

The GIG consortium

Geophysical Inversion to Geology

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Abrahamsen

FORCE, Stavanger

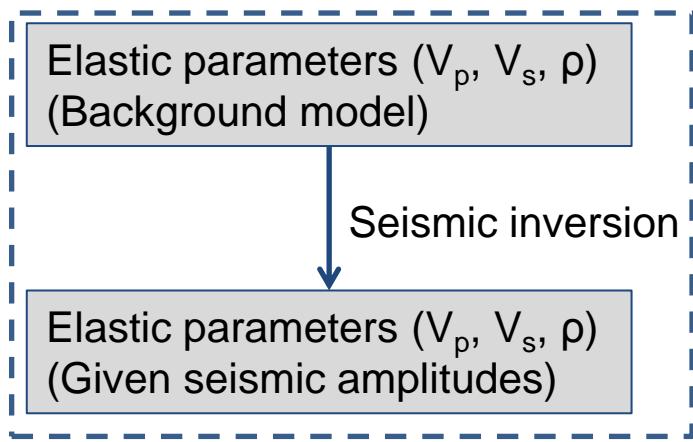
17. November 2016



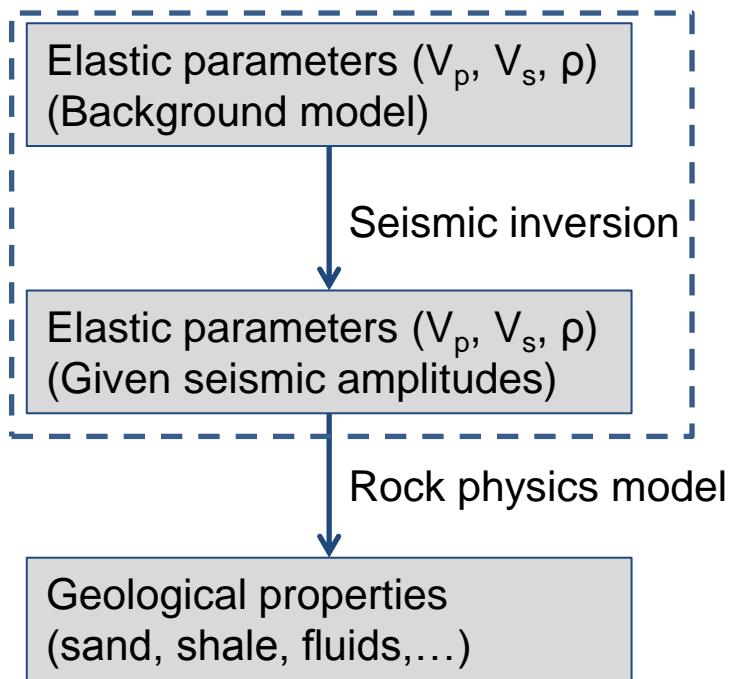
Consortium goals

- ▶ Better estimation of reservoir parameters from geophysical measurements
 - Research
 - Methods
 - Software
- ▶ Quantify uncertainty and risk using stochastic models
- ▶ Use established geophysical and rock physics relationships

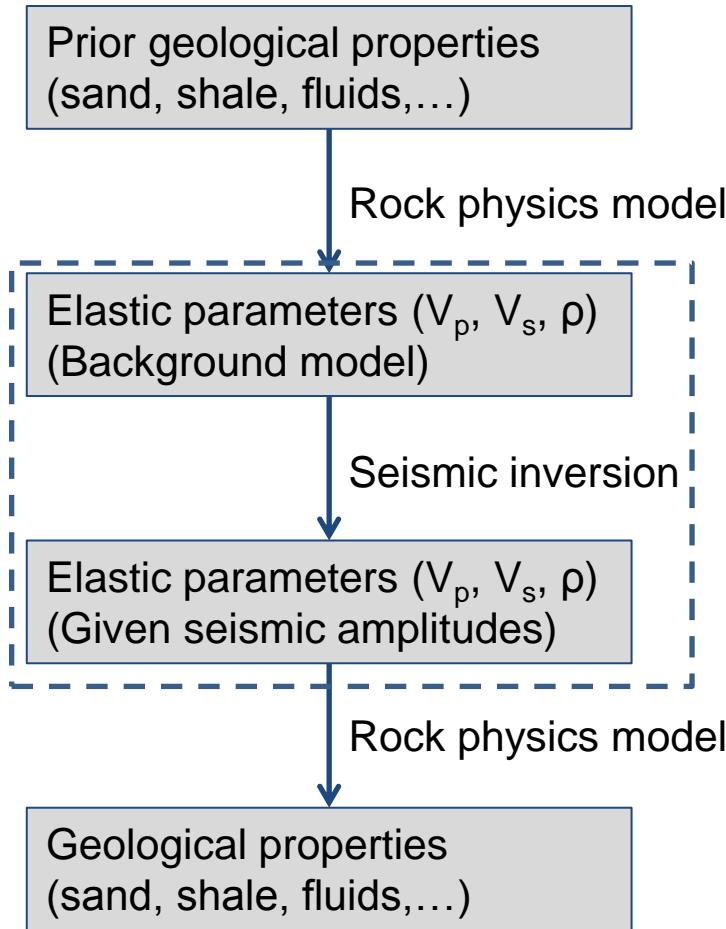
Standard seismic inversion



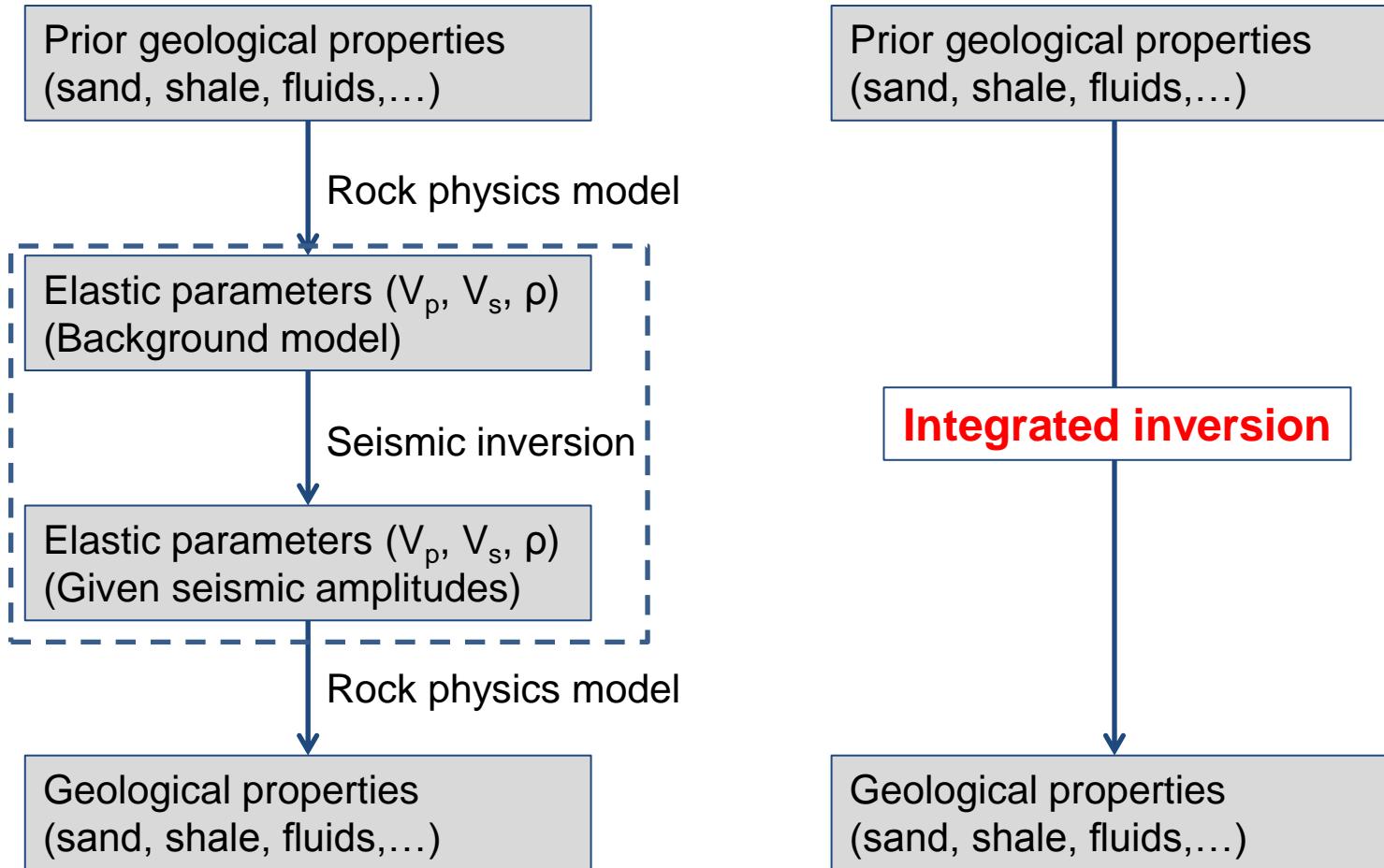
Standard seismic inversion with geological output



Standard seismic inversion with geological output and input

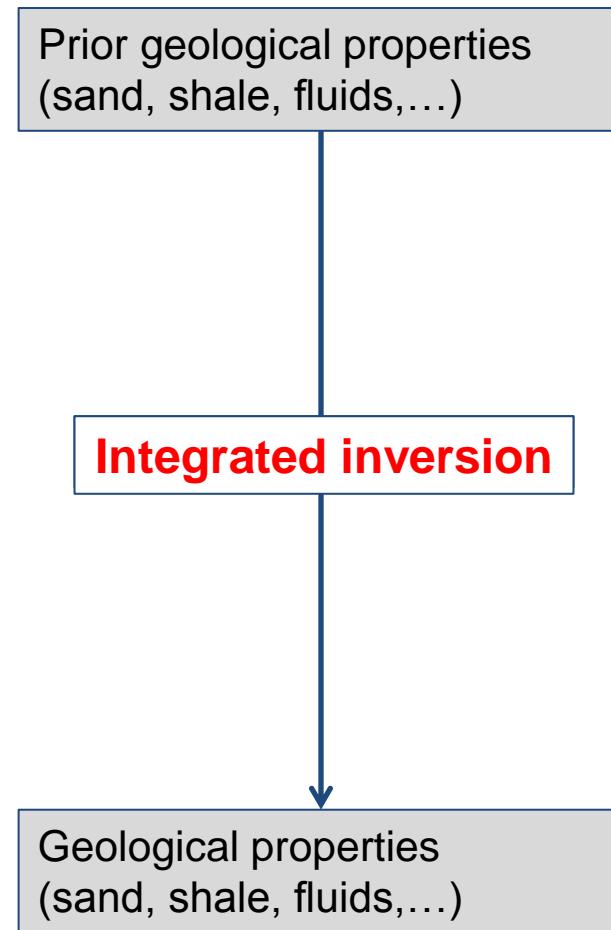


Seismic inversion using geological constraints



Seismic inversion using geological constraints

- ▶ Honors geological constraints in inversion
 - Fluid ordering
 - Stratigraphic ordering
 - Elastic parameters per lithology/fluid
- ▶ Reduces prediction uncertainty
- ▶ Elastic parameters are a by-product

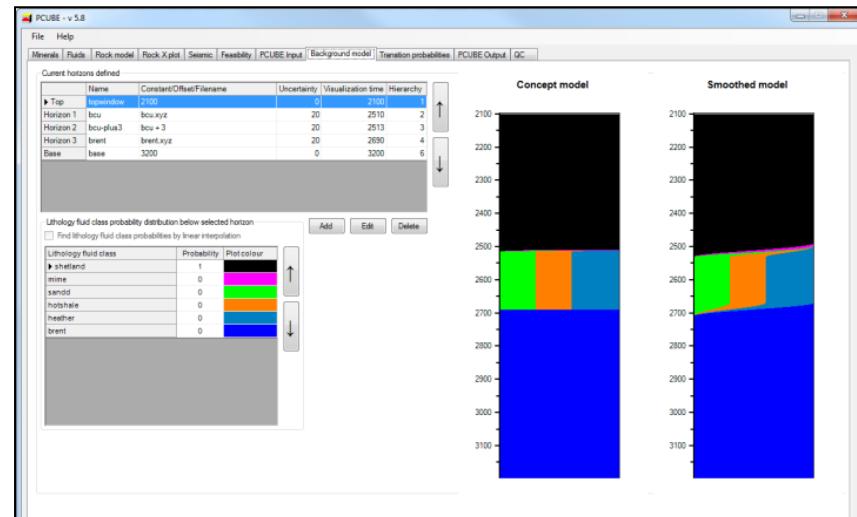
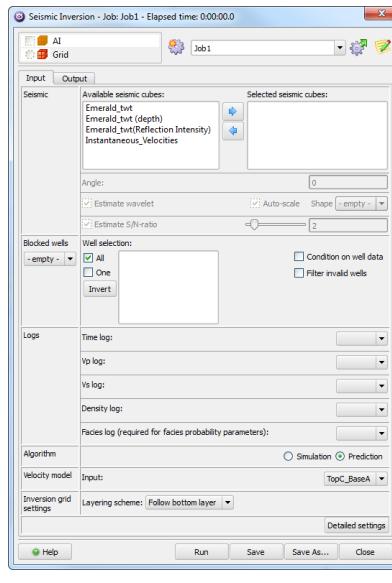


General framework

- ▶ We use established geophysical models
- ▶ We honor geological constraints in inversion
 - Increases value of data
 - Allows advanced QC of data
- ▶ We use stochastic models
 - Allows risk quantification
 - Allows integration of data from multiple sources
- ▶ We use focused inversion
 - Zone of interest
 - Invert for lithology and fluid

Geophysical inversion at NR

- Software developed at NR, since 2002:
 - CRAVA Bayesian simultaneous inversion
 - PCube Pointwise lithology and fluid prediction
 - PCube+ Lithology and fluid prediction in a neighborhood



Geophysical inversion at NR

- ▶ Numerous experimental algorithms
 - Lithology/fluid prediction using Monte Carlo methods
 - 4D seismic inversion for CO₂ monitoring
 - 4D gravimetric inversion
 - Bayesian Dix inversion
 - CSEM inversion

first break volume 30, March 2012

special topic **fb**

Modelling/Interpretation

Seismic inversion and its applications in reservoir characterization

Krishnakumar Narayan^a, Odd Kalsnes^b and Arne Skorstad^a, review seismic inversion and propose a fast and efficient way of estimating elastic properties and porosity probability patterns using the results from seismic inversion and through the incorporation of facies tag.

