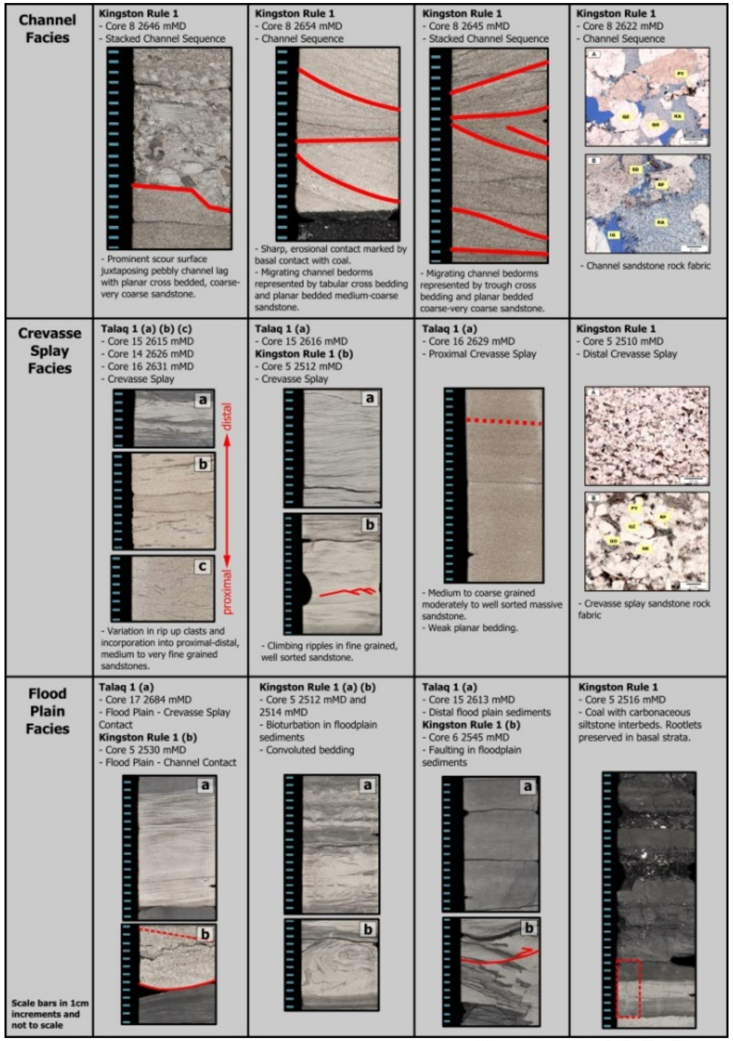
Geology

Sedimentology

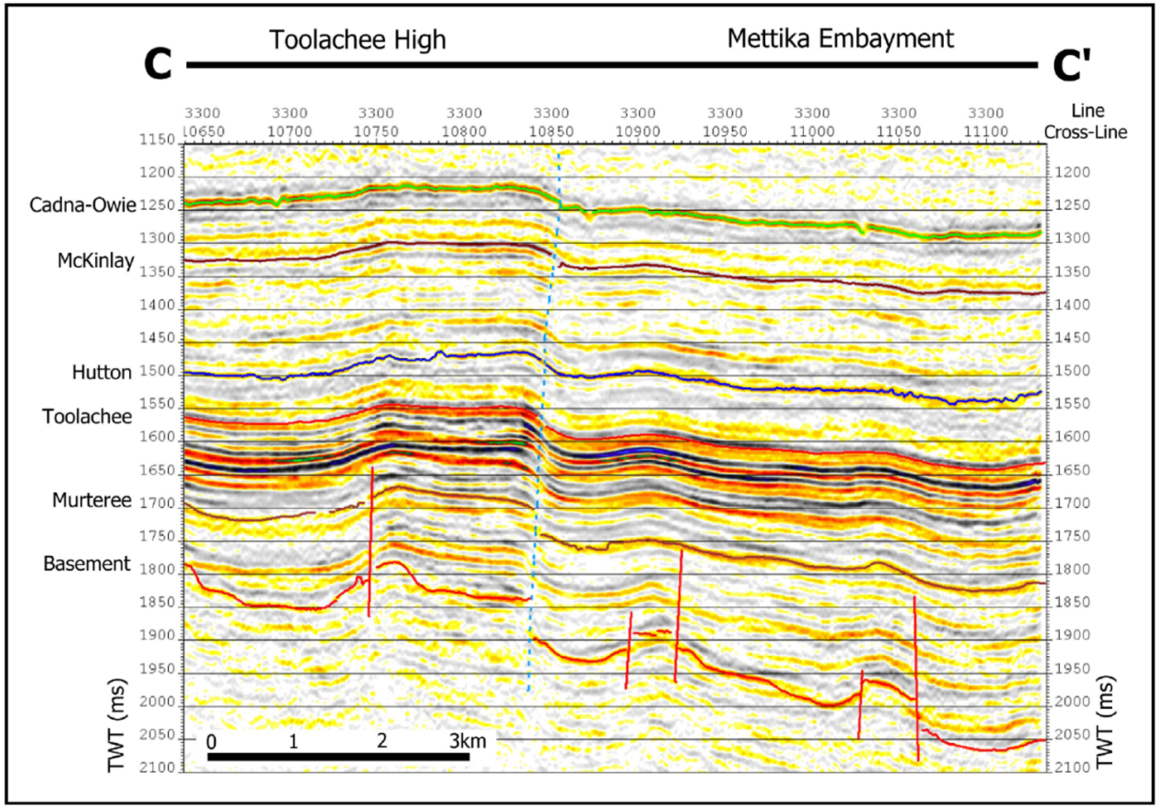
- Three major facies present:
    1. **Channel facies**
    2. **Crevasse splay facies**
    3. **Flood plain facies**
- Net sand dominated by channel and proximal crevasse splay facies
- Sedimentologically and mineralogically mature
- Organic rich floodplain mudstones and coal source rocks in contact and surround sandstone reservoirs
- Subsidence was coeval with sedimentation resulting in high potential for intra-formational seals



