Analogs in Resource Assessment and Beyond

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C&C Reservoirs

The intelligence behind the world’s most successful oil and gas companies
Outline

• Roles of analogs in petroleum resource assessment
• Digital Analogs Knowledge System-DAKS
• Applications of DAKS for resource assessment and beyond
  • Success cases for explorers
  • Success cases for developers
  • Success cases for producers
  • Success cases for portfolio managers
• DAKS application workflow
• Q&A
Petroleum Reserves

• Petroleum reserves cannot be measured directly.
• Estimates of reserves and future production, combine information and assumptions about economics, feasible technology and geology.
• To use reserves estimates sensibly it is necessary to have some understanding of how they are generated and to have confidence in the integrity of the estimating process.
• Until a flexible, consistent and comprehensive system is widely adopted, great care needs to be exercised in interpreting numbers which purport to describe reserves of oil and gas.

The Digital Analogs Knowledge System is that system
Reserve Bookings

• The process of declaring the reserves in a financial statement
• Strict conditions are applied by enterprises reporting ‘proven’ reserves for financial purposes
• Proven reserves are estimated with a high degree of certainty >= 90%
• Securities Exchange and Commission (SEC) rules dictate that companies are required to report reserves to investors through their financial statements.
• Oil still in the ground is not considered an asset
• Reserves decrease with production

analogs are key component of the reserve booking process
Petroleum Resource Management System (PRMS) is standard governed by SPE and adopted by SEC

Others are:

2. UK Statement of Recommended Practices (SORP-2001)
4. Russian Ministry of Natural Resources (RF-2005)

PRMS is not the sole international standard
Exploration
• “Lithology, including net-to-gross, and porosity can be loosely estimated from a depositional model of the reservoir based on well data, 3D seismic facies analysis, and field analogs”

Development
• Refinement and verification of large geocellular models with actual analogs

Production
• If analogous reservoirs are achieving levels of recovery efficiency significantly better than the reservoir under consideration, it is possible that there are development options that have been overlooked
Application of analogs through project maturation
• **Analogs** are widely used in resources estimation, particularly in the exploration and early development stages when direct measurement information is limited.

• **Analogs** are frequently applied for aiding in the assessment of economic producibility, production decline characteristics, drainage area, and recovery factor (for primary, secondary, and tertiary methods).

• Comparison to several analogs, rather than a single analog, often improves the understanding of the range of uncertainty in the estimated recoverable. *Geographical proximity alone may not be the primary consideration.*
Are reserves bookings important?

Shell Financial Statement 2016:

“A central group of reserves experts, who on average have around 29 years' experience in the oil and gas industry, undertake the primary assurance of the proved reserves bookings. This group of experts is part of the Resources Assurance and Reporting (RAR) organisation within Shell.”
Basic needs of using analogs in resource assessment

1. A collection of ideal analogs that meet the requirement of resource assessment
2. A consistent and systematically built analog system with all representative reservoir analogs that fit every type of reservoir of interest
3. Systematic searching and analytical tools to find and analyze analogs
4. Evaluators personal rich experiences and good judgements in selecting and using analogs in resource assessment
An ideal analog should include the detailed documentation for at least the following attributes of the reservoirs:

1. Rock depositional environments, architecture and properties
2. Geological structure
3. Fluid properties
4. Reservoir conditions
5. Drive mechanisms
6. Advanced development stage and reservoir management technologies applied
7. Reservoir performance history
8. Primary recovery factor, incremental recovery factors for the secondary and tertiary recoveries and ultimate recovery factors
9. Geographical location
Our approach since early 1990’s

• Document key facts, lessons learned and best practices from the world’s most important fields and reservoirs by highly experienced world class geoscientists and engineers

• Establish rigorous standards, rules and classification to consistently capture reservoir and field knowledge and codify them into a coherent knowledge base

• Develop a cloud-based software platform that facilitates translation of this knowledge base into real-time intelligence and insight
In-depth analysis and systematic documentation of the world’s most important fields and reservoirs

- *Exploration history*: play concept & discovery techniques
- *Regional-scale info*: basin evolution & source rock
- *Field-scale info*: trap, seal, reservoir & fluid properties
- *Resources and recovery*: development strategy, reservoir management & improved recovery methods
- *Reference list and table of parameters*: (> 400 parameters)
- *Figure*: map, cross-section, log, plot and production history
Field and reservoir knowledge base

