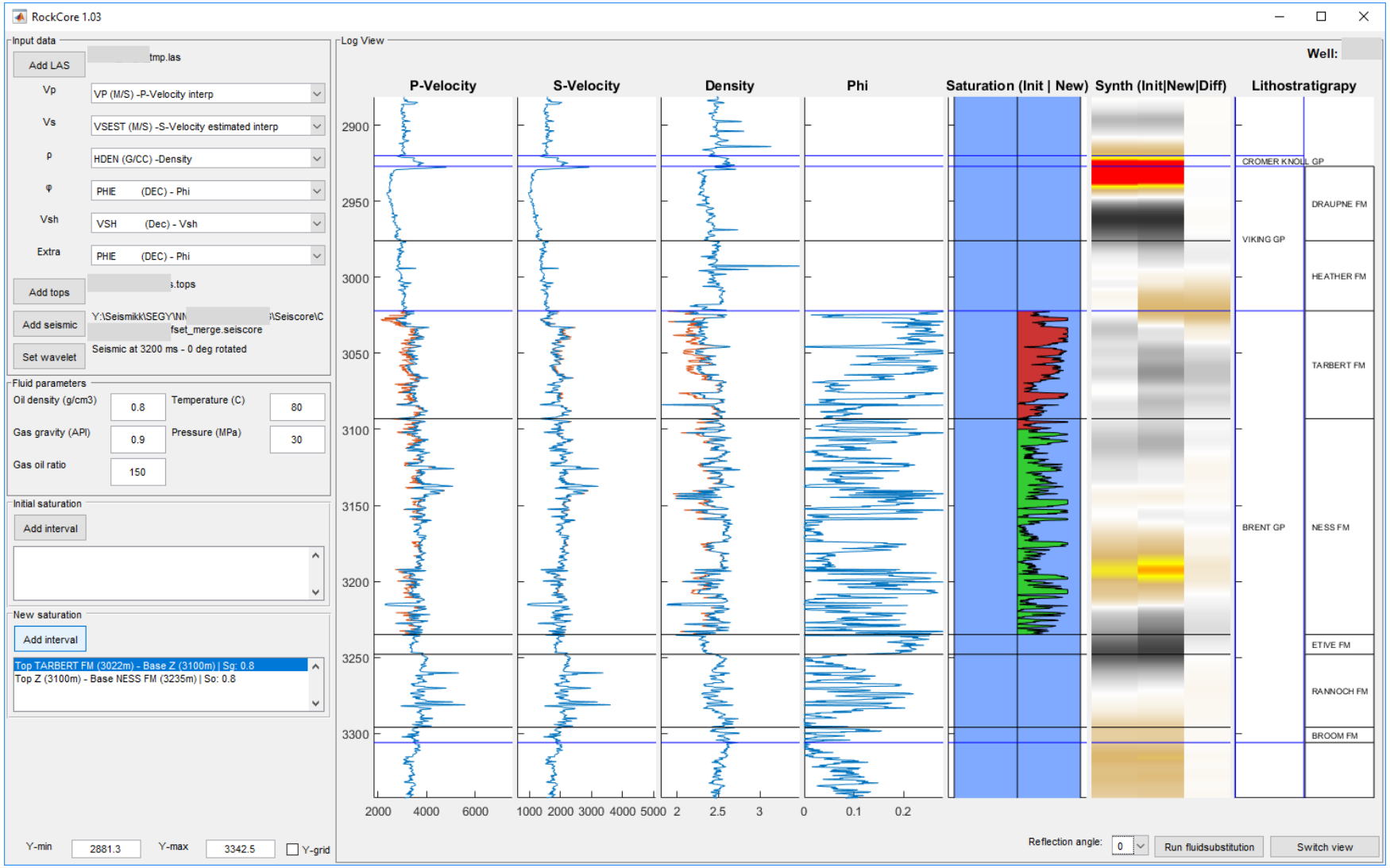
Simplified rock physics and seismic modelling for explorationists

FORCE workshop – 17.10.2017

Espen Oen Lie

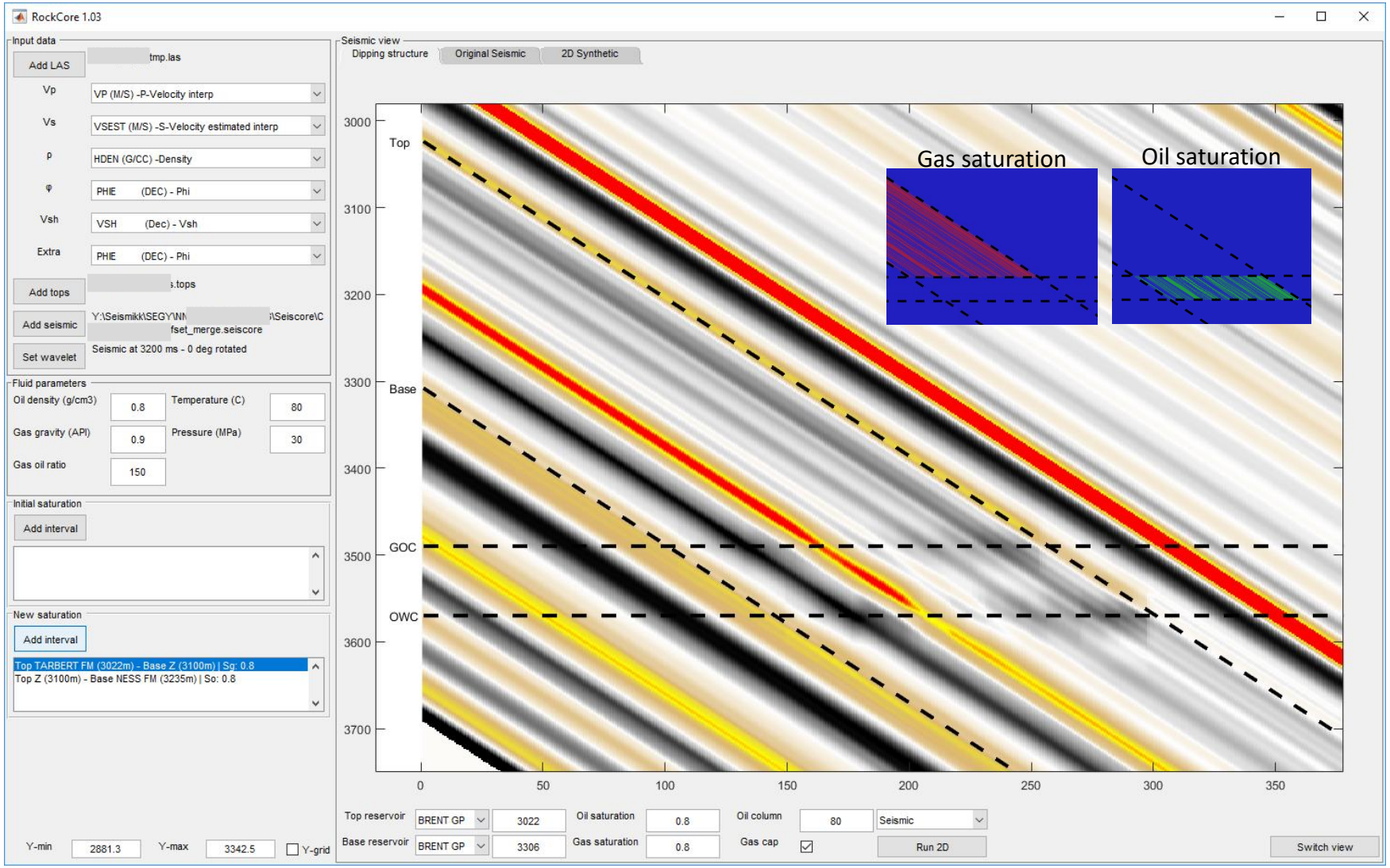
Standard fluid substitution

- Traditionally fluid substitution has been 1D
- Main goal is response at
  - Different depth
  - Different angles
  - For different wells
- It is often hard to relate to real seismic



