OVERCOMING CHALLENGES OF LOGGING AND FORMATION EVALUATION IN A DEPLETED HPHT RESERVOIR ENVIRONMENT

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Reserves: Our use of the term “reserves” in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term “resources” in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the definitions of the Society of Petroleum Engineers.

Organic: Our use of the term “organic” includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.

Resources plays: Our use of the term “resources plays” refers to tight, shale and coal bed methane oil and gas acreage.

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DATA ACQUISITIONS

Field/Well Objectives
Reservoir Management
Assist Well Execution:
- Drilling performance
- Perforation Strategy

Requirements

Seismic survey
During Drilling:
- Formation Evaluation/ Integrity logging
- Pressure indication (Mud weight/perf.)

Data Collections
During Production:
- THP
- CH logging (saturation/flow)

Formation properties/ environmental condition
Well condition/ profile
Cost

Limitations

E&A
Development
Production
Abandon
- Shell (Operator), partnership: ExxonMobil, BP
- Discovered 1988, first production 2000
- 90m water depth, Gas/condensate HPHT fields (Heather, Fulmar, Pentland)
- Primary reservoir: Fulmar sandstone
  - Initial pressure 15400 psi @16900ft
  - Reservoir temperature 182°C /360°F
- 7 Development wells 1998-2003
MATURE RESERVOIR TARGET (FULMAR)

Well Objective:
- Upper and Lower Fulmar. The Upper Fulmar is depleted and pose risk of sand production
- Drilling option (Drill in Liner Vs open hole drilling) is dependent on sand presence above Fulmar (virgin condition) and its exposure to Fulmar sand (depleted).
- Minimise risk in drilling the overburden; narrow drilling window in Hod Mass Flow. Possible inflow from fracture. Use Managed Pressure Drilling
- Ensure casing integrity and sufficient cement bond as barrier to reservoir (well Integrity)

Well Risks:
- Borehole instability in the Kimmeridge Fm.
- Gas kicks in the Kimmeridge Fm. or Heather Fm.
- Borehole collapse and stuck BHA in the overburden
- Low formation strength in the chalk (weak zones, open fractures)
- Differential sticking in the Chalk Group
- Isolation of Hod Mass Flows
Logging Objective:

- Identification of fluid type in the overburden
- Select Perforation interval: Fulmar porosity and cement quality across production liner
- Overburden + Fulmar Formation Evaluation: Net-To-Gross, Porosity, Water Saturation
- Confirm the TOC, cement quality across production casing and ID across packer setting depth

<table>
<thead>
<tr>
<th>Hole size</th>
<th>MWD/LWD</th>
<th>Wireline</th>
</tr>
</thead>
<tbody>
<tr>
<td>20&quot;</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>16&quot;</td>
<td>RES/GR/DIR</td>
<td>N/A</td>
</tr>
</tbody>
</table>
| 12 ¼"     | RES/GR/SONIC/DEN/NEU/DIR | 1A: Borehole Imaging  
1B: Pressure/Sampling  
1C: GR/CCL/CBL/VDL
10" cased hole:  
GR/CCL/CBL/VDL  
Ultrasonic cement tool |
| 8 ½"      | RES/GR/SONIC/DEN/NEU/DIR | 5" cased hole:  
GR/CCL/CBL/VDL  
Ultrasonic cement tool |
Vendor selection was based on cost competitiveness vs. capability/performance. LWD & Wireline vendors were different for the first two wells.

**LWD**
- GR/RES/DEN/NEU/SON rating of 350°F maximum
- Power: battery HSE, solid limitation, position in the tool string
- Real time: 2 samples/ft minimum
- Contractual obligation readiness if tool is pushed beyond spec

**Wireline**
- GR/RES/DEN/NEU/SON rating of 500°F maximum
- Tools survival is limited by exposure to heat, power the tools close to target.
- Capstan installation
- Pressure/sampling: Depth control, stationary/sampling time. Temperature limitation of optical analyser ~350°F
PHASE II DEVELOPMENT
Overburden: GR-RES-(DEN-NEU-SON) obtained. Wireline run in Chalk Gp experienced stick-slip at Run 1. Subsequent run (pressure/samples) was cancelled. Note: () obtained in Chalk Gp.

