A Pragmatic Approach to Exploration Petrophysics in Lacustrine Shales*

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Abstract

The thick, regionally extensive lacustrine shales of the Cooper Basin were discovered more than half a century ago, but it was not until recently that the source rock and reservoir potential of the shales were recognised, particularly within the Nappamerri Trough, which is the deepest and largest of the structural troughs in the Cooper Basin, South Australia. In 2010, at the commencement of an extensive exploration and evaluation program, there were no pre-existing analogues for the Nappamerri Trough shale play, as all commercially produced shale plays in North America involve marine rather than lacustrine shales. Data from existing wells in the area provided a preliminary indication of shale potential, in particular, the organic content, maturity, mineralogy and extent of overpressure. A thorough wireline logging and core-analysis program was designed for the initial exploration wells to expand the understanding of key shale characteristics. The high geothermal gradient proved to be challenging for evaluation with some logging runs having to be curtailed. As a starting point, published methods for evaluating shales were applied to the Nappamerri Trough shales with limited success. Using a deterministic interpretation method and core calibration, petrophysical evaluations were completed which are not only suitable for initial shale assessment, but they also identified where the key petrophysical uncertainties were and how they could be addressed in the future.

Reference Cited

Passey, Q.R., S. Creaney, J.B. Kulla, F.J. Moretti, and J.D. Stroud, 1990, Practical model for organic richness from porosity and resistivity logs: AAPG Bulletin, v. 74, p. 1777-1794.

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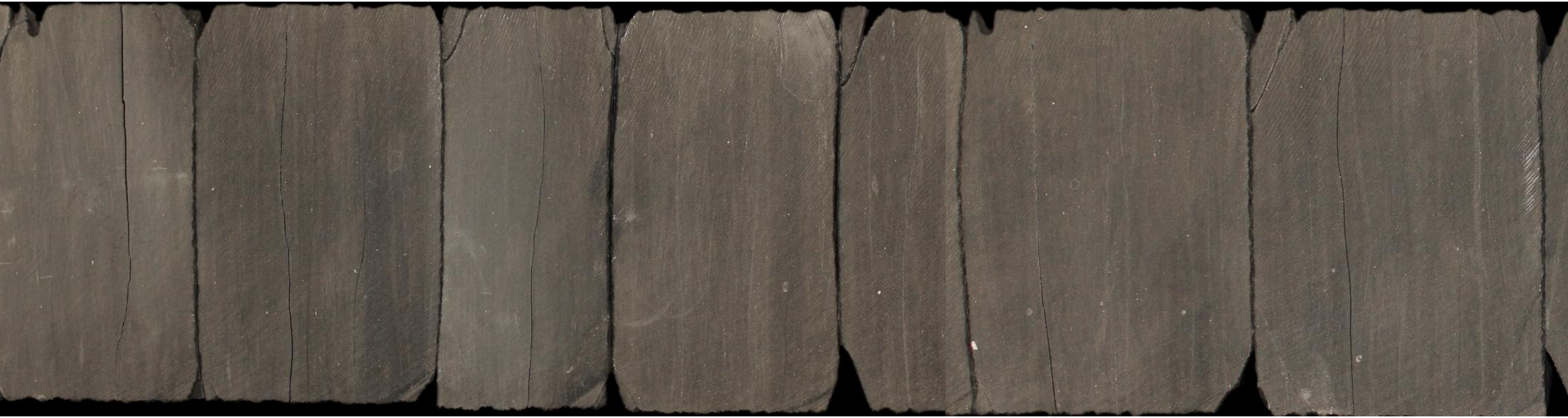

