

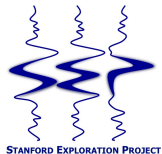
Cyclic 1D matching of time-lapse seismic data sets: A case study of the Norne Field

Gboyega Ayeni

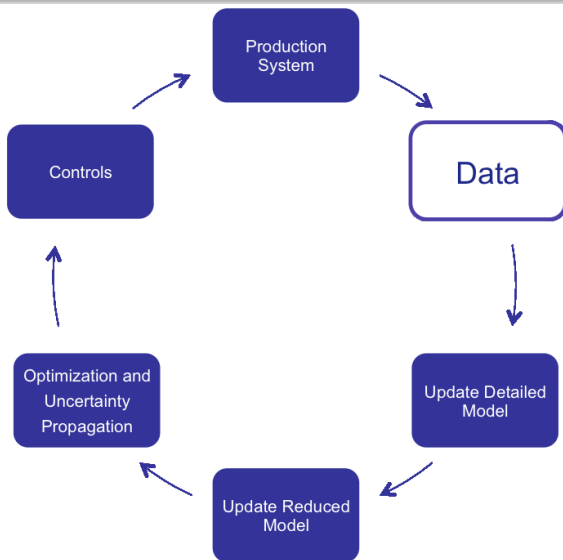
Stanford Exploration Project
Geophysics Department
Stanford University, CA, US



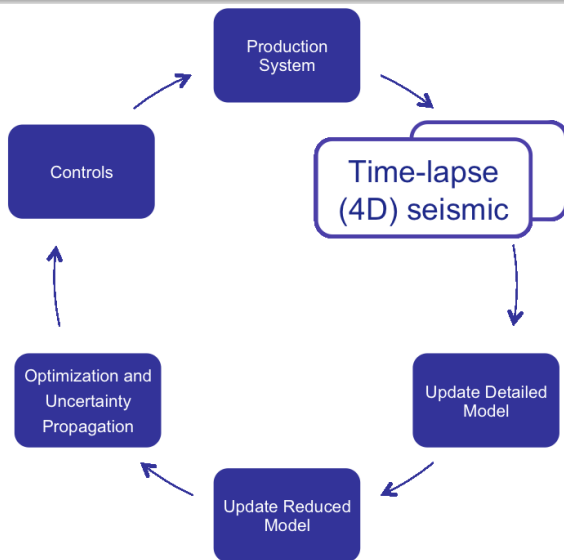
SEP Annual Meeting
May 26, 2010
(SEP140: Pg 193-210)



Stanford Smart Fields



Stanford Smart Fields

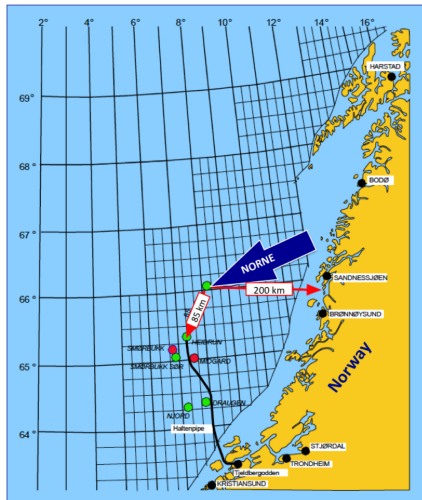


Outline

- 1 Introduction
- 2 Method
 - Time-lapse seismic processing
 - Vertical displacements, strain & velocity change
 - Lateral displacements
 - Optimized match-filtering
- 3 Results
 - Apparent Displacements
 - Velocity change
 - Amplitude change
 - Oil-water contact
- 4 Conclusions
 - Conclusions
 - Future work

Norne Field: Intro

① Location: South Nordland II (Norwegian Sea)

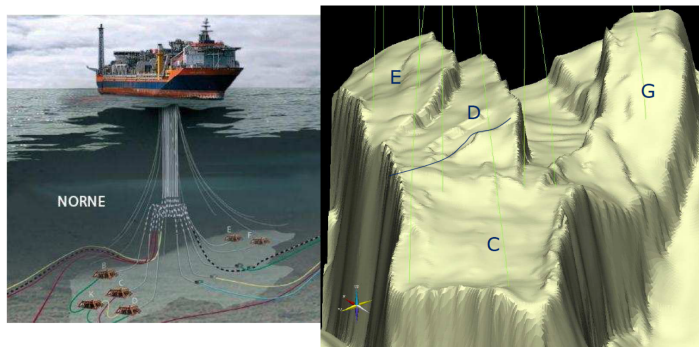


STATOIL Annual Report (2006)



Norne Field: Intro

- 1 **Location:** South Nordland II (Norwegian Sea)
- 2 **Main field:** a horst block ($\sim 9 \text{ km} \times 3 \text{ km}$)



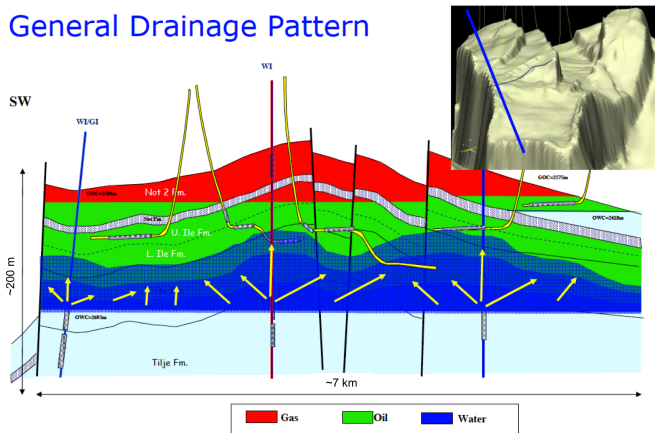
Source: N. Cheng & B. Osdal, 2008, Updating the Norne Reservoir Model Using 4D Seismic Data. IOCenter workshop on reservoir management, Trondheim, Norway



Norne Field: Intro

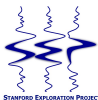
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General Drainage Pattern



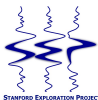
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- 2 **Main field:** a horst block ($\sim 9 \text{ km} \times 3 \text{ km}$)
- 3 **Reservoir rocks:** Lower and Middle Jurassic sandstones
- 4 **Reserves:**
 - Gas cap: $\sim 75 \text{ m}$ thick mainly in the Garn formation
 - Oil leg: $\sim 110 \text{ m}$ thick mainly in Ile and Tofte formations
- 5 **Reservoir quality (very good):**
 - Porosity: 25–32%,
 - Permeability: 200–2000mD
 - Net-to-gross: ~ 1



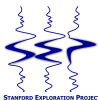
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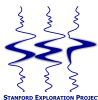
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Summary: Post-imaging time-lapse seismic processing

- **Image alignment**

- Estimate apparent displacements between baseline and monitor
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- Remove displacements between baseline and monitor



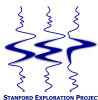
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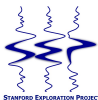
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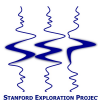
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● Match-filtering

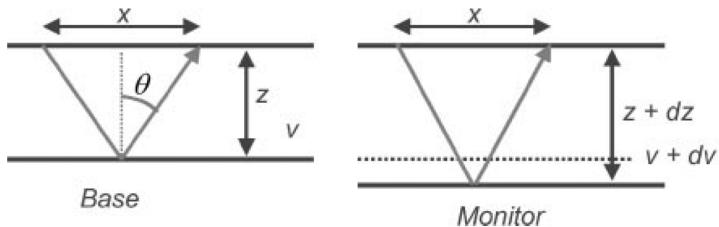
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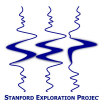
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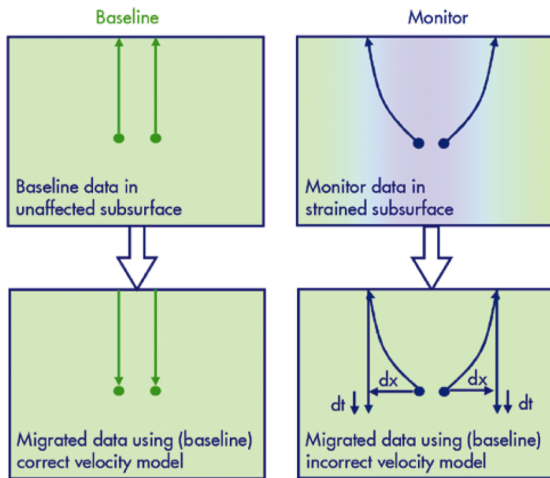
Apparent displacements



Adapted from: Landrø, M., & Stammeijer, J., 2004, Quantitative estimation of compaction and velocity changes using 4D impedance and traveltime changes, *Geophysics*, **69**, 949-957



Apparent displacements



Adapted from: Cox, B., & P. Hatchell, 2007, Straightening out lateral shifts in time-lapse seismic, First Break, 26, 93-98



