Reservoir Surveillance and Successful Infill Well Delivery in a Mature Asset

Adrian Zett, Mary Ward, Chris Pearse, Dawn Houliston - BP

Parijat Mukerji - Schlumberger

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Outline

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Production Petrophysics plays a key role in reservoir surveillance and field management. This is particularly true for mature assets which present several challenges related to fluid contact movement, connectivity of reservoir layers and well productivity. Identification of infill targets therefore requires an integration of all subsurface data. This paper presents a case study from a mature North Sea field where cased hole surveillance helped minimize risks in a high cost infill project.

The Machar field, located in the UK Central North Sea is a fractured Cretaceous chalk and Palaeocene sandstone oil reservoir.

Machar is a subsea field development and therefore petrophysical surveillance has been restricted due to limited well access and logistical challenges. During the infill drilling, it was therefore decided to use the opportunity and capture cased hole saturation and production logs in the existing wells. This data enabled the asset teams to understand fluid displacement mechanisms and upon integration with LWD and other logs provided the basis for the side track strategy. In particular, location of the imbibition flood front, fracture conduits and differentiation between formation and injection water were critical in the delivery of a successful producer.

Two wells have been drilled on the eastern flank, one in 2008 and another in 2010. Baseline petrophysical surveillance was part of the data acquisition program in both wells. The initial objective was to use such data in Time Lapse mode with later surveillance. However, in-depth work identified immediate use when integrating with LWD data.
Field Background

- **Location:** Central North Sea, 150 miles east of Aberdeen
- **Block number 23/26a (100% BP)**
- **Water Depth:** 95m
- **Discovered:** 1976
- **Phased Development:**
  - Phase I – Natural Depletion, 1994
  - Phase II – Water Injection Pilot, 1995
  - Phase III – Field Development, 1998
- **Gas Lift commenced 2003**
- **Subsea production manifold:** 16” production flowline, 12” injection line 35km to Central Processing Facility
(“Ben” Machar) Reservoir Summary

Ben Nevis height
-1344m (tvdss)

- Salt diapir structure with Palaeocene Sand and Cretaceous Chalk reservoirs
- 7 current producers and 3 water injectors
- Large variations in reservoir thickness
- High level of reservoir uncertainty
- Main production from fractured chalk
- Initial pressure close to bubble point
- Pressure support crucial
- Understanding fracture pathways critical
- 845m of core taken in reservoir section
Well Location

Mapping from 2007 PSDM

TOP CHALK DEPTH
Metres TVDss
Surveillance History

- Producer completion
- Injctor completion
- Shut-in wells

- 12Z(W125ST)
- 18Z(W181)
- 18Y(W121)
- 20Y(W121)
- 19Z(W181)
- 19Y(W121)
- 13Z(W126)
- 13Z(W182)
- 20Y(W121)
- 19Z(W181)

- A04Z(W125)
- RST/PLT-1999; RST-2009
- RPM-2004
- RPM-2002
- RPM-2000

- A07(W124)
- A09Z(W128)
- A01(W120)
- A04Z(W125)
- A08(W127)
- A02(W123)

- TOP CHALK DEPTH
- Metres TVDss

- Block 23/26A
- Mapping from PSDM finalised 2007

- OWP @ top Forties
- OWC @ top Chalk
- RST Baseline-2010
- RPM/PLT-2002
- RPM-PDT–1995, 96
- RPM/PLT-2002
- RPM/PLT-2002
- A01(W120)
- TDT-1994

- TOP CHALK DEPTH
- Metres TVDss
Uncertainty & Challenges

• Well access
  • Subsea completion with long intervals for logging

• Interpretation Uncertainty
  • Water salinity variation
  • Changes in Porosity
  • Presence of Fracture Conduits
  • Cement Quality
  • Lithology Variations

Objectives of Intervention

- Acquire baseline saturation log through casing (Reservoir Saturation Tool in Pulsed Neutron Capture & Spectroscopy mode)
Logging Summary

Log up in sigma mode at 1800 ft/hr from 3045m to 2300m MDBRT

CO passes – 3 passes over each of the following intervals at 3ft/min:
3045m to 2985m MDBRT
2800m to 2700m MDBRT
2650m to 2560m MDBRT

<table>
<thead>
<tr>
<th>Well Information</th>
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<tbody>
<tr>
<td>Bit Size</td>
<td>8 1/2&quot;</td>
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<tr>
<td>Casing Size</td>
<td>5.5&quot;</td>
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<tr>
<td>Casing Internal Diameter</td>
<td>4.892</td>
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<tr>
<td>Casing Weight</td>
<td>17 lb/ft</td>
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<tr>
<td>Matrix Type</td>
<td>Mixture sandstone-limestone derived from spectral lithology evaluation</td>
</tr>
</tbody>
</table>
Variable Salinity Challenges

- GR (gapi)
- Porosity (v/v)
- Sigma (ohm-m)
- Resistivity (v/v)
- Sw Resistivity (v/v)
- Sw Sigma (v/v)

Depth (ft):
- 540
- 560
- 580
- 600
- 620
- 640
- 660
- 680
- 700

Sw uncertainty:
- 35 ppk
- 210 ppk

Oil and water levels:
- 50.2
- 5.75
- 10.15
Resistivity-Sigma Numerical Method

At each depth, search ppm such that $||Sw_{\text{Res}} - Sw_{\text{Sig}}||^2$ is minimum.

The numerical method uses a minimization algorithm to search for ppm that gives $Sw_{\text{Res}} \approx Sw_{\text{Sig}}$ at each depth.
Resistivity-Sigma Application (Well: ME2)

\[ Sw = 1 \]
\[ Rt = \frac{a \cdot Rw}{d_m} \]
\[ \Sigma_{log} = (1 - \phi) \cdot \Sigma_m + \phi \cdot \Sigma_w \]

\[ Sw = 0, \quad Rt = \infty \]
\[ \Sigma_{log} = (1 - \phi) \cdot \Sigma_m + \phi \cdot \Sigma_{ic} \]
Pulsed Neutron Evaluation (Well: ME2)
Spectral Lithology Evaluation

Enhanced Spectral Standards

Gamma-Ray Spectra

Elemental Yields

Dry Weight % Elements

Si, Ca, Fe, S, Ti, Gd

Clay, Carbonate, Anhydrite, QFM (Quartz, Feldspar, Mica)
Imbibition Height (Well: ME)

Synthetic Sigma using only formation water helps identifying the imbibition contact (where it departs from the measured base Sigma)

Saturation Height Function also points towards the same imbibition contact
Outcome

Rebuilding of the reservoir model as imbibed zones not expected initially

Impact on perforation strategy for future wells

Role of fractures in injection water movement

Need to understand matrix variations while evaluating pulsed neutron logs

Spectrolith processing provided key inputs for formation evaluation

Baseline Cased Hole Saturation complements the Formation Evaluation data acquired in Open Hole providing valuable information with regards to:
- imbibed zones
- nature of fluid/salinity profile
Future work and Recommendations

- Surveillance logging (Pulsed Neutron Capture & Spectroscopy) in Machar East or any new well in the field to help characterize and capture changes

- **A dual baseline** should be considered to:
  - Ensure continuity between OH data and subsequent time lapse data.
  - This should reflect changes in porosity due to acid frac stimulation as well as real changes in saturation due to fluid displacement processes.
  - First baseline immediately after setting the casing and another after acid frac.
References


Zett A, Mukerji P, 2008, Subsea Logging and Intervention – Challenges and Solutions on Machar Field, 14th SPE ICoTA European Well Intervention Round Table, Aberdeen, Scotland.

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