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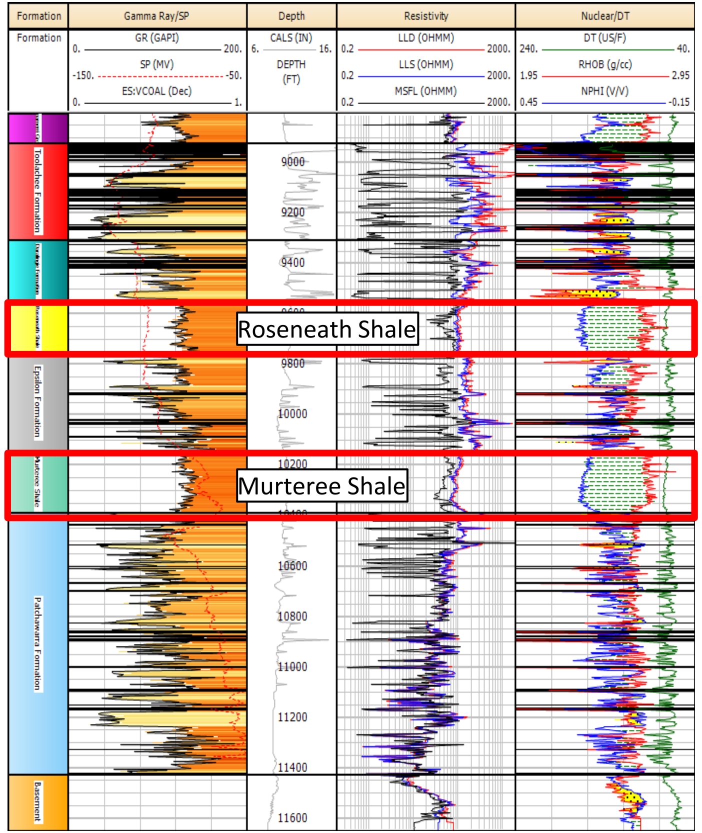
The Cooper Basin and Nappamerri Trough

- Beach Energy operates two large exploration permits in the Nappamerri Trough, Cooper Basin, ex PEL 218 and ATP 855
- It is the deepest and largest of the troughs in the Cooper Basin
- It contains a thick Permian section of coals, siltstones, sandstones and shales
- The Roseneath and Murteree shales were deposited in very large freshwater lakes
- The first two exploration wells of the most recent drilling campaign, Encounter-1 and Holdfast-1, were drilled in 2010/2011 to test the shale gas and basin-centered gas potential of the Nappamerri Trough

The Cooper Basin and Nappamerri Trough

Bulyeroo-1 (existing well within structural closure)