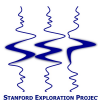
Velocity, depth and travel time changes

$$dz = v dt$$

dz : depth interval

v : baseline velocity

dt : vertical travel time



Velocity, depth and travel time changes

$$dz = v dt$$

$$d(\delta z) = \delta v dt + v d(\delta t)$$

dz : depth interval

v : baseline velocity

dt : vertical travel time

δz : change in depth

δv : change in velocity

δt : change in travel time

assumption: $\delta z \ll dz$; $\delta v \ll dv$; $\delta t \ll dt$



Velocity, depth and travel time changes

$$dz = v dt$$

$$\frac{d(\delta z)}{dz} = \frac{\delta v}{v} + \frac{d(\delta t)}{dt} = \epsilon_{zz}$$

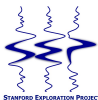
dz : depth interval

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$d(\delta z)/dz = \epsilon_{zz}$: vertical “depth” strain

$d(\delta t)/dt = \epsilon_{tt}$: apparent “time” strain



Velocity, depth and travel time changes

$$dz = v dt$$

$$\frac{\delta v}{v} = -R\epsilon_{zz} = -\frac{R}{1+R}\epsilon_{tt}$$

dz : depth interval

v : baseline velocity

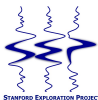
dt : vertical travel time

$d(\delta z)/dz = \epsilon_{zz}$: vertical “depth” strain

$d(\delta t)/dt = \epsilon_{tt}$: apparent “time” strain

R : dilation factor

travel time changes due to velocity vs. path length changes



Velocity change and vertical strain

$$\delta v = -v \cdot \frac{R}{1+R} \frac{d(\delta t)}{dt}$$

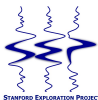
$$\epsilon_{zz} = -\frac{1}{R} \frac{\delta v}{v}$$

R varies from **1** to **6**.

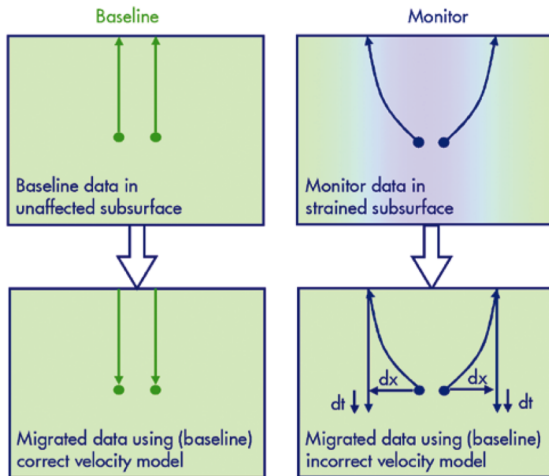
For most common reservoir rocks R varies from **5** to **6**

Cox, B., & P. Hatchell, 2007, Straightening out lateral shifts in time-lapse seismic, *First Break*, 26, 93-98

Hodgson et al., 2007, Inverting for reservoir pressure change using time-lapse time-strain: Application to the Genesis Field, Gulf of Mexico, *Leading Edge*, 26, 649-654



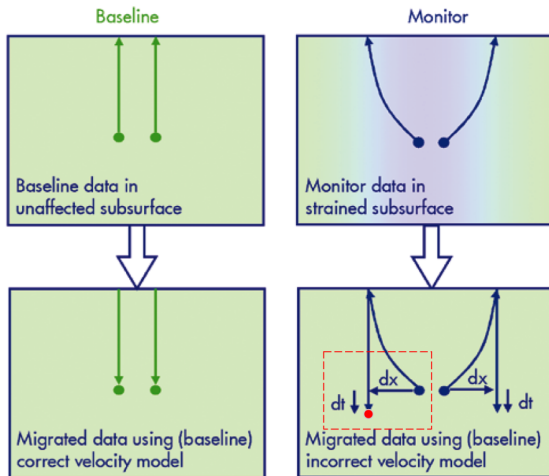
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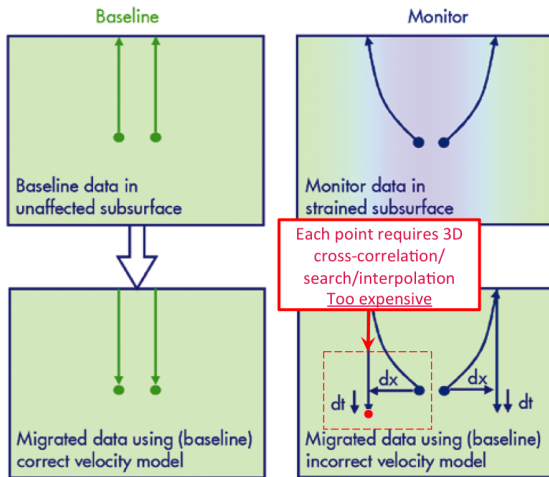
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1D cyclic search

