Overburden 4D time shifts; Snorre Field*

Thomas Røste

Statoil

** Paper submitted to The Leading Edge*

Outline

- Why monitor overburden?
- Intro Snorre Field
- 4D time shifts
- Geomechanics
- Discussion / Conclusions

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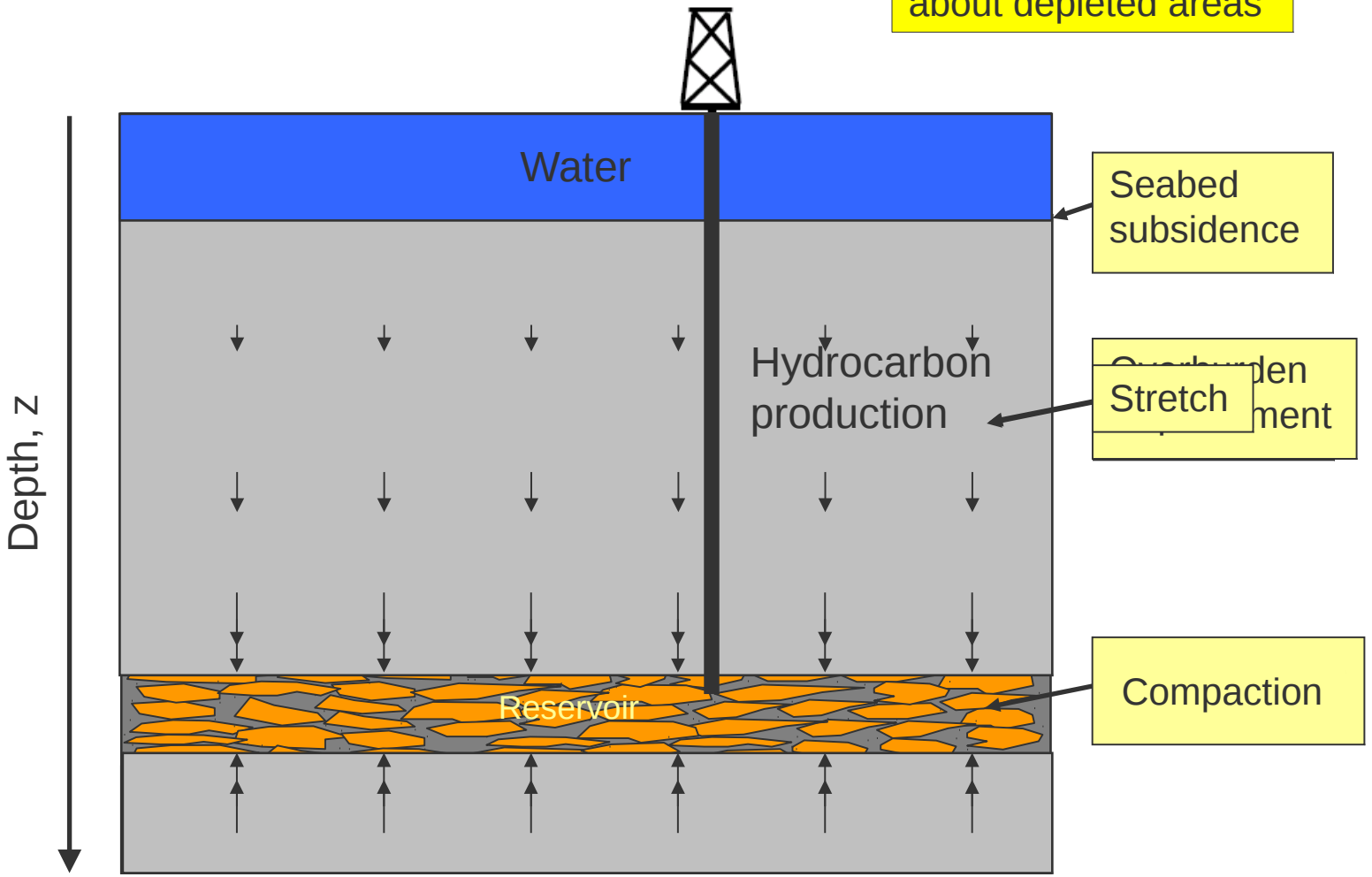
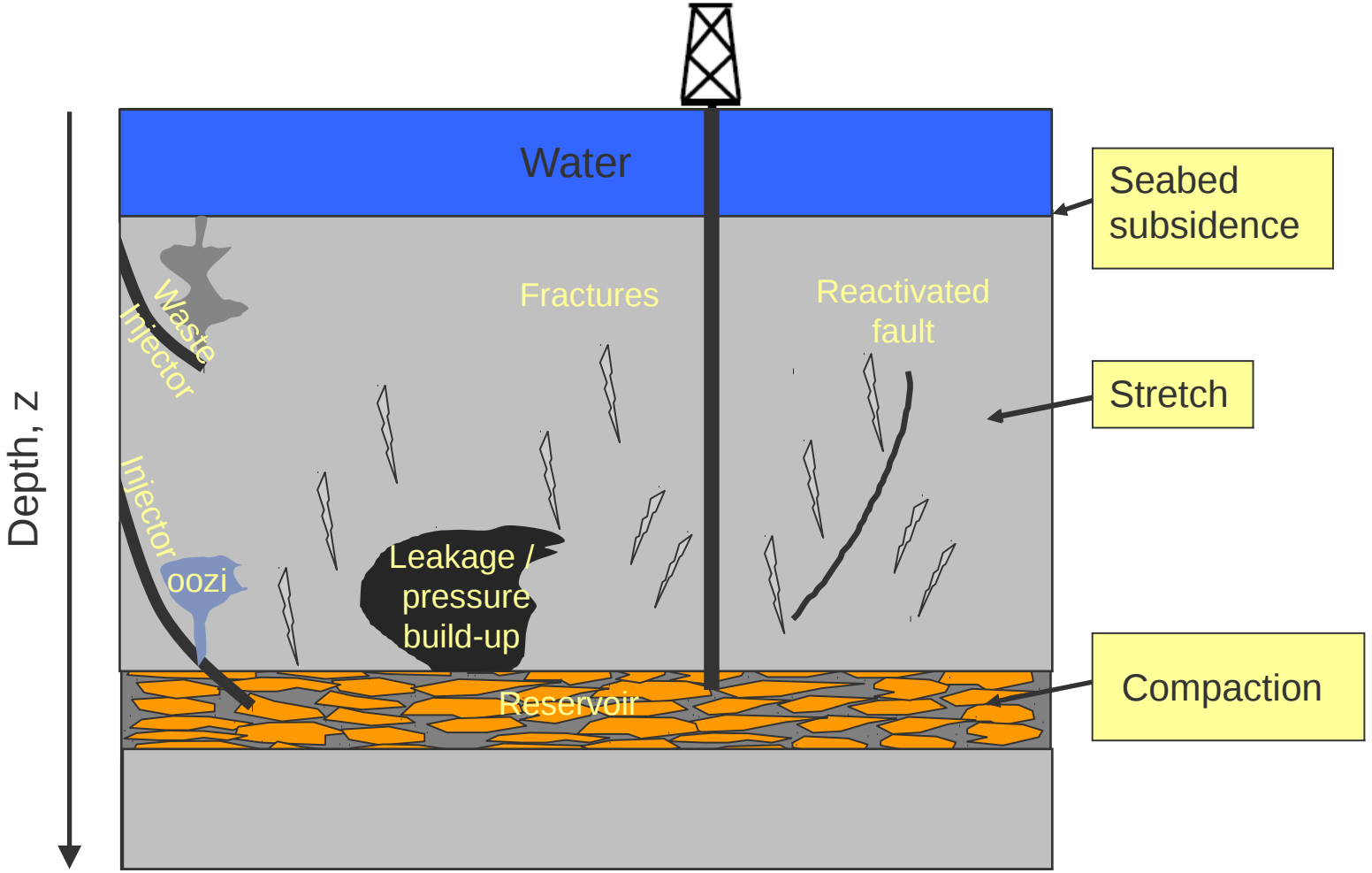
Why monitor overburden?

Gives information about depleted areas



Why monitor overburden?



Effects inducing velocity changes might be observed on 4D seismic.
Important with cross-disciplinary work in order to discriminate the effects.

