ELASTIC IMPEDANCE ANALYSIS FOR METHANE AND CO$_2$ DISCRIMINATION IN COALBEDS

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OUTLINE

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• Theoretical development
  - Gassmann Fluid Substitution
  - Elastic Impedance
• Area of study
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OBJECTIVE

• Attempt to discriminate coals saturated with methane from coals saturated with CO₂ by estimating Elastic Impedance

• Evaluate the possibility of monitoring the movement of the CO₂ flood by using this attribute
Coalbed Methane

- Unconventional resource
- Dual porosity system
- Methane production
- Coal matrix deformation
Gassmann fluid substitution

\[ K^* = \frac{K_{sat} \left( \frac{\phi K_0}{K_{fl}} + 1 - \phi \right)}{\frac{\phi K_0}{K_{fl}} + \frac{K_{sat}}{K_0} - 1 - \phi} - K_0 \] 

(1)

Gassmann’s equation (1951)

Applications:

- Information for well data analysis
- AVO Response
- 4D surveys
ELASTIC IMPEDANCE (EI)

- EI derivation is based on the Aki and Richards (1980) linearization for the Zoeppritz equation

- EI is defined as:

\[
EI = V_p^{(1+\tan^2\theta)} V_s^{(-8K\sin^2\theta)} \rho^{(1-4K\sin^2\theta)}
\]  \(2\)

\(\theta = \) incidence angle

\(K = \left(\frac{V_s}{V_p}\right)^2\)

- For \(\theta=0\), EI=AI
Applications of EI:

- Calibration of far offset seismic data
- Perform a preliminary evaluation of the amplitude versus offset (AVO) response
- Changes in Elastic Impedance can be evaluated to determine a correlation with any rock property that allows us to achieve; for example, lithology or fluid discrimination
AREA OF STUDY

San Juan Basin Fruitland Coal- Location map

The Fruitland Fairway

Colorado
New Mexico

La Plata Co.
Archuleta Co.
San Juan Co.
Rio Arriba Co.

Basin Margin
Pictured Cliff Outcrop

Stratigraphic column of the San Juan Basin

Kirtland Shale
Fruitland Formation
Pictured Cliffs Sandstone
Lewis Shale
Mesaverde Group

(Figure 1 from Ramurthy and Lyons, 2007)
(Modified from Figure 2, Young et al., 1991)
METHODOLOGY: Fluid simulation

- Proxy model of the Fruitland Coal Fairway in the San Juan Basin

- Vertical single well model: it allow us to evaluate the relative permeability and relative adsorption data

- The reservoir model was developed the following properties:

<table>
<thead>
<tr>
<th>Model assumptions</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal thickness</td>
<td>15.24 m (50 ft)</td>
</tr>
<tr>
<td>Top of the coalbed</td>
<td>914.4 m (3000 ft)</td>
</tr>
<tr>
<td>Grid size</td>
<td>175x175x1</td>
</tr>
<tr>
<td>Area of study</td>
<td>31.4 km²</td>
</tr>
<tr>
<td>Absolute permeability</td>
<td>80 mD</td>
</tr>
<tr>
<td>Initial pressure</td>
<td>1616 psia</td>
</tr>
<tr>
<td>Temperature</td>
<td>41.66 °C</td>
</tr>
<tr>
<td>Initial water saturation</td>
<td>100%</td>
</tr>
</tbody>
</table>
METHODOLOGY: Fluid simulation

Reservoir model:

• Perform the production forecast of primary depletion for 24 wells in the area of study

• The production forecast started in 1999 and extends until 2031

• Perform production forecast of enhanced coalbed methane by CO$_2$ injection. In this case, 4 CO$_2$ injection wells were added to the model

• Assume that the injection started in July 2003 and was shut in October 2010 and the forecast continuous until 2031
METHODOLOGY: Gassmann fluid substitution

<table>
<thead>
<tr>
<th>Parameters for fluid substitution</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_p$</td>
<td>2450 m/s</td>
</tr>
<tr>
<td>$V_s$</td>
<td>1025 m/s</td>
</tr>
<tr>
<td>Density</td>
<td>1.6 g/cm$^3$</td>
</tr>
</tbody>
</table>

a) Sonic log of Glover Well 1, Archuleta County, San Juan Basin (Modified from Figure 6, Jones et al., 1984) and b) $V_p$, $V_s$ and density model from the Hamilton 3 well, Cedar Hill, San Juan Basin. (Figure 8, Ramos and Davis, 1997)
• Estimate the fluid properties with equations presented by Batzel and Wang (1992)

• Based on fluid simulation results, we perform a Gassmann fluid substitution for the following cases:
  - Primary production
  - Enhanced coalbed methane by CO$_2$ injection. Two years after injection started
  - One year after stopping CO$_2$ injection

• Estimate Elastic Impedance for each model
METHODOLOGY

Fluid simulation
- Vertical Single well
- Reservoir model

Fluid substitution
- Initial state: 100% Brine
- Primary production (2002 model)
- Enhanced Coalbed methane by CO\(_2\) injection. Two years after injection (2005 model)
- One year after stopping injection (2011 model)

Elastic Impedance
- Primary production (2002 model)
- Enhanced Coalbed methane by CO\(_2\) injection. Two years after injection (2005 model)
- One year after stopping injection (2011 model)
RESULTS: Fluid simulation

Methane Saturation decrease 80% to less than 15%
RESULTS: Fluid simulation

CO₂ Saturation 2002

CO₂ Saturation 2005

CO₂ Saturation 2011

CO₂ Saturation increase from 20% to 85%

★ Injector
● Producer
RESULTS: Gassmann Fluid Substitution

Vp decrease:
~ 55m/s for the primary production case
~ 65m/s after CO₂ injection

★ Injector
● Producer
RESULTS: Gassmann Fluid Substitution
RESULTS: Gassmann Fluid Substitution
RESULTS: Elastic Impedance (EI)

- $\text{CO}_2$ flood during and after injection
SUMMARY

• The fluid simulation gives us important information about the distribution of CO$_2$, methane and brine, as well as the saturation of each of them

• The fluid simulation provides the data required to perform the fluid substitution and estimate changes in $V_p$, $V_s$ and density

• The changes in $V_p$, after replacing brine by methane, were a decrease $\sim 55$m/s for the primary production case and $\sim 65$m/s after CO$_2$ injection

• The movement of the CO$_2$ flood can be appreciated in the velocity maps and it is associated to a decrease in $V_p$
SUMMARY

• In the case of the $V_s$ and density, the changes present a small magnitude

• Elastic Impedance was not able to completely differentiate the presence of CO$_2$ and methane but it was possible to monitor the movement of the CO$_2$ flood during and after injection
REFERENCES


Connolly P. 1999. Elastic Impedance. The Leading Edge 18, 438-452


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