UK Case Study:
Wessex Shale Oil Resource Estimation

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UK Shale Resource Studies

- Preliminary assessments undertaken by BGS on behalf of OGA (formerly DECC)
- Potential distribution and in-place resource for shale oil and shale gas onshore UK
- Assessments are of the hydrocarbons present in the shale strata only
- Does not include volumes which have migrated into potential tight conventional or hybrid plays
- No production data available to apply a more refined methodology like the USGS’s ‘Technically Recoverable Resources’ top-down estimate
Wessex Study Area: Exploration History

- Exploration activity since the 1930s
- First production in 1961 from the Kimmeridge Oilfield
- Wytch Farm Oilfield is the largest onshore oil accumulation in NW Europe
- As of March 2016, 301 hydrocarbon wells have been drilled (Exploration – 77; Appraisal – 10; Development – 214)
- No unconventional or hybrid wells have been drilled in the study area
Wessex Study Area: Structure

- Composed of several fault-controlled sub-basins and highs
- Complex tectonic history
- Formed during episodic pulses of Permian-Cretaceous extension, linked to the reactivation of Variscan faults
- The study area is dominated by 3 major E-W trending lines of inversion, developed along the basin bounding faults
- Two significant phases of uplift and erosion – in the mid-Cretaceous and in the Tertiary
Wessex Study Area: Stratigraphy

- The Jurassic consists of a series of shallowing-upwards sequences
- There are five marine shale units within the Jurassic
- The amount of organic matter in these units varies across the area, both laterally and temporally
- Organic rich shales (with TOC > 2%) occur regionally in the Kimmeridge Clay, the lower section of the Oxford Clay, and the Lower Lias
- The Upper and Middle Lias have well-developed clay intervals but the potential in these is more limited
Database: Seismic

- Interpretation on ~4400 km 2D seismic of various vintages and quality and a coarse grid from the Wytch Farm 3D survey
- Data is of fair to good quality in areas with little structural deformation, but quickly deteriorates across major fault zones
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Database: Well Control

- Time-depth data was available for 47 wells of sufficient depth in the study area.
- This was used to tie the seismic interpretation and build the velocity.
- Deviation surveys were also loaded where necessary.
Database: Geochemical Data

- Geochemical data was available from 14 wells, 3 boreholes and 8 outcrop localities.
- This study utilised data from well reports, published literature, academic work and company proprietary data.
Methodology

Seismic data
Wells - stratigraphy & lithology
Structural and palaeogeographical model

Well & model-driven Organic carbon

Maturity data from wells including new BGS analyses
Burial history (uplift)

Seismic data
Wells - stratigraphy & lithology
Structural and palaeogeographical model

gross rock volume
shale percentage
net shale volume
net mature shale volume
maturity cut-off
apply depth cut-off
from US data
final mature shale volume

from well data
Oil yield

final mature shale volume
= total in-place oil volume
Methodology: Gross Rock Volume

- Seismic data
- Wells - stratigraphy & lithology
- Structural and palaeogeographical model

Well & model-driven
Organic carbon

Maturity data from wells including new BGS analyses
Burial history (uplift)

Shale percentage

Net shale volume

Net mature shale volume

Apply depth cut-off (from US data)

Final mature shale volume

Final mature shale volume

Oil yield

Total in-place oil volume
3D Model

- Interpretation was completed on 6 key horizons, constrained by well data and outcrop geology, using DecisionSpace Geoscience
- The interpretation was depth converted using a 3D velocity model which incorporated well time-depth data and faults to account for the major lateral changes in velocity in areas of complex structure
- The depth grids show an overall trend of deepening to the SE
3D Model

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- The depth grids show an overall trend of deepening to the SE.
Methodology: Net Shale Volume
Shale Volume

- Source rock quality determined from Rock Eval analysis (TOC, HI, S1, S2)
- Potential source rock intervals where TOC > 2% and S2 > 5 mgHC/gRock
- Detailed petrophysics evaluation of log and core data not undertaken for this study
- Percentage of organic-rich shale within each formation estimated from available data

- Data quality a potential issue due to age of the wells and availability of samples
- Most analyses performed on cuttings, which limits the quality of the sample due to caving and mixing of lithologies
- Samples from wells drilled with OBM potentially contaminated
Methodology: Net Mature Shale Volume

- Seismic data
- Wells - stratigraphy & lithology
- Structural and palaeogeographical model

Well & model-driven
Organic carbon →
gross rock volume →
shale percentage
net shale volume

Maturity data
from wells including
new BGS analyses
Burial history (uplift)

