The Lancaster Field
Progress in opening the UK’s Fractured Basement Play
Overview

• Geological setting and reservoir characteristics of the Lancaster Field
• Technical progress so far achieved in de-risking the Lancaster Field
• UK basement potential
• Could basement represent an infrastructure led opportunity?
Geological cross-section

- Similarities between uplifted basement reservoir at Lancaster and Clair

- Differences include thick Devonian sandstone present on Clair is absent from Lancaster
Lancaster exploration history

Shell Well (205/21-1a) 1974
Oil and fractures in basement core

Exploration well (205/21a-4) 2009
Oil outside structural closure
Oil to surface during test
Oil to surface during test which was compromised by mud system

Appraisal well (205/21a-4Z) 2010
Excellent well data
Test compromised by skin

Development well (205/21a-6) 2014
Highly successful test
High flow rates, high PI, low skin

Hurricane Exploration well 205/21a-4
Hurricane Appraisal well 205/21a-4Z
Hurricane Development well 205/21a-6
Shell well 205/21-1a

Top hole location  Top basement penetration
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
Fracture characteristics at different scales of measurement

Core plug

Borehole

Dynamic well test

3D seismic survey
Micro fractures
Joints

Example of a single joint picked from electrical and acoustic image logs
### Joint types

#### Fractured Basement

<table>
<thead>
<tr>
<th>Joints Type</th>
<th>Mean Dip/Strike</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Joints</td>
<td>Mean dip/strike: 76° N,SE</td>
</tr>
<tr>
<td>Cross Joints &gt; 60°</td>
<td>Mean dip/strike: 74.5° EW and a secondary trend NS</td>
</tr>
<tr>
<td>Cross Joints &gt; 20°, &lt; 60°</td>
<td>Mean dip/strike: 47.9° N,SE</td>
</tr>
<tr>
<td>Cross Joints &lt; 20°</td>
<td>Mean dip/strike: 14.7° N,SE and a minor trend NW,SE</td>
</tr>
<tr>
<td>Large Aperture Fractures</td>
<td>Mean dip/strike: 61.9° N,SE</td>
</tr>
</tbody>
</table>
Minimum fracture aperture measured from thin sections is 20 microns, which indicates high permeability and no irreducible water saturation.
### Fractured Basement

<table>
<thead>
<tr>
<th>Fracture Type</th>
<th>Fractured basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Joints</td>
<td>11</td>
</tr>
<tr>
<td>High Angle Cross Joints</td>
<td>12</td>
</tr>
<tr>
<td>Cross Joints</td>
<td>5</td>
</tr>
<tr>
<td>Low Angle Cross Joints</td>
<td>1</td>
</tr>
<tr>
<td>Large Fractures</td>
<td>3</td>
</tr>
</tbody>
</table>
Micro fractures and joints are present throughout the Fractured Basement and Fault Zones.

Fault Zones
- Represent pervasively fractured volumes of rock, that include preferentially enhanced aperture fractures and therefore improved reservoir characteristics. Fault Zones are associated with seismically-resolvable faults.

Fractured Basement
- The intervening host rock is pervasively fractured and also contributes to fluid flow.
Highly faulted structure
Faults tied to well interpretation

205/21a-4 and -4Z show good tie to Ant Tracking

Fault zones in 205/21a-6 well compared to Ant Tracking
Faults and Fault Zones
Faults and Fault Zones
Effective poroperm
Log data integration

Hurricane | PGC | 30 September 2015
MDT Sample point: 4695ft MD

MDT Sampling Response
A High Quality formation pressure was recorded at this station.
Log data integration

**P1: Flow Scanner general design**
Hurricane | Lancaster

Dynamic losses
HC-Arom/Alc
GCT: THC
FLAIR: THC
GCT: C1/ROP
Porosity
Fractures
ALD
AFR
Resistivity
Neutron/Density-PEF
GammaRay-Caliper
ROP
Basement porosity distribution

<table>
<thead>
<tr>
<th>Zone</th>
<th>Thickness md ft</th>
<th>PHIE (frac)</th>
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</thead>
<tbody>
<tr>
<td>FZ</td>
<td>1419.6</td>
<td>48.85%</td>
</tr>
<tr>
<td>FB</td>
<td>1486.5</td>
<td>51.15%</td>
</tr>
<tr>
<td>All</td>
<td>2906.1</td>
<td>100%</td>
</tr>
</tbody>
</table>