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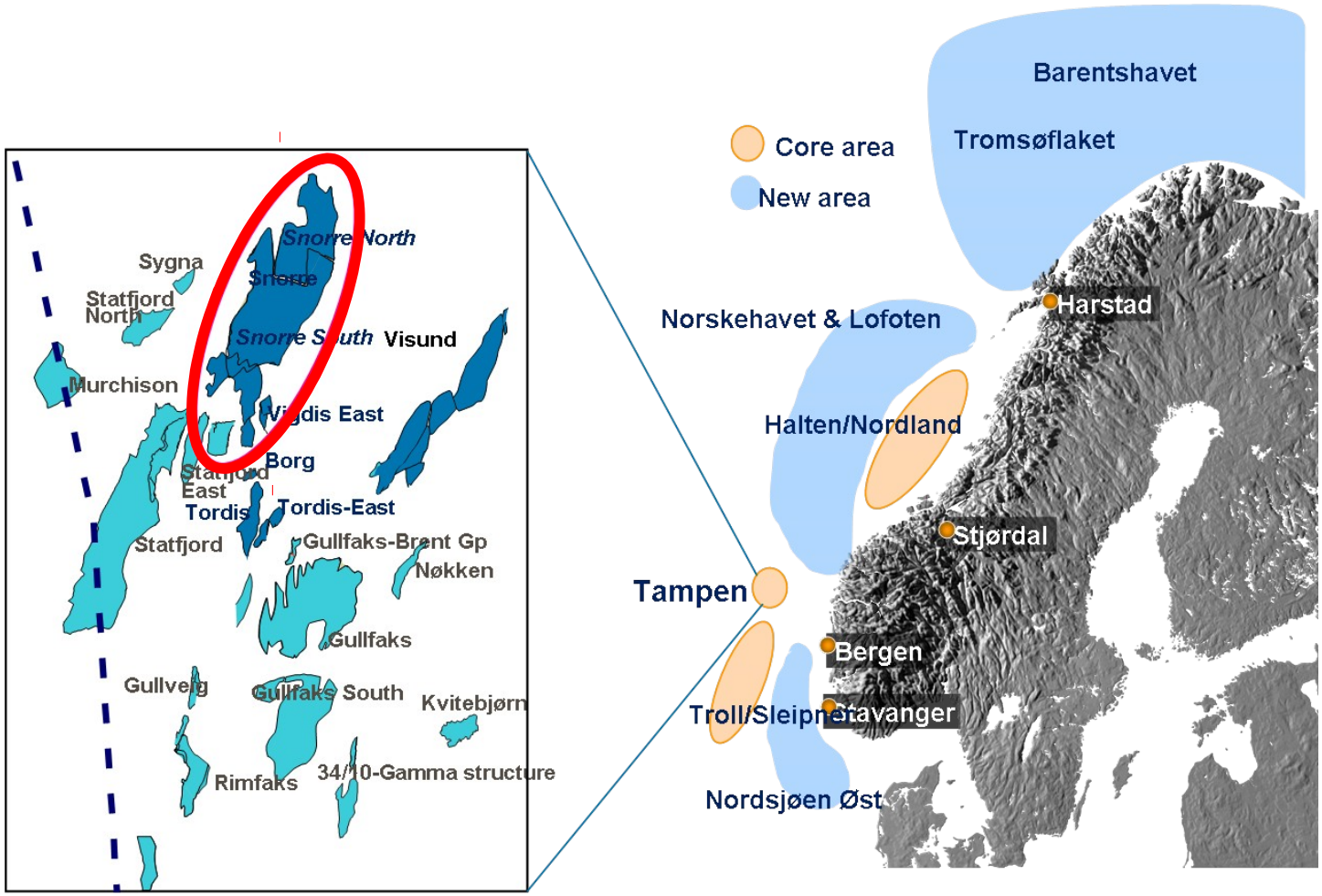
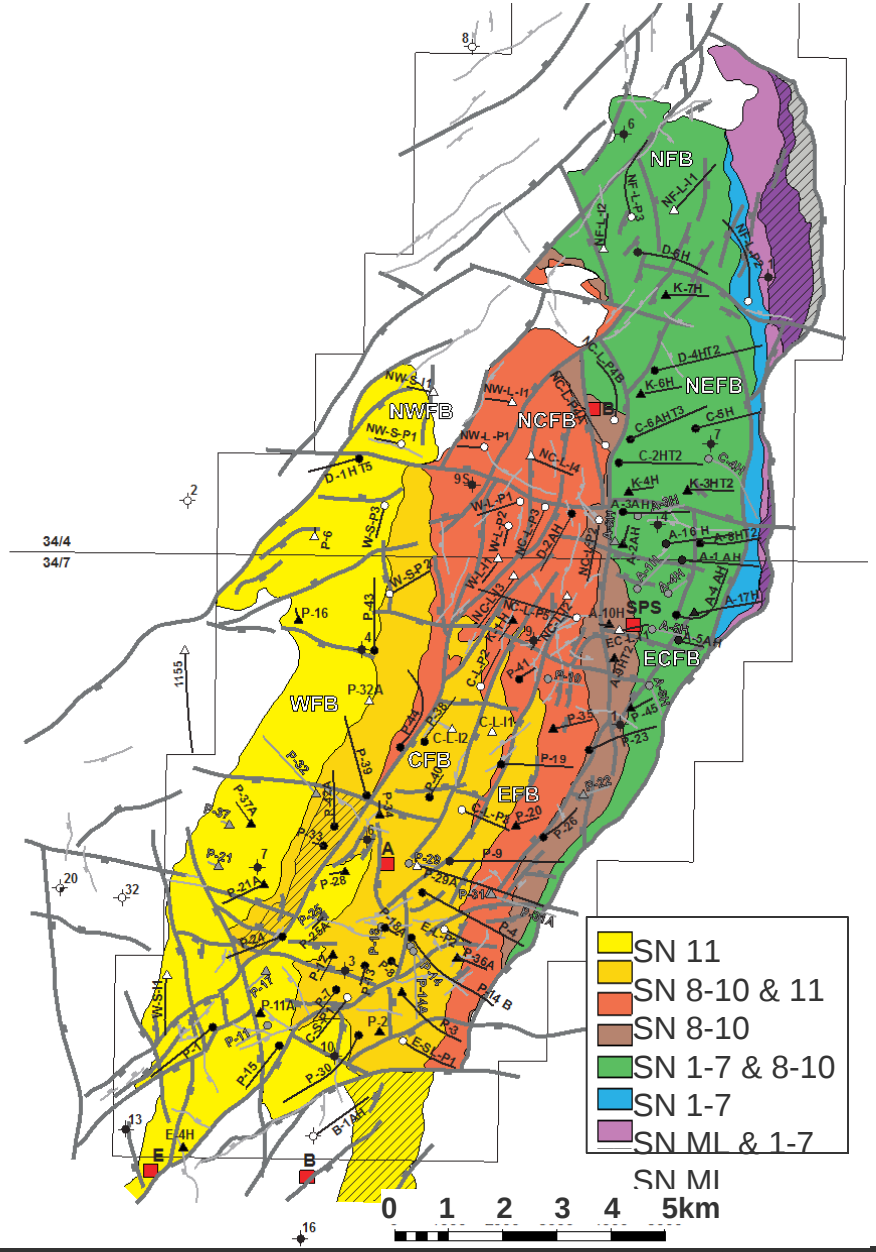
Intro Snorre Field