Geology and regional setting

Seismic section

- Early Permian normal faulting
- Progressive onlap onto flanks of Mettika Embayment
- Warburton paleotopography and paleostructure reflected in late Triassic compressional episode
- Post-Cretaceous (Tertiary) compressional/strike-slip fault reactivation of existing features



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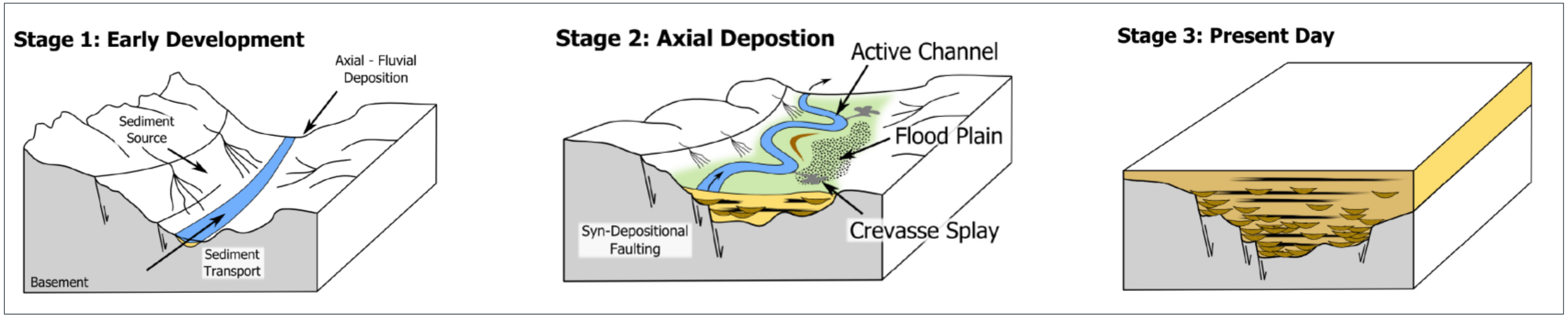
Geology and regional deposition

Depositional model for the Mettika Embayment



- Axial, south to north sediment fluvial system, minor lateral input
- Channels were bed-load dominated, low sinuosity with moderate levels of vertical and lateral contact with both crevasse splay and floodplain elements
- Multiple cross-cutting channels leads to complex reservoir architecture and variable connectivity
- Sandstone channel bodies separated by relatively impermeable mudstone, siltstone and coal

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Potential trapping styles

1. Structural
2. Combination Structural & Stratigraphic

→ **Mechanism well understood and exploited in the area**

3. Stratigraphic
4. Basin Centred Gas (continuous)

→ **Difficult to define charge mechanism and traps: A challenge!**

General observations:

- Gas production with no apparent closure
- Nearby BCG analogue in Nappamerri Trough
- Patchawarra Formation is tight and does not flow naturally
- Complex fluvial reservoir architecture
- 'Mixed' lithology, large generative potential
- A proven hydrocarbon province

→ **Many elements in place for a stratigraphic or BCG system**

Identifying a BCG play

Engineering, petrophysics, geology

Start with the basics:

- Acquired extensive amount of core and core data
- Modern logging tools and interpretation
- Identify pressure regimes and analyse production data
- Geological modelling
- Production test the two pilot wells
- Acquired water resistivity from produced samples

Some obstacles:

- Sparse well control and sub-surface data
- Few *off-structure* analogue wells and production data
- Limited in-house experience assessing BCG and deep-gas plays

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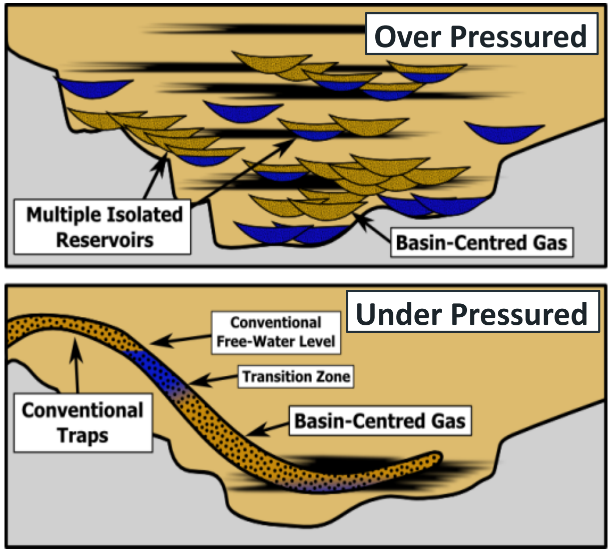
Two broad categories for BCG plays

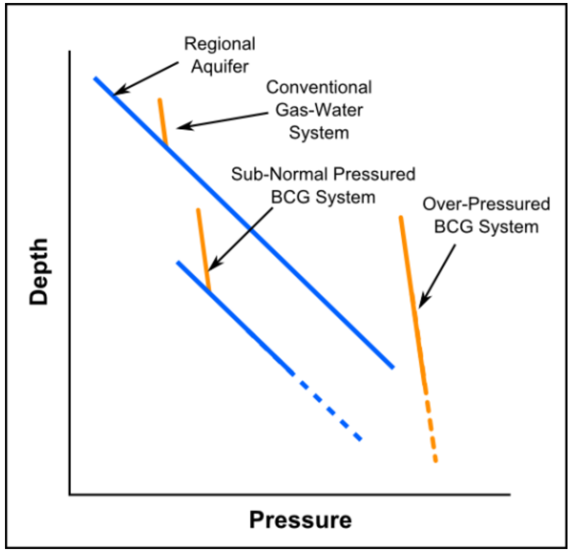
Over-pressured

- Complex reservoir architecture
- Mixed lithologies
- Low reservoir quality through diagenesis
- Stimulation and complex wells required

Under-pressured

- Moderate to good porosity, permeability & connectivity
- High generative potential
- Poor or limited down-dip aquifer connectivity