We have shown in earlier papers that seismic inversion can estimate the elastic properties of reservoir rocks with greater vertical resolution and acceptable noise levels (Kalsnes et al., 2008; Narayan et al., 2009). We provide an assessment of uncertainty which helps to validate the results.

The primary goal of this article will be to illustrate the application of seismic inversion to reservoir characterization. Reservoir models often use seismic attributes from broad bands of seismic data to estimate reservoir properties at local scales. However, such band-limited seismic data doesn't represent the full range of seismic frequencies, and therefore the earth's filtering, and it is difficult to interpret the results of seismic inversion.

The required information is in our seismic properties as well as facies probability parameters to characterize reservoirs for management purposes. The result will be higher quality and more accurate reservoir models. In addition, the facies tag information can be used to guide facies studies.

seismology to guide facies studies

In a previous paper we demonstrated that as a result of a few decades convolution with facies reflectivity sets, the reflection coefficients of the reservoir facies are very similar and hence, the reverse process of estimating seismic properties from the reflection coefficients is feasible.

Let's initially consider the simultaneous geostatistical estimation of seismic properties and reservoir facies. This approach to reservoir modeling, to put it in perspective, implies that the reservoir facies are estimated simultaneously with elastic parameters using geostatistical methods (Figure 1) – this is in contrast to the common approach of first estimating the facies and second elastic parameters. To achieve an optimal fit between the seismic data and the reservoir model, we integrated with the ray trace requirements including angle migration, and the seismic properties were also angle-migrated with the ray trace requirements including angle migration.

TWT logs: A facies log is not necessary unless it is used for data face prediction.

Interpretation methodology

As mentioned above, seismic inversion is a sophisticated process of deriving the seismic data into elastic properties of the reservoir. The seismic inversion process is a two-step process. First, we estimate the elastic properties and then, based on these elastic properties, we estimate the facies surface from seismic data.

For a reservoir study, seismic properties such as ΔV_p wavelet, ΔS_p wavelet, ΔV_S wavelet, ΔS_S wavelet, and seismic facies logs. Log transforms of the elastic properties can be performed to obtain the seismic properties in terms of seismic properties (m) and seismic ANA (d). Seismic data can be represented by a set of seismic properties $\{m\}$ and seismic ANA $\{d\}$ (Walsh et al., 2003). The term \mathbf{W} is the seismic wavelet, \mathbf{S} is the seismic source, \mathbf{R} is the recorded wavefield, \mathbf{C} is a differentiation matrix, and \mathbf{D} is the derivative operator.

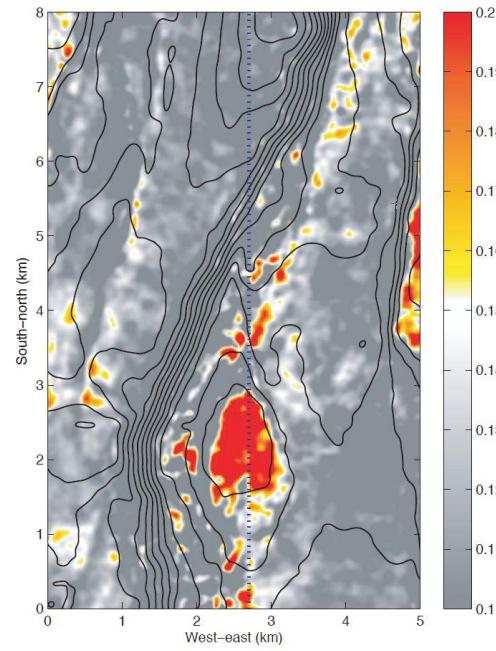
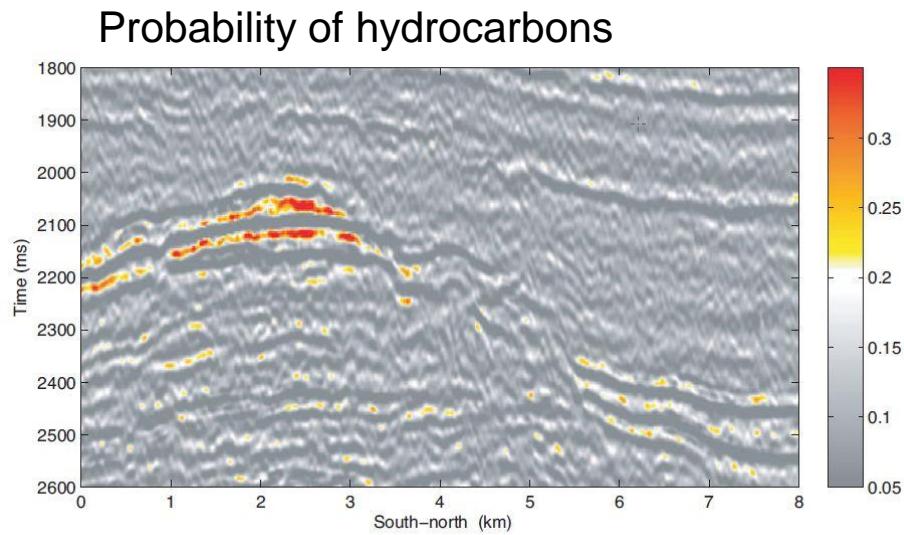
Ridgeless regression does this because the problem is the problem closest for performing geostatistical seismic inversion.

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^bNorwegian Petroleum Center
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 INTELLECTUAL PROPERTY OFFICE
<h1>Certificate of Grant of Patent</h1>
<p>Patent Number: G18246/3242</p> <p>Proprietor(s): StatOilHydro ASA</p> <p>Inventor(s): Odd Kolbjørnsen Ragnar Haug Ardal Balstad</p> <p><i>This is to Certify that, in accordance with the Patents Act 1977,</i></p> <p><i>a Patent has been granted to the proprietor(s) for an invention entitled</i> <i>"Method of modelling a subterranean region of the earth"</i> <i>disclosed</i> <i>in an application filed 3 September 2008.</i></p> <p>Dated 7 November 2012</p> <p style="text-align: right;">  John Atty Comptroller-General of Patents, Designs and Trade Marks Intellectual Property Office </p> <p>The attention of the Proprietor(s) is drawn to the important notes overleaf.</p> <p>Intellectual Property Office is an operating name of the Patent Office</p>

Approaches for trace by trace lithology fluid prediction

1. Pointwise inversion (PCube)
Fast, but no lithology fluid ordering



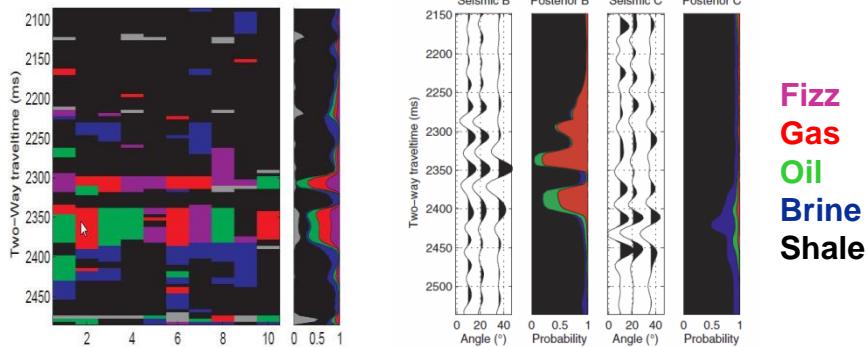
Buland, A.; Kolbjørnsen, O.; Hauge, R.; Skjæveland, Ø.; Duffaut, K. (2008)
Bayesian lithology and fluid prediction from seismic prestack data Geophysics 73(3) pp C13-C21

Approaches for trace by trace lithology fluid prediction

1. Pointwise inversion (PCube)
Fast, but no lithology fluid ordering
2. Monte Carlo methods for complete traces

(Hammer and Tjelmeland 2008, Kjønsberg et. al. 2010)

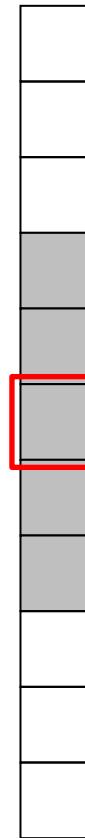
“Correct” solution, but very slow



Approaches for trace by trace lithology fluid prediction

1. Pointwise inversion (PCube)
Fast, but **no lithology fluid ordering**
2. Monte Carlo methods for complete traces
(Hammer and Tjelmeland 2008, Kjønsberg et. al. 2010)
“Correct” solution, but **very slow**
3. Neighborhood inversion (PCube+)

Kolbjørnson, O., R. Hauge and A. Buland, 2012,
Method for modelling a subterranean region of
the earth, UK Patent GB2463242

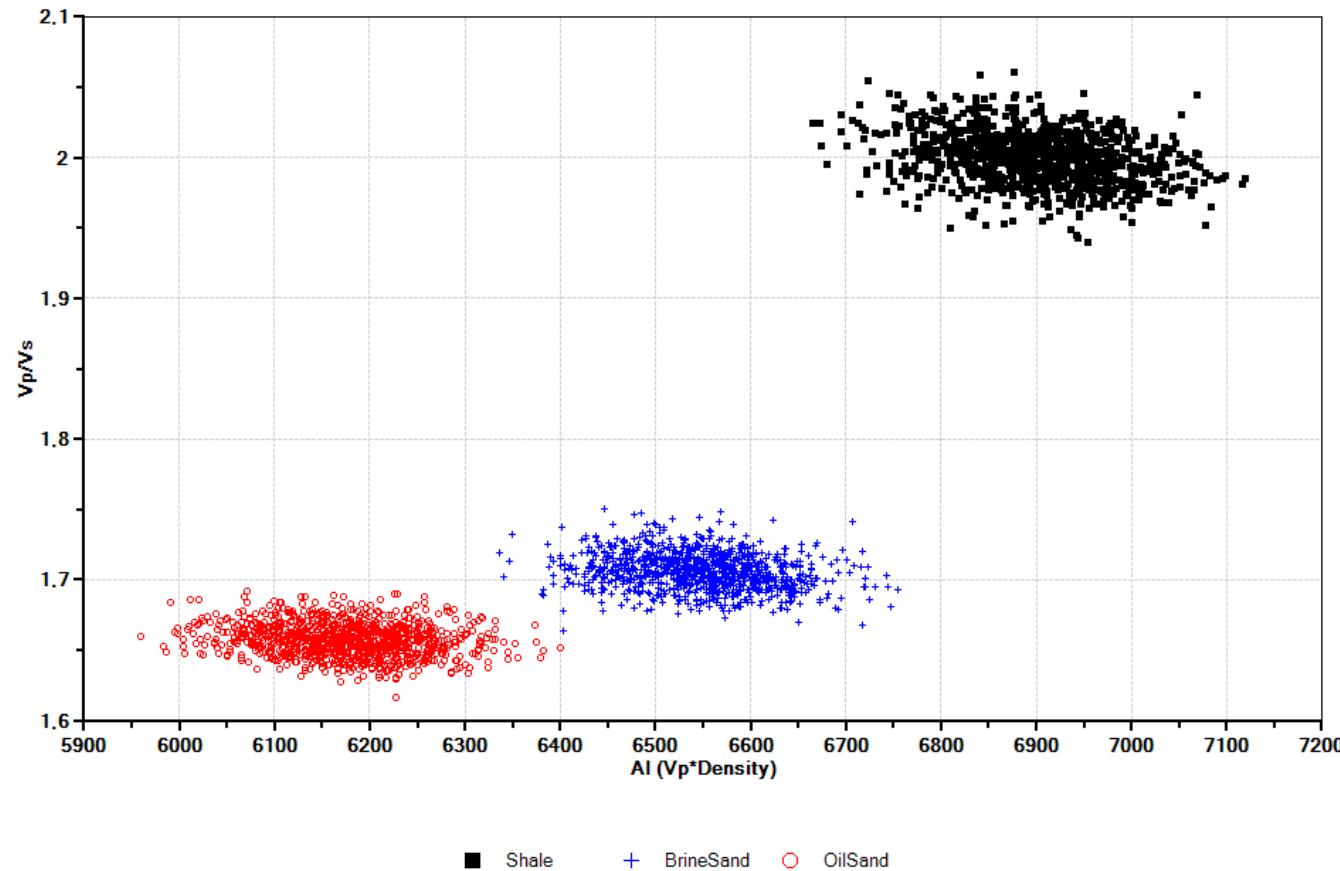


PCube+: Simple synthetic case

- ▶ Three lithology fluid combinations: Shale, oil-saturated sand and brine-saturated sand
- ▶ Prior model