Algorithm 1: Apparent displacements by 1D cyclic search

```

while  $s_{max}^{ia=1:3} \geq s_{stop}^{ia=1:3}; j = 1 : j_{max}$  do
  for  $axis = 1:3$  do
    if  $axis = 1$  then
       $s^1 = s[xcorr_{peak}(m_j|b)]$ 
       $z^1 \leftarrow s^1 < z^1 > + s^1$ 
       $z^2 \leftarrow s^1 < z^2 >$ 
       $z^3 \leftarrow s^1 < z^3 >$ 
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s : shifts

z : cumulative displacements

b : filtered base

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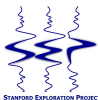
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Hale, D., 2009, A method for estimating apparent displacement vectors from time-lapse seismic images: *Geophysics*, 74, V99-V107



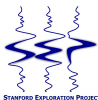
1D cyclic search

- Pre-process data: remove low frequencies in all directions
- Sequentially perform cyclic 1D search for correlation peaks along the different coordinate axes (vertical, inline, cross-line)



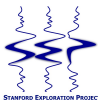
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1D iterative match filtering

$$\mathbf{F}(\omega) = \frac{\overline{\mathbf{M}}(\omega)\mathbf{B}(\omega)}{\overline{\mathbf{M}}(\omega)\mathbf{M}(\omega) + \epsilon^2}$$

$\mathbf{F}(\omega)$: Match-filter

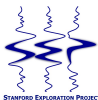
$\mathbf{B}(\omega)$: Baseline data