Field level (58 parameters)
Reservoir information (330 parameters)
  • General
  • Well
  • Source rock
  • Trap
  • Seal
  • Reservoir characteristics (56)
  • Fluid properties
  • Resources and recovery factors
  • Improved recovery
  • Reservoir management

Reservoir production (40 parameters)
  • Reservoir production data
  • Reservoir performance data

Parameter
  • Reservoir age
  • Depositional environment
  • Sand body type
  • Fluid flow restriction
  • Gross reservoir thickness
  • Net reservoir thickness
  • Net to gross ratio
  • Net pay thickness
  • Reservoir lithology
  • Wettability/sensitivity
  • Unconventional reservoir type
  • Diagenetic reservoir type
  • Fracture origin
  • Porosity type
  • Matrix/fracture porosity
  • Air/well test permeability
  • Kv/Kh ratio
**Pioneering classification: LACUSTRINE ENVIRONMENT**

<table>
<thead>
<tr>
<th>DEPOSITIONAL SYSTEM</th>
<th>DEPOSITIONAL ENVIRONMENT</th>
<th>DEFINITION</th>
<th>CONCEPTUAL MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacustrine beach or barrier bar</td>
<td>Lacustrine beach or barrier bar</td>
<td>Lake-margin facies formed by reworking by wave action or longshore currents. Typically elongate reservoirs, paralleling the lake shore.</td>
<td><img src="image1" alt="Conceptual Model of Lacustrine Beach or Barrier Bar" /></td>
</tr>
<tr>
<td>Lacustrine delta</td>
<td>Lacustrine river-delta</td>
<td>Deposited at river mouths within low-relief distributary systems. Dominated by fluvial processes and interaction with lacustrine wave/malongshore currents.</td>
<td><img src="image2" alt="Conceptual Model of Lacustrine River-Delta" /></td>
</tr>
<tr>
<td>Lacustrine fan-delta</td>
<td>Lacustrine fan-delta</td>
<td>Coastal prisms delivered to lake margin by alluvial fans and deposited mainly in shallow water. Developed in high relief basins, typically in semi-arid areas.</td>
<td><img src="image3" alt="Conceptual Model of Lacustrine Fan-Delta" /></td>
</tr>
<tr>
<td>Sub-lacustrine fan</td>
<td>Sub-lacustrine fan</td>
<td>Turbidites typically deposited downslope of lacustrine river-deltas and pass laterally into deep-lacustrine shales.</td>
<td><img src="image4" alt="Conceptual Model of Sub-lacustrine Fan" /></td>
</tr>
</tbody>
</table>
### Pioneering classification: EROSIONAL TRUNCATION

<table>
<thead>
<tr>
<th>Stratigraphic - Fluidic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sub-unconformity truncation</strong></td>
<td>Reservoir truncation beneath a regional unconformity.</td>
</tr>
<tr>
<td><strong>Regional subcrop</strong></td>
<td>Reservoir truncation beneath regional-scale unconformity.</td>
</tr>
<tr>
<td><strong>Paleostructural subcrop</strong></td>
<td>Erosional truncation of faulted / folded structure.</td>
</tr>
<tr>
<td><strong>Buried erosional relief</strong></td>
<td>Trapping beneath a local truncation surface and/or within a buried hill reservoir.</td>
</tr>
<tr>
<td><strong>Buried-hill</strong></td>
<td>Erosional truncation of basement reservoir.</td>
</tr>
<tr>
<td><strong>Truncation-Edge</strong></td>
<td>Reservoir truncation beneath local / subregional unconformity or sequence boundary.</td>
</tr>
<tr>
<td><strong>Onlap onto erosional surface</strong></td>
<td>Onlap pinch-out of reservoir onto relative high.</td>
</tr>
<tr>
<td><strong>Onlap onto regional unconformity</strong></td>
<td>Onlap pinch-out onto a regional unconformity.</td>
</tr>
<tr>
<td><strong>Onlap onto structural flank unconformity</strong></td>
<td>Onlap pinch-out onto flanks of structural / basement high.</td>
</tr>
<tr>
<td><strong>Erosional trough fill</strong></td>
<td>Lateral termination of reservoir against an erosional trough.</td>
</tr>
<tr>
<td><strong>Channel-fill</strong></td>
<td>Reservoir confined within a channel incision.</td>
</tr>
<tr>
<td><strong>Valley-fill</strong></td>
<td>Reservoir confined within a major channel incision.</td>
</tr>
<tr>
<td><strong>Canyon-fill</strong></td>
<td>Reservoir confined within deepwater submarine erosional trough.</td>
</tr>
</tbody>
</table>
Digital Analogs Knowledge System - DAKS

