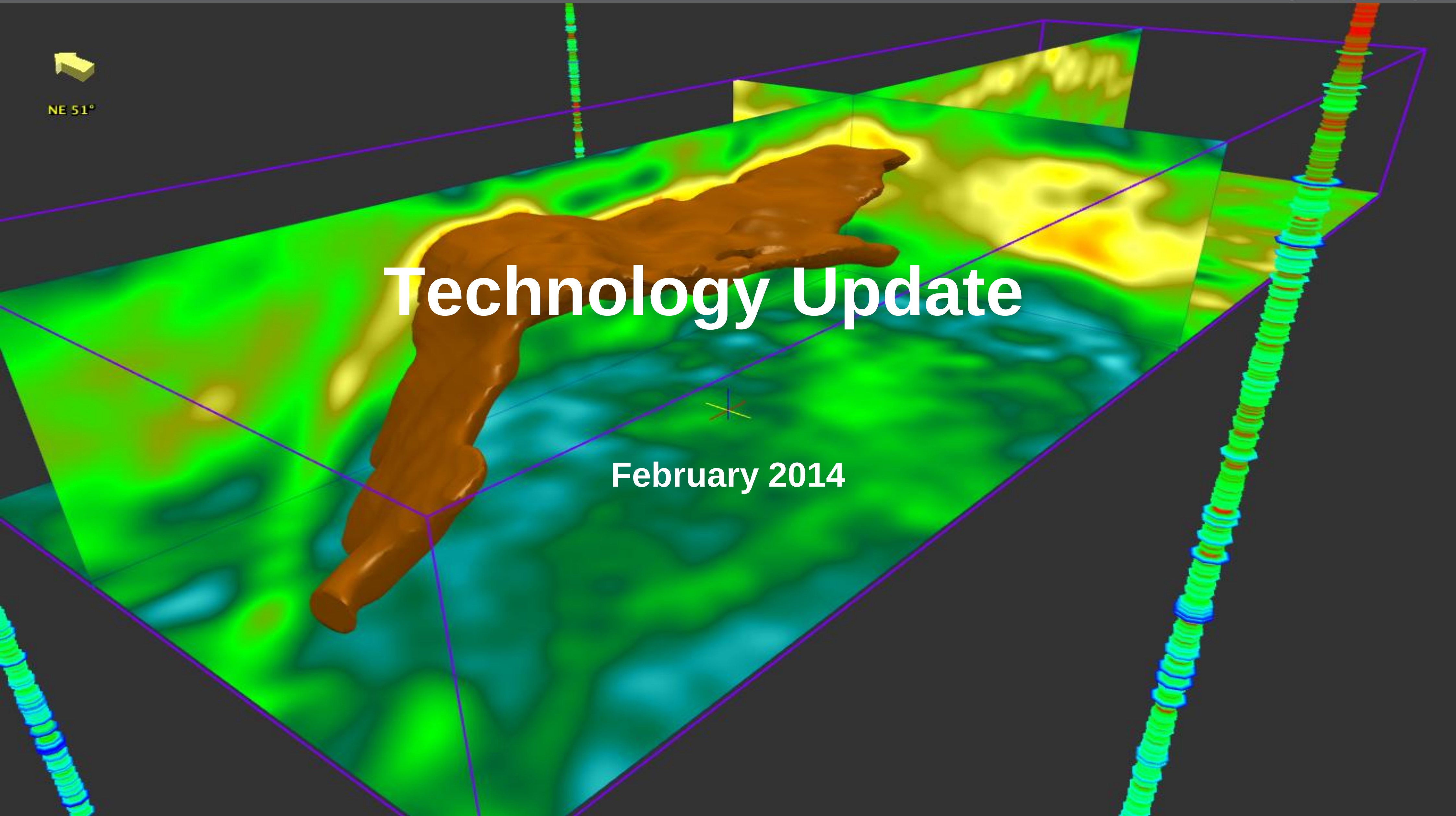


Technology Update

February 2014

DownUnder – who are we?

Employee owned private Geophysical Company with long term vision

170 people

Petaflop compute

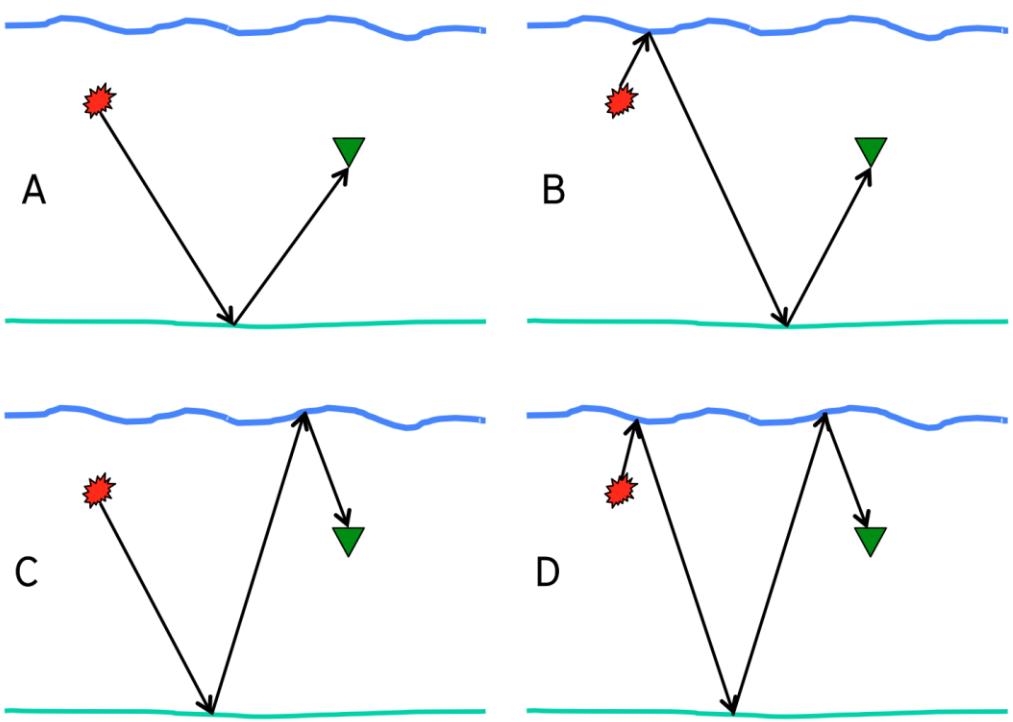
DownUnder – what do we do?

