High Resolution Field-based Studies of Hydrodynamics – Examples from the North Sea

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Location & Regional Context

Regional overpressure map based on 100’s wells and 1000’s data points
Huntington Oil Field - Summary

Huntington is a light oil field located in Block UK 22/14b in the UK Central North Sea.

• It is located approximately 205 km east of Aberdeen, in a water depth of about 298.5 ft.

The Huntington field was discovered by Oilexco (acquired by Premier Oil in 2009) in June 2007 by the discovery well 22/14b-5.

• The discovery well was drilled to a total depth of 13324 ft in the Triassic Skagerrak Formation.
• The well encountered oil in two separate zones;
  • Palaeocene Forties was encountered at a depth of 8960 ft and discovered a 122 ft oil column
  • Upper Jurassic Fulmar was encountered at a depth of 12769 ft and discovered a 136 ft oil column
• Wireline pressure and sampling tools have recovered high-quality oil;
  • 41° API gravity from the Forties
  • 39° API gravity from the Fulmar

The first phases of appraisal drilling of the Forties sand was completed in December 2007.

• Initial phase of the Huntington development project covered the Palaeocene Forties reservoir.
• Development drilling on Huntington began in April 2011 and finished in July 2012.
• First oil from Huntington was produced in April 2013.
High Resolution Dataset

Data were available from eight wells; 22/14b-5, -6Q, -6S, -6T, -6U, -6V, -6X and -6Y. The overpressure data from Huntington is sourced from a variety of reservoir pressure test tools; MDT, Stethoscope and XPT. Each well is summarised below.

22/14b-5 (MDT)
• FWL at 8736 ft TVDss.
• Aquifer overpressure of 24 psi.

22/14b-6Q (MDT)
• No useful information can be drawn from this well.

22/14b-6S (XPT)
• FWL of 8687 ft TVDss.
• Aquifer overpressure 37.4 psi supporting tilt to NW and similar value to Stethoscope pressures in 22/14b-6V.
• Also FWL is shallower than recorded at 22/14-5, supporting a tilt to NW.

22/14b-6T (XPT)
• A FWL of 8736 ft TVDss from interpolation of the gradients but confidence is low.
• Aquifer overpressure 28 psi which is higher than at 22/14b-5 arguing against tilt in this direction to NW.

22/14b-6U (MDT)
• The same aquifer overpressure as 22/14b-5 would suggest a shared aquifer i.e. no evidence for hydrodynamics.

22/14b-6V (Stethoscope)
• Aquifer overpressure of 35.4 psi
• Higher overpressures at this location support a tilt to the NW.

22/14b-6V (XPT)
• Aquifer overpressure 30 psi.

22/14b-6X (Stethoscope)
• Shallow water-leg data suggests water pressures of 37.6 psi.
• Higher overpressures here than in 22/14b-5 argues against tilt to NW.

22/14b-6Y (Stethoscope)
• Aquifer data plots along the same aquifer overpressure as the 22/14b-5 data suggesting pressure communication in the water-leg and suggesting no hydrodynamic gradient in NW of field.
Unedited/Raw Pressure-Depth Plot

Multiple FWLs?  Multiple HC Legs?  Different Sands?  Fault Compartments?
Variation in Wells/Fluids/Pressures

Based on the previous slide;

- **22/14b-5, -6S, -6V** support a hydrodynamic tilt to the north-west matching the regional fluid drive.
- **Wells 22/14b-6T and -6X** contradict a hydrodynamic model.
- **22/14b-6U and -6Y** suggest pressure equilibration with 22/14b-5 implying no tilt in the north-west of the field.
- **Other wells contain only log contacts**

There are many possible explanations for varying fluid contacts and overpressure magnitudes between wells within the same field, which can be categorised into the broad groups below.

Other reasons for varying contacts/pressures must be investigated and ruled out before hydrodynamics can be proven.
Reservoir Faulting? = Unlikely

Alba Field (UK 16/26)
- Pervasive faulting
- Eocene to Middle-Miocene
- Younger than Forties reservoir

Norwegian Måløy Slope (NOR 35 & 36)
- Polygonal faulting
- Upper Cretaceous and Lower Palaeocene.
- Older than the Forties reservoir

Faulting is present either in stratigraphically younger or older intervals, and limited to the mud-rich lithologies

Possible to infer no structural barriers to fluid flow/communication within the Forties Formation.

The sand distribution at Huntington may be influenced any underlying/overlying faults but these faults do not penetrate the Palaeocene Forties Formation and do not compartmentalise the reservoir.
Continuous Connected Sand

The far-offset (30–40°) seismic line illustrates a possible channel complex where the mapped horizon is absent.

The dim amplitude trending SE from the 22/8-3 is interpreted to represent a channel sandstone.

Hollywood & Olson, (2010)
Core Analysis (Molyneux et al, 2008)

22/14-6q is interpreted as an erosive sand/conglomerate base with subsequent mud-filled channel sequence.

22/14-8 is laterally off axis of this channel and appears to record a mix of sandy turbidites and muddier slurry beds, either as part of a winged edge of this same 22/14-6q channel axis or a sequence that is being cut into by the 22/14-6q channel.
Channel Definition

- Edges well defined in shale filled channel.
- Some evidence for prominent channel edges through the central parts of the structure
- Could these be the boundaries separating the fluid contacts?
Net to gross based on seismic attributes. Forties TWT + 5ms Relative Gradient Impedance

Strontium isotope data shows that the 14-8 and 14-6q are in fluid communication (Molyneux et al 2008)
Reservoir Shale Out? = No

Seismic attribute data display several deep-water low sinuosity channel-like features and apparent depositional lobes in the Upper Forties section analogous to the Forties Field.