An industry-leading knowledge base delivered via a cloud-based software platform with a robust search engine and powerful set of analytics tools.
Key Element and Capabilities of DAKS

- Comprehensive field evaluation report
- Consistent, reliable and high-quality reservoir knowledge
- Standardized and well-defined classification system
- Every petroleum basin, reservoir type, production technology and improved recovery method around the world
- Input tool to capture knowledge on users’ E&P assets
- Benchmark users’ assets against global analogs to discover critical issues and identify opportunities for improvement
Analytics: Benchmarking all attributes of the target reservoir against a group of analog reservoirs

<table>
<thead>
<tr>
<th>Category</th>
<th>Parameter</th>
<th>Units</th>
<th>Count</th>
<th>Target</th>
<th>Rank</th>
<th>Mean</th>
<th>Min</th>
<th>P90</th>
<th>P50</th>
<th>P10</th>
<th>Max</th>
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<tbody>
<tr>
<td>General</td>
<td>Reservoir Temperature (Original)</td>
<td>°C</td>
<td>88</td>
<td>160</td>
<td>0</td>
<td>74.41</td>
<td>49</td>
<td>7.1</td>
<td>4.2</td>
<td>2.1</td>
<td>1.9</td>
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<tr>
<td>Trap</td>
<td>Hydrocarbon Column Height (Original) - Oil</td>
<td>m</td>
<td>95</td>
<td>515</td>
<td>1</td>
<td>144.54</td>
<td>15.5</td>
<td>32.3</td>
<td>12.4</td>
<td>7.1</td>
<td>3.1</td>
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<tr>
<td>General</td>
<td>Reservoir Pressure (Original)</td>
<td>kPa</td>
<td>97</td>
<td>60,453.23</td>
<td>2</td>
<td>21,317.67</td>
<td>344.74</td>
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<td>Hydrocarbon Column Height (Original) - Total</td>
<td>m</td>
<td>97</td>
<td>515</td>
<td>2</td>
<td>164.65</td>
<td>21</td>
<td>32.4</td>
<td>11.9</td>
<td>7.0</td>
<td>3.0</td>
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<td>Well</td>
<td>Well Rate (Initial) - Oil</td>
<td>m³/day</td>
<td>39</td>
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<td>724.05</td>
<td>3.02</td>
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<td>10.18</td>
<td>11.99</td>
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<td>Trap</td>
<td>Depth to Top of Reservoir</td>
<td>m TVD</td>
<td>106</td>
<td>3582.5</td>
<td>4</td>
<td>1765.27</td>
<td>30.48</td>
<td>579.12</td>
<td>1719.97</td>
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<td>Trap</td>
<td>Top of Reservoir Subsea Depth</td>
<td>m TVDSS</td>
<td>106</td>
<td>3650</td>
<td>4</td>
<td>1592.68</td>
<td>-274.32</td>
<td>335.28</td>
<td>1996</td>
<td>3017.52</td>
<td>4227.58</td>
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<td>Reservoir</td>
<td>Single Reservoir Flow Unit Thickness (Average)</td>
<td>m</td>
<td>45</td>
<td>40</td>
<td>5</td>
<td>11.5</td>
<td>0.91</td>
<td>1.63</td>
<td>7.62</td>
<td>31.06</td>
<td>45.72</td>
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<tr>
<td>Fluid</td>
<td>GOR Initial (Average)</td>
<td>m³/m³</td>
<td>56</td>
<td>196.92</td>
<td>6</td>
<td>90.76</td>
<td>0.45</td>
<td>12.91</td>
<td>75.51</td>
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<td>494.96</td>
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<td>Well</td>
<td>Well Spacing (Current) - Oil</td>
<td>cm²</td>
<td>71</td>
<td>1</td>
<td>13</td>
<td>0.56</td>
<td>0.016</td>
<td>0.056</td>
<td>0.32</td>
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<td>Fluid</td>
<td>Bubble Point Pressure - Oil (Average)</td>
<td>kPa</td>
<td>78</td>
<td>21,029.61</td>
<td>14</td>
<td>13,272</td>
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<td>Well</td>
<td>Well Rate (Plateau) - Oil</td>
<td>m³/day</td>
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<td>781.58</td>
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<td>514.13</td>
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<td>86.69</td>
<td>953.87</td>
<td>3872.25</td>
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<tr>
<td>Well</td>
<td>Well Rate (Maximum) - Oil</td>
<td>m³/day</td>
<td>51</td>
<td>3100.26</td>
<td>16</td>
<td>1454.62</td>
<td>7.15</td>
<td>16.23</td>
<td>317.97</td>
<td>4483.44</td>
<td>12260</td>
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<td>Trap</td>
<td>Trap Flank Dip (Average)</td>
<td>degrees</td>
<td>103</td>
<td>6</td>
<td>19</td>
<td>3.94</td>
<td>0.1</td>
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<td>2.0</td>
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<td>45</td>
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<td>Field</td>
<td>Discovery Year (Field)</td>
<td></td>
<td>190</td>
<td>1960</td>
<td>20</td>
<td>1965</td>
<td>1833</td>
<td>1546</td>
<td>1971</td>
<td>1990.8</td>
<td>2013</td>
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<td>Field</td>
<td>Plateau Recovery % of EUR - Oil (Field)</td>
<td>%</td>
<td>75</td>
<td>10</td>
<td>20</td>
<td>7.61</td>
<td>0.8</td>
<td>2.3</td>
<td>5.83</td>
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<td>53.9</td>
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<td>General</td>
<td>Plateau Recovery % of EUR - Oil</td>
<td>%</td>
<td>64</td>
<td>10</td>
<td>21</td>
<td>8.65</td>
<td>1.01</td>
<td>2.87</td>
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<td>15.16</td>
<td>53.9</td>
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</tbody>
</table>