Dipping structure

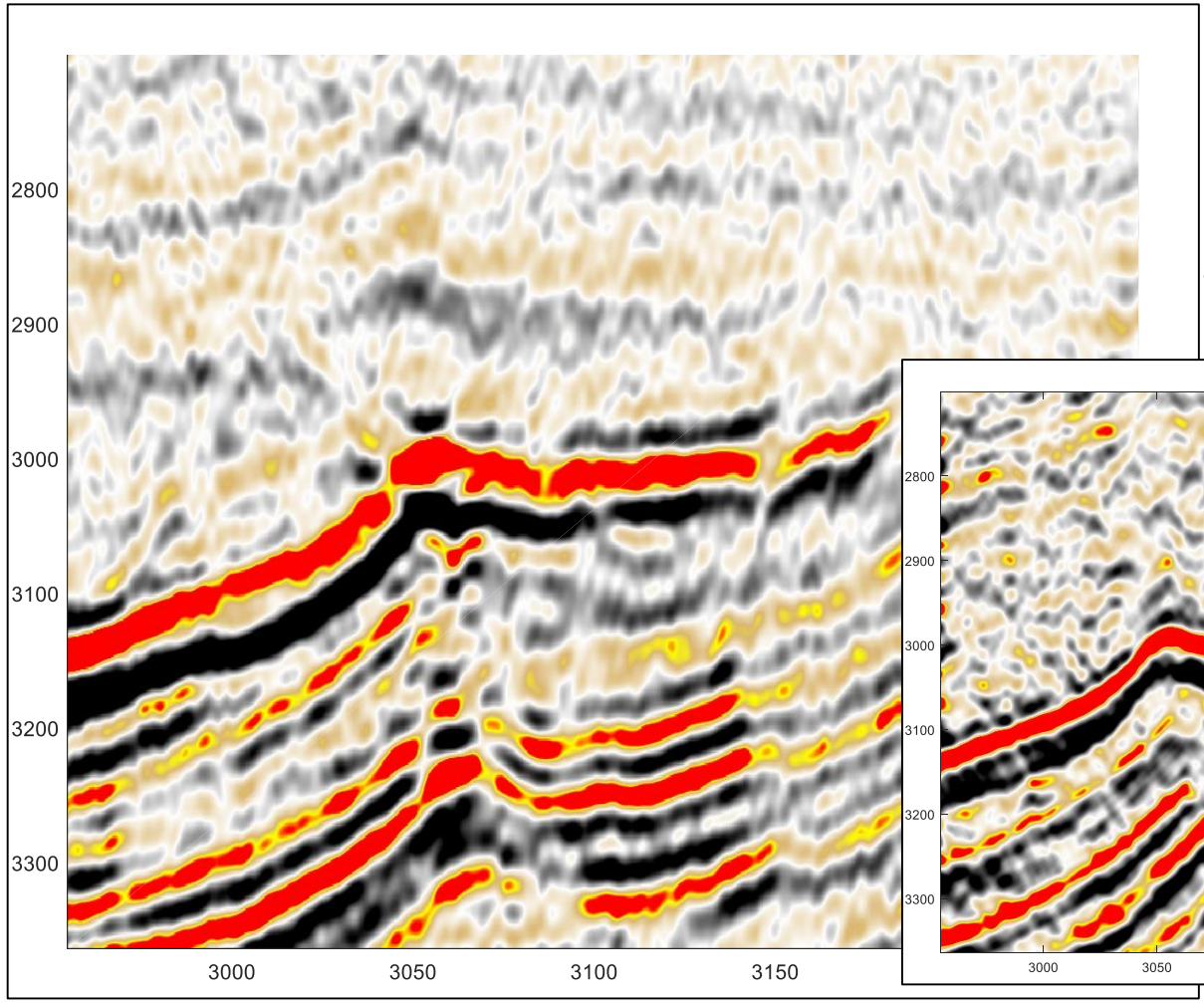
- A generic dipping structure can improve on this
  - Response on all levels
  - Tuning behavior near contact
  - Visually more similar to seismic
- Need very little user input:
  - Top, base and oil column thickness



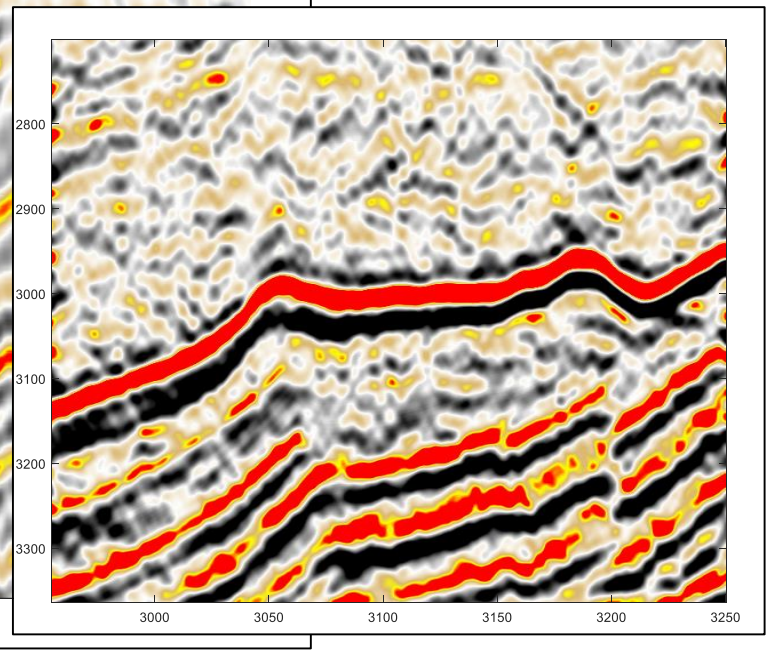
Can we improve?

- Our seismic contains
  - Thinning, change in overburden, faults, erosion, noise
- Can we model such case within the time limits of screening in exploration?
  - Target: Half day from well to seismic
- What does it take?

Real seismic



Synthetic seismic

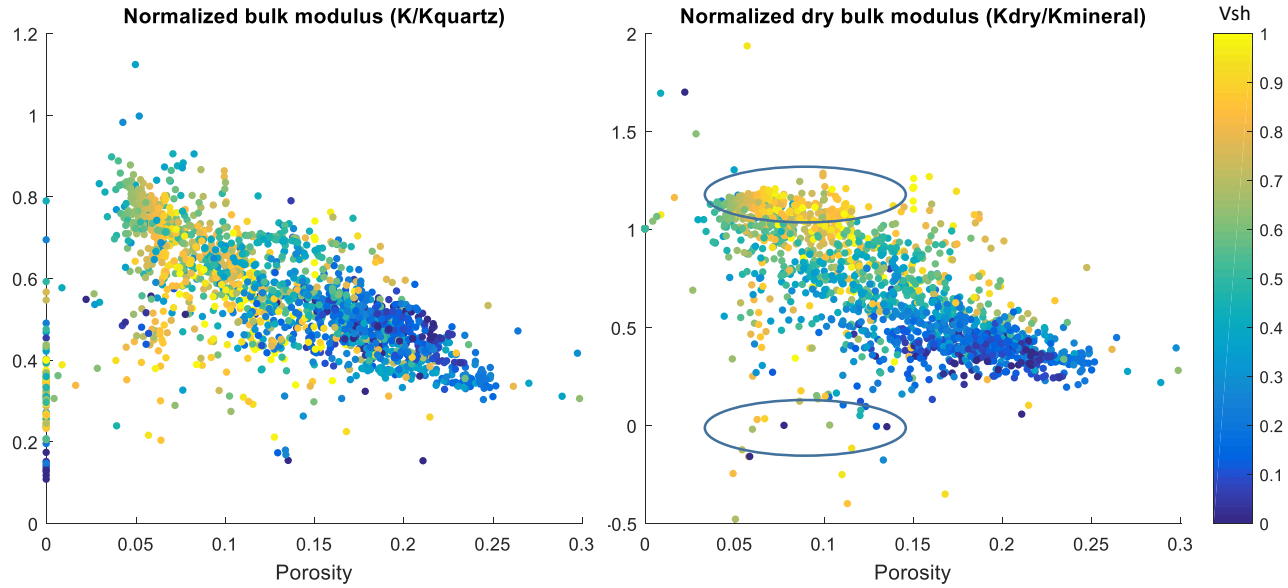


Overview

- Fluid substitution
  - Avoid manual parameter setting in Gassmann
    - Fluid substitute in sand, not mineral mixtures
    - Regression to theoretical model
- Fast track geomodel
  - Combined interface - fault picking
  - Stratigraphic / erosion surfaces
- Seismic modelling
  - How to model sequences of thin layers - prestack
  - Lateral resolution
  - Noise

Fluid substitution – simply challenging

- Simple recipe
  - Calculate bulk and shear moduli
  - Find K_{dry}
  - Adjust bulk moduli and density to new fluid content
  - Calculate velocities
- Main problem is that Gassmann assumes monolithological rock
- For measured values K_{dry} often become unphysical
- Even if we correct $K_{mineral}$ with clay content, results have a large span



- Common way to handle it, is to filter out all unphysical values
- But what about border values?
- Adjust or fix cut thresholds?

Alternatively – only substitute in sand

- Can we get around the mineral mixing problem?
- Assume that the sample consist of discrete homogenous volumes
  - Clean sand layers and impermeable layers (shale, coal, other lithologies)
- Suggested method
  - Find a model for the sand layer
  - Find a mixing model for layers
  - Substitute in sand layer
  - Assemble the rock

When we measure 50% Vshale do we have:

Mix quartz and clay minerals

or

Reuss sand and shale average

or

Voigt sand and shale average

- By substituting in clean sand, we avoid Gassmann inconsistency
- Cost is that a mixing model for lithologies must be introduced
  - And a sand model must be estimated

Alternatively – only substitute in sand

- By assuming Reuss averaging of lithologies, we get for initial and fluid substituted sample

$$\frac{1}{K_0} = Vsh\frac{1}{K_{sh}} + (1 - Vsh)\frac{1}{K_{sa_0}} \quad \text{and} \quad \frac{1}{K_1} = Vsh\frac{1}{K_{sh}} + (1 - Vsh)\frac{1}{K_{sa_1}}$$

