Workshop Introduction:

Pitfalls in salt imaging and interpretation

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Introduction

The overall theme of this workshop is the uncertainty related to interpreting imperfect salt images.

In this brief introductory overview, we’ll outline some of the known pitfalls related to both the description, pre-processing, imaging, and interpretation of salt structures.
Potential concerns:

- Our ability to adequately describe geological reality
- Inappropriate pre-processing
- Poor illumination
- Historic time imaging pitfalls
- One-way versus two-way imaging issues
- Anisotropy representation
- Anisotropy parameterisation
- Refraction events
- Mode converted events
- Stress-induced effects
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Salt itself is anisotropic (~7%) due to flow and/or stress induced grain elongation - but we usually ignore this!
Salt has complex internal structure: Flow induced - often can’t see this seismically, so can’t incorporate it.
Salt bodies may be composed of different evaporites - but we often use a constant velocity hardness and density to assess their properties.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Composition</th>
<th>Hardness</th>
<th>Density $\text{kgm}^{-3}$</th>
<th>Velocity $\text{ms}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Halite</td>
<td>NaCl</td>
<td>2.5</td>
<td>2200</td>
<td>4500</td>
</tr>
<tr>
<td>Gypsum</td>
<td>CaSO$_4 \cdot 2\text{H}_2\text{O}$</td>
<td>1.5-2</td>
<td>2300</td>
<td>5700</td>
</tr>
<tr>
<td>Anhydrite</td>
<td>CaSO$_4$</td>
<td>3.5</td>
<td>2900</td>
<td>6500</td>
</tr>
<tr>
<td>Tachydrite</td>
<td>CaMg$_2$Cl$_6 \cdot 12\text{H}_2\text{O}$</td>
<td>2</td>
<td>1660</td>
<td>3500</td>
</tr>
<tr>
<td>Sylvite</td>
<td>KCl</td>
<td>1.5-2</td>
<td>1990</td>
<td>4110</td>
</tr>
<tr>
<td>Carnallite</td>
<td>KMgCl$_3 \cdot 6$(H$_2$O)</td>
<td>2.5</td>
<td>1600</td>
<td>3900</td>
</tr>
<tr>
<td>Kieserite</td>
<td>MgSO$_4 \cdot \text{H}_2\text{O}$</td>
<td>3.5</td>
<td>2550</td>
<td>?</td>
</tr>
<tr>
<td>Langbeinite</td>
<td>K$_2$SO$_4 \cdot 2\text{H}_2\text{O}$</td>
<td>3.5-4</td>
<td>2820</td>
<td>5860</td>
</tr>
<tr>
<td>Polyhalite</td>
<td>K$_2$SO$_4 \cdot \text{MgSO}_4 \cdot 2\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$</td>
<td>2.5-3.5</td>
<td>2790</td>
<td>5300</td>
</tr>
<tr>
<td>Dolomite</td>
<td>CaCO$_3 \cdot \text{MgCO}_3$</td>
<td>3.5-4</td>
<td>2870</td>
<td>6300</td>
</tr>
</tbody>
</table>
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$V_{\text{int}}(z)$
Double bounce crossing-ray: flat T.Balder to overhanging salt

Double bounce: flat T.Balder to dipping T.Balder

Single bounce at dipping part of T.Balder

Double bounce: overhanging salt to dipping T.Balder

Double bounce: overhanging salt to flat T.Balder

Single bounce at flat part of T.Balder

CMP 2280

x=8 km

Top Chalk

Base Chalk

Top Balder

Top Hod

Bottom Balder
FD elastic modelled data (E3D CMPs)

Double bounce (DB) prism events
These synthetic data have many SALT FLANK reflections. In this migration with a ‘no-salt’ model, the flanks correctly appear due to the imaging condition for sediment-only raypaths.
These synthetic data have many SALT FLANK reflections. They have been damaged by the conventional demultiple + denoise processing on the input data.
Input NMO’d CMP gathers

Image shown courtesy of Talisman Sinopec Energy UK and partners GdF-Suez, EON, & Idemitsu. Input data courtesy of CGG
Radon CMP Gathers

Image shown courtesy of Talisman Sinopec Energy UK and partners GdF-Suez, EON, & Idemitsu. Input data courtesy of CGG
RTM using preliminary starting model on original input

Image shown courtesy of Talisman Sinopec Energy UK and partners GdF-Suez, EON, & Idemitsu. Input data courtesy of CGG
RTM using preliminary starting model on Radon input

Image shown courtesy of Talisman Sinopec Energy UK and partners GdF-Suez, EON, & Idemitsu. Input data courtesy of CGG
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Typical path taken by the rays that illuminate the target zone.
Reflection point count on Top Reservoir (based on 200m source and receiver grid)

poor illumination on target
Poor illumination on flanks.
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False mushroom shape

Stack

Sketches courtesy of Dave Waltham
False mushroom shape

Sketches courtesy of Dave Waltham
False mushroom shape

Interpretation

Sketches courtesy of Dave Waltham
False mushroom shape

The flank wells are in salt
Through-salt PPPP and PSSP ray paths

The model has no ‘base salt’
Through-salt PPPP and PSSP ray paths
preSTM: through-salt PPPP and PSSP ray paths?

- Top salt (and/or anhydrite cap)
- Mid-Miocene unconformity
- Top Balder
- Top Chalk
- Base Chalk
- False base salt reflection?
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WEM
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Conventionally, for a TTI medium we assume that $V_{\text{fast}}$ is parallel to the bedding planes (at least for post-depositional deformation)
With stress-induced fractures, $V_{\text{fast}}$ is not as fast as in an unfractured medium.

Is the TTI ‘$V_{\text{fast}}$’ slower than $V_{\text{slow}}$?!

Need for orthorhombic rather than TTI characterisation.
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TTI Lower Tertiary epsilon - 14% (initial model)

Image shown courtesy of Talisman Sinopec Energy UK and partners GdF-Suez, EON, & Idemitsu. Input data courtesy of CGG
TTI Lower Tertiary epsilon - 20%

Image shown courtesy of Talisman Sinopec Energy UK and partners GdF-Suez, EON, & Idemitsu. Input data courtesy of CGG
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Dave Waltham, pers. comm.
Example courtesy of Markus Mohr
Head wave bounce off salt

Legitimate double bounce

Critical refraction

Salt
Vint(z) with salt

4.4km to salt wall

9km cable length

4500m/s

2000m/s

4000m/s

10km model width

True aspect ratio

Shot location

Top chalk reflector

Salt body

Sediment

1km
Shot, 4.4km from wall

4.4km to salt wall

9km cable length

Direct arrival
Primary chalk reflection
Other stuff
Shot, 4.4km from wall

Primary chalk reflections
Shot, 4.4km from wall

Top salt ‘direct’ scattered events

Top salt ‘direct’ scattered events
Shot, 4.4km from wall

Double bounce (prism wave)
Shot, 4.4km from wall

Double bounce (prism wave)

Point of tangency special case (same travel time)
Shot, 4.4km from wall

Farthest reflected refraction (pseudo prism wave) arrival is at ~ 3.6km, Arrival time also ~4.3s
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Nomenclature for various P and S ray paths

- PPPP
  - Top salt
  - Base salt

- PSPP

- PPSP

- PSSP
S-Wave Salt Flood Depth Migration
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Stress increased in vicinity of salt weld

Salt pillow

Migration pull-up of underlying features
Salt

Migration pull-up of underlying features
Summary

The overall theme of this workshop is the uncertainty related to interpreting imperfect salt images.

Clearly, it is important to have an understanding of the possible sources of imperfection and confusion when working with complex salt imaging, and to take these effects into account during interpretation.
Unused slides
Vint(z) with salt: showing primary chalk reflections

True aspect ratio

Measure head wave wall-bounce arrival times…
Vint(z) with salt: showing top salt scattered reflections

True aspect ratio

Measure head wave wall-bounce arrival times…
Vint(z) with salt: showing double bounce reflections (prism waves)

True aspect ratio

Measure head wave wall-bounce arrival times…
Vint(z) with salt: showing double bounce reflections (prism waves) and simple chalk reflection

6km max offset for single reflection
3km offset for farthest double bounce

Point of tangency special case (same travel time)

Double bounce arrival
Simple chalk reflection

4500m/s
2000m/s
4000m/s

1km
t

10km model width

True aspect ratio

Measure head wave wall-bounce arrival times…
Vint(z) with salt: showing reflected refractions (pseudo prism waves)

- 5.25km offset for farthest headwave
- 3.6km offset for farthest reflected refraction
- 3.46km critical angle offset

- Farthest headwave arrival is at ~ 5.25km, Arrival time ~4.3s
- Farthest reflected refraction (pseudo prism wave) arrival is at ~ 3.6km, Arrival time also ~4.3s

- Refraction travels 1.7km @4km/s = 0.86s
- 4500m/s
- 2000m/s
- 4000m/s

1km model width

True aspect ratio

Measure head wave wall-bounce arrival times…