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### Analytics: Characterization of Global Offshore Deep-Water Clastic Oil Reservoirs

<table>
<thead>
<tr>
<th>Category</th>
<th>Parameter</th>
<th>Units</th>
<th>Count</th>
<th>Mean</th>
<th>Min</th>
<th>P90</th>
<th>P50</th>
<th>P10</th>
<th>Max</th>
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<tbody>
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<td>Resource</td>
<td>Original In-Place - Oil</td>
<td>MM m³</td>
<td>86</td>
<td>177.72</td>
<td>2.48</td>
<td>14.94</td>
<td>68.21</td>
<td>407.11</td>
<td>1812.46</td>
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<tr>
<td>Resource</td>
<td>Resource Density - Oil</td>
<td>M m³/km³</td>
<td>74</td>
<td>5345.92</td>
<td>153.61</td>
<td>1777.5</td>
<td>3862.58</td>
<td>10808.0</td>
<td>29159.56</td>
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<td>Resource</td>
<td>EUR - Oil</td>
<td>MM m³</td>
<td>92</td>
<td>67.45</td>
<td>0.84</td>
<td>5.29</td>
<td>23.31</td>
<td>160.4</td>
<td>494.0</td>
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<tr>
<td>Resource</td>
<td>Recovery Factor Primary - Oil</td>
<td>%</td>
<td>13</td>
<td>25.95</td>
<td>8.06</td>
<td>9.40</td>
<td>22.00</td>
<td>46.40</td>
<td>55.00</td>
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<tr>
<td>Resource</td>
<td>Recovery Factor Ultimate - Oil</td>
<td>%</td>
<td>12</td>
<td>41.28</td>
<td>8.90</td>
<td>22.70</td>
<td>44.00</td>
<td>55.72</td>
<td>72.50</td>
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<tr>
<td>Resource</td>
<td>Recovery to Date of In-Place - Oil</td>
<td>%</td>
<td>76</td>
<td>30.81</td>
<td>0.00</td>
<td>7.70</td>
<td>31.97</td>
<td>52.70</td>
<td>58.53</td>
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<tr>
<td>Resource</td>
<td>Recovery Factor Water-free - Oil</td>
<td>%</td>
<td>67</td>
<td>6.50</td>
<td>0.00</td>
<td>0.016</td>
<td>4.40</td>
<td>14.80</td>
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<td>Resource</td>
<td>Recovery Factor Pre-injection - Oil</td>
<td>%</td>
<td>39</td>
<td>4.71</td>
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<td>0.00</td>
<td>1.14</td>
<td>15.23</td>
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<tr>
<td>Resource</td>
<td>Reservoir Performance Index - Oil</td>
<td>%</td>
<td>37</td>
<td>0.067</td>
<td>-0.087</td>
<td>-0.033</td>
<td>0.05</td>
<td>0.16</td>
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<tr>
<td>Resource</td>
<td>Original In-Place - Gas</td>
<td>BCM</td>
<td>6</td>
<td>4.75</td>
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<td>Resource</td>
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<td>MM m³/km³</td>
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<td>48.91</td>
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<td>37.00</td>
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<td>69.00</td>
<td>69.00</td>
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<tr>
<td>Resource</td>
<td>Recovery Factor Ultimate - Gas</td>
<td>%</td>
<td>4</td>
<td>68.00</td>
<td>37.00</td>
<td>37.00</td>
<td>60.00</td>
<td>83.00</td>