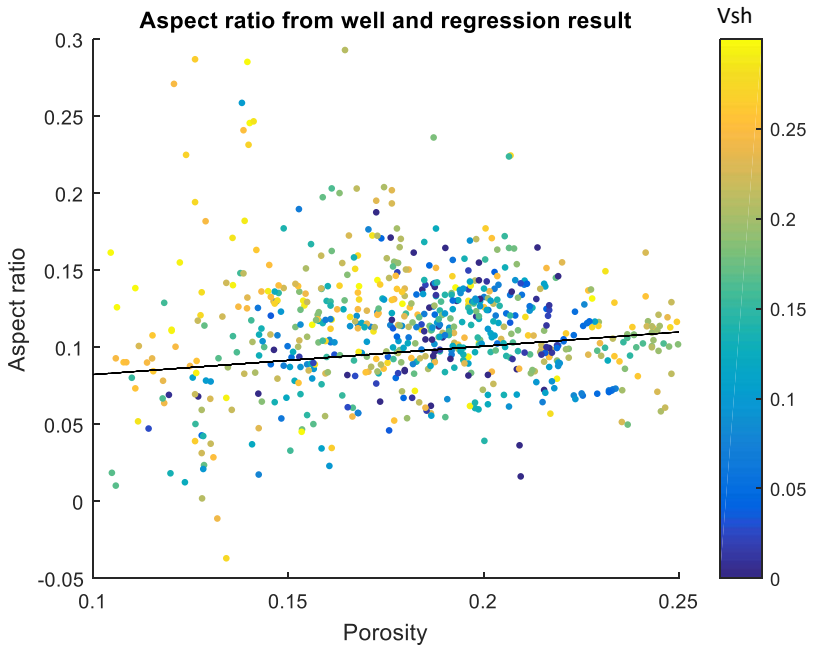
- If we have a sandstone model, we get

$$\frac{1}{K_1} = \frac{1}{K_0} + (1 - Vsh)\left(\frac{1}{K_{sa_1}} - \frac{1}{K_{sa_0}}\right)$$

- Fluid sensitivity is governed by pore space stiffness K_φ

$$\frac{1}{K_{sa}} = \frac{1}{K_{min}} + \frac{\varphi}{K_\varphi + K_{fl}} \qquad K_\varphi \approx \alpha(\varphi)K_{min}$$

- Usually it is eliminated, but instead aspect ratio $\alpha(\varphi)$ can be estimated, which results in a sandstone model



Method:
Estimate $K_{dry}(\varphi, Vsh)$.
Use regression to find $K_\varphi(\varphi, Vsh = 0)$. Other parameterizations are possible (formation, depth, gamma ray,…)

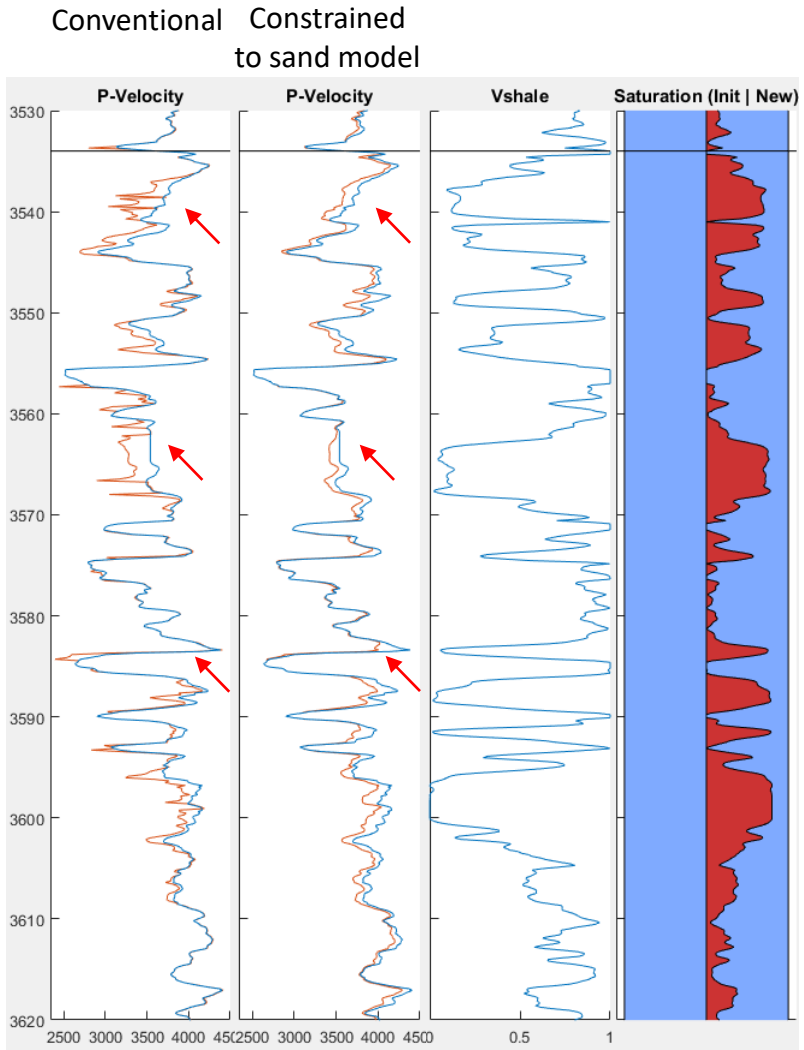
Alternatively – only substitute in sand

- Since we no longer rely on K_{dry}, result is much more stable

$$\frac{1}{K_1} = \frac{1}{K_0} + (1 - Vsh)\left(\frac{1}{K_{sa_1}} - \frac{1}{K_{sa_0}}\right)$$

Only dependent on regression result

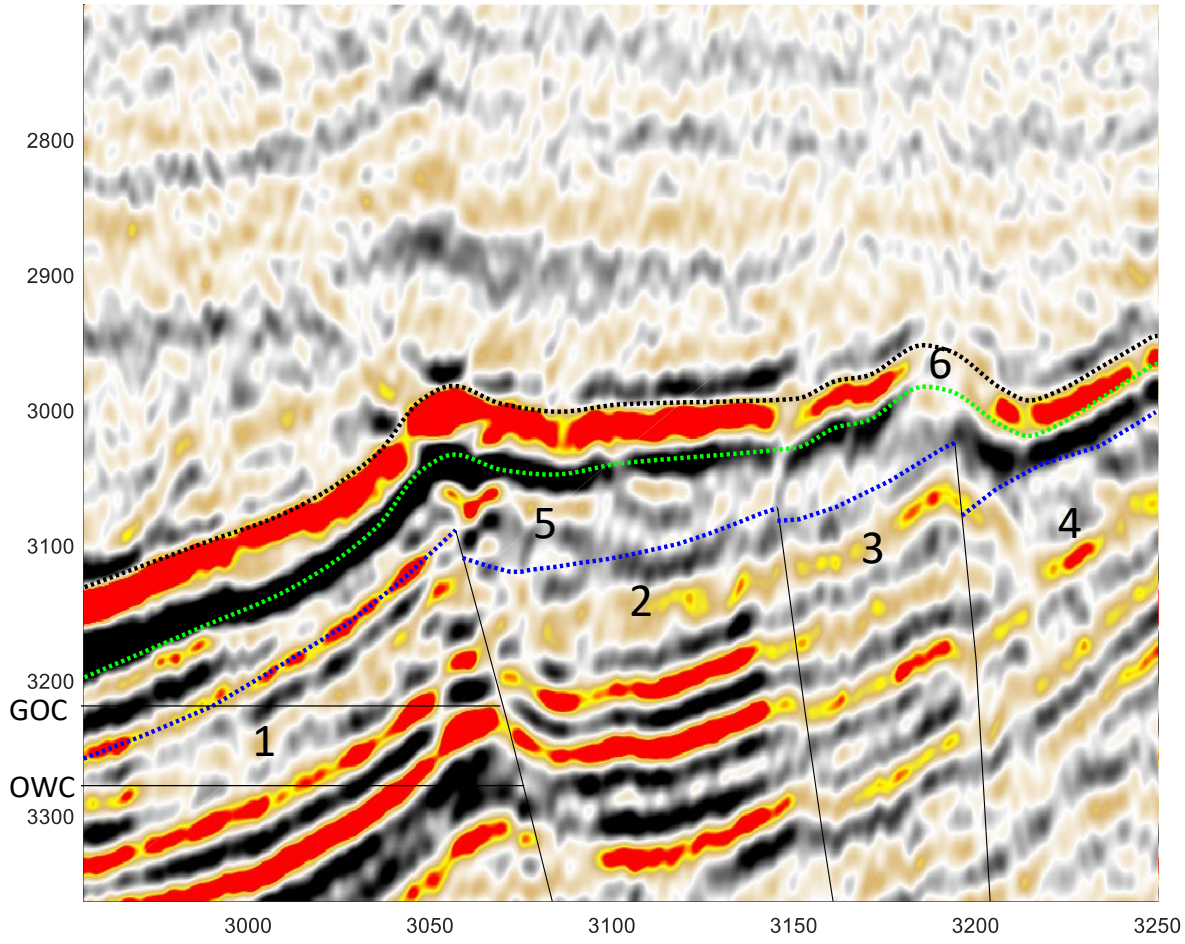
- Impermeable part cancels out – Can be other lithologies than shale (coal, calcite)
- K_{min} of mixtures enters initially (estimate of K_{dry})
  - Effect is small since regression is evaluated for Vsh=0
  - Calibration of K_{clay} is no longer needed?
- Can we define a universal regression model?
- Automatic fluid substitution for our geomodel?