$\mathbf{M}(\omega)$: Monitor data

ϵ : Damping factor

ω : Frequency

Ref: Ayeni, G., and Nasser, M., 2009, Optimized local matching of time-lapse seismic data: A case study from the Gulf of Mexico, SEG Technical Program Expanded Abstracts, 28, 3939-3943

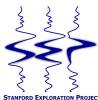


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Perform parameter optimization by Evolutionary Programming

Ref: Ayeni, G., and Nasser, M., 2009, **Optimized local matching of time-lapse seismic data: A case study from the Gulf of Mexico**, SEG Technical Program Expanded Abstracts, 28, 3939-3943



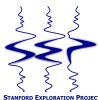
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Optimization parameters:

- Estimation window: trace segments, tapering, etc
- Filter length
- Epsilon

Ref: Ayeni, G., and Nasser, M., 2009, *Optimized local matching of time-lapse seismic data: A case study from the Gulf of Mexico*, SEG Technical Program Expanded Abstracts, 28, 3939-3943

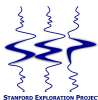


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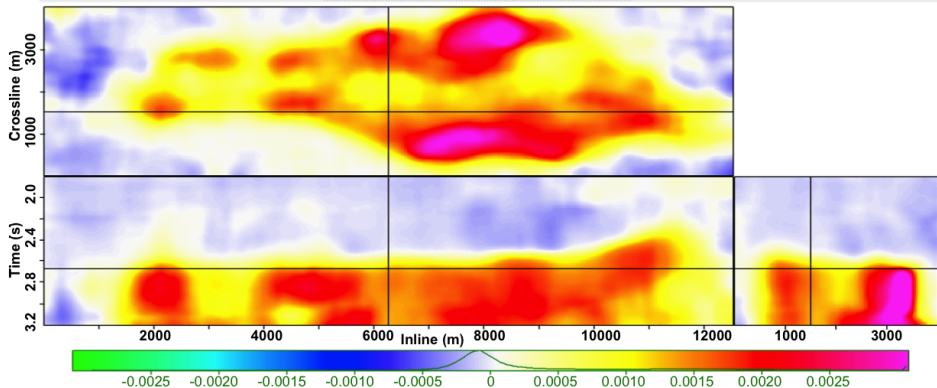
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Data

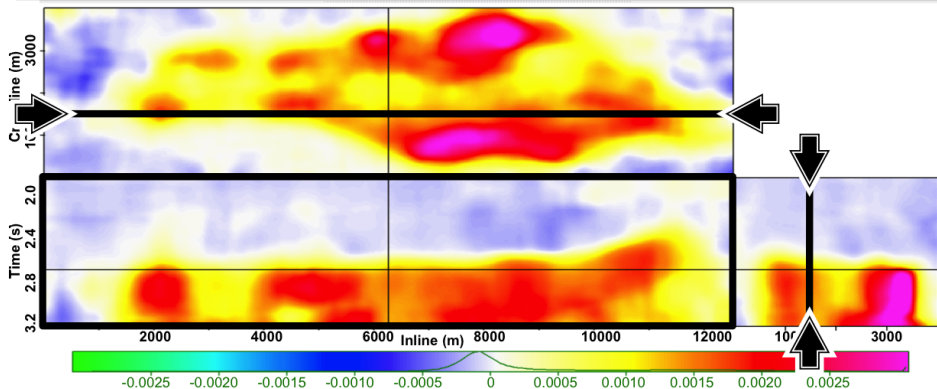
- Four PSTM seismic data sets
- 2001 (Baseline), 2003, 2004, 2006



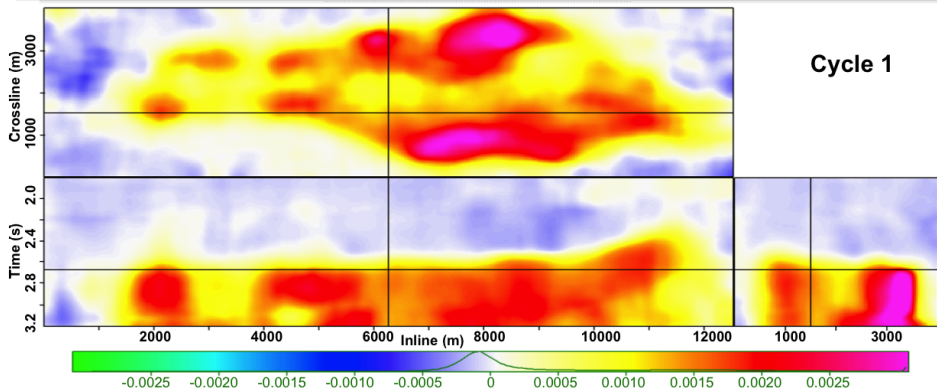
