Integrating Stochastic Rock Physics in Seismic Pre-drill Prospect Risk and Reservoir Quality Assessment

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Our goal

• Method for pre-drill assessment of potential well locations
  – probability of discovery
  – hydrocarbon volumes with uncertainty
• Using seismic amplitude data
• Studying 1D vertical profile
Predicting HC volumes

Point-wise probabilities

- shale
- brine sand
- HC sand
Predicting HC volumes

Point-wise probabilities

P(HC volume V > v)

Different vertical correlation structures
- E(V) identical
- P(V > 0) different

Which curve to trust? Need sound modeling!

shale
brine sand
HC sand
Model overview

\[ p(f) \rightarrow p(m \mid f) \rightarrow p(d \mid f, m) \]

Lithology, Fluid \hspace{2cm} Elastic parameters \hspace{2cm} Seismic

rock physics model \hspace{2cm} seismic forward model
Model overview

\[ p(f) \xrightarrow{\text{rock physics model}} p(m \mid f) \xrightarrow{\text{seismic forward model}} p(d \mid f, m) \]

Lithology, Fluid

Elastic parameters

Seismic

\[ p(f, m \mid d) \propto p(d \mid f, m)p(m \mid f)p(f) \]

posterior likelihood prior
Prior lithology model

\[ p(f) \]

lithology = shale background + sand objects
Prior lithology-fluid model

\[ p(f) \]

\[
\text{lithology} + \text{fluid contacts} = \text{facies realisation}
\]

- shale
- sand

- gas
- oil
- brine

- gas sand
- oil sand
- brine sand
Prior lithology-fluid model

\[ p(lithology) \cdot p(\text{fluid contacts}) = p(f) \]
Prior rock physics model

- stochastic model per lithology-fluid (LF) class
- vertical correlations

\[ p(m|f) \]
# Likelihood

<table>
<thead>
<tr>
<th>Vp (km/s)</th>
<th>Vs (km/s)</th>
<th>Rho ($10^3$ kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>3.51</td>
<td>2.52</td>
</tr>
<tr>
<td>3.51</td>
<td>2.52</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Seismic amplitudes

\[ p(d \mid f, m) \]

- linear Aki & Richards
- convolution model
\[ d = Gm + e \]

Posterior

\[
p(f, m | d) \propto p(d | f, m)p(m | f)p(f)
\]

- Compute volumes and discovery probabilities from posterior
- Posterior not available on analytic form
- Construct sampling algorithm
Sampling posterior

- Markov chain Monte Carlo method
  - iterative algorithm
  - generates samples of lithology–fluid and elastic parameters
  - tailor made sample generation

- Observe regularly
  - lithology–fluid
  - volumes and porosity
Case study. Seismic data from prospect

Near offset angle

Medium offset angle

Far offset angle

Horizontal distance (km)

Time (ms)
Case study. Lithology–fluid prior

<table>
<thead>
<tr>
<th>Lithology–fluid model</th>
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<thead>
<tr>
<th>Point-wise probabilities</th>
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<tbody>
<tr>
<td>2200</td>
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<td>2400</td>
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<table>
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<th>Discovery probabilities</th>
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<tr>
<td>Prior: $P(V &gt; 0) = 0.53$</td>
</tr>
<tr>
<td>No HC</td>
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<tr>
<td>-------</td>
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<tr>
<td>Prior</td>
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</table>
Case study. Rock physics prior
Lithology–fluid results

Prior

Seismic Center

LF posterior Center

Seismic Outskirts

LF posterior Outskirts

- shale
- gas sand
- oil sand
- brine sand
Volumes and discovery probability

\[ P(V > 0) = 0.97 \]
\[ P(V > 0) = 0.53 \]
\[ P(V > 0) = 0.44 \]
Oil and gas scenarios at prospect center

Discovery probabilities

<table>
<thead>
<tr>
<th></th>
<th>No HC</th>
<th>Oil</th>
<th>Gas</th>
<th>Gas and Oil</th>
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</thead>
<tbody>
<tr>
<td>Prior</td>
<td>0.47</td>
<td>0.18</td>
<td>0.20</td>
<td>0.15</td>
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<tr>
<td>Prospect center</td>
<td>0.03</td>
<td>0.06</td>
<td>0.45</td>
<td>0.46</td>
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</tbody>
</table>

![Histogram for Gas pore volume](image)

![Scatter plot for Gas and Oil pore volumes](image)
Concluding remarks

• Pre-drill assessment of well locations

• Realistic modeling
  – seismic amplitudes
  – rock physics
  – vertical continuity in lithology–fluid and elastic parameters
  – correct ordering of fluids

• Gives realistic results
  – probability of discovery
  – hydrocarbon volumes
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