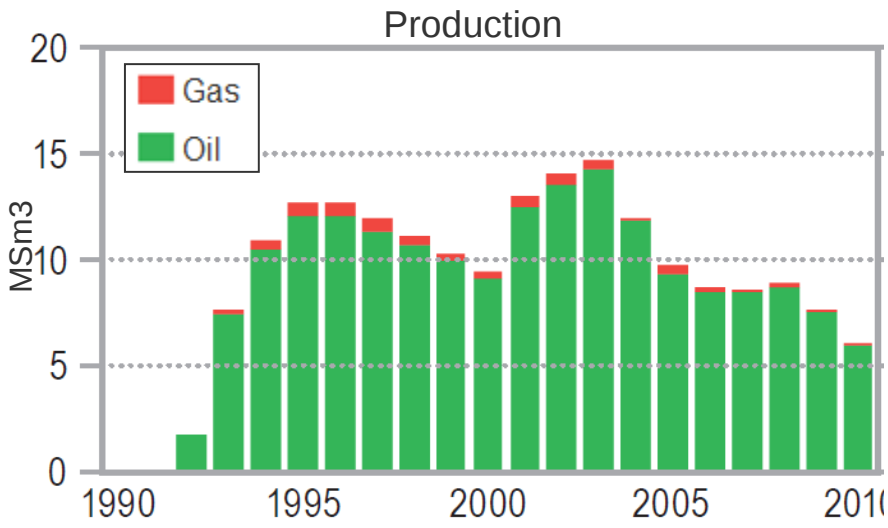


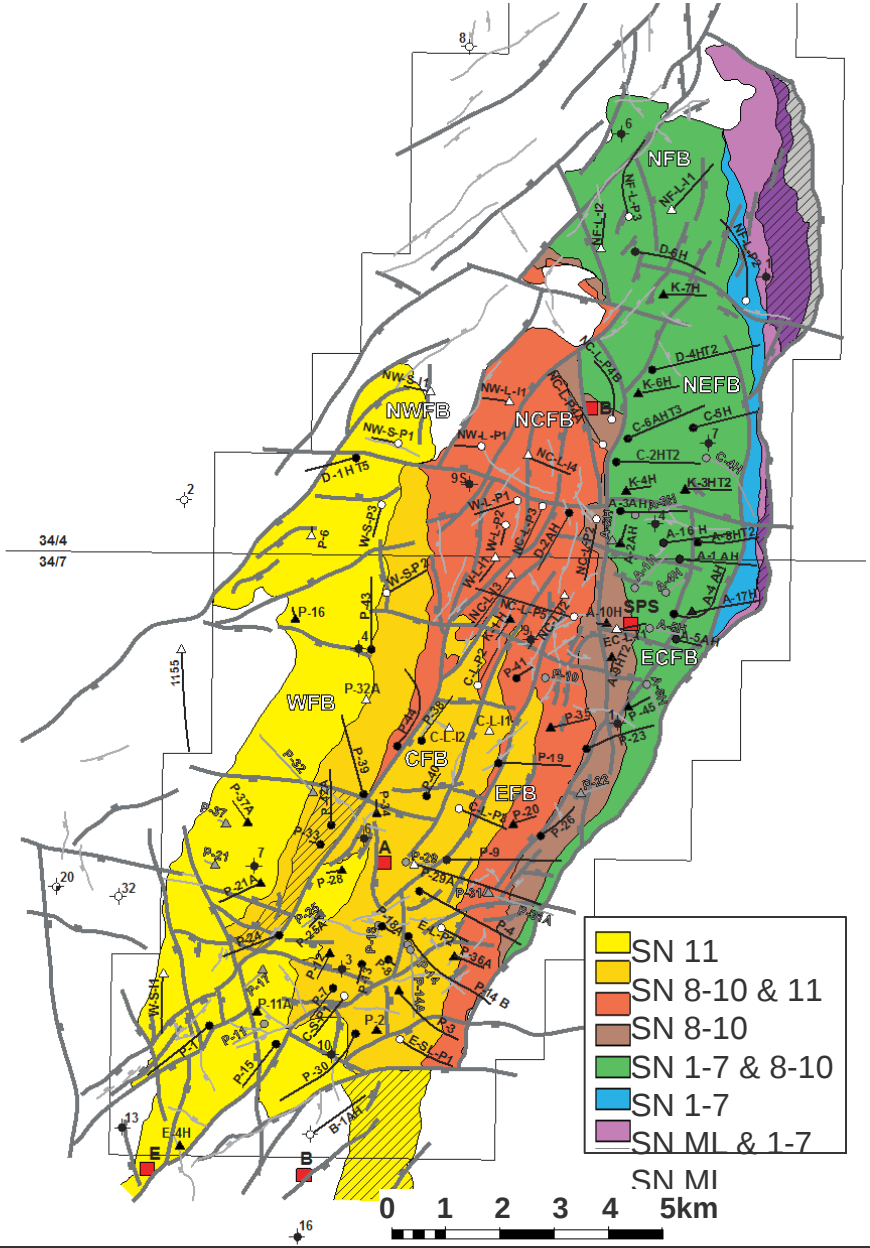
Intro Snorre Field



Intro Snorre Field

- Production start: 1992
- Oil reserves (NPD, 2014)
  - Total: 260 MSm3
  - Remaining: 65 MSm3
- 130 wells (production and exploration)





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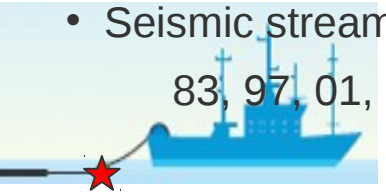
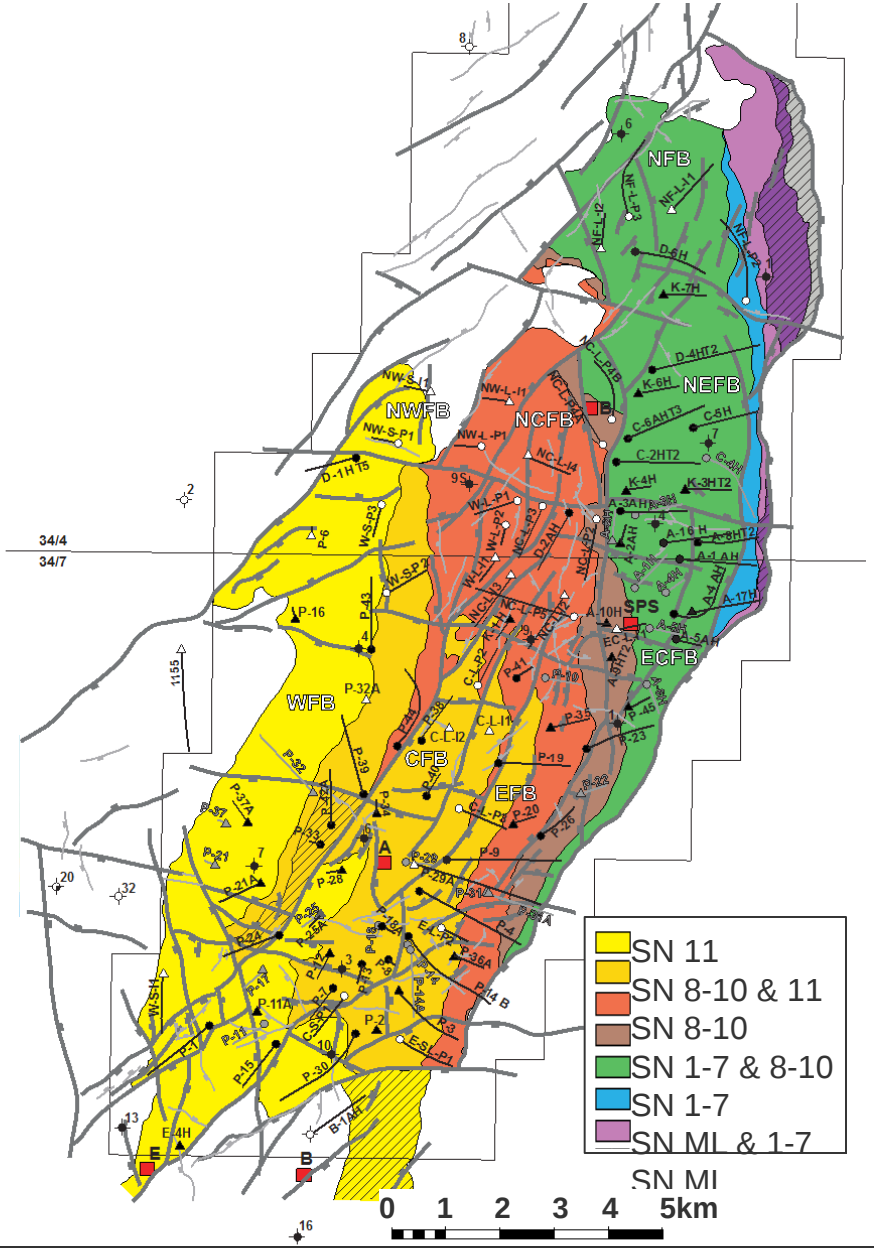
Intro Snorre Field

- Production start: 1992
- Oil reserves (NPD, 2014)
  - Total: 260 MSm3
  - Remaining: 65 MSm3
- 130 wells (production and exploration)
- Seismic streamer surveys:
  83, 97, 01, 05, 06, 09, 12





