Integrated Approach for Fractured Basement Characterisation: The Lancaster Field, a Successful Case Study in the UK

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Objectives

• Provide an industry perspective – how a small company like Hurricane can successfully build confidence in an underexplored play (fractured basement, West of Shetland) to raise funds for development

• Demonstrate an integrated and practical approach to reservoir evaluation – adapting tools and methods to this unique reservoir

• Promote an appreciation for fractured basement, as it remains largely ignored even in forums such as these, despite the many producing fields around the world
Outline

1. Introduction to the Lancaster Field
2. Overview of fractured basement reservoir characteristics
3. Building the Lancaster static model
4. Dynamic modelling and uncertainty analysis
5. Future plans – the Lancaster Early Production System
The Lancaster Field
Hurricane Asset Locations

- Schiehallion
- Foinaven
- Strathmore
- Shetland Islands
- Orkney Islands
- Isle of Lewis
- Isle of Skye
- Aberdeen
- Warwick
- Lancaster
- Halix
- Solan
- Strathmore

Map showing the locations within the Shetland and Faroe-Shetland Basins.
Greater Lancaster Area (GLA)
Lancaster Cross-section Comparison with Clair
• Drilled by Shell in 1974 (205/21-1A)
• Hurricane discovered extensive oil column in 2009 (205/21a-4)
• Additional deep well (205/21a-7) refined OWC depth range
• Horizontal wells (205/21a-6 and 205/21a-7Z) demonstrate productivity of reservoir and are suspended for use as production wells

<table>
<thead>
<tr>
<th>Reserves</th>
<th>Contingent Resources</th>
<th>EUR (Reserves + Resources)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low / 1P + 1C</td>
<td>28 MMbbl</td>
<td>129 MMbbl</td>
</tr>
<tr>
<td>Best / 2P + 2C</td>
<td>37 MMbbl</td>
<td>486 MMbbl</td>
</tr>
<tr>
<td>High / 3P + 3C</td>
<td>49 MMbbl</td>
<td>1,117 MMbbl</td>
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</tbody>
</table>

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

Mobile oil swabbed
205/21-4
1,597m TVDSS
Fractured Basement Reservoirs
What is Fractured Basement?

Recovery dominated by fracture network

Recovery dominated by rock properties

Type I

Basement is a Type 1 Naturally Fractured Reservoir

Oil storage and mobility entirely depends on the fracture network

Definitions of Naturally Fractured Reservoirs, after Nelson 2001
What is Fractured Basement?

- Igneous or metamorphic rock underlying the sedimentary cover
- Lancaster is primarily tonalite and approximately 2.5 billion years old
  - Secondary dolerite (likely from segregation of initial melt) has little effect on fracture network poroperm properties
- An extensive geological history has formed a well-developed fracture network, enhancing pre-existing cooling joints
- Images from the Isle of Lewis, outcrop analogue
Lancaster Well 205/21a-4Z

Joints interpreted from image logs

Microfracturing visible on image log

PLT demonstrates open fractures contributing to flow
Dual porosity interpretation

- No intergranular matrix porosity exists within the granite
- Dual porosity response is caused by interaction of different scales of fractures within the reservoir
Fault Zones

• Tectonic activity causes seismic scale faults

• These faults have related damage zones, where poroperm characteristics are enhanced

• This means that fault zones are associated with enhanced reservoir properties, and are therefore primary reservoir targets
Conceptual Model

1. Fault Zone Facies
   Preferentially higher poroperm characteristics
   Seismically identifiable features
   Widths based on log data

2. Fractured Basement Facies
   Permeable, connected fractures present between Fault Zones
   Contributes to flow

Dolerite – not modelled
   Presence of dolerite cannot be predicted
   Appears to have little to no impact on poroperm characteristics so is not modelled

Bimodal facies model constructed:

Two broad families of fracture to consider
Both fracture sets exist pervasively throughout both facies:

Joints
Features cutting the borehole
Can be interpreted on image logs
Include regional joints, cross joints, shear fractures etc.
Provide primary permeability pathways

Microfractures
Pervasive small-scale fracturing present throughout the reservoir
Individual features that are hard to distinguish on image logs
Contributes to bulk porosity; logs cannot distinguish joints from microfractures
Acts like a matrix component of a dual porosity system in a dynamic sense
Static Model
Fault Interpretation

- Combination of manual fault interpretation and automated techniques (ANT Tracking) to define the fault network on the field.
- Good correlation between faults identified through ANT Tracking (at Top Basement) and log-interpreted Fault Zones (at depth) demonstrates generally near-vertical faults and the viability of the seismic fault interpretation.
Petrel Fault Modelling

740 modelled faults
Manual fault interpretation is time consuming but ensures robustness of fault model for simulation

Faults modelled vertically to avoid simulation errors
Distance to Fault property enables modelling of Fault Zones

Current fault model underpopulated in the east, apparent reduction in faulting is artificial
Model Resolution

10x10 metre areal grid cells enable accurate modelling and stochastic variation of Fault Zone widths.
Properties in the model are distributed deterministically, based on whether the cell is within a Fault Zone:

- Cells within Fault Zones are generally higher porosity and permeability.

No reliable data exists for distribution of properties away from well control using conventional algorithms – no depositional or layering model exists for this ancient igneous rock.

Each cell is attributed properties for the primary joint/ fracture network and the secondary microfractures (treated as ‘matrix’ in the model).

DFN work and REV’s used to constrain properties in geocellular grid.

