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Not exactly as presented: Inversion testing part 4 and 5 added. Maps and sections cropped. Modelling slides removed. Some backup slides added

Pcube+ inversion – connecting rock physics and seismic amplitudes

FORCE seminar Practical Rock Physics and Inversion for Exploration and Production, 17/10-17

Ø. Skjæveland and R. P. Srivastava, Statoil

23 august 20

Objective

- Present a robust and relatively fast workflow
  - For using prestack seismic inversion to understand your seismic data
  - To be run by asset geophysicists - supported by inversion specialists
  - That can take noisy data as input - to be run before doing gather cleaning

- Dataset:
  - Statoil operated producing field on NCS
  - Current focus in asset: Maturing new well targets
  - Reservoir below BCU. Faulting, slumps and reworking of sands common
  - Fairly shallow water – heavily contaminated by multiples

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Workflow in short

Create angle gathers. Ca 5 degrees bin interval.

Match frequencies across gather. Target: ~35 deg stack.

Relative

Calculate intercept and gradient from ~10 to ~35 degrees

Derive relative AI and vp/vs from intercept and gradient.

Use Shuey modeled reflectivity as relative inversion synthetics

Absolute

Define rough Lithology Fluid Classes (LFC's) and build a prior LFC model using horizons

Do a rough prestack tie to find rough wavelets

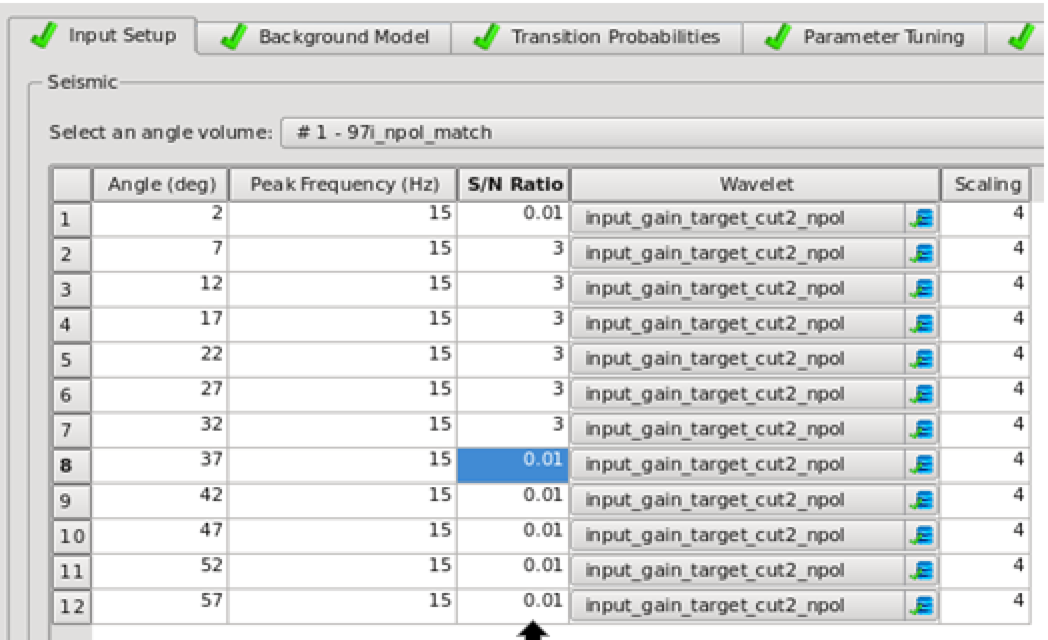
Run a Pcube+ inversion

Calculate NRMS diff between seismic and synthetics

Investigate inversion results. Wells, locations of interest, low and high NRMS. Simple forward models helpful.

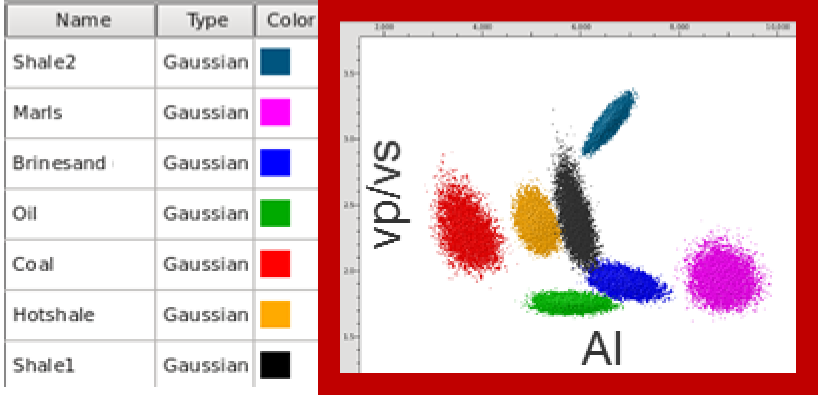
Apply data conditioning to input data and check effect of this and of inversion parameter variation. Consider if rough is good enough and if there is data support for going to details.

Pcube+ inversion input



	Angle (deg)	Peak Frequency (Hz)	S/N Ratio	Wavelet	Scaling
1	2	15	0.01	input_gain_target_cut2_npol	4
2	7	15	3	input_gain_target_cut2_npol	4
3	12	15	3	input_gain_target_cut2_npol	4
4	17	15	3	input_gain_target_cut2_npol	4
5	22	15	3	input_gain_target_cut2_npol	4
6	27	15	3	input_gain_target_cut2_npol	4
7	32	15	3	input_gain_target_cut2_npol	4
8	37	15	0.01	input_gain_target_cut2_npol	4
9	42	15	0.01	input_gain_target_cut2_npol	4
10	47	15	0.01	input_gain_target_cut2_npol	4
11	52	15	0.01	input_gain_target_cut2_npol	4
12	57	15	0.01	input_gain_target_cut2_npol	4

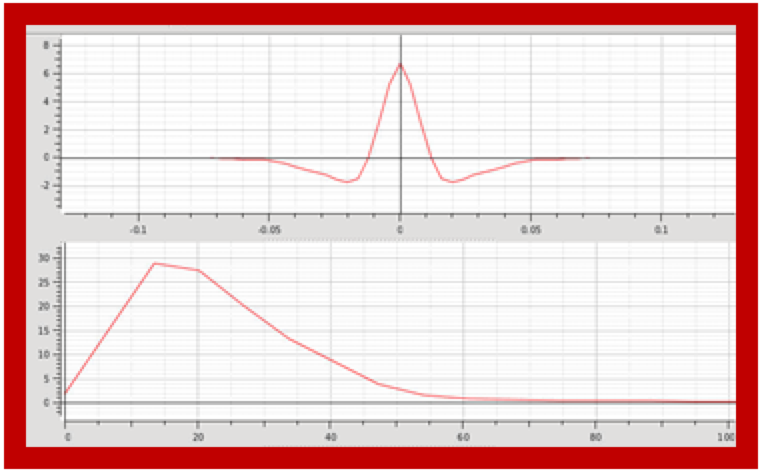
Turn off individual angles by setting S/N close to zero



Name	Type	Color
Shale2	Gaussian	
Marls	Gaussian	
Brinesand	Gaussian	
Oil	Gaussian	
Coal	Gaussian	
Hotshale	Gaussian	
Shale1	Gaussian	

LFC's – in this case extracted from well data. PDF's in vp,vs,density.

Here: Same wavelet for all angles. Statistical from 37 degree stack



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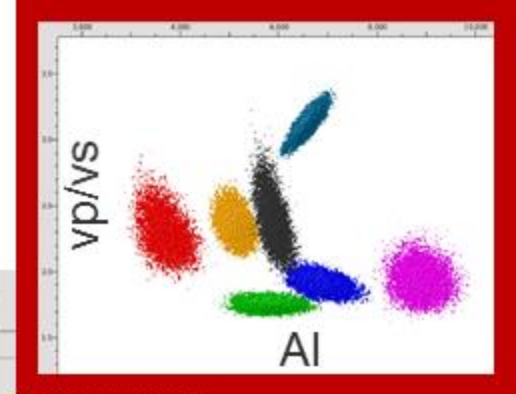
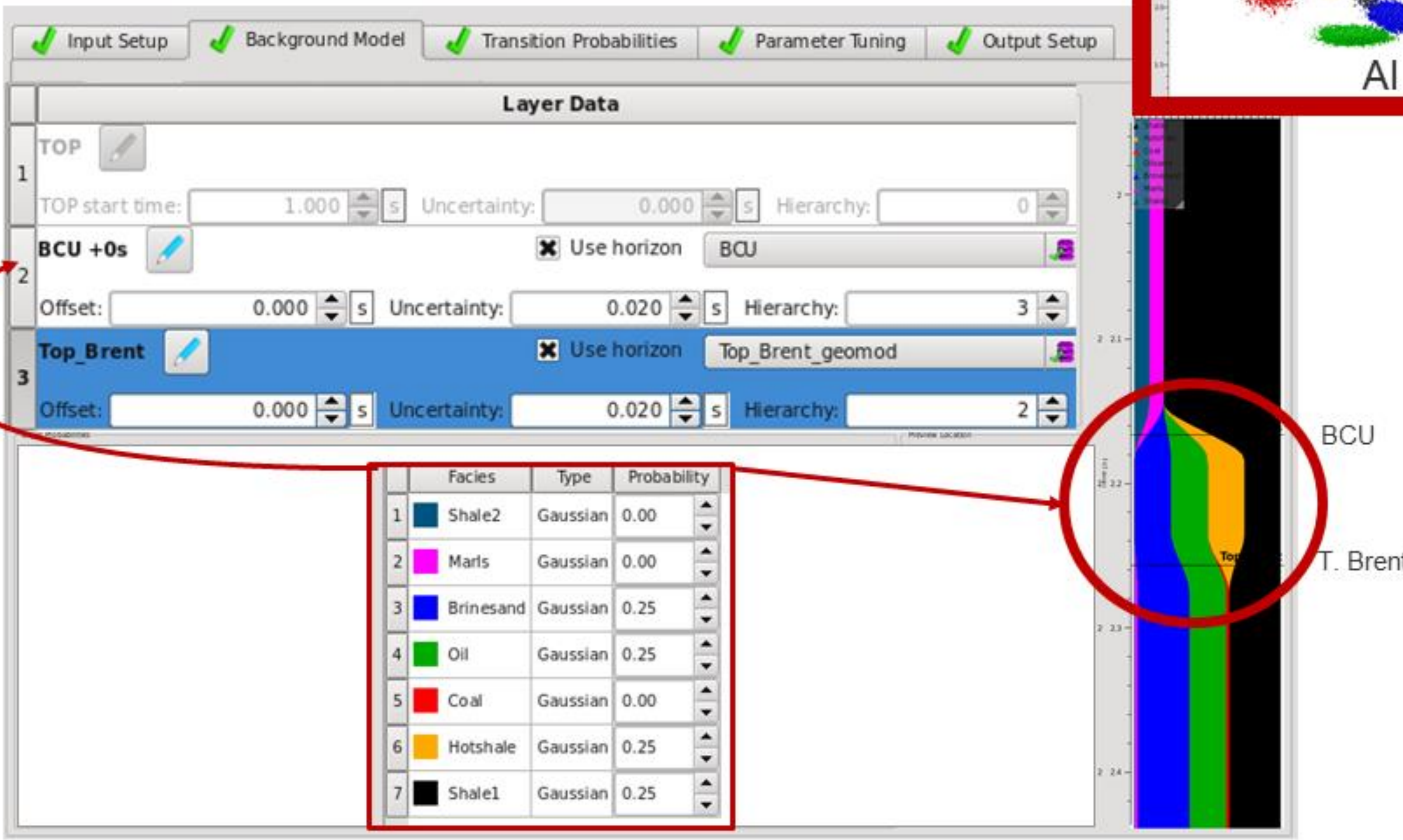
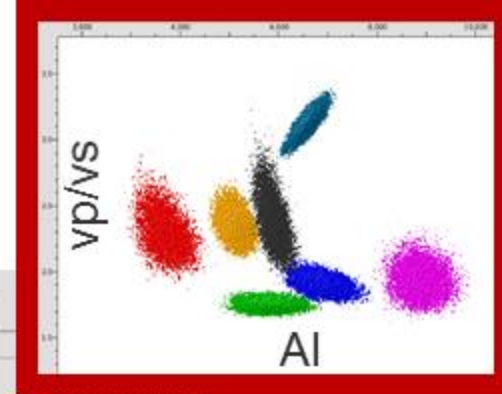
Background model definition