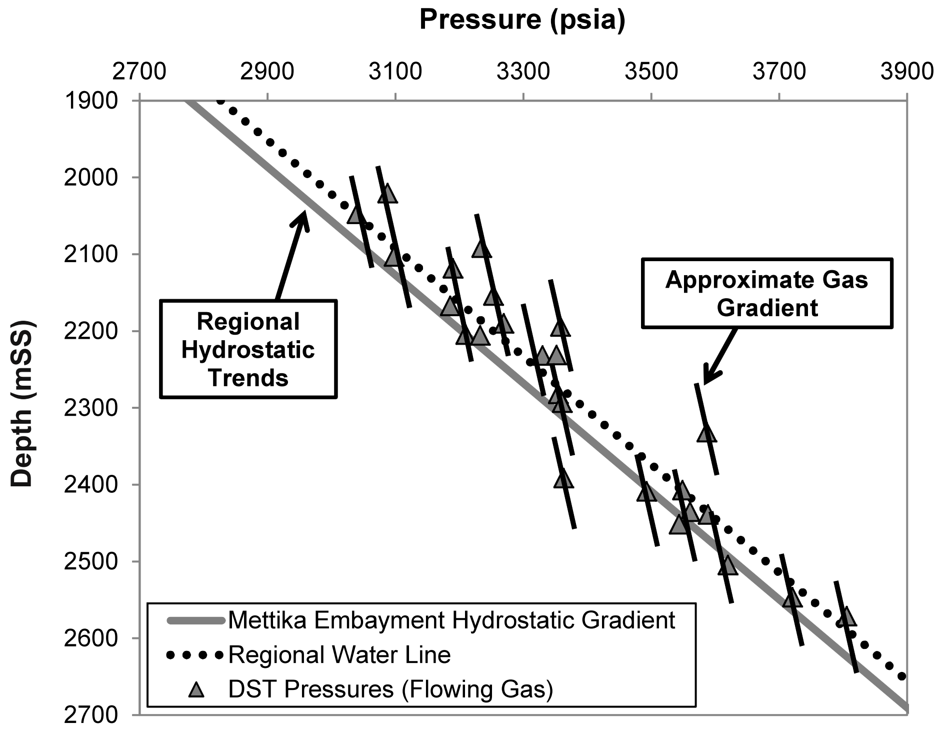




Pressure regimes

Mettika Embayment appears to be normally pressured

- Complex reservoir architecture and compartmentalisation
- Very difficult to correlate pressure trends between wells
- Pressure regime does not resemble a BCG system
- Stacked gas pay and variable contacts
- A ‘myriad’ of reservoirs



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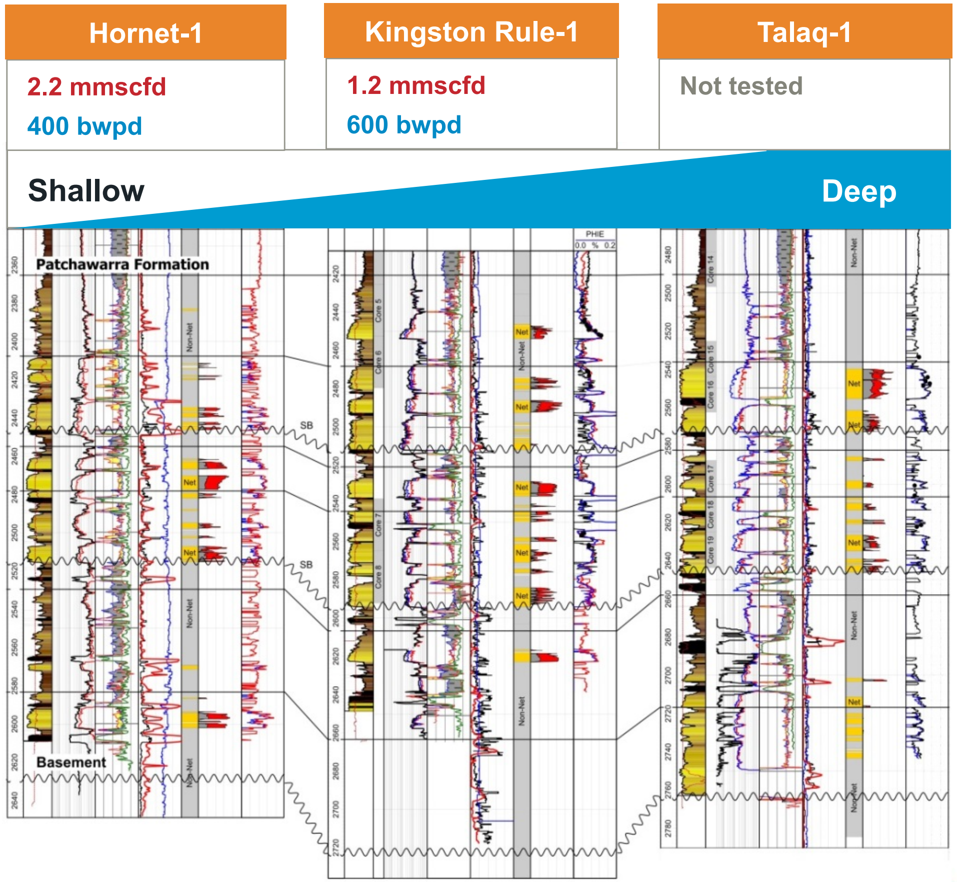
Log analysis and production data

Increasing water saturation with depth

- High water saturation in Talaq-1
- Good gas saturation and production in Hornet-1
- Significant hole break-out
- Difficult to assess basic parameters such as porosity
- Sonic-neutron used throughout and calibrated to plug data