Land & Marine
Processing and Imaging
Quantitative Interpretation
Velocity model building
Petrophysics
Rock Physics
Software

DownUnder – where are we?

London
Houston
Perth
KL
Jakarta
Brisbane
Singapore

DUG Broad – Ghostbuster!



Primary and ghost reflections

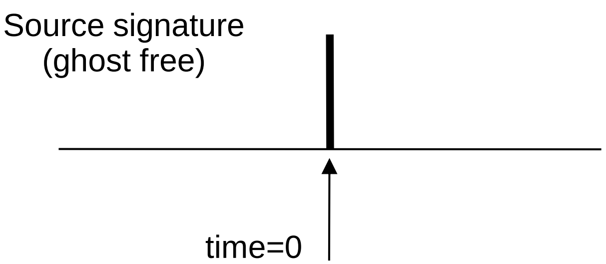
A: Primary

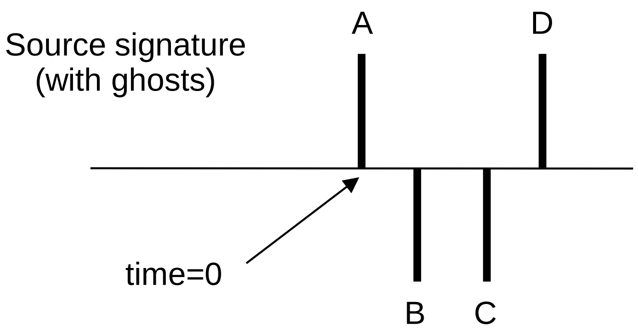
B: Source ghost

C: Receiver ghost

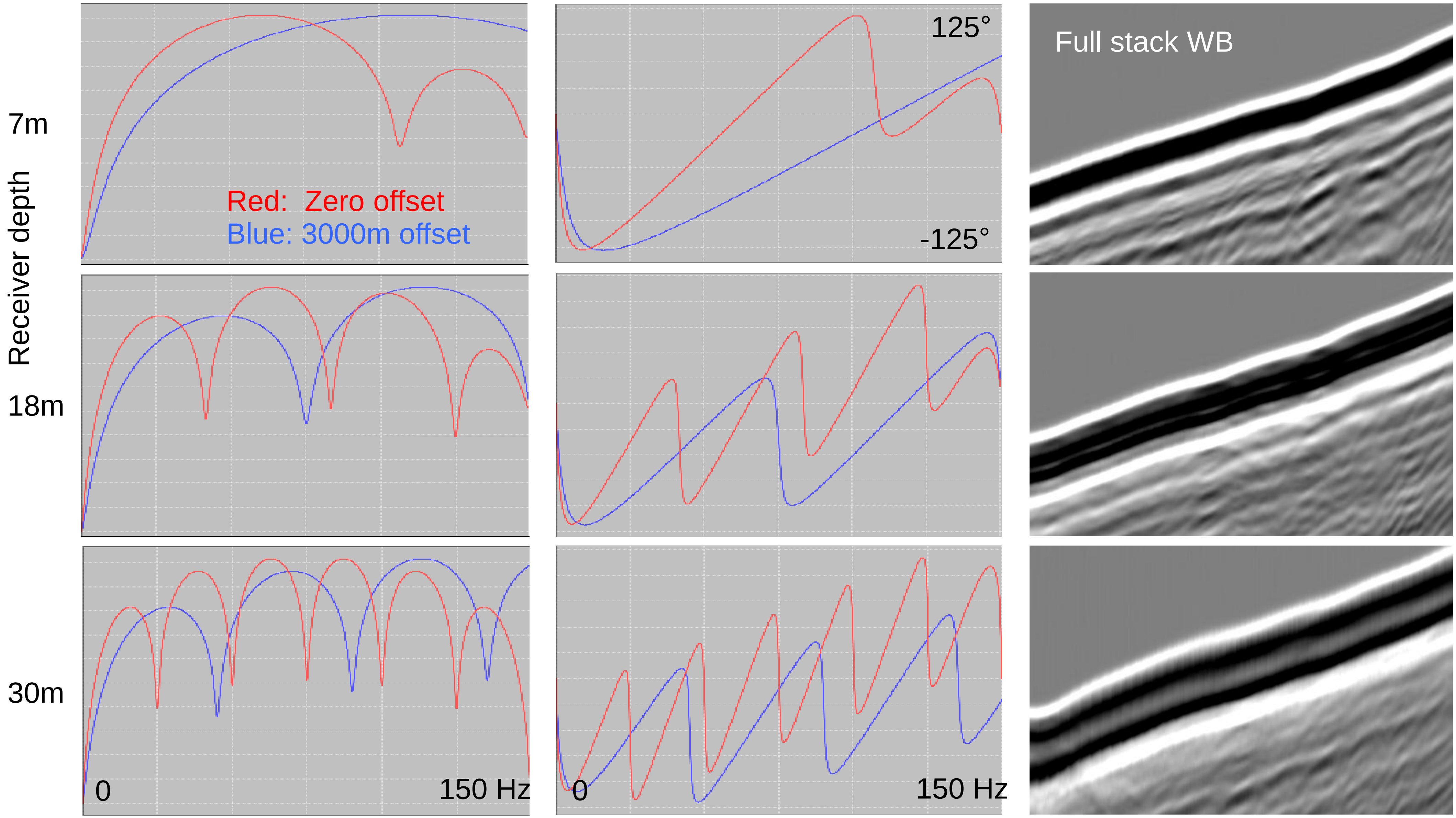
D: Double ghost

Lets assume for a moment we live a wonderful place where beer is free and the source signature is a perfect spike.