	Facies	Type	Probability
1	Shale2	Gaussian	0.00
2	Marls	Gaussian	0.00
3	Brinesand	Gaussian	0.25
4	Oil	Gaussian	0.25
5	Coal	Gaussian	0.00
6	Hotshale	Gaussian	0.25
7	Shale1	Gaussian	0.25

Background model definition



Input Setup | Background Model | Transition Probabilities | Parameter Tuning | Output Setup

Layer Data

1 TOP
TOP start time: 1.000 s Uncertainty: 0.000 s Hierarchy: 0

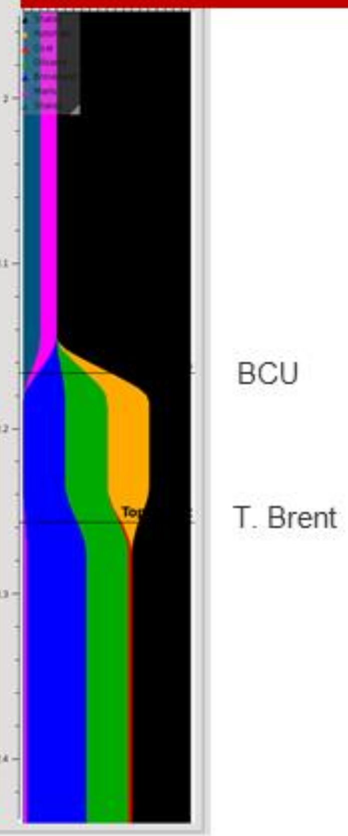
2 **BCU +0s** Use horizon BCU
Offset: 0.000 s Uncertainty: 0.020 s Hierarchy: 3

3 **Top_Brent** Use horizon Top_Brent_geomod
Offset: 0.000 s Uncertainty: 0.020 s Hierarchy: 2

	Facies	Type	Probability
1	Shale2	Gaussian	0.10
2	Marls	Gaussian	0.10
3	Brinesand	Gaussian	0.00
4	Oil	Gaussian	0.00
5	Coal	Gaussian	0.00
6	Hotshale	Gaussian	0.00
7	Shale1	Gaussian	0.80

	Facies	Type	Probability
1	Shale2	Gaussian	0.00
2	Marls	Gaussian	0.00
3	Brinesand	Gaussian	0.25
4	Oil	Gaussian	0.25
5	Coal	Gaussian	0.00
6	Hotshale	Gaussian	0.25
7	Shale1	Gaussian	0.25

	Facies	Type	Probability
1	Shale2	Gaussian	0.00
2	Marls	Gaussian	0.02
3	Brinesand	Gaussian	0.35
4	Oil	Gaussian	0.25
5	Coal	Gaussian	0.02
6	Hotshale	Gaussian	0.00
7	Shale1	Gaussian	0.35



This is the full specification of the prior model. Lateral variation controlled by horizons

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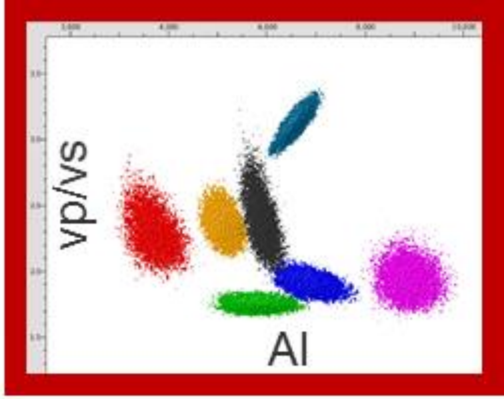
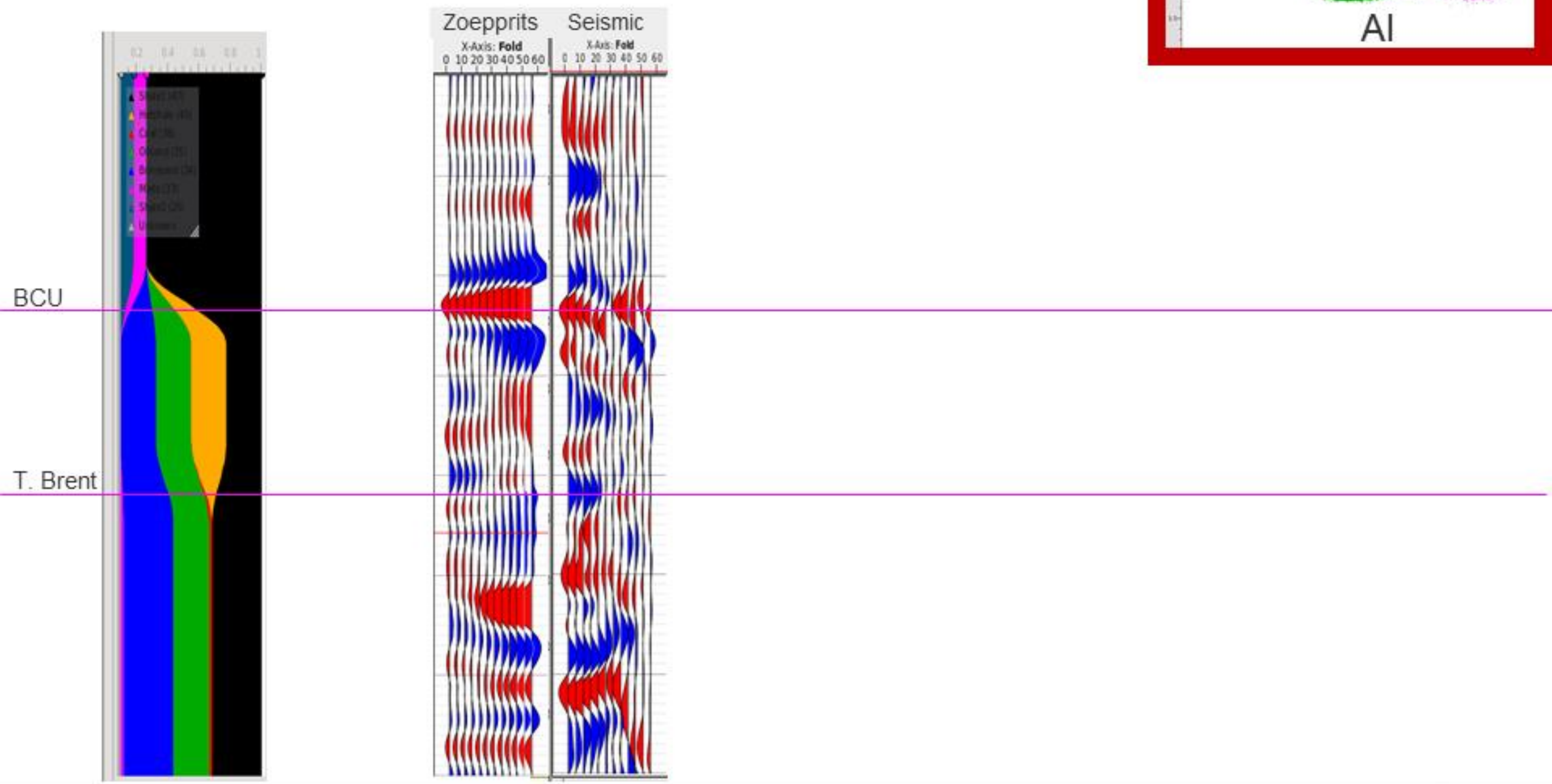
Welltie & Inversion QC





Slanted well and vertical traces. Strictly only correct at BCU

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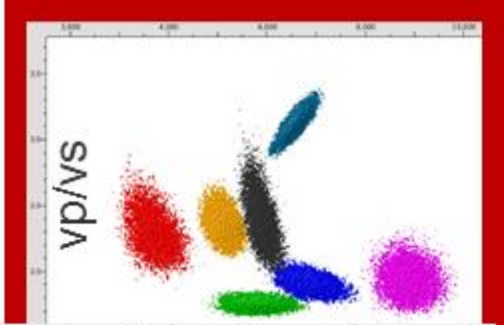
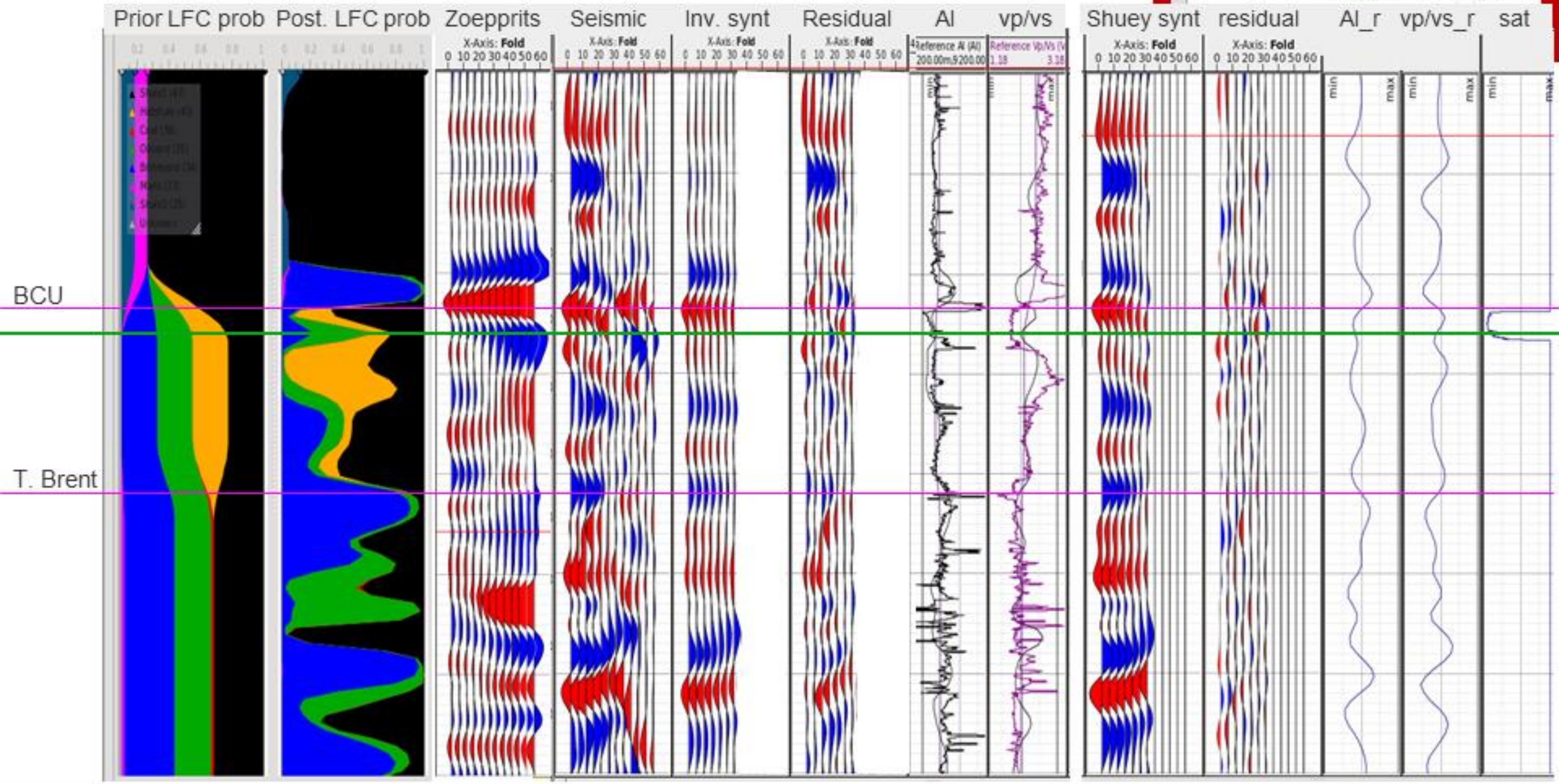
Welltie & Inversion QC

