Enabling Geological Scale Dynamic Modelling of a Fractured Basement Reservoir using a high-Resolution Simulator - A UKCS Case Study

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Abstract

‘New Kids on the Block’ theme, using new ideas and new technology to help unlock developments

Lancaster is a substantial (207 MMboe 2C) fractured basement field West of Shetland. As a Type 1 Naturally Fractured Reservoir, hydrocarbon potential is provided entirely by the fracture network. This network is a product of initial cooling joints and subsequent tectonic events occurring throughout the 2.5 billion year history of this Precambrian rock. This has generated an exceptionally well connected fracture network, further enhanced by fluid flow, producing a potentially world class hydrocarbon reservoir.

Two reservoir facies are identified: (1) Fault Zones, seismically resolvable features with generally enhanced aperture fractures and increased porosity/permeability; and (2) Fractured Basement, pervasively fractured background host rock providing flow and interconnectivity between Fault Zones.

The strong permeability contrasts present cause Conventional Reservoir Simulators (CRS) to struggle solving and converging simulations. Fine scale gridding is also required to accurately depict the fault and fracture network. Previous Lancaster CRS simulation performance was poor, requiring coarsening to complete the runs in practical timeframes.

This paper describes the implementation of a High-Resolution Simulator (HRS) to build a dynamic model of Lancaster by matching data acquired in the highly successful 2014 Lancaster Horizontal well test using fine-scale (75-million cells) in the model. This has already proved invaluable in forecasting production, assessing the impact of uncertainties, and improving technical confidence in the dynamic reservoir properties while preserving practical runtimes of a few hours using a 16-core workstation.

This represents a step change in Hurricane’s evaluation of its basement assets, further de-risking and unlocking the fractured basement play for the UKCS.
Introduction
Hurricane

- Founded by Dr. Robert Trice in 2004 to explore the UKCS Fractured Basement Play

- Currently holds 100% of 3 licences West of Shetland

- Two large Fractured Basement discoveries:
  - Lancaster – 207 MMboe 2C *
  - Whirlwind – 205 MMboe 2C *

* Hurricane CPR, RPS 2013
What is Fractured Basement?

- Crystalline rock exhibiting fractures associated with cooling, tectonic activity, epithermal and hydrothermal processes
- Often associated with buried hills or uplifted ridges
What is Fractured Basement?

- Basement is a Type 1 Naturally Fractured Reservoir
- Oil storage and mobility entirely depends on the fracture network
Why Target Fractured Basement?

- Basement works around the world

Global basement activity

Venezuela

Vietnam

Yemen
The Lancaster Field
Lancaster

- Uplifted basement ridge
- Crest ~1km TVDss
- Water depth ~150m
- Juxtaposed source rock
- Prolific kitchen to the north, additional kitchen to the south
Lancaster

- Originally drilled by Shell in 1974
- Hurricane have appraised with three wells since 2009, demonstrating:
  - Oil below mapped structural closure
  - Seismically-interpreted fault network is confirmed by well penetrations
Lithology

Tonalite (2.3-2.4 Ba)
- Plutonic rock, quartz rich granite
- 80-95% of GRV based on well data

Dolerite (2.3 Ba)
- Dark plutonic rock, likely part of initial melt rather than later intrusion
- 5-20% of GRV based on well data

Fractures define reservoir properties, not rock type
Fault Zones represent areas of damaged rock, associated with seismically-resolvable faults, that include more large aperture fractures and therefore improved reservoir characteristics.

Fractured Basement: The intervening host rock between Fault Zones is pervasively fractured and contributes to flow.

Regional joints: High frequency regional joint set with preferred NE-SW orientation and high permeability, crossing Fault Zones and Fractured Basement.

Shear fractures: Seismic and sub-seismic faults displaying clear shear offset.