→ maturity cut-off →
net mature shale volume

apply depth cut-off
from US data

final mature shale volume

from well data →
final mature shale volume
Oil yield =
total in-place
oil volume
Maturity Data

- Maturity determined from vitrinite reflectance and Tmax data
- Tmax data can be converted to vitrinite reflectance (Jarvie, 2001)
- For the Wessex area, the Tmax data largely predicts a higher maturity for a given burial depth compared to the measured data

- Both of these measures of maturity potentially have a high degree of uncertainty
- Vitrinite enhancement or suppression indicated by a wide spread of data points at a particular depth
- Tmax data are less reliable when:
  - TOC is low
  - S2 < 0.5 mgHC/gRock
  - in cases of severe recycling of organic matter
Magnitude of Erosion

- Estimating the amount of missing section is fundamental for determining the maximum burial depth of the Jurassic shale intervals
- Several methods for calculating this; we used interval velocity comparison and stratigraphic restoration
- This study predicts a maximum missing section of ~1600 m, with erosion greatest to the south of the Purbeck-Isle of Wight Disturbance
- Published studies give estimates from 500 to > 2000 m
Palaeomaturity

- Present day, only the Lower Lias in the Channel Basin may be in the oil window.
- Palaeotemperature data suggests the rocks reached higher maturity during the time of maximum burial, attained prior to the uplift/erosion events.
- North of the Purbeck-Isle of Wight Disturbance, maximum burial was achieved in the Early Cretaceous; south of this structure, maximum burial occurred prior to Tertiary inversion.
- A plot of the maturity data vs the reconstructed depth data shows a more consistent trend.
- Jurassic shales considered mature for oil generation at $VR = 0.6\% - 1.1\%$ (after Charpentier & Cook, 2011), equivalent to maximum burial depths approx. 2130-2440 m and 3660-3960 m below surface.
Methodology: Final Mature Shale Volume

- Seismic data
  - Wells - stratigraphy & lithology
  - Structural and palaeogeographical model
- Well & model-driven
  - Organic carbon
- Maturity data
  - from wells including new BGS analyses
  - Burial history (uplift)
- Gross rock volume
- Shale percentage
- Net shale volume
- Maturity cut-off
- Net mature shale volume
- Apply depth cut-off
  - from US data
- Final mature shale volume
- From well data
- Oil yield
- Total in-place oil volume
Depth Cut-offs

- An upwards truncation was applied at two alternative depths:
  - 1200 m BML, based on UK legislation
  - 1500 m BML, as proposed by Charpentier & Cook (2011)
- These cut-offs are applied regionally
- The depth at which shale oil (or shale gas) productivity becomes an issue in terms of pressure and hydrogeology will need to be addressed locally.
Methodology: Oil Yield

- Seismic data
- Wells - stratigraphy & lithology
- Structural and palaeogeographical model
  
  Well & model-driven
  Organic carbon

  Maturity data
  from wells including
  new BGS analyses
  Burial history (uplift)

  gross rock volume
  shale percentage
  net shale volume
  maturity cut-off
  net mature shale volume
  apply depth cut-off
  final mature shale volume
  from US data

  final mature shale volume
  Oil yield

  total in-place oil volume
Oil Saturation Index

- For the calculation of the in-place shale oil resource, an estimation of the in-situ free oil content of each shale unit is required.
- The oil saturation index (OSI) is a measure of the free oil from Rock Eval measured S1 in relation to TOC, which is the component that can potentially extracted after fracture stimulation.
- OSI > 100 indicate the presence of potentially producible oil.
Oil Saturation Index

- Need to correct S1 for ‘evaporative loss’ of light oil from samples to convert the present-day S1 figures into data that are likely to pertain to the shales under reservoir conditions at depth
- Evaporative loss equation (Michael et al., 2013)
  - \%C15 minus lost = (oil API – 20.799)/0.412
- For Wessex/Weald, this gives correction factors of 1.53 – 2.42
- Other authors suggest evaporative loss could be a more significant issue with correction factors up to 4 or 5.
Methodology: Oil In-Place Volume

1. **Seismic data**
   - Wells - stratigraphy & lithology
   - Structural and palaeogeographical model

2. **Well & model-driven**
   - Organic carbon

3. **Maturity data**
   - from wells including new BGS analyses
   - Burial history (uplift)

4. **Gross rock volume**
   - Shale percentage
   - Net shale volume
   - Maturity cut-off
   - Net mature shale volume
   - Apply depth cut-off
   - Final mature shale volume
   - Total in-place oil volume