	Shale	Brine-sand	Oil-sand
Probability for lithology fluid combination	0.85	0.10	0.05
Acoustic impedance, mean (g/ccm x km/s)	6.9	6.6	6.2
AI P10-P90 range (g/ccm x km/s)	6.8-7.0	6.5-6.7	6.1-6.3

Prior: Rock Physics distributions

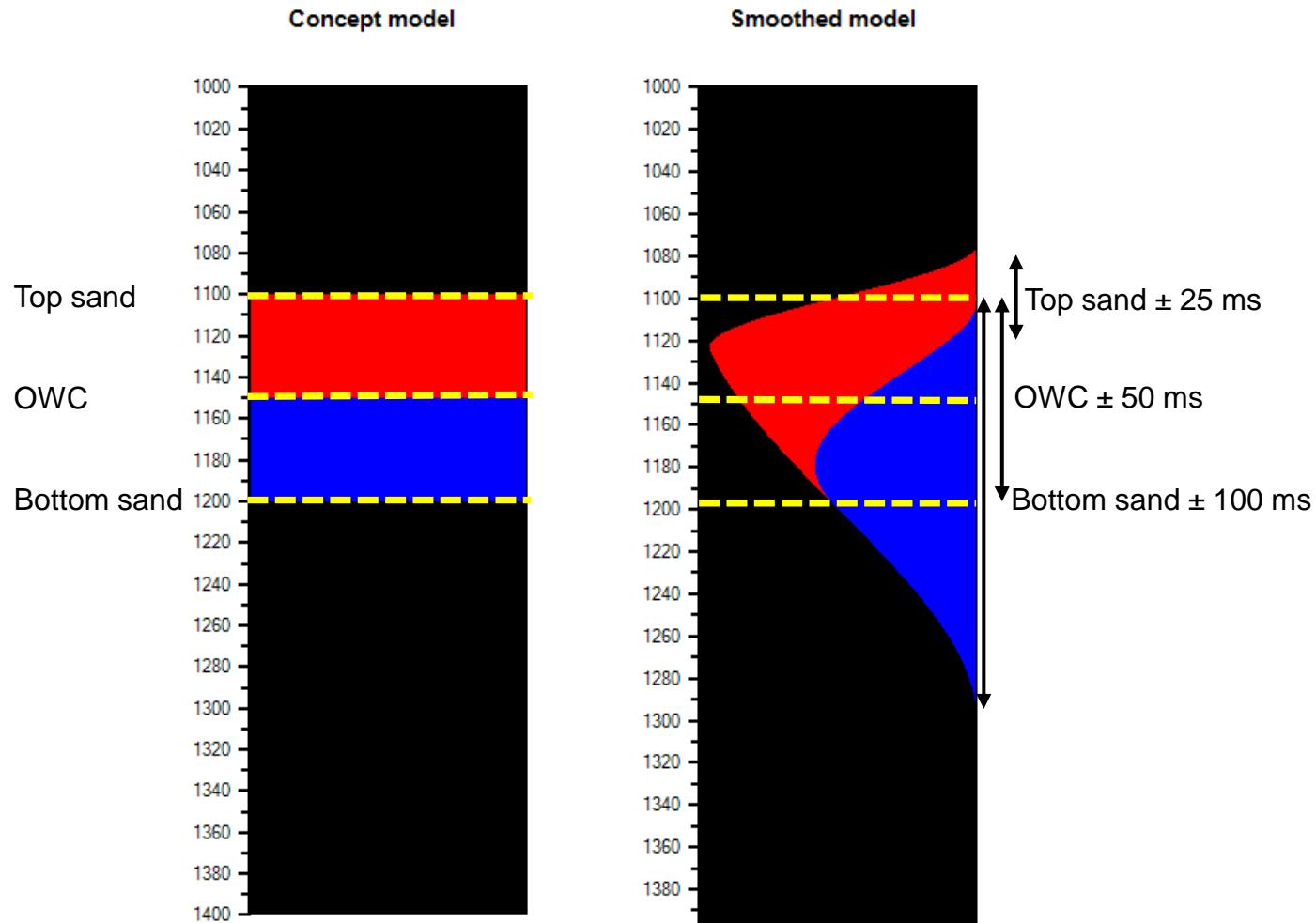


Prior: Zone model – concept model

Zone	Zone boundary definition - Top of zone	Uncertainty on zone boundary (ms)	LFC content in zone
Overburden	Top of model		100% Shale
Oil zone	Top sand	25	100% Oil-filled sand
Water zone	OWC	50	100% Water-filled sand
Base	Bottom sand	100	100% Shale

