Real time data interpretation and integration leads to significant resource volume increase in Lancaster fractured basement field West of Shetland

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Hurricane Background
Hurricane Asset Locations
Geological Cross-section

Lancaster

Clair
Greater Lancaster Area (GLA)

- Westray Fault Zone
- Halifax Fault Zone
- Lancaster Fault Zone

Top Basement depth structure
Contour increment 100m

- Lancaster FWL 1,680m TVDSS
- Brynhild Fault Zone
Fractured Basement characteristics

- Oil storage and mobility entirely depends on a hydrodynamic fracture network
- Fracture characteristics define reserves
- Static description is critical

Definitions of Naturally Fractured Reservoirs, after Nelson 2001
Fractured Basement Reservoir

- Primarily tonalite with minor dolerite intrusions
- 2.3-2.4 billion years old
- Exceptionally long and complex geological history
- Extremely fractured

Exposed tonalite on Isle of Lewis, outcrop analogue
Lancaster Schematic (CPR 2013)

1,597m TVDSS (CPR 2C OWC)

1,781m TVDSS (CPR 3C OWC)

1,380m TVDSS (4-way dip closure)

205/21a-4Z
205/21a-4
205/21-1A

Lancaster block boundary

Mobile oil swabbed
205/21-4
1,597m TVDSS

Hurricane | DEVEX May 2017
Lancaster Schematic (CPR 2017)

Max ESP rate 15,375 stb/d
205/21a-7Z (2016)

Max ESP rate 9,800 stb/d
205/21a-6 (2014)

205/21a-4Z
205/21a-4
205/21a-6
205/21a-7
205/21a-7Z

205/21-4
205/21-7

1,597m TVDSS (CPR 1C OWC)
1,653m TVDSS (CPR 2C OWC)
1,678m TVDSS (CPR 3C OWC)

Wireline oil samples
205/21-7
Deepest 1,669m TVDSS

Mobile oil swabbed
205/21-4
1,597m TVDSS
FWL Evidence

Resistivity logs
205/21a-7
OWC 1,678m TVDSS

NMR analysis (3rd party)
205/21a-7
Min ODT 1,620m TVDSS

Wireline oil samples
205/21a-7
Deepest 1,669m TVDSS

Mobile oil swabbed
205/21a-4
1,597m TVDSS

GC Tracer analysis (3rd party)
205/21a-7
OWC 1,685m TVDSS

Pressure-derived FWL
Multiple wells
FWL ~1,680m TVDSS

Mudlogging gas report
205/21a-4
OWC 1,643m-1,693m TVDSS
### 2013 vs. 2017 CPR STOIIP

<table>
<thead>
<tr>
<th></th>
<th>RPS 2013 CPR</th>
<th>RPS 2017 CPR</th>
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<tbody>
<tr>
<td>Low</td>
<td>471 MMbbl</td>
<td>1,571 MMbbl</td>
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<tr>
<td>Best</td>
<td>1,056 MMbbl</td>
<td>2,326 MMbbl</td>
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<tr>
<td>High</td>
<td>2,076 MMbbl</td>
<td>3,333 MMbbl</td>
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### 2013 vs. 2017 CPR Recoverable

<table>
<thead>
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<th>RPS 2013 CPR</th>
<th>RPS 2017 CPR</th>
<th>EUR (Reserves + Resources)</th>
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<tr>
<td><strong>Contingent Resources</strong></td>
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<tr>
<td>Low / 1P + 1C</td>
<td>60 MMbbl</td>
<td>28 MMbbl</td>
<td>129 MMbbl</td>
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<tr>
<td>Best / 2P + 2C</td>
<td>200 MMbbl</td>
<td>37 MMbbl</td>
<td>486 MMbbl</td>
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<tr>
<td>High / 3P + 3C</td>
<td>437 MMbbl</td>
<td>49 MMbbl</td>
<td>1,117 MMbbl</td>
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</table>

** Recoverable Volumes (MMbbl)**

- **1C** 60 MMbbl
- **1C/1P** 157 MMbbl
- **2C** 200 MMbbl
- **2C/2P** 523 MMbbl
- **3C** 437 MMbbl
- **3C/3P** 1,166 MMbbl

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Well 205/21a-7

(Lancaster inclined appraisal well)
205/21a-7 (2016) Appraisal Well

- Inclined appraisal well designed to investigate depth of the oil column and aquifer properties.

