The GIG consortium

Geophysical Inversion to Geology

Per Røe, Ragnar Hauge, Petter Abrahamsen

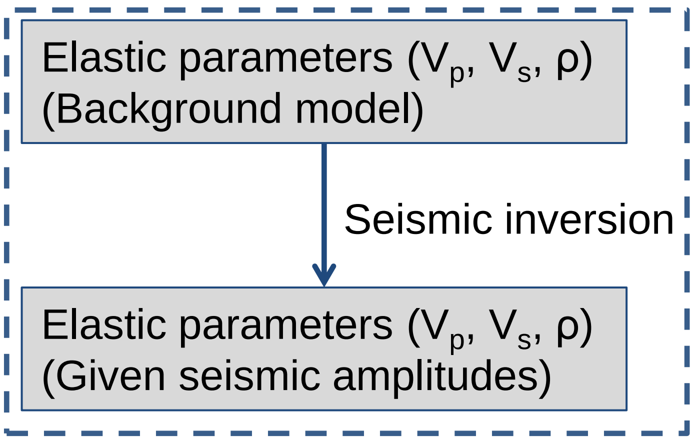
FORCE, Stavanger

17. November 2016

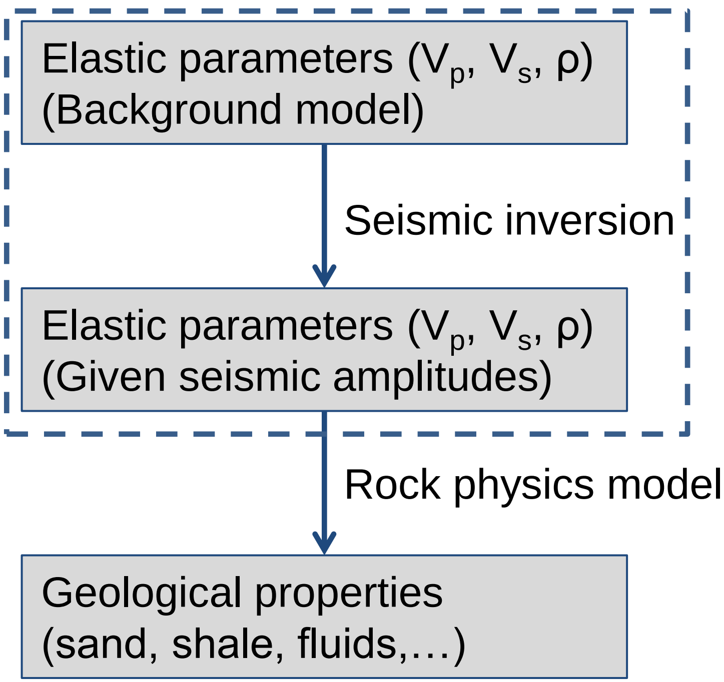
Consortium goals

- 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

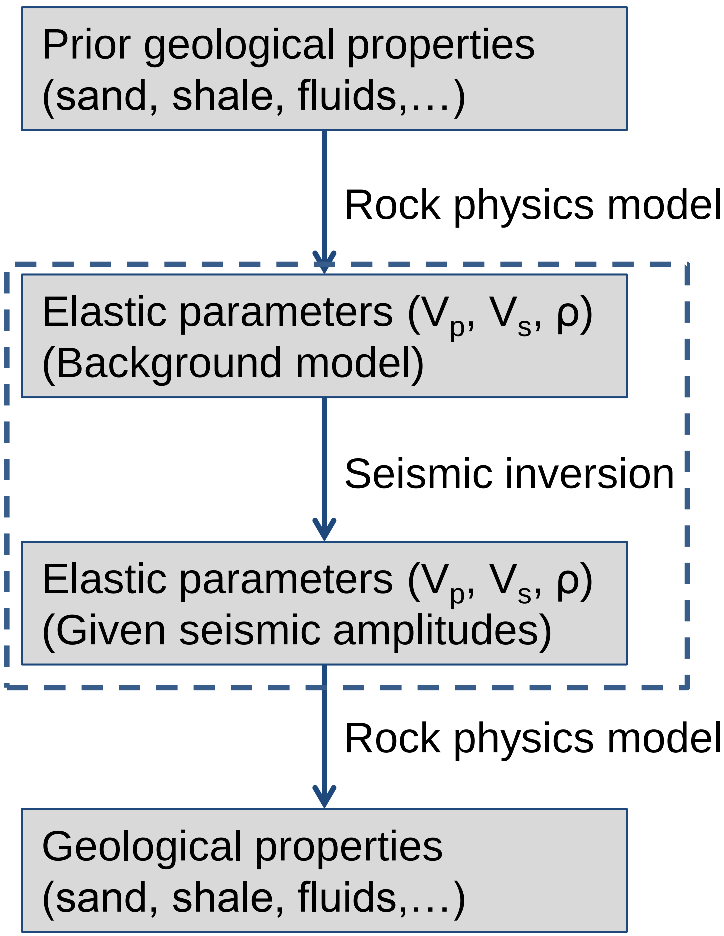
Standard seismic inversion



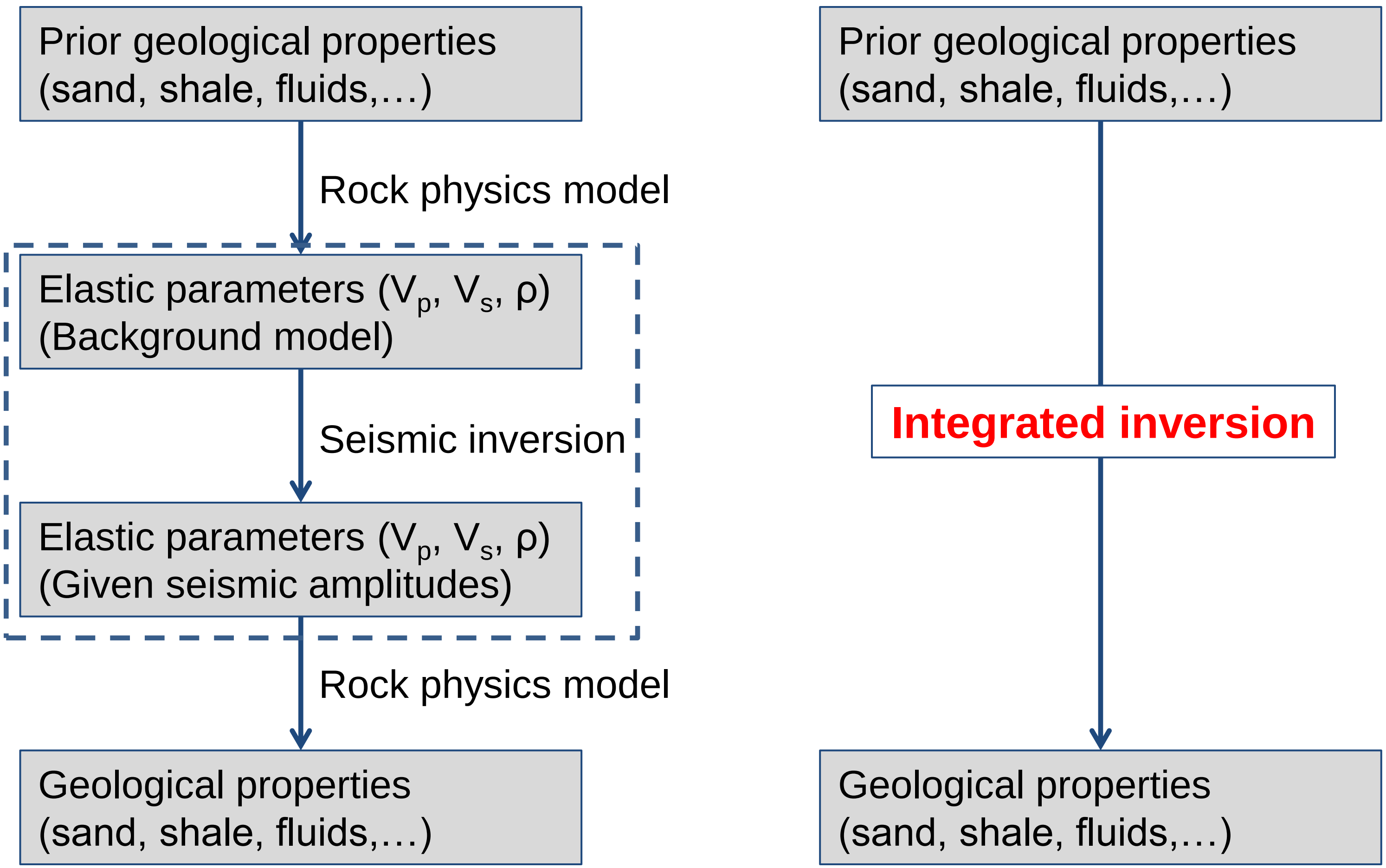
Standard seismic inversion with **geological output**



Standard seismic inversion with geological output <u>and input</u>

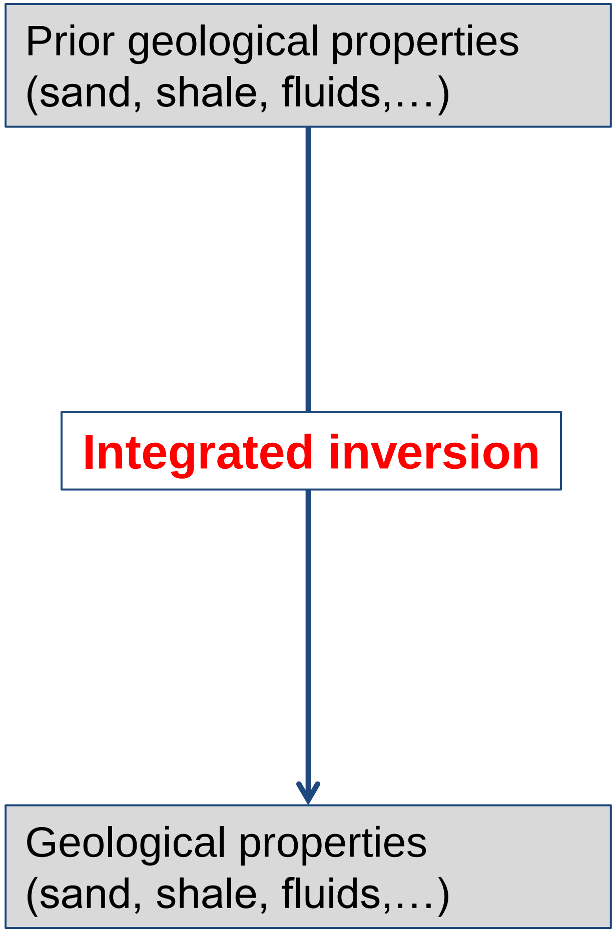


Seismic inversion using geological constraints



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

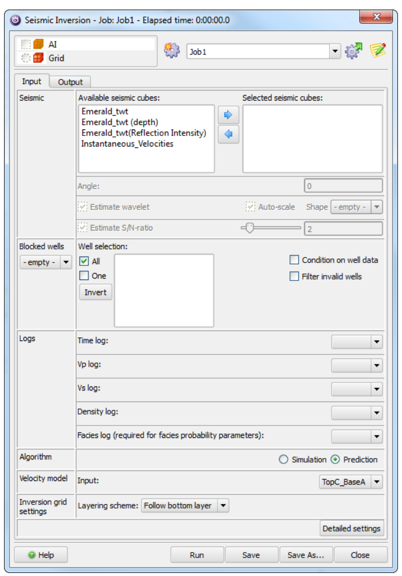


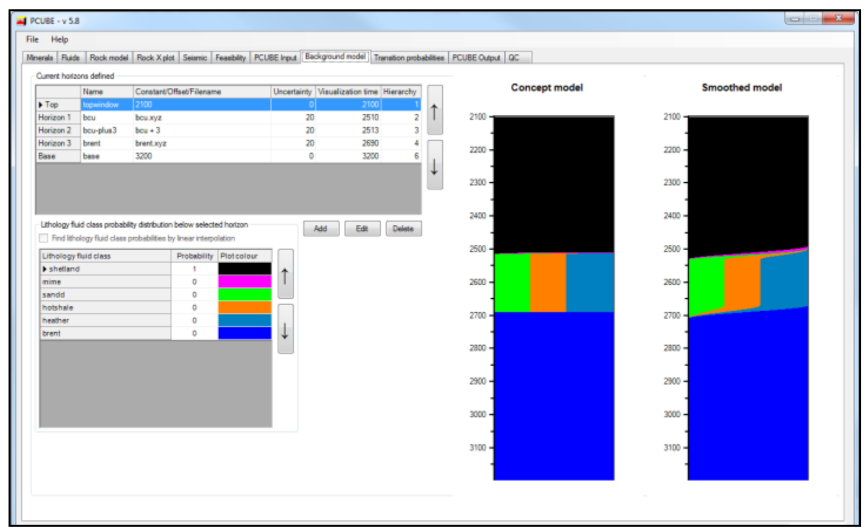
General framework

- 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 CO_2 monitoring
  - 4D gravimetric inversion
  - Bayesian Dix inversion
  - CSEM inversion