Vertical-shifts [2006-2001] (δt |sec)



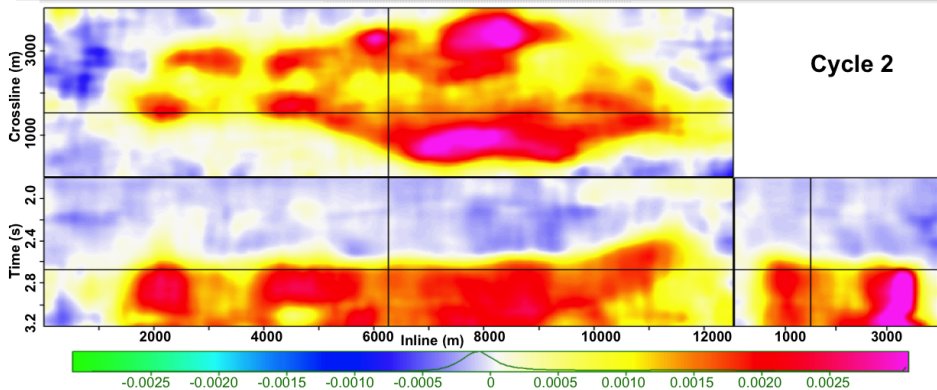
Vertical-shifts [2006-2001] (δt |sec)



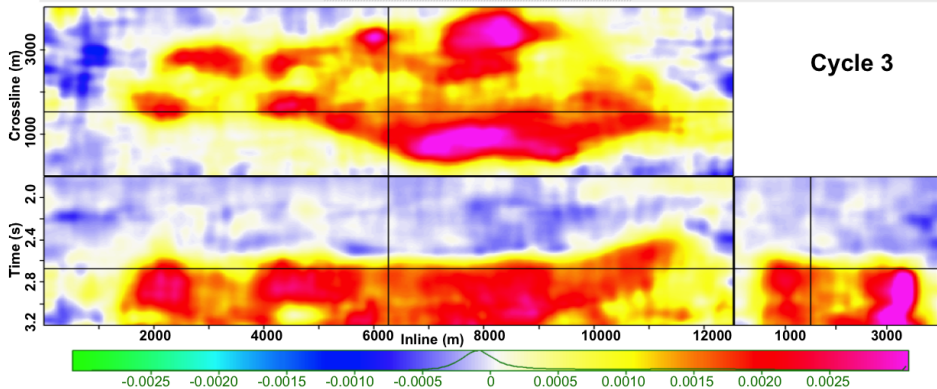
Vertical-shifts [2006-2001] (δt |sec)



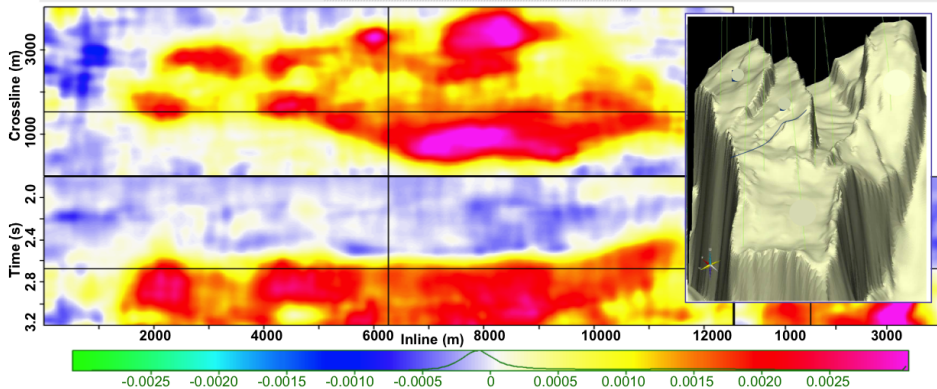
Vertical-shifts [2006-2001] (δt |sec)



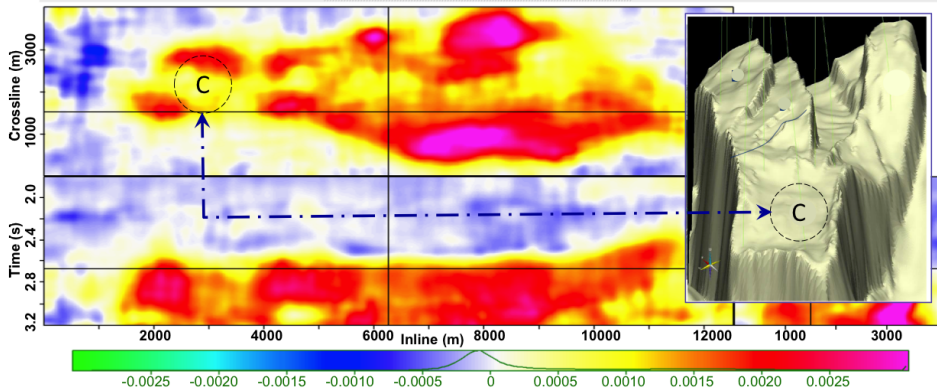
Vertical-shifts [2006-2001] (δt |sec)



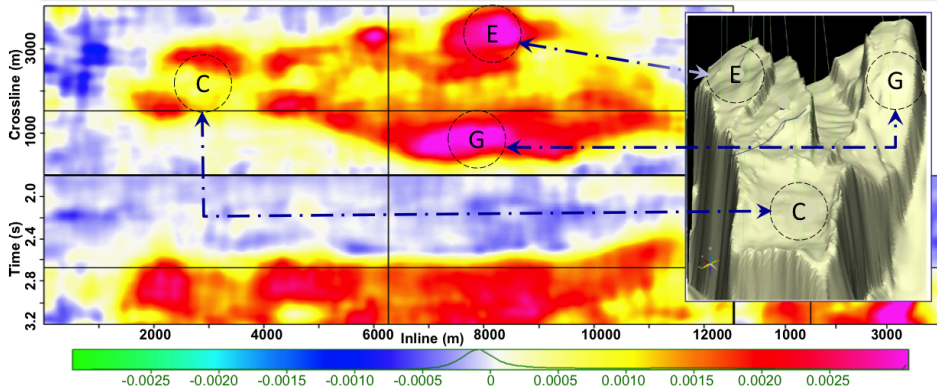
Vertical-shifts [2006-2001] (δt |sec)



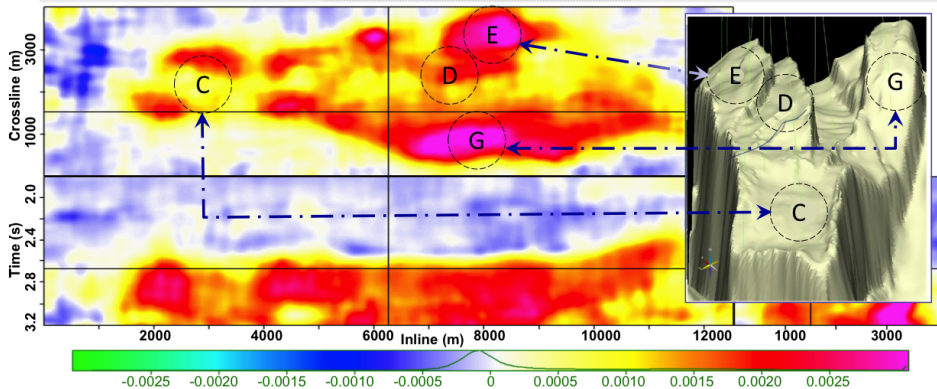
Vertical-shifts [2006-2001] (δt |sec)



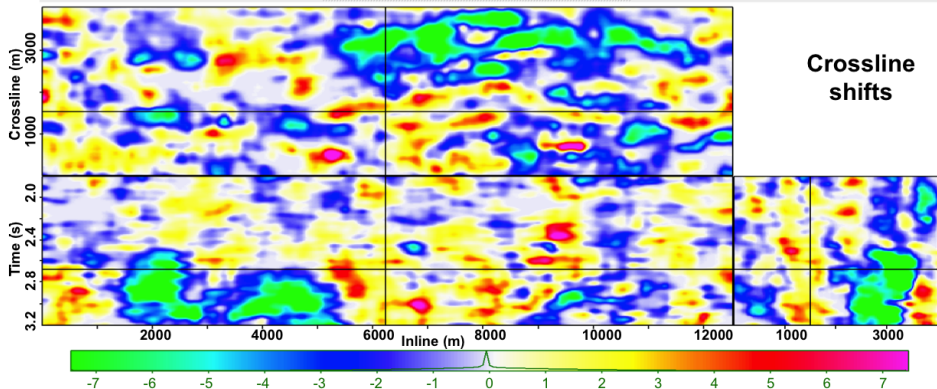
Vertical-shifts [2006-2001] (δt |sec)



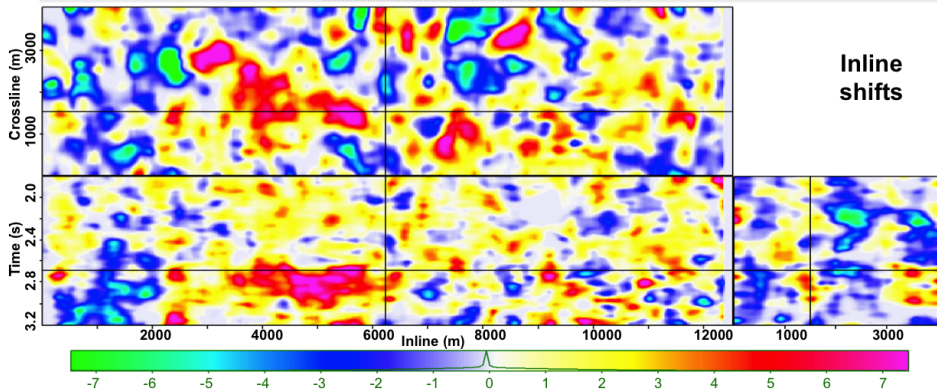
Vertical-shifts [2006-2001] (δt |sec)



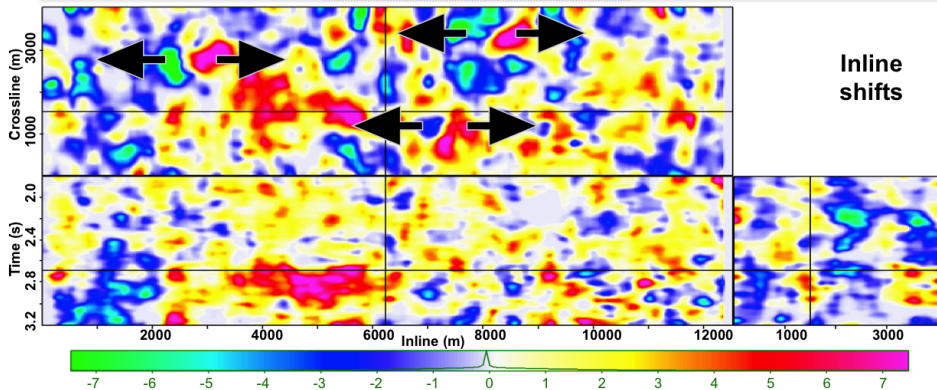
Crossline-shifts [2006-2001] ($\delta y|m$)



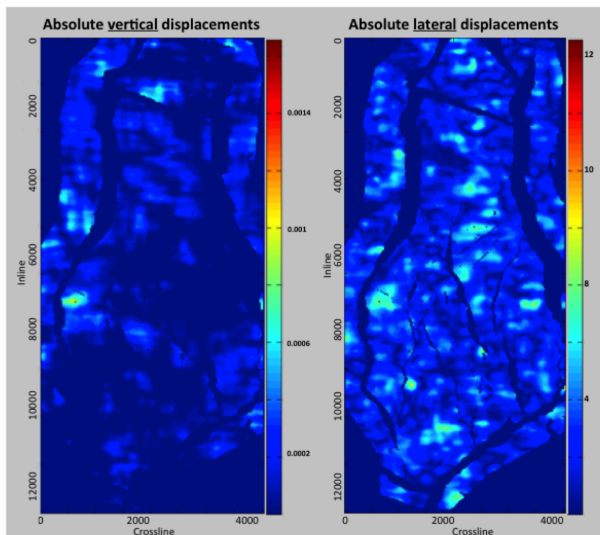
Inline-shifts [2006-2001] ($\delta x|m$)



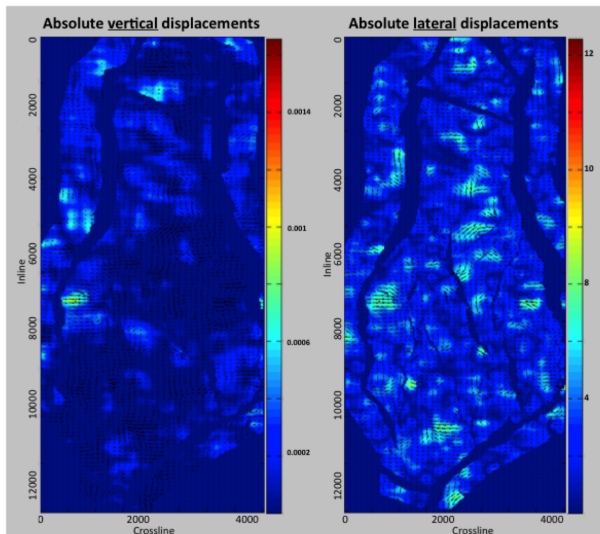
Inline-shifts [2006-2001] ($\delta x|m$)



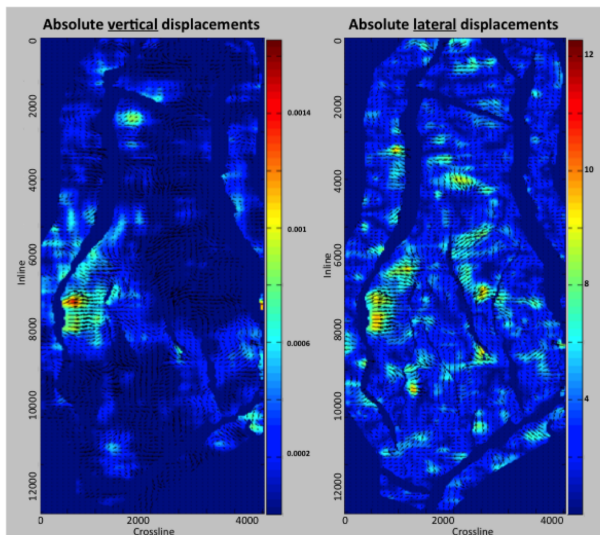
Spatial distribution of shifts [2003-2001]



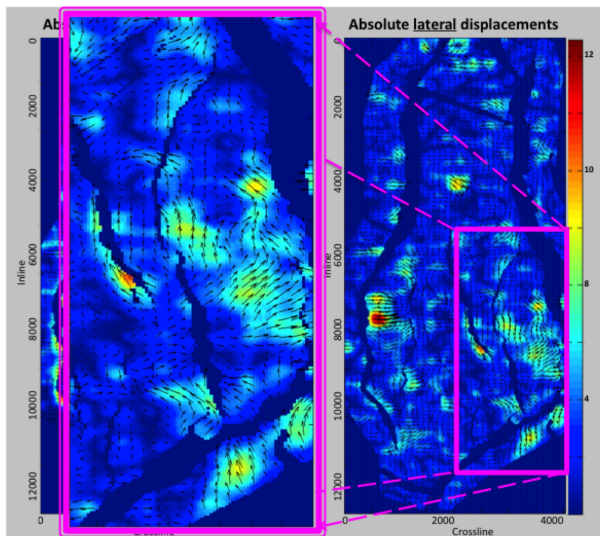
Spatial distribution of shifts [2003-2001]



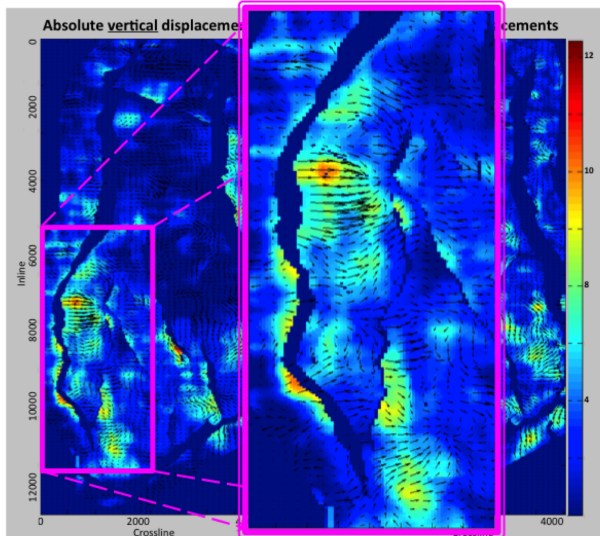
Spatial distribution of shifts [2004-2001]



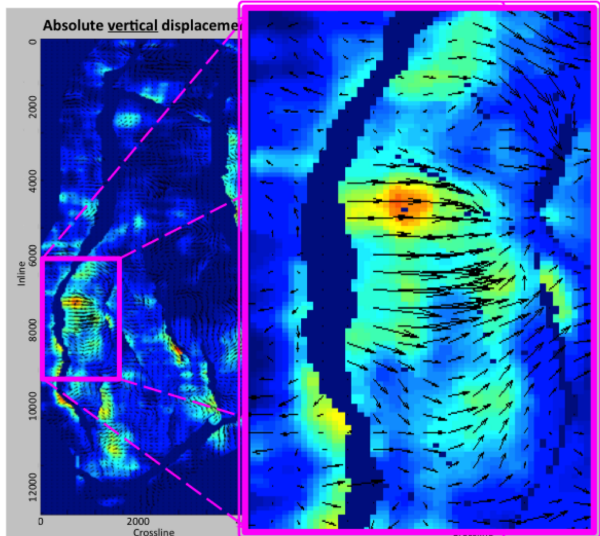
Spatial distribution of shifts [2006-2001]



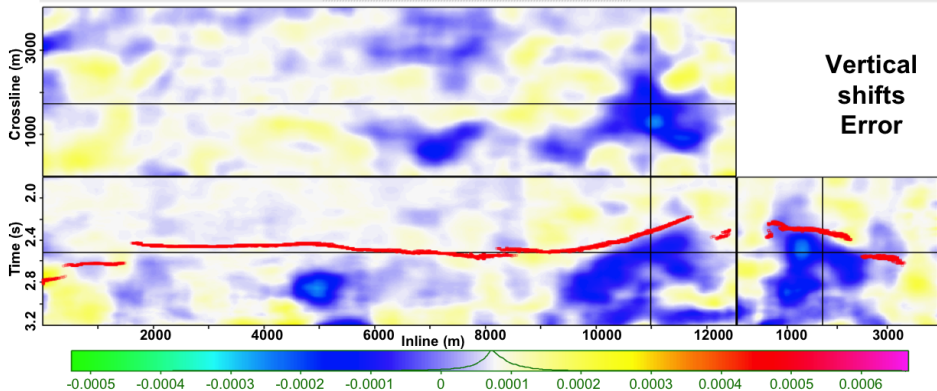