Cross joints: Variable-orientation, permeable cross joints contribute to flow within Fault Zones and Fractured Basement and provide additional lateral connectivity.
Modelling Challenges

- Confident identification of the fractures that are contributing to fluid flow (hydrodynamic fractures)

- Accurate characterisation of the hydrodynamic fracture network

- Fine gridding to capture heterogeneity of the hydrodynamic fracture network

- Practical methodology to accommodate high contrasts in poroperm and allow for anisotropy within a continuum model

- Computer and software power to simulate a full field reservoir model which needs to accommodate over 450 faults as permeability “high ways”
Static Modelling
Seismic Fault Interpretation

• Fault modelling is key to understanding major fluid flow pathways

Automated techniques

Manual fault interpretation

Comparisons with analogue outcrop locations
Lancaster Fault Map Evolution

- New seismic techniques and increased well control have allowed fault map to be continually improved
Fault Ties to Wells

- Good tie between seismic interpretation at top basement with well-interpreted fault zones
- Indicates faults are vertical or near-vertical
- Accurate prediction for future well placement
1. Fault model (vertical faults)
2. Distance from fault property
3. Base Case facies model (40m wide fault zones)
Dynamic Modelling
Historical DFN Modelling

- Discrete Fracture Network (DFN) modelling is designed to model the behaviour of individual fractures.
- A successful match to the 205/21a-4z PLT was achieved.
- However, DFN models are not designed for production forecasting.
Historical Sector Modelling

- Reasonable results achieved, but:
  - Long run times
  - Requirement to coarsen grid
  - Boundary edge effects

- 4km x 4km sector model constructed to run in ECLIPSE
- Testing scenarios from 2013 Competent Persons Report
High-Resolution Simulator

• Dynamic modelling efforts provided valuable insight into properties of the field, indicating:
  - Highly connected hydrodynamic fracture network
  - Likelihood of supportive aquifer
  - Support for oil outside structural closure

• However, neither the sector or DFN model are suitable tools for full field simulation

• Therefore, a new solution was required that would allow practical simulation of the Lancaster Field

• INTERSECT, by Schlumberger, was selected for testing
**Improved Run Time**

- On a comparable dual core machine, INTERSECT improves run time of sector model from 65 to 3 hours.

**INTERSECT allows better scalability with more processor cores**

- 16 core desktop workstation runs sector model in 20 minutes (no change to results)
Benefits of INTERSECT

• High resolution model
  - Fine scale to model geological complexity of fracture network
  - No need to unrealistically upscale

• Unstructured grid
  - Enables more complex fault / fracture patterns to be modelled

• Faster run times
  - Allows many more simulation cases to be run in a realistic timeframe
  - Uncertainty analysis on many factors to increase confidence in range of outcomes
  - Opportunity for full field simulation rather than limited sector model
Dynamic Modelling Process

1. Historic DFN and sector modelling
2. New dynamic reservoir data (205/21a-6)
3. INTERSECT sector model test runs vs. ECLIPSE
4. First pass full field scenario modelling
5. Further uncertainty analysis
6. Full field development planning
205/21a-6 – 2014 horizontal well results
• In 2014, Hurricane drilled the first 1km horizontal well targeting fractured basement on the UKCS

• This highly successful well confirmed commercial rates from the basement

• Provided new dynamic data for simulation modelling
205/21a-6 – a high quality dynamic dataset

- Max stabilised flow rates:
  - 5,300 bopd (natural)
  - 9,800 bopd (ESP)
  - Both constrained by surface equipment
- No formation water encountered
- World class P.I.
  - 160 stb/d/psi
- Minimal skin
- Excellent quality dynamic dataset
Currently simulating single well in full field model

Ability to increase to simulation of full development plan
First Pass Simulation Well Test Match

- Excellent well test match achieved with a range of scenarios
- No barriers observed
- Extremely well connected system
Implications from First Pass Simulation Results

- Plateau response, no immediate decline
- Does not require 2km horizontal well to achieve commercial rates
- Potential for reduced well count in Full Field development
Conclusions

• Acquiring a high quality dynamic dataset from the 2014 horizontal well has improved Hurricane’s understanding of the behaviour of the fractured basement reservoir

• Utilising an innovative high-resolution simulator (INTERSECT) has been key to modelling this challenging reservoir

• This work represents a step-change in Hurricane’s ability to continue unlocking value in this emerging play of the UKCS

• Work is ongoing to feed into Full Field development planning
  - Presentation this afternoon by Neil Platt, COO, on hub development concepts