- Tophole location to be used as second producer via a horizontal sidetrack (25m from 205/21a-6).
Hurricane on the rig

- Hurricane staff (including CEO) onboard during operations to gather and interpret data, making decisions in real time
A number of flowing and shut-in periods were executed to enable a multitude of PLT runs to be performed

15 day testing programme
Advanced PLT Tool

Head
Electrical Release Device
Weight Bar 1
Weight Bar 2
Telemetry
GR, CCL, P, T
Swivel

Flow Scan Imager
Knuckles x2
Centraliser

Flow Caliper Tool
XY Caliper
E Probes
Spinner
Relative Bearing

Formation
Cement
Casing
Gas
Oil
Water

Flow Scanner FloView probe
Flow Scanner optical probe
Flow Scanner minispinner swept area
Brine Interface (shut-in)

- Clear Oil Water interface at 1378.8m MD
- No cross-flow detected
- Confusing results due to evidence of deeper oil from earlier wells

Pass coloring:
- Up pass1, Up pass2, Up pass3, Up pass4
- Down pass1, Down pass2, Down pass3, Down pass4
Brine Interface (Flowing)

- Interface has not moved
- Still no cross-flow
- Well flowing at >9,000 bopd
- Brine not moving (demonstrated by spinners)

Pass coloring:
- Up pass1, Up pass2, Up pass3, Up pass4
- Down pass1, Down pass2, Down pass3, Down pass4
Flow contribution

- Flow entirely dominated by two large aperture fractures at the top of the basement reservoir
- Combined aperture of fractures ~9”
Wireline samples

- Wireline samples collected using single phase cylinders from Expro, run on the Schlumberger FSI string
  - ~550-600 cm³ per sample
  - 5 samplers on a string
  - Controlled by simple timers
- Wireline samplers well depth controlled
- Presence of oil within these samplers indicates oil presence in the reservoir at this depth or deeper
- Decanting of samples onsite during first run was key real-time information for Hurricane to aid in interpretation of PLT data
Electrical Probe Holdup

- E-probes use electrical conductivity of water to distinguish between the presence of water and hydrocarbon.
- In addition to holdup, the sensor also records the number of bubbles/sec or bubble count, an information very useful to derive rates.
- Measurement independent of deviation.

- The signal from the probes is used to derive holdup.
- Thresholds are used based on the continuous phase changes and size of bubble.
- White time is the Hydrocarbon phase.
- Blue time is the Water phase.

\[ Y_w = \frac{\sum t_w}{t} \]
\[ N_{bc} = \frac{n_{bc}}{t} \]
• Schlumberger have interpreted the deepest point where oil bubbles were found as 1730m MD

• Bubbles of oil indicates oil moving through the brine column in the wellbore
## Gradio Density Changes

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Sample data for each depth level showing density changes over time.
Hurricane performed a number of shut-in PLT passes as well as flowing ones, to try and establish the static conditions within the wellbore.

Shut-in conditions changed throughout the course of the test:

- Brine interface deepened.
- Density profile changed, indicating heavier brine mixing downwards with lighter formation water.
Conclusion

• Fractured basement remains an under-explored play in the UKCS and Hurricane is utilising a number of innovative techniques with existing technology to evaluate the reservoir.

• This well presented a confusing dataset that required Hurricane staff offshore (including the CEO) to work closely with Schlumberger wireline staff, both offshore and onshore, to optimise the data acquisition programme.

• Early interpretation of the wellsite data provided Hurricane management sufficient confidence to raise funds and progress the drilling of Lincoln and Halifax.