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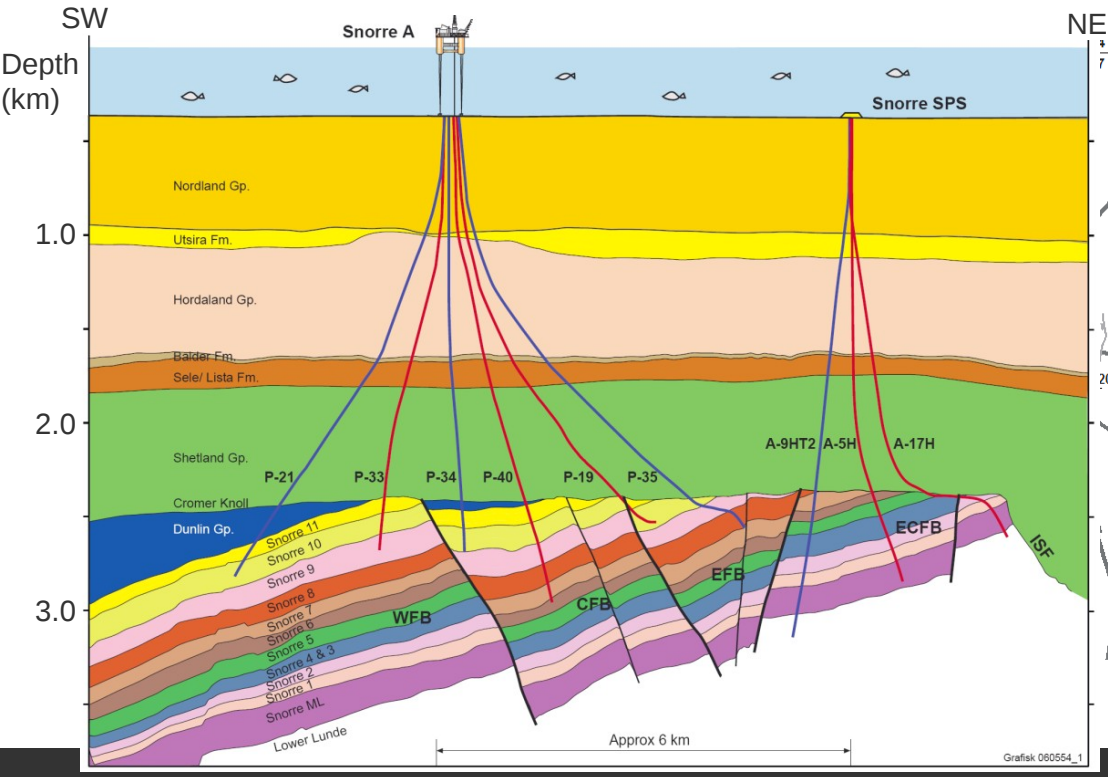
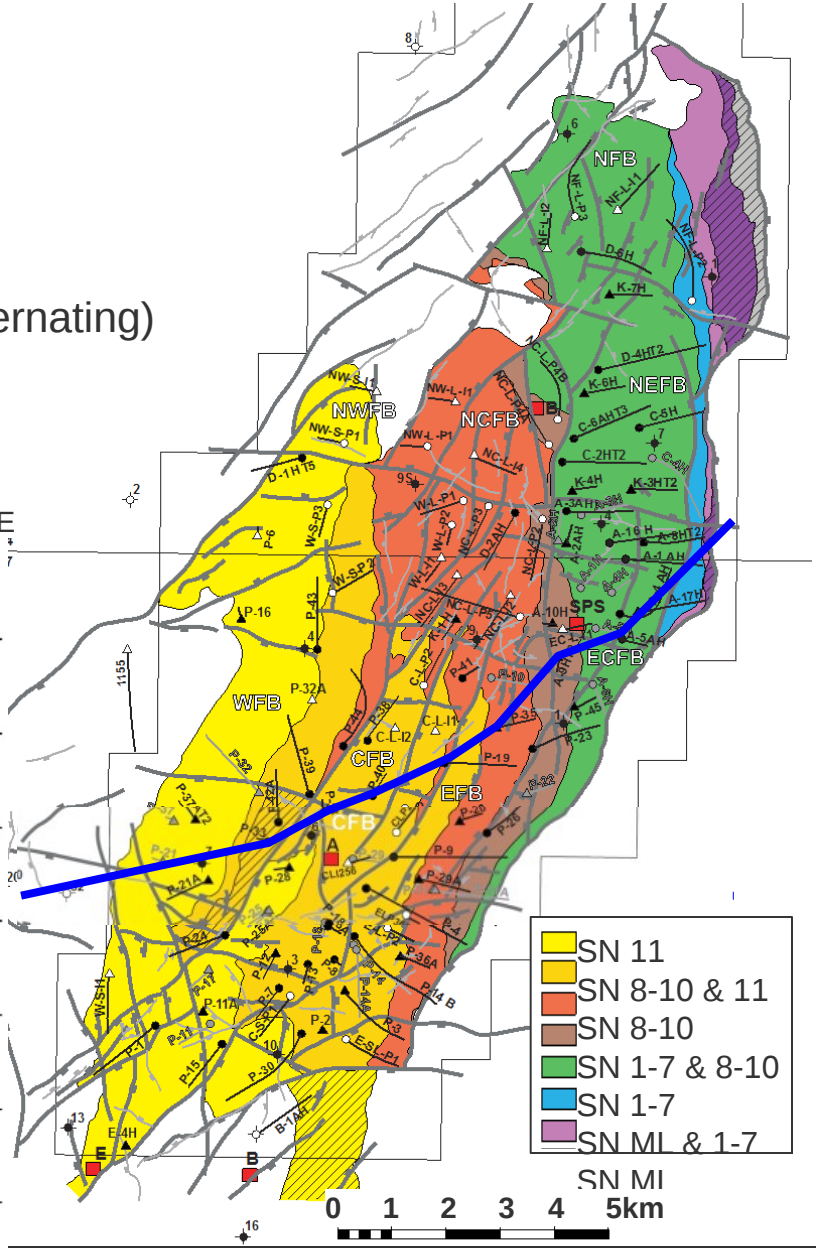
Intro Snorre Field

- Reservoir description:
  - Thickness: 1.0 km
  - Thin sequences of sandstones and shales (alternating)
  - Fluvial sandstones
  - Faulted with multiple oil-water contacts





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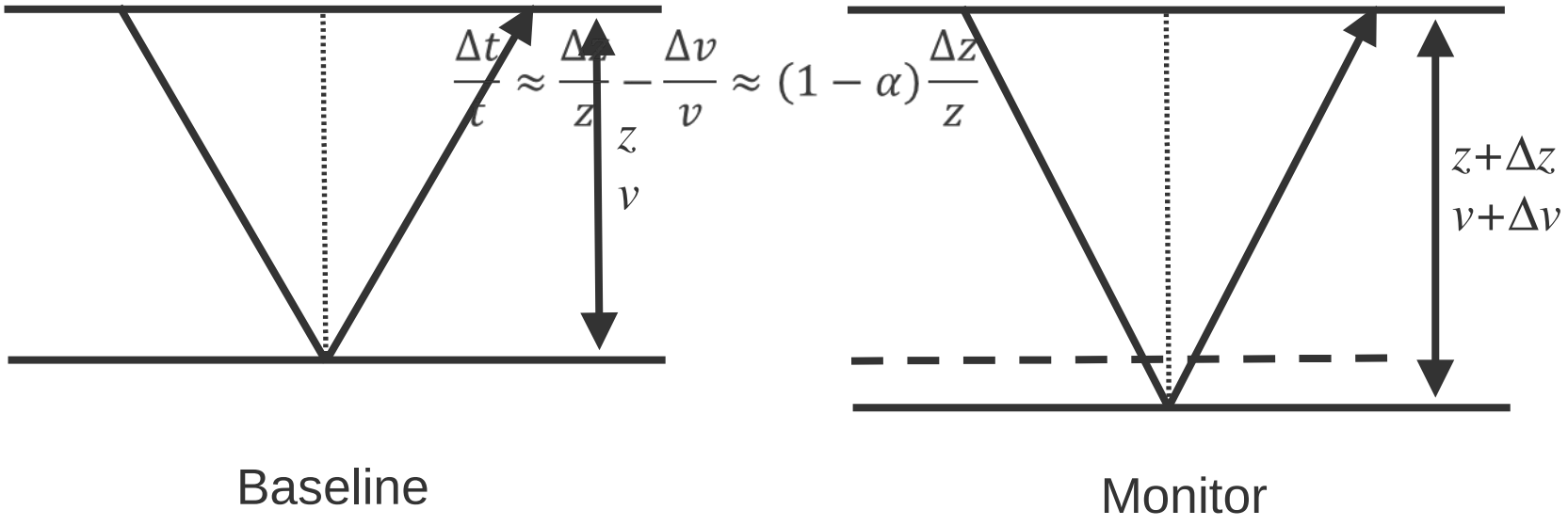
4D time shifts

- Time shifts capture changes in both thickness and velocity
- Røste et al. (2005) and Hatchell et al. (2005) independently assumed:

$$\frac{\Delta v}{v} \overset{(1)\,*}{\approx} \alpha \frac{\Delta z}{z}$$

- Time shifts can then be expressed as:

$$\frac{\Delta t}{t} \approx \frac{\Delta z}{z} - \frac{\Delta v}{v} \approx (1-\alpha)\frac{\Delta z}{z} \quad (2)$$



* Note! Hatchell et al. (2005) used *R* instead of α in Equation (1). The relation is $R = -\alpha$

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4D time shifts

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or expressed in terms of vertical strain ():