Model-based fluid factor for controlled source electromagnetic data

Odd Kolbjørnsen[1], Ragnar Hauge[1], Maren Drange-Espeland[2], and Arild Buland[3]

ABSTRACT

INTRODUCTION

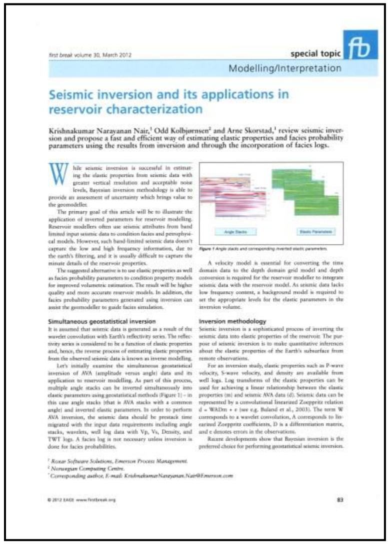

Geophysical Prospecting EAGE

Lithology and fluid prediction from prestack seismic data using a Bayesian model with Markov process prior

Hugo Hammer,[1*] Odd Kolbjørnsen,[2] Håkon Tjelmeland[3] and Arild Buland[4,5]

ABSTRACT

1 INTRODUCTION


special topic fb

Modelling/Interpretation

Seismic inversion and its applications in reservoir characterization


INTELLECTUAL PROPERTY OFFICE

Certificate of Grant of Patent

Patent Number: GB2463242

Proprietor(s): StatoilHydro ASA

Inventor(s): Odd Kolbjørnsen, Ragnar Hauge, Arild Buland

This is to Certify that, in accordance with the Patents Act 1977,

a Patent has been granted to the proprietor(s) for an invention entitled "Method of modelling a subterranean region of the earth" disclosed in an application filed 3 September 2008.

Dated 7 November 2012

John Alty

Comptroller-General of Patents, Designs and Trade Marks

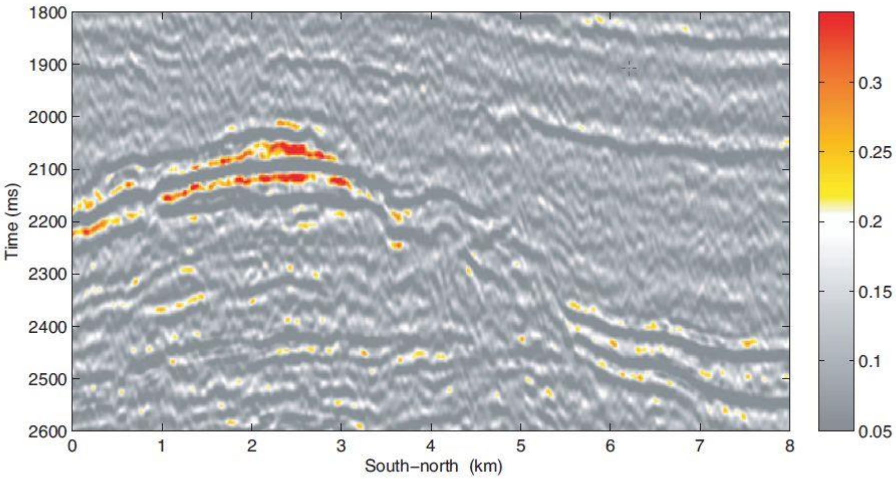
Intellectual Property Office

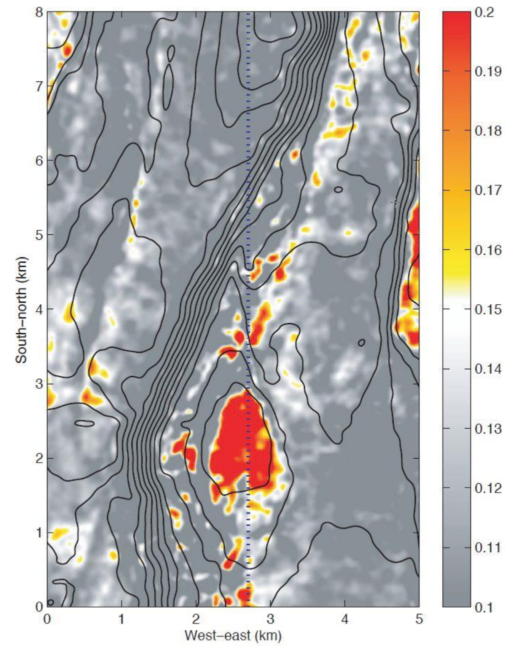
The attention of the Proprietor(s) is drawn to the important notes overleaf.

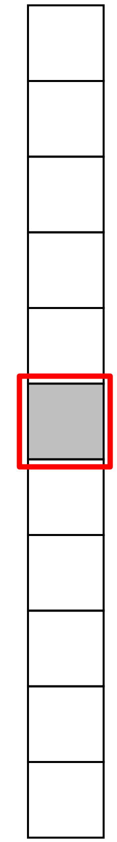
Approaches for trace by trace lithology fluid prediction

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

Probability of hydrocarbons







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

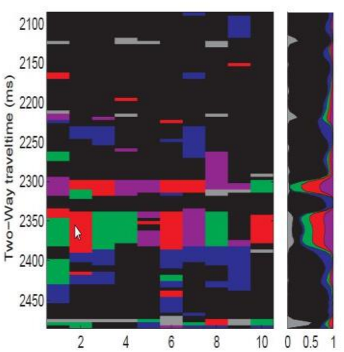
Approaches for trace by trace lithology fluid prediction

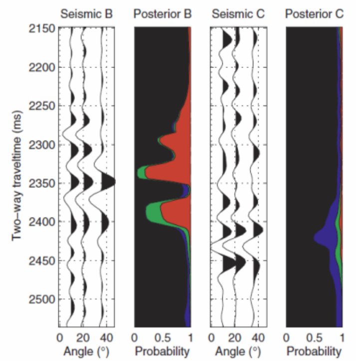
1. Pointwise inversion (PCube)
   Fast, but no lithology fluid ordering

2. Monte Carlo methods for complete traces

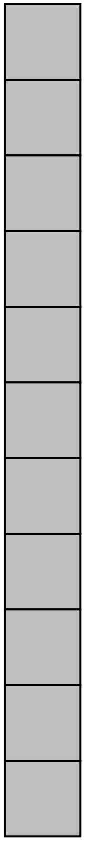
   (Hammer and Tjelmeland 2008, Kjønsberg et. al. 2010)

   “Correct” solution, but very slow





Fizz
Gas
Oil
Brine
Shale



Approaches for trace by trace lithology fluid prediction

1. Pointwise inversion (PCube)
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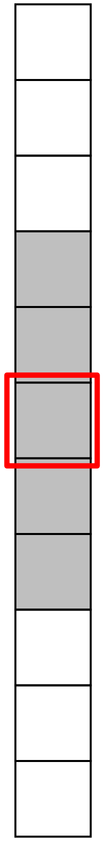
   "Correct" solution, but very slow

3. Neighborhood inversion (PCube+)



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

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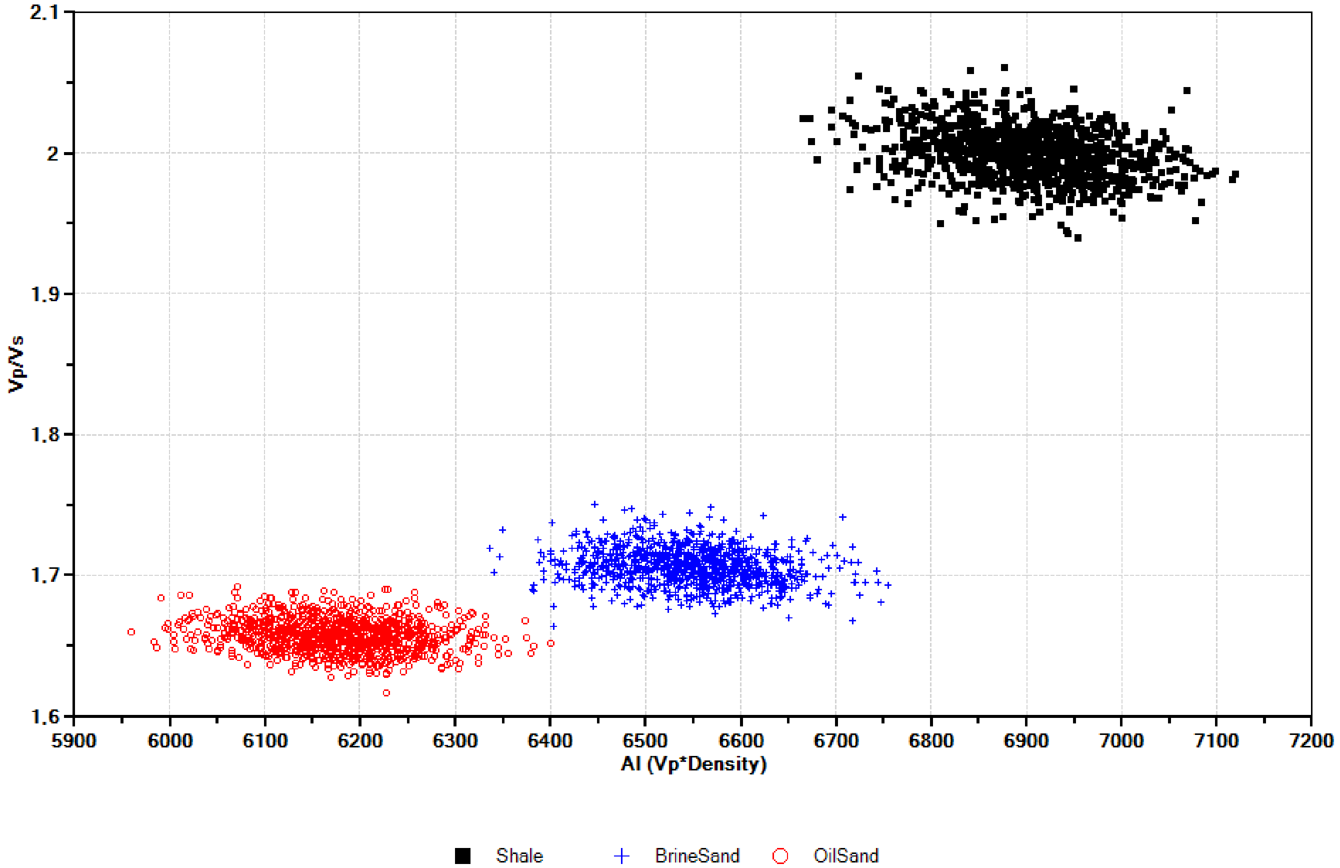
PCube+: Simple synthetic case