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Core analysis

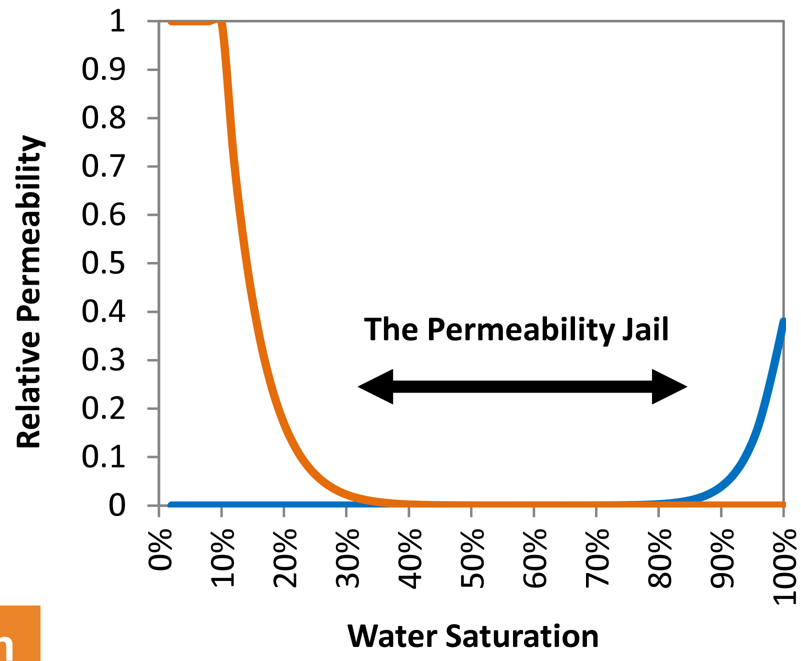
Special analysis – Relative permeability and the Permeability Jail

Premise:

- Do the core derived relative permeability curves resemble a ‘phase trap’ or permeability jail?
- Can the jail explain the off structure gas?

Result:

- Curves **do not** indicate a phase trap.
- Gas is mobile even at 70% Sw
- Water mobile at 50% Sw
- Over geological time, some permeability to both phases remains



How does a permeability jail inhibit migration of hydrocarbons in a BCG system?

Core analysis

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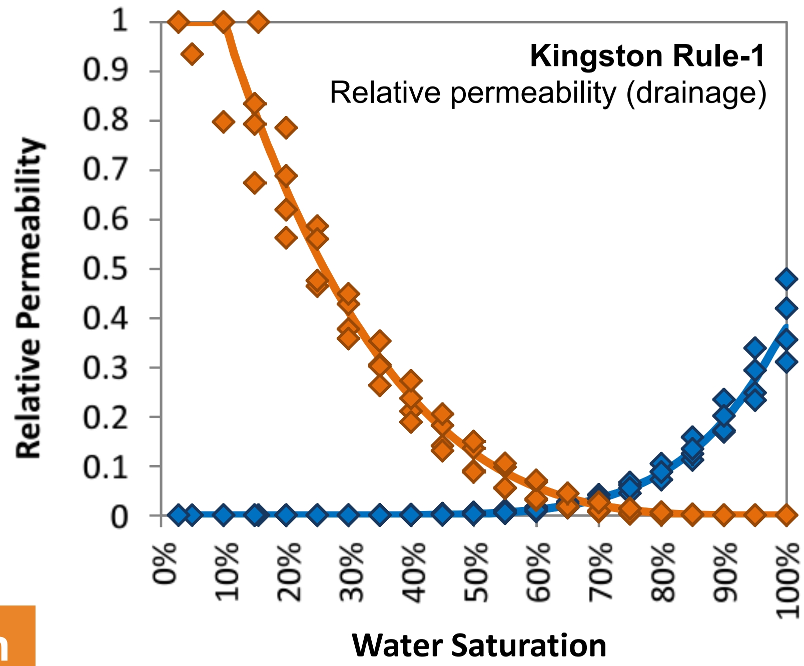

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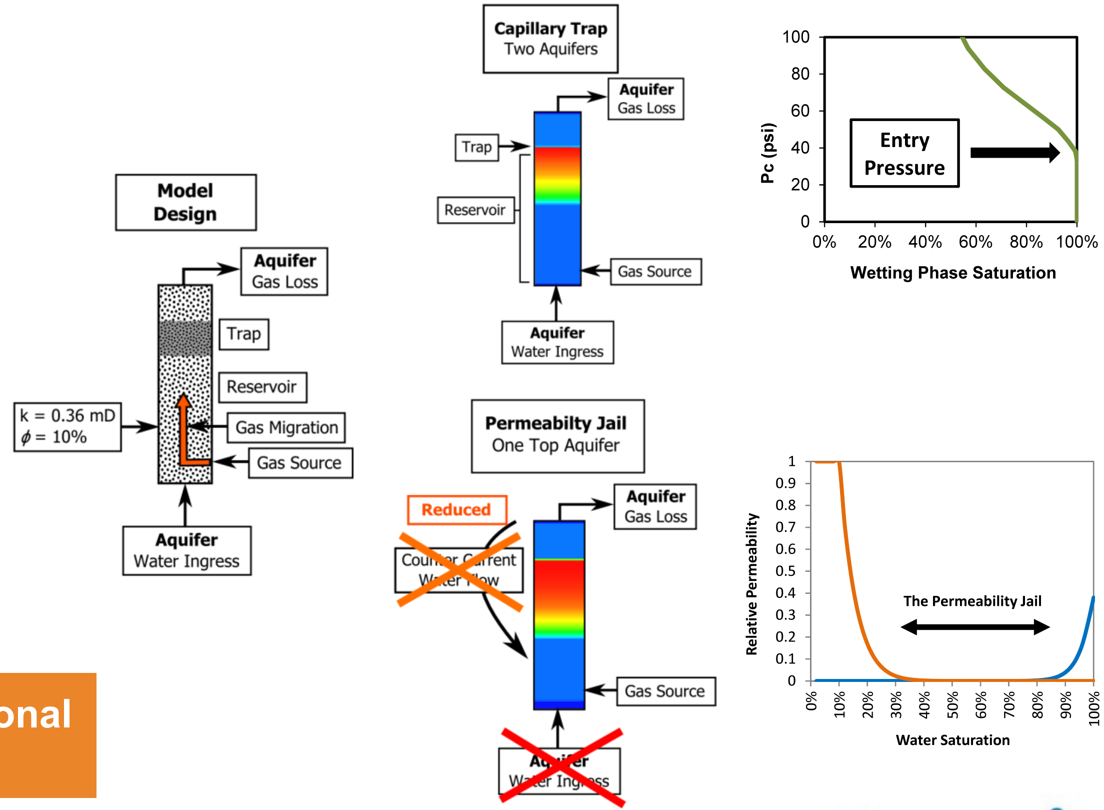
Charge mechanisms