Spatial distribution of shifts [2006-2001]



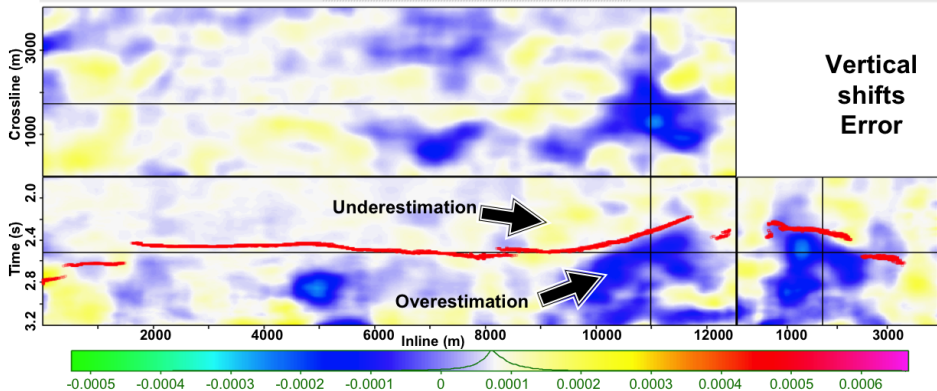
Spatial distribution of shifts [2006-2001]



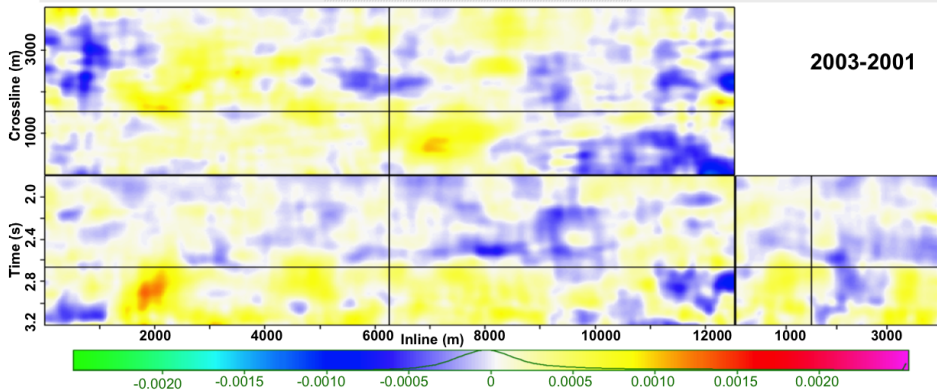
Vertical-shifts Error [2006-2001] ($[\delta t^{xyz} - \delta t^z]$)



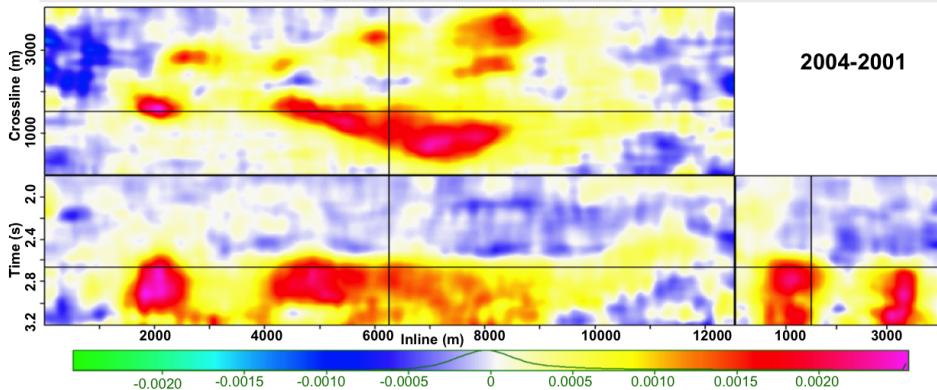
Vertical-shifts Error [2006-2001] ($[\delta t^{xyz} - \delta t^z]$)



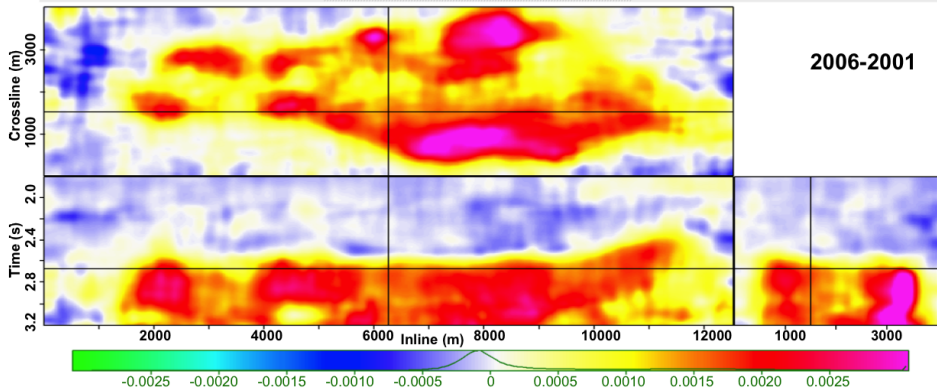
Vertical-shifts [2003-2001] (δt |sec)



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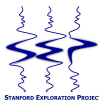


Vertical-shifts [2006-2001] (δt |sec)

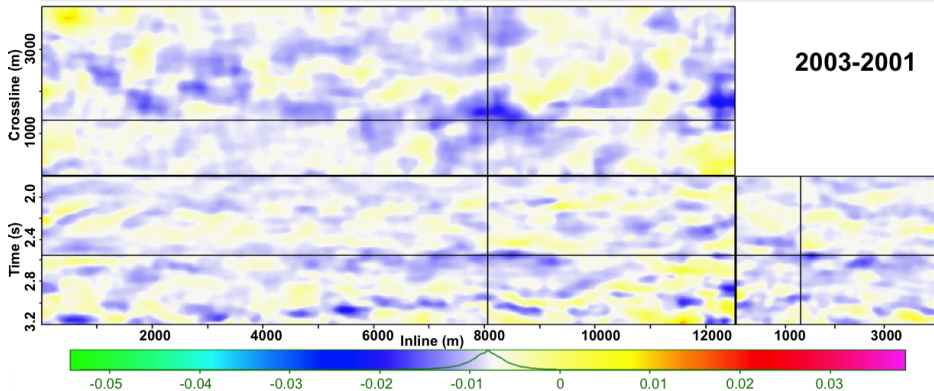


Velocity change

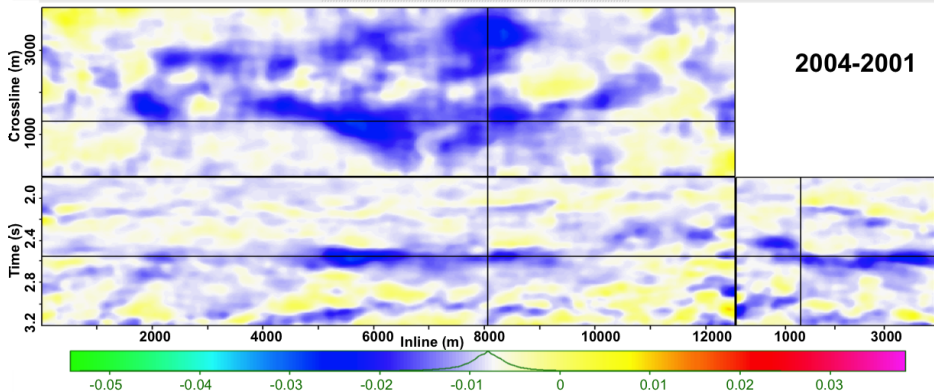
- Related to compaction, permeability, saturation and other changes in and around the reservoir



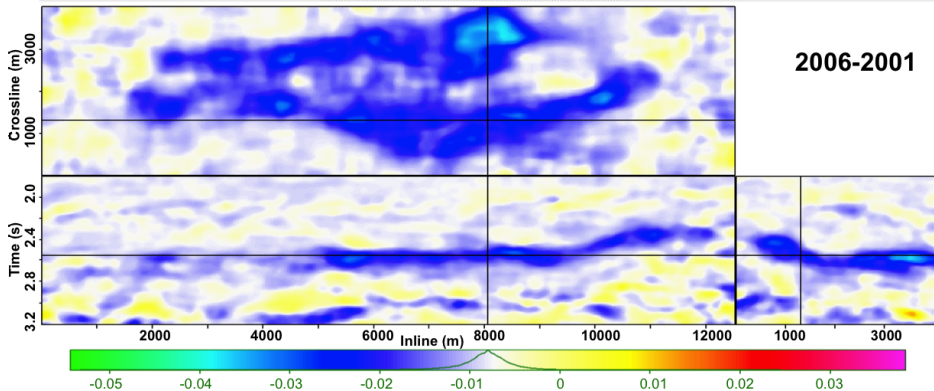
Velocity change [2003-2001] ($\frac{\delta v}{v}$)



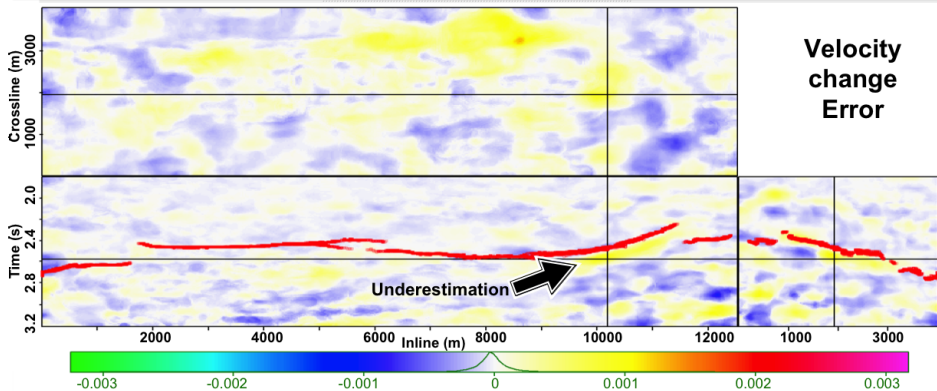
Velocity change [2004-2001] ($\frac{\delta v}{v}$)



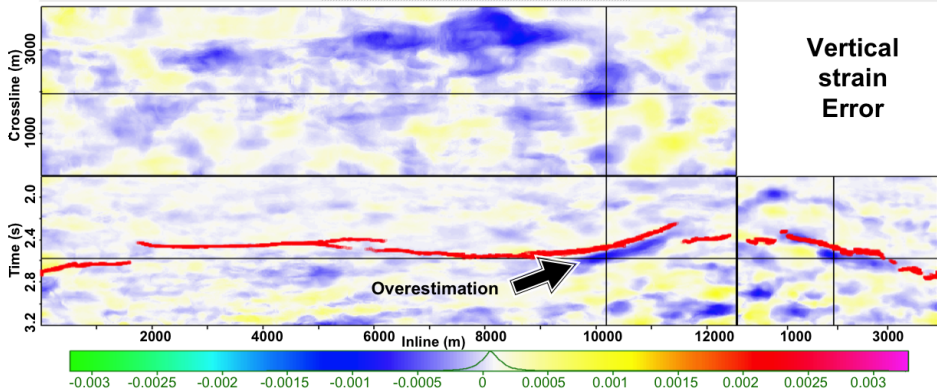
Velocity change [2006-2001] ($\frac{\delta v}{v}$)



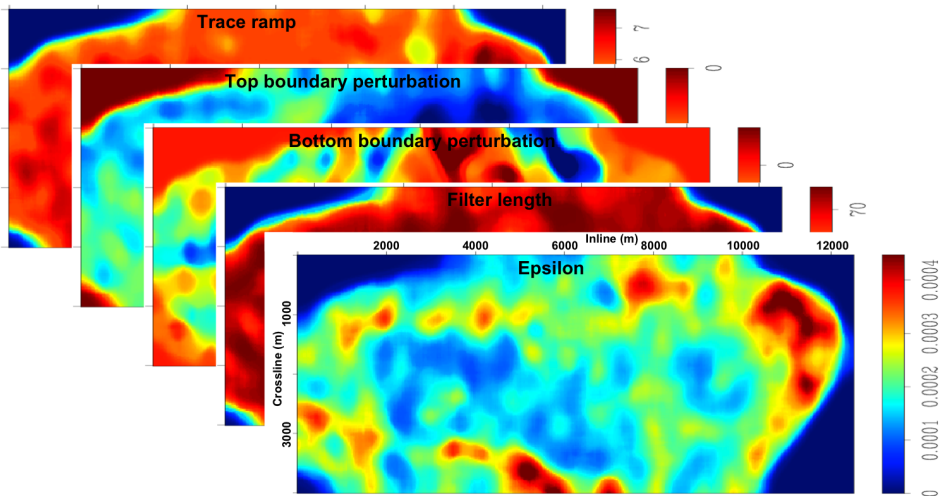
Velocity change error [2006-2001] ($[\frac{\delta v^{xyz}}{v} - \frac{\delta v^z}{v}]$)



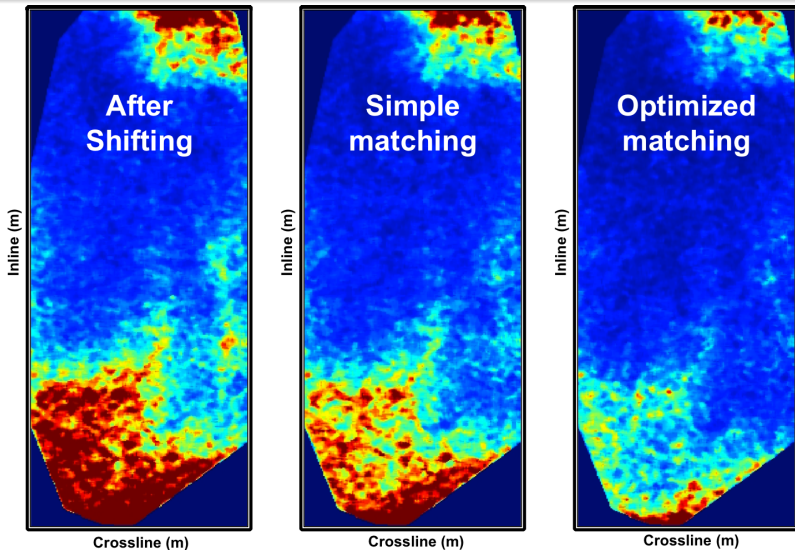
Vertical strain error [2006-2001] ($[\epsilon_{ZZ}^{xyz} - \epsilon_{ZZ}^z]$)



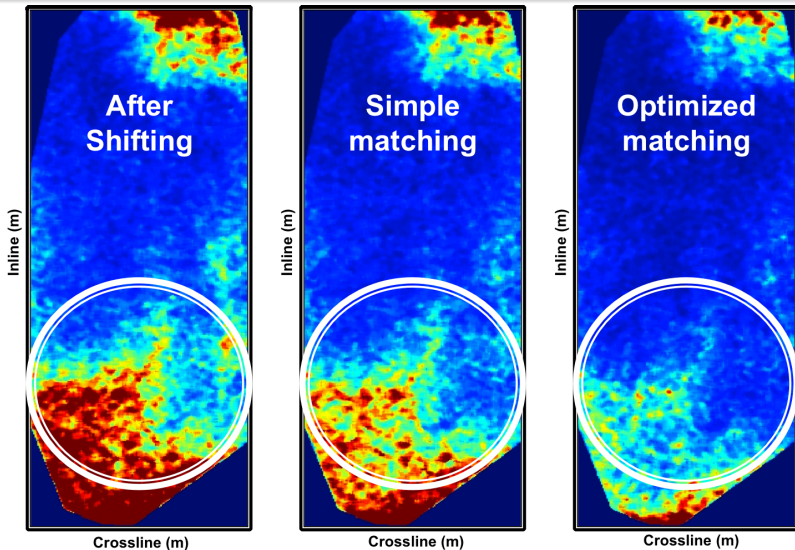