- 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

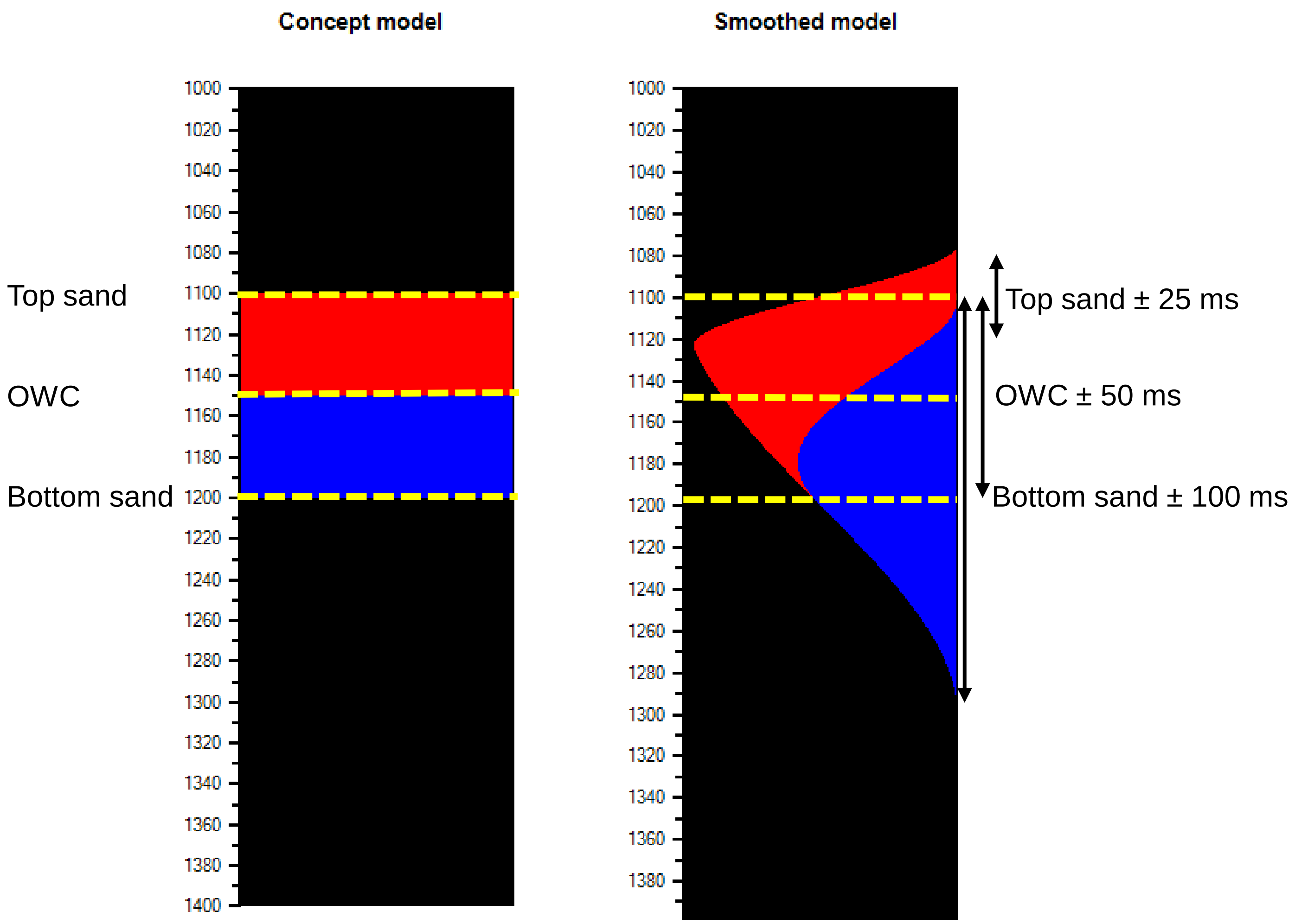


Prior: Zone model – concept model

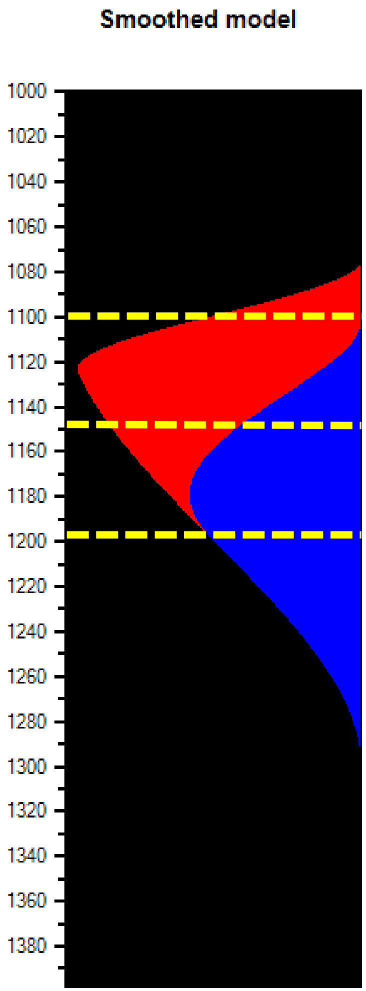
Zone	Zone boundary definition - Top of zone	Uncertainty on zone boundary (ms)	LFC content in zone
Overburden	Top of model		100% Shale
Oil zone	Top sand	25	100% Oil-filled sand
Water zone	OWC	50	100% Water-filled sand
Base	Bottom sand	100	100% Shale

Courtesy of Statoil Petroleum

Prior: Zone concept model and smoothed model for single trace



Prior: Lithology / fluid ordering



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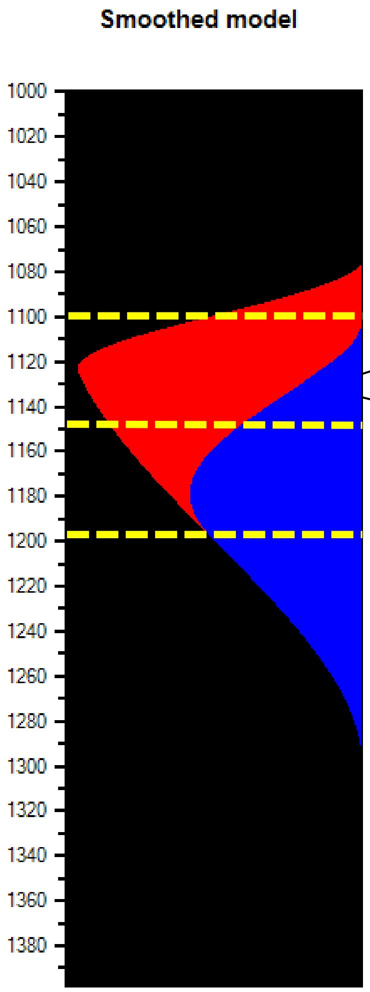
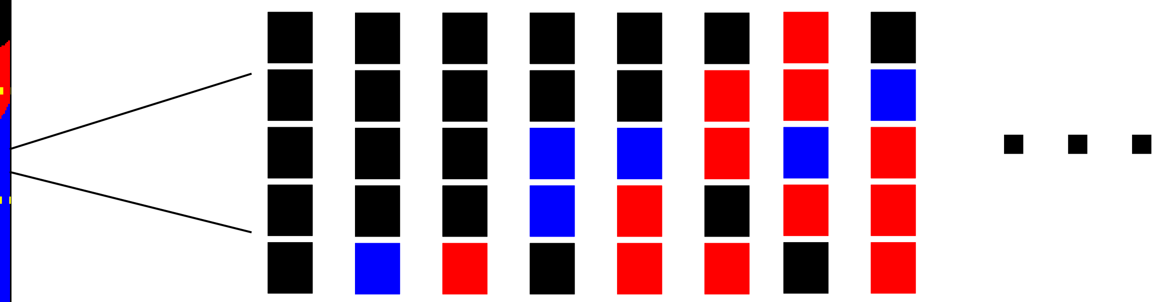
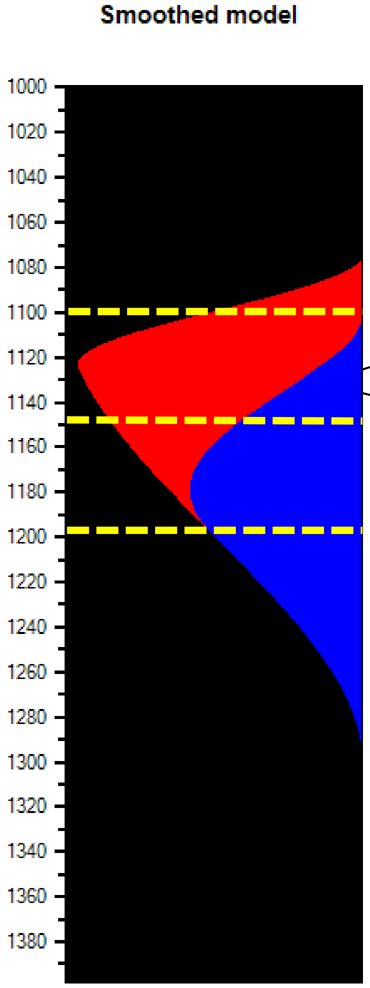
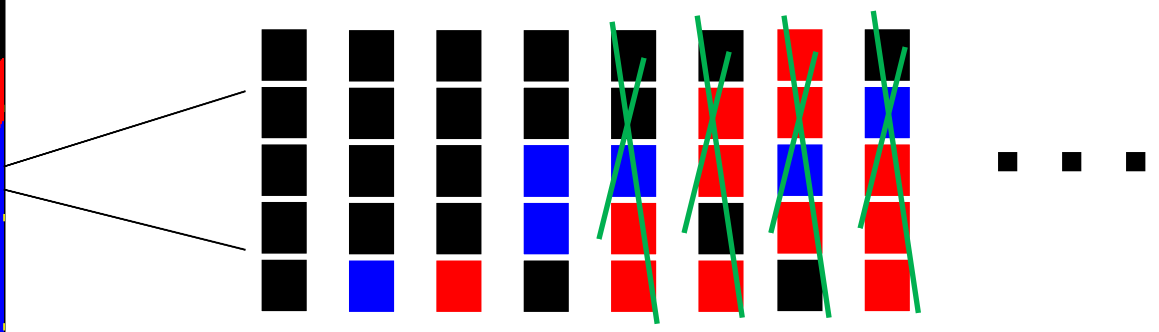