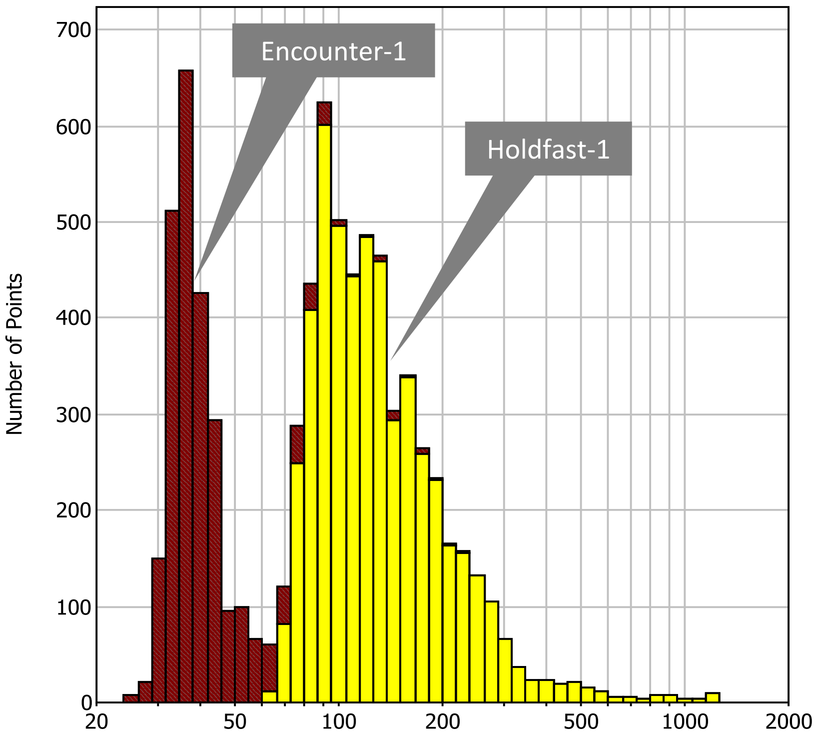


- What was known from existing wells?
  - Thick shales
  - Overpressured in deep trough
  - Mineralogy, organic content and maturity from cuttings
  - Gas saturated section within structural closure
  - High temperature gradient of 4.5–5.5°C/100m in Permian section
- Existing data supported the possibility a shale gas play was present, but sufficient data were then not available for a reliable analysis of the resource potential
- The primary objective of the first two exploration wells was to assess the gas content and mechanical properties of the shales and, if initial indications were positive, to undertake fracture stimulation and attempt to get gas to surface

Data collection in Encounter-1 and Holdfast-1

- Approximately 65% of the planned wireline evaluation programme was successfully executed
- Successful coring program – 482m of core acquired and used in a full suite of shale analysis
- Problems encountered with logging were associated with:
  - Temperature: high geothermal gradient, wellbores heated up very quickly once circulation stopped (NMR failed)
  - Resistivity: induction tools used as they were more likely to withstand predicted temperatures but outside of R_t/R_m tolerance
  - Hole conditions and differential sticking over permeable sands

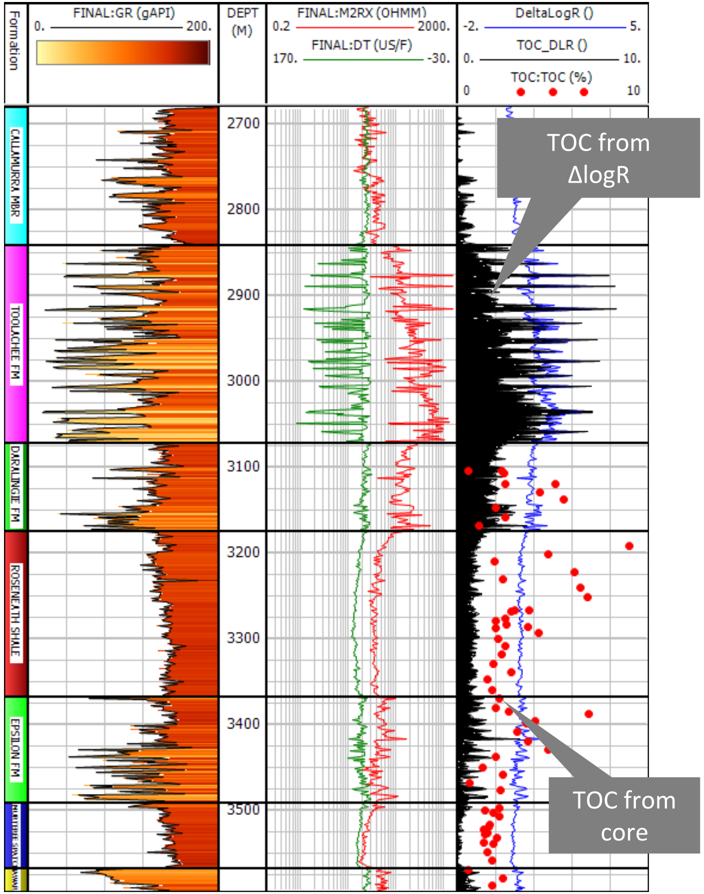
Deep Resistivity (Roseneath Shale)



Difference in resistivity due to induction tools being run outside of Rt/Rm tolerance