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or expressed in terms of vertical strain (ϵ_{zz}):

$$\frac{\Delta t}{t} \approx (1-\alpha)\epsilon_{zz} \quad (3)$$

Links 4D seismic (time shifts) with geomechanics (vertical strain)

* Note! Hatchell et al. (2005) used *R* instead of α in Equation (1).
The relation is $R = -\alpha$

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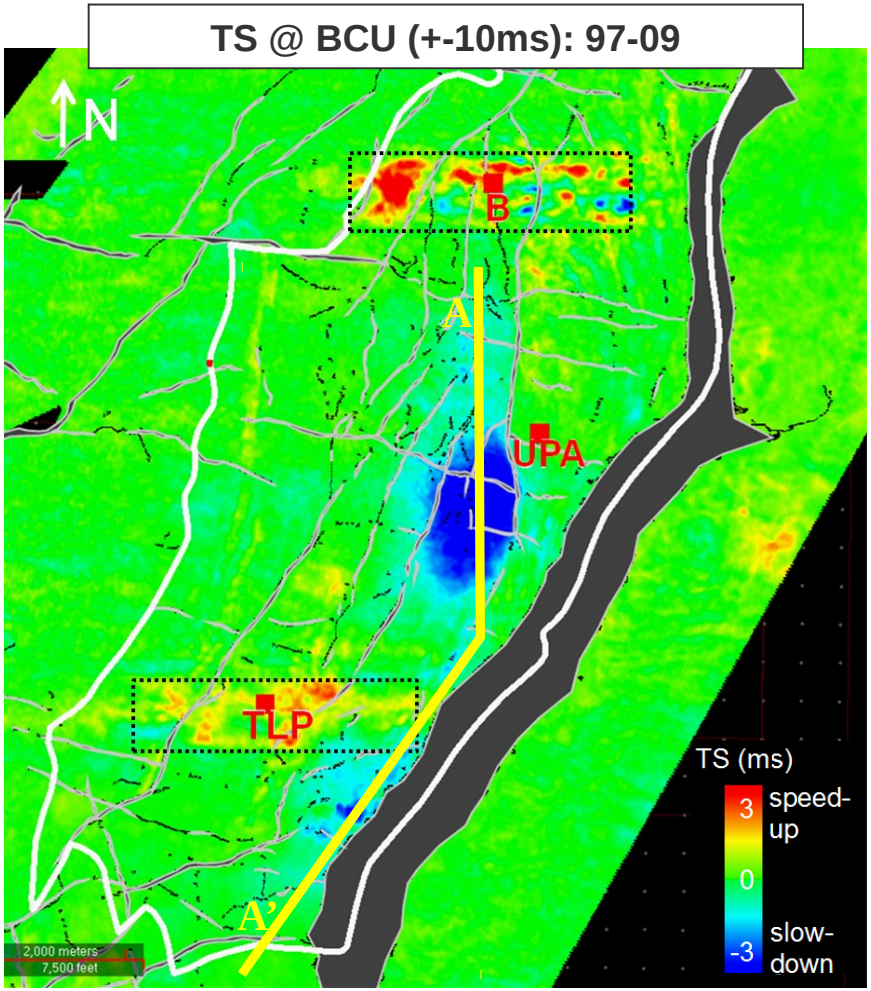
4D time shifts 97-09; Snorre



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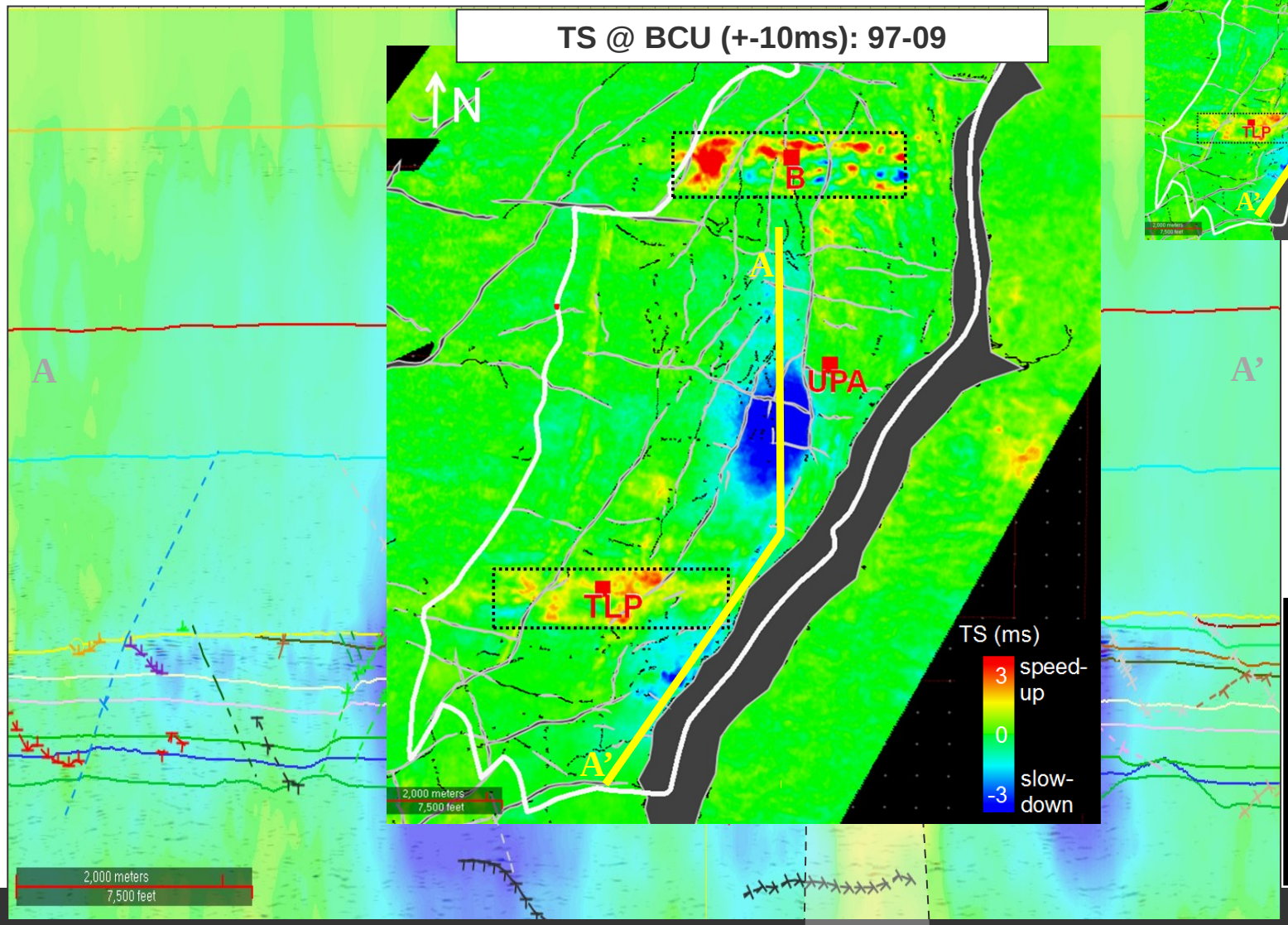
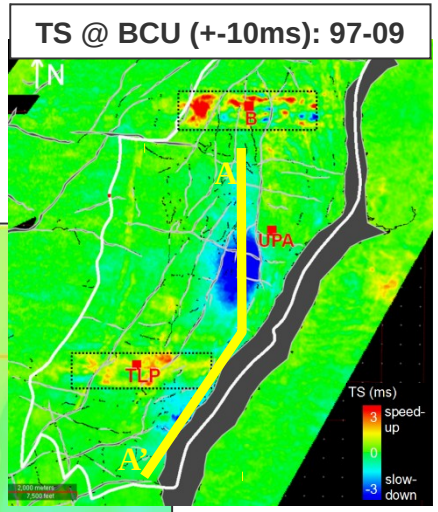
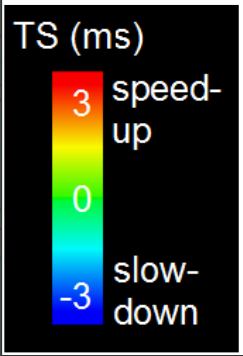
4D time shifts 97-09; Snorre