BCG and conventional traps: The impact of relative permeability and capillarity

A simple reservoir simulation was created to examine phase trapping

Summary :

- Severe phase interference *can trap gas*
- Insufficiently adverse relative permeability allows leakage
- Aquifers are important
- **Capillary entry pressure** can have the same overall effect



In our case, we still need conventional charge and trapping concepts

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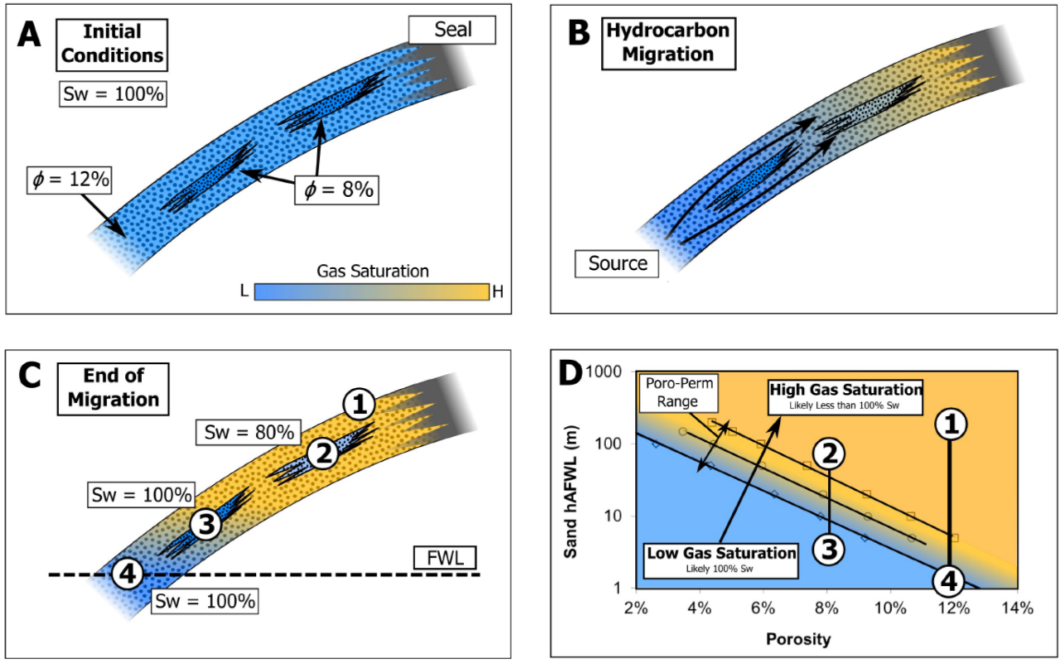
A conventional charge and trap model

Limited well data available, but:

- Evidence suggests the embayment is not a BCG system
- Conventional stratigraphic and subtle structure traps
- Can we devise a pragmatic method to efficiently explore?

Capillary pressure (Pc)

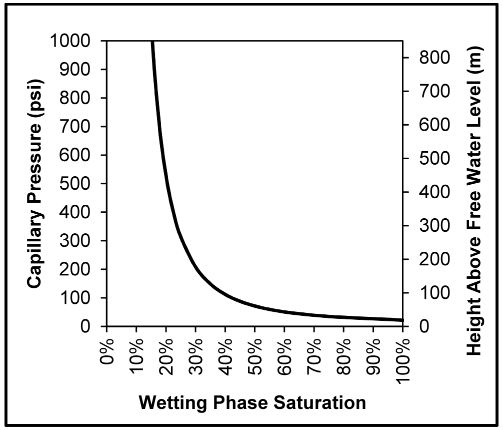
- Capillarity controls distribution and migration of hydrocarbons
- It is a useful tool to understand migration and charge



Conclusion: Drill the upper limit of traps even in complex depositional environments

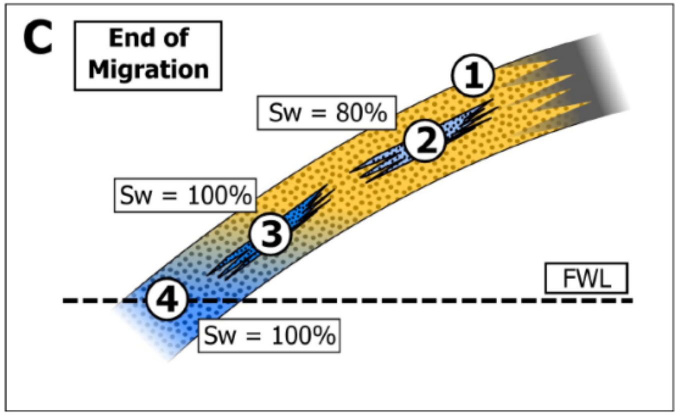
Capillary pressure

Capillary pressure can be used to assess the potential for reservoirs with sparse well control to produce hydrocarbon at useful rates



$$J = \frac{Pc}{\sigma cos\theta}\sqrt{\frac{k}{\phi}}$$

The Leverett J function is used to normalise raw Pc as it is a useful and simple relationship between many important reservoir parameters