Using published workflows, trends and assumptions

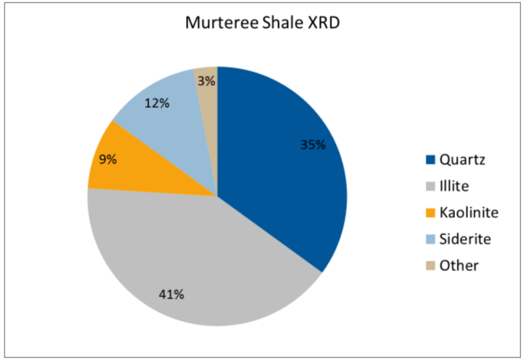
- Delta Log R (Passey et al., 1990) to estimate TOC content
  - Does not work in the Nappamerri Trough due to overmature shales, overpressure, presence of siderite and lack of “fine-grained, non-source rock” for a calibration point
- Density vs TOC trend to derive a continuous TOC curve
  - Does not work as facies with higher TOC also have higher proportion of siderite which increases bulk density
- Uranium vs TOC trend to derive a continuous TOC curve
  - Does not work due to limited uranium in fresh water lake and lack of pH/Eh dependency on uranium and TOC distribution

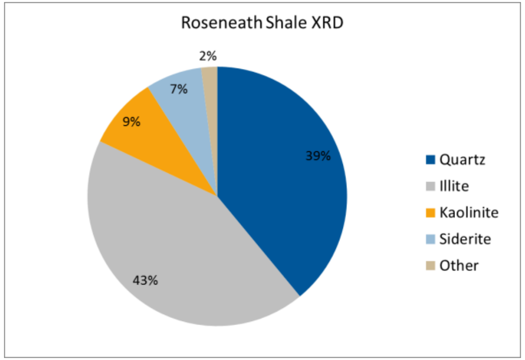


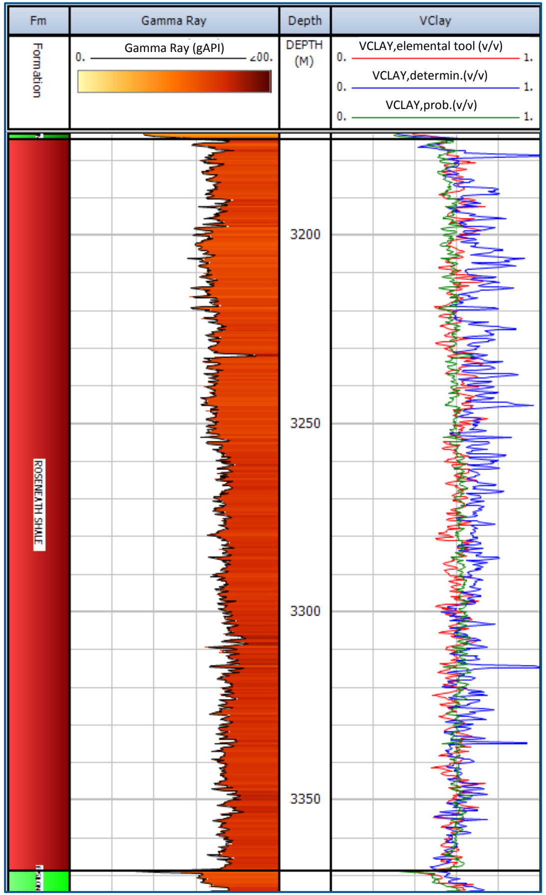
Lacustrine shale evaluation

Volume of clay

- Simple clay mineralogy, end point of diagenesis
- Based on XRD both shales contain ~50% clay
- Once calibrated to XRD, both the GR and Neutron-Density produce consistently reliable VClay
- Deterministic and probabilistic interpretation yield similar Vclay
- Low level of uncertainty