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<tr>
<td>Resource</td>
<td>Recovery to Date of In-Place - Gas</td>
<td>%</td>
<td>1</td>
<td>74.27</td>
<td>74.27</td>
<td>74.27</td>
<td>74.27</td>
<td>74.27</td>
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<tr>
<td>Resource</td>
<td>EUR - Condensate</td>
<td>MM m³</td>
<td>1</td>
<td>2.86</td>
<td>2.86</td>
<td>2.86</td>
<td>2.86</td>
<td>2.86</td>
<td>2.86</td>
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</tbody>
</table>
Analytics: Benchmark the column height of the target reservoir

Benchmark the well rate and well EUR of the target reservoir
Analytics: Field productivity by basin, offshore clastics

Field Productivity

Well EUR Oil (MBO)

Well Rate Plateau (BOPD)

Campos  Carnarvon  Gippsland  Gulf Of Mexico  Niger Delta  North Sea  Sabah
Calibrate uncertainty, support resource assessment and beyond

Benchmark & Validate Key Value Drivers

- Refine geologic model
- Benchmark production performance
- Assess reservoir management program
- Screen and evaluate IR methods
- Identify best practices and solutions

- Reservoir and fluid characteristics
- Drive mechanism (natural and injection)
- Development options
- Well type and number, pace of production
- EUR/well and recovery factor

- Petroleum system analysis
- Reservoir
- Trap & seal
- In-place volume
- EUR/well, initial well rate, recovery factor
Key applications of DAKS beyond resource assessment

- Generate and/or test new ideas for exploration & production
- Calibrate prospect uncertainty ranges
- Validate field development plan
- Identify best practices and optimal solutions for production improvement
- Support resources assessments and reserves booking
- Benchmark and enhance E&P portfolios
Search for applicable global analogs

**Exploration**
- Play Analogs
  - Tectonic setting
  - Depositional system
  - Trapping mechanism
  - Reservoir age

**Development**
- Development Analogs
  - Hydrocarbon type
  - Onshore/offshore
  - Lithology/
  - Depositional environment
  - Diagenetic reservoir type
  - Net to gross ratio
  - API gravity/viscosity
  - Field size

**Production**
- Identify Solutions to Production Challenges
  - Find broad analogs relevant to specific production challenges
  - Static attribute benchmark
  - Performance benchmark
  - Recovery factor benchmark
  - Identify best-in-class analogs through sub-search & analysis
Analog solution to various E&P challenges

Evaluating prospects or new discoveries, screening for development options and identifying opportunities for reserve growth

- Characterization
- Calibration
- Benchmarking
- Validation
- Idea generation

DAKS Platform ➔ Answer Questions/Provide Solutions

- What are the next exploration opportunities?
- How to quantify and justify the opportunity
- Should I invest in this opportunity?
- Should I drill this prospect?
- Should I approve this development?
- Are my resource evaluation reasonable and justifiable?
- Are there upside potential for this producing field?
- What improved recovery techniques should I use?
- How do I rank and optimize my exploration and production portfolio?
Success cases for explorers