Hurricane | PGC | 30 September 2015
Basement productivity
Productivity

- Natural flow period
  - 35 psi drawdown
  - 5,300 STB/d
- ESP main flow period
  - 70 psi drawdown
  - 9,800 STB/d
- PI = 160 STB/d/psi
- Minimum connected volume >200 MMrb
  - No barriers
- Permeability thickness
  - 265,000 mD-m (860,000 mD-ft)
  - Average total system permeability = 265 mD
Tidal corrections to BHP

205/21a-6 Well Test Overview

Oil Production (STB/d)  Water Production (STB/d)  Downhole pressure (psig)
Tidal corrections to BHP

a. Entire well test operation highlighting early shut-in period
b. Raw downhole pressure recorded by lower gauge during this time period, displaying clear tidal effect
c. Seabed data recording tidal pressure during this time period
d. Downhole gauge data corrected for tidal effect, as used in well test analysis
205/21a-6 pressure build up analysis

Final PBU Derivative Match
Reservoir observations – model input

Static observations (petrophysics and geophysics)

• **Fault Zones**
  - High priority reservoir targets
  - ~40m average width
  - 50% of the GRV
  - 60% of the pore volume

• **Fractured Basement**
  - Intervening rock between Fault Zones
  - 50% of the GRV
  - 40% of the pore volume

Dynamic observations (well test analysis)

• High conductivity fractures (present in Fault Zones and Fractured Basement)
  - Provide primary production
  - Extremely high permeability
  - Incompressible
  - 33% of the pore volume

• Dynamically compressible fractures (present in Fault Zones and Fractured Basement)
  - Provide secondary production – similar to a conventional “matrix” response
  - Compressible
  - 67% of the pore volume
Full field simulation model

Total number of active cells ~80 million
750 faults currently in model
Technical de-risking
Technical de-risking operations

- Hurricane has drilled over 2 kilometres of Lewisian basement reservoir
- Basement drilling can be achieved with minimum bit changes and relatively fast ROP
  - Average ROP’s of 8 metres an hour are achieved in vertical and horizontal sections
  - 430 metres have been achieved in a single bit run
- A combination of brine with viscosifier provides an optimum drilling fluid accommodating loss management, hole cleaning and effective FE
Technical de-risking formation evaluation

• Confident fluid detection during drilling operations
• Acquired high quality LWD with minimal vibration
• Confident acquisition of SWC
• Multiple MDT pressures acquired
• (T2) in low porosity formation
• Use of PLT in open hole
• Established an effective methodology for DST acquisition
• Independently verified work flow for resource evaluation
Technical de-risking simulation

- Full field simulation at geological resolution enables history match of well test:
  - Cell size 10m x 10m x 30m in oil column
  - Accurate representation of interpreted Fault Zones (average width 40m)

- Enables testing of different uncertainty parameters
  - ODT depth
  - Aquifer strength
  - Length of wellbore contributing during test

- Further dynamic data acquisition planned to continue improving model

- Current model proves an excellent match for 205/21a-6 well test data
UK basement potential
Rona Ridge

Rockall Ridge (north)

Rockall Ridge (south)

Atlantic Margin
- Large, Silurian–Devonian granitic (intrabasinal) highs
- Adjacent to a prolific kitchen
- Evidence of oil in overlying sediments
Faulted margin of the Viking Graben
Mappable closure for de-risked volume
Adjacent to a prolific kitchen
Evidence of oil in overlying sediments
Basement an infrastructure led opportunity?

- Basement underlies much of the Central and Northern North Sea
- Global basement analogues indicate the CNS/NNS is a likely candidate for basement field development
- Basement exploration risk is low given the subsurface is well constrained by well data and 3D seismic
- The CNS/NNS is rich in infrastructure
- CNS/NNS basement prospectivity is poorly quantified by either industry or government and therefore represents an overlooked prospectivity for infrastructure led exploration
Summary

• The geological setting and reservoir characteristics of Lancaster are indicative of a working basement play in the West of Shetland

• Further de-risking of the play through long term production is required before the industry accepts this new play type as proven

• UK basement potential is currently unquantified, however its resource potential is of strategic significance and potentially a game changer for the UK oil industry