Courtesy of Statoil Petroleum

Prior: Zone concept model and smoothed model for single trace

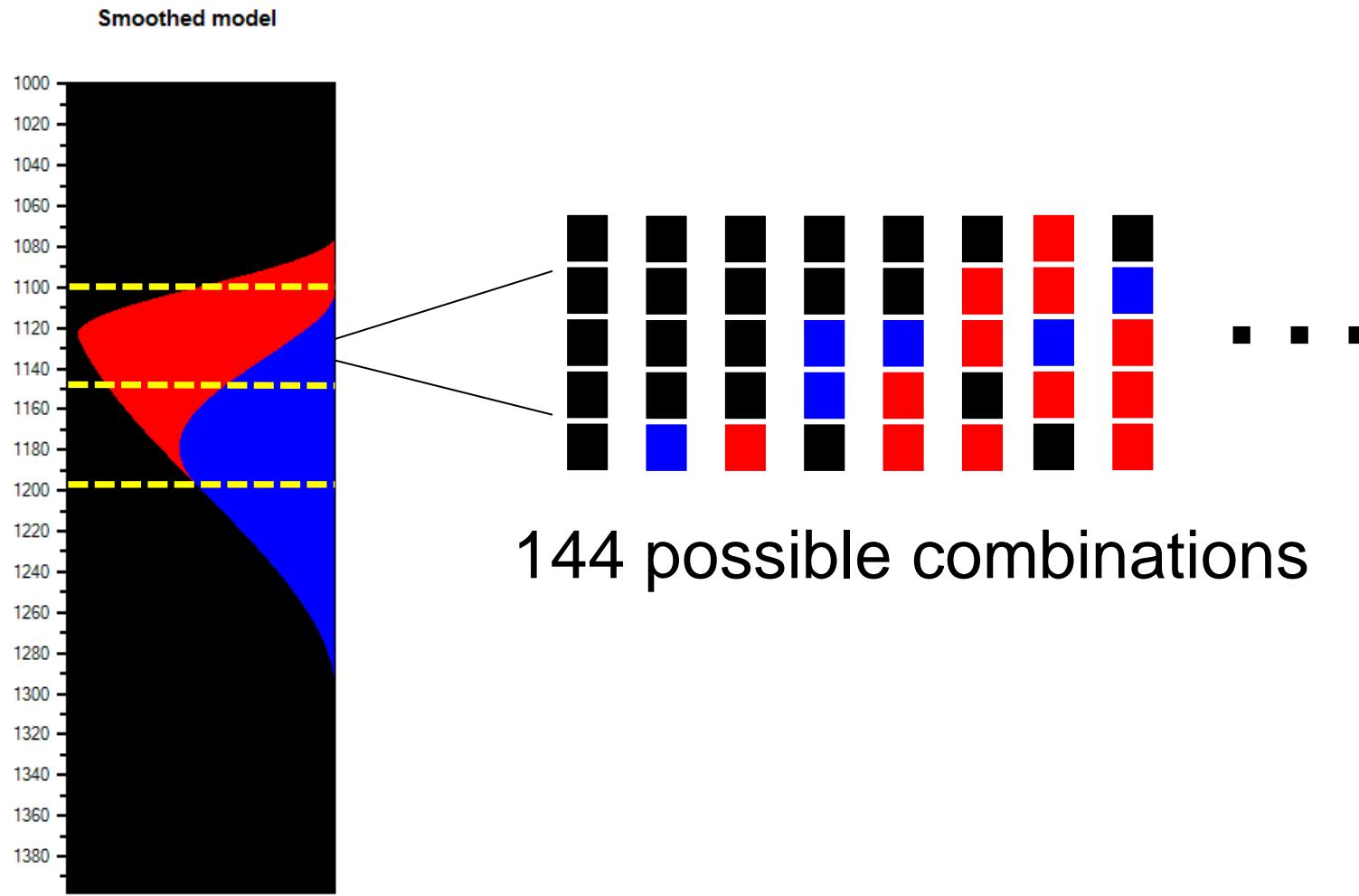


Prior: Lithology / fluid ordering

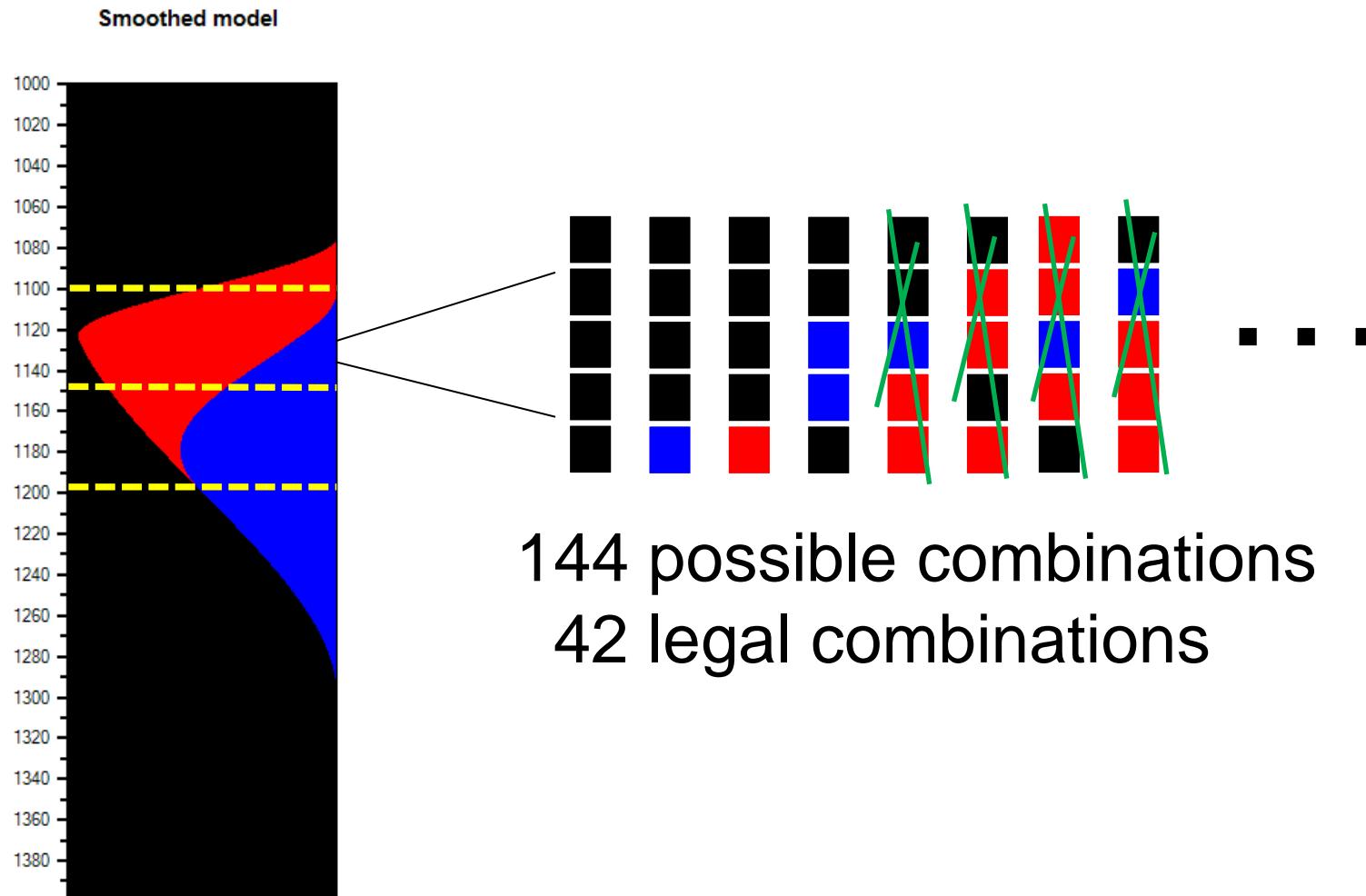
Smoothed model



Prior: Lithology / fluid ordering

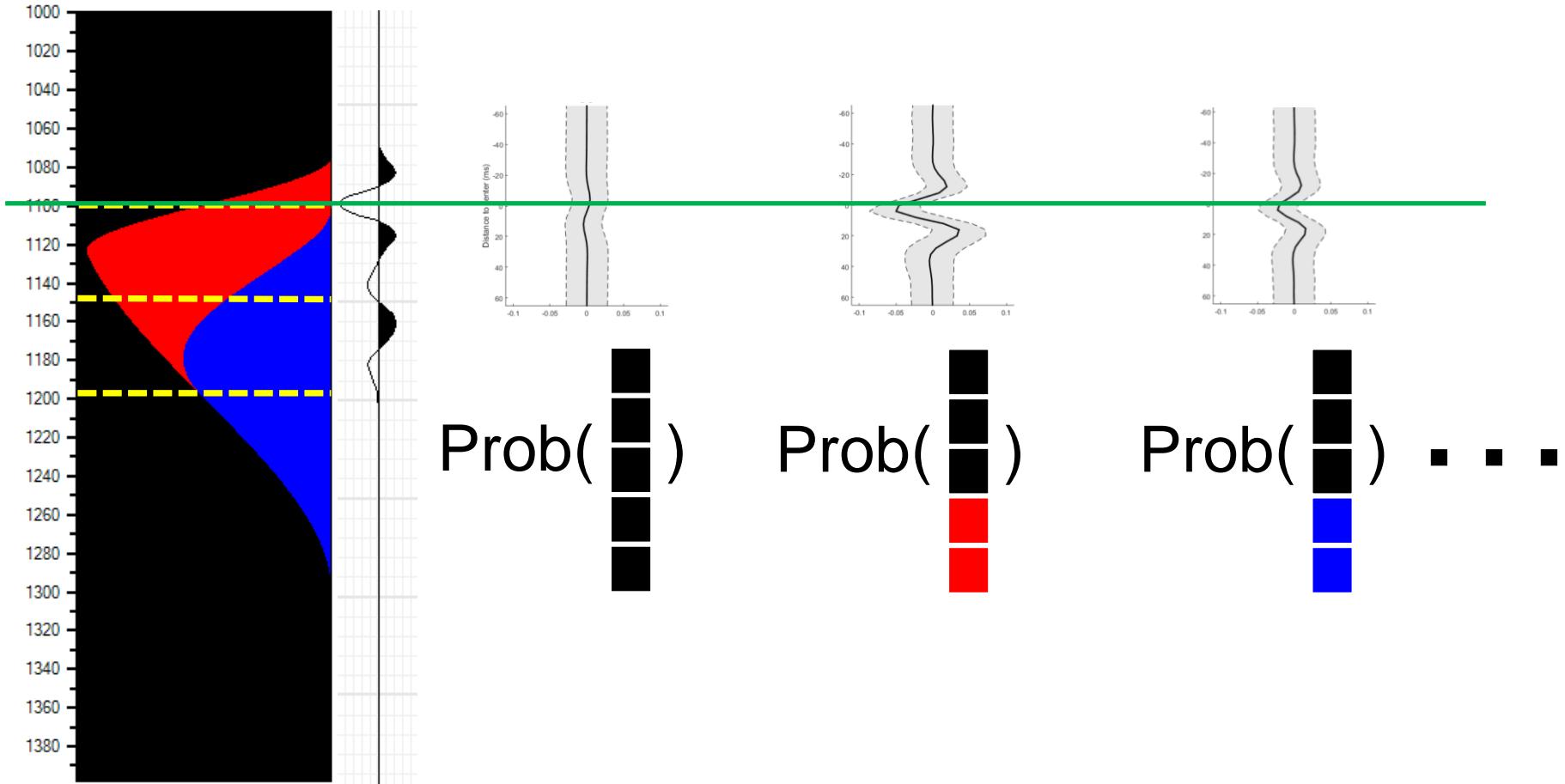


Prior: Lithology / fluid ordering

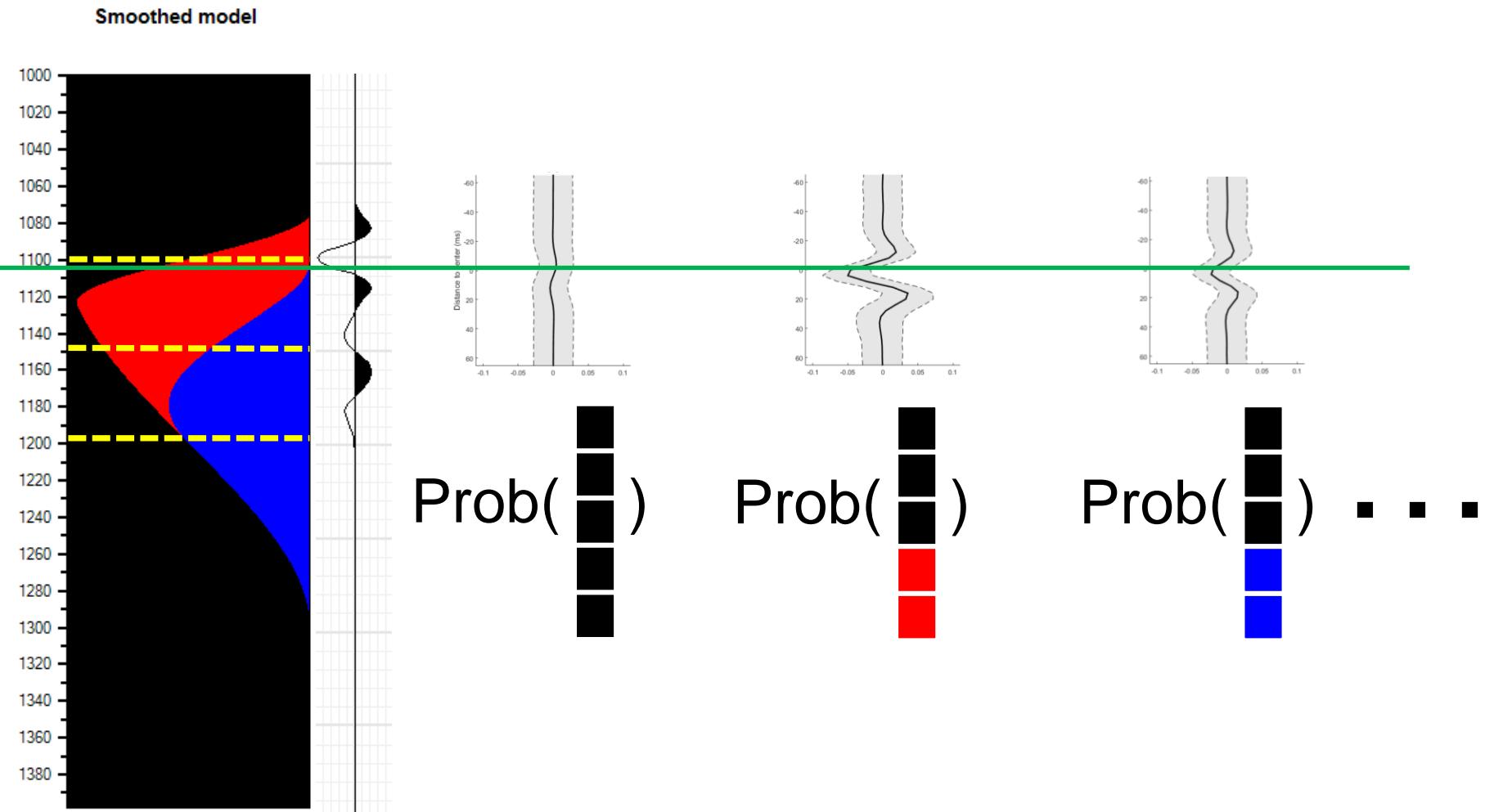


Lithology and fluid is found by comparing with seismic signal

Smoothed model

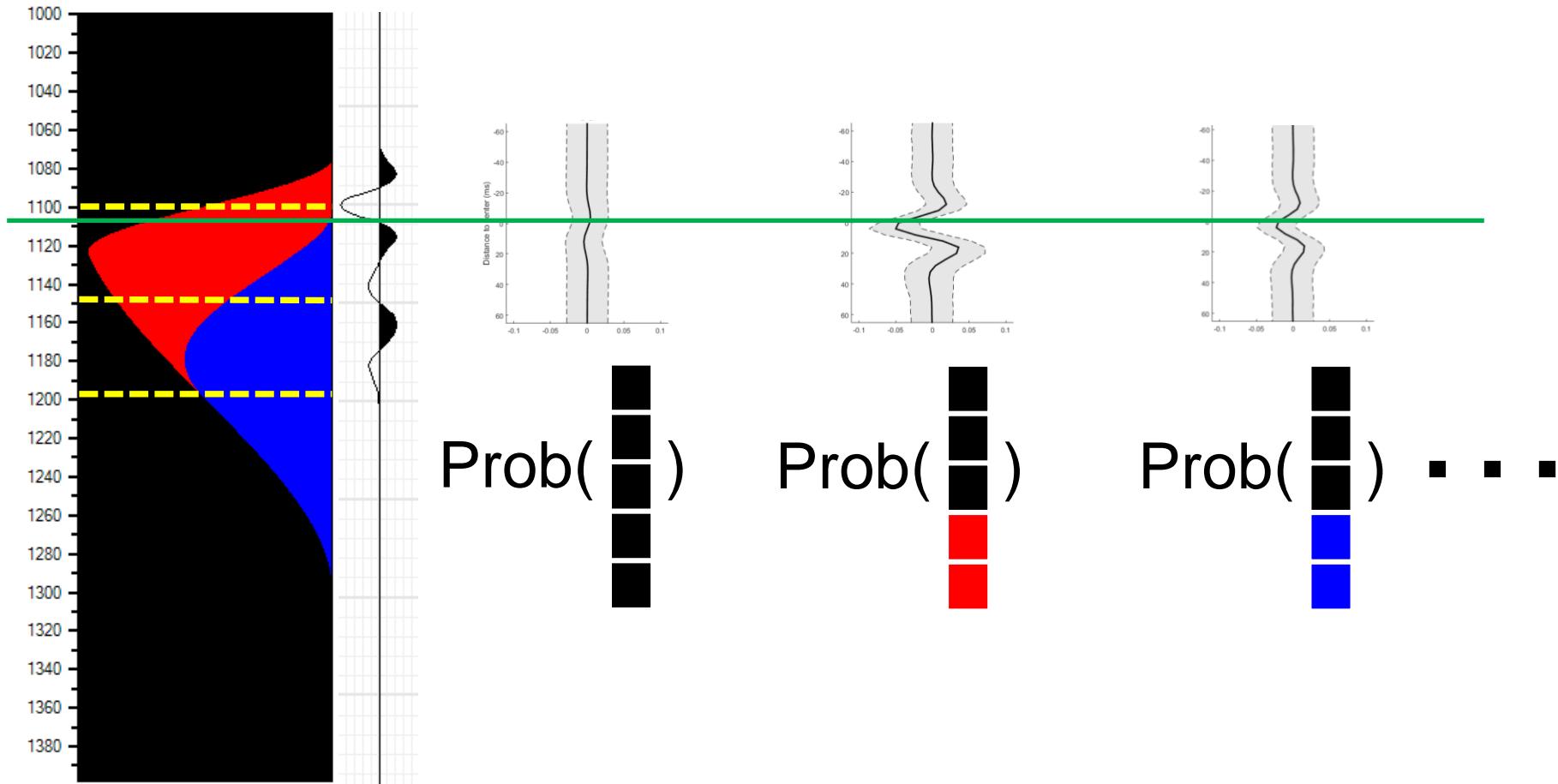


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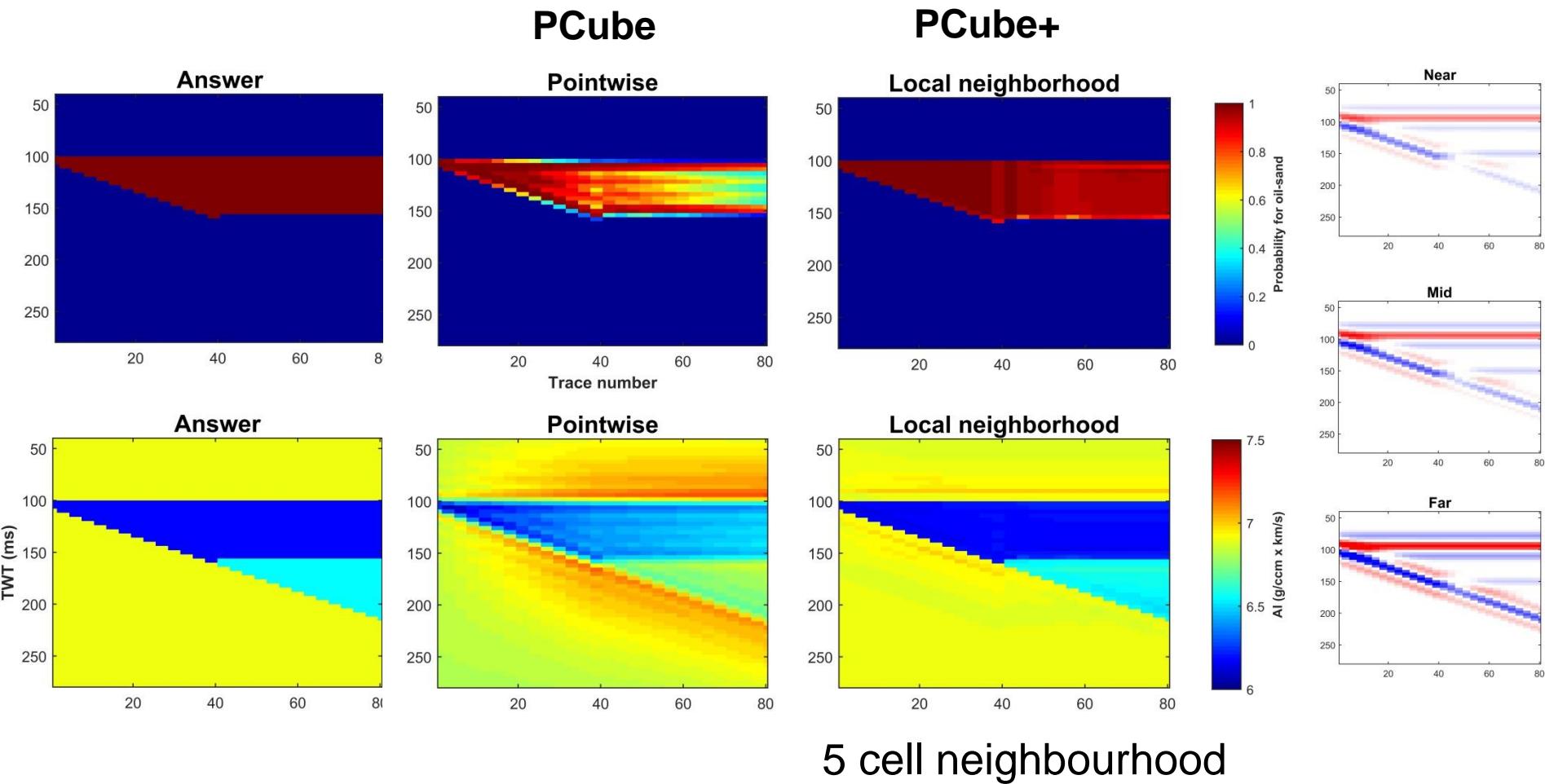


Lithology and fluid is found by comparing with seismic signal