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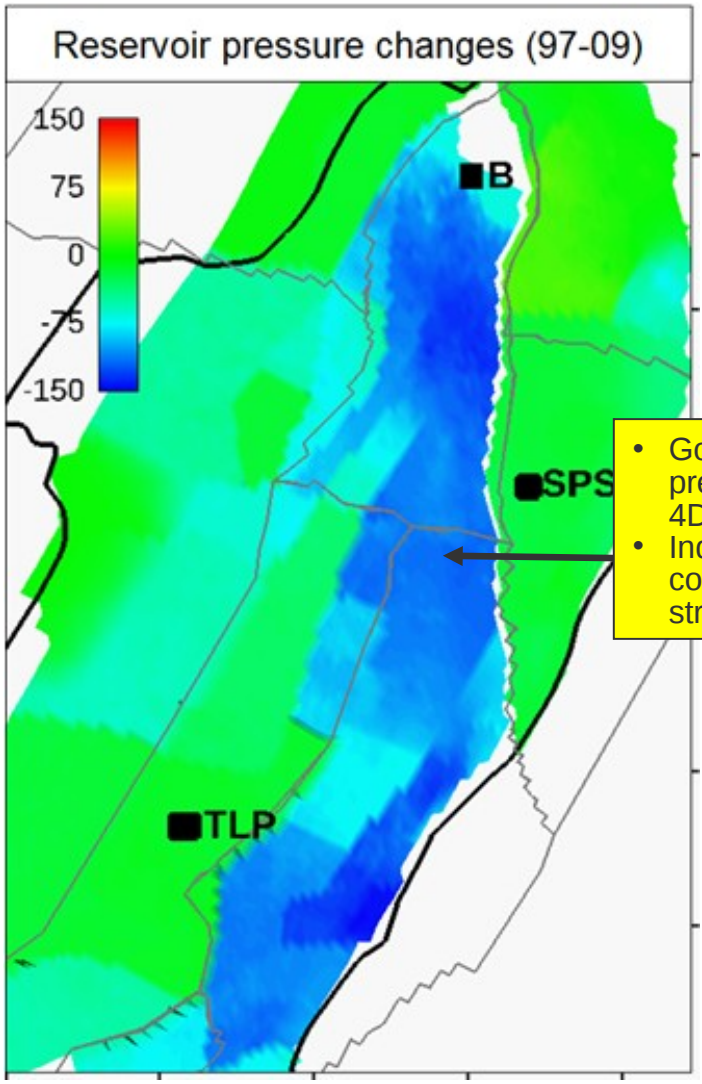
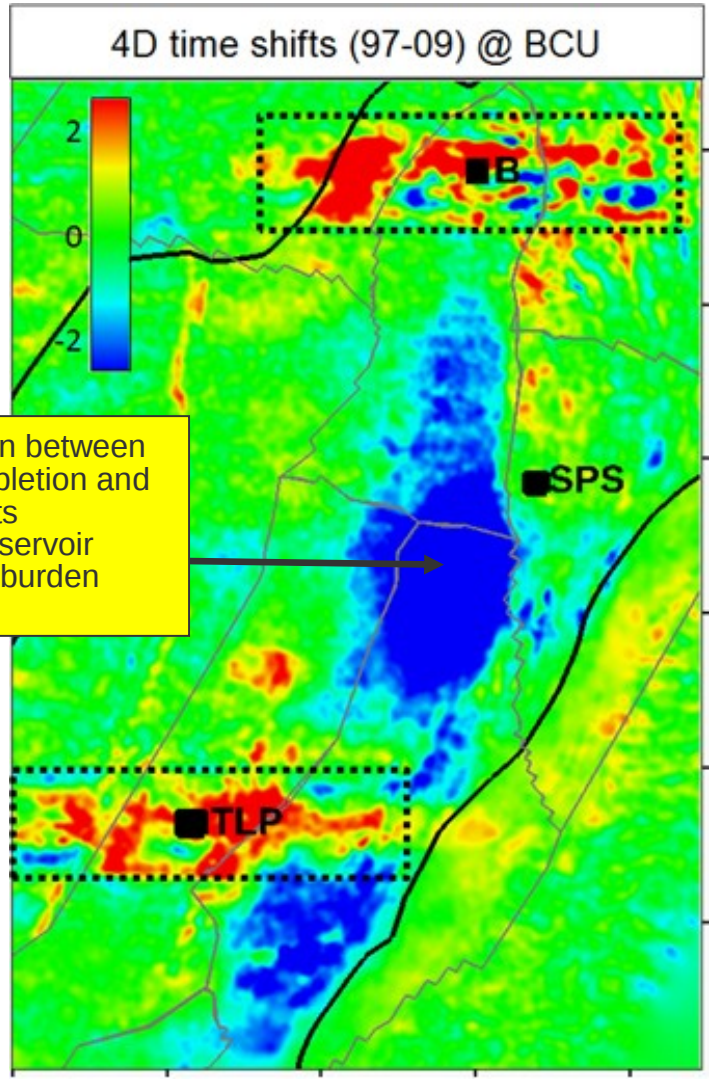
Pressure changes (Eclipse) vs 4D time shifts





- Good relation between pressure depletion and 4D time shifts
- Indicating reservoir comp. / overburden stretch

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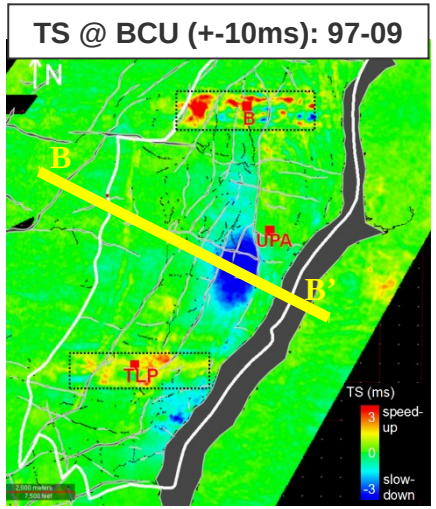
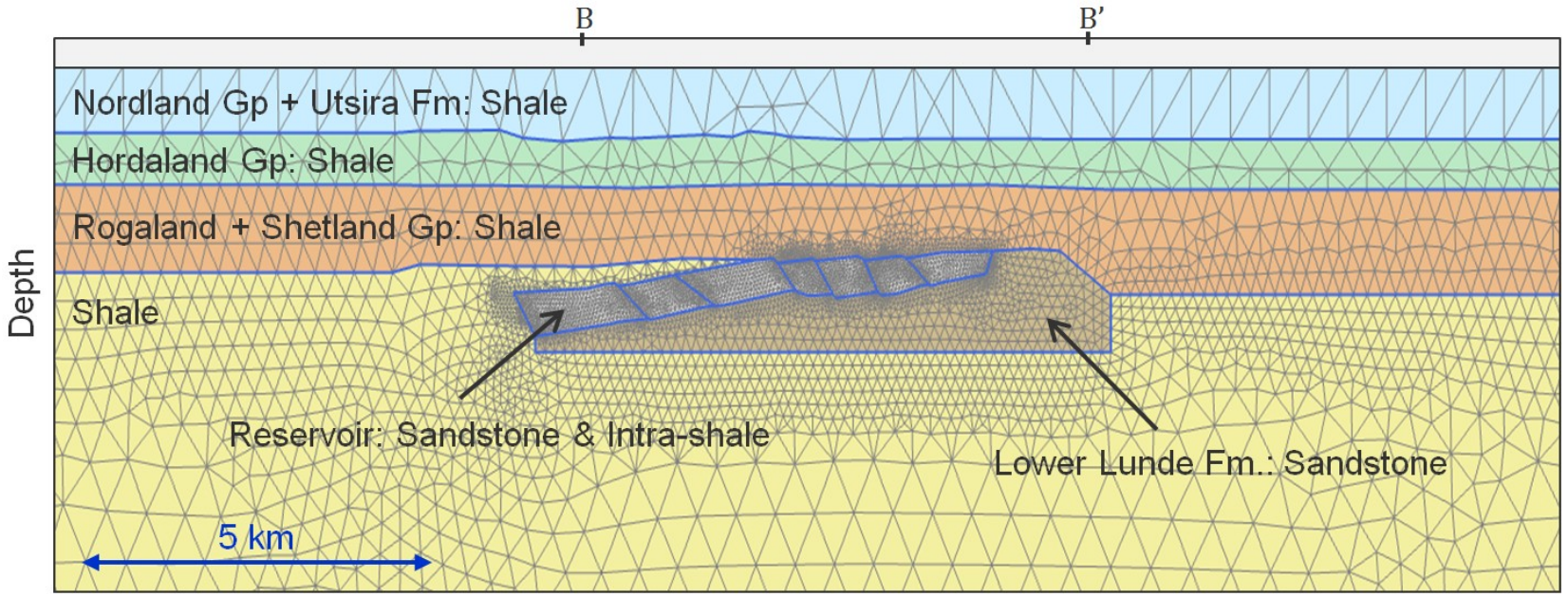
2D geomechanical model

Finite element model

- Standard linear elastic model
- Divided into 6 layers
- Reservoir geometry from Eclipse model
- Reservoir is classified by major faults (leading to 7 segments)





