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

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Kamaljeet Singh – Schlumberger
Hurricane Background
Hurricane Asset Locations

[Map of Scotland showing locations of assets such as Schiehallion, Foinaven, Shetland, Orkney Islands, Isle of Lewis, Isle of Skye, Aberdeen, Warwick, Whirlwind, Lancaster, Halifax, Lincoln, Solan, Strathmore, and Rona Ridge.]
Geological Cross-section

Lancaster

Clair
Greater Lancaster Area (GLA)

Lancaster FWL 1,680m TVDSS

Westray Fault Zone

Halifax

Lancaster

Brynhild Fault Zone

Top Basement depth structure
Contour increment 100m
Fractured Basement characteristics

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

Type 1 Naturally Fractured Reservoirs

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 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-7Z

205/21a-7

205/21a-6

205/21a-4Z

205/21a-4

205/21-1A

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
- Wireline oil samples 205/21a-7, Deepest 1,669m TVDSS
- Mobile oil swabbed 205/21a-4, 1,597m TVDSS
- NMR analysis (3rd party) 205/21a-7, Min ODT 1,620m TVDSS
- GC Tracer analysis (3rd party) 205/21a-7, OWC 1,685m TVDSS
- Mudlogging gas report 205/21a-4, OWC 1,643m-1693m TVDSS
- Pressure-derived FWL, Multiple wells, FWL ~1,680m 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>
<tr>
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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>Contingent</td>
<td>Low / 1P + 1C</td>
<td>60 MMbbl</td>
<td>129 MMbbl</td>
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<tr>
<td>Resources</td>
<td></td>
<td>28 MMbbl</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Best / 2P + 2C</td>
<td>200 MMbbl</td>
<td>486 MMbbl</td>
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<td></td>
<td></td>
<td>37 MMbbl</td>
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</tr>
<tr>
<td></td>
<td>High / 3P + 3C</td>
<td>437 MMbbl</td>
<td>1,117 MMbbl</td>
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<tr>
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<td></td>
<td>49 MMbbl</td>
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</tbody>
</table>

**Recoverable Volumes (MMbbl)**

- 1C: RPS CPR 2013 Resources
- 1C/1P: RPS CPR 2017 Reserves
- 2C: RPS CPR 2017 Resources
- 2C/2P: RPS CPR 2017 Resources
- 3C: RPS CPR 2017 Resources
- 3C/3P: RPS CPR 2017 Resources
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 staff (including CEO) onboard during operations to gather and interpret data, making decisions in real time.
205/21a-7 DST periods

- 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

Flow Scan Imager

Knuckles x2

Centraliser

Weight Bar 2

Telemetry

GR, CCL, P, T

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 uses electrical conductivity of water to distinguish between the presence of water and hydrocarbon.
- In addition to holdup, the sensor also records 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.

\[
Y_w = \frac{\sum t_w}{t} \quad N_{bc} = \frac{n_b}{t}
\]
- 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
Brine / formation water mixing

- 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.

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**Lancaster 205/21a-7 PLT Fluid density (TVDSS)**

- Pre-Flow
- Shut-in 1
- Natural Flow
  - Flow Rate 1
  - Flow Rate 2
  - Flow Rate 3
- Natural Flow PBU
  - Post-Flowing Period
  - Shut-in 2
- 1st Sampling Run
  - Shut-in 3
  - Stations only
- End of 48 hour PBU
  - Pre-Flowing Period
  - Shut-in 4
- ESP Max Flow
  - Flowing Period
  - Flow Rate 4
- 2nd Sampling Run
  - Shut-in 5
  - Stations only

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Hurricane | DEVEX May 2017
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.