Integration of uncertain subsurface information into multiple reservoir simulation models

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Outline

• Description of Stybarrow oil field
• Use of sparse spike inversion and the correlation wavelet
• Probabilistic wavelet derivation giving critical noise level
• Probabilistic model based inversion with uncertainty
• “Massaging” the results into the reservoir simulation model
• “Decoration” and “Enforcement”
  – adding the subseismic structure
Location of Stybarrow field
Structure map of Stybarrow field
Geologic cross section of Stybarrow

Integration of uncertain subsurface information into multiple reservoir simulation models

Page 5  4 April 2005
Seismic data and sparse spike inversion with secant amplitude extraction

2.16 s

2.40 s

Stybarrow-2
Stybarrow-3
Stybarrow-4
Stybarrow-1
Definition of secant amplitude and area

impedance vs. time

net sand = secant area * Vsand / 2 Rsand
Net sand calculated from secant area
Geometry used for inversion benchmark

8500 ft/s  
2.33 gm/cc  
68% N/G

7134 ft/s  
2.01 gm/cc

9434 ft/s  
2.37 gm/cc

400 ft

station 0  200
Inversion benchmark

- Uninverted data
- Industry inversion #1
- Industry inversion #2
- New inversion
- True value

Integration of uncertain subsurface information into multiple reservoir simulation models

Page 10   4 April 2005
Oil probability map calculated from secant amplitude
Tie of seismic data to synthetic seismic using probabilistic wavelet derivation

green = seismic
red = synthetic
Most likely probabilistic wavelet compared to correlation wavelet

-60 ms

0 ms

60 ms

note: probabilistic wavelet is much shorter than correlation wavelet
Most likely probabilistic wavelet compared to ensemble of possible wavelets

-20 ms

0 ms

20 ms

note: noise is 17% size of oil reflector, SNR is 15 dB
Probabilistic model based inversion

• Layer based model built at seismic loop scale using sparse spike inversion
• Standard rock physics correlations estimated with uncertainty
• Fundamental properties of layers are:
  – net-to-gross ratio (N/G)
  – layer top and base
  – fluid type
• Ensemble of models generated that are consistent with seismic to within estimated noise level
Ensemble of models at Stybarrow-1 well location show effect of model based inversion.

Before realization:
- 2.2 s
- 2.4 s

After realization:
- Soft acoustic impedance
- Hard acoustic impedance
Effect of model based inversion on match of synthetic seismic to seismic data

before          after

2.24 s          2.36 s

seismic
Inversion tightens the range of possible net sand

probability of oil increased to 97% from 50% (oil in sand at this location)
Effect of inversion on estimation of N/G in main hydrocarbon (krieged to wells)
Estimation of oil probability

well control only

inversion only

0%

100%
Cross sections of mean model

2.16 s

2.40 s

before

after
Net sand prediction ahead of drill bit

<table>
<thead>
<tr>
<th>well</th>
<th>prediction (m)</th>
<th>result (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stybarrow-3</td>
<td>9.1 ± 6.4</td>
<td>2</td>
</tr>
<tr>
<td>Stybarrow -4</td>
<td>12.3 ± 4.3</td>
<td>7.6</td>
</tr>
</tbody>
</table>

40% probability well values larger deviation than observed
Results of model based inversion "massaged" onto reservoir model

- Lateral correlation added
- Short range noise eliminated
- Put onto irregular corner point geometry
- Fault blocks honored
- Inter-layer and inter-property correlation honored
Difference between the seismic grid and the reservoir simulation grid

seismic grid

reservoir simulation grid

1.2 km x 1.2 km
Effect of massaging on mean net sand map

**before**

**after**

7 km x 7 km

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Page 25  4 April 2005
Realizations of net sand generated by massager.
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Cross sections through model realizations

Note: models in depth
Reservoir simulation models are “decorated with subseismic structure”.

- **before decoration**
- **after proportional decoration**
- **after offlapping decoration**

![Graph showing different stages of decoration](image-url)

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Page 28  4 April 2005
Conclusions

• Ensemble of reservoir simulation models consistent with:
  – Seismic data
  – Well information
  – Geologic concepts

• Gives:
  – Volumetric distributions
  – Minimum net sand (well completion)
  – Etc.

• Range of production profiles
  – Potential production
  – Risks for development