Seismic detection of cracks in carbonates associated with potash mining

Zimin Zhang & Robert Stewart
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Outline

• Introduction

• Modeling the cracks
  ✓ Rock physics models for cracked media
  ✓ Predicting shear velocity from $V_p$ and $\rho$
  ✓ Model results

• PP and PS synthetic seismograms

• Summary
Areal distribution of potash-bearing rocks in the Elk Point Basin (from Fuzesy, 1982).
Areal distribution of potash-bearing rocks in the Elk Point Basin (from Fuzesy, 1982).
Areal distribution of potash-bearing rocks in the Elk Point Basin (from Fuzesy, 1982).
Objectives

1) Do cracked rocks have a seismic signature?
2) Can we use multicomponent seismic to detect it?
Well logs (Well A)

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>SP</th>
<th>Deep R</th>
<th>Medium R</th>
<th>SFL</th>
<th>PE</th>
<th>PHID (LS)</th>
<th>PHIN (LS)</th>
<th>GR</th>
<th>DTP</th>
<th>DTS</th>
<th>Vp/Vs</th>
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<td>0.1</td>
<td>0.1</td>
<td>0</td>
<td>0.45</td>
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</table>

Ore interval
Predicting Vs from Vp and $\rho$

$\mu = 0.0 \times M^2 + 0.2687 \times M + 1.7864$

$\mu$: shear modulus; M: P-modulus

(Han and Batzle, 2004)
Predicting Vs from Vp and ρ

\[ \mu = 0.0 \times M^2 + 0.2687 \times M + 1.7864 \]

\( \mu \): shear modulus; \( M \): P-modulus

(Han and Batzle, 2004)
Modeling cracked rocks

- Penny-shaped, water-saturated cracks in rocks using:
  - Kuster-Toksöz model: isotropic randomly oriented and distributed cracks
  - Hudson’s model: anisotropic vertically aligned cracks

- Can we detect cracks?
  - model fractures/cracks
  - find the difference between uncracked & cracked
Results of crack modeling on logs (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)

Penny-shaped cracks (aspect ratio = 0.01)

12.5% lower with cracks
Results of crack modeling on logs (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)

Penny-shaped cracks (aspect ratio = 0.01)

20% lower with cracks
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical cracks
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical cracks
Modeling cracked formations (1% crack porosity) (Dawson Bay including Second Red Bed Shale) vertical cracks

3.5% lower with cracks

vertical propagation velocity
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical cracks

Hudson Model (Vertical)

Vertical propagation velocity

26% lower with cracks

vertical propagation velocity
Modeling cracked formations (1% crack porosity)  
(Dawson Bay including Second Red Bed Shale)  
vertical cracks
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical cracks
Modeling cracked formations (1% crack porosity) 
(Dawson Bay including Second Red Bed Shale) 
vertical cracks

26% lower with cracks

horizontal propagation velocity
P-wave velocity anisotropy from vertical cracks
(the isotropic background averaged over the Dawson Bay)
P-wave velocity anisotropy from vertical cracks
(the isotropic background averaged over the Dawson Bay)

Hudson’s model
S-wave velocity anisotropy from vertical cracks (the isotropic background averaged over the Dawson Bay)

Hudson’s model
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical + horizontal cracks
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical + horizontal cracks

Propagation in XZ plane
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical + horizontal cracks
Modeling cracked formations (1% crack porosity)
(Dawson Bay including Second Red Bed Shale)
vertical + horizontal cracks

Propagation in YZ plane
Synthetic seismograms

- Ricker wavelet
- Dominant frequency (based on the amplitude spectrum of surface seismic)
  - PP section: 106Hz
  - PS section: 29Hz
PP and PS synthetic seismograms
(using Hudson’s vertical P and S velocities)
PP and PS synthetic seismograms
(using Hudson’s vertical P and S velocities)

Dimming and push down
PP and PS seismograms (zoomed)
PP and PS seismograms (zoomed)
Correlation with surface seismic
Summary

- Velocity decreases when cracks are present (Kuster-Toksöz & Hudson)
- S velocity drops significantly (over 20%)
- Vp/Vs increases with cracking
- P- and S-velocity anisotropy with aligned cracks
- Visible changes in PP and PS synthetic seismograms with cracking
- Changes in converted-waves (PS) with cracking show promise as an indicator of rock alteration
Acknowledgements

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