5. From well data
   - Oil yield

From US data: Final mature shale volume
Oil In-Place Calculation

- The volumes of potentially productive shale and average oil yields were used as the input parameters for a statistical calculation of the in-place oil resource.
- A range of values is presented based on a Monte Carlo analysis to give a measure of uncertainty in the resource estimation.
- Oil in-place (bbls/acre-ft) = corrected S1 (mgHC/gRock) * rock density (g/cm3) / oil density (g/cm3) * unit conversion factor (unit conversion factor to convert from cm3/m3 to bbl/acre-ft = 7.758)

- For this study, the paucity of geochemical data precludes a full understanding of free oil contents that are necessary to estimate in-place resources
- We modelled two end members:
  - Use Jarvie oil saturation index, and if < 100, assume that most/all of the measured S1 is associated with kerogen. In this scenario, the free oil density will be negligible.
  - Assume that the sorbed oil is restricted to S2 and that all the S1 is free oil. Then correct the S1 for evaporative loss and use this as the free oil density.
Example Monte Carlo Input Parameters

5. Monte Carlo input parameters

<table>
<thead>
<tr>
<th>R&lt;sub&gt;s&lt;/sub&gt; = 0.6% at 7,000 ft</th>
<th>Accessible/viable volume of net mature shale (x10&lt;sup&gt;6&lt;/sup&gt; m&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Net organic-rich and potentially productive shale (%)</th>
<th>Free oil content (mg/g shale)</th>
<th>Correction for evaporative loss</th>
<th>Shale density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Oil density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Lower cut-off</td>
<td>5,800 ft cut-off</td>
<td>5,900 ft cut-off</td>
<td>Upper cut-off</td>
<td>min</td>
<td>ml</td>
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<tr>
<td>Kimmeridge</td>
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<td>5.3</td>
<td>220.4</td>
<td>262.5</td>
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<td>62</td>
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<tr>
<td>Corallian</td>
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<td>49.4</td>
<td>201.5</td>
<td>222.6</td>
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<td>27</td>
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<tr>
<td>Oxford</td>
<td>77.6</td>
<td>97.0</td>
<td>214.8</td>
<td>236.3</td>
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<td>30</td>
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<tr>
<td>Upper Lias</td>
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<td>87.4</td>
<td>137.7</td>
<td>150.9</td>
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<tr>
<td>Mid Lias</td>
<td>106.3</td>
<td>132.9</td>
<td>155.9</td>
<td>194.5</td>
<td>9</td>
<td>20</td>
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</table>

Table 1a. Input parameters for the Monte Carlo simulation used to determine the total oil in place in the five main Jurassic shale units, Weald area, southern Britain using a maturity cut-off at 7,000 ft (2,130 m) maximum, pre-uplift burial depth. S = volume of shale below various depth cut-offs.

<table>
<thead>
<tr>
<th>R&lt;sub&gt;s&lt;/sub&gt; = 0.6% at 8,000 ft</th>
<th>Accessible/viable volume of net mature shale (x10&lt;sup&gt;6&lt;/sup&gt; m&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Net organic-rich and potentially productive shale (%)</th>
<th>Free oil content (mg/g shale)</th>
<th>Correction for evaporative loss</th>
<th>Shale density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
<th>Oil density (g/cm&lt;sup&gt;3&lt;/sup&gt;)</th>
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</thead>
<tbody>
<tr>
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<td>Lower cut-off</td>
<td>8,300 ft cut-off</td>
<td>8,400 ft cut-off</td>
<td>Upper cut-off</td>
<td>min</td>
<td>ml</td>
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<tr>
<td>Kimmeridge</td>
<td>0.5</td>
<td>0.6</td>
<td>66.8</td>
<td>73.5</td>
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<td>63</td>
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<td>118.3</td>
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<tr>
<td>Oxford</td>
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<td>66.1</td>
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<td>30</td>
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<tr>
<td>Upper Lias</td>
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<tr>
<td>Mid Lias</td>
<td>85.3</td>
<td>106.6</td>
<td>156.8</td>
<td>172.5</td>
<td>9</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 1b. Input parameters for the Monte Carlo simulation used to determine the total oil in place in the five main Jurassic shale units, Weald area, southern Britain using a maturity cut-off at 8,000 ft (2,440 m) maximum, pre-uplift burial depth. S = volume of shale below various depth cut-offs.
Oil In-Place Volumes for the Wessex Area

- The potential for the presence of oil-mature shale has been identified in several intervals in the Jurassic of the Wessex area.
- The Lower Lias is the only interval with shale oil potential, in a localised area largely south of the Purbeck-Isle of Wight Disturbance where a full Jurassic section is preserved.
- There is no significant Jurassic shale gas potential.