- Generate new exploration ideas
- Characterize exploration play
- Benchmark prospects
- Calibrate volumetric uncertainty
- Calculate production profile
- Rank and mature prospect portfolio
Exploration opportunities in North Sea

Global rift and back-arc basin

West of Shetland Basin
Stratigraphic trap potential in the Middle East

Trapping mechanisms in global foreland basin

[Bar chart showing various trapping mechanisms with different frequencies]
Benchmarking HC column height

Tertiary organic buildup

210 m/690 ft

Benchmarking target = 2300 ft
Success cases for development managers

- Screen development scenarios
- Understand reservoir management program
- Calibrate geologic model input
- Validate model output from reservoir simulation
- Reality-check well type, number of wells, well rate, EUR/well, pace of production, recovery factor
- Reduce uncertainty in estimating production rates and recoverable reserves
Benchmarking field productivity

Why does this point have a relatively low EUR/well for its high production rate?

Ram Powell compartmentalised reservoir with perched aquifers

Offshore Tertiary clastics
Benchmarking recovery factor

Deep-water reservoir

Benchmarking target = 47%
Validating production forecast

- Target Field
- Romashkino
- East Texas

- Reservoir management & IR control recovery efficiency when water-cut exceeds 25%
- Viscosity and relative permeability control recovery efficiency when water-cut is < 25%
Success cases for producers

- Test new ideas for production improvement
- Establish reservoir technical limits
- Screen and evaluate EOR opportunities
- Understand factors that control reservoir performance and recovery efficiency
- Identify opportunities for reserves growth
- Determine what the best-in-class analogs are doing
Benchmarking reservoir performance

Amal Field, onshore Libya

OOIP: 5 BBO
Recovery to date: <21% of OOIP

Benchmarking identifies 1 BBO upside potential
Benchmarking recovery factor

Heavy oil reservoir

Best-in-class analogs

Viscosity - Oil (Average) (cP)

Recovery Factor Ultimate - Oil (%)

Target Reservoir
EOR methods for best-in-class analogs

- Polymer flood: 6
- Alkaline flood: 4
- Steam injection: 4
- Surfactant flood: 2
- In-situ combustion: 2
- Foam flood: 1
- Alkaline-polymer flood: 1
- CO2 miscible flood: 1
- Surfactant-polymer flood: 1
Recovery factors vs flowability

Offshore deep marine oil reservoir

Flowability – Oil (Average) (mD-ft/CP)

Recovery Factor Ultimate – Oil (%)
Establish RF predictive model using machine learning

North Sea Clastic Oil Reservoir

\[ y = 0.4051x + 25.434 \]
\[ R^2 = 0.712 \]
Success cases for portfolio managers

- Ensure the best prospects are drilled through a ranking process
- Identify assets for divesture
- Identify under-performing fields for further development
- Evaluate common themes that can be tested against the companies’ strategic intent and research focus
Portfolio benchmarking and ranking

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<table>
<thead>
<tr>
<th>Reservoirs</th>
<th>TOP</th>
<th>Total Score</th>
<th>Average Score</th>
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<td>Ravne - Ravne</td>
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<th>Sample Size</th>
<th>Intra-Porosity - Oil (Average)</th>
<th>Permeability - Air (Average)</th>
<th>API Gravity - Oil (Average)</th>
<th>Oil Saturation - Original (Average)</th>
<th>GOR Initial (Average)</th>
<th>Gas Saturation - Original (Average)</th>
<th>Wall EUR - Oil (Average)</th>
<th>Condensate Yield Initial (Average)</th>
<th>Water Depth (Meter)</th>
<th>Depth to Top of Reservoir</th>
<th>Sulphur (Average)</th>
<th>G Oil (G)</th>
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DAKS Application Workflow

1. Define problems and objectives
2. Capture knowledge for target reservoir
3. Find analogs relevant to specific problems
4. Characterize and analyze analogous reservoirs
5. Benchmark against analogs to discover critical issues
6. Identify best practices and optimal solutions