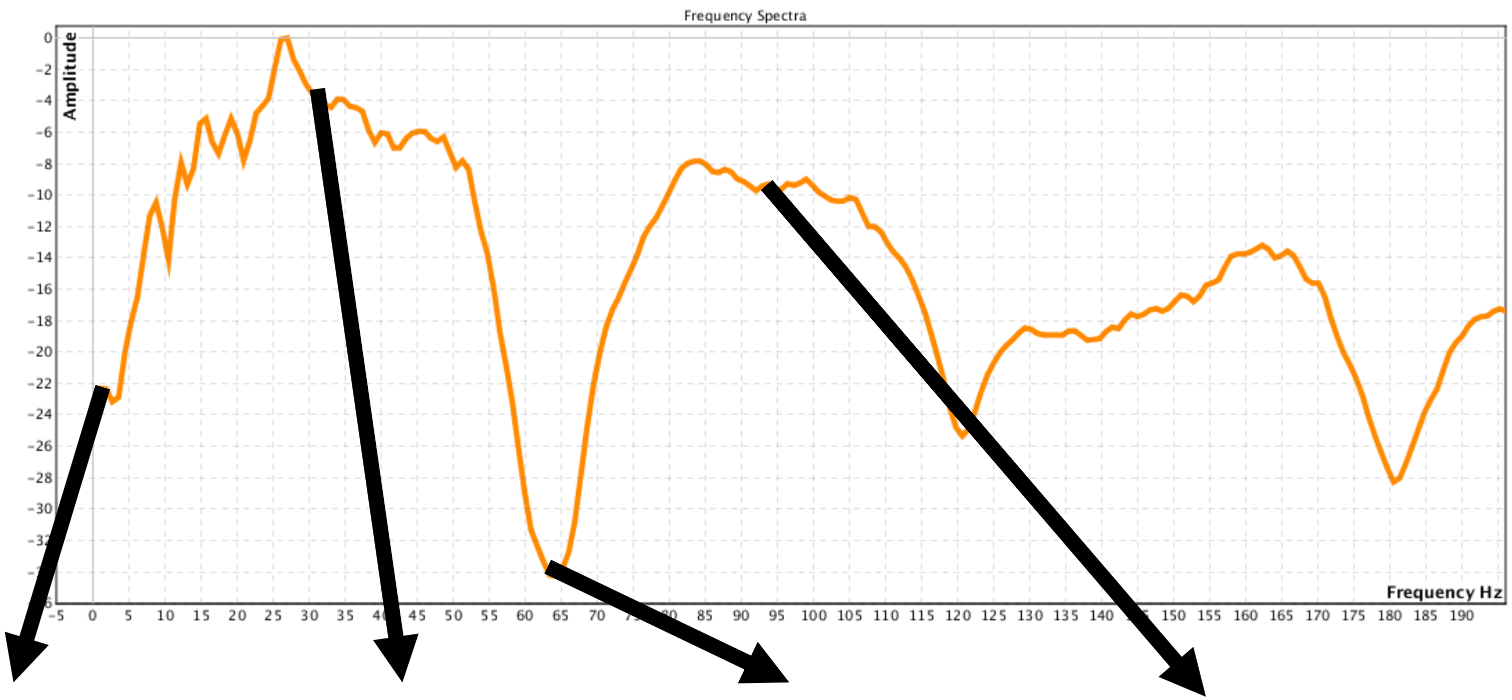




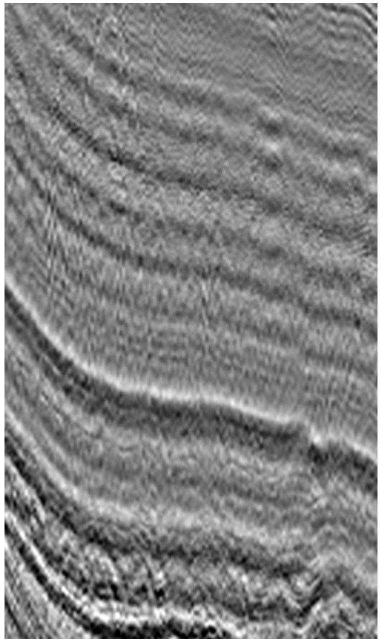
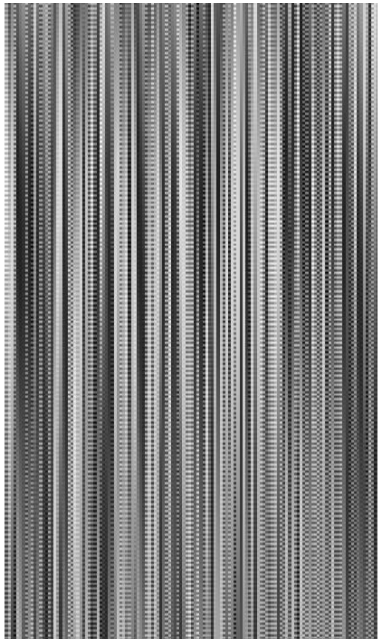
Spectra and water bottom reflections (source depth=5m)

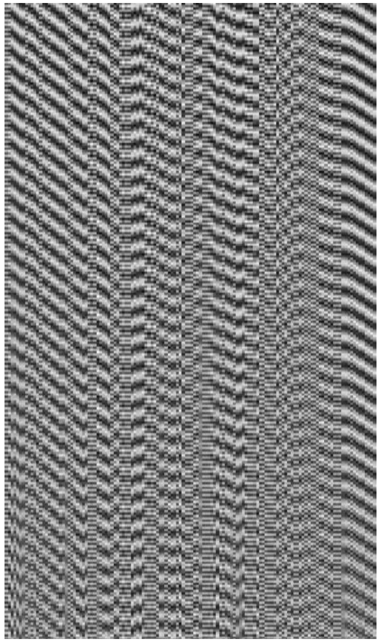
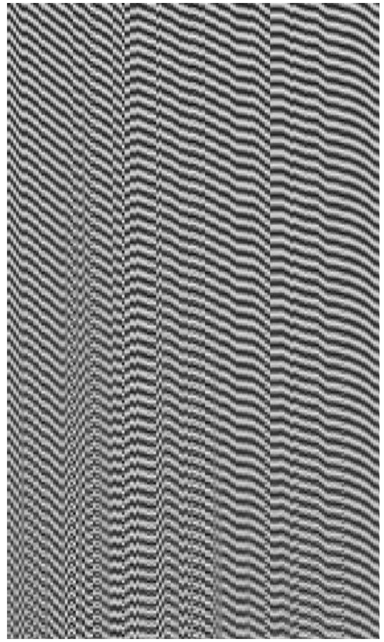


There is signal in them there notches!