Optimal Match-filter parameters [2006-2001]



Non-reservoir Normalized RMS [2006-2001]

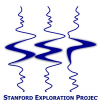


Non-reservoir Normalized RMS [2006-2001]

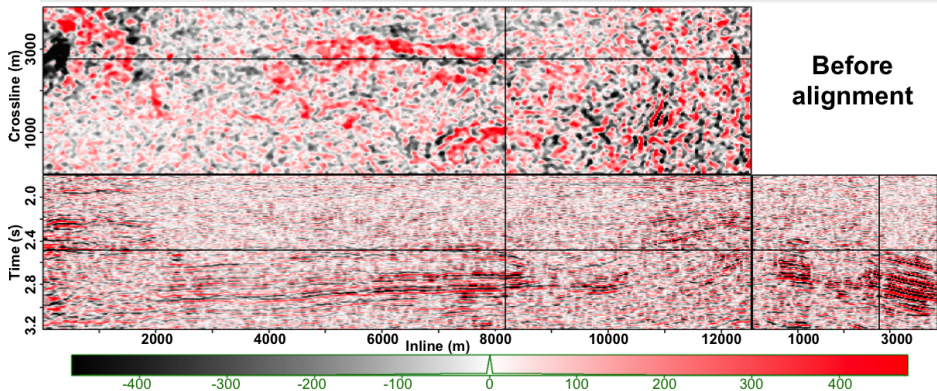


Time-lapse amplitudes

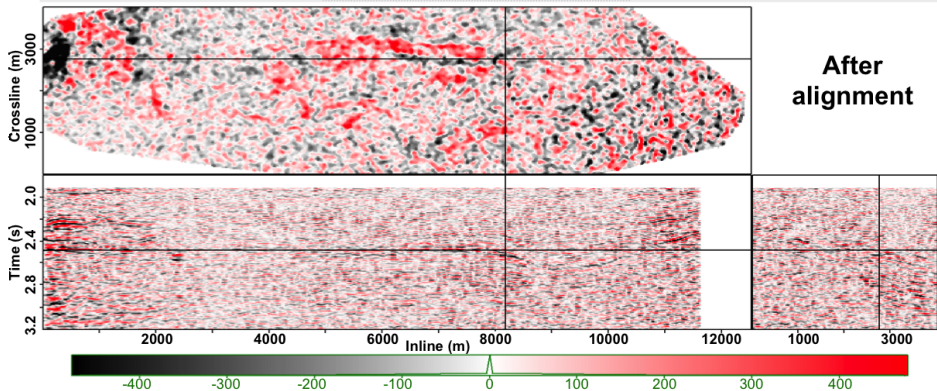
- Related to production-induced rock/fluid property and pressure changes



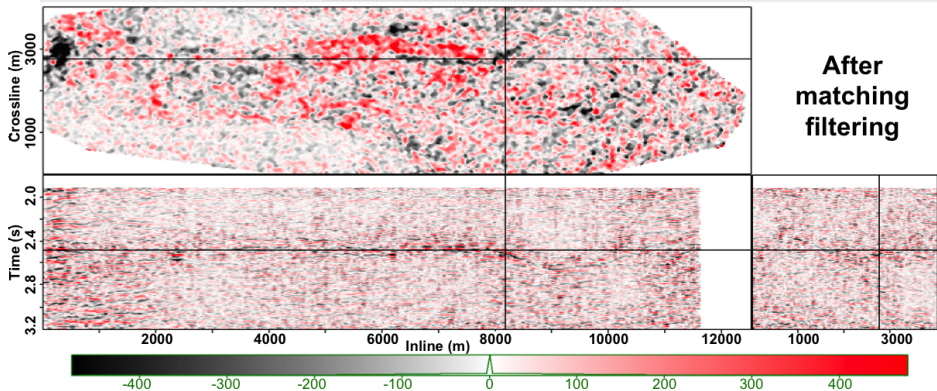
Time-lapse amplitudes [2006-2001]: Before alignment



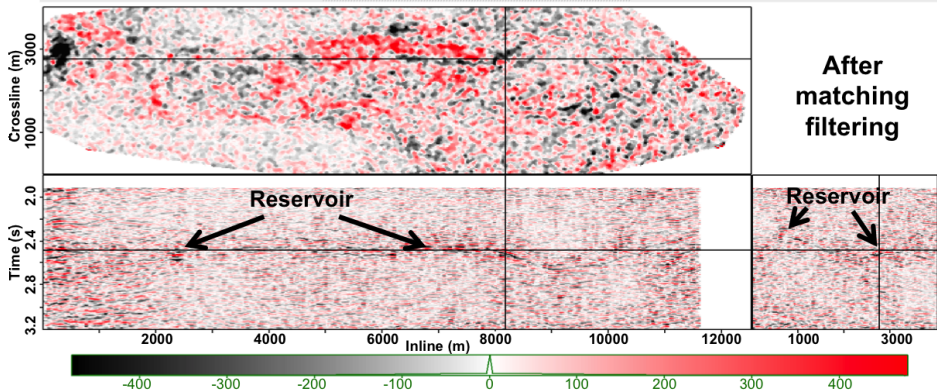
Time-lapse amplitudes [2006-2001]: After alignment



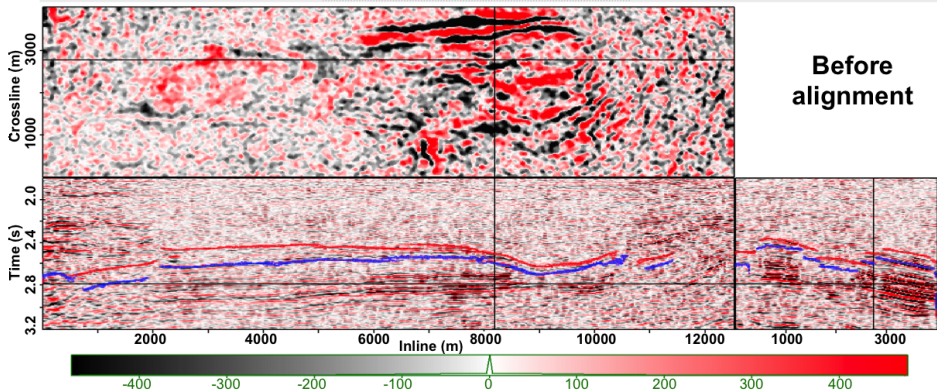
Time-lapse amplitudes [2006-2001]: After Match filtering



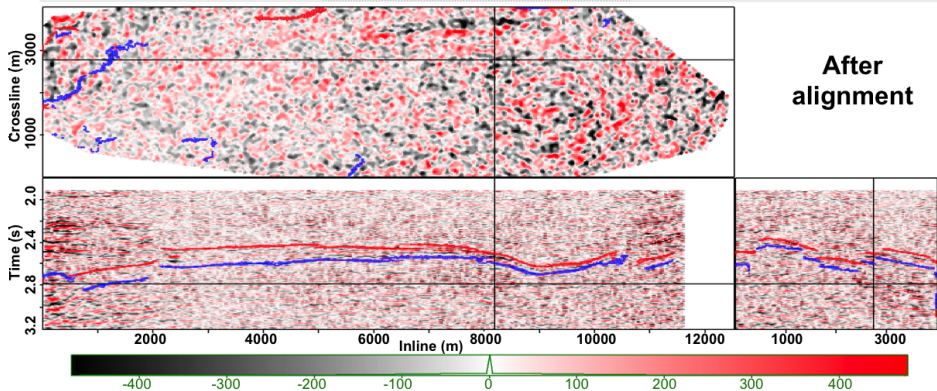
Time-lapse amplitudes [2006-2001]: After Match filtering



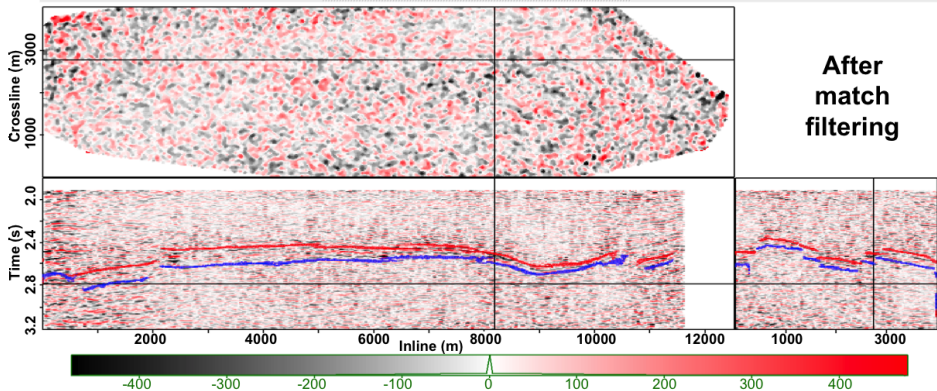
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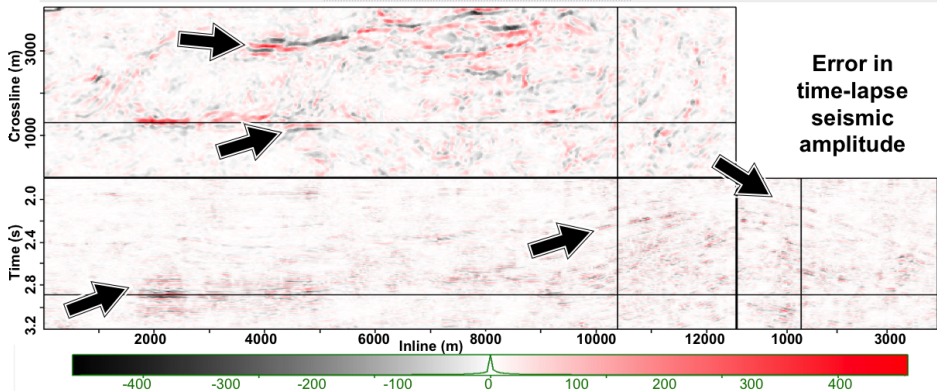
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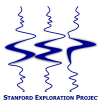


Time-lapse amplitudes [2006^{xyz} – 2006^z]: Shifting Error

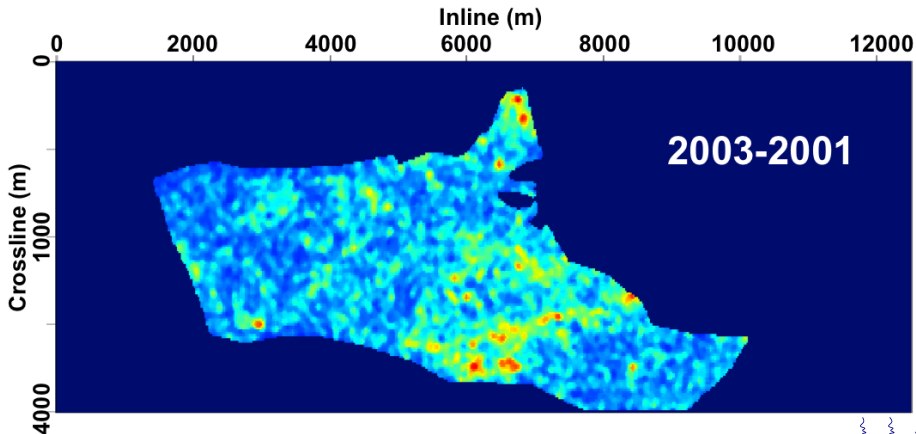


Time-lapse amplitudes

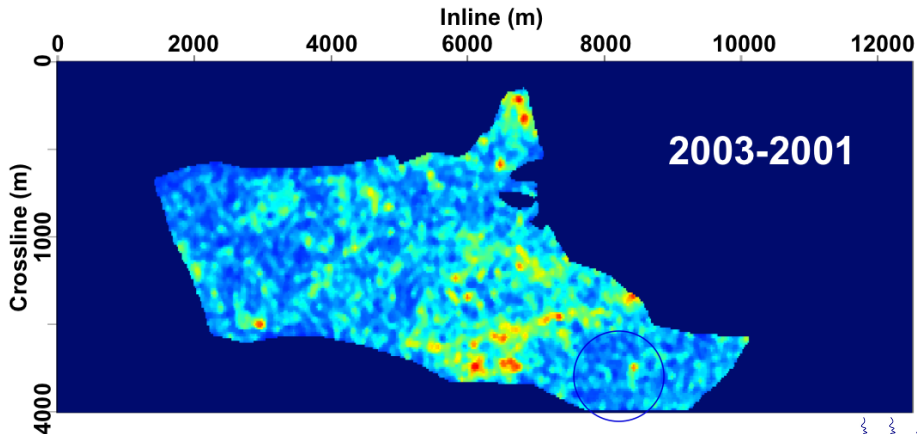
- Related to injection-induced changes and contact movements at the oil-water contact



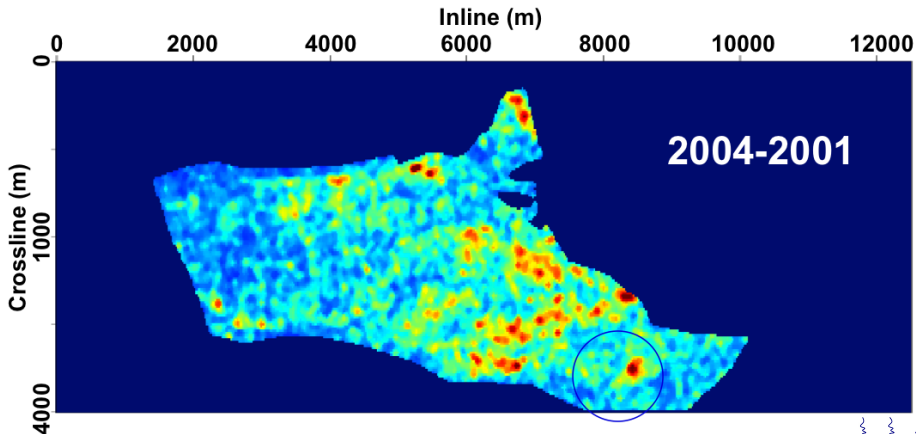
Absolute amplitude changes at Oil-water contact



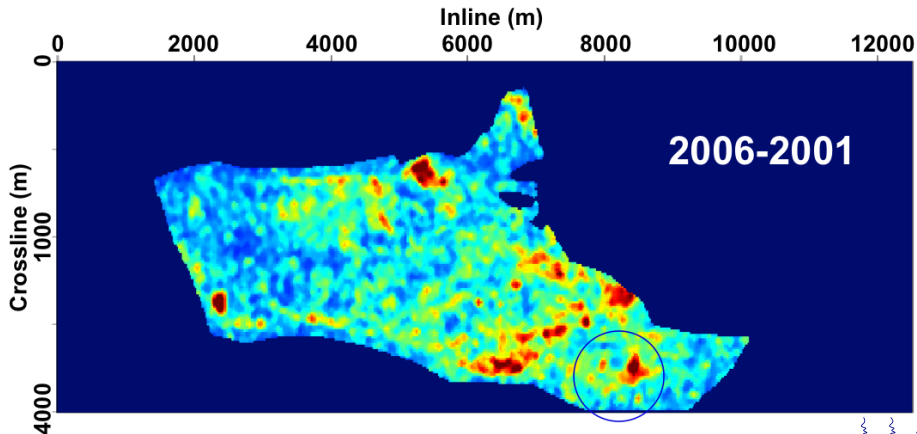