Core taken in 22/14-6q
  • Erosive sand/conglomerate base
  • Subsequent mud filled channel sequence
  • Upper, predominantly back-filled sandy turbidite channel fill with minor slurry beds

Core taken in 22/14-8 (laterally off axis of this channel; approximately 1.5 km W)
  • A mix of sandy turbidites and muddier slurry beds
  • Strontium isotope work indicates that the 22/14-6q and -8 well are in fluid communication

Both rock types however are excellent reservoirs for oil, and only in the very muddy cases will these act as reservoir baffles.

Given the widespread deposition of sand-dominated facies it is highly unlikely that any sedimentalogical barriers between wells exist.

Based on the lack of faulting within the Forties sand and the proven communication between neighbouring wells, the most likely explanation for variation in FWL/OP/Fluid-type distribution is hydrodynamics.
Variation in Wells/Fluids/Pressures

<table>
<thead>
<tr>
<th>Well</th>
<th>Oil/Water FWL (ft TVDss)</th>
<th>Overpressure (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14b-6t</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>14b-6u</td>
<td>24</td>
<td>37.6</td>
</tr>
<tr>
<td>14b-6x</td>
<td>37.6</td>
<td></td>
</tr>
<tr>
<td>14b-6y</td>
<td>24</td>
<td></td>
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<tr>
<td>14b-5</td>
<td>8736</td>
<td></td>
</tr>
<tr>
<td>14b-6v</td>
<td>30 XPT</td>
<td>35.4 Stetho</td>
</tr>
<tr>
<td>14b-6s</td>
<td>8687</td>
<td>37.4</td>
</tr>
</tbody>
</table>

Structural Spill Point

Well Oil/Water FWL (ft TVDss) Overpressure (psi)
Variation in Wells/Fluids/Pressures

Forties depth structure with far-offset (30–40°) A-amplitude anomaly.

Amplitude extends beyond independent structural closure shown by blue dashed contour.

Contour interval is 10 ft (Hollywood & Olson, 2010)
Incorporating Log-only Contacts

Huntington 22/14b-6W

FWL = Free water level
OWC = Oil water contact
OWC(P) = Productive oil water contact
Swi = Irreducible water saturation
TZ = Transition zone
Pe = Capillary entry pressure - oil begins to invade pore spaces
Pd = Capillary displacement pressure - oil invades connected pore spaces (usually approximates to the OWC(P))
Huntington – Forties Well Results

Evidence for a dipping contact?
Evidence for multiple dipping contacts; geological and production effects?

All wells shown in TVDSS

Shale Barrier to NE?
Low Net:Gross

Structural Spill Point
Summary So Far

- 10 wells in Huntington record varying overpressure and free-water levels
  - Faulting seems unlikely to be compartmentalising the reservoir based on local analogues
  - There are no sedimentalogical barriers to fluid communication
    - Implied from analogue fields (Forties)
    - Proven from seismic attribute & core data
- Regional pattern of decreasing overpressure towards the North-West within the Forties Formation
  - Implies tilt of HWC down to the North-West
- Majority of well data match regional model of hydrocarbon tilt down to the North-West
  - Some wells do not match the model
  - WFT prove hydrocarbons outside structural closure
  - Log data suggest tilt matching the regional model
  - Seismic attribute data also indicate hydrocarbons present outside structure in the same direction as the implied tilt
- Can a hydrodynamic model be built that matches known fluid distributions and fluid contacts?
Unedited/Raw Pressure-Depth Plot

Multiple FWLs? Multiple HC Legs? Different Sands? Fault Compartments?
Corrected Pressure-Depth Plot

Different tools can lead to different pressure readings within the same fluid type.

- Compare the hydrocarbon data in 22/14b-5 and 22/14b-6s

Important to migrate all data on to a common HC gradient to assess FWLs/OPs

A 3-5 psi shift required to align all the HC well data on to 22/14b-5
Corrected Pressure-Depth Plot

A 3-5 psi shift required to align all the HC well data on to 22/14b-5
Corrected Pressure-Depth Plot

Now we have a single HC leg with multiple aquifers, multiple FWLs and multiple OPs.

Just the deepest and shallowest FWLs shown
Calculated Hydrodynamic Tilts

1) Using Local OP Data = 22-33 ft/km
2) Using Regional Data = 25 ft/km
3) Using Log Data = 23.5 ft/km
4) Using FWL’s = 25-30 ft/km
Huntington Hydrodynamic Model

Model has to resolve 4 wells with proven hydrocarbons outside structural closure

Oil Wells
Water Wells
Structural Closure
FWL contours are controlled by tilt magnitude (~25 ft/km) as well as matching known FWL values in wells; known fluid distributions and known overpressure values.
Huntington Hydrodynamic Model

Up-dip Spill?

Shale-out Fluid Barrier

Oil Wells
Water Wells
Structural Closure
FWL Contours
Hydrodynamic Closure

Sand
Shale
Up-Dip Spill > New Opportunity?
Geological vs. Production Time Scales

Overpressure < 50 psi

Hydrodynamic Flow Directions

Overpressure > 2000 psi

Andrew Sandstone Outline
Conclusions

Huntington Oil Field

• A hydrodynamic model reconciles all (most!) of the data
• Substantial additional volumes of movable oil in NW part of structure
• AVO and Far amplitude phase reversal mapping still gives a reliable image of where we have live oil
• Integration of seismic attributes, regional OP mapping, FWL vs. log contacts etc. to generate a predictive model and up-dip potential

Hydrodynamic Modelling

• Geological-scale fluid flow direction defines the regional tilt model
• Field-scale production locally influences the tilt direction and magnitude
• Modelling relies on well data which are static measurements of pressures and fluids so any hydrodynamic model is only as accurate as the time the wells were drilled
Thank you – Any Questions?

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