Near Trace Section | 1 Hz | 32 Hz | 63 Hz | 94 Hz

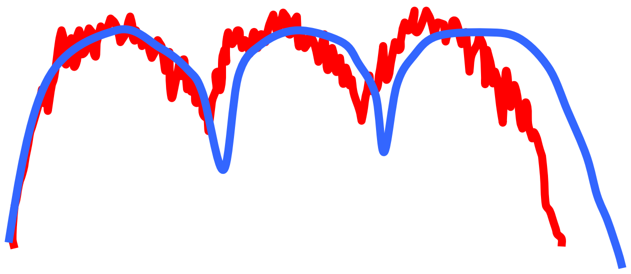



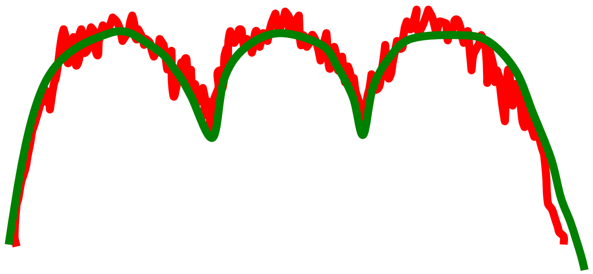



Overview

- Our modeling uses 5 parameters
- Notch position is very sensitive to these parameters
- Our acquisition contains uncertainties which are significant to the notch positions
- Our 5 model parameters vary within and between our shot records
- Notches contain useful data
- We need to know the notch position in order to address them

The DUG Broad algorithm - 1





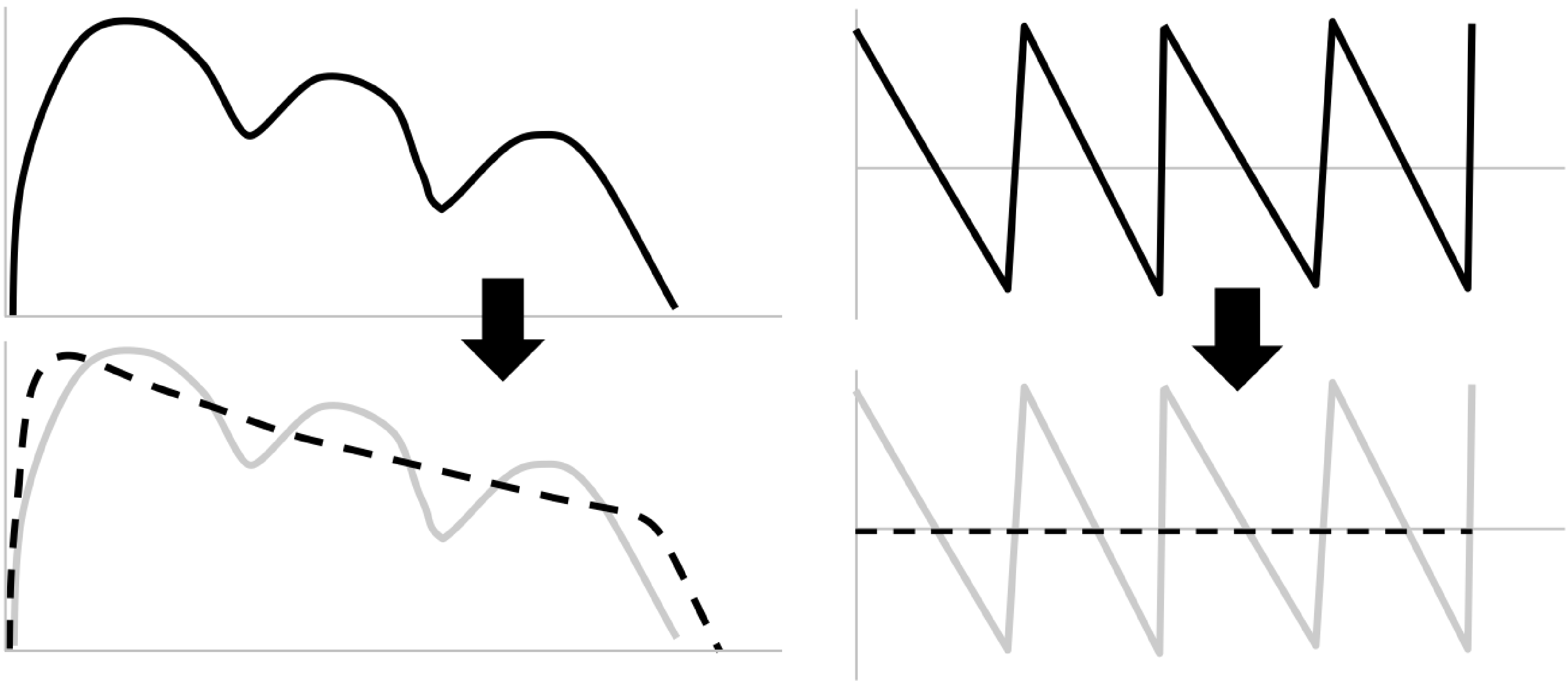
Calculate the spectrum in "localised" design space.

