Awakening the Giant: Hydraulic Fracturing Technology as an Enabler for Greater Clair

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Clair Field Overview

- 75 km west of Shetland
- 150m water depths
- UK’s Largest known resource
  - 220 km² (55,000 acres)
  - STOIIP c.7 billion barrels

- **Complex Field:**
  - 500-800m of interbedded, fluvial sediments
  - Diagenetically altered Devonian sandstones (2-20mD)
  - Highly variable reservoir quality (moderate-poor)
  - Low API oil (24-21)

... and naturally (or proppant!) fractured
Campaign of several appraisal phases dating back to 1977

Vertical wells only drilled in first 15 years

- Typically low PI associated with LCG matrix
- Exception to this in 1991 with 206/8-8 hitting highly fractured core of Clair

Drill High-Angle Wells!!

Fractures!!
High-Angle Appraisal Wells drilled to test Fracture Deliverability

- High PI (2 orders of magnitude greater than matrix)
- EWT conducted that led to Phase 1 development
Successful appraisal of Fracture Deliverability

- Led to 2 phases of concept development – both leading to field development

Greater Clair (green) tested dynamically and structurally interpreted as low likelihood of natural fracturing

- How to develop this resource??!!
What are we trying to develop?
Clair South LCG ~750mmstb

What are we trying to develop?

- Thickest column in Horst, 300+ m
- Column decreases going down-dip
Large Vertical Scale
What are we trying to develop?

1 out of 6 units!
Permeability Heterogeneity
What are we trying to develop?

Braided fluvial reservoirs
- Deposits of high, variable energy systems and poorly sorted, often immature, sediments
- Characterised by very variable petrophysical properties
- Fine-scale LCG matrix heterogeneity identified from a large variance in permeability for a given porosity

Very high Dykstra-Parsons Heterogeneity Coefficients of 0.8 - 0.9 are calculated for all flow units, including the high NTG units (V/III), which indicate significant heterogeneity is present almost homogeneously.
Horizontal permeability in Unit V relatively homogeneous at an inter-well scale

- Dynamic KH ~5,000 mD•ft repeatable across multiple well tests

- Static horizontal core ~20 mD average x 250 ft = 5,000 mD•ft

No problems horizontally! Vertically??
Vertical Permeability

Vertical permeability in Unit V relatively heterogeneous at a local scale

- Static geometric average $K_v < 1 \text{mD}$
- Low $K_v/K_h \sim 0.005$

Need for fractures vertically!
Hydraulic Fracturing Opportunity!

Effectiveness of Remedial Operations - Change in PI

- Acidisation
- Fracking

Matrix Only

Uplift in Flow Capacity at 100hrs of 60%
- Pre-Frac => 5,800mD.ft
- Post-Frac => 9,500mD.ft

Appraisal data demonstrates mechanism to get through low Kv/Kh and contact full range of permeability
How are we trying to develop it?
How to Prop Frac a Waterflood?
How are we trying to develop it?

Analogues

- Use of horizontal wells and multistage fracture designs key to developing Nuqsut reservoir and Oooguruk Field
- Successfully waterflooded for more than 5 years without breakthrough
- Mechanical diversion provided significant benefits relative to dynamic diversion
Reservoir Development Concepts
How are we trying to develop it?

Objectives
Investigate, understand & appraise a range of Reservoir Development Concepts (well count, target frac height, #fracs per well, WF direction, ...)

Concept still evolving – reflects view at Concept Select
Reservoir Development Concepts
How are we trying to develop it?

Concept Select Base Case

- 23 fracced wells in ~750mmstb STOIIP
- Horizontal wells in combination with multi-stage hydraulic fracturing a significant value enhancement to the project:
  - Considerable acceleration in rate (+100%)
  - Uplift in UR of 50% from unfracced

 Risked Prop Frac Height?
**Prop Frac Height – Geomech Basis**

*How are we trying to develop it?*

- Dec ‘16 – Initial StimPlan modelling
- June ‘17 – Mudstone concept identified
  - Development of mudstone facies scheme
  - Hunt for preserved samples containing mudstone, represervation of select samples
- Sept ‘17 – Executing geomech lab programme
  - Integration of historical CEP data, geomech database development
  - Initial StimPlan modelling
- Jan ‘18
  - Geological characterisation – explore ideas around mudstone clustering and inter-well correlation
  - Ongoing geomechanical data acquisition
- April ‘18
  - XRD analysis commenced
  - Finescale StimPlan modelling started
  - Hard, tight sandstones integrated into stress model
- May ‘18
  - Intern to characterise LCG mudstones
  - Acquisition of compatibility / conductivity testing
- July ‘18
  - Integration of compatibility / conductivity testing into finescale StimPlan model
  - Output of Reference, Downside, Upside fracture descriptions (by initiation point) to Nexus LGR

**Unit V** 600ft  **Unit VI** 600ft

Integration => more accurate description of subsurface

300ft  100ft?
Benchmarking
How are we trying to develop it?

Clair Phase 1 – Fold of Increase, Waterflood
Four stage development well due to be fracced summer 2019

Khazzan – propped height

SPE/Russia – FOI, Waterflood
Summary

What are we trying to develop?
• The Lower Clair Group is thought to be unfractured in the Clair South development area, resulting in low average effective permeabilities (3-20mD)

How are we trying to develop it?
• 23 fracced wells in ~750mmstb STOIIP
• Horizontal wells in combination with multi-stage hydraulic fracturing

Reservoir Performance Prediction
Hydraulic fracturing is a significant value enhancement to the project:
• Considerable acceleration in early rate (+100%)
• Uplift in UR of 50% from unfracced
• Benchmarking: Clair (1992, 2019), Khazzan, Alaska, Russia

What are the uncertainties?
• Geological controls on propped frac growth due to stress contrasts (finescale mudstones, differential depletion) and leak-off (natural fractures, faults, fracture complexity)
• Subsurface reservoir outcome (STOIIP, relperm, KH)
• SIMOPS (deck space, weather windows, logistics, POB)
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- **BP Colleagues**