<table>
<thead>
<tr>
<th>Facies</th>
<th>Fracture / Joint porosity</th>
<th>Microfracture (‘matrix’) porosity</th>
<th>Porosity average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault Zone</td>
<td>2.3%</td>
<td>2.9%</td>
<td>5.2%</td>
</tr>
<tr>
<td>Fractured Basement</td>
<td>0.7%</td>
<td>2.9%</td>
<td>3.6%</td>
</tr>
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<tr>
<td>Fault Zone</td>
<td>796 mD</td>
<td>0.06 mD</td>
<td>352 mD</td>
</tr>
<tr>
<td>Fractured Basement</td>
<td>796 mD</td>
<td>0.06 mD</td>
<td>155 mD</td>
</tr>
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</table>

Note that these are bulk average values for a representative elementary volume, including the tight rock and open fractures.
Dynamic Modelling & Uncertainty Analysis
Highly productive horizontal well tests

- **205/21a-6 (2014)**
  - 1km horizontal, openhole completion
  - Stable ESP rate 9,800 bopd constrained by equipment
  - P.I. 160 stb/d/psi

- **205/21a-7Z (2016)**
  - 1km horizontal, openhole completion
  - Stable ESP rate 15,372 bopd constrained by equipment
  - P.I. 147 stb/d/psi
  - Natural flow shows evidence that entire wellbore did not flow
Highly productive fractures

- 205/21a-7 (2016)
  - Inclined well
  - Flowed 11,000 bopd through two fractures (combined aperture ~9")
Calibration of grid properties with DFN

- DFN models used to match well test behaviour
- Calibration used to constrain geocellular grids
- Limitations of using geocellular grids include the ‘smearing’ of fracture properties – improvements are required
- Uncertainty analysis must appreciate the limitations of various approaches
Lancaster Simulation Model

Previous Eclipse Sector Model
4,000,000 cells

Equivalent results achieved in a fraction of the time, run in-house by Hurricane with support from Schlumberger

Current Full Field INTERSECT Model
79,552,000 grid cells
Impact of varying fracture porosity

Well test match insensitive to porosity variation

Forecast highly sensitive to porosity variation

Varying Average Porosity in Hurricane Quicklook Dual Porosity Model
Aquifer Presence

- Aquifer support is likely to be present
  - RPS, Axis and Schlumberger have all made this comment
  - Open fractures exist to the TD of 205/21a-4, they are highly likely to be present below this depth and must be filled with something

- The strength of this aquifer is currently unknown
  - Various scenarios have been modelled

- Simulation modelling is absolutely clear that the 205/21a-6 well test result cannot be matched using the expansion of oil within structural closure only
  - There must be significant pressure support from below structural closure – additional oil and/or a supportive aquifer
Impact of varying aquifer strength

- Varying the strength of the aquifer has little impact on the history match to the well test, but does significantly alter the single well forecast
Gas cap generation – Hurricane dual porosity model

2018 – no gas cap

2024 – low gas saturation in ‘matrix’ top two layers (~1%), higher gas saturation in fractures top layer only (50-100%)

2033 – 100% gas saturation in to layer fractures, increasing saturation in matrix deeper down (still <5%)
Early Production System
Lancaster EPS

- The EPS is a two-well tieback to provide long term production data and generate cashflow to accelerate and optimise the Full Field Development on Lancaster.
# Summary of EPS Oil Profiles

<table>
<thead>
<tr>
<th></th>
<th>Low Case EPS</th>
<th>Base Case EPS</th>
<th>High Case EPS</th>
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</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td>OWC: Structural closure only</td>
<td>Oil swab / 2C depth</td>
<td>Oil swab / 2C depth</td>
</tr>
<tr>
<td></td>
<td>(1,380m TVDSS)</td>
<td>(1,597m TVDSS)</td>
<td>(1,597m TVDSS)</td>
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<tr>
<td><strong>Porosity</strong></td>
<td>Low case (2.9% average)</td>
<td>Base case (4.4% average)</td>
<td>Base Case (4.4% average)</td>
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<tr>
<td><strong>Aquifer</strong></td>
<td>Passive/weaker</td>
<td>Passive/weaker</td>
<td>Active/stronger</td>
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<tr>
<td><strong>Field plateau (20,000 bopd)</strong></td>
<td>3 years</td>
<td>7 ½ years</td>
<td>12 ¼ years</td>
</tr>
<tr>
<td><strong>Cumulative oil production</strong></td>
<td>205/21a-6 22 MMbbl</td>
<td>205/21a-7 14 MMbbl</td>
<td>Lancaster 36 MMbbl</td>
</tr>
<tr>
<td></td>
<td>205/21a-6 22 MMbbl</td>
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Data gathering during production

- Working closely with the facilities engineers to ensure all data streams are suitable to understanding reservoir behaviour
- Main EPS goal is improving understanding of the reservoir to refine simulation model and optimise further development plans
Forward Planning

- What is the difference in modelled pressure between High and Low cases?
  - ~40 psi after 1 year
  - ~80 psi after 2 years
  - ~135 psi after 3 years

- When will we be comfortable that we are in a High vs. Low case for Lancaster?
Conclusions

• Fractured basement can be a viable reservoir
• Hurricane put a lot of time and effort into interpreting fractures, but incorporate many data sources and multiple disciplines to effectively model the dynamic behaviour of the reservoir
• The major flowing fractures on Lancaster appear to be related to cooling joints that have been reactivated many times
• A dual porosity effect provided by the interaction of microfractures and joints contributes to the complexity of the well test response
• A measured, integrated and practical approach to reservoir evaluation and modelling has enabled Hurricane to raise sufficient funds to being developing this field on a 100% basis
• The EPS will provide vital dynamic data to incorporate into Hurricane’s future modelling and allow a Full Field development plan to be created
• Hurricane’s integrated approach is successful!