Reservoir section was drilled using Drill in Liner and Formation evaluation performed on cased hole (CH) wireline data.

- Maximum measured temperature was 356°F (almost equal to estimated formation temperature).
- Applied sonic porosity and twinned well for evaluation.
**POROSITY LOG**

Density
Working but run out of spec

Sonic
Used for porosity calculation

**Twin (offset) well**
D-N porosity (left) Vs Compressional sonic (left)

**Well 1**

[Image of the graph showing porosity and sonic data with markers at specific points labeled 1, 2, and 3.]
The ultrasonic tool was working but run outside the tool specification (designed for water environment but dips into mud accumulation at the bottom of the hole ~ 15.4 ppg)
Tool managed to deliver several good quality intervals after a few log passes
WELL # 1 LESSON LEARNT

Operational:

- (LWD) **Ensure good Real time data quality**, in case Recorded mode is damaged (burnt, Left In Hole or run out of memory due to unplanned delays)
- (LWD) **Manage memory space**, start recording closer to interval of interest
- (WL) **Minimise electronics temperature**, power up closer to interval of interest

Evaluation:

- Maximise possibility of good cement data & evaluation in OBM environment (prior to displacement to water). Also, compare the cement evaluation qualitatively with good quality CH sonic interval
- **Selection of sonic porosity parameter is assisted by the twin well evaluation**. Evaluate uncertainty based on porosity changes as a function of depletion
- **Water Saturation profile is evaluated based on scenarios (current and future application)**: consider alternative cases of shallower FWL, or possibility of water influx through zones of higher permeability when water is produced
Overburden: GR-RES-(SON) obtained. Note: () obtained in Chalk Gp

Reservoir section was evaluated using:
- LWD Tools for formation evaluation. Maximum measured temperature was 296°F (est. 59°F cooling effect)
- CH WL tools for cement evaluation lowest rating is 350°F. Maximum measured temperature was 344°F (est. 11°F cooling effect)

Lesson Learnt:

LWD sonic formation signal is masked by environmental effects (collar arrival). Solution is to reprocess using CH wireline as reference
SONIC ACQUISITION

Well 1 CH WL

Well 2 Processed LWD OH (Red) & CH WL (blue)

LWD DTCO

WL CH DTCO

140 USPF 40

LWD Reprocessed

140 USPF 40
WELL # 3 – NFE PROSPECT

- **Overburden**: GR-RES-(SON) obtained. Note: () obtained in Chalk Gp

- **Reservoir section is logged using LWD trip after TD**
  - While drilling, the maximum measured temperature was 360°F (est. 13 deg F cooling effect). No LWD log obtained while drilling.
  - Attempted wireline but unable to run in the hole. Measured temperature was 340°F just after 10” csg shoe (~2000 ft vertical depth to TD, est. 15 deg cooling effect).

- Acquired data on dedicated wiper trip with LWD one week after TD – maximum measured temperature was 315°F (est. 55 deg F cooling effect).
WELL # 3 – NFE PROSPECT

Logging at Reservoir level
- GR, Resistivity, Sonic, Density, Neutron, Cement log

Perforation strategy (Porosity cut-off and cement quality)

Formation evaluation (drainage volume).

Estimate productivity (includes uncertainty)

Reservoir model calibration

Overburden: GR-RES-(SON) obtained. Note: () obtained in Chalk Gp

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WELL # 3 LESSON LEARNT

Operational:

- **Temperature can rise while drilling in a deviated hole** (e.g. due to friction). If expected temperature is at the limit of LWD operating envelope, then best to log by LWD wiper trip or on wireline.

Evaluation:

- **Invasion effects when logging during wiper trip can be expected**, evaluation uncertainty is increased at a step out area with limited reservoir property information.

- **Properties derived from logs and samples may vary significantly from those expected.** NFE prospect is some distance from and deeper than the main block.
  - Collect and use regional analogues to develop scenarios.
SUMMARY

✓ Job Preparation accounts for 50% success, if not more!

✓ Risk v Reward:
  ✓ Have contingency/decision tree prepared
  ✓ Be flexible and ready to implement/execute changes to plan at short notice as driven by risk

✓ Establish and maintain line of communication between subsurface, drilling and contractors.
Q&A