The value of integrated borehole image analysis to refine geological models: an example from the Greater Burgan Field, Kuwait

Boris Kostic\textsuperscript{1}, Bashar Al-Enzi\textsuperscript{2}, J.M. Filak\textsuperscript{2}, Fatma Al-Mahmeed\textsuperscript{2} and Nicolas Foote\textsuperscript{1}

\textsuperscript{1}Badley Ashton & Associates
\textsuperscript{2}Kuwait Oil Company
## Introduction and aims

- Informally, the Burgan Formation is subdivided into 4 reservoir zones:
  - 3SU - wave-influenced delta, shoreface sandstones and mudrocks
  - 3SM - tide-influenced channel sandstones
  - 3SL - wave/tide-influenced delta heterolithics
  - 4S - fluvial channel sandstones

- The Wara Formation comprises marine to brackish bay mudrocks and sandstones, incised by valley fill sandstones
Introduction and aims

• The depositional interpretations of the Burgan and Wara Formations are based on
  • core sedimentology
  • biostratigraphy
  • chemostratigraphy
  • conventional wireline logs

• In addition, 3 wells have been selected for a pilot borehole image study to
  • assess the resolution of the image logs relative to core data and wireline logs
  • provide key information on directional data (palaeoflow)

• Using examples from the Burgan and Wara Formations, the aim of this presentation is to show the value of integrated core and image analysis for refined geological modelling
Dataset

- Total of >35,000ft of core from 123 wells
- 3 imaged wells - full FMI coverage
  - Well A: 238ft of core (Upper Burgan)
  - Well C: 184ft of core (Wara)
- Good quality core (>4" slabbed core width)
- Image quality reduced over mud-prone intervals as a result of borehole damage
  - generally allows for confident, high-resolution image assessment
Image workflow

1. Data review
   • Data review and loading
   • Image processing

2. Data analysis and interpretation
   • Image-to-core calibration
   • Manual dip picking
   • Structural dip evaluation and correction
   • Classification of image facies
   • Palaeoflow assessment
   • Sedimentological and stratigraphic interpretation
Image facies

Bed to sub-bed scale characterisation of image logs, calibrated against core and wireline logs

**Cross-bedded sandstone**

**BHI Character:** Regularly laminated sandstones with persistently high-angle dip magnitudes (typically >10°) and locally upward-steepening trends. Within individual bedsets azimuths are consistent.

**Log Character:** Low to moderate GR response with moderate to wide sand-type neutron/density separation.

**Core Lithotypes:** Analogous to high-angle cross-stratified sandstones, although these may not always be accurately recorded in core due to core slabbing not carried out parallel to maximum dip. As a result this may also encompass laminated and massive sandstones.
Image facies

Selected heterolithic example - note different resolution of heterolithics in image (cm to dm-scale) and core (mm to cm-scale)

**BHI Character:** Dm-scale alternations of sandstones and mudrocks appearing as contrasting conductive and resistive laminae. Typically characterised by low-angle dips (<10°), rare moderate dip magnitudes (c. 10-25°) after structural correction.

**Log Character:** Moderate to high GR response with moderate to wide mud-type neutron/density separation. Mud-dominated heterolithics display slightly higher GR and wider mud-type neutron/density values than sand-dominated heterolithics.

**Core Lithotypes:** These are represented in core by laminated sand and mud-dominated heterolithics, but may also include dm-thick interbeds of laminated or even massive sandstones. Laminations observed in core are typically mm to cm-scale, while they appear thicker (generally cm to dm-scale) in the image due to the lower resolution of the resistivity tool.
Value of image data for refined depositional interpretations

<table>
<thead>
<tr>
<th>Formation</th>
<th>Image-based Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. Depth</td>
<td>FMI</td>
</tr>
<tr>
<td>Gamma ray/Caliper</td>
<td>Neutron/Density</td>
</tr>
<tr>
<td>Channel-fill sandbody</td>
<td>Sequence Boundary</td>
</tr>
<tr>
<td>Marine mud-prone succession</td>
<td>Marine setting</td>
</tr>
</tbody>
</table>

Image interpretation supported by core sedimentology

---

Paper 187635 • The value of borehole image analysis to refine geological models: an example from the Greater Burgan Field, Kuwait • Boris Kostic
Palaeoflow data and its value to assess channel sinuosity

- **Burgan 4S**: dominance of high-angle cross-bedded sandstones stacked within fluvial channels
- Dip magnitudes vary between 10-25°
- Majority of dip azimuths towards NE/E
- Stronger easterly direction in Well C
- Bedset boundaries generally aligned with sandstone dips
- SE/E direction towards 4S top in all three wells - *gross directional change of the 4S channel system prior to its abandonment?*

- Dominance of downstream migrating bedforms within low-sinuosity channels
Palaeoflow data and its value to assess channel sinuosity

- **Burgan 3SM**: high-angle cross-bedded sandstones stacked within tidally-influenced channels
- Dip magnitudes vary between 10-25°
- Directional spread in the order of 60-90°, dominant N to E orientation
- Dipset boundaries locally oriented oblique to surrounding sandstone packages - *lateral accretion surfaces*?

- Some lateral/point bar development and higher channel sinuosity?
Conclusions

• Resistivity image logs provide a detailed and cost-effective tool for sedimentological and structural evaluations, in particular, when calibrated against core
  • Recognising the limit of image resolution
  • Systematically classifying meaningful image facies
  • Improving the understanding of depositional and structural reservoir heterogeneity

• The geological understanding of the origin of sandstone dips is crucial for the reliable assessment of sandbody orientations, channel sinuosity and ultimately fluid flow behaviour
  • Greater variability of bar types in the middle Burgan (3SM) channel sandbodies compared to the lower Burgan (4S)
  • Potentially implies presence of higher sinuosity channels and a more complex reservoir architecture and fluid flow pathways in the 3SM reservoir
  • Requires confirmation from larger image well dataset
Acknowledgements / Thank You / Questions

The authors would like to thank KOC for permission to publish this work, Kuwait Institute for Scientific Research (KISR), in particular Dr. A. Al-Hashem, and Middle East Oilfield Services (MEOFS) for their support with this study.