One parameter is critical to achieving sufficient productivity: Water Saturation

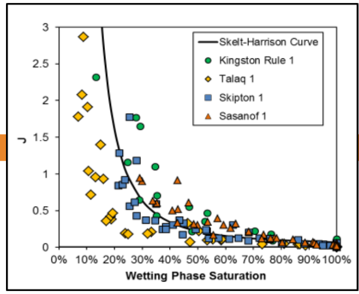
Solution scheme

Conversion of Pc/Sw to hAFWL/porosity curves

Normalise raw Pc data to Leverett-J

Fit Skelt-Harrison Function to data

$$S_w = \left[1 - e^{\left(\frac{a_0}{J - J_D}\right)^{a_1}}\right] \times (1 - S_{irr}) + S_{irr}$$



Invert Skelt-Harrison to solve for J from Sw

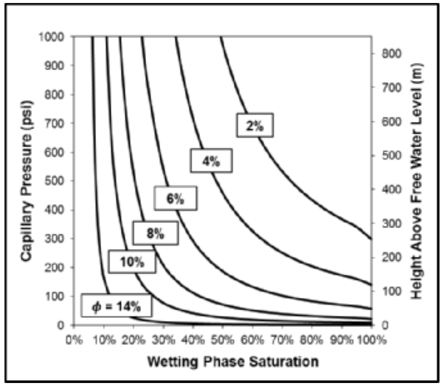
$$J = \left[a_0 + J_D\left(-\ln\left(1 - \frac{S_w - S_{irr}}{1 - S_{irr}}\right)\right)^{\frac{1}{a_1}}\right] \times \left[-\ln\left(1 - \frac{S_w - S_{irr}}{1 - S_{irr}}\right)^{\frac{-1}{a_1}}\right]$$

Solve Standard Pc equation for hAFWL and Pc

$$h = \frac{J\,\sigma\cos\theta}{\Delta\rho g\sqrt{\frac{k}{\phi}}}$$

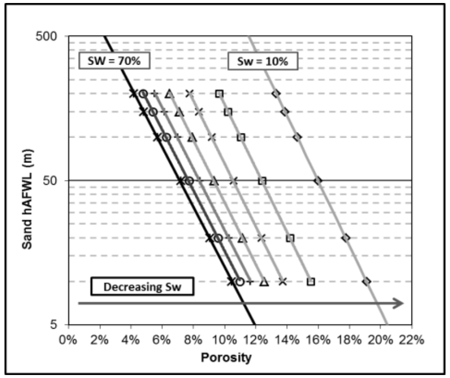
&

$$Pc = \frac{J\,\sigma\cos\theta}{\sqrt{\frac{k}{\phi}}}$$



We now have a simple tool to create 'any' Capillary Pressure curve

Calculate hAFWL for various porosities and water saturation and plot



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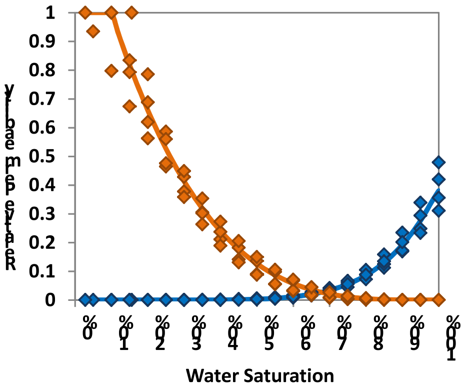
Solution scheme

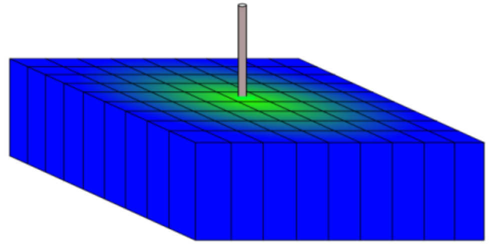
Estimation of water-gas-ratio and saturation cut-off parameter

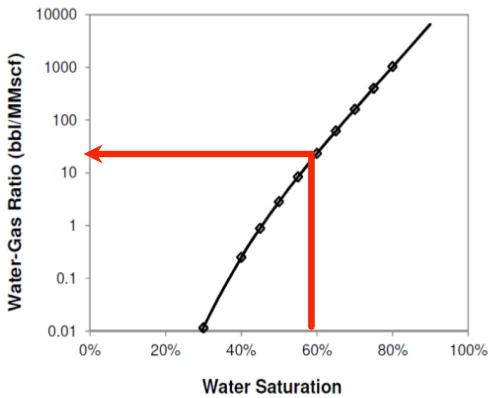


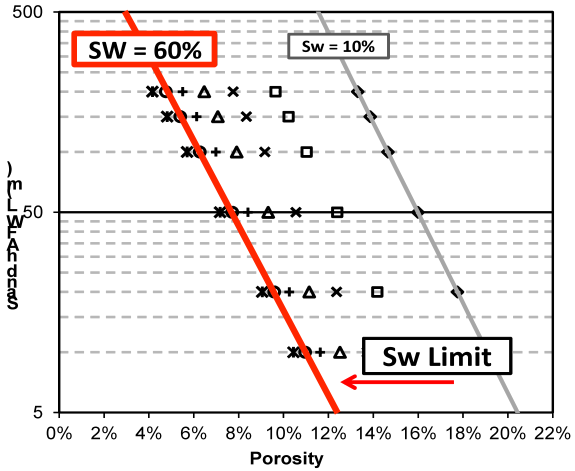
Simulate simple two-phase single well tank model:

'Static' Input:
Relative permeability
Rock properties
Fluid properties
Initial conditions