Absolute amplitude changes at Oil-water contact



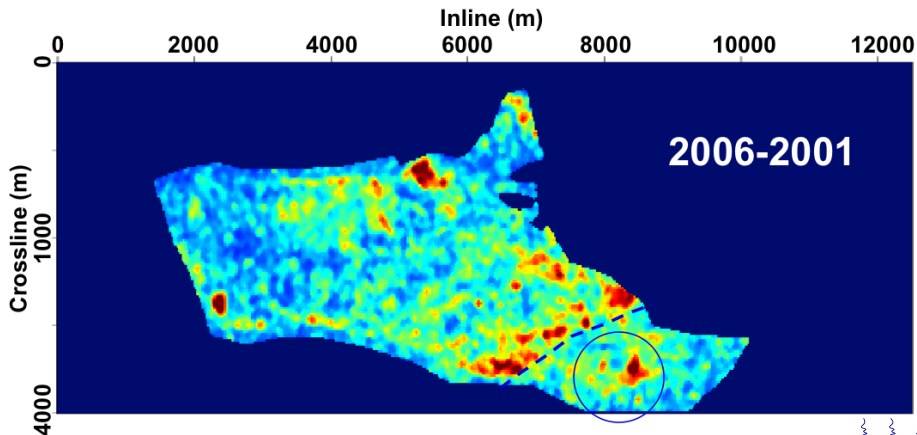
Absolute amplitude changes at Oil-water contact



Absolute amplitude changes at Oil-water contact



Absolute amplitude changes at Oil-water contact



Outline

- 1 Introduction
- 2 Method
 - Time-lapse seismic processing
 - Vertical displacements, strain & velocity change
 - Lateral displacements
 - Optimized match-filtering
- 3 Results
 - Apparent Displacements
 - Velocity change
 - Amplitude change
 - Oil-water contact
- 4 Conclusions
 - Conclusions
 - Future work

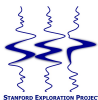
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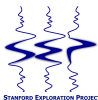
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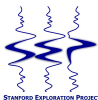
Future work

- 1 Time-lapse cross-equalization by linearized wave-equation inversion
- 2 Application of linearized wave-equation inversion to rock/fluid property estimation

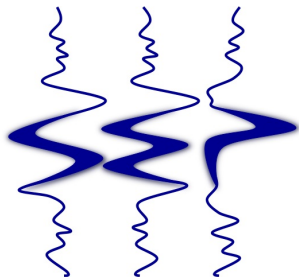


Acknowledgments

- Thanks to Statoil for release of the Norne data
- Thanks to the Bard Osdal, Henrietta Sorensen and Trine Alsos (Statoil), Alexey Stovas and Mohsen Dadashpour (NTNU/IO CENTER) and David Echeverria (Smart Fields) for their assistance throughout this study



Thanks



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