Make initial model based on best info

Optimise the model parameters by notch search

- Fit a Gaussian to all model parameters
- Only allow them to vary as they would physically

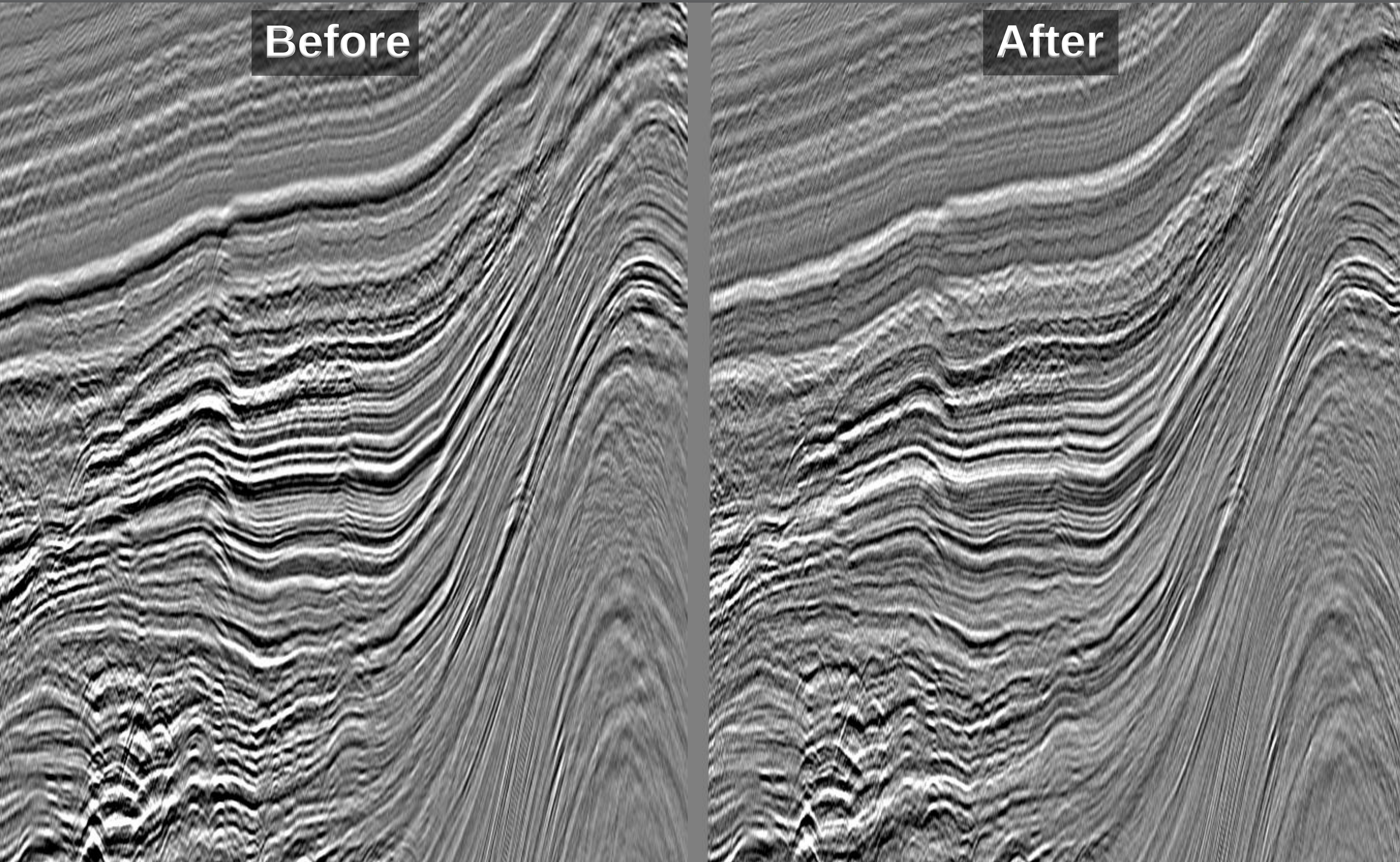
The DUG Broad algorithm - 2



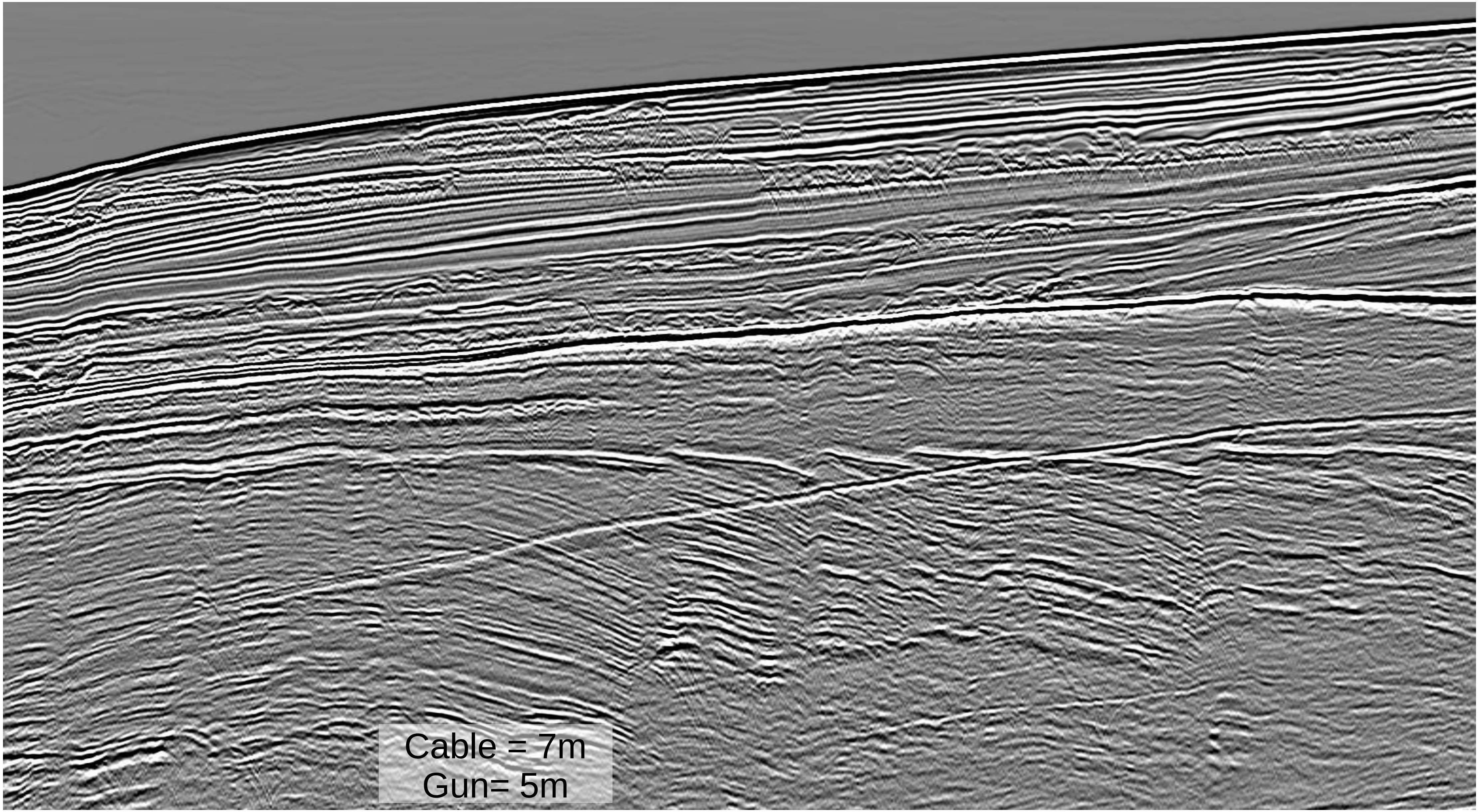
D Calculate inverse operator both amplitude and phase

