Information content in forward 4D seismic modeling and elastic inversion

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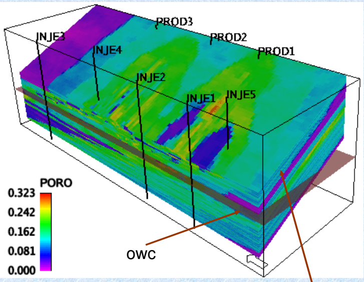
TASK

- Generate a realistic synthetic reservoir with corresponding seismic response
- Do reservoir characterization without more knowledge about the true reservoir than well logs and seismic response
- Investigate the information content in the seismic response – how much more do we gain from 4D data?
- Suggests a novel quick update procedure for the permeability field that accounts for the 4D seismic effect

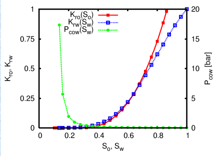
The "truth"



Contain a thin (2m) high-permeable thief zone 20 m below top reservoir close to well PROD1

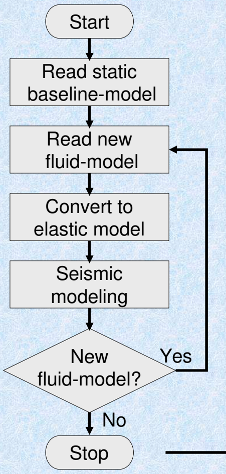
Use a synthetic, tilted, 180 m thick shallow marine reservoir with realistic petrophysical properties

8 vertical wells

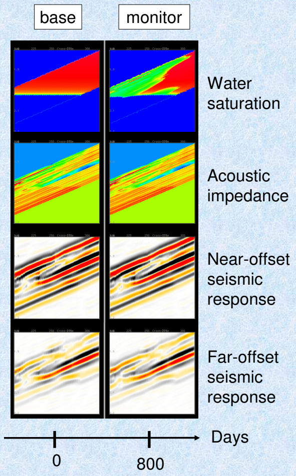


Run flow on the true reservoir

Reservoir pressure and saturations in time



Forward seismic modeling workflow



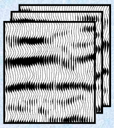
Run forward seismic modeling at two times to produce seismic responses similar to realistic input data for a real reservoir characterization project

Want to generate a realistic reservoir characterization based on realistically known data:

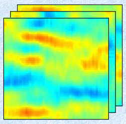
Seismic responses at various offsets and angles

Well data – Permeabilities, porosities, elastic parameter logs: Vp, Vs, ρ

Seismic inversion



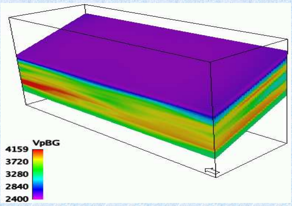
far-offset + mid-offset + near-offset



Vp + Vs + ρ

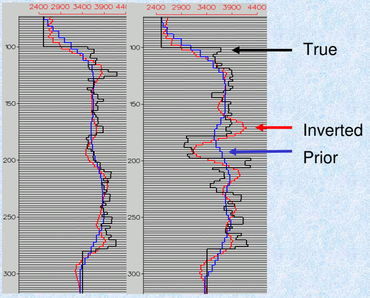
Generates elastic parameters for conditioning in the reservoir characterization

Bayesian inversion need a prior model. Therefore, generate background Vp, Vs, ρ in whole reservoir



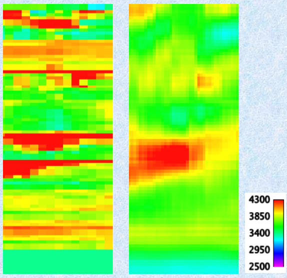
Use elastic parameter logs to generate background model through long-range kriging

Inverted Vp compared to True in two traces



At well INJE2

At location far from wells



Inversion not as detailed as the true in a flattened East-West view

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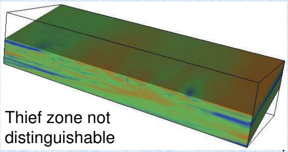
3D conditioning

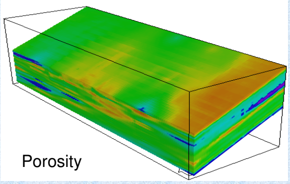
Combine well logs and elastic parameters into a new parameter:

parameter = f (Vp, Vs, ρ | well logs)



