“Net & Pay” – The Petrophysicist’s input to quantifying the reserves

“Contentious ambiguity!”

Dr Peter Fitch
Department of Earth Science & Engineering,
Imperial College London.
( @peterophysics )
Outline

• STOIIP & Reserves – reminder
• Concepts of Net & Pay
• Defining cutoffs
• Application to LPS dataset
STOIIP

Stock tank oil initially in place

\[
\text{STOIIP} = \text{GRV} \cdot \phi \cdot (N/G) \cdot (1-S_w) / \text{FVF}
\]
STOIIP

Stock tank oil initially in place

\[
\text{STOIIP} = \text{GRV} \cdot \phi \cdot (N/G) \cdot (1-S_w) / \text{FVF}
\]

- Gross rock volume
- Net to gross ratio
- Formation volume factor
- Porosity
- (1 - Water saturation)
- Oil saturation
Reserves

• Prospective resources
  – Undiscovered / potentially recoverable
  – Exploration

• Contingent resources
  – Discovered recoverable only
  – Appraisal

• Reserves
  – Discovered, remaining, recoverable, & commercial
  – Development
  – Recovery factor(s) / Estimated Ultimate Recovery

_Sensu. Worthington (2010)_
Qualitative example (LPS dataset)
Qualitative example (LPS dataset)

Net / Gross = 238 / 410 = 58 %
Qualitative example (LPS dataset)
Qualitative example (LPS dataset)
Qualitative example (LPS dataset)

- Shale volume (frac.)
  - 0.0
  - 0.5
  - 1.0

- Porosity (frac.)
  - 0.4
  - 0.2
  - 0.0

- Water Saturation (frac.)
  - 0.0
  - 0.5
  - 1.0

Measurements at:
- 9050
- 9100
- 9150
- 9200
- 9250
- 9300
- 9350
- 9400
- 9450
- 9500

Graph shows variations in shale volume, porosity, and water saturation across different depths.
Qualitative example (LPS dataset)

Net / Gross = 238 / 410 = 58%

Pay / Gross = 112 / 410 = 27%
Net & Pay – Definitions

• **Net Sand**
  – Any rock within the gross interval that has useful reservoir properties

• **Net Reservoir**
  – Any rock within the Net Sand that has useful reservoir properties and the capability to store and flow fluids
    • e.g. is not tight (low porosity)

• **(Net) Pay**
  – Intervals of Net Reservoir that contain hydrocarbons
<table>
<thead>
<tr>
<th>Gross interval thickness</th>
<th>Non-reservoir</th>
<th>Non-reservoir</th>
<th>Pay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low / no porosity</td>
<td>Hydrocarbon</td>
<td>Water</td>
</tr>
<tr>
<td>Non-reservoir</td>
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<td>Water</td>
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</tbody>
</table>

Net & Pay – concepts

OWC
HOW CAN WE QUANTIFY NET & PAY?
What is a cut-off?

- Thresholds
- Limiting factors
  - Above or below
  - Accept or reject

- Traditional cut-offs
  - Net Sand
  - Net Reservoir
  - Pay
Sand cut-off

- Histogram:

- Core calibration:

Shale volume (%)

Frequency

Shale volume (%)

Depth

Vsh cut-off

Sedimentary log
Reservoir cut-off

- Histogram:

- Permeability x-plot:

+ choice of Net Sand cut-off
Pay cut-off

- Histogram:
  - Water Saturation (%)
  - Saturation cut-off

- Percentiles:
  - Cumulative Frequency
  - Water Saturation (%)
  - Saturation cut-off

+ choice of Net Sand & Reservoir cut-offs
Dynamically conditioned cut-offs

\[ RQI = \frac{k}{\phi} \]

Or might use \( k_{ro}(S_{wirr}) \)

Lower limit of hydraulic behaviour

Porosity cut-off

Repeat for different rock types...

(Modified from Worthington, 2010)
• Establish cut-offs

Cut-offs:
- $\text{PORO}_c = 17.5\%$
- $V_{shc} = 15.8\%$
- $S_{wc} = 34.8\%$
Quantitative example (LPS dataset), 3

<table>
<thead>
<tr>
<th></th>
<th>Count</th>
<th>Ratio to Gross (%)</th>
<th>Cumulative Thickness (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross</td>
<td>781</td>
<td>100.0</td>
<td>390.00</td>
</tr>
<tr>
<td>Net Sand</td>
<td>448</td>
<td>57.4</td>
<td>223.71</td>
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<tr>
<td>Net Res</td>
<td>412</td>
<td>52.8</td>
<td>205.74</td>
</tr>
<tr>
<td>Pay</td>
<td>196</td>
<td>25.1</td>
<td>97.87</td>
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</table>
## Alternative definitions & cut-offs

<table>
<thead>
<tr>
<th></th>
<th>Egbele et al.</th>
<th>Etris &amp; Stewart</th>
<th>Worthington &amp; Consentino</th>
<th>Pfeffer Theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Thickness</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Gross Reservoir</td>
<td>None</td>
<td>Gross Reservoir</td>
<td>Gross Rock None</td>
<td>Gross Reservoir</td>
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<tr>
<td>Net Reservoir</td>
<td>$V_{sh}$ &amp; $\varnothing$</td>
<td>$V_{sh}$</td>
<td>$V_{sh}$</td>
<td>$V_{sh}$</td>
</tr>
<tr>
<td>Gross Pay</td>
<td>$S_w$ &amp; $OWC$</td>
<td>Gross Pay $OWC$</td>
<td>Net Reservoir $\varnothing$</td>
<td>Gross Pay $S_w$</td>
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<tr>
<td>Net Pay</td>
<td>$BVW$</td>
<td>$S_w$</td>
<td>Net Pay $S_w$</td>
<td>Gross Pay $S_w$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Net Pay $BVW$</td>
</tr>
</tbody>
</table>

Modified from Egbele et al. (2005)
Summary

• Net Sand & Reservoir – *Any rock within that has useful reservoir properties, & the capability to store and flow fluids*

• (Net) Pay – *Intervals of Net Reservoir that contain hydrocarbons*

• Cut-offs are used as threshold values to quantify Net & Pay

• Many approaches for conventional cut-offs
• Even more approaches for carbonates & unconventional reservoirs
• Some are company, individual or economically defined

• Key in constraining STOIIP and Reserves
Suggested references

• LPS Seminar Publications (www.lps.org.uk)
• Egbele et al. (2005), Net-To-Gross Ratios: implications in integrated reservoir management studies. SPE 98808
• Jensen & Menke (2006), Some statistical issues in selecting porosity cutoffs for estimating net pay. Petrophysics, 47 (4), 315-320
• Worthington & Cosentino (2005), The role of cutoffs in integrated reservoir studies. SPE 95428
• Worthington (2010), Net Pay – What is it? What does it do? How do we quantify it? How do we use it? SPE 123561

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