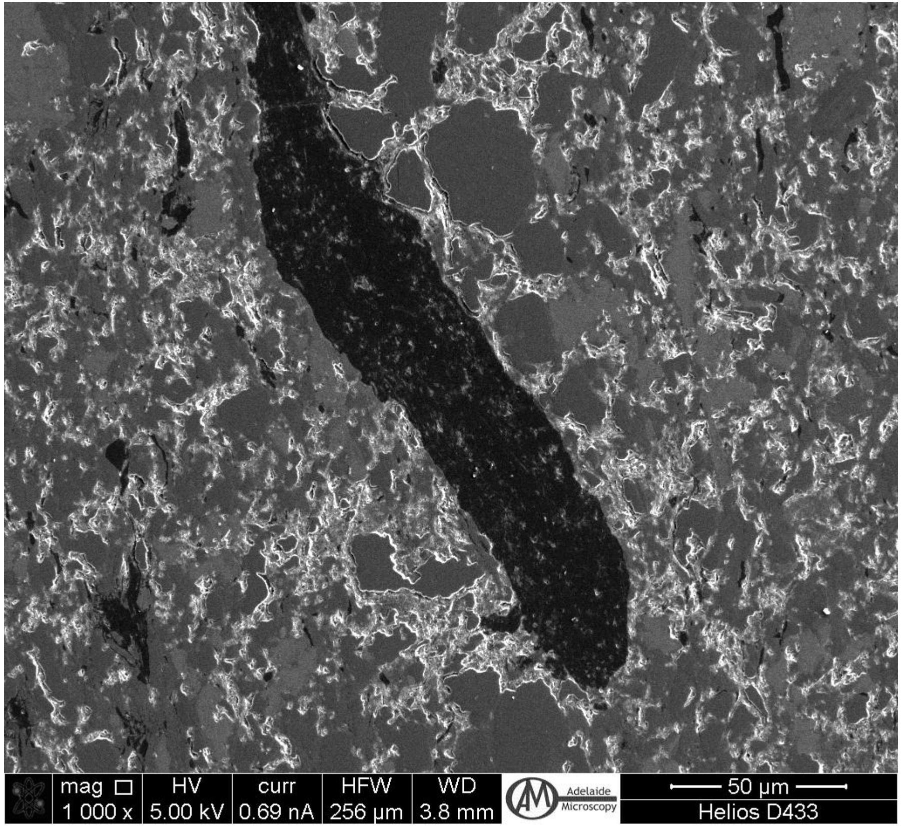




Lacustrine shale evaluation

TOC Distribution

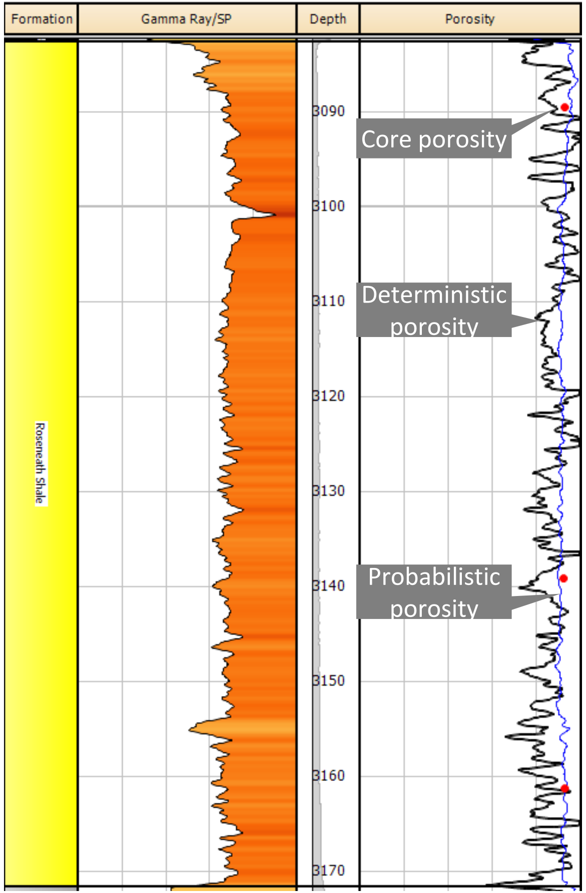
- TOC abundance determined from RockEval Pyrolysis
- Determined using core and where necessary in-filled with analysis from cuttings
- TOC predominantly between 1-3% with a tight distribution
- Low level of uncertainty