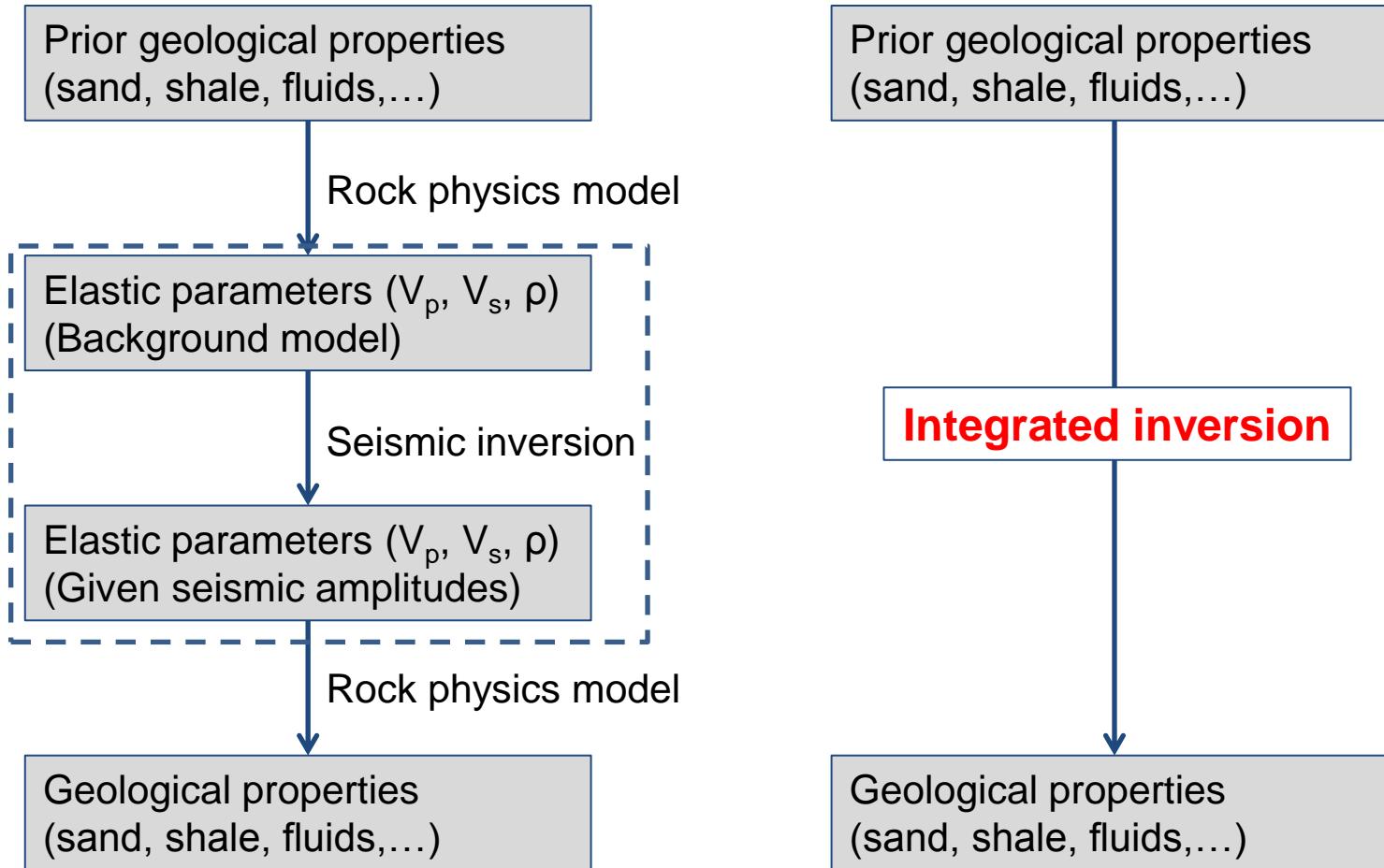
Smoothed model



Inversion results for wedge

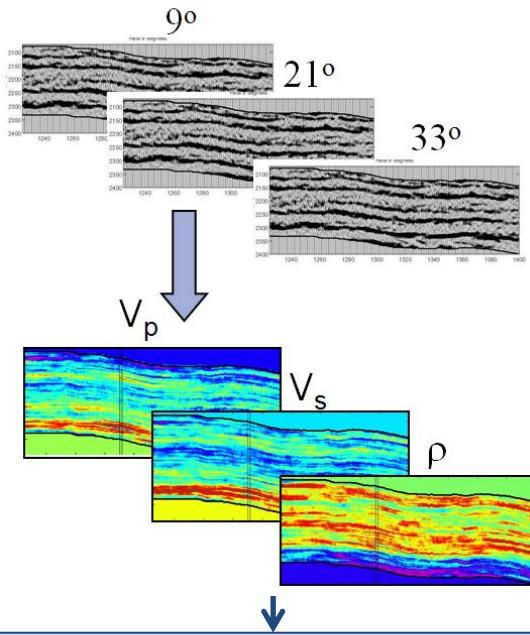


Seismic inversion using geological constraints

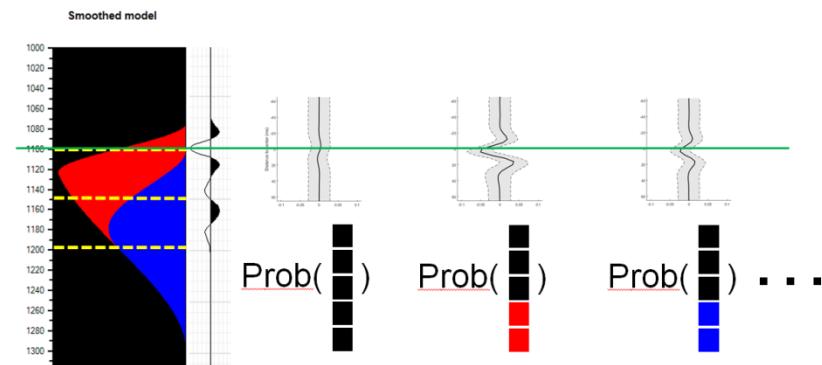


Seismic inversion using geological constraints

Prior geological properties
(sand, shale, fluids,...)



Prior geological properties
(sand, shale, fluids,...)



Current and future work

Improvements of inversion algorithms

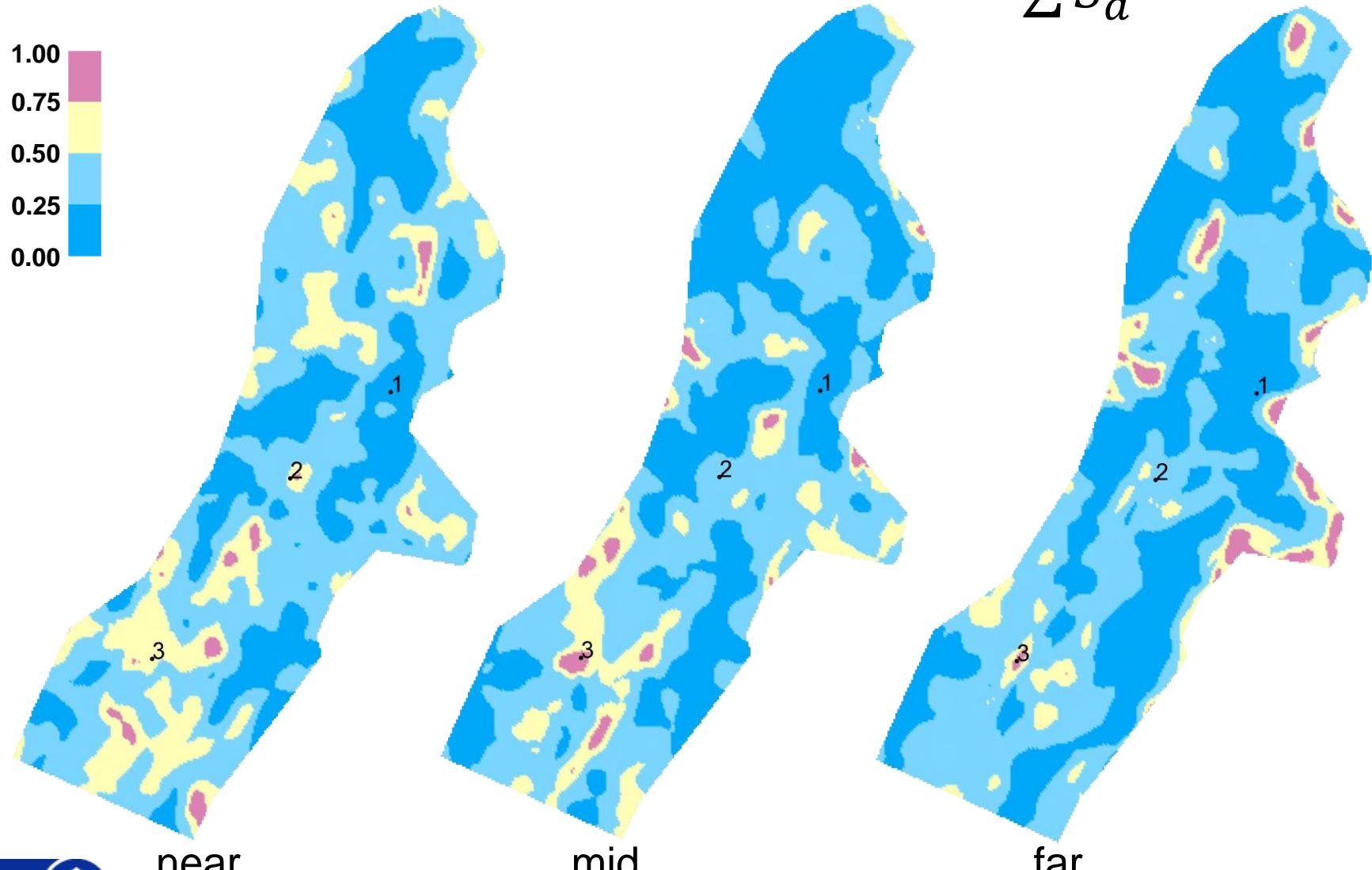
- ▶ Lateral correlations
- ▶ Trends in rock physics
- ▶ Non-stationary wavelet
- ▶ Anisotropy
- ▶ More sophisticated stratigraphic model