144 possible combinations

Prior: Lithology / fluid ordering

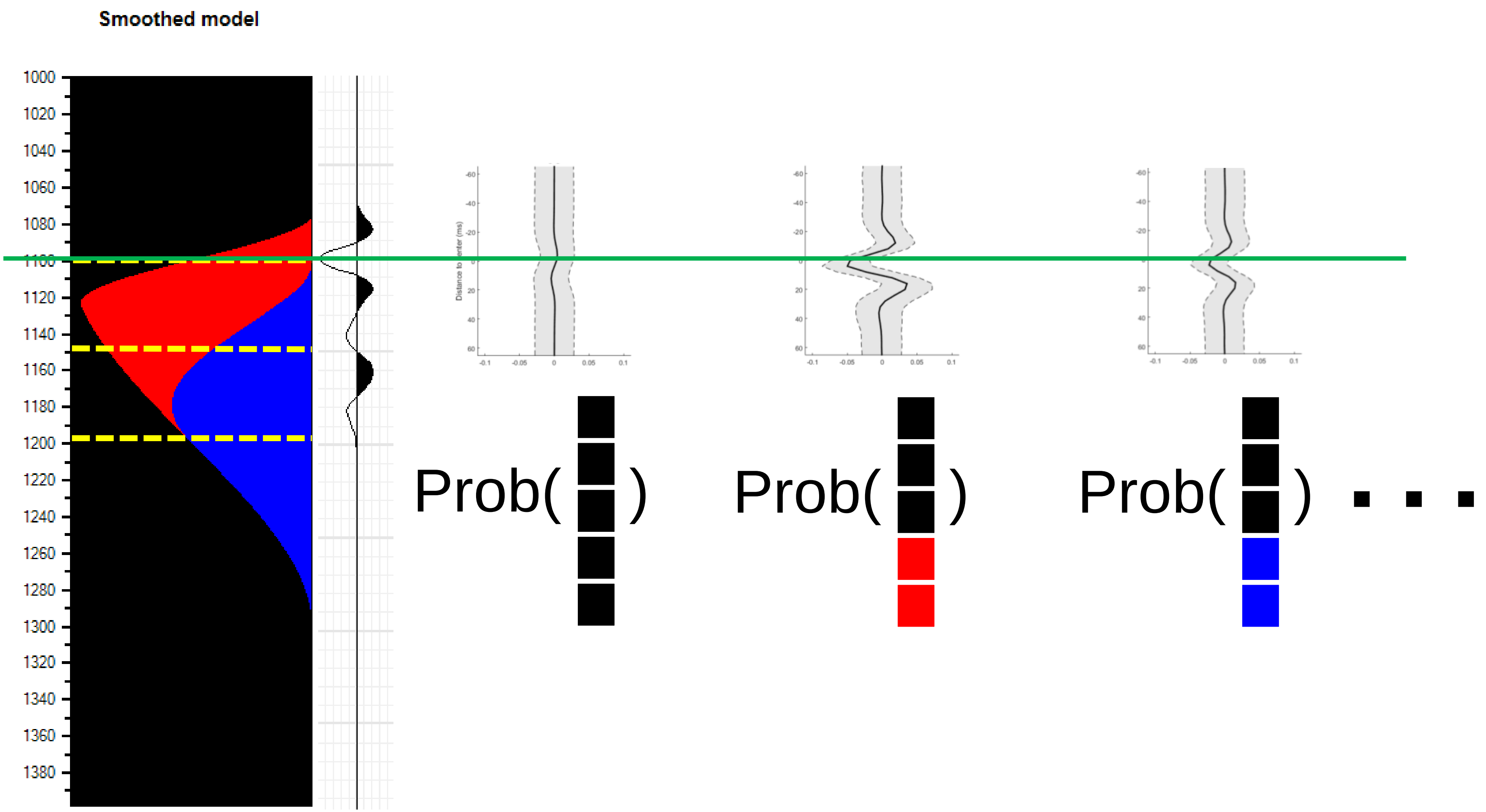




144 possible combinations

42 legal combinations

Lithology and fluid is found by comparing with seismic signal



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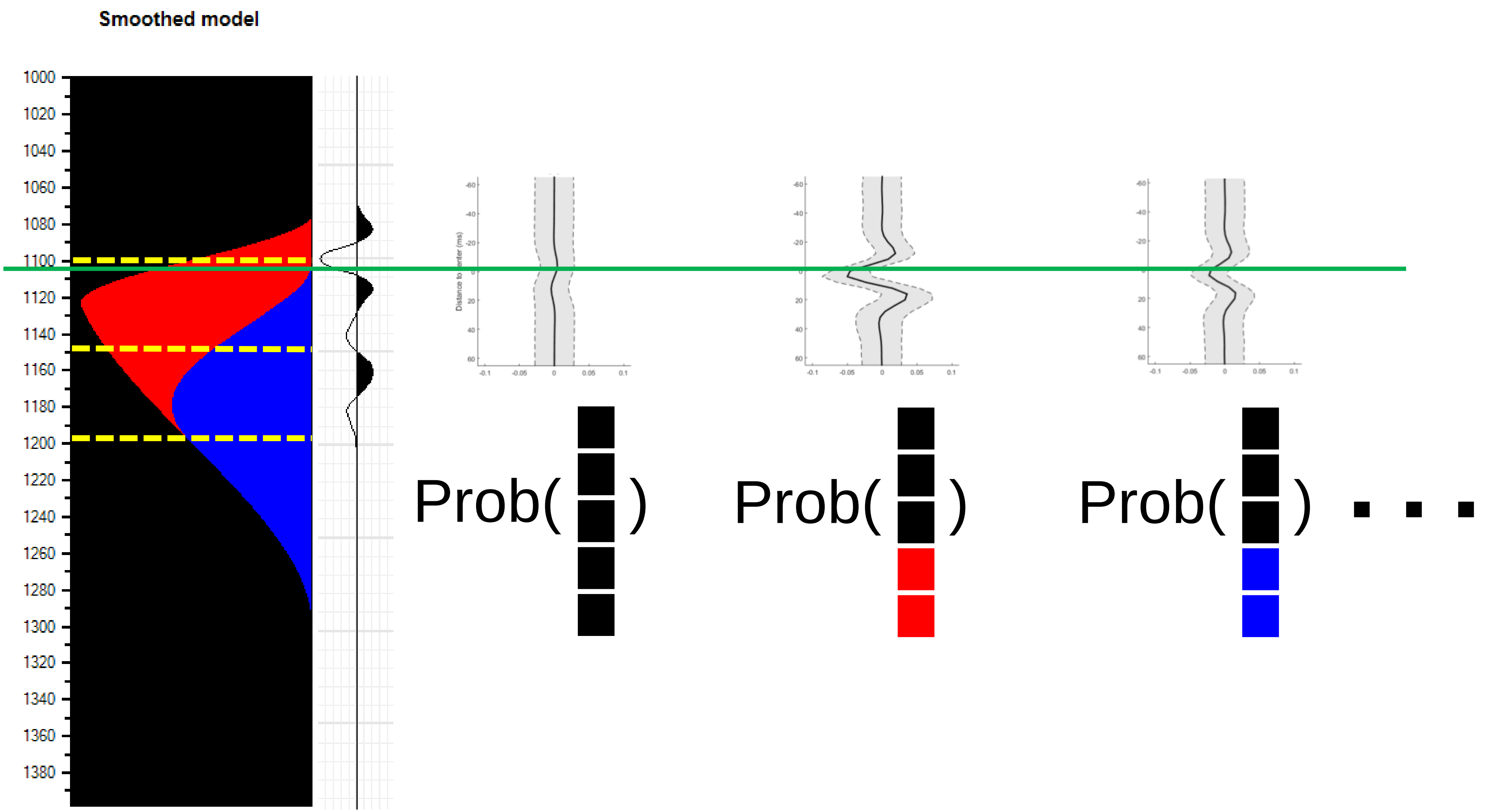

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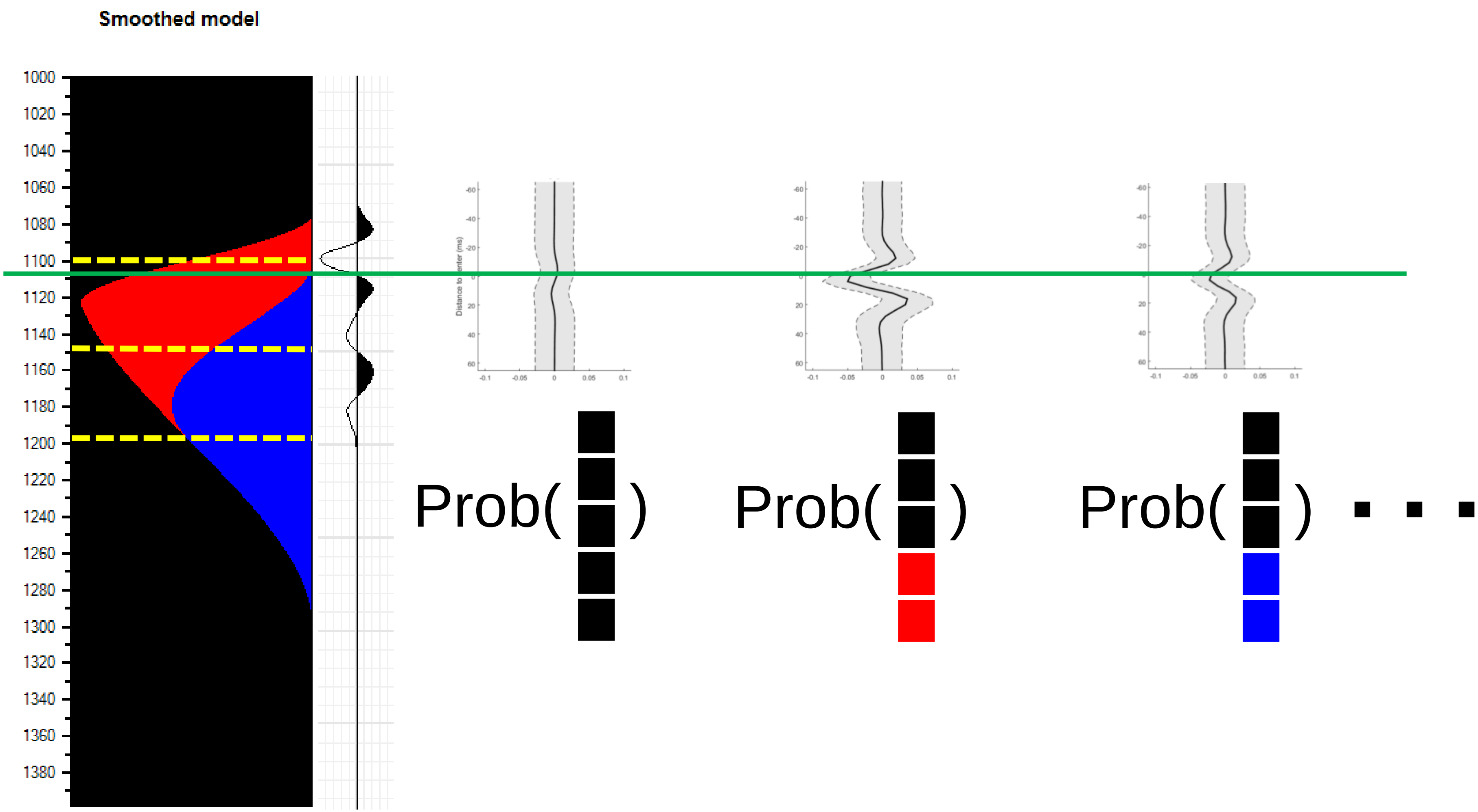
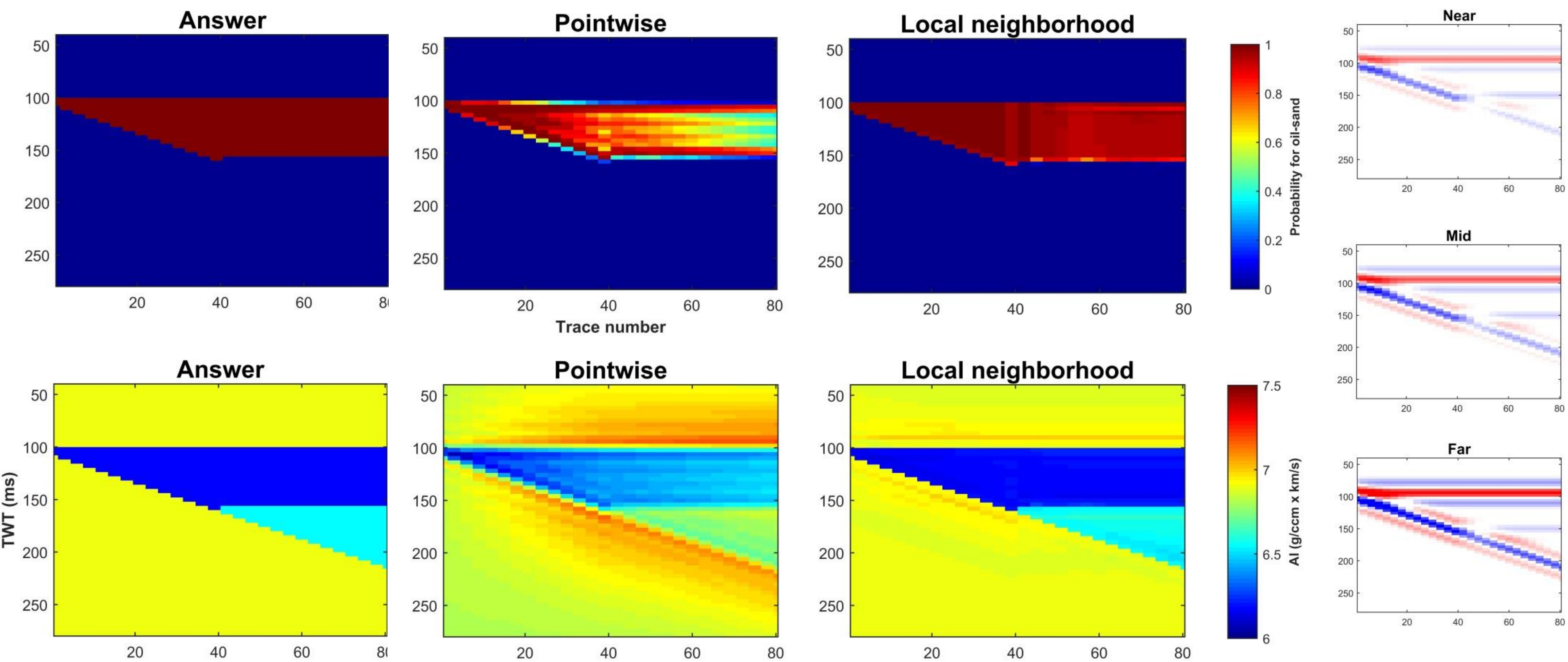