Lacustrine shale evaluation

Porosity

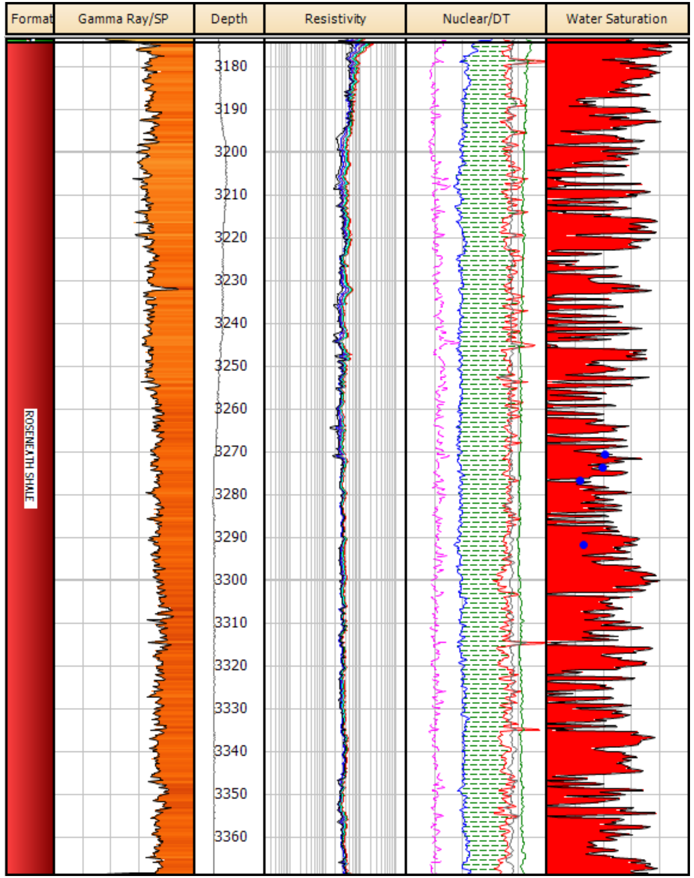
- To determine the best log(s) to use for porosity, need to take into account what each tool is affected by
- How do you take into account microporosity in clays and siderite, but not in the organics?
- Rely on core analysis to guide parameters and to calibrate results but need to be aware if the porosity reported is effective or total porosity…is there a difference in these shales?
- Probabilistic porosity does fit reasonably well to the few core points available, but the deterministic porosity (driven by the density) illustrates variability
- Use the difference in porosity from the two methods to define distribution of porosity for volumetric calculations
- Moderate level of uncertainty



Lacustrine shale evaluation

Water saturation

- Uncertainty of Archie saturation input parameters
  - Rw: not known, can only extrapolate TDS from water samples on structural ridges (>1,000m shallower)
  - Rt: known issue with data quality, affected by overmature kerogen
  - Porosity: some uncertainty but range is reasonably understood
  - n and m: not known, how relevant are these in shales?
- More uncertainty is added when using Simandoux, Waxman-Smits, etc. because *in-situ* clay resistivity or CEC is unknown
- Can get a reasonable match to core Sw (crushed method) but probably not reliable in this play where fluids are being introduced into a shale core that is likely to have desiccated clays
- High level of uncertainty



