Facies modeling in unconventional reservoirs using seismic derived facies probabilities

Reinaldo J. Michelena
Omar G. Angola
Kevin S. Godbey

Presentation at the Annual Meeting of the Society of Exploration Geophysicists
Dallas, Texas, October 18-2016
Typical well density in unconventional reservoirs

Area ~ 200 square miles

Vertical wells

Horizontal wells

1 mile
### Unconventional well data inventory: example

<table>
<thead>
<tr>
<th>Wells</th>
<th>N (Verticals)</th>
<th>DT log</th>
<th>DTS log</th>
<th>RHOB log</th>
<th>GR log</th>
<th>MUD log</th>
<th>Length sampled (ft)</th>
<th>Cum production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verticals</td>
<td>13</td>
<td>10</td>
<td>6</td>
<td>13</td>
<td>13</td>
<td>6</td>
<td>thousands</td>
<td>13</td>
</tr>
<tr>
<td>Horizontals</td>
<td>582</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>582</td>
<td>563</td>
<td>millions</td>
<td>582</td>
</tr>
</tbody>
</table>

**Summary of data inventory:**
- **Verticals**: scarce, data rich
- **Horizontals**: abundant, data poor

Area ~ 200 square miles
Matrix modeling workflow in conventionals

- Petrophysical modeling
- Facies definition
- Form logs to seismic: rock physics
- Prestack seismic inversion
- Facies probabilities
- Stochastic facies modeling
- Porosity and permeability modeling
Matrix modeling workflow in unconventionals

- Petrophysical modeling
- **Facies definition** along horizontal wells
- Form logs to seismic: **rock physics** along horizontal wells
- Prestack seismic inversion
- **Facies probabilities** using horizontal wells
- Stochastic facies modeling using horizontal wells
- Porosity and permeability modeling
Matrix modeling workflow in unconventional.

- Petrophysical modeling
- **Facies definition along horizontal wells**
- Prestack seismic inversion
- **Form logs to seismic: rock physics along horizontal wells**
- **Facies probabilities using horizontal wells**
- **Stochastic facies modeling using horizontal wells**
- Porosity and permeability modeling
FACIES DEFINITION
Area of interest for geological modeling

- 1 deviated pilot well
- 8 horizontal wells

Seismic area ~ 3.6 square miles
Brittle/non-brittle facies definition along pilot well

**Rock types**

- Packstone
- Mudstone
- Clay

**GR Norm**

- Tight
- Packstone
- Mudstone
- Clay

**Brittleness**

- Brittle
- Non-brittle

**Facies**

- Brittle
- Non-brittle

70 API GR cutoff

200 ft
Brittle/non-brittle facies along horizontal wells

Facies generated using normalized LWD GR
Histograms of productivity per facies in larger area

Brittle facies are related to productivity

Data from 95 horizontal wells

Brittle (GR < 70)

Non-brittle (GR > 70)

180 days cum oil (barrels)

Length (ft)

80000

0

30000

40000

50000

60000

70000

80000

90000

30000

40000

50000

60000

70000

80000

90000

0

40000

80000

180 days cum oil (barrels)

Length (ft)
SEISMIC SCALE FACIES CALIBRATION AND MAPPING
Inverted elastic attributes along horizontal wells

Inverted AI

Inverted VpVs Ratio

Facies flags

GR < 70, Brittle
GR > 70, Non-brittle
AI vs VpVs ratio in volume of interest

Points from whole volume (population)

Inverted AI

Inverted VpVs

1.5

1.7

1.9

30000

40000

45000

© 2016 iReservoir.com, Inc.
AI vs VpVs ratio in volume of interest

Points from whole volume (population)
Points along horizontal well paths (sample)

GR < 70, Brittle (60%)
GR > 70, Non-brittle (40%)
AI vs VpVs ratio along horizontal well paths

Inverted AI vs Inverted VpVs data from 8 horizontal wells.

Brittle and Non-brittle data points are plotted.

Data from 8 horizontal wells.
Probability of brittle rock along horizontal well paths

Inverted Vp/Vs

Inverted AI

Brittle rock
Probability of brittle rock on coarse grid cells

Inverted Vp/Vs

Inverted AI

Brittle rock
Probability of brittle rock in all grid cells

Inverted Vp/Vs

Inverted AI

Brittle rock

1.5  1.7  1.9

30000  40000  45000

© 2016 Reservoir.com, Inc.
Our approach is *Frequentist*, as opposed to the most commonly used *Bayesian* approach for facies probability estimation.

*Frequentists* and *Bayesian* approaches differ mainly in the way prior information is handled.

*Frequentist* approaches are a snapshot of the reality and do not speculate about what *should be* based on our prior knowledge.

The two approaches are complementary: models used to forecast the outcome of the current US presidential election use a combination of polls and historical data.
Output* of probability estimation ("opinion poll")

\[ \text{Error} = 1.645 \sqrt{\frac{P_{\text{brittle}}(1-P_{\text{brittle}})}{n}} \]

(assuming a confidence level of 90%)

* Results extracted near the middle of the reservoir interval
Brittle rock flags vs probability along horizontal wells

Facies flag (GR < 70) (0-1)

Seismic Probability (0.5 - 0.6)

Acoustic impedance
3D FACIES MODELING
Seismic information for facies modeling

• Input
  – Probability of brittle/non-brittle rock
  – Sample size related to probability estimation
  – Margin of error in probabilities

• How is it used?
  – Only points with high probability, large sample size, and small errors are used as hard data to constrain facies modeling
  – Selection of adequate cutoffs for each variable is an iterative process
Probability of brittle facies vs margin of error

Probability estimates are more reliable for abundant brittle facies than less abundant non-brittle facies.

\[ Error = 1.645 \sqrt{\frac{P_{\text{brittle}} (1-P_{\text{brittle}})}{n}} \]
From facies log along pilot to vertical proportion curve

Depth (ft)

Layer number

Facies log

Estimated proportion

Non-brittle

Brittle

0.5 ft sampling

1.5-2.5 ft layer thickness

0 % 100
Input for stochastic (SIS) facies modeling

Selected seismic constraints  Facies proportions  Facies logs

Estimated proportion

Layer number

Non-brittle  Brittle
Vertical proportion curve modeling

20% seis points
Non Brittle: 0.42
Brittle: 0.58

10% seis points
Non Brittle: 0.44
Brittle: 0.56

8% seis points
Non Brittle: 0.32
Brittle: 0.68

6% seis points
Non Brittle: 0.32
Brittle: 0.68

3.5% seis points
Non Brittle: 0.33
Brittle: 0.67

Grid VPC using only seismic probabilities

Grid VPC using seismic probabilities and well VPC based filter

Pilot well VPC
Facies distribution for layer 5 of grid

- Probability of brittle facies
- Selected hard data points
- Facies model
Final facies model
Summary

• Disparities in data inventory between horizontal and vertical wells creates challenges for facies modeling in unconventional reservoirs that are not observed in conventionals.

• Facies definition along horizontals requires careful calibration with facies along pilot well.

• Facies probabilities are estimated from crossplots of inverted elastic properties extracted along horizontals using a Frequentist, opinion polling method. The method also yields estimates of margin of error.

• Only the most likely and most reliable information from seismic is used as hard data to constrain the stochastic facies modeling.

• The method honors the facies flags along the wells and the VPC along the pilot well.
Acknowledgements

- Thanks to BHP Billiton Petroleum for permission to present these results
- In particular, thanks to Juan-Mauricio Florez for his support during this project