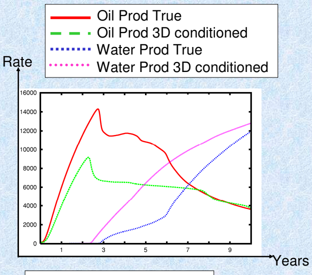
The combined elastic parameter is an optimal linear combination of elastic parameters Vp, Vs and ρ

Condition permeabilities and porosity on well logs and co-krige with combined elastic parameter



3D conditioned realizations of porosity and permeabilities

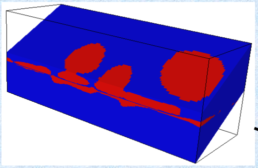
Flow simulation with optimal (identical) settings as for the true reservoir

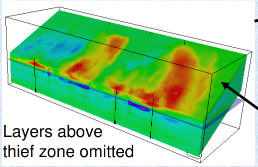


As always: Room for improvements

4D conditioning

Indicator parameter: Change in oil and water saturation for previous realization between monitor and base seismic survey times





Find ΔVp between monitor and base survey

Idea: Fast update of petrophysical field based on both ΔS and ΔVp.

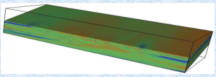
How: As a 3D trend parameter in petrophysical modeling.

Where do these agree/disagree?

Layers near thief zone shows higher ΔVp than others.

2 conditioning parameters for petrophysical modeling:

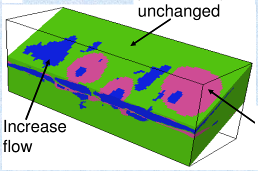
1



Combined elastic 3D parameter

+

2

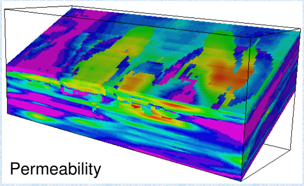


Little info, keep permeability unchanged

Increase flow

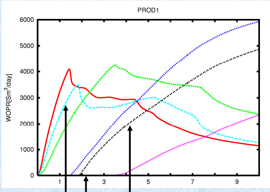
Decrease flow, i.e. permeability

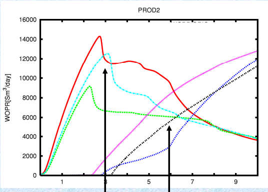
Combined trend parameter, ΔS and ΔVp both taken into consideration

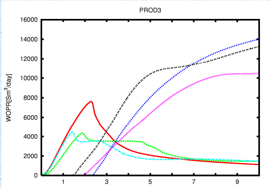


Updated permeability parameter is identical where trend information parameter is zero. Conditioning from combined 3D parameter is kept.

Flow comparisons at producers







- Oil Prod True
- Oil Prod 3D conditioned
- Oil Prod 4D updated
- Water Prod True
- Water Prod 3D conditioned
- Water Prod 4D updated

Clear improvement in predicting both oil and water production

Monitor survey at 800 days

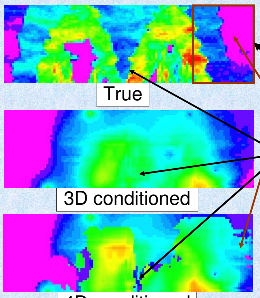
Clear improvement in predicting both oil and water production

Marginal improvement in predicting oil and water production

Why? The other producers have higher 4D effects at the monitor time as they are located nearer the high permeable regions

CONCLUSIONS AND COMMENTS

- Thin thief zone not visible on 3D, but affects the 4D conditioning
- A simple and fast 4D updating procedure is suggested that combines both the seismic response changes and the saturation changes
- Flow simulations on updated reservoir show significant improvements on production rate predictions
- Method is iterative; it can be repeated for any number of new monitor survey times
- The suggested 4D based trend parameter can be continuous, and also account for the change in Vs and ρ, enabling the possibility to distinguish the 4D effect more than the simple indicator parameter used here



Horizontal permeability at 1 layer below thief zone:

Thief zone area in adjacent layer

Thief zone affects a thicker part than true in 4D data.

Low-perm area corrected

Improvements seen although only considered early production 4D seismics

4D conditioned permeability is more heterogeneous than the 3D conditioned

Acknowledgments: The Research Council of Norway