Note, Sw shown in scale other than 1-0 to show detail

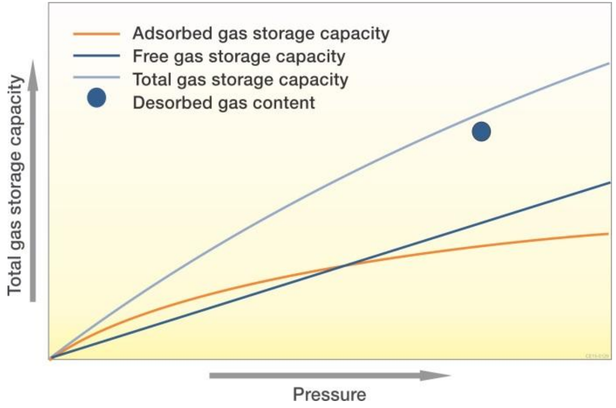
Lacustrine shale evaluation

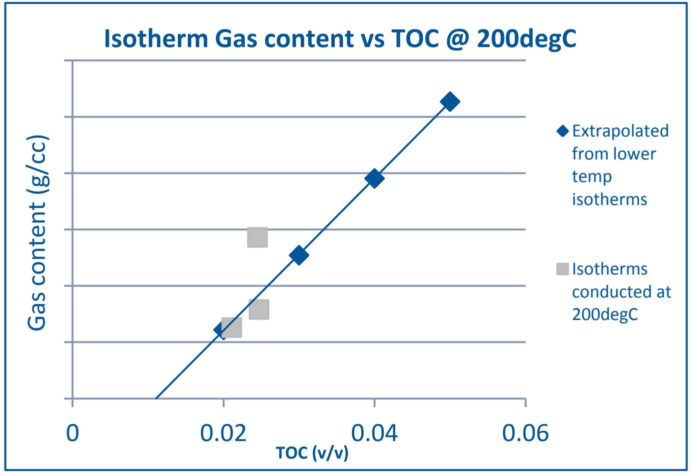
Gas content

- In theory, should be able to QC the different methods of gas content calculation by using the assumption that:

  Free Gas (logs) + Adsorbed Gas (isotherms) = Total Gas (desorption)

- The time taken to get the core to surface was long (> 10 hours) plus additional time sampling on surface; therefore high proportion of lost gas interpreted
- Great difficulty in replicating in situ temperature conditions for isotherms, necessary to extrapolate results
- Uncertainties are too large for any gas content QC process to be effective
- High level of uncertainty





Summary

- Encounter-1 and Holdfast-1 achieved their primary objective of proving producible gas outside of structural closure
- Analogues are not available for the Nappamerri Trough with the depositional environment, mineralogy and maturity being unique (for now); therefore most published workflows were not suitable for the shales within the Nappamerri Trough
- HPHT environment provided some initial challenges which required the subsequent evaluation programs to be redesigned
- Subsequent to Encounter-1 and Holdfast-1, 16 more wells were drilled in the trough with further logging and core evaluation
- Equations and parameters have been revised to best fit the new information resulting in an improved overall understanding of the shale petrophysical parameters
- Despite remaining uncertainty, confidence in assessment is such that further resolution of shale reservoir properties is not required

Acknowledgements

- I would like to gratefully acknowledge
  - Beach Energy for permitting the material to be presented
  - The many consultants working on the core analysis and geological studies that provided valuable input for the evaluation

Compliance statements

Disclaimer

This presentation contains forward looking statements that are subject to risk factors associated with oil, gas, geothermal and related businesses. It is believed that the expectations reflected in these statements are reasonable but they may be affected by a variety of variables and changes in underlying assumptions which could cause actual results or trends to differ materially, including, but not limited to: price fluctuations, actual demand, currency fluctuations, drilling and production results, reserve estimates, loss of market, industry competition, environmental risks, physical risks, legislative, fiscal and regulatory developments, economic and financial market conditions in various countries and regions, political risks, project delays or advancements, approvals and cost estimates.

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Unless otherwise noted, all references to reserves and resources figures are as at 30 June 2015 and represent Beach’s share.

Questions?