E Apply as appropriate – fix phase even in low SNR regions

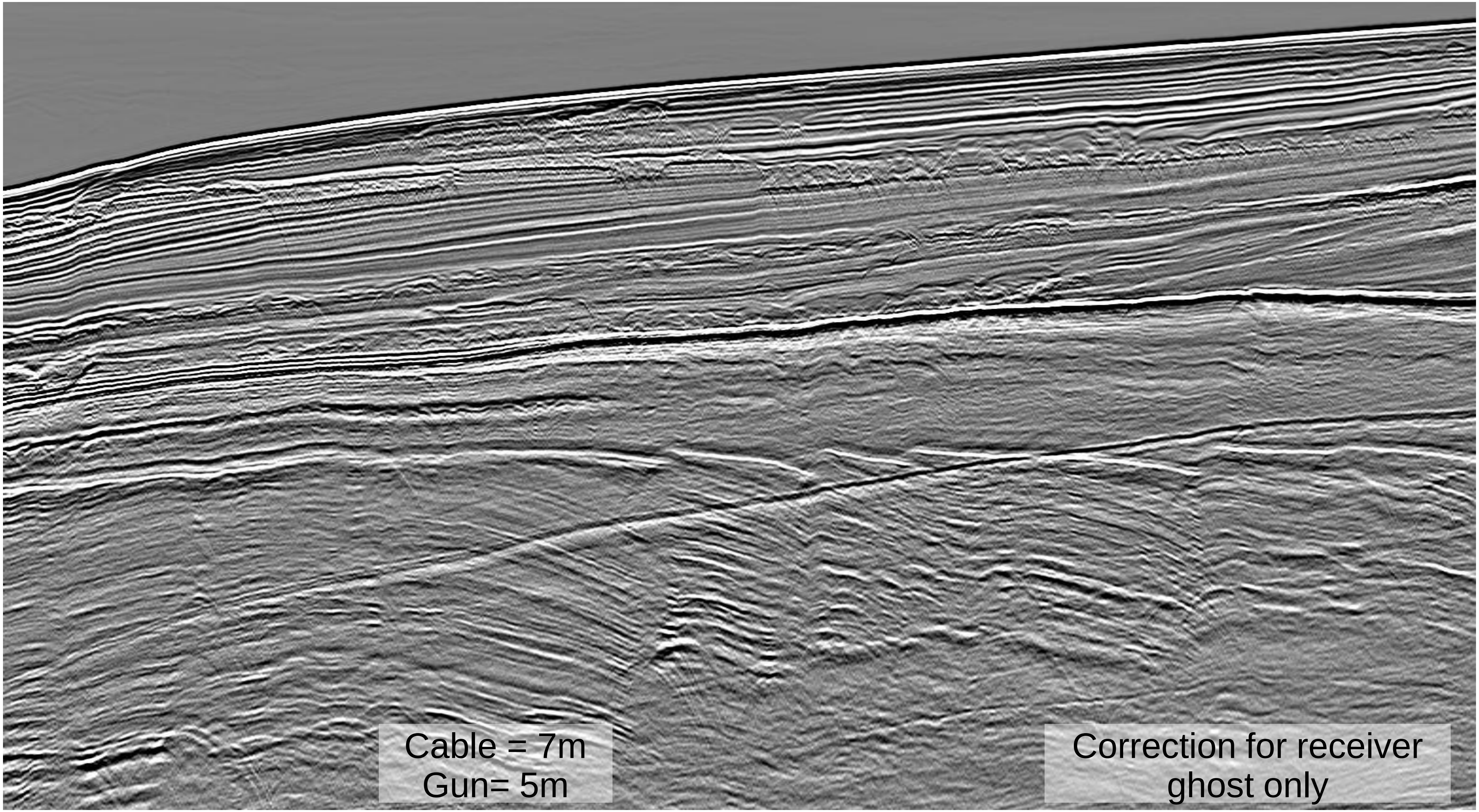
Gun at 5m -- Cable at 18m



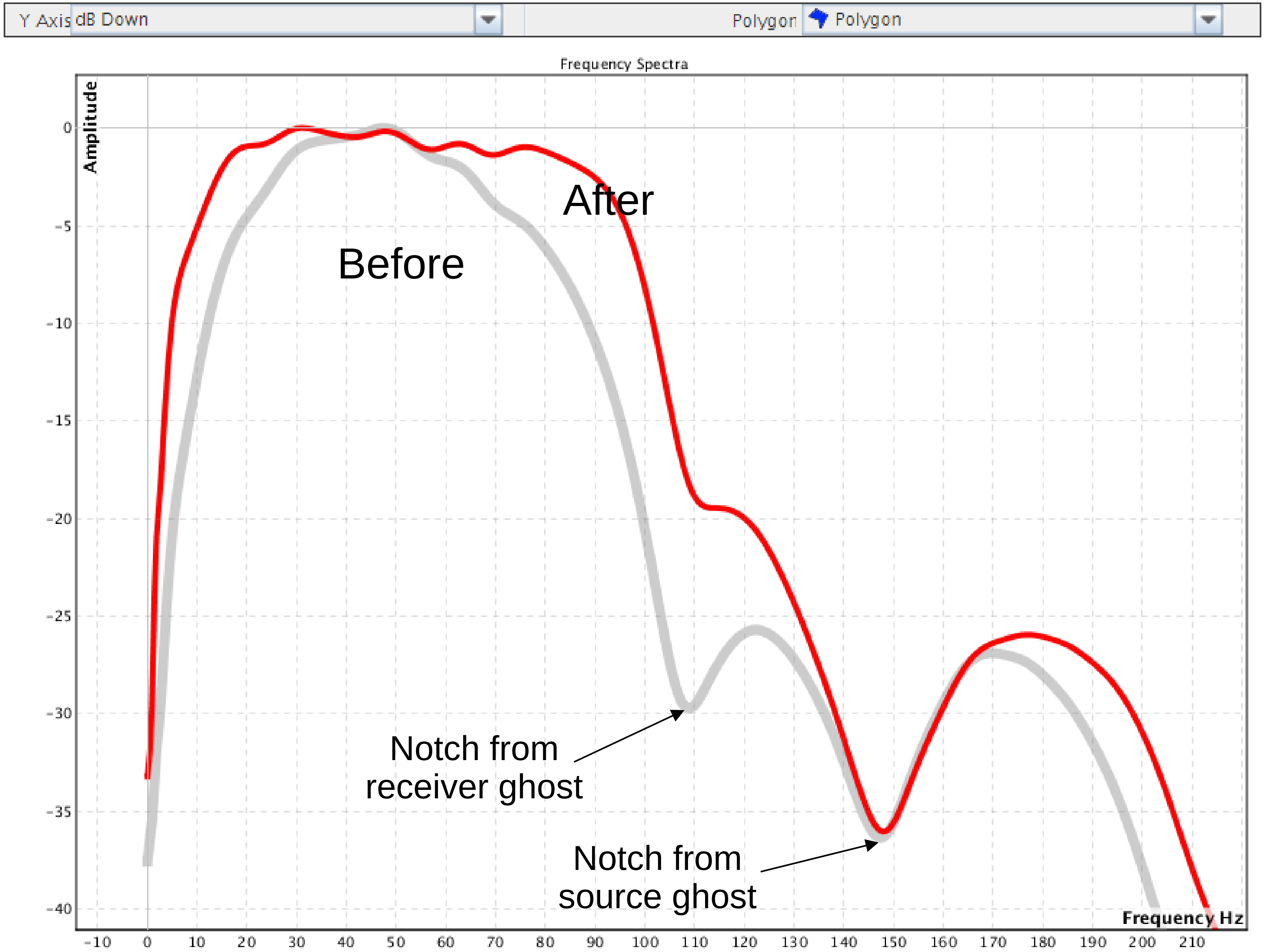
ConVG – Raw full stack



ConVG – Post DUG Broad full stack



Spectra 1 – receiver only correction



The shallow gun and cable depths mean the notches are outside the dominant seismic bandwidth. This spectra shows the before and after results correcting only the receiver ghost.

Cable = 7m
Gun= 5m

Kirchhoff PreSDM

- True relative amplitudes
- Turning rays
- Anisotropic
  - VTI
  - TTI
  - Tilted Orthorhombic