QC

- ▶ Evaluate input data
 - Quality of seismic data
 - Well logs
 - Stationarity in seismic data
- ▶ Establish trust in inversion results

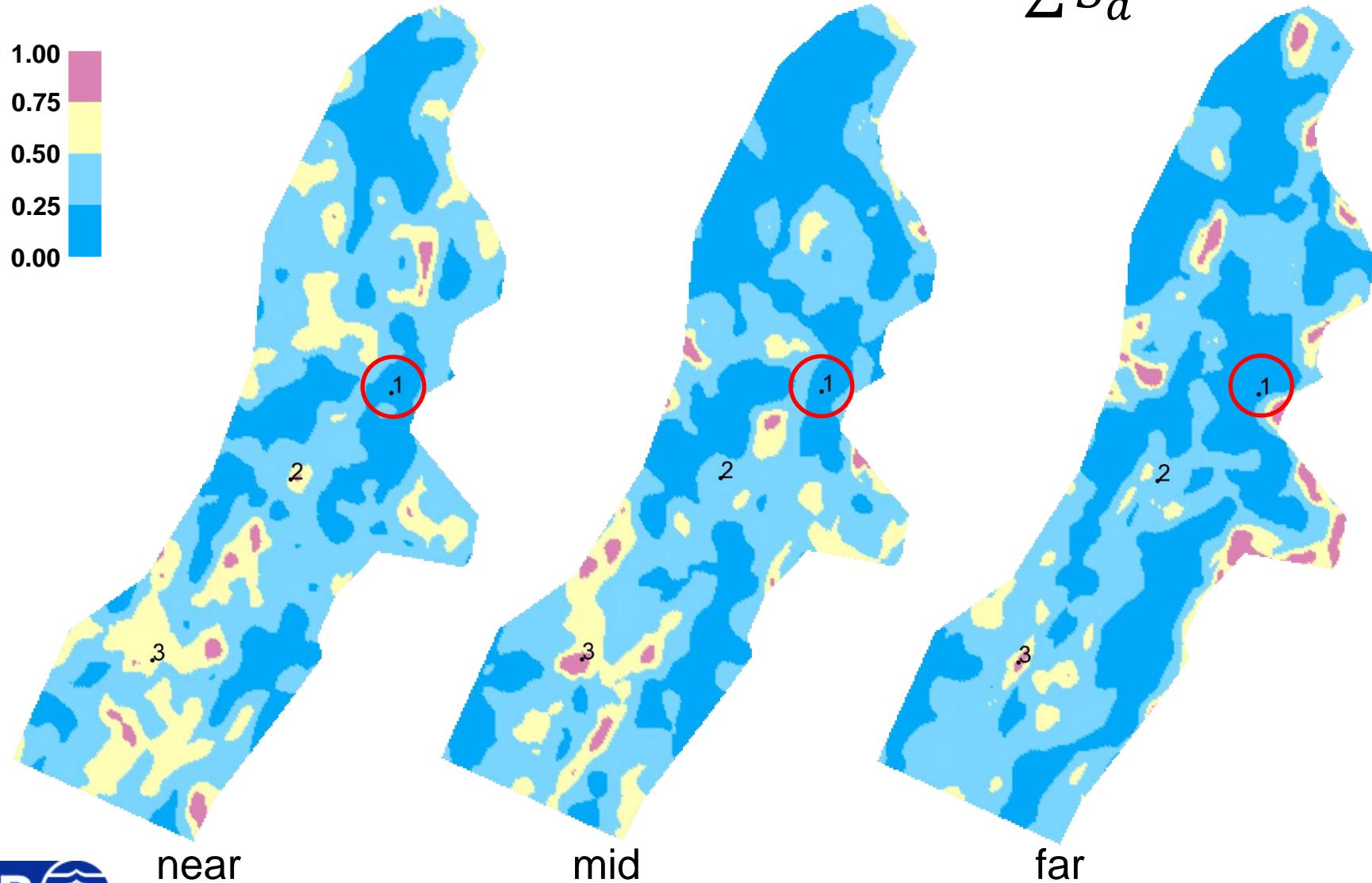
Relative residual energy

$$\frac{\sum(S_i - S_d)^2}{\sum S_d^2}$$

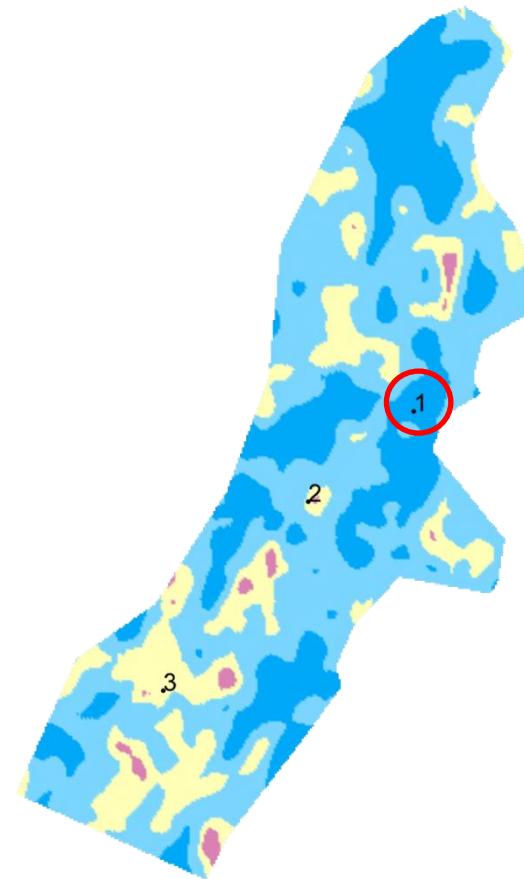
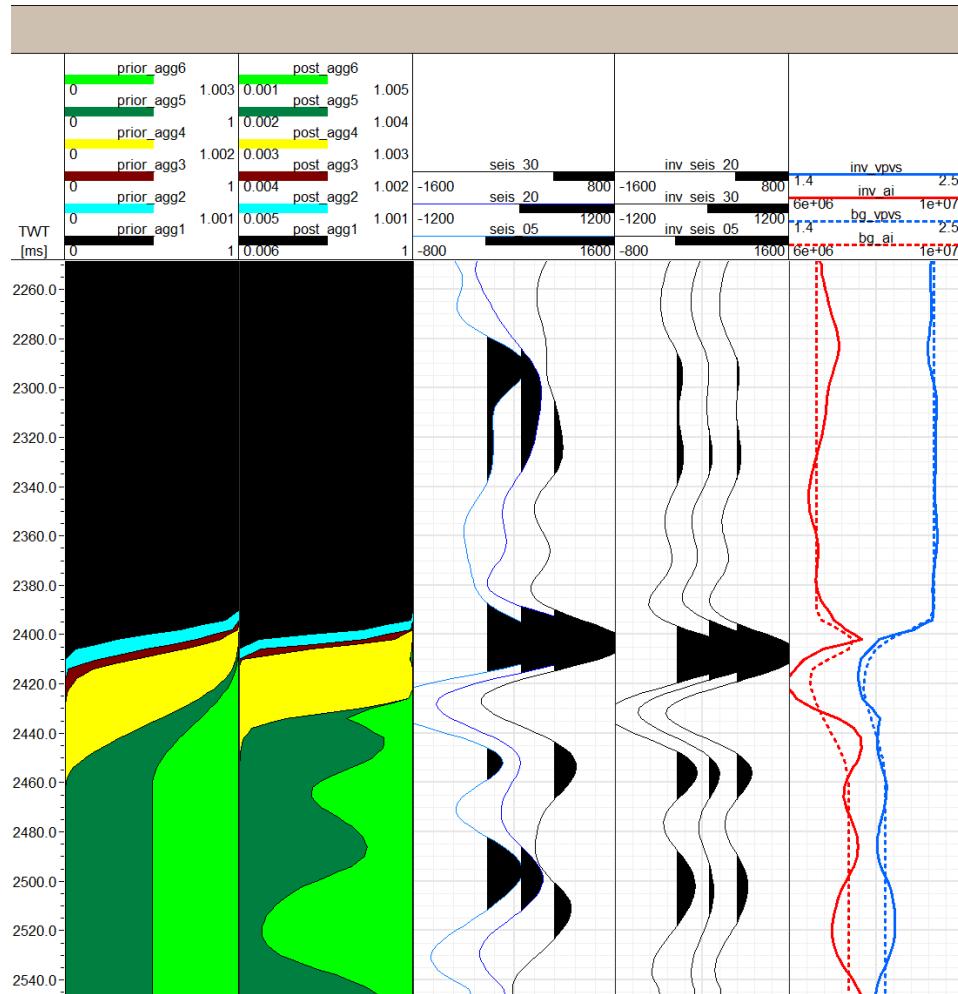


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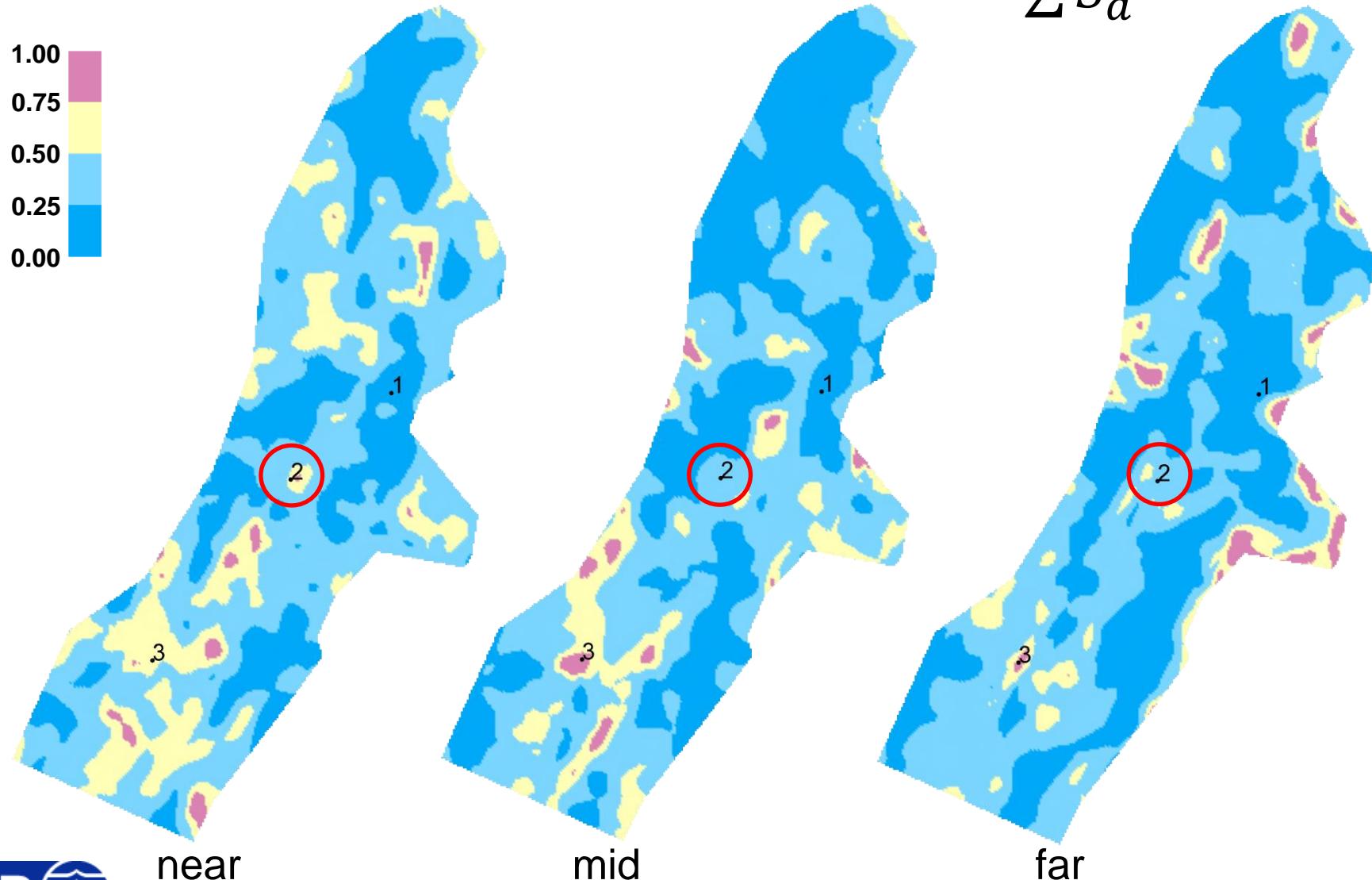


