Facies probabilities from multidimensional crossplots of seismic attributes

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What to do with inverted seismic volumes?

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Inverted volumes from pre-stack inversion
## Motivation

<table>
<thead>
<tr>
<th>Seismic results world</th>
<th>Interpretation world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic impedance</td>
<td>Pay rock</td>
</tr>
<tr>
<td>Shear impedance</td>
<td>Brittle rock</td>
</tr>
<tr>
<td>LMR, Vp/Vs RHO</td>
<td>Porous rock</td>
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<tr>
<td>...</td>
<td>Seal rock</td>
</tr>
<tr>
<td>Multiple inverted attributes</td>
<td>One or two attributes at the time are used</td>
</tr>
<tr>
<td>Sophisticated inversion algorithms</td>
<td>Simplistic interpretation rules (usually cutoffs or polygons)</td>
</tr>
<tr>
<td>Low vertical resolution results</td>
<td>High vertical resolution needs</td>
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Objective of this presentation

- Use a field data example to show our approach based on simple probability definitions to:
  1. Map rock types of interest
  2. Analyze multiple inverted volumes at the same time
  3. Increase vertical resolution
Mamm Creek Field (Piceance Basin, Colorado)

• Ultra tight reservoir: median total porosity of 9% and median permeability ranges from 0.02 to 0.04 mD
• Complex reservoir architecture: high degree of vertical and lateral compartmentalization, particularly in fluvial sands of Williams Fork Formation (braided river system)
• Most gas production comes from fluvial sands but deeper marine sands also contribute

Sand mapping is a critical component in the development of this field
Area of interest in Mamm Creek Field: 2.5 sqm

109 highly deviated wells drilled in the study area for the time of this study
Data inventory

• **Seismic:**
  – 3D, PP pre-stack time migrated data
  – 3D PS_fast and PS_slow stack volumes (not part of same survey as PP data)

• **Well:**
  – 102 density logs. Most wells with Gamma Ray, Neutron Porosity and Resistivity
  – 3 sonic logs
  – 2 dipole sonic logs (one of them cross dipole)
  – Formation tops
  – 8 cores
Summary of inversion workflow

- Perform petrophysics/rock physics diagnostics
- QC seismic data
- Precondition pre-stack gathers for AVO analysis
- Interpret PP data
- **Interpret PS data (consistent with PP interpretation)**
- Invert PP pre-stack data for Vp, Vs and density
- **Invert PS stack data for pseudo shear impedance pSI**
- Generate velocity models that honors all marker and horizon information in PP and PS time
- Convert to depth all seismic derived information
Inverted seismic volumes in depth

- **RHO**
- **Vp**
- **Vs**

- **Fluvial**
- **Marine**

- **pSI fast**
- **pSI slow**

- **UMV**
- **MiddleSS**
Challenges from rock physics diagnostics

Potential difficulties:
1) Sands and shales show significant overlap in log scale crossplots of elastic properties.
2) Presence of thin coal layers may mask "real" seismic response from surroundings sands and shales.
Seismic scale attribute crossplots

- 5 inverted seismic attributes (3 from PP and 2 from PS) can be cross plotted in many different ways
- Focus only on 6 of such combinations:
  - $V_p$ vs $V_s$
  - $V_p$ vs $\rho$
  - $V_s$ vs $\rho$
  - $pSI\_fast$ vs $pSI\_slow$
  - $V_p$ vs $V_s$ vs $\rho$
  - $V_p$ vs $V_s$ vs $\rho$ vs $pSI\_fast$ vs $pSI\_slow$

Two dimensions

Three dimensions

Five dimensions
Seismic attribute extracted at well locations

Sampling interval: 1 ft

Price Coal
UMV
MiddleSS
Rollins
Cozette
Mancos

Inverted density trace
Sand flags based on lithology rules

Sampling interval: 1 ft
Thick sands facies (~> 15 feet) from sand flags

Sampling interval: 1 ft
Seismic scale crossplots (color = log scale facies)

thick sand background

- Vp vs Vs
- RHO vs Vp
- RHO vs Vs
- pSI slow vs pSI fast
Log scale crossplots (color = lithology)

- $V_p$ vs $V_s$
- $RHO$ vs $V_p$
- $RHO$ vs $V_s$
- $pSI$ slow vs $pSI$ fast

Sands
Seismic scale crossplots (color = log scale facies)

- thick sand background

- pSI fast

- pSI slow

- Vp

- Vs

- RHO
Probabilities from seismic attribute crossplots

Higher probability of red

Channel

No channel

Lower probability of red

(2/7)

(5/9)
Comments about facies probability estimation

• Data driven. No rock physics model is used to relate inverted attributes and rock types of interest
• Based on simple probability definitions
• Bayes’ formula could be also applied if a reliable prior can be built
• Works best when the response of the target rock is clustered
• Probabilities can be interpreted as seismic scale estimates of net-to-gross
Seismic scale Vp vs RHO (color= sand probability)
Sand probabilities from seismic

Rho  Vp  Vs

pSI_fast  pSI_slow

Thick sand probability

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Los scale QC at well 21B-28 (marine interval)

MIDDLE SANDSTONE

ROLLINS

Gamma Ray Lithology Sand flag Ave sand 2 2 2 3 5
Vp, Vs Vp, Rho Vs, Rho Vp, Vs, Rho Vp, Vs, Rho, 3C

Inverted RHO trace

# of attributes

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NTG from wells vs NTG from seismic (fluvial int)

- **Channel probabilities generated from 5-dimensional crossplots**

- **Sand NTG from interpolation of well data**

- **Average sand probability from seismic**

- **R² = 0.70**

- **Net to gross probability from seismic**
Analog braided river system

Google Earth, 2010
Base of Big Kahuna – Stratigraphic slide

- Flood plains
- Main river edge

Thick sand probability

2000 ft

Base

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River sediments

Base of Big Kahuna minus 100 ft

Thick sand probability

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Base of Big Kahuna minus 200 ft
Base of Big Kahuna minus 300 ft
Base of Big Kahuna minus 400 ft

Upstream: probably two different sources of sediments
Conclusions from Mamm Creek field

- Facies probability estimation from multidimensional crossplots of seismic attributes yields useful, high resolution results even when elastic properties of sandy and background facies completely overlap
- PP data yields the best results when using Vp, Vs, and RHO simultaneously
- The best separation is achieved when using all five attributes from PP and PS data
- Crossplots provide an adequate framework for joint analysis of multiple seismic scale attributes and log scale information
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