Fast track Geomodel

- Need to handle
  - Fault blocks
    - Integrate top and fault picking to define fault blocks
  - Depositional surfaces
    - Extrapolate formations to match thickness – not stretch and squeeze
  - Erosional surfaces
    - Cut prior elements
- This model
  - 4 fault blocks (1-4)
  - 2 Depositional surface (5,6)
  - Fluid substitution in block 1

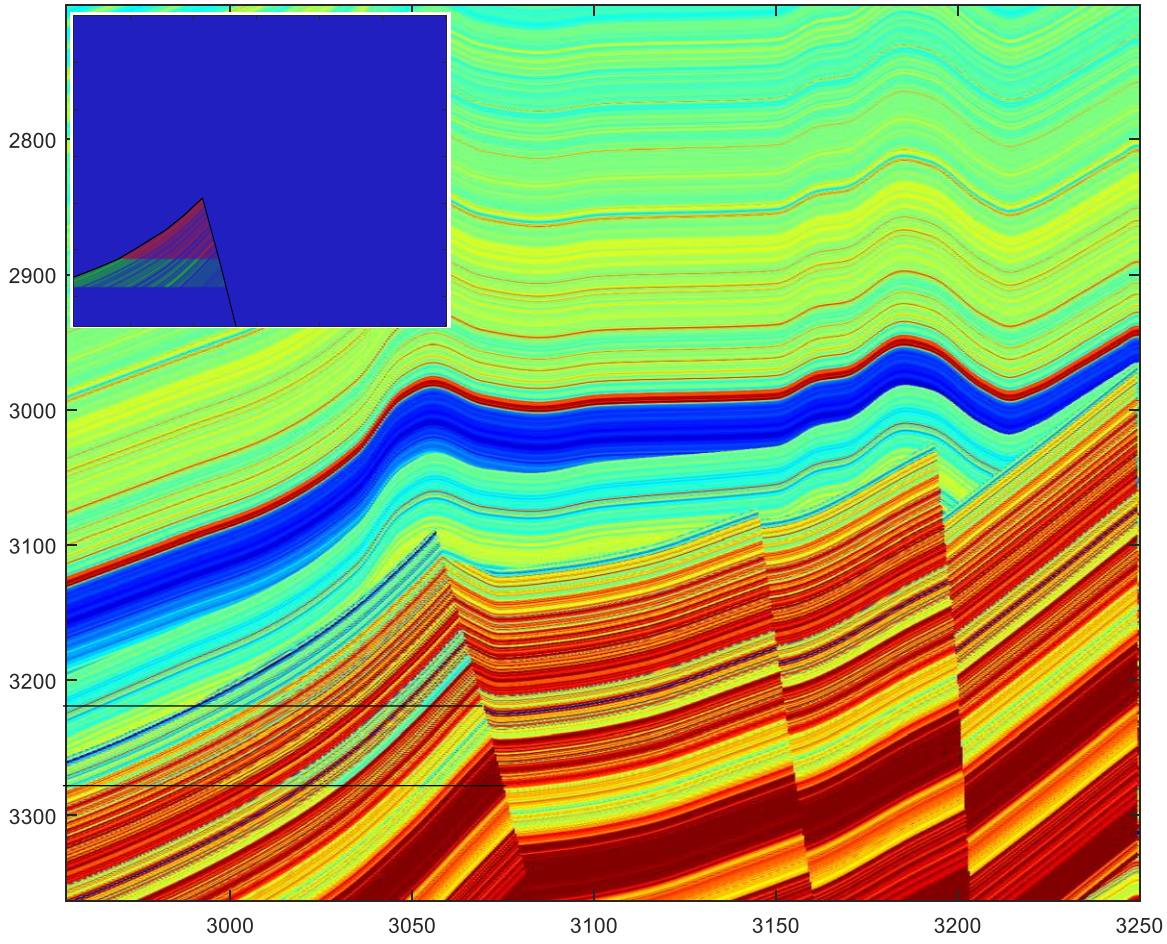
Real seismic



Fast track Geomodel

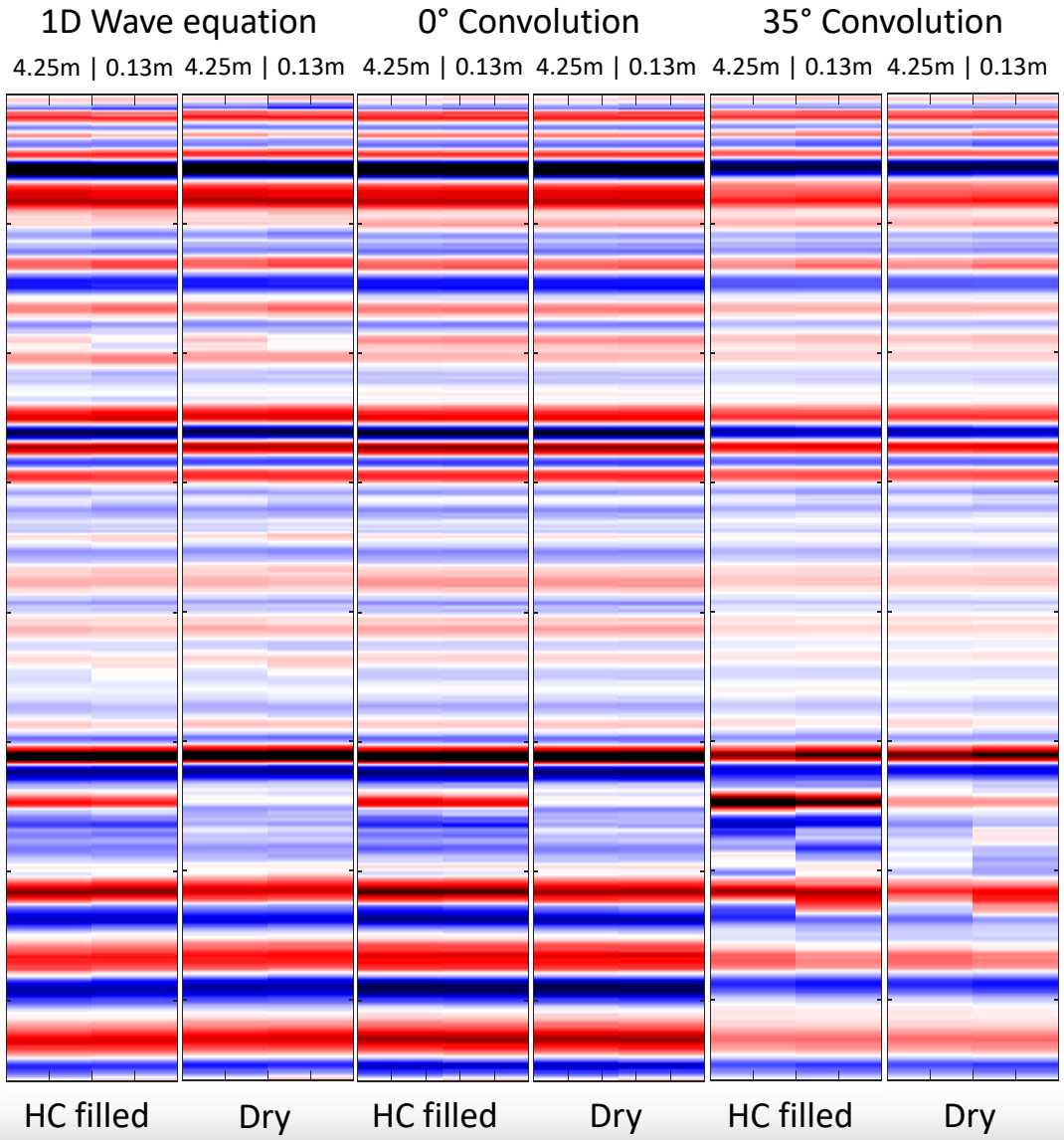
- Quite complex model based on the 6 elements and a well log
- Should be fully automated (ongoing)
- Fault blocks are tricky to lay out correct
- Need some more work on extrapolating formation properties
  - Extrapolate trends and bootstrap properties
- So how to model it?

Acoustic impedance (with HC) and saturation model



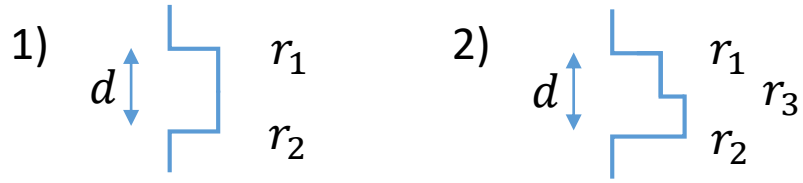
Seismic modelling – importance of scale

- Zero offset modelling is insensitive to layer thickness
  - Backus averaging to 33x layer thickness give similar response
  - True for both 1D wave equation and convolution (1500 m overburden)
  - No major differences on results
- Linearized Zoeppritz is sensitive to scale
  - Upscaling gives different result
  - Need to be consistent on scale



Seismic modelling – importance of scale

- Well logs are filled with thin layers
  - AVO-models are derived from two half-space
  - How are their thin layer response?
- Consider a thin layer embedded in a background 1) and 2)
- Physically the reflection of this layer disappear when d becomes small
- To be consistent we require:
  - In model 1), $r_1 = -r_2$
  - In model 2), $r_1 + r_2 + r_3 = 0$



- Zoeppritz fail in both models!
  - Unphysical thin layer reflections adds up to large AVO effects
- Both linearized Zoeppritz and zero offset reflectivity fail in model 2)
- Why is the problem only visible for large angles?

$$R(\theta) = \frac{1}{2}\left(1 - 4\frac{\beta^2}{\alpha^2}\sin^2\theta\right)\frac{\Delta\rho}{\rho} + \frac{1}{2}\sec^2(\theta)\frac{\Delta\alpha}{\alpha} - 4\frac{\beta^2}{\alpha^2}\sin^2\theta\frac{\Delta\beta}{\beta}$$

- Main suspect is velocity ratio!