Location 1: Low residual all angles

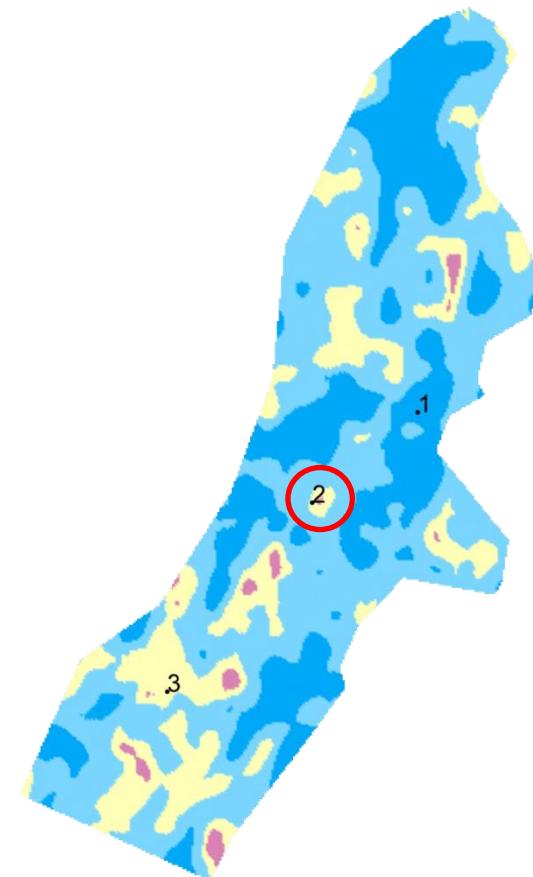
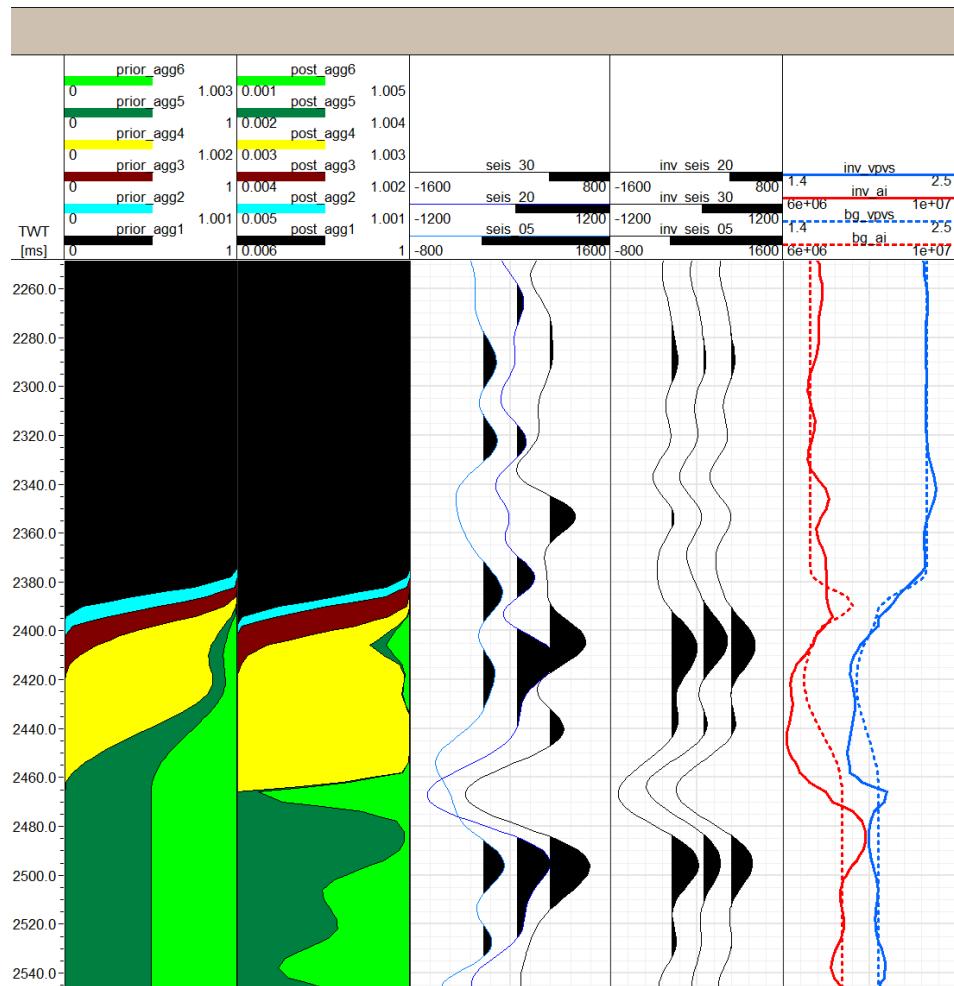


Relative residual energy

$$\frac{\sum(S_i - S_d)^2}{\sum S_d^2}$$

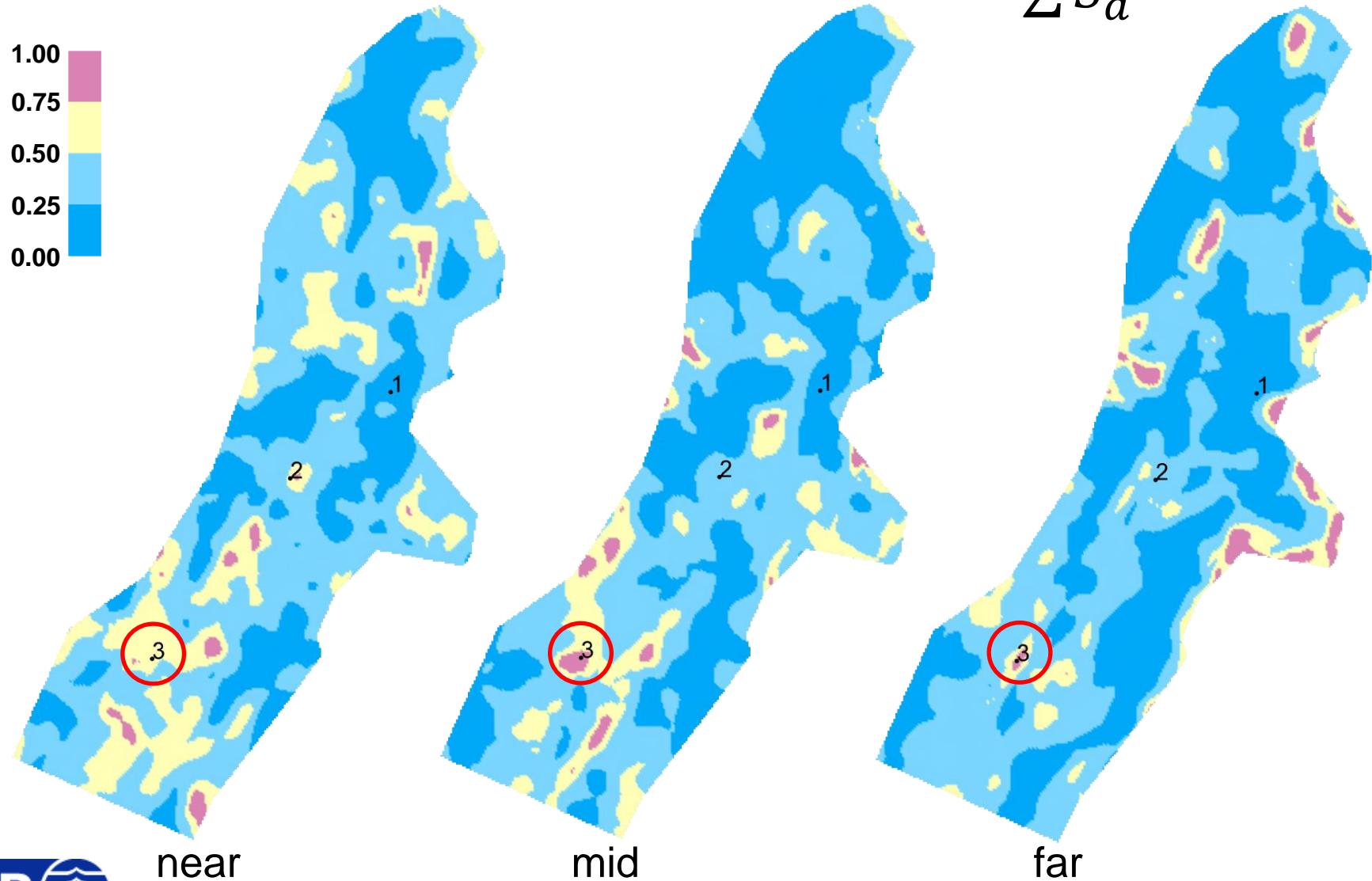


Location 2: High residual near, less mid/far

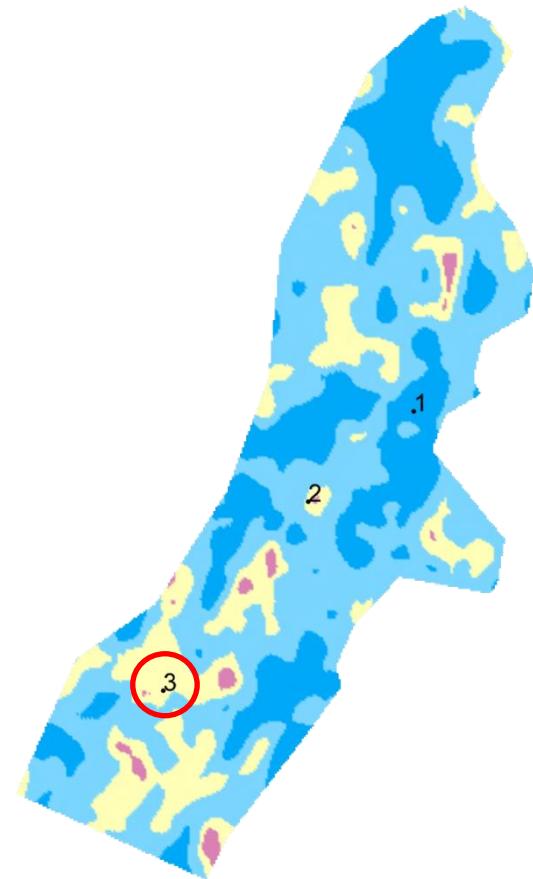
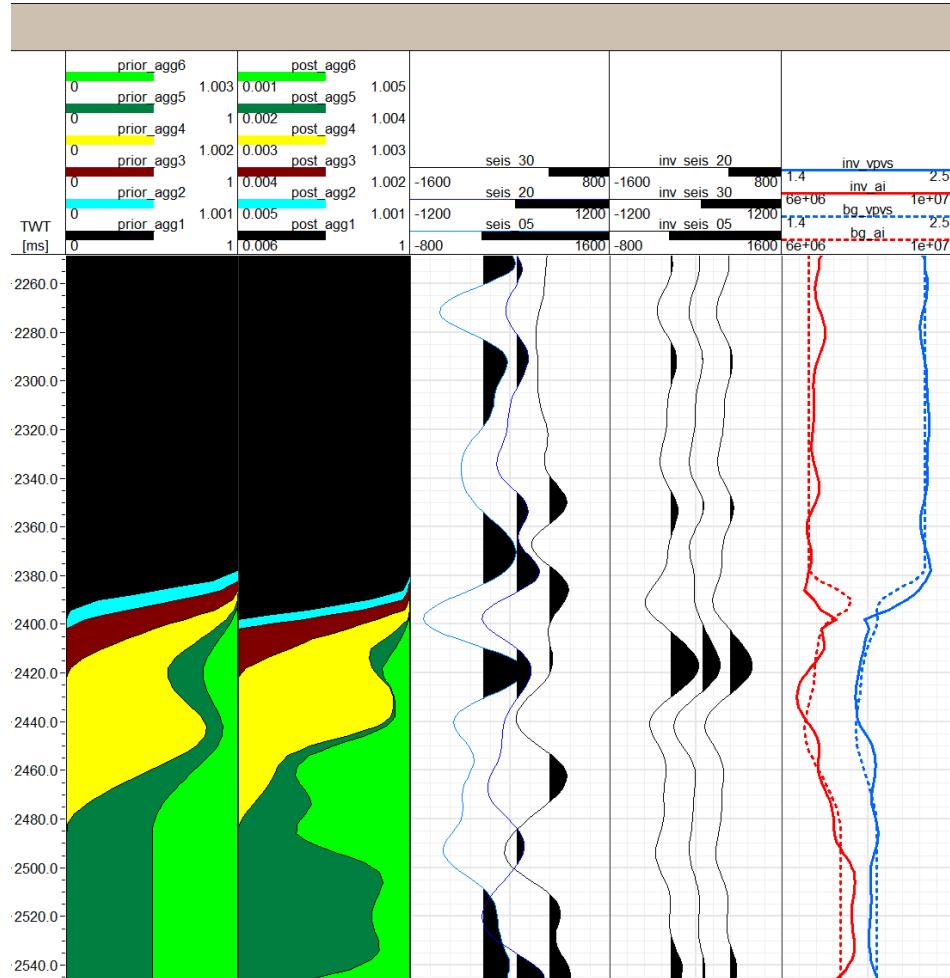