7-32 degrees input both to Pcube and relative.



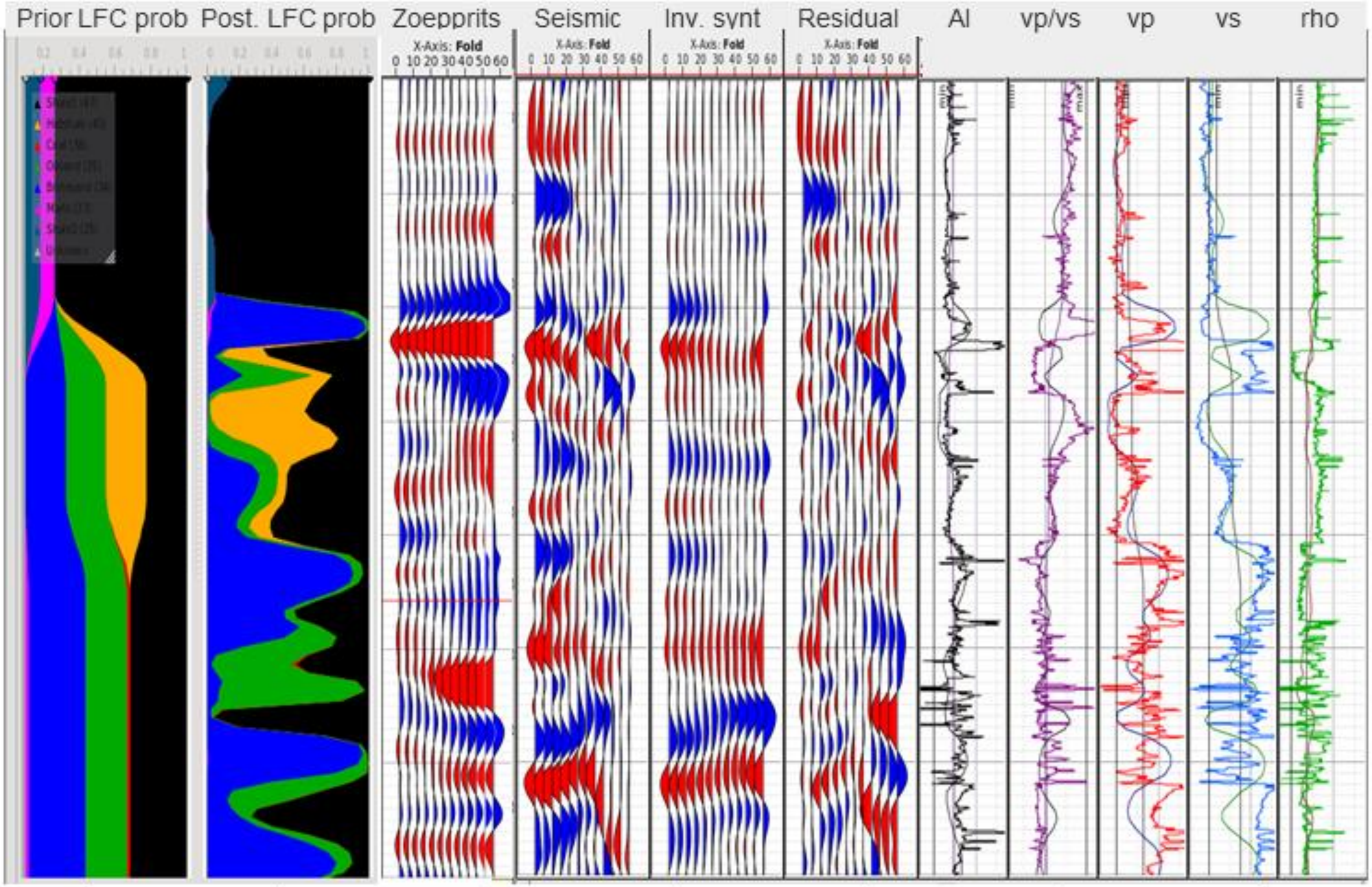


Slanted well and vertical traces. Strictly only correct at BCU. Relative quantities are -90 deg phase rotation of IC and IC+GR

Inversion QC in well position

7-32 degrees w/logs

NB: Inversion synthetic and residual shown for full gather, but S/N set to 0.01 for angles outside 7-32 degrees. Effectively treating the others as blind tests.



7-32 SN3 W4 | 7-42 SN3 W4 | 7-42 SN3 W3 | 7-42 SN3 W5 | 7-42 SN1 W4 | 7-42 SN99 W4 | Exit

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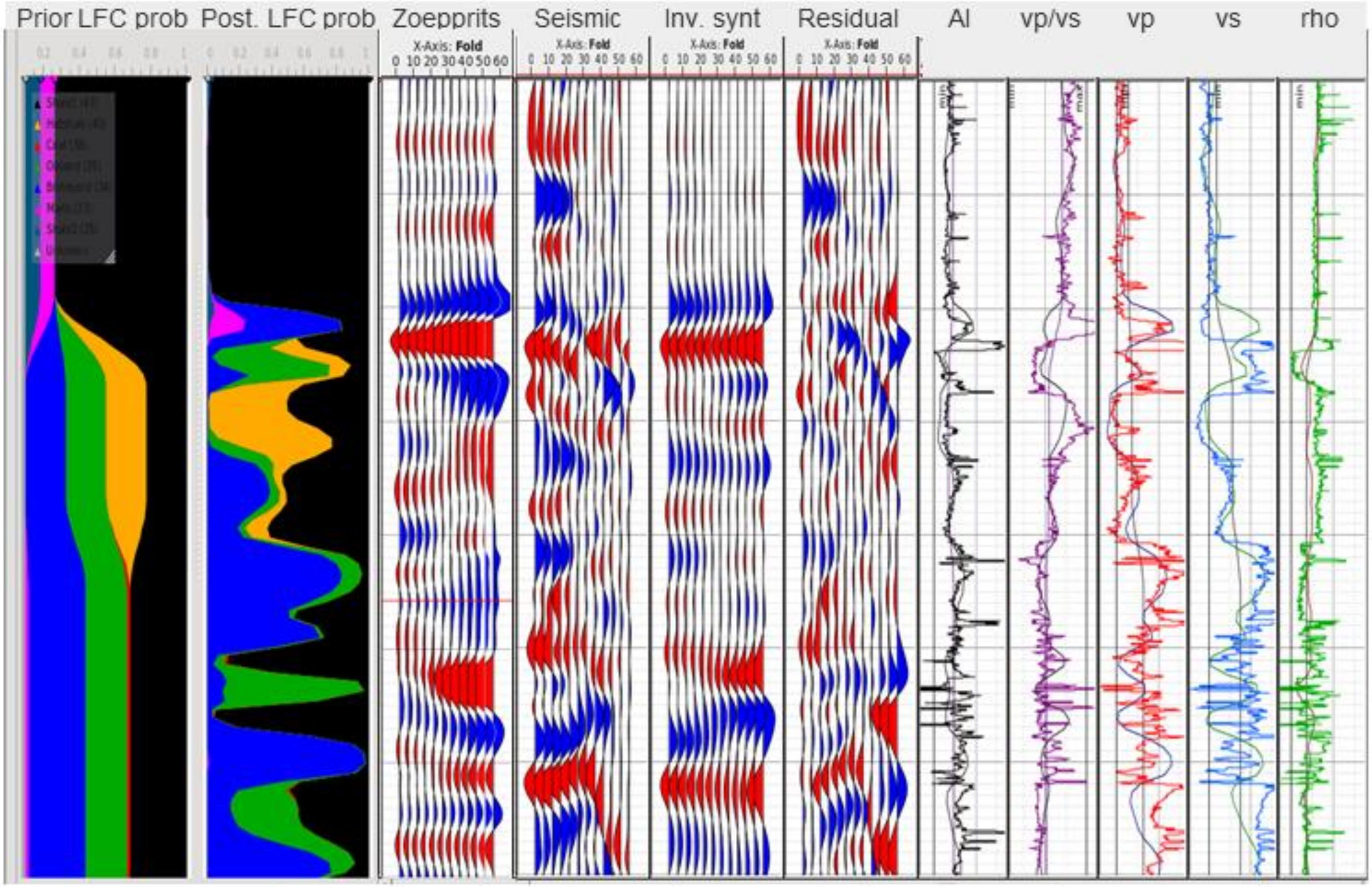
Testing effect of varying parameters part 1