Why is multilayer Zoeppritz modelling wrong?

- The dramatic AVO effect in Zoeppritz is due to mode-conversions
- This mode-conversion does not occur in thin layers
- *"Zoeppritz equations should not be used for synthetic seismograms without including the locally converted shear wave"* [1]
- A peculiar fact is that Zoeppritz is most incorrect when it is supposed to be exact (large angles)

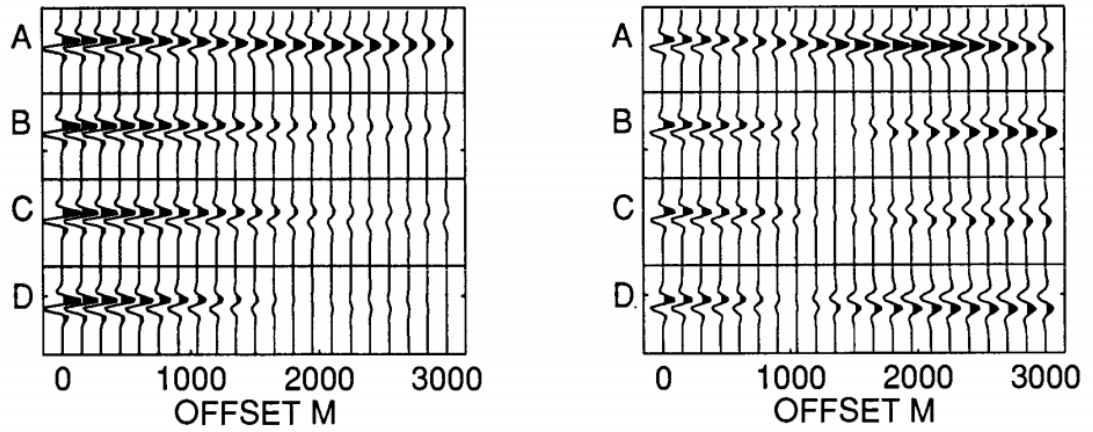


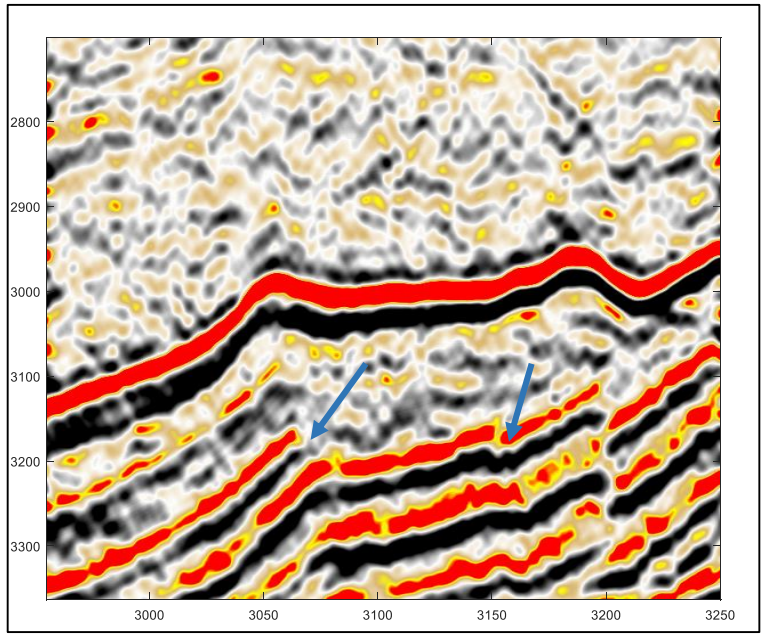
FIG. 10. Comparison of the reflection coefficients and seismograms of the 17-percent-porosity models in Table 4. Zoeppritz reflection coefficients-solid, linearized approximation-dashed, composite-base reflection-bold solid. (a) Primaries-only Zoeppritz, (b) single-leg shear wave added to (a), (c) reflectivity method, and (d) primaries-only linearized approximation.

[1] "AVO modeling and the locally converted shear wave" Simmons and Backus (Geophysics, 1994)

Why not use wave-equation?

- Need fine layering to avoid internal multiples
  - Runtime can be problematic for 2D
- Response is dependent on overburden / distance to source
- Our seismic images are processed
  - Wave-equation modelling produce data, that must be processed
  - Introduce several new issues
- After all these years: No optimal AVO reflectivity model!
  - Best option: Constant scale linearized Zoeppritz

Synthetic seismic

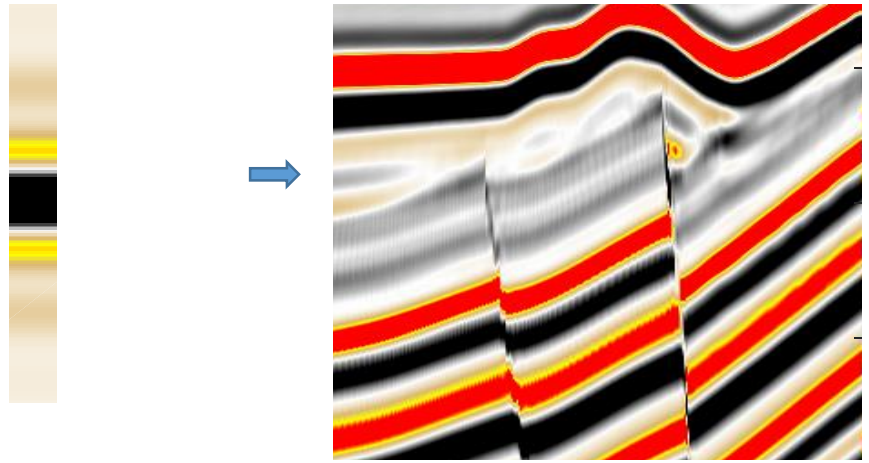


- But how can we model the lack of lateral resolution?

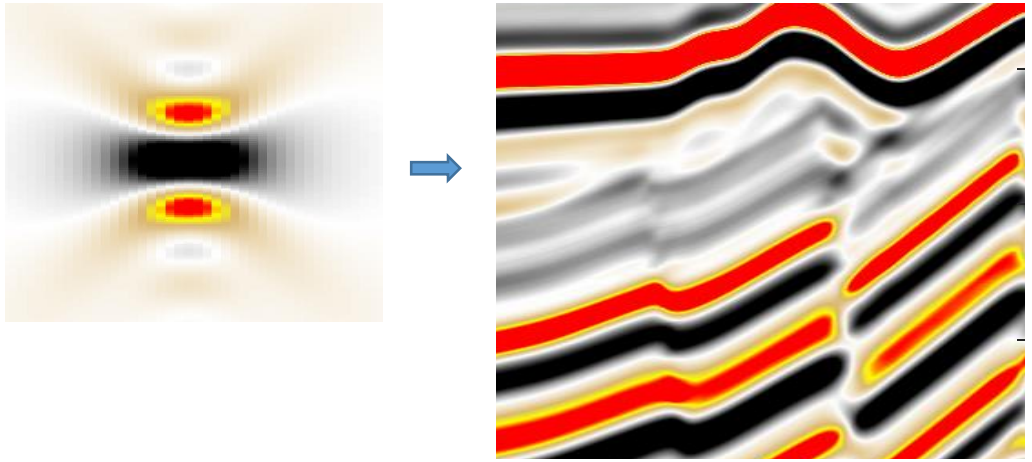
Pseudo-Kirchoff 2D modelling

- Our data is acquired in a 3D world with bandlimited wavelet
  - Reflections in the underground are mixed
- Can be modelled by impulse response of
  - Kirchoff modelling + migration
- Result is a 2D convolution of operator dependent on
  - Depth, velocity, offset
  - Wavelet
  - Time / lateral sampling
- This is not a full modelling-imaging process, but an approximation

1D convolution



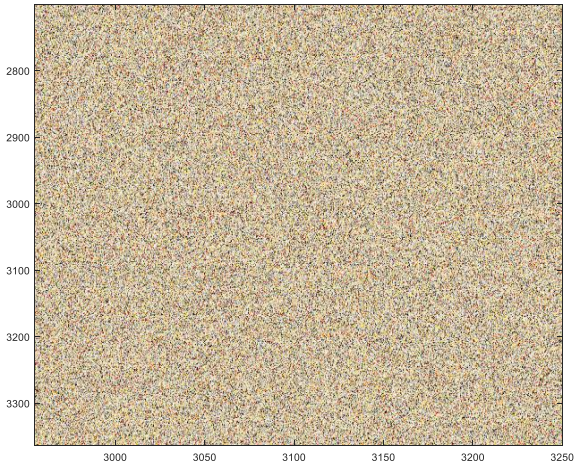
Pseudo Kirchoff modelling



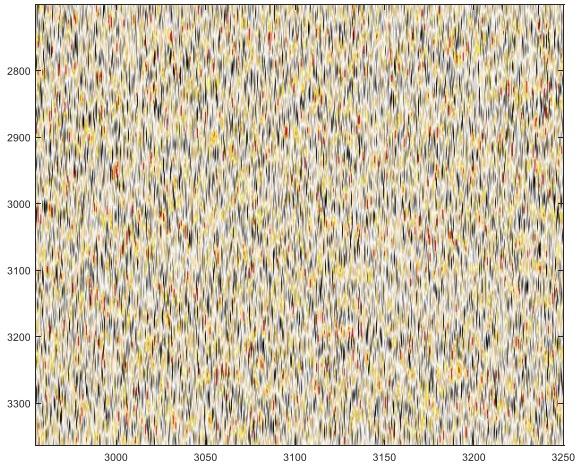
Final step - noise modelling

- Fluid responses are often visible on differences or perfect data
- How do we address if it is visible on real data?
- Modelling of noise is an option
  - Simple noise is quite easy to filter out (eyes / processing)
  - Real noise is similar to seismic in character (residual noise)
- Now the seismic can be assembled