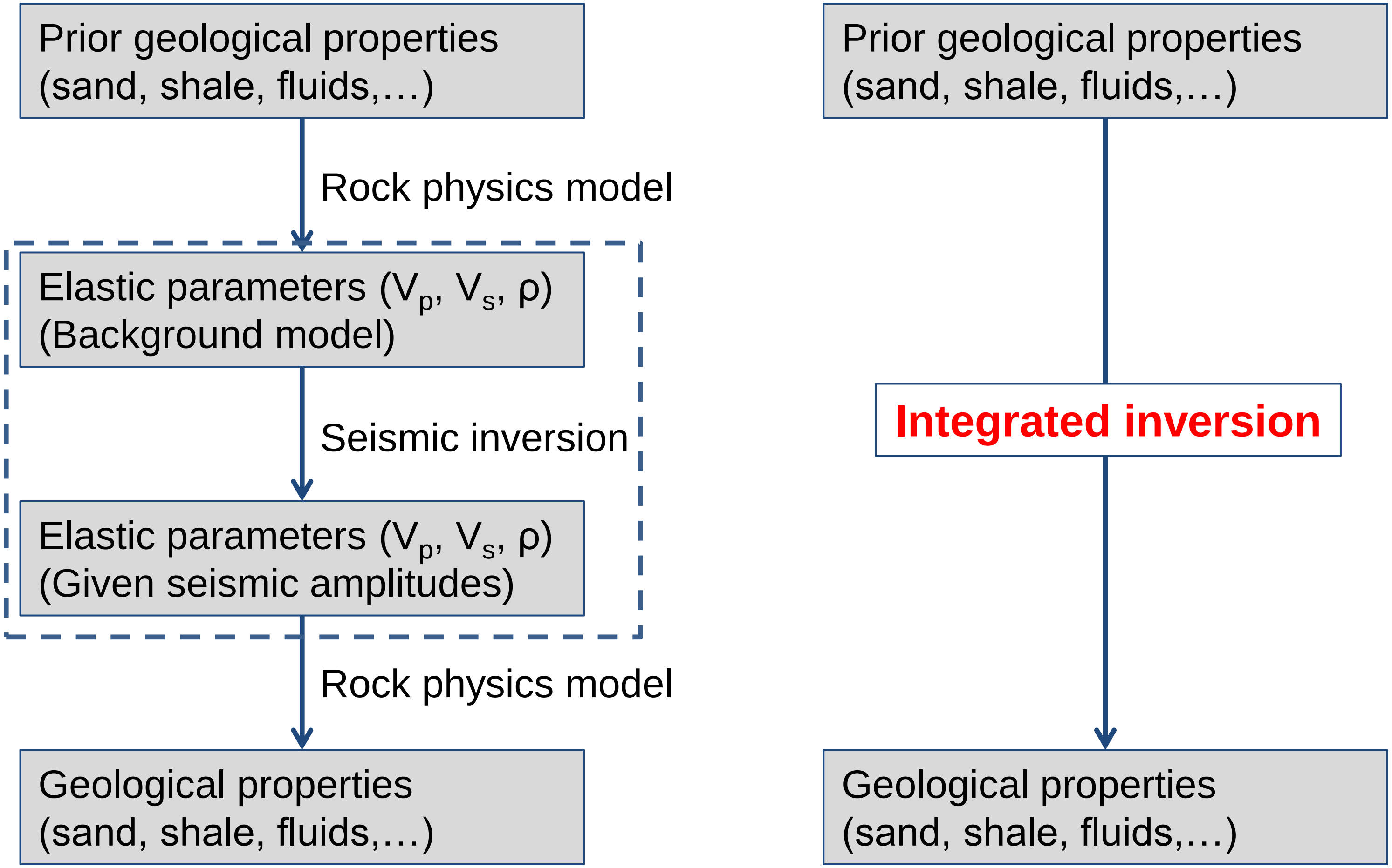
Inversion results for wedge

PCube PCube+



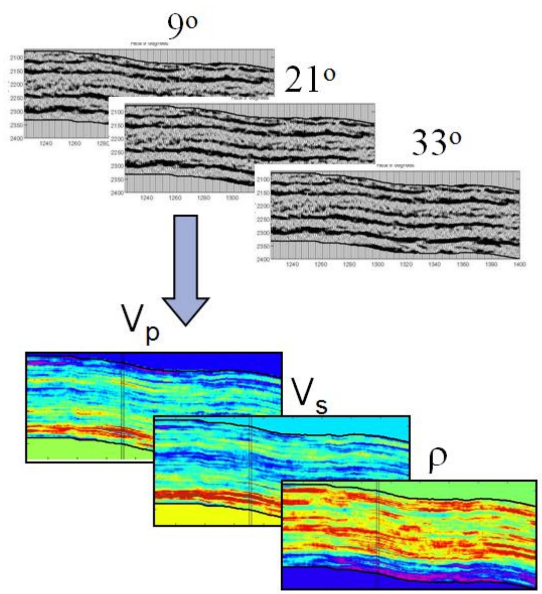
5 cell neighbourhood

Seismic inversion using geological constraints



Seismic inversion using geological constraints

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



Geological properties
(sand, shale, fluids,…)

Prior geological properties
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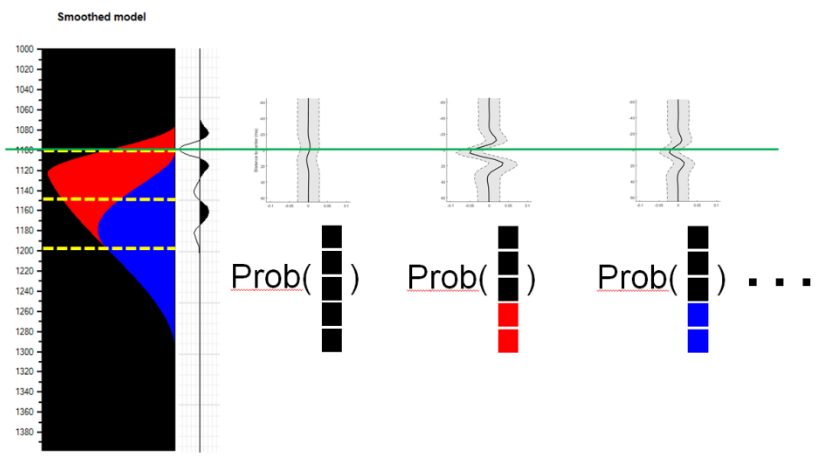


Geological properties
(sand, shale, fluids,…)

Current and future work

Improvements of inversion algorithms

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

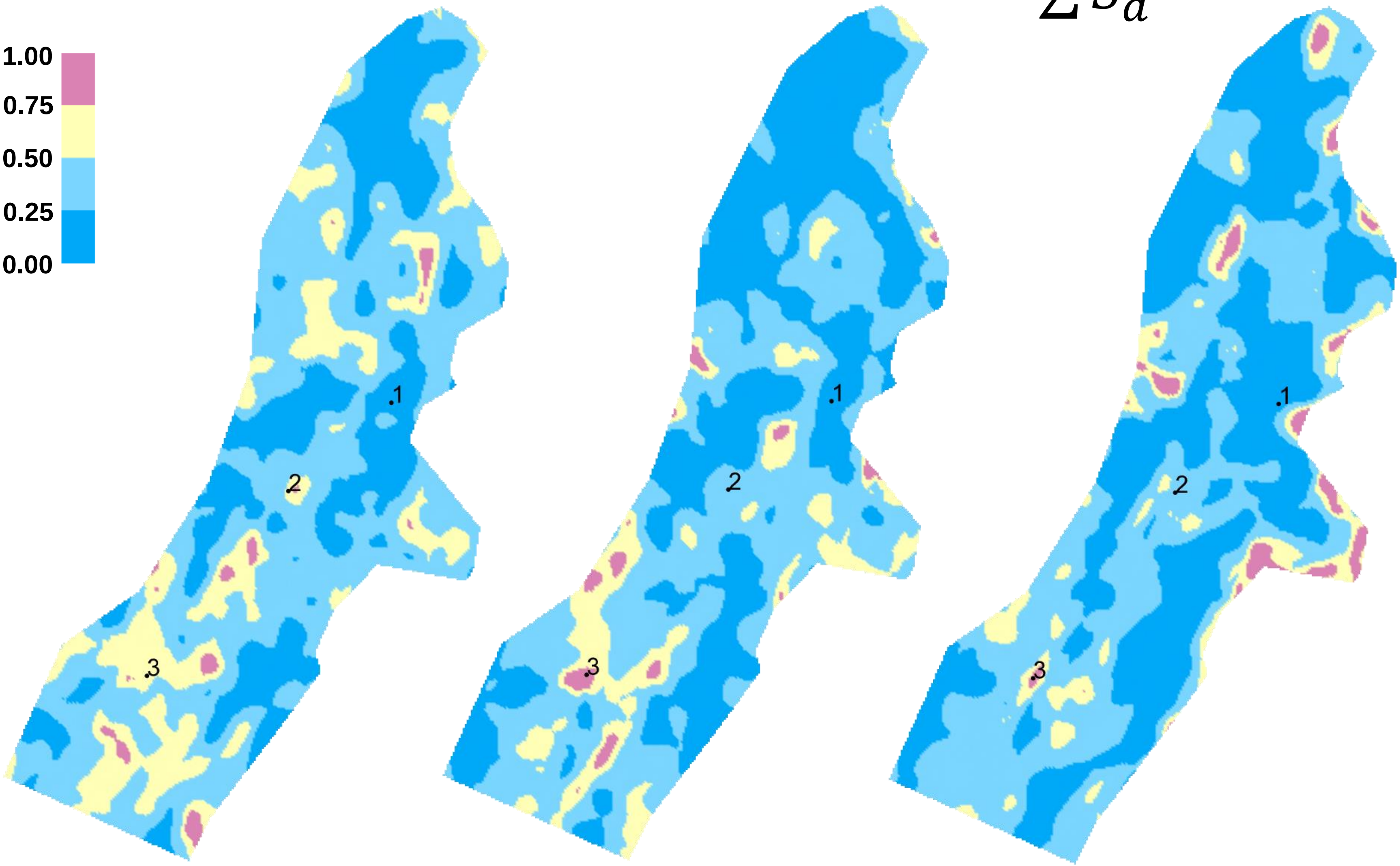
QC

- Evaluate input data
  - Quality of seismic data
  - Well logs
  - Stationarity in seismic data

- Establish trust in inversion results

Relative residual energy

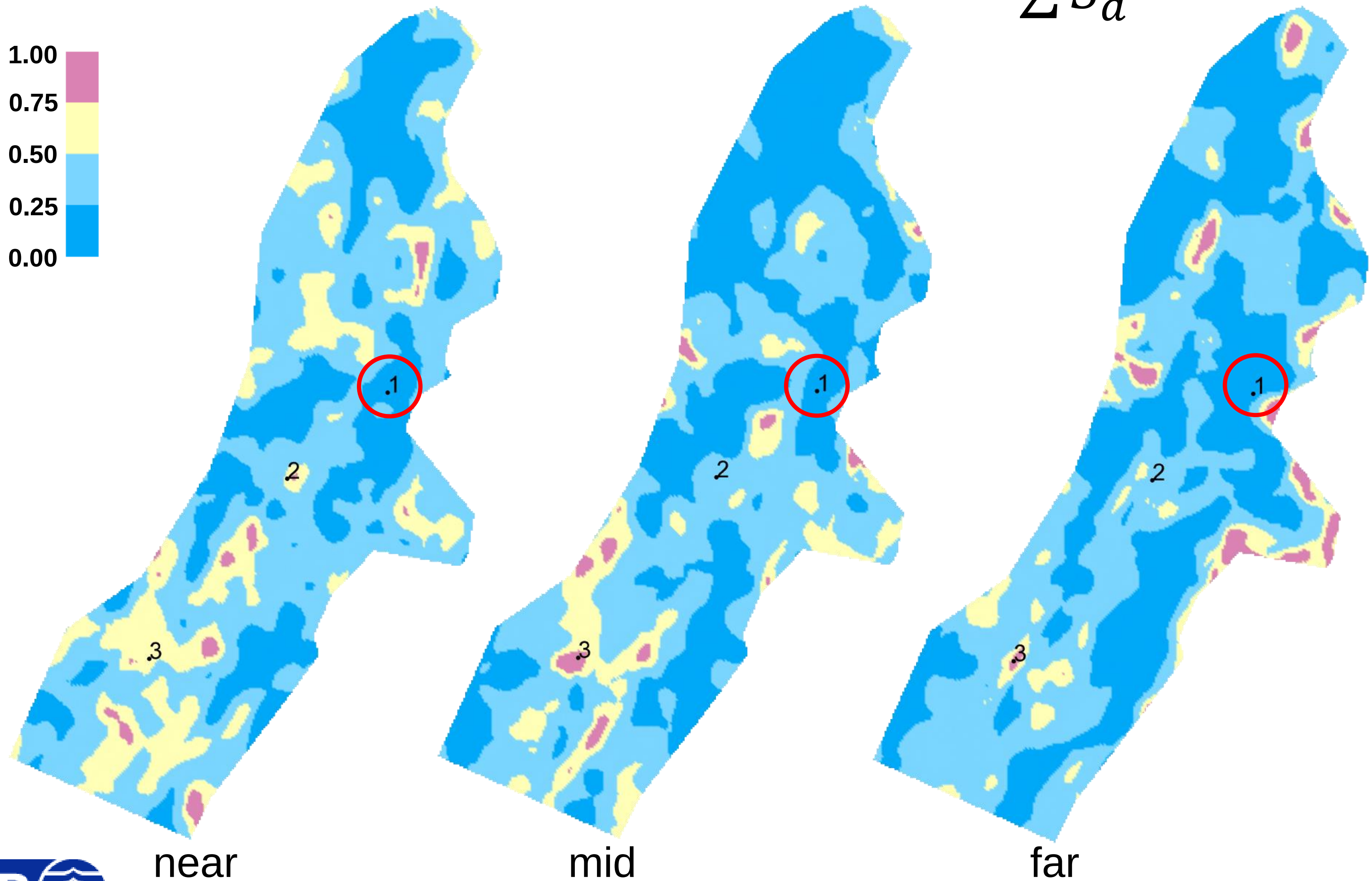
$$\frac{\sum (S_i - S_d)^2}{\sum {S_d}^2}$$



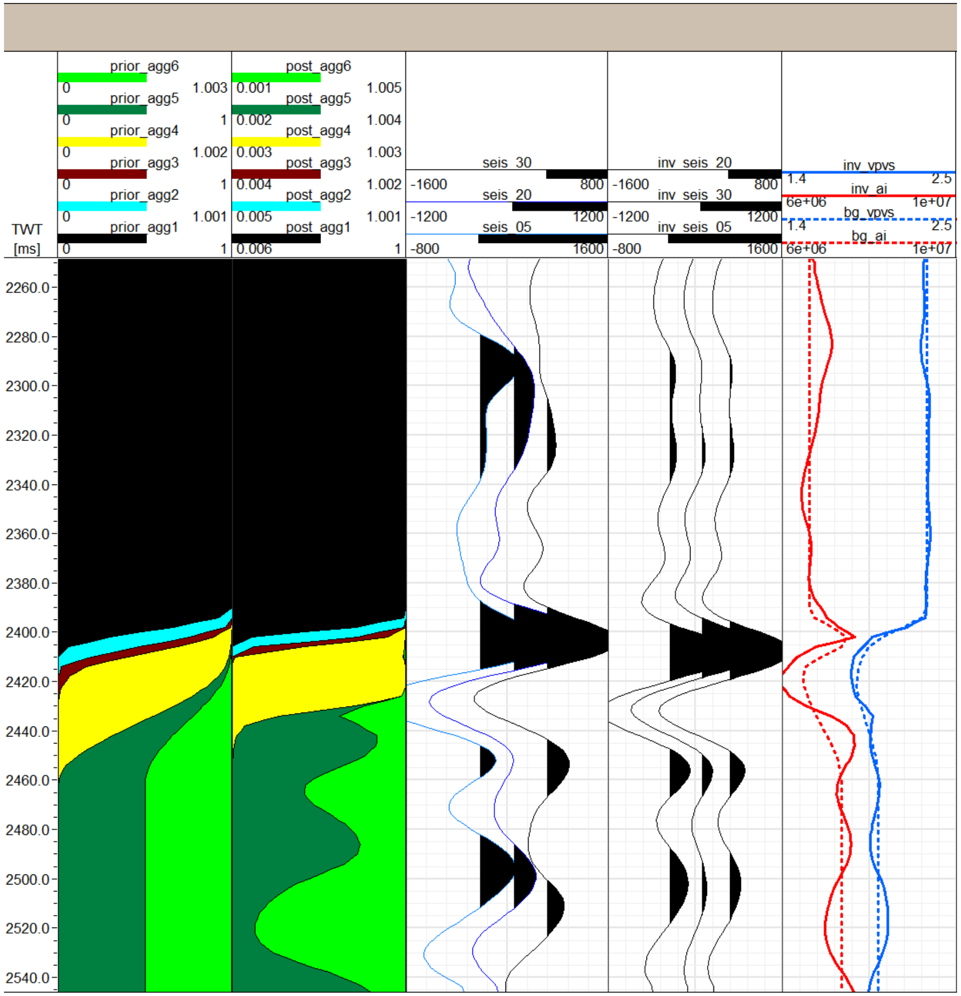
near mid far

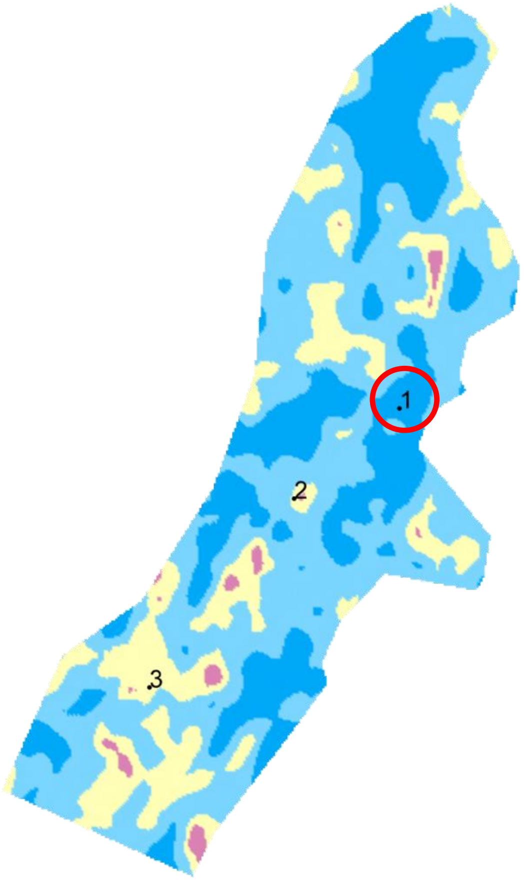
Relative residual energy

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



Location 1: Low residual all angles





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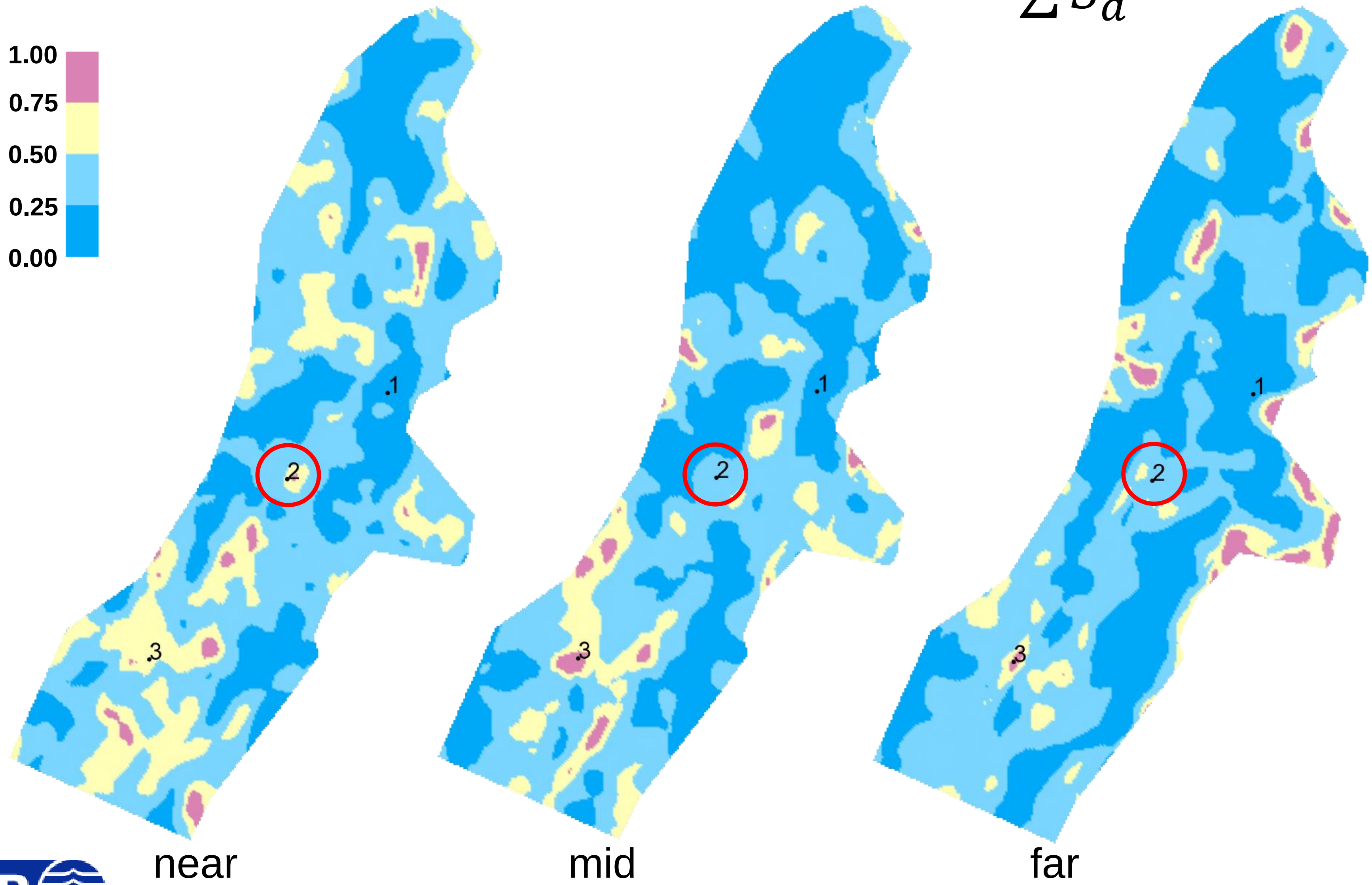
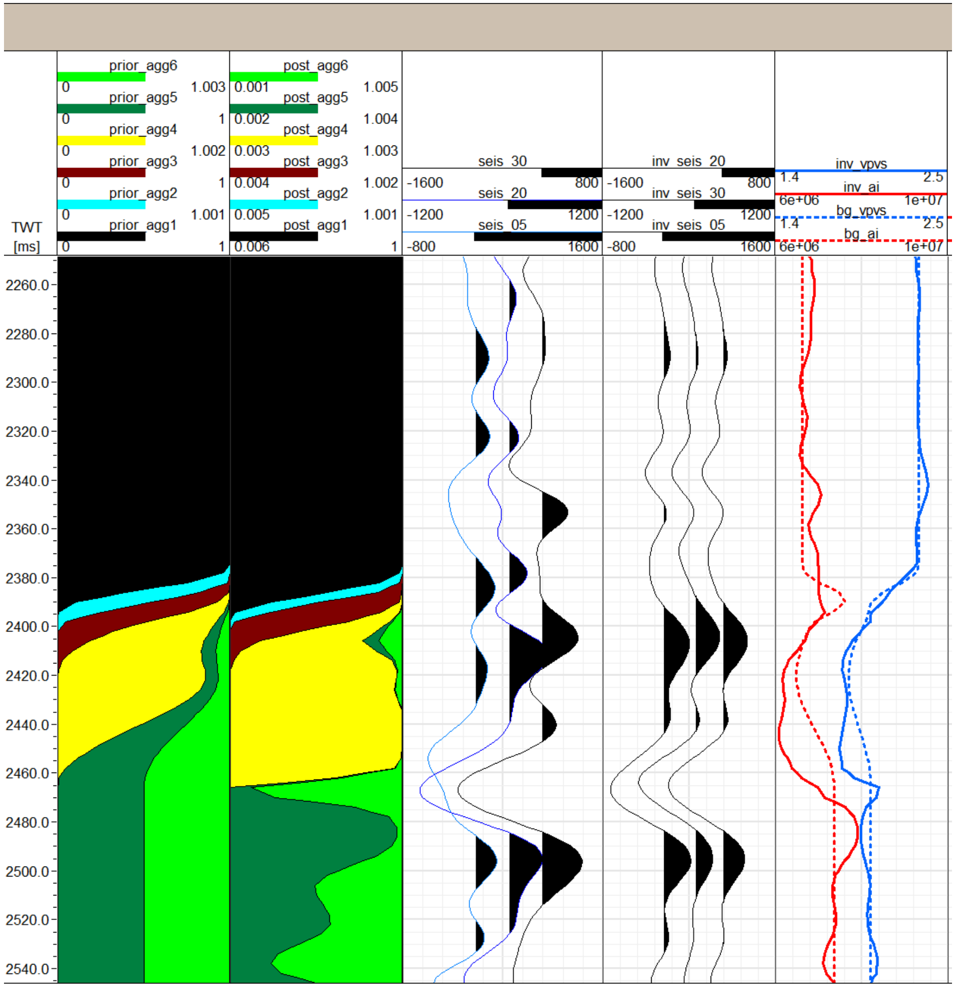
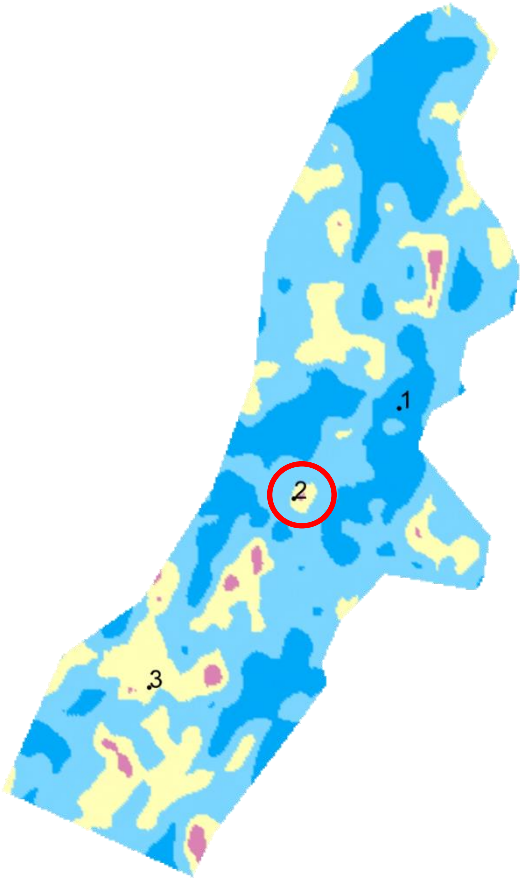
$$\frac{\sum(S_i - S_d)^2}{\sum {S_d}^2}$$



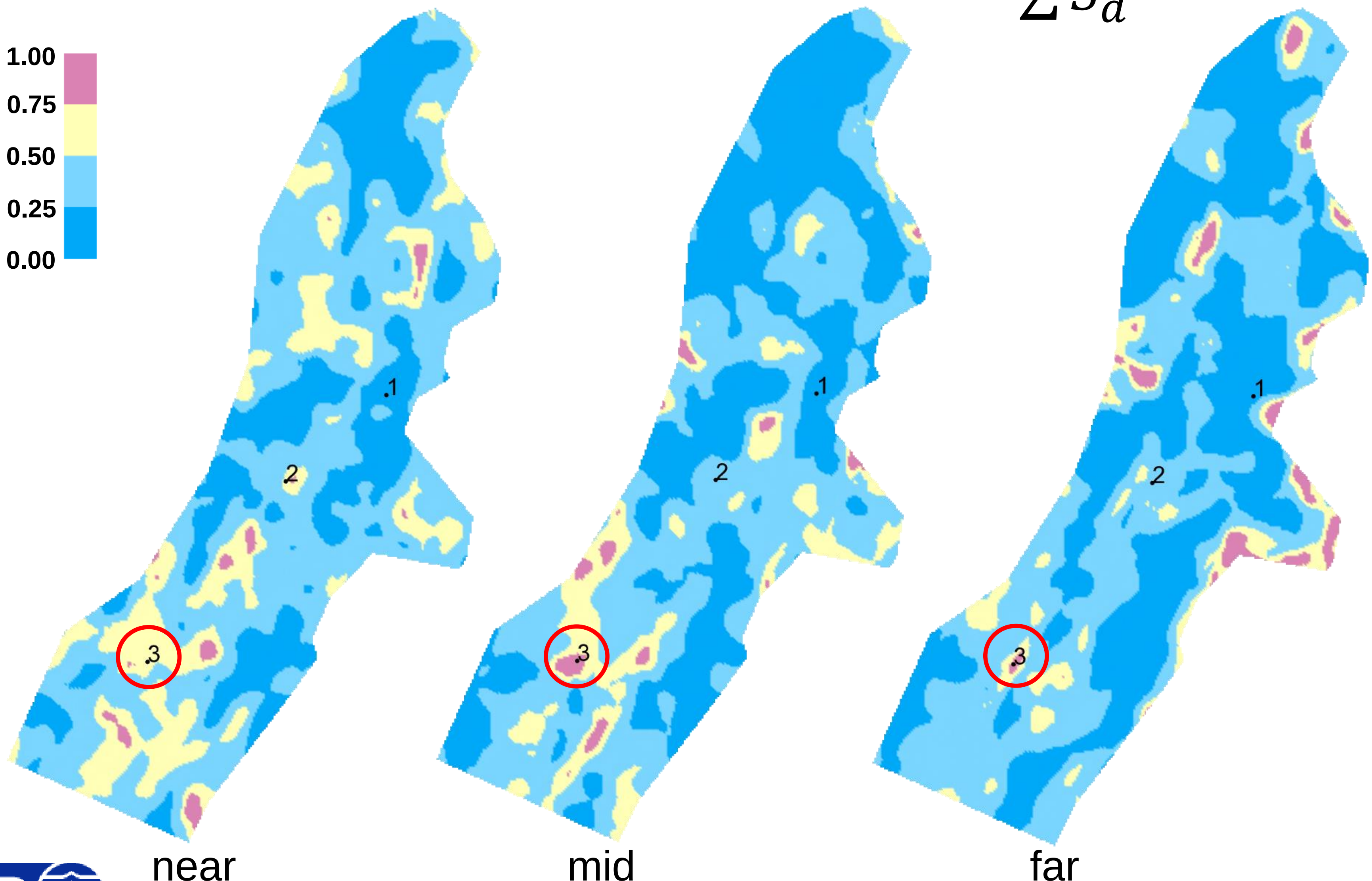
Location 2: High residual near, less mid/far



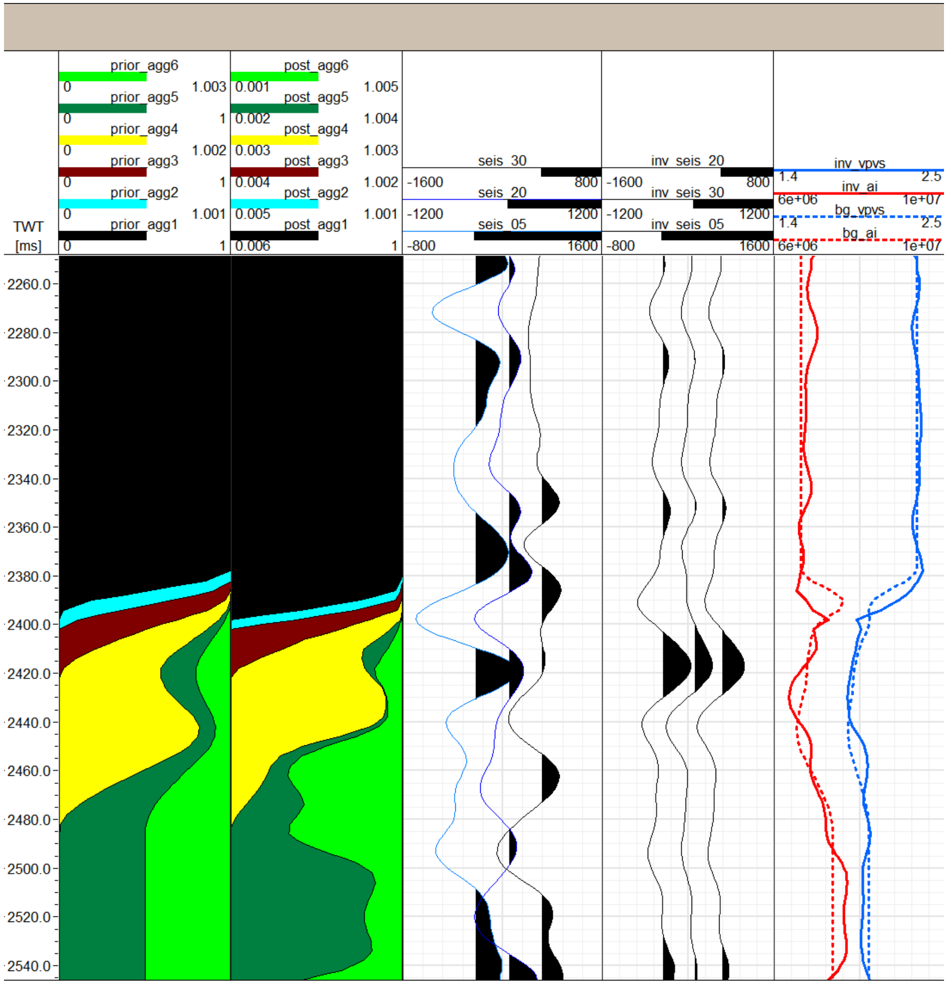


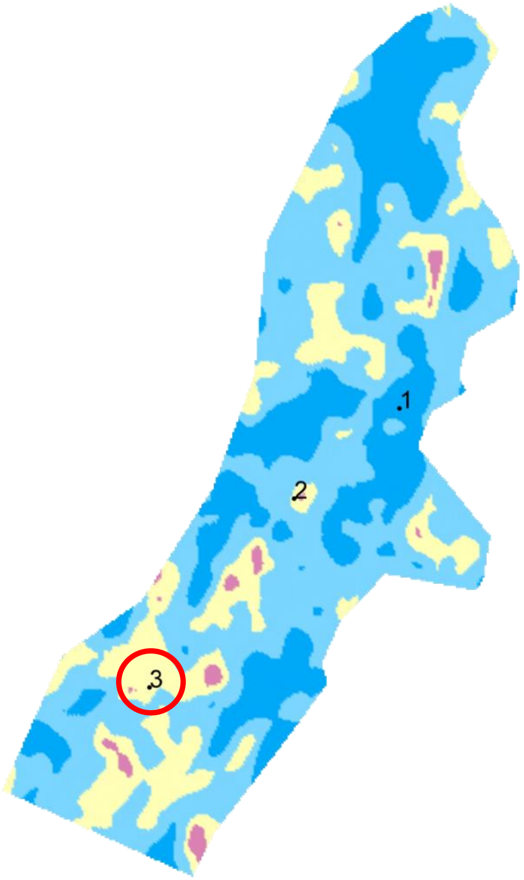
Relative residual energy

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



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



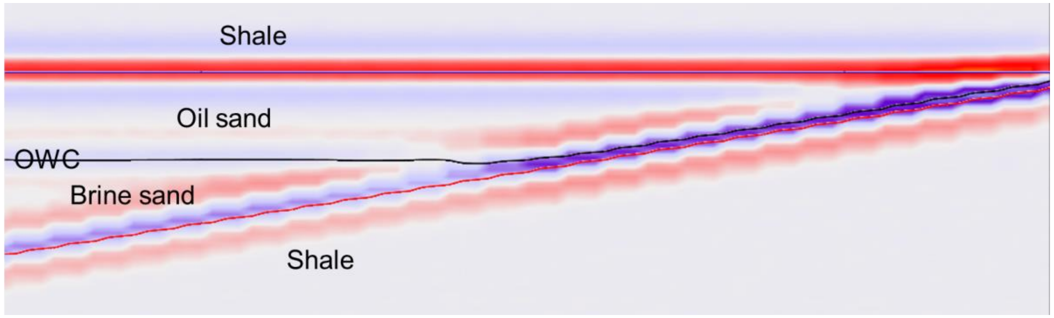


QC: Future work

- 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 phyics models
- More precise identification of inversion problems

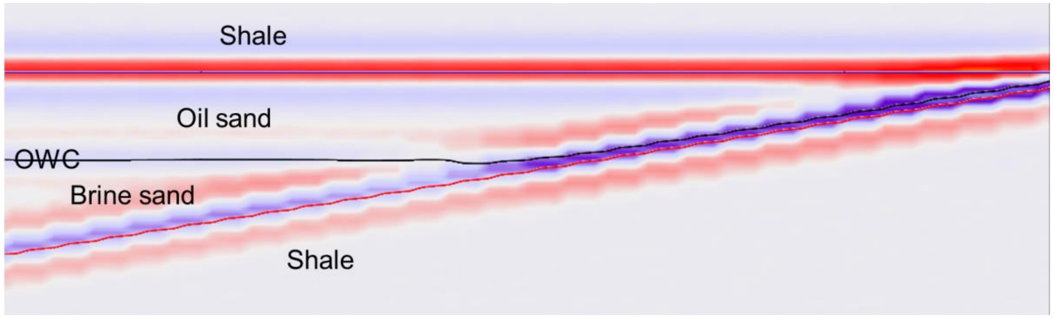
Inversion of horizon location

- Based on PCube+ inversion, but focusing on horizons



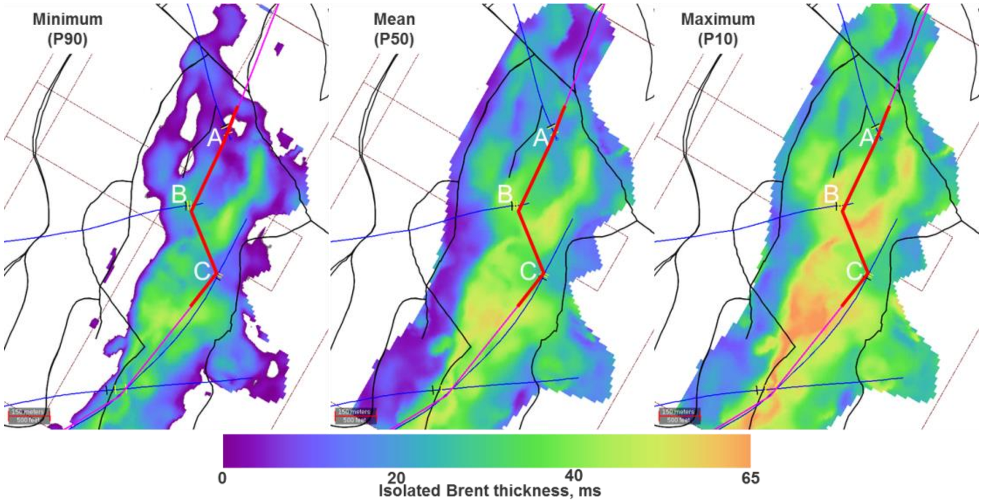
Inversion of horizon location

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



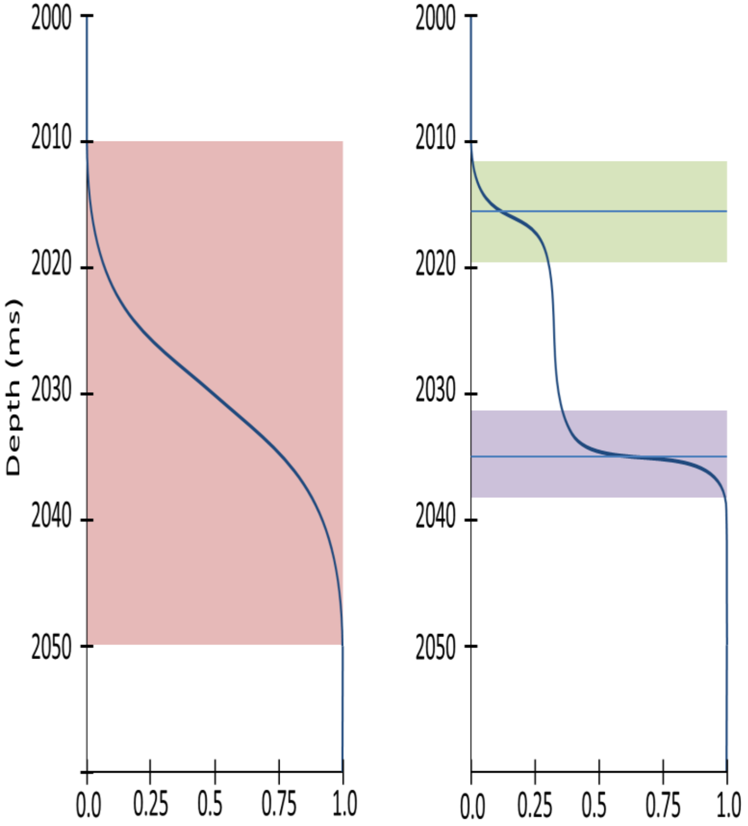
Inversion of horizon location

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



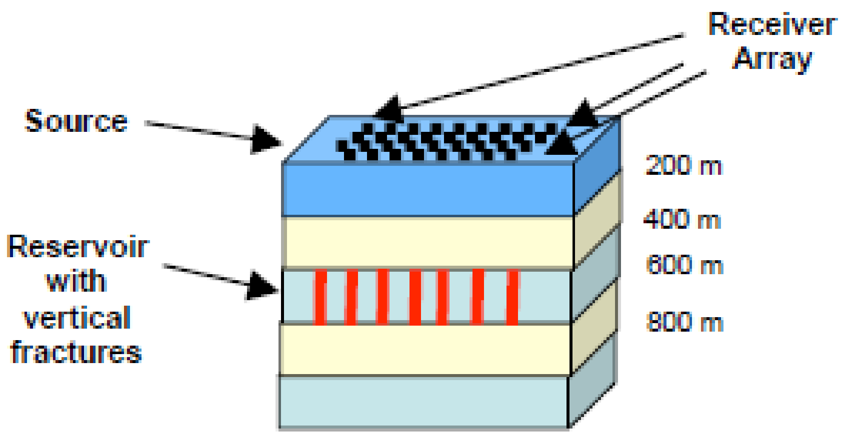
Inversion of horizon location

- 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

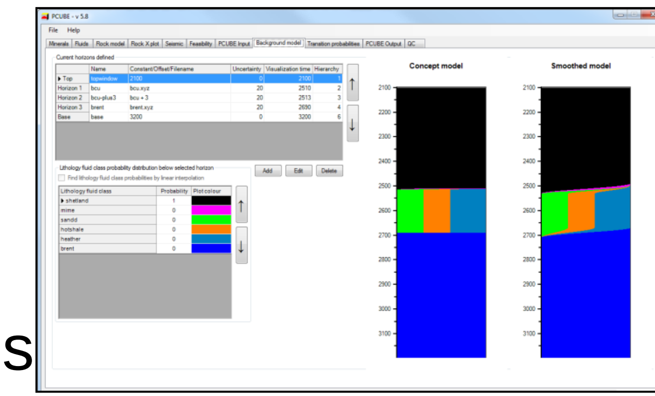
- Better control input data
- Better prediction of geology and fluids

- 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



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:

Statoil AkerBP Lundin Norway