7-42 degrees w/logs. Waveletscale 4. S/N 3

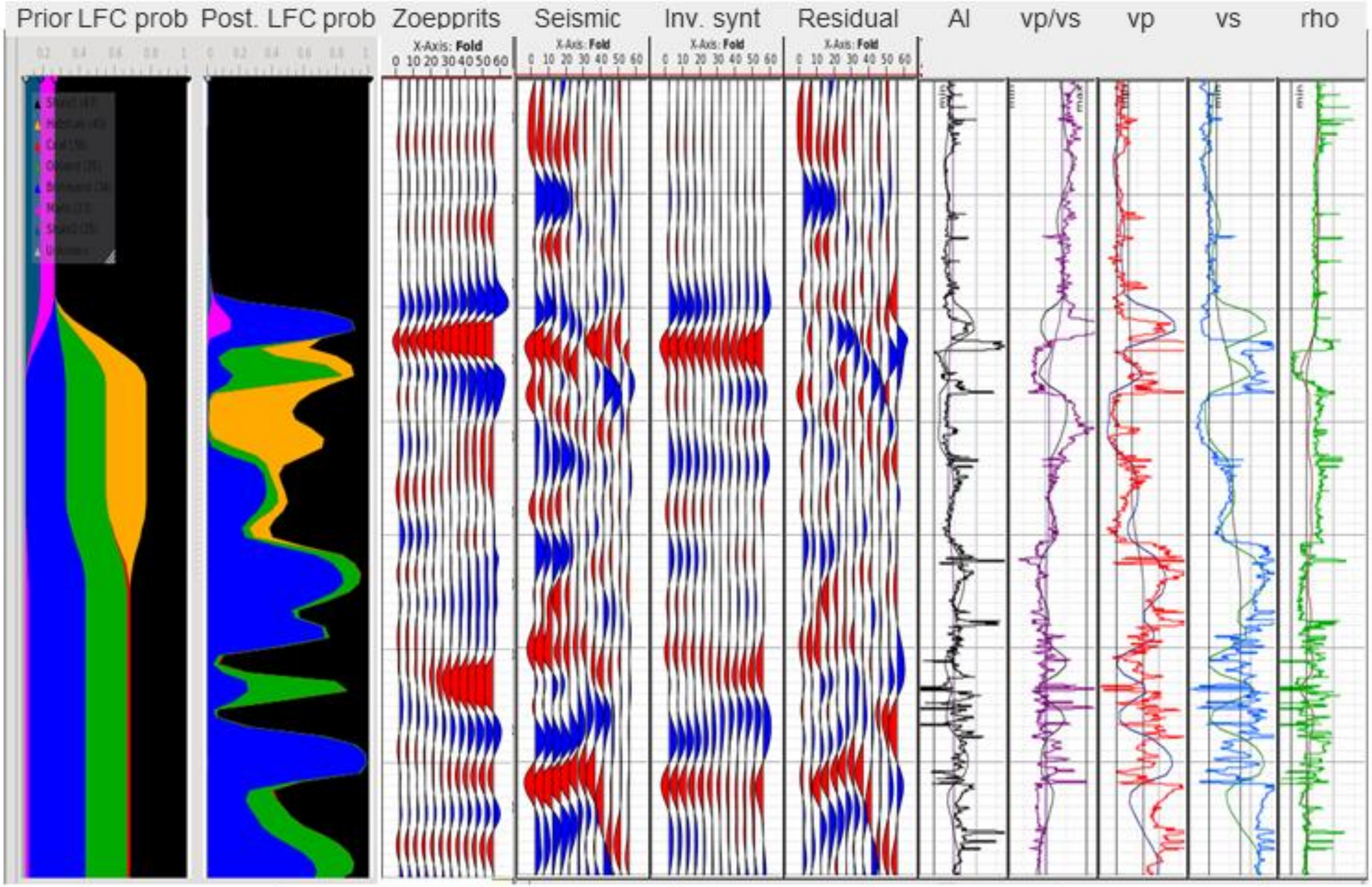


7-32 SN3 W4 | 7-42 SN3 W4 | 7-42 SN3 W3 | 7-42 SN3 W5 | 7-42 SN1 W4 | 7-42 SN99 W4 | Exit

Statoil

Testing effect of varying parameters part 2

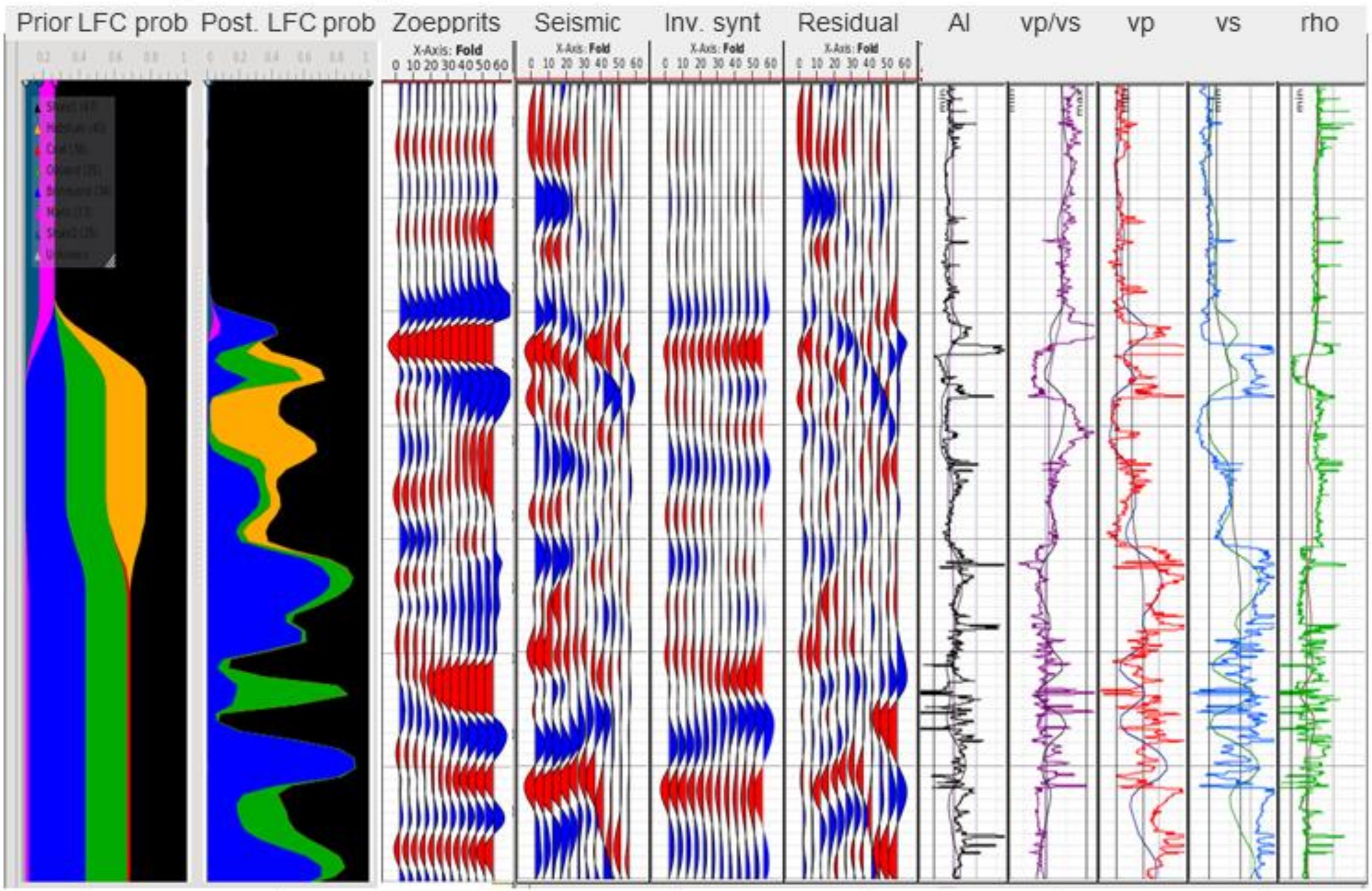
7-42 degrees w/logs. Waveletscale 3. S/N 3



