Reservoir Petrophysical Modeling from Seismic Impedance Volumes

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1. Background

• Initially (1980’s) HC volumes in the 3D space were determined using the Gross Rock Volume (GRV), net reservoir to gross thickness (NTG), average porosity (PHI), average saturation (So) and an expansion constant (Bo) determined from at least one discovery well, according to the following equation: 

\[ \text{STOIIP} = \text{GRV} \times \text{NTG} \times \text{PHI} \times \text{So} \times \frac{1}{\text{Bo}} \]

• This should only be used as a “quicklook” estimation.
• Averages remove the variation in reservoir quality.
• The GFC could never have been predicted using averages.
• Similarly, good reservoir quality will never be predicted using averages.
2. Current Condition/Situation

- 5-10 Exploration/Appraisal wells are typically required (at approx. $100mill each) before Financial Investment Decision is made.
- Approx. 5 years of conceptual based modelling is required before Development drilling starts.
- The “end of field” HC volumes from too many MCP’s are found to be outside the initial uncertainty range and most of these are below the initial low case.
- Petrophysical cut-offs and averaging often over-estimate net pay (due to cognitive bias), but this results in under-estimating permeability, requiring perm scale factors of 3x-5x at best to material balance the field production.
- Too often, the variation around the average value of the property is modelled, without regard to the probability of the precise value.

Initial HC volume uncertainty range

- High
- Low

End of Field HC volumes

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2. Current Condition/Situation

Consider the state of a drunk, wandering around on a busy highway. His average position is the centerline, so........
3. Objective

- **Increased accuracy** – validation with blind testing.
- **Reduced cost** – requiring less appraisal wells and less processing time.
- Use science, physics and mathematical relationships rather than conceptual/stochastic models based upon averages.
- Use a deterministic approach calibrated to an exploration/discovery well(s).
- Develop a robust 3D prediction, that can be used with “old” or “new” Seismic.
4. Action

- Calculate the reservoir Petrophysical properties constrained/referenced to the 3D seismic trace/impedance.
- Develop relationships for water, gas, oil and residual HC at the calibration well(s). (e.g. Gassmann)
- Blind test predictions with new or existing well(s). This will validate the model.
- Populate into the 3D space with the predictions based upon the calibrated well(s)
- Use existing relationships of permeability and saturation, in the 3D volume.
5. Petrel Field - example
5. a) Calibration: - Petrel-1A

<table>
<thead>
<tr>
<th>GR/CALI/SP</th>
<th>Depth</th>
<th>Rt/Rxo</th>
<th>RHOB/NPHI/DTC/DTS</th>
<th>SSS</th>
<th>Log Imped</th>
<th>Seismic Trace</th>
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Clay Silty Sand (SSS) Petrophysics

Log Imped Petrophysics

Seismic Petrophysics

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

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5. b) Blind Test: - Petrel-4

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<th>SSS</th>
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Clay Silty Sand (SSS)
Petrophysics

Log Imped
Petrophysics

Seismic Petrophysics

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia
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5. b) Blind Test: - Petrel-5

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia
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5. b) Blind Test: - Petrel-6

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia
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5. b) Blind Test: - Petrel-7

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia
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5. c) 3D Property Model: - Petrel Field

Each pixel is a “pseudo” well 200m x 200m x 2m sampling
5. d) 4D Property Model: - Petrel Field

Drainage/Imbibition

1. Drainage
2. Spontaneous Imbibition
3. Forced Imbibition (EOR)

Imped. Vol. STOIIP/Drain


Imped. Vol. Difference

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6. Wheatstone Field - example
6. a) Calibration: - Wheatstone-3

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia

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6. b) Calibration: - Wheatstone-1

<table>
<thead>
<tr>
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<th>Log Imped</th>
<th>Seismic Trace</th>
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<td>3200</td>
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Silty Shaly Sand (SSS) Petrophysics
Seismic Petrophysics
Seismic Petrophysics

Log Data from Department Mines and Petroleum WA, Seismic Data from GeoScience Australia
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6. 3D Property Model: - Wheatstone

Ultimate Recoverable Volumes?

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7. Uncertainty:

Log PHIT vs Seismic PHIT

Log Vclay vs Seismic Vclay

PHIT uncert.
P10 = -0.1
P90 = +0.1

Vclay uncert.
P10 = -0.35
P90 = +0.15

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8. Conclusions

• Differences to current Industry standard modelling:
  – Significant reduction in appraisal wells with blind testing possible.
  – No Geological conceptual based modelling used, no stochastic predictions, no co-kriging of dependant variables/properties.
  – No use of averages, no probabilities or “spread” of data varying from the average, no facies and no cut-offs used.
  – Property predictions take 2 to 4 weeks rather than 6 months or more.
• Products:
  – Porosity, Vclay, Permeability and Saturation properties populated into the **3D Seismic space**
  – Uncertainty around the precise predicted value of the property not uncertainty around the average property.
  – 4D Seismic prediction using drain/imbib SHF.
8. Conclusions

• Data Requirements: -
  – Minimum of one exploration/appraisal well, preferable 3-4 wells for calibration if available.
  – Super-combo logs – GR, CALI, SP, RXO, RT, RHOB, NPHI, PEF, DRHO, DTC, DTS
  – Well location/coordinates, directional data.
  – 3D Seismic cube, preferably Impedance depth data.
  – Preferably WFT to determine fluid levels.
  – Preferably RCA (poro-perm) and SCAL (CapPress – Drain/Imbib, XRD)
  – FMI, NMR, Tensor Resistivity etc not required.

• Seismic Uncertainty: -
  – Accuracy of Seismic band-limited trace matched to Impedance values?
  – Seismic quality, high frequency loss and constructive/destructive interference?
  – Seismic to log resolution matching?
  – TWT to log depth match?
9. References

3. Savage, S (Professor Stanford University), The Flaw of Averages, Wiley Publications
11. Adams, S., PE 84298, Modelling Imbibition Capillary Pressure Curves
10. Questions?