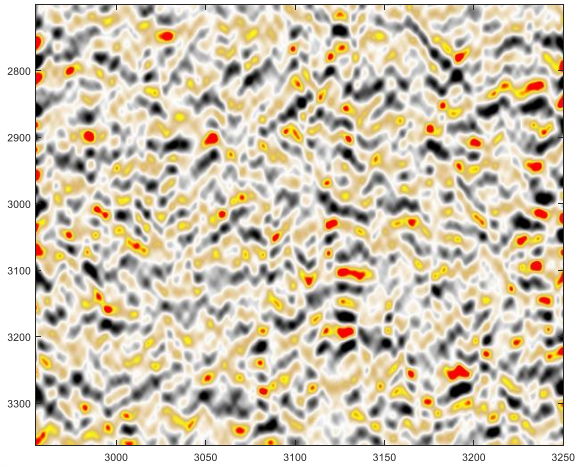
Gaussian noise



Coloured noise



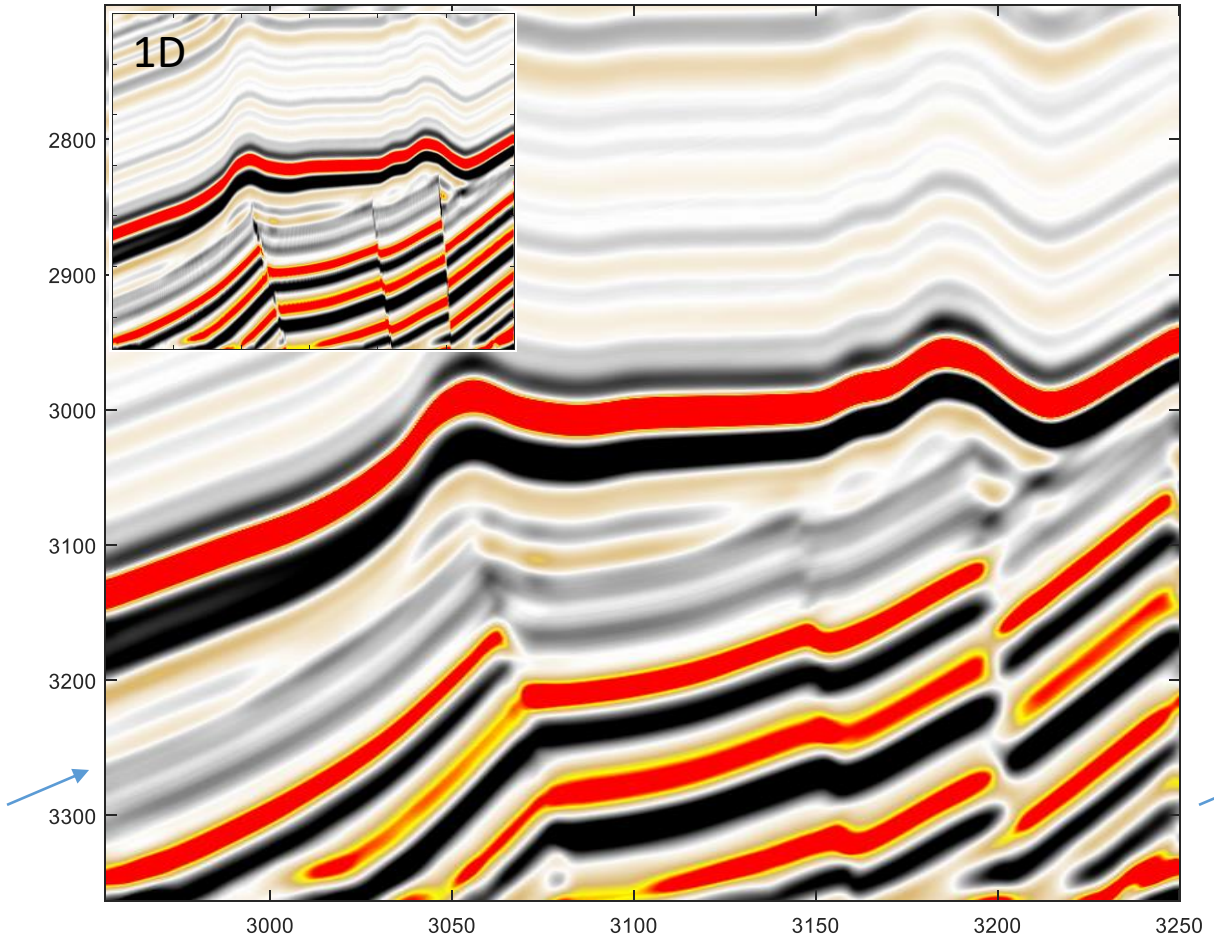
Realistic noise



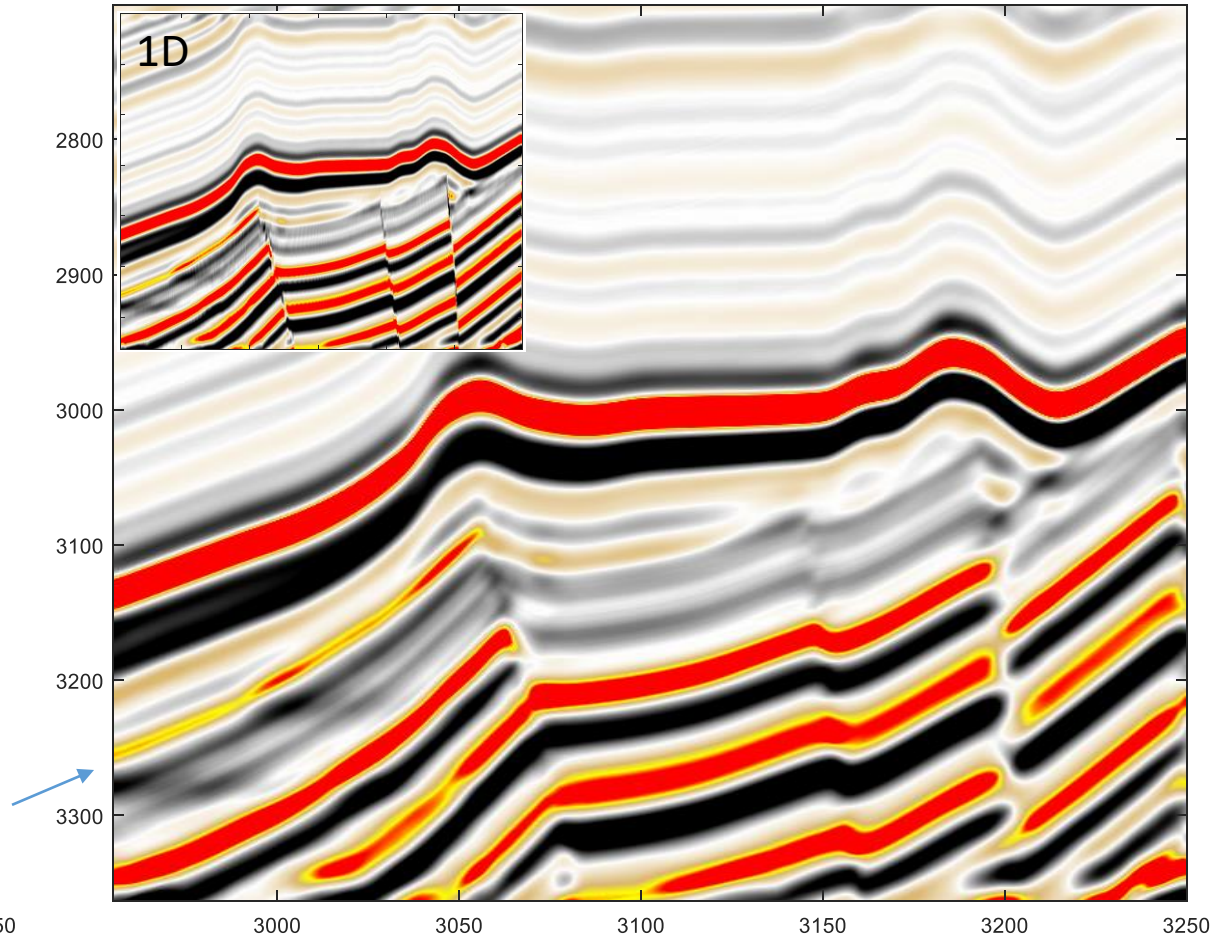
Pseudo Kirchoff modelling vs 1D convolution