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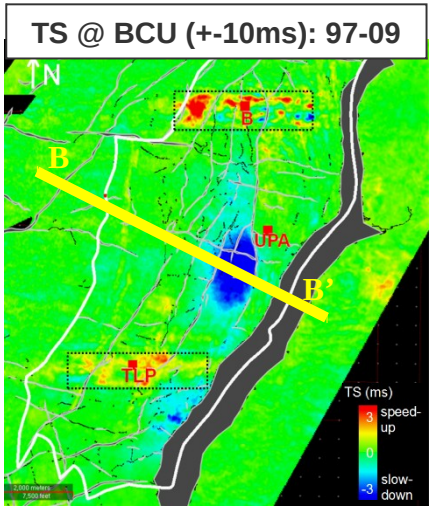
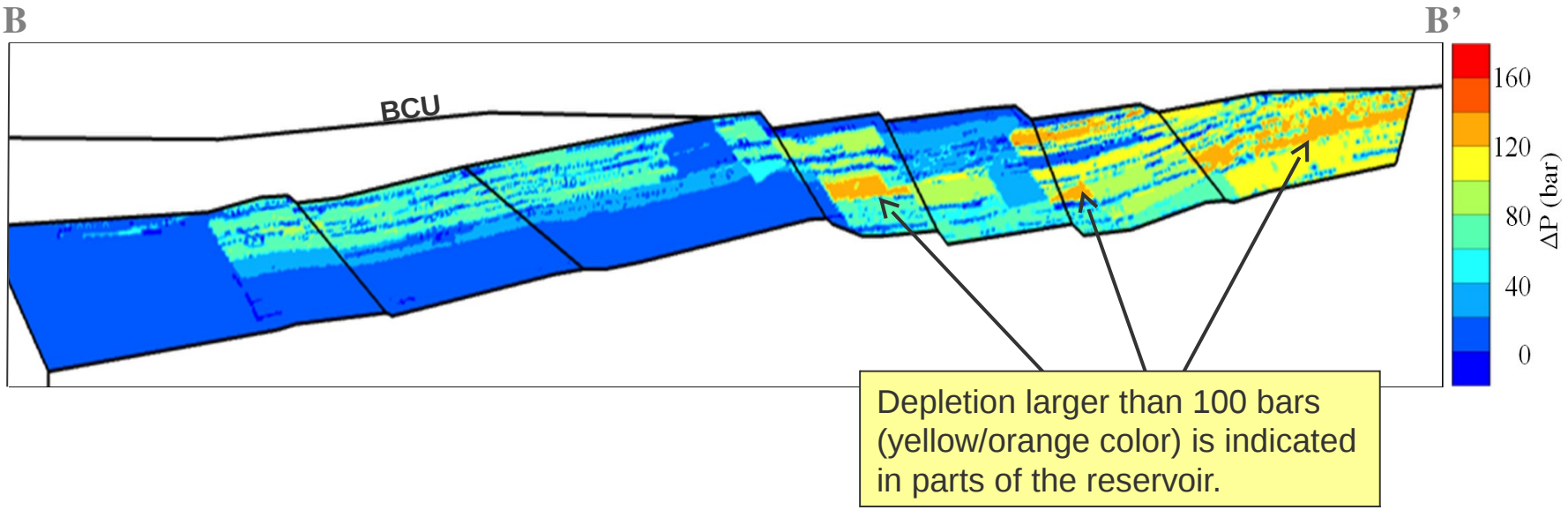
2D geomechanical model

Reservoir pore pressure depletion (97-09)

- Taken from Snorre dynamic simulation model
- Input to the geomechanical model





Depletion larger than 100 bars (yellow/orange color) is indicated in parts of the reservoir.

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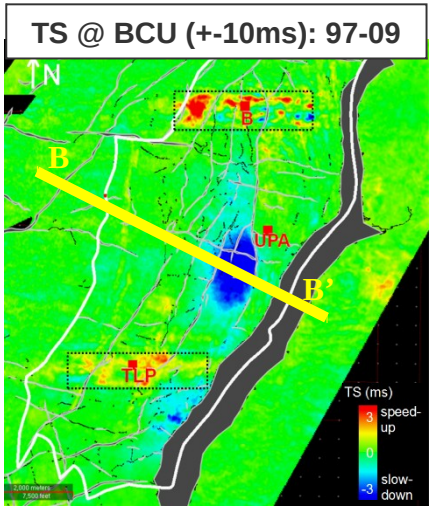
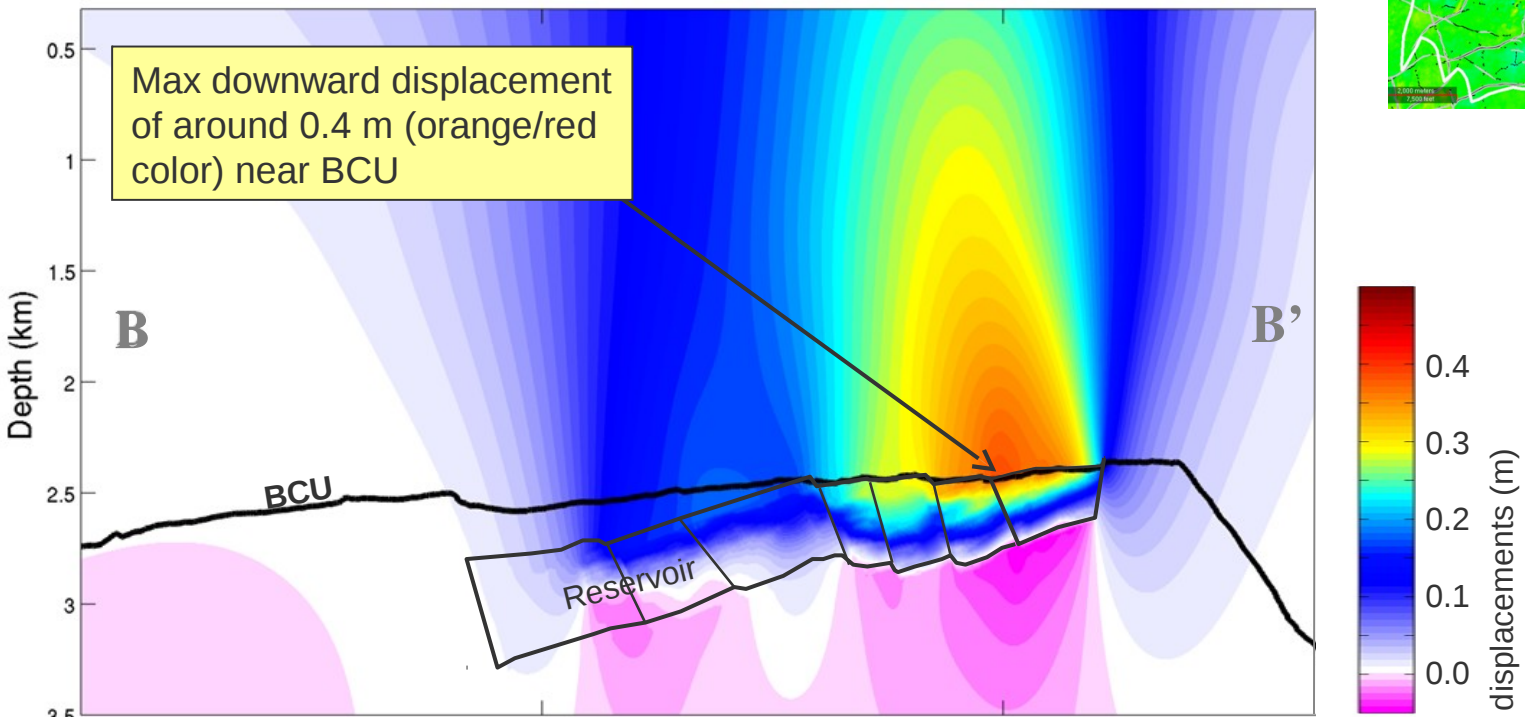
2D geomechanical model

Vertical displacements (97-09)





Positive displacements indicate downward displacements (colors from blue to red)