7-32 SN3 W4 | 7-42 SN3 W4 | 7-42 SN3 W3 | 7-42 SN3 W5 | 7-42 SN1 W4 | 7-42 SN99 W4 | Exit

Testing effect of varying parameters part 3

7-42 degrees w/logs. Waveletscale 5. S/N 3

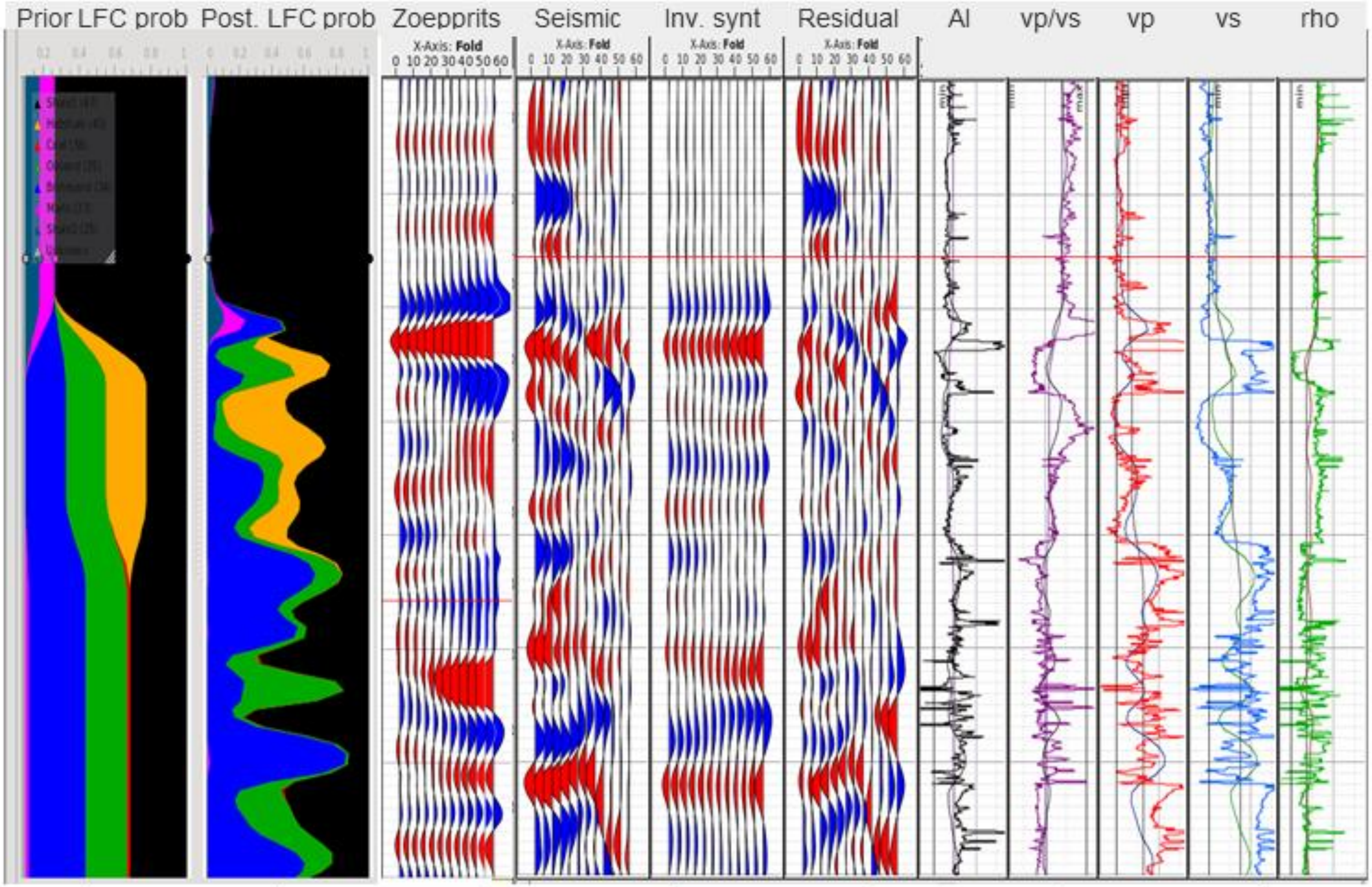


7-32 SN3 W4 | 7-42 SN3 W4 | 7-42 SN3 W3 | 7-42 SN3 W5 | 7-42 SN1 W4 | 7-42 SN99 W4 | Exit

Statoil

Testing effect of varying parameters part 4

7-42 degrees w/logs. Waveletscale 4. S/N 1

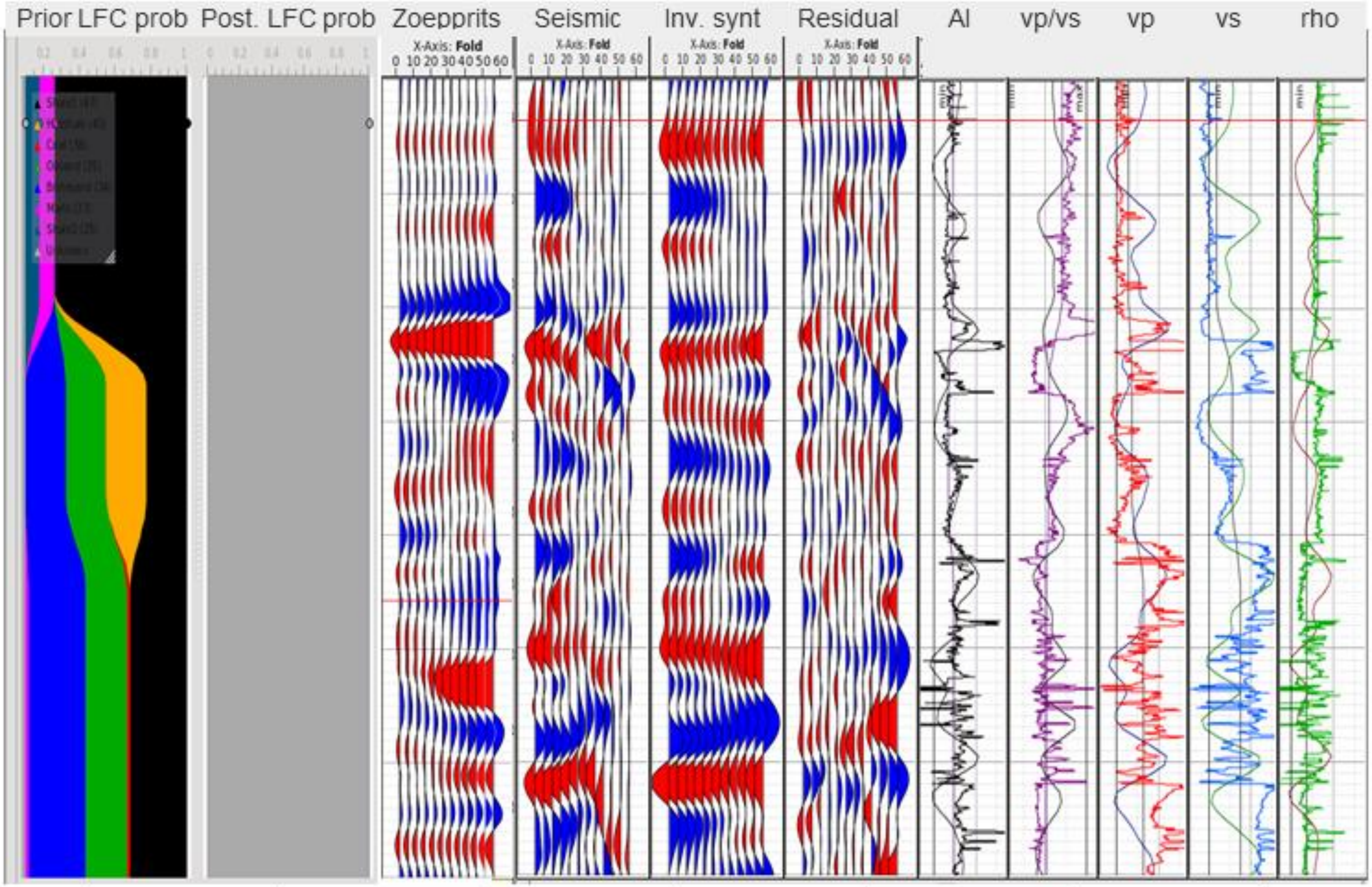


7-32 SN3 W4 | 7-42 SN3 W4 | 7-42 SN3 W3 | 7-42 SN3 W5 | 7-42 SN1 W4 | 7-42 SN99 W4 | Exit

Statoil

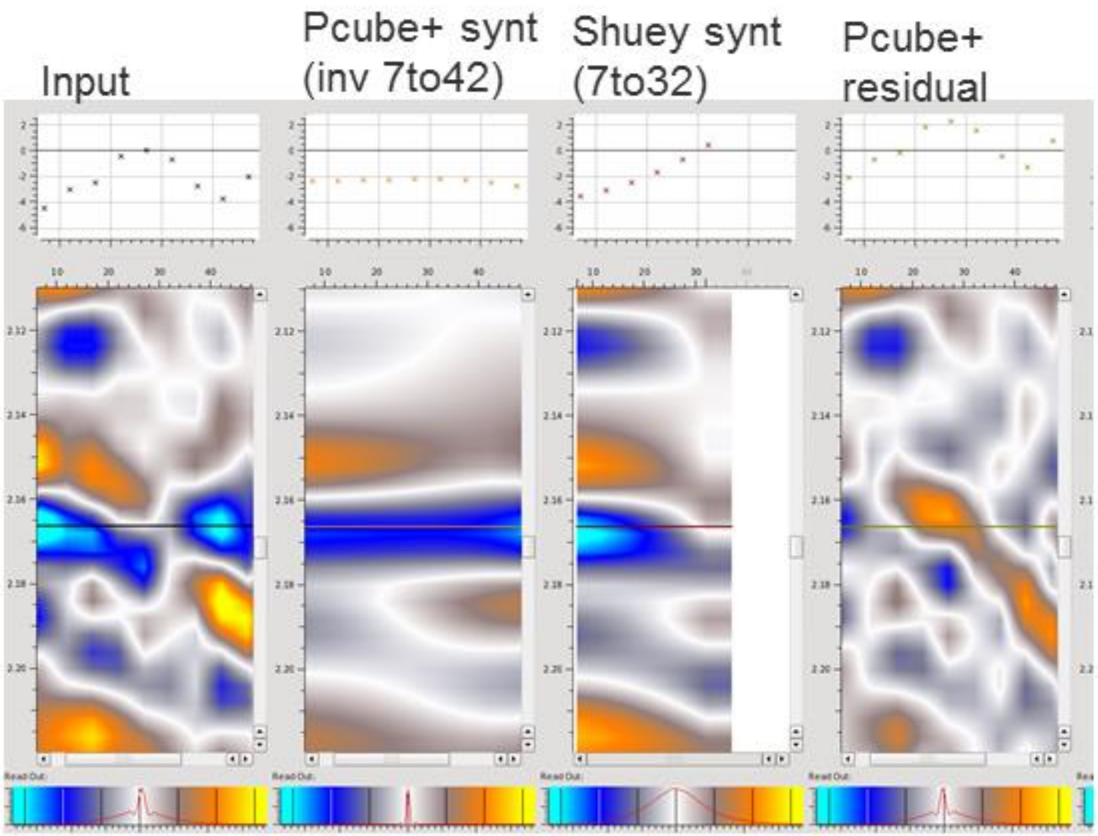
Testing effect of varying parameters part 5

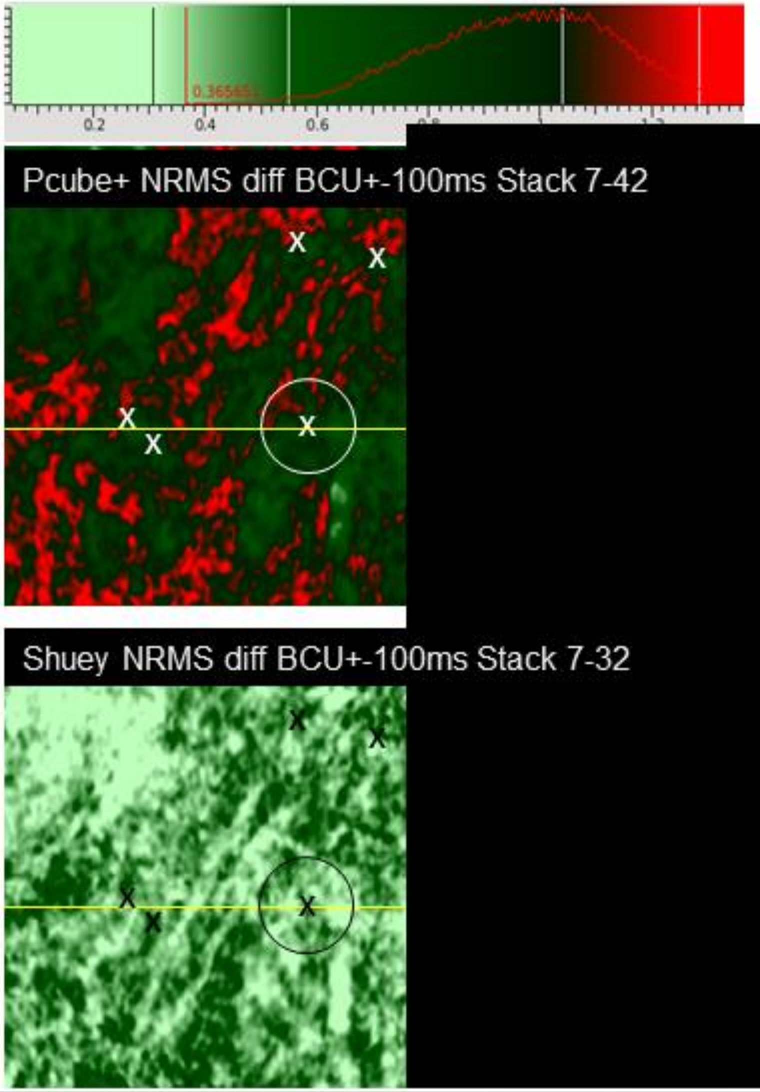
7-42 degrees w/logs. Waveletscale 4. S/N 100