Relative residual energy

$$\frac{\sum(S_i - S_d)^2}{\sum S_d^2}$$



Location 3: High residual all angles – mismatch seismic and prior model

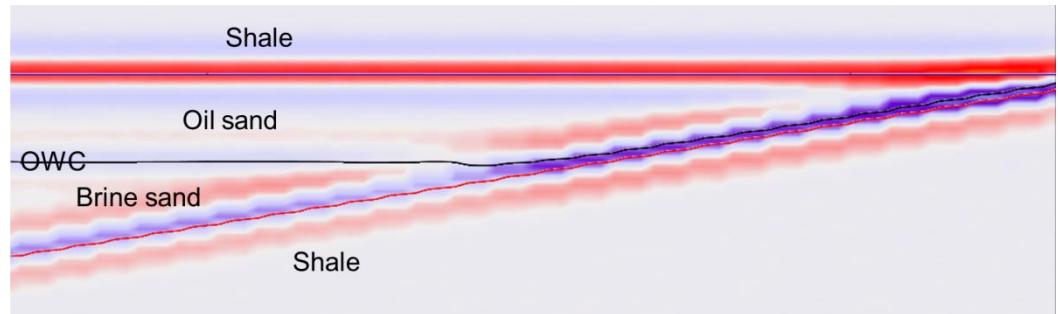


QC: Future work

- ▶ Quantification of uncertainty in inversion input
 - Seismic
 - Well logs
- ▶ Evaluation and ranking of prior models
 - Wavelet scale
 - Signal to noise ratios for different stacks
 - Number of lithology fluid class
 - Rock physics models
- ▶ More precise identification of inversion problems

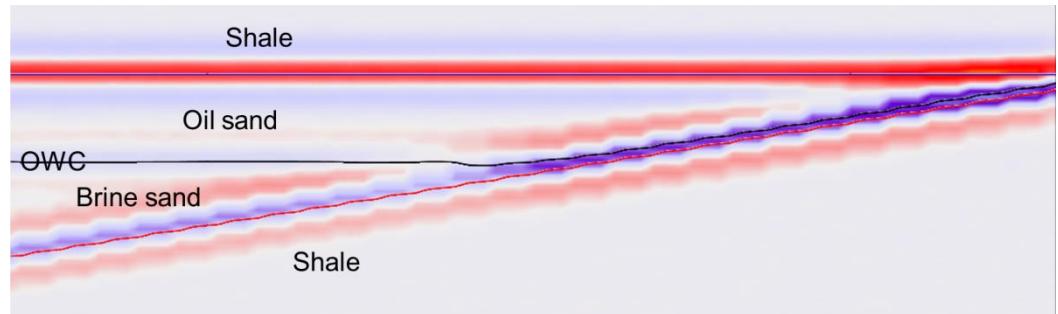
Inversion of horizon location

- Based on PCube+ inversion, but focusing on horizons



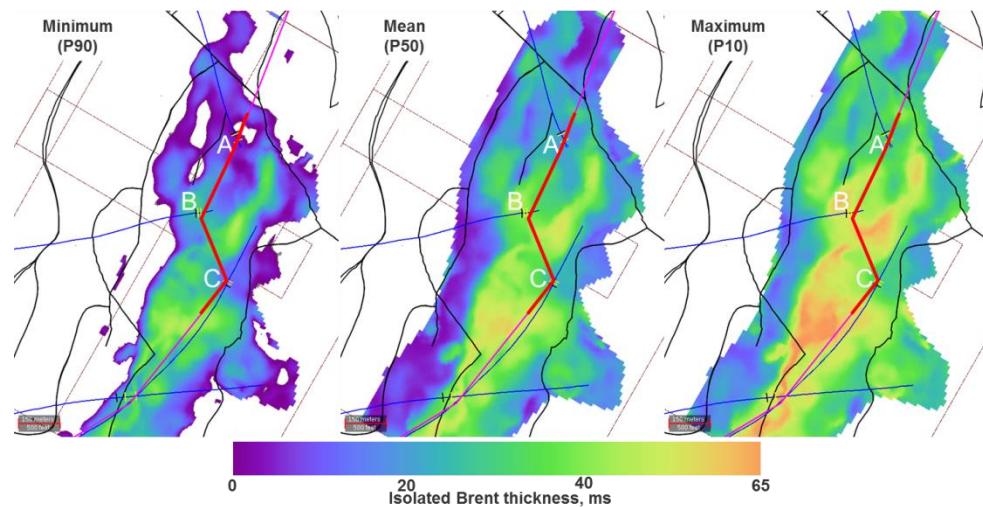
Inversion of horizon location

- ▶ Based on PCube+ inversion, but focusing on horizons
- ▶ Subsample resolution



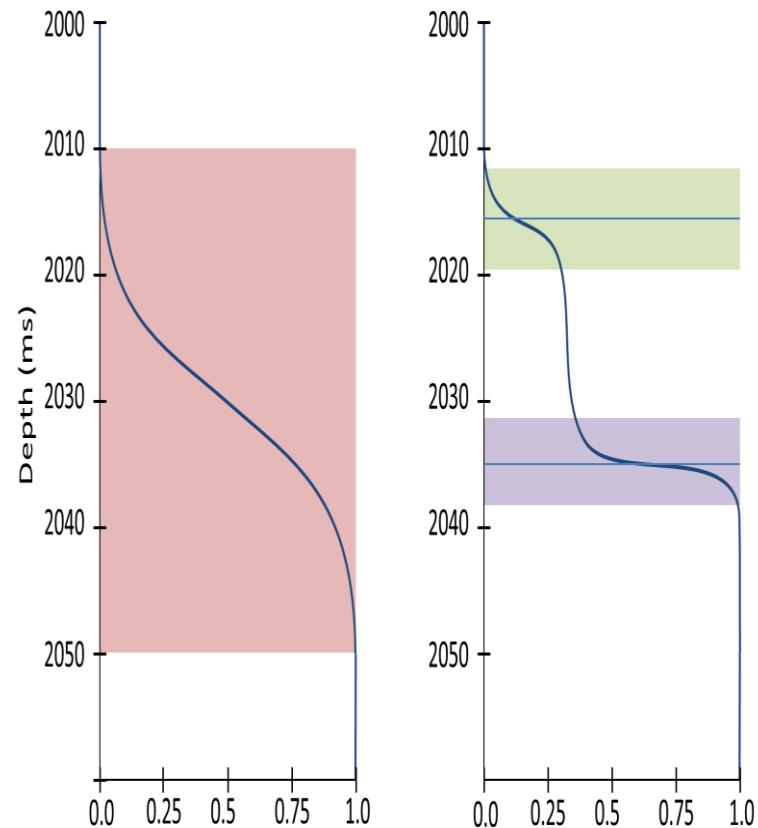
Inversion of horizon location

- ▶ Based on PCube+ inversion, but focusing on horizons
- ▶ Subsample resolution
- ▶ Zone thickness distributions



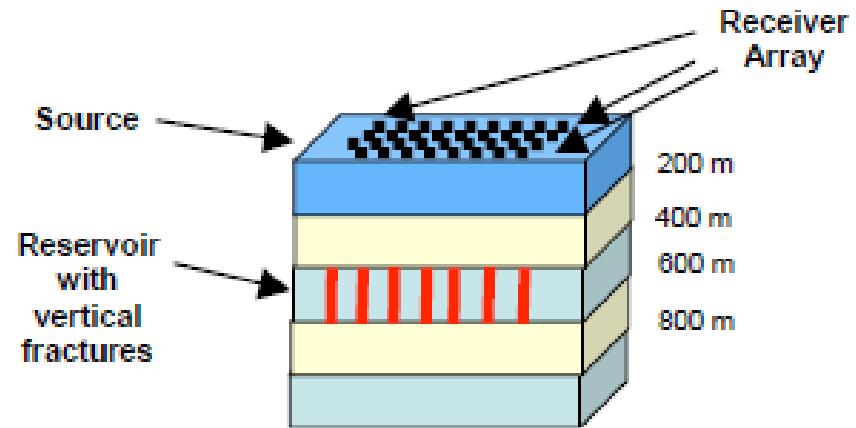
Inversion of horizon location

- ▶ Based on PCube+ inversion, but focusing on horizons
- ▶ Subsample resolution
- ▶ Zone thickness distributions
- ▶ Handling multiple scenarios



Horizon inversion as first step in two-step inversion

- ▶ Zone properties
 - NTG
 - Fractures
 - Saturations
 - Porosity
 - ...
- ▶ Integration with other data
 - EM
 - 4D seismic
 - Shear wave seismic



From Willis et. al. (2006) Spatial orientation and distribution of reservoir fractures from scattered seismic energy.

Wrap-up future work

- ▶ Better control input data
- ▶ Better prediction of geology and fluids

- ▶ Get more information from your geophysical data

Final words

Sponsor benefits

- ▶ New knowledge and methods
 - Influence on priorities
- ▶ Early access to results
 - Reports (only available to sponsors)
 - Software prototypes
- ▶ PCube+ and PCube
- ▶ PCube+ and PCube integration in Pre-Stack Pro from Sharp Reflections

Geophysical Prospecting
Geophysical Prospecting, 2012, 58, 500–513
doi:10.1111/j.1365-2486.2011.01012.x

EAGE THE EUROPEAN ASSOCIATION OF ENERGY ENGINEERS

Norsk Geoteknisk Institutt
NORWEGIAN GEOTECHNICAL INSTITUTE

Elastic inversion and quality markers in windowed PCUBE

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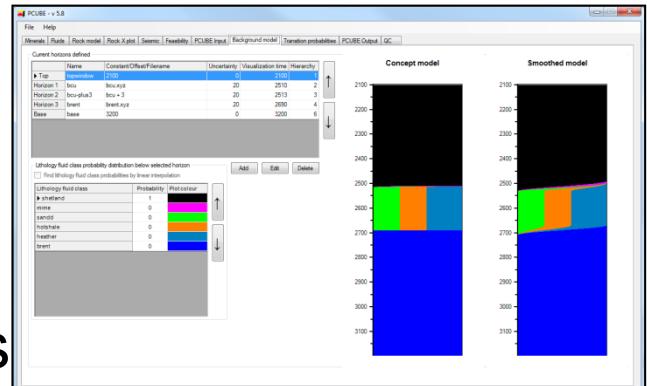
Received December 2010; revision accepted August 2011

ABSTRACT
We invert pre-stack seismic data to find rock properties of a vertical profile. We do this by applying a Bayesian approach to the problem and include vertical dependencies of the rock properties. This allows us to compute quantities valid for the full profile such as the probability that the vertical profile contains hydrocarbons. In addition to the vertical profile, we can also invert for a single point, these quantities can then be assessed. We formulate the problem in a Bayesian framework where the prior information is given by a set of rock models. The relationship between rock properties and elastic parameters is established through a stochastic rock model, and a convolutional model links the reflection to the seismic. A Markov chain Monte Carlo algorithm is used to sample from the posterior distribution that balances both the seismic data and the prior beliefs and respects the additional constraints imposed by the rock models. The MCNC algorithm is used to perform a quality check of the algorithm and to compare it with a similar method. The inversion results are presented in terms of vertical profiles. The vertical profiles show how one profile will correlate. For all six cases the MCNC algorithm provides reliable estimates with uncertainty quantification within three hours. The inversion results are compared with the MCNC algorithm and the results are similar. Seismic amplitude make a significant impact on the inversion result even if the data have been scaled. The vertical profiles show that the vertical correlation of the seismic amplitude influence the spatial pattern of the volume distribution. The original data were scaled to obtain the same vertical profiles since the MCNC algorithm is compute demanding.

Key words: inversion, noise, numerical study, rock physics, seismic

<http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2486.2011.01012.x>

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EANDOIS14
Odd Kolbjørnsen
1. aug. 2014



PRE-STACK PRO



Inversion studies

- ▶ 2016: pilot with Det norske / Aker BP
- ▶ Exploration setting
 - Well-tie
 - Wavelet estimation
 - Inversion
 - QC
- ▶ Amount of data:
 - 4 seismic angle stacks, each 130 GB
 - 10 wells
 - 3 interpreted surfaces



Consortium agreement

- ▶ All sponsors represented in consortium board
- ▶ Work plan decided by consortium board
- ▶ All sponsors get full access to all consortium results

GIG consortium

Yearly fee: 1.0 MNOK (2016)

Enrolment fee: 0.5 MNOK (2016)

Current partners:

