Project overview

Sleipner CO₂ plume

TNO | Knowledge for business

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Sleipner CO$_2$ injection

CO$_2$ injection commenced 1996
~ 1 Mt CO$_2$ injected per annum
> 11 Mt currently *in situ*

**Time-lapse monitoring**
1994  3D seismic baseline
1999  3D seismic
2001  3D seismic
2002  3D seismic
2004  3D seismic
2006  3D seismic
2008  3D seismic
[2D hi-res]
[Seabed gravity]
[CSEM]
[Seabed imaging]

Courtesy CO2STORE
Sleipner: the reservoir
Sleipner: Forward modelling
Detailed synthetic modeling of the seismic response

- Top reservoir
- Bottom reservoir
- Thickness of 127 m
- TWT of 123 ms
- Tuning effect at the top of the reservoir
- "Push-down" effect below the CO₂ accumulation

- Thickness CO₂ accumulation below the shale barriers (m)
- Amplitude (blue trough)

- Sand
- CO₂
- Shale

EBN-TNO amplitude conference

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Aim
(EU CO₂ReMoVe)

- Study Sleipner CO₂ plume
  - Development through time
  - Focus on “undisturbed” top layer
  - Confirm properties of CO₂ filled Utsira reservoir

- Method
  - Shot gathers from Inline data (2D)
  - Common Focus Point (CFP)
    → AVP data
  - AVP data → rock physics
CFP work flow (1)

Shot gathers

Operators

DTS

CFP gathers

Grid point $g$

After Berkhout
Local characterization

Amplitude (p)

Reflectivity gather

τ - p transform

After Berkhout; Winthaegen
CFP work flow (2)

- Shot gathers
- Operators
- DTS
- CFP gathers
- Grid point g.

After Berkhout

Amplitude
Velocity
Time lapse CFP work flow

Baseline

Shot gathers

Operators

DTS

CFP gathers

Grid point g.

Cross focusing
(cross equalization: travel time, amplitude)

Saturation

Stress

Pore fluid

Amplitude

Velocity

Amplitude

Velocity

Shot gathers

Operators

DTS

CFP gathers

Grid point g.

After Winthaegen
Cross focusing: travel time

Redatum source and receivers (new acquisition level)

Baseline survey

Monitor survey

\[ \approx (\Rightarrow \Delta t) \]

Use the same operator for the monitor survey and update (in case of changes)

Note: focusing includes regularization/interpolation at new datum level

After Winthaegen
Focusing: time correction

Operator \((A,t)\) for overburden

Differential time = 0

Reflectivity After Winthaegen
Cross equalization: time

Apply kinematic correction using the base line operator to the monitor data (and update)

Operator (A,t) for overburden

?? T_{Otl} = T_{Obl}

DTS

Reflectivity
Cross equalization: amplitude

\[ A_{\text{Stl}} = 4A_{\text{Sbl}} \]

\[ A_{\text{OtI}} = 0.5 A_{\text{Obl}} \]

Datum = 0

Changed reservoir \( \neq 0 \)

Reflectivity (AVP)
2008 data set

- CFP processing on top Utsira Fm
- Clear reflection in plume, weak reflection elsewhere
2008 data set
AVP Top Utsira

• AVP panel

• AVP curves
  • red: ‘left’ of plume
  • green: ‘in’ plume
  • blue: ‘right’ of plume

• Data contain interval (approx.)
  $4 \times 10^{-5} < p < 0.0003$
2008 data set
Synthetic AVP curves

- Plume zone higher amplitude
- Plume zone higher gradient
Plume AVP panels

- Plume imprint on data increases
- Consistent results for time lapse surveys
AVP curves

- Red: ‘left’ of plume
- Green: ‘in’ plume
- Blue: ‘right’ of plume

- Data contain interval (approx.)
  4e-5 < p < 0.0003

- Interference from shallower reflections
  - Restricts validity of results to interval 0<p<0.0002 (approx.)

- More far offsets in more recent data sets
Future work

- Interpretation in terms of rock physics
- Image and analyse deeper parts of the plume (next slide)
First reflections inside plume
AVP panels and curves
Sleipner surveys
Inline through plume