7-32 SN3 W4 | 7-42 SN3 W4 | 7-42 SN3 W3 | 7-42 SN3 W5 | 7-42 SN1 W4 | 7-42 SN99 W4 | Exit

NRMS diff as tool for inversion data fit



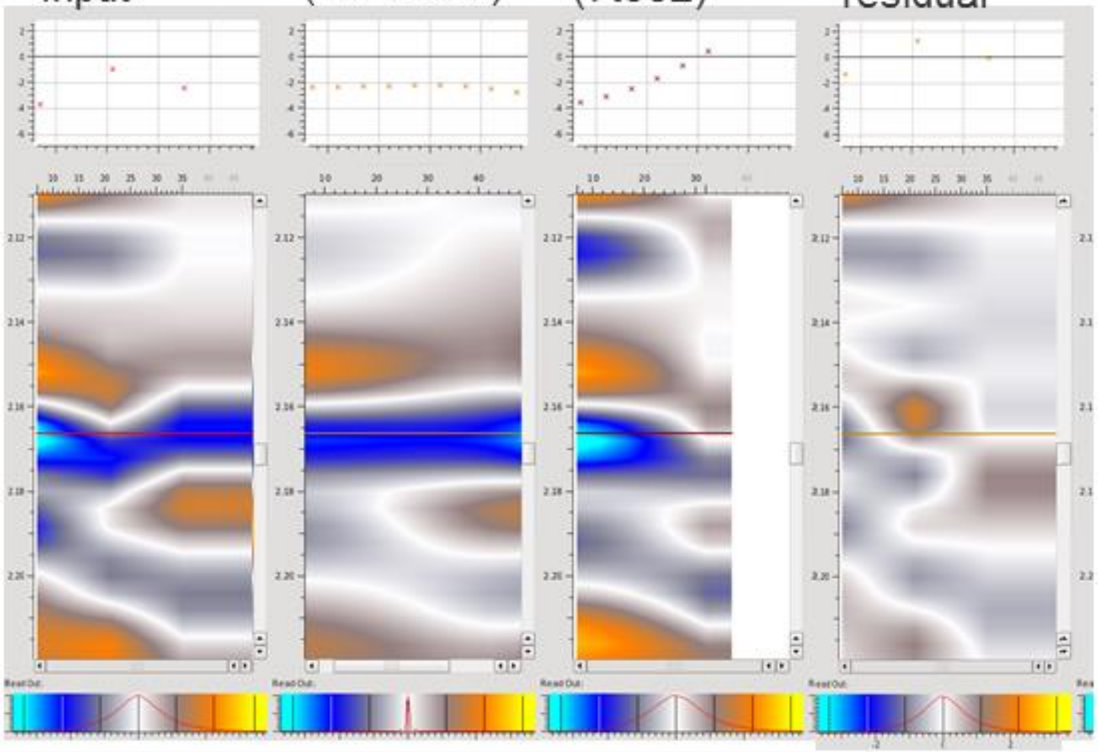


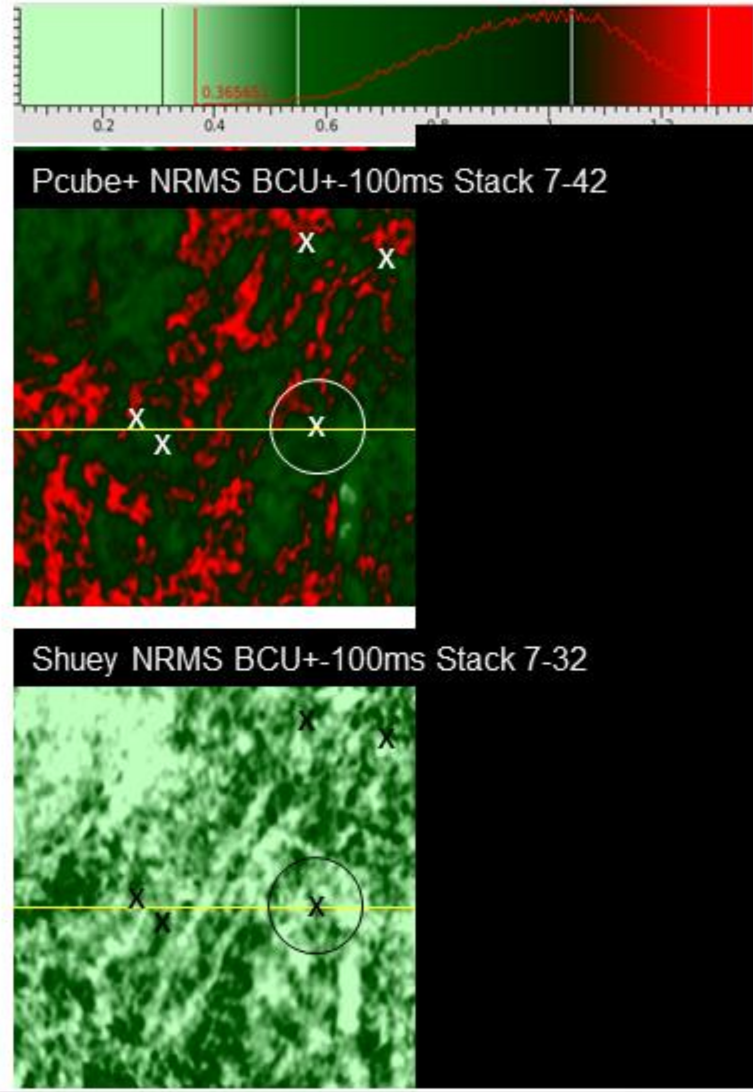
NRMS as tool for inversion data fit

Substacking input and residual.
3 stacks from 7 to 42 (vs 8 on previous slide).

Many angle bins data give much superior QC than few

Input | Pcube+ synt (inv 7to42) | Shuey synt (7to32) | Pcube+ residual



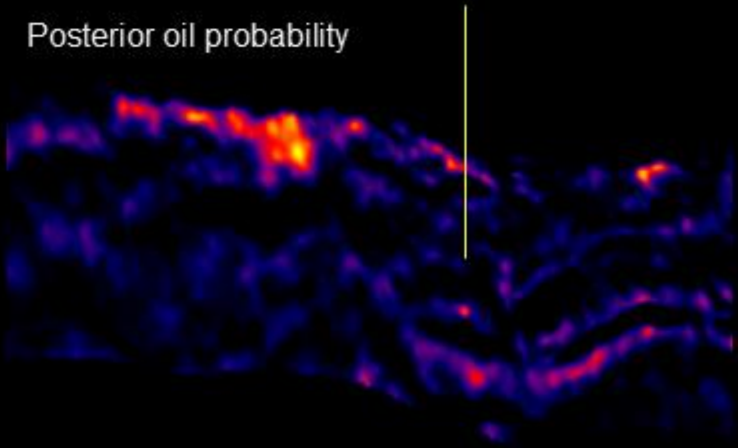


Prior and posterior oil probability

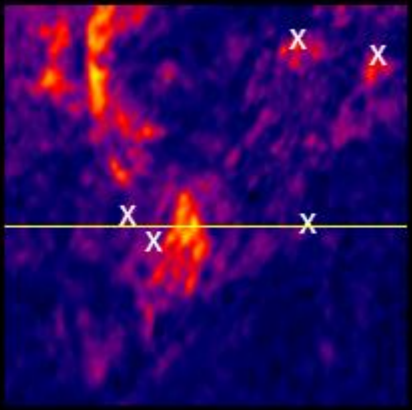
By construction, the prior oil probability is constant below BCU

Prior oil probability

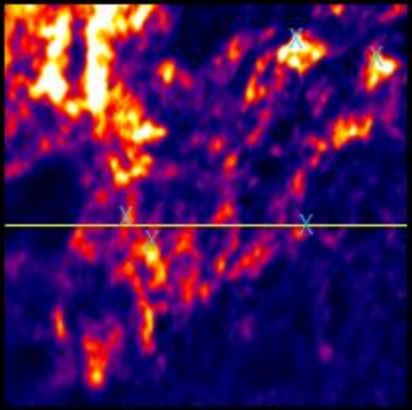
Posterior oil probability



Mean oil probability BCU +- 100ms

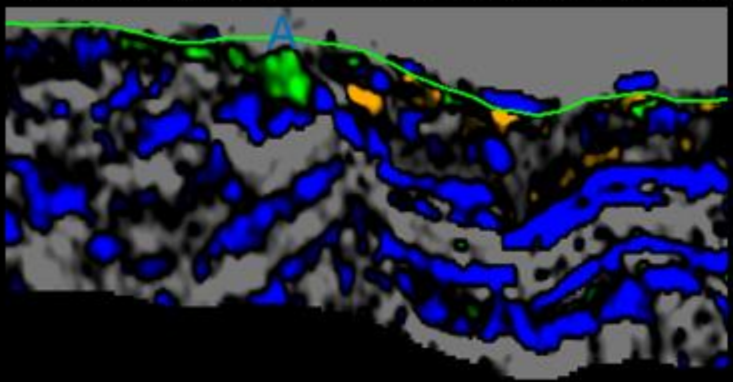


Mean oil probability BCU +- 24ms

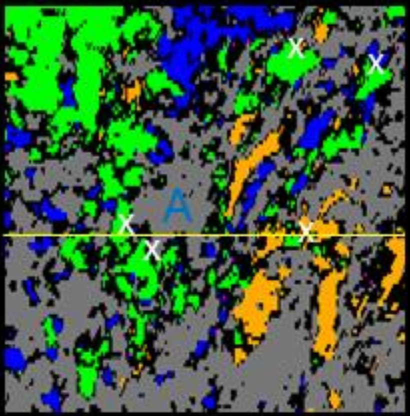


Classification volume (LFC of max probability)

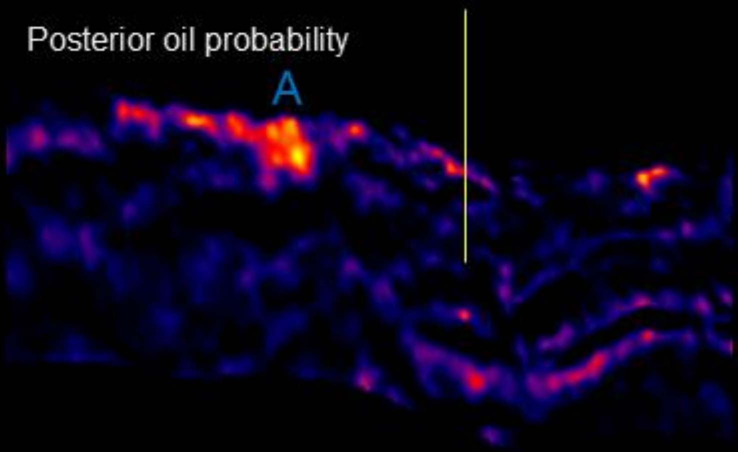
Classification volume. Darkening from probability 0.8 (bright) to 0.5 (black)