Beam Mig

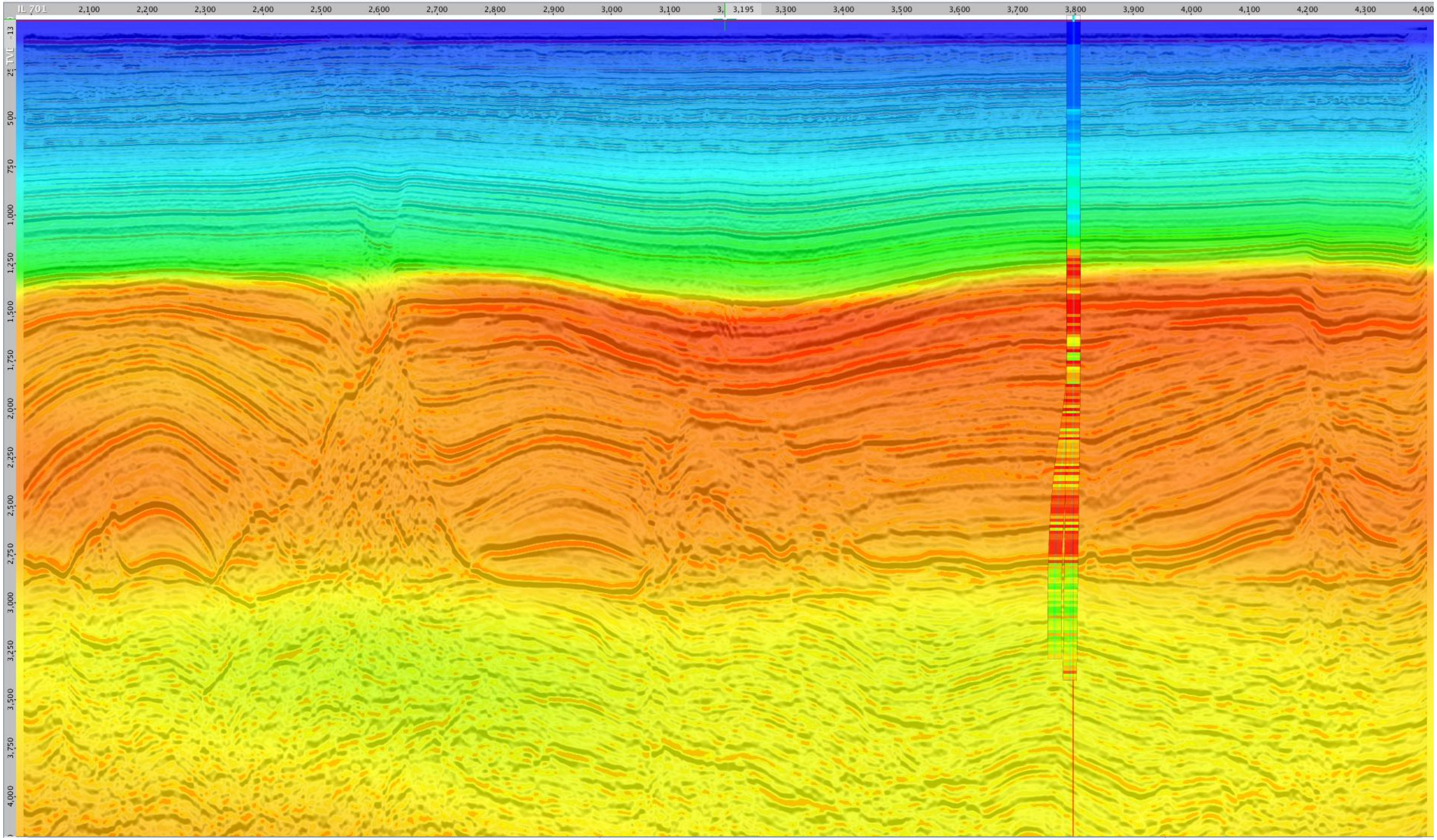
RTM

- Anisotropic
  - VTI
  - TTI
  - Angle Gathers

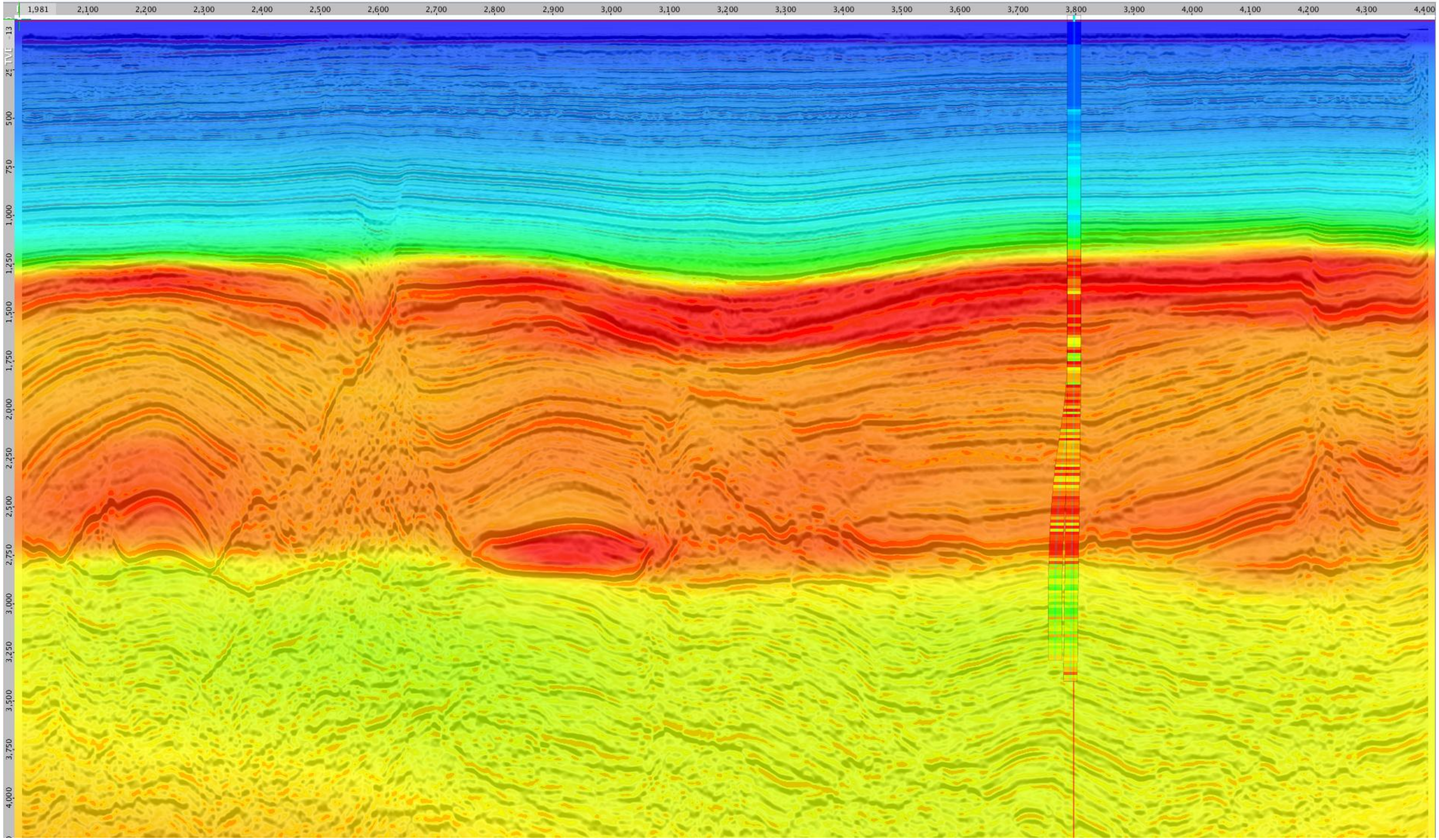
DUG HRTomo - Reflection Tomography

- Multi-azimuth, input picks along any azimuth
- Anisotropy updates
- Horizon and grid consistent
- Stratigraphy based smoothing
- Complete control over what part of the velocity model is updated, independent of input picks. For example full volume picks can be used to update the shallow layer only
- Refraction & reflection simultaneously
- Weighted & confidence value RMO picks
- Reweighting of RMO picks during the tomography run in order to miminise the influence of outliers
- Clusterised allowing virtually unlimited model size, largest model to date = 15000 sqkm
- RMO picks may be horizon or volume based or combination
- RMO events can be any shape, no parabolic assumption