GEOCORE
Consultancy, Research and Exploration

Dry case



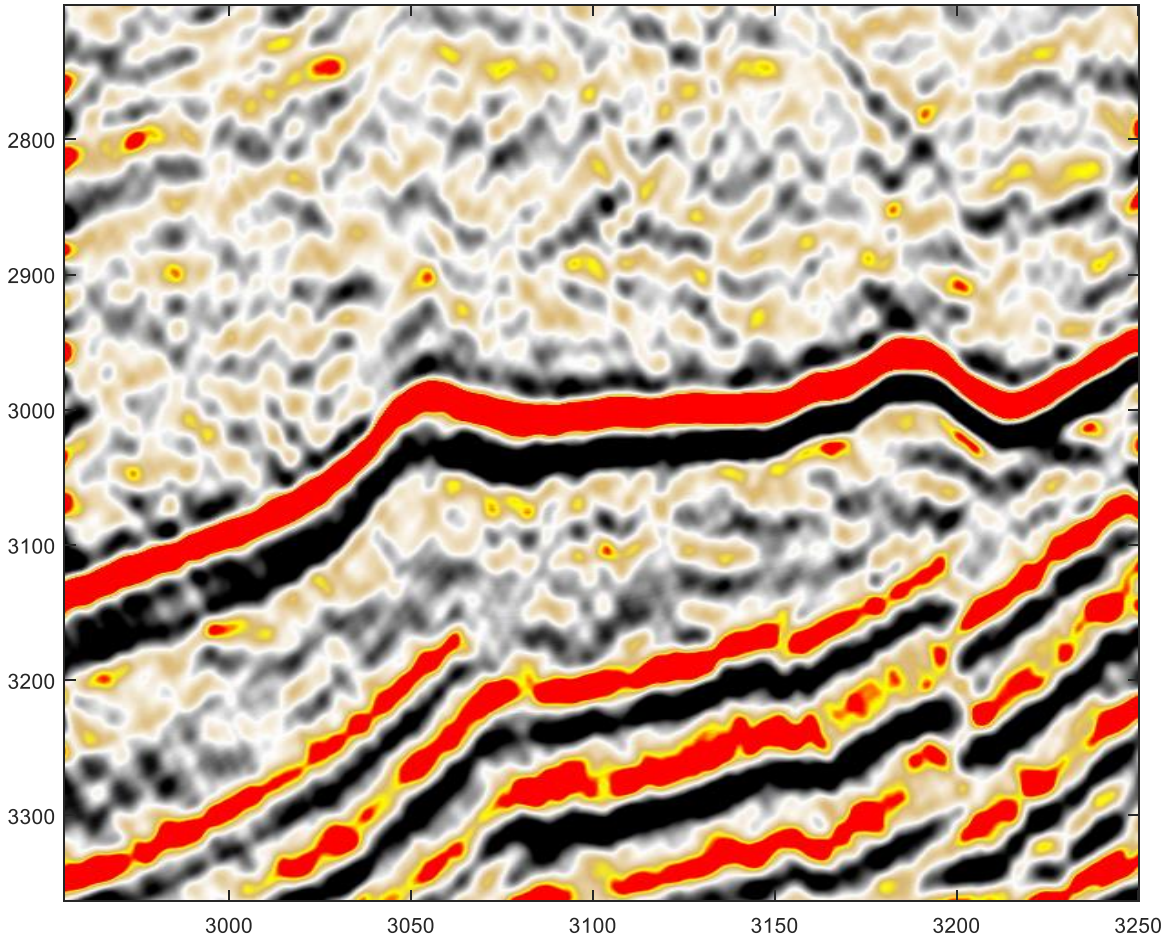
HC filled



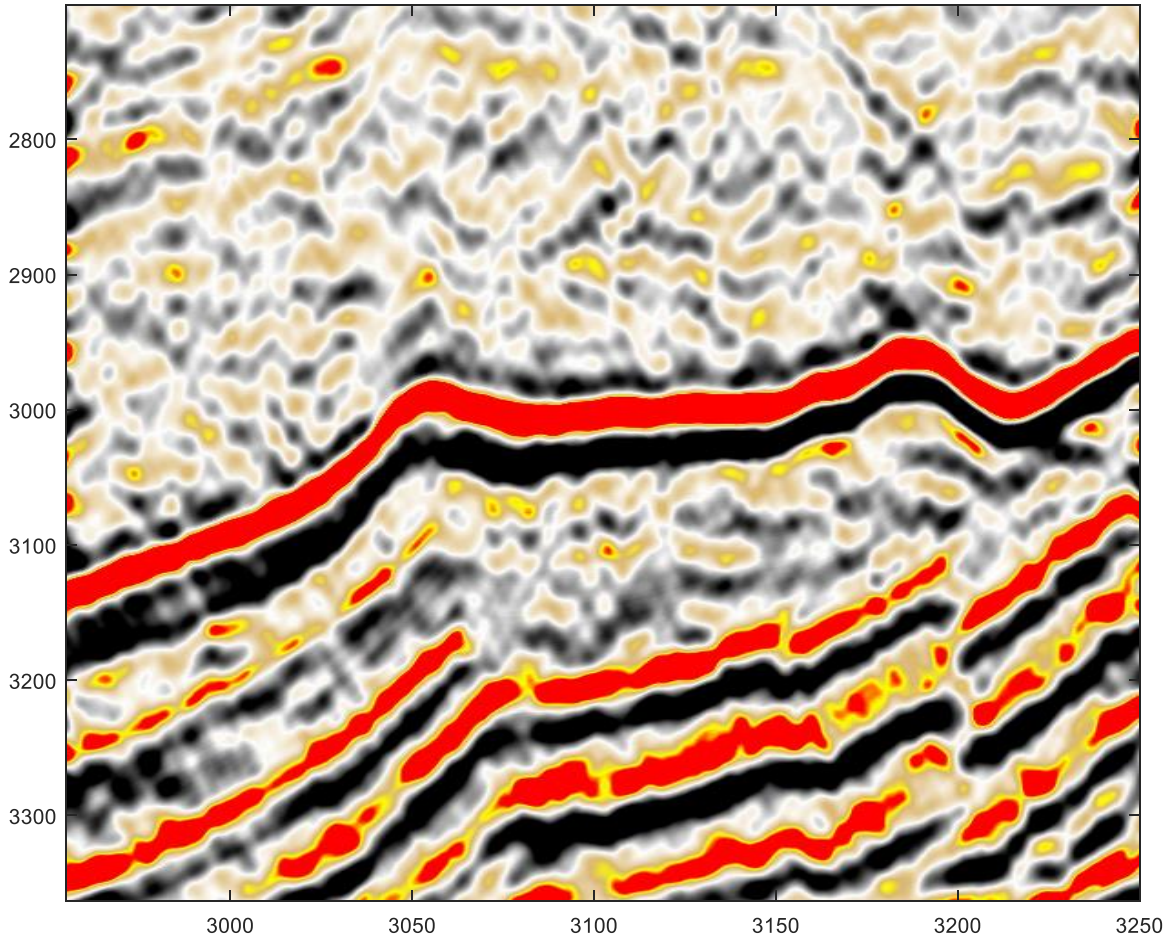
Pseudo Kirchoff modelling with noise

GEOCORE
Consultancy, Research and Exploration

Dry case

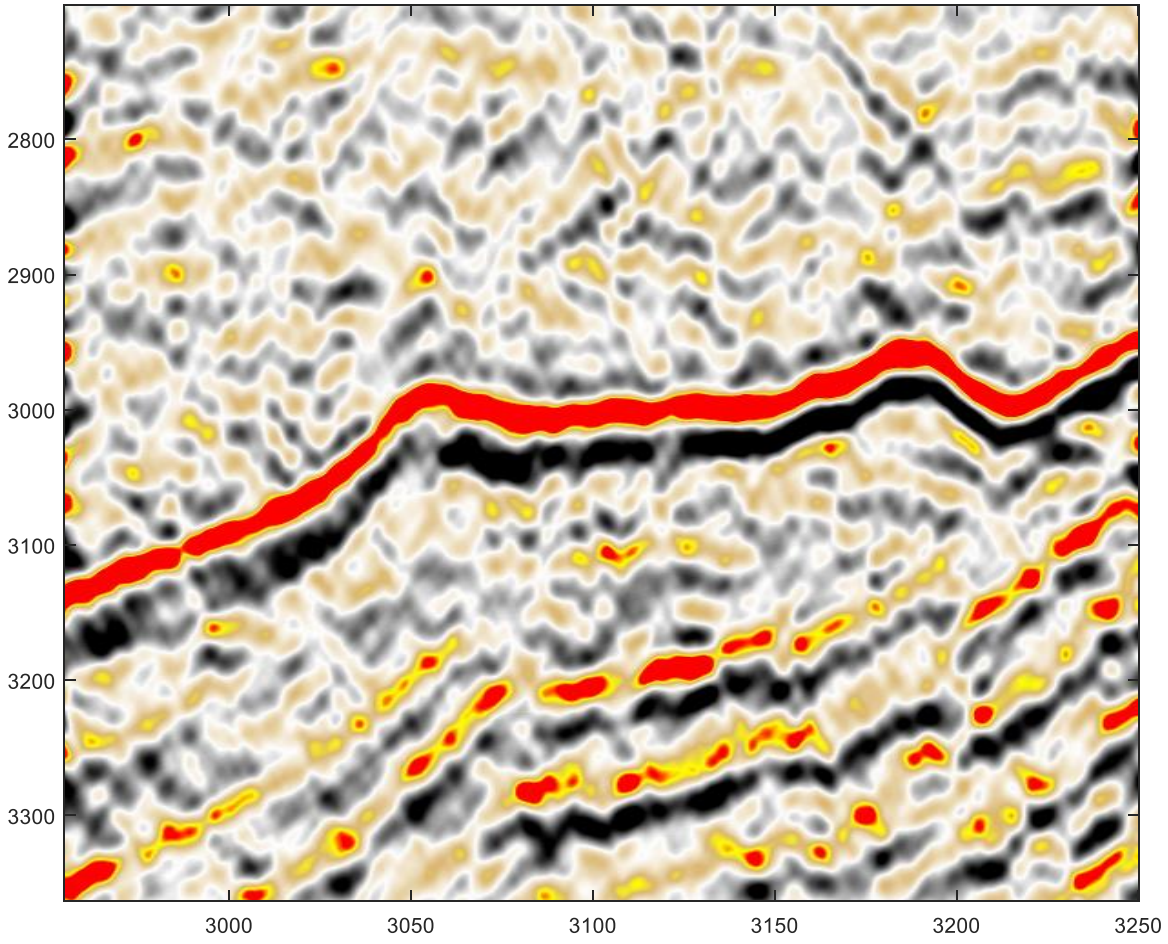


HC filled

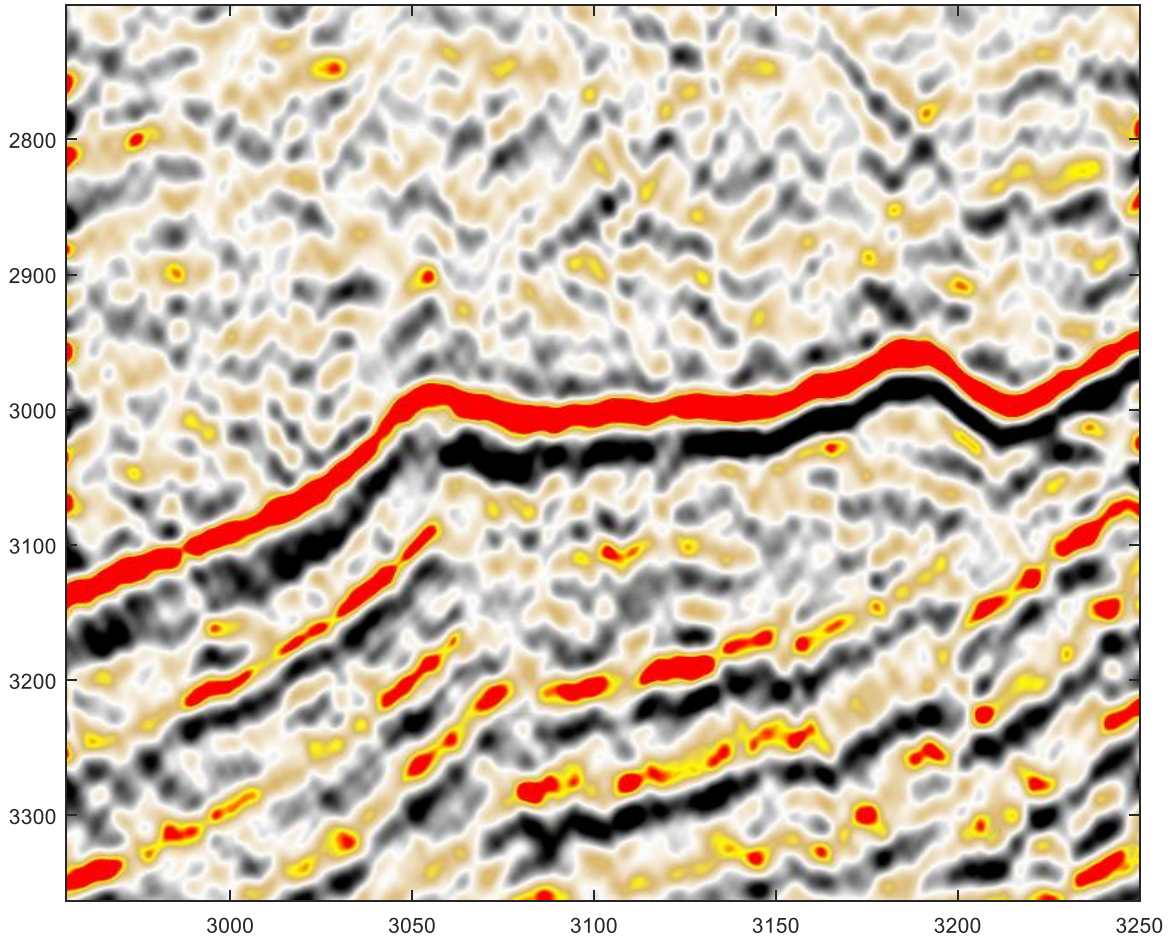


AVO 30 degrees – Linearized Zoeppritz with noise

Dry case



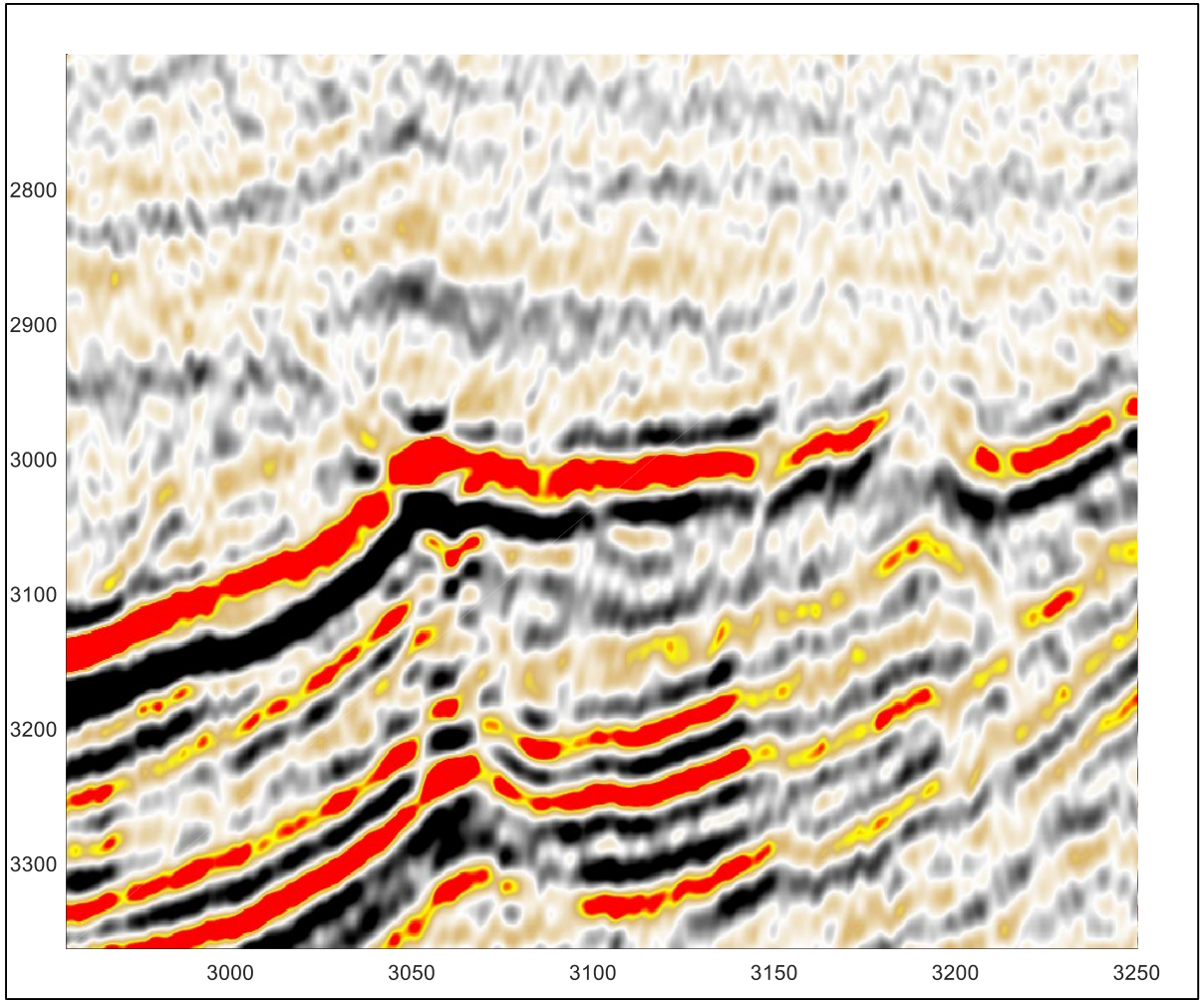
HC filled



Final thoughts

- Seismic modelling should be easy for the user
  - Not for the programmer
- Process should have few pitfalls
  - Less options
- Geological model should be made interactively by interpreter
- End result should look like imaged seismic
  - Not measured seismic which is for the processing department

Real seismic



Conclusion

- It is possible to do fluid substitution without relying on strange K_{dry} values
- Stop using Zoeppritz modelling!
- More effort should be put into making more reliable prestack reflectivity models
- Realistic prestack seismic modelling is feasible in an exploration setting

- Future work:
  - Include offset stretch modelling
    - Straightforward, but care must be taken not to use wavelet multiple times
  - Reliable formation properties extrapolation
    - Not all formations can be extrapolated

Acknowledgement

- Thanks to Concedo ASA for letting us present results using their data

- Contact:
  espen@geocore.no
  www.geocore.no