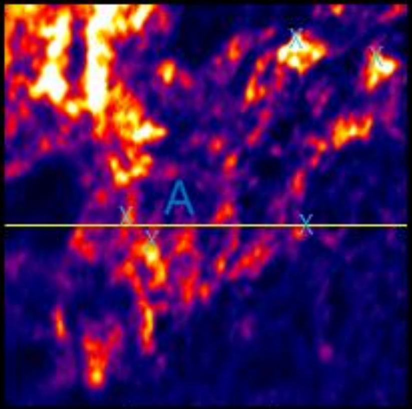
Classification volume 12 ms below BCU



Posterior oil probability



Mean oil probability BCU +- 24ms



Prior | Class. | 42 | 37 | 32 | 27 | 22 | 17 | 12 | 07 | Exit

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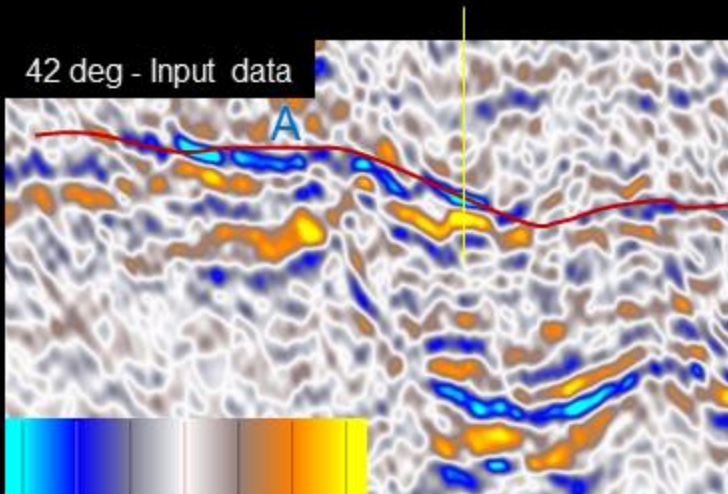
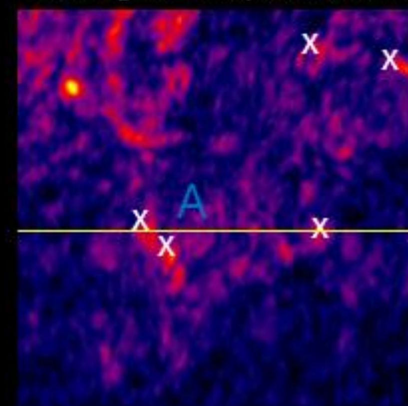
42 deg stack input and oil prob

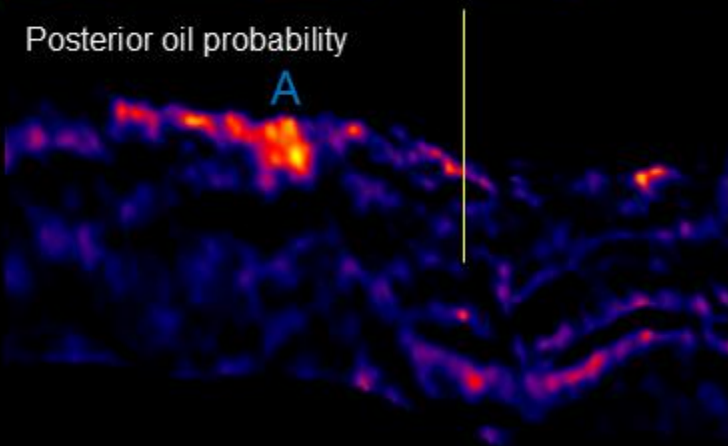
42 deg - Input data



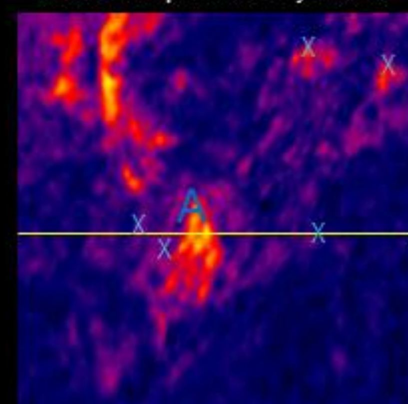
42 deg min amplitude in window BCU +- 24 ms



Posterior oil probability



Mean oil probability BCU +- 100ms



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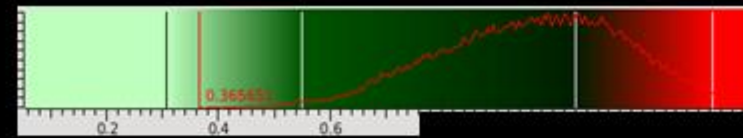
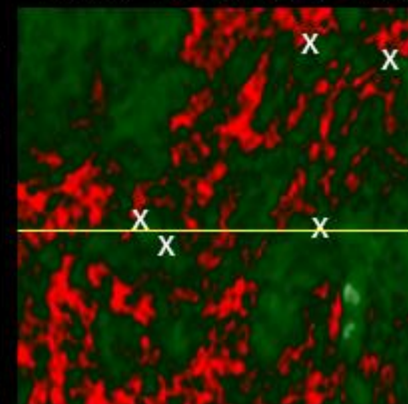
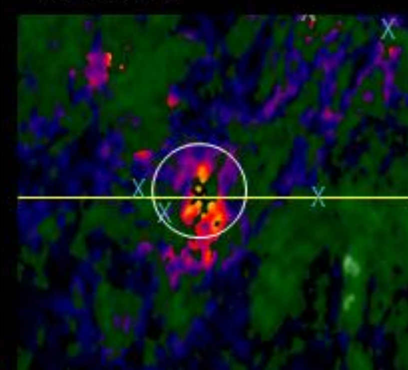
QC of invididual traces

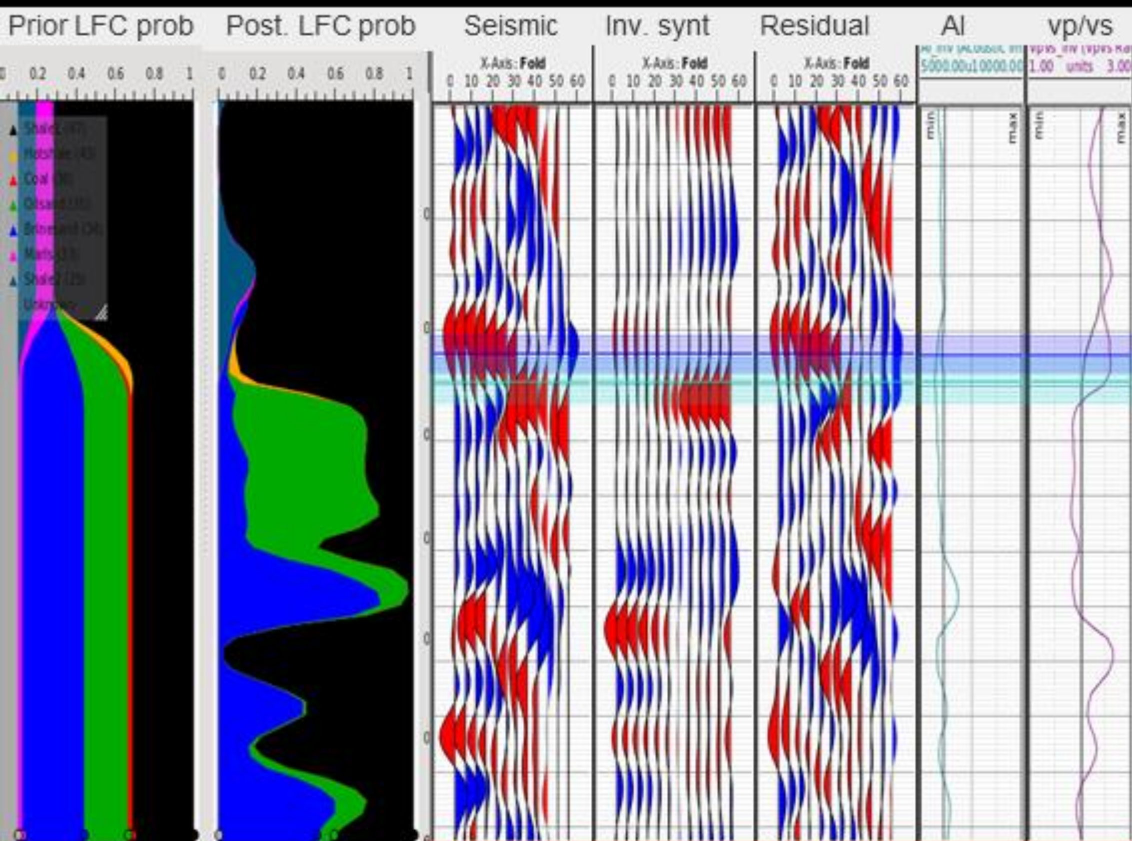


Pcube+ NRMS BCU+-100ms Stack 7-42



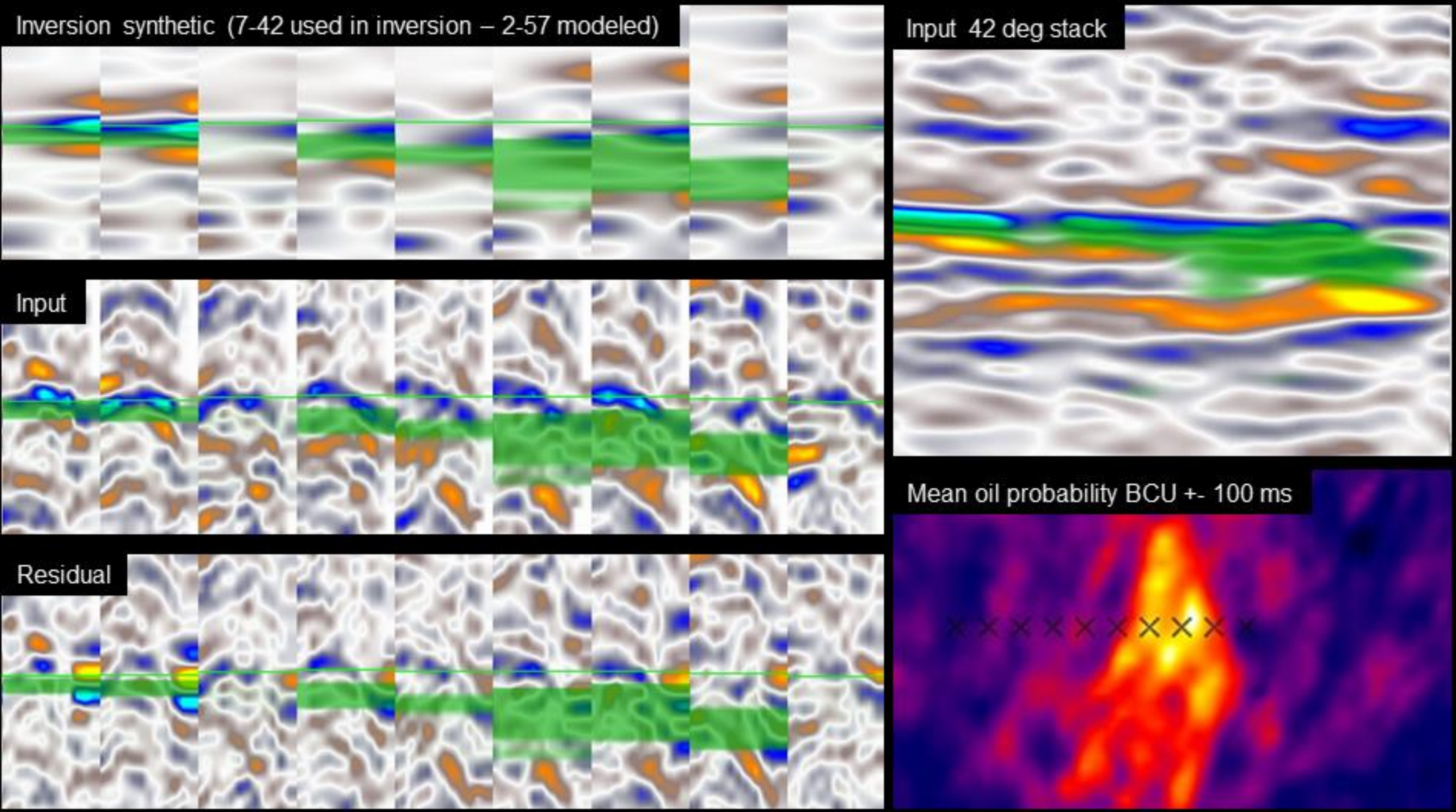
Mean oil probability BCU +- 100ms where NRMS > 1





NRMS: stack over gather of RMS(residual)/RMS(input)

Gather behavior, geometries, map expressions



Oil probability as green overlay

Workflow in short

Create angle gathers. Ca 5 degrees bin interval.

Match frequencies across gather. Target: ~35 deg stack.

Calculate intercept and gradient from ~10 to ~35 degrees

Derive relative AI and vp/vs from intercept and gradient.

Use Shuey modeled reflectivity as relative inversion synthetics

Define rough Lithology Fluid Classes (LFC's) and build a prior LFC model using horizons

Do a rough prestack tie to find rough wavelets

Run a Pcube+ inversion

Calculate NRMS diff between seismic and synthetics

30 mins

1 – 5 days?

Investigate inversion results. Wells, locations of interest, low and high NRMS Simple forward models helpful.

Apply data conditioning to input data and check effect of this and of inversion parameter variation. Consider if rough is good enough and if there is data support for going to details.

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Summary

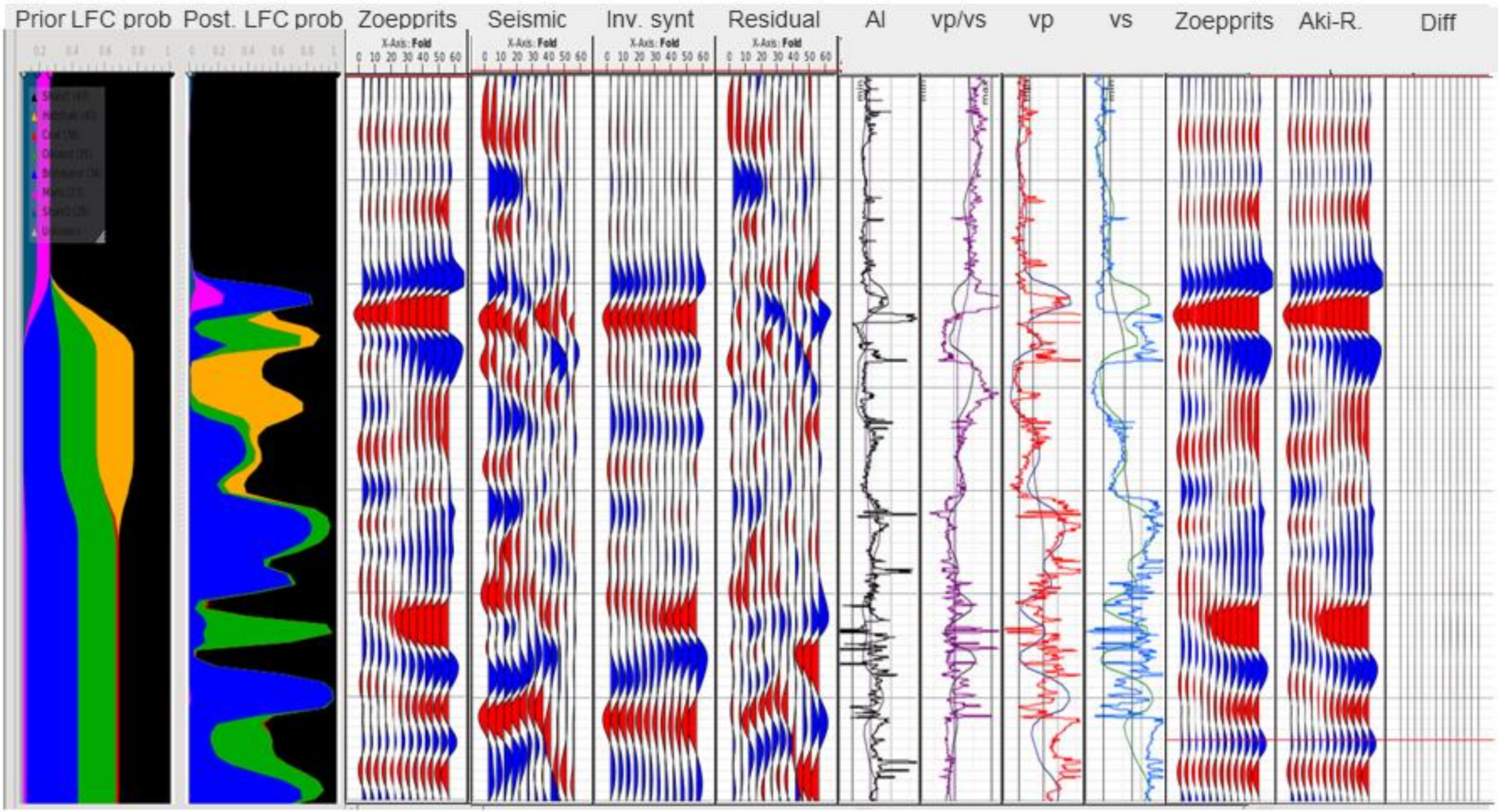
- Pcube+ allows for relatively fast prestack inversion to Lithology Fluid Classes
- Constraining the inversion by limiting the freedom in vp, vs density space gives some robustness towards seismic noise in input data
- Direct output of LFC's (no separate classification step) gives some advantages
  - The effect of parameter variation (wavelets, background model, ..) on oil probability can be tested interactively
  - It supplies a starting point for modelling exercises
- No krieging of wells is involved to create the background model – all wells are blind tests.
- Tuning is handled properly
- Running on angle gathers give better QC options than running on sparse stacks.

Thanks

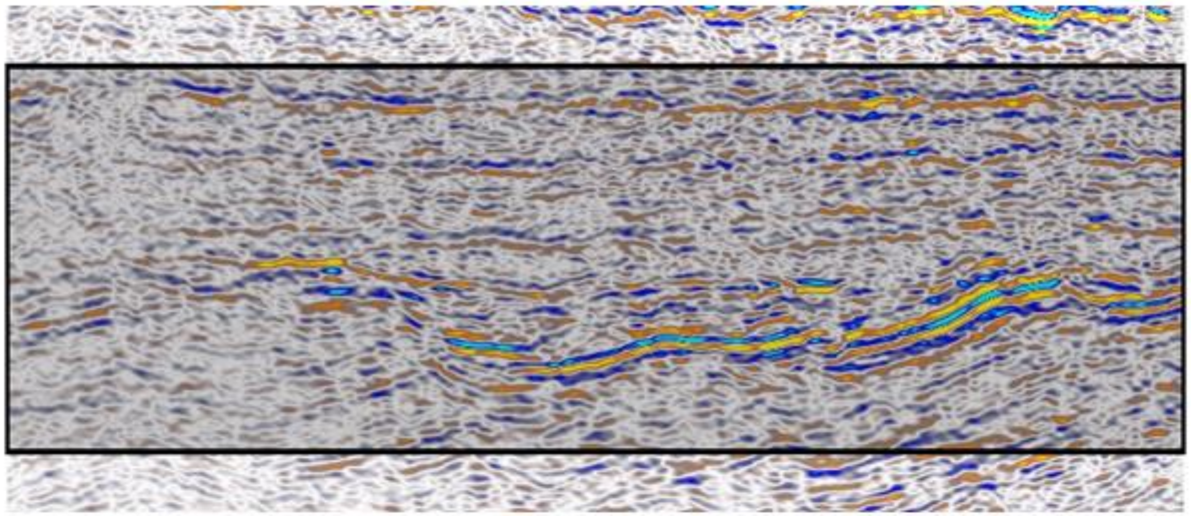
- To my co-author Ravi Srivastava
- To you for listening

Zoeppritz vs Aki-Richard

7-42 degrees w/logs. Waveletscale 4. S/N 3

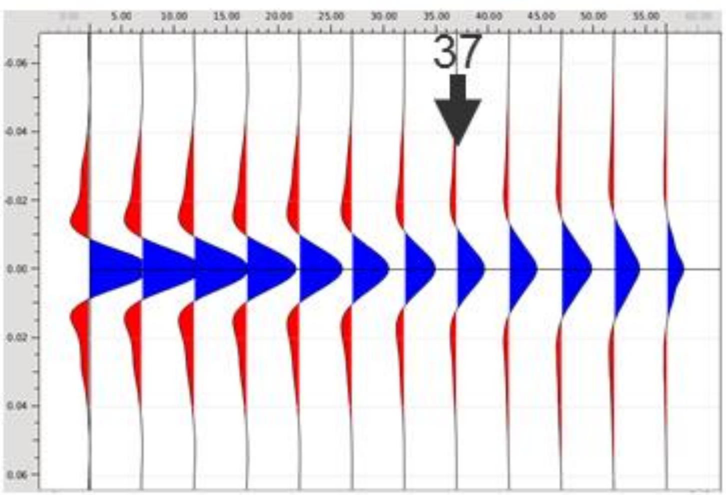


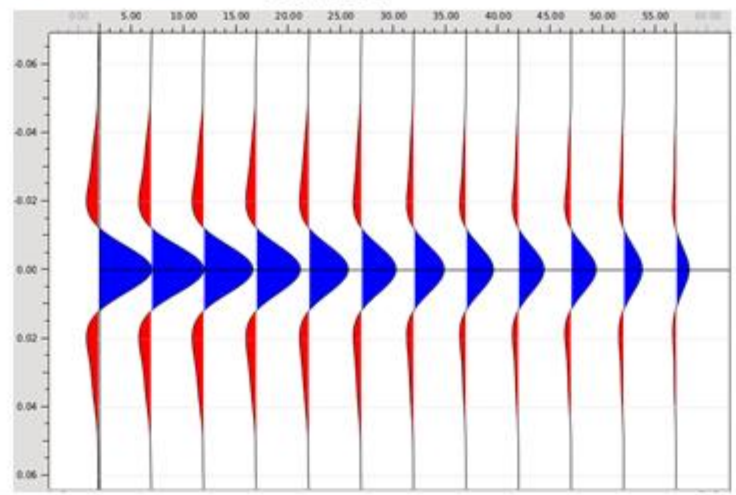
Wavelet extraction



Target window – basis for statistical wavelets.

Matching to 37 degrees wavelet. Separate, filter for each angle. Constant filter for whole cube.





Effect of matching filter