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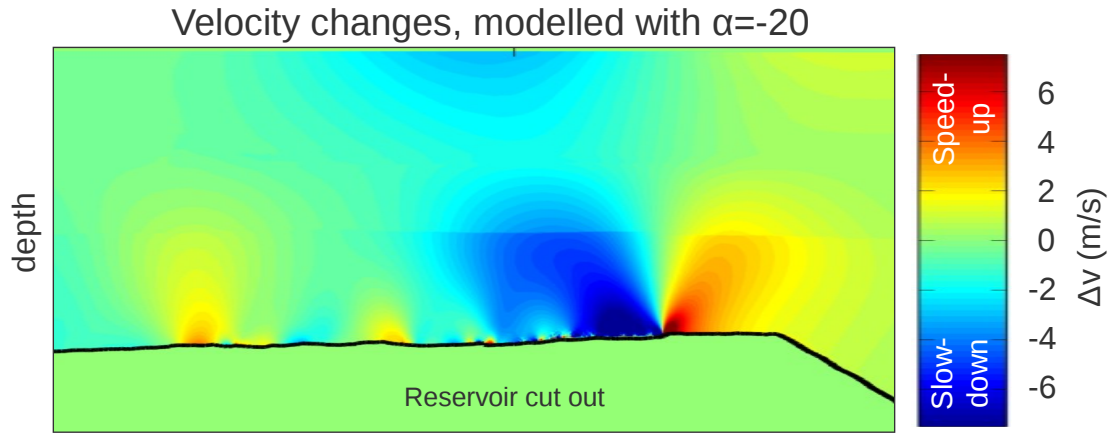
Linking geomechanics and 4D time shifts

Modelled from geomechanical model:

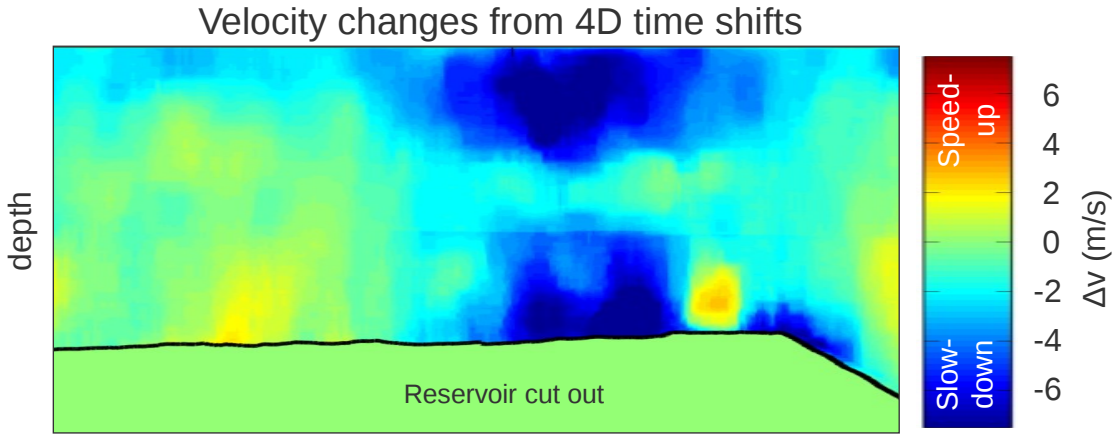
$$\frac{\Delta v}{v} \approx \alpha \cdot \epsilon_{zz}$$



From 4D seismic time shifts:

$$\frac{\Delta v}{v} \approx -\frac{\Delta t}{t}$$

assuming $\frac{\Delta v}{v} \gg \frac{\Delta z}{z}$



Indicating that 4D time shifts are induced by geomechanical changes

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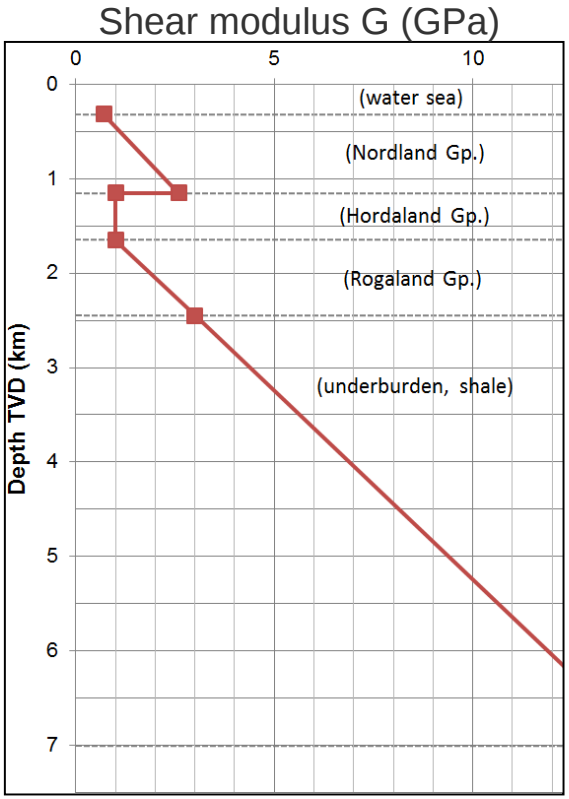
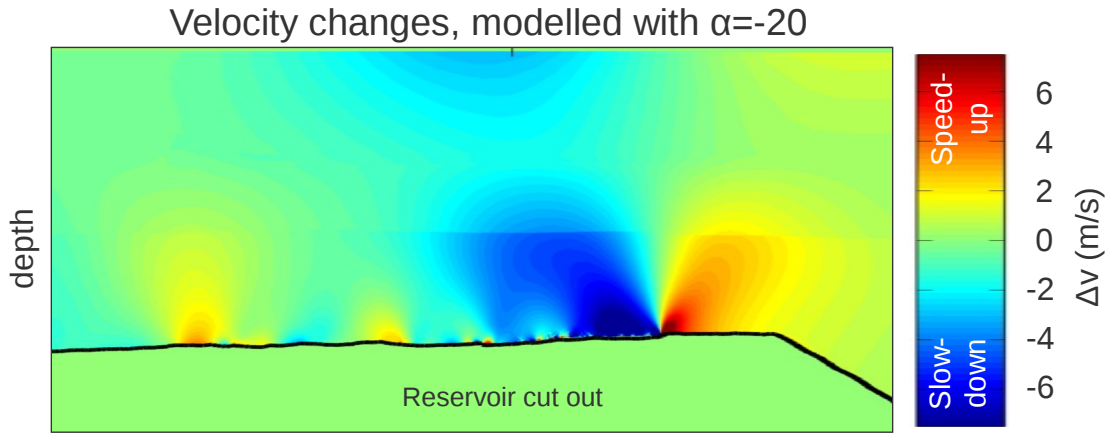
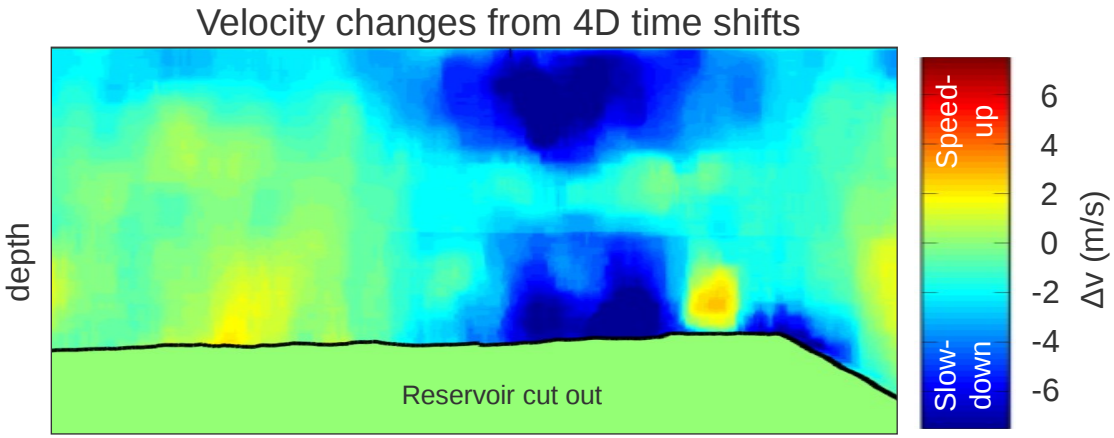
Linking geomechanics and 4D time shifts







Indicating that 4D time shifts are induced by geomechanical changes

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Discussion / Conclusions

- Overburden time shifts induced by reservoir compaction is typical for chalk and HPHT fields. However, this research indicates potential also for sandstone reservoirs

- Why investigate overburden time shifts and geomechanics?
  - might be used to map out depleted areas (particularly useful for gas fields)
  - important to map out areas with large geomechanical changes
  - important to discriminate geomechanical changes from other changes (e.g. oozi, leakage, pressure build-up)

- Time shifts up to 4 ms obtained in Snorre overburden:
  - Clear observation
  - Correlate well with pressure depleted areas
  - Match well with 2D geomechanical model, assuming $\alpha \approx -20$ for overburden

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Acknowledgments

- Snorre Petec for valuable input
- Colleagues in Statoil and Martin Landrø for discussions
- Snorre partnership for permission to present the Snorre data

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