Varied:
Water saturation







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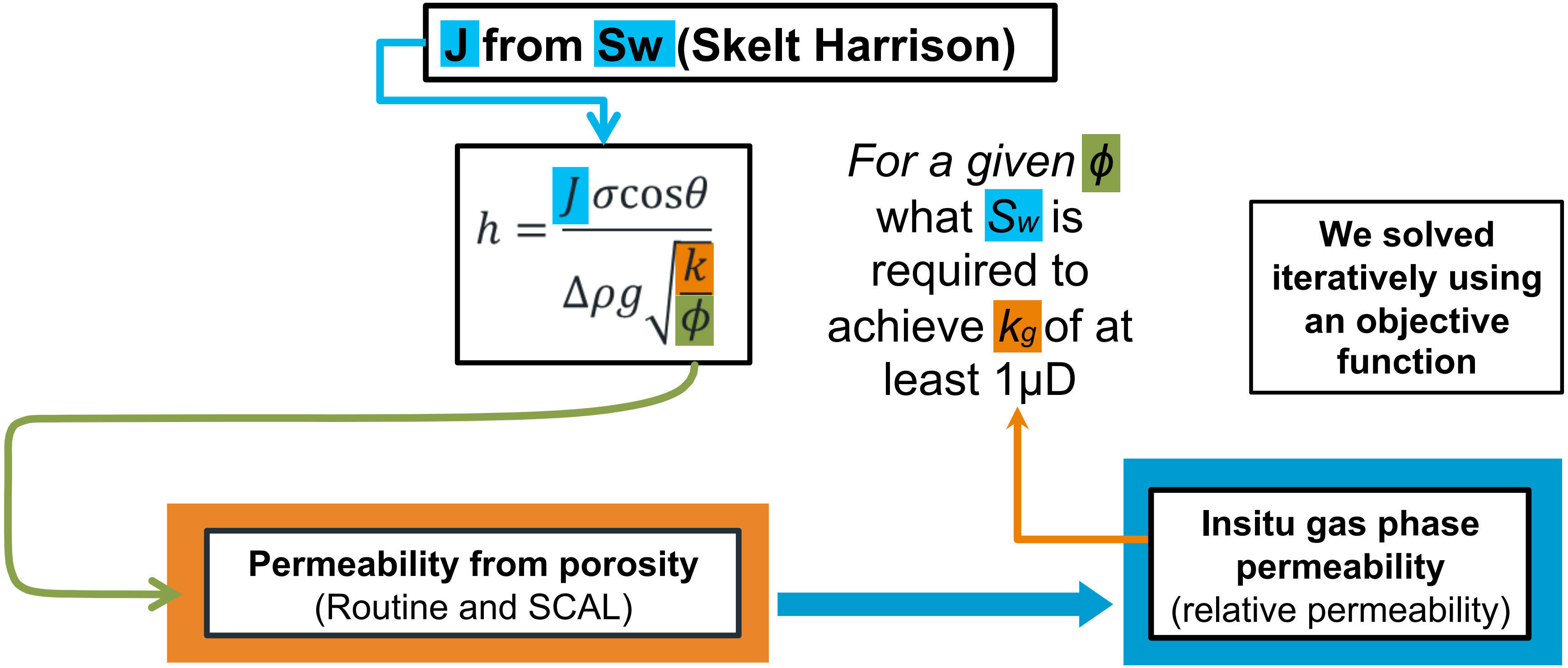
Solution scheme

Estimation of permeability cut-off parameter



Solution scheme

Estimation of permeability cut-off parameter

$$J = \left[a_0 + J_D\left(-\ln\left(1-\frac{S_w - S_{irr}}{1-S_{irr}}\right)\right)^{\frac{1}{a_1}}\right] \times \left[-\ln\left(1-\frac{S_w-S_{irr}}{1-S_{irr}}\right)^{\frac{-1}{a_1}}\right]$$

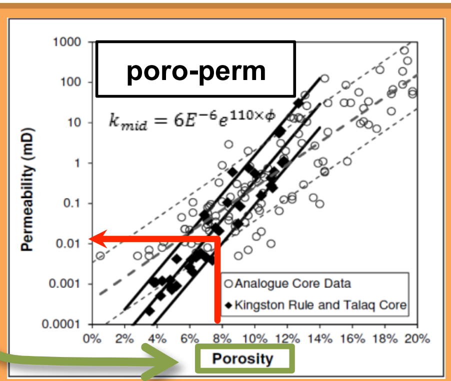
$$J = \frac{\Delta\rho g h}{\sigma\cos\theta}\sqrt{\frac{k}{\phi}}$$

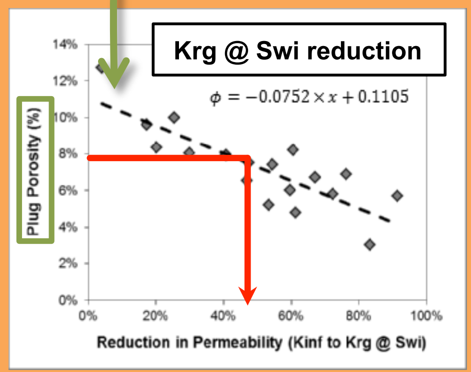
Solve for hAFWL

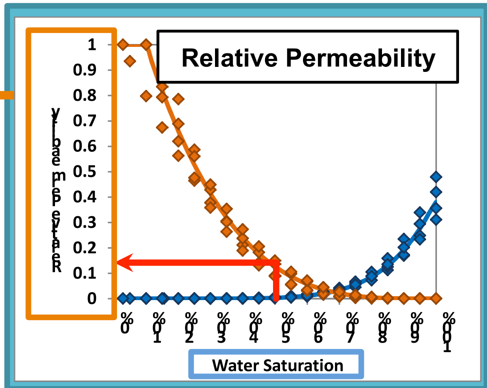
$$h = \frac{J\sigma\cos\theta}{\Delta\rho g\sqrt{\frac{k}{\phi}}}$$

For a given ϕ what S_w is required to achieve k_g of at least 1μD

We solved iteratively using an objective function







Capillary pressure and productivity

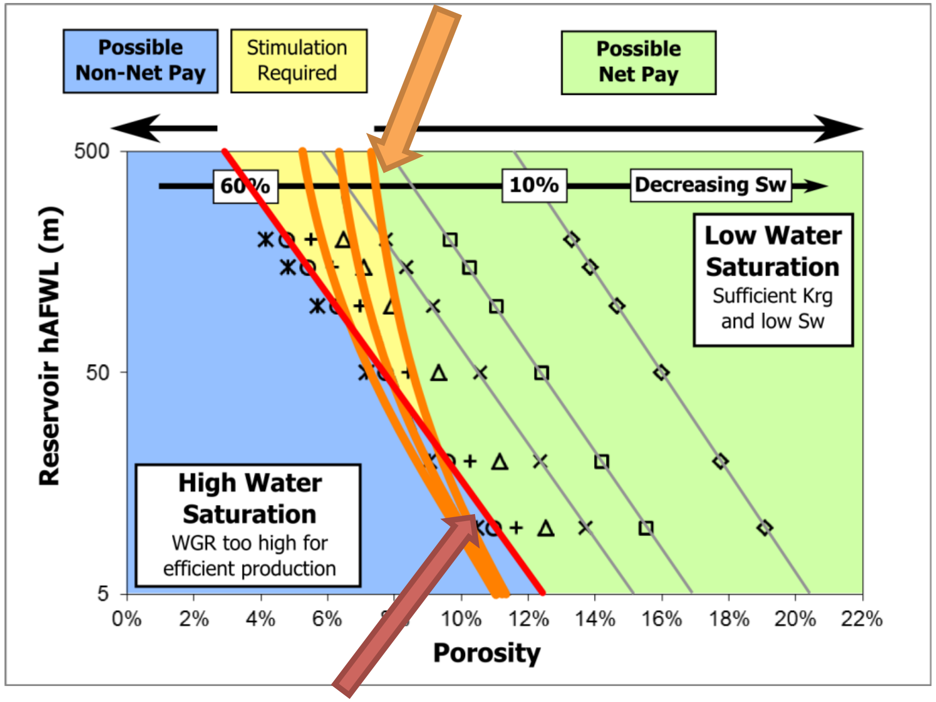
Combining Pc, relative permeability, poro-perm and productivity

The chart describes three reservoir zones

1. **Green**
   Porosity and water saturation are high enough to achieve a gas phase permeability >1µD (most likely much higher)
2. **Yellow**
   The reservoir is high enough in structure to give a low Sw but permeability is below 1µD
3. **Blue**
   Porosity is too low, leading to high Sw and very low gas phase permeability

Now, map both height above the FWL and porosity and assign each gridded node to one of these three 'areas'

The relative permeability limit
Three lines for high, mid & low k/ϕ relationships



The water saturation limit
One line based on water-gas-ratio

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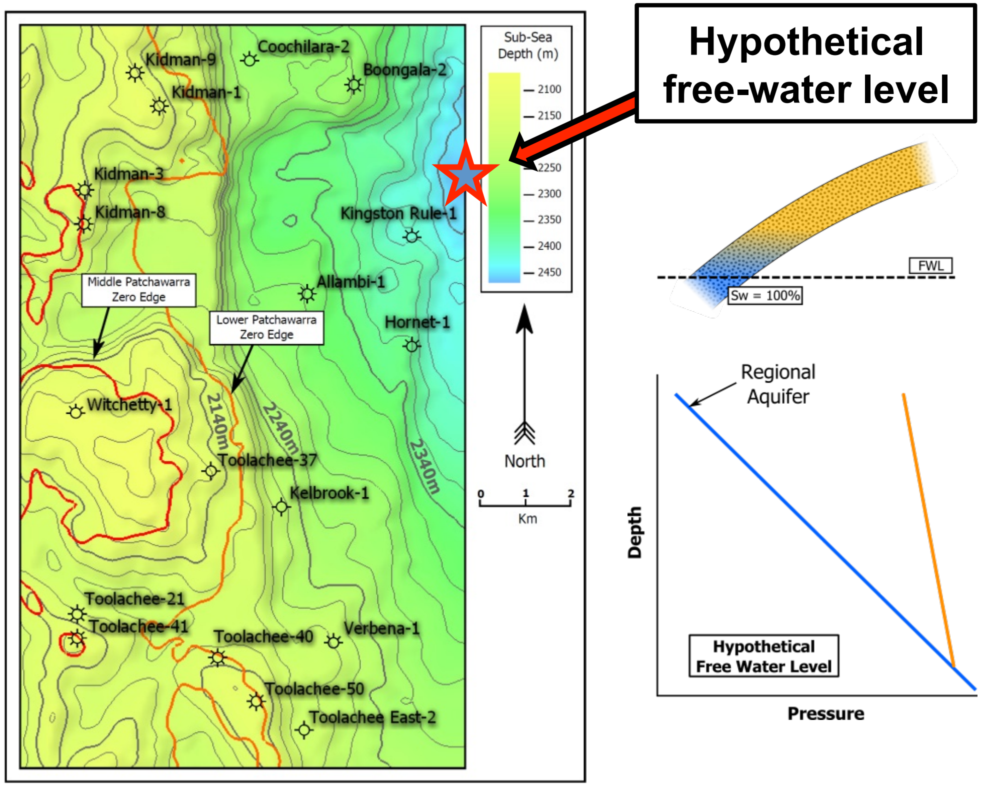
Productivity mapping

Combining Pc, relative permeability, poro-perm and productivity

- Now assume that gas fills the structure down to the lowest spill point deep in the basin
- Gas saturation occurs everywhere and the entire structure is one system: **<u>'the best possible case'</u>**

This is unrealistic given reservoir architecture, but:

- By taking the most optimistic scenario, we can say that if the mapped reservoir node still falls in the blue chart area, gas productivity may be low.
- We can avoid these areas for our next appraisal well locations



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Findings

- **Deep gas discovery in the Mettika Embayment is likely a conventional stratigraphic trap**
- **A targeted method proposed to direct future exploration and appraisal**
- **Priority is given to the shallowest reservoirs where:**
  - Water saturation is likely to be lowest
  - Porosity is highest
  - Therefore, gas productivity is most likely to be high
  - *In complex fluvial systems, the method needs continual evaluation.*
- **Conventional rock physics and concepts may be useful to explore deep flank plays:**
  - Pick the low apple first and establish production in shallow reservoirs
  - Understand Water saturation trends and production limits
  - Then step out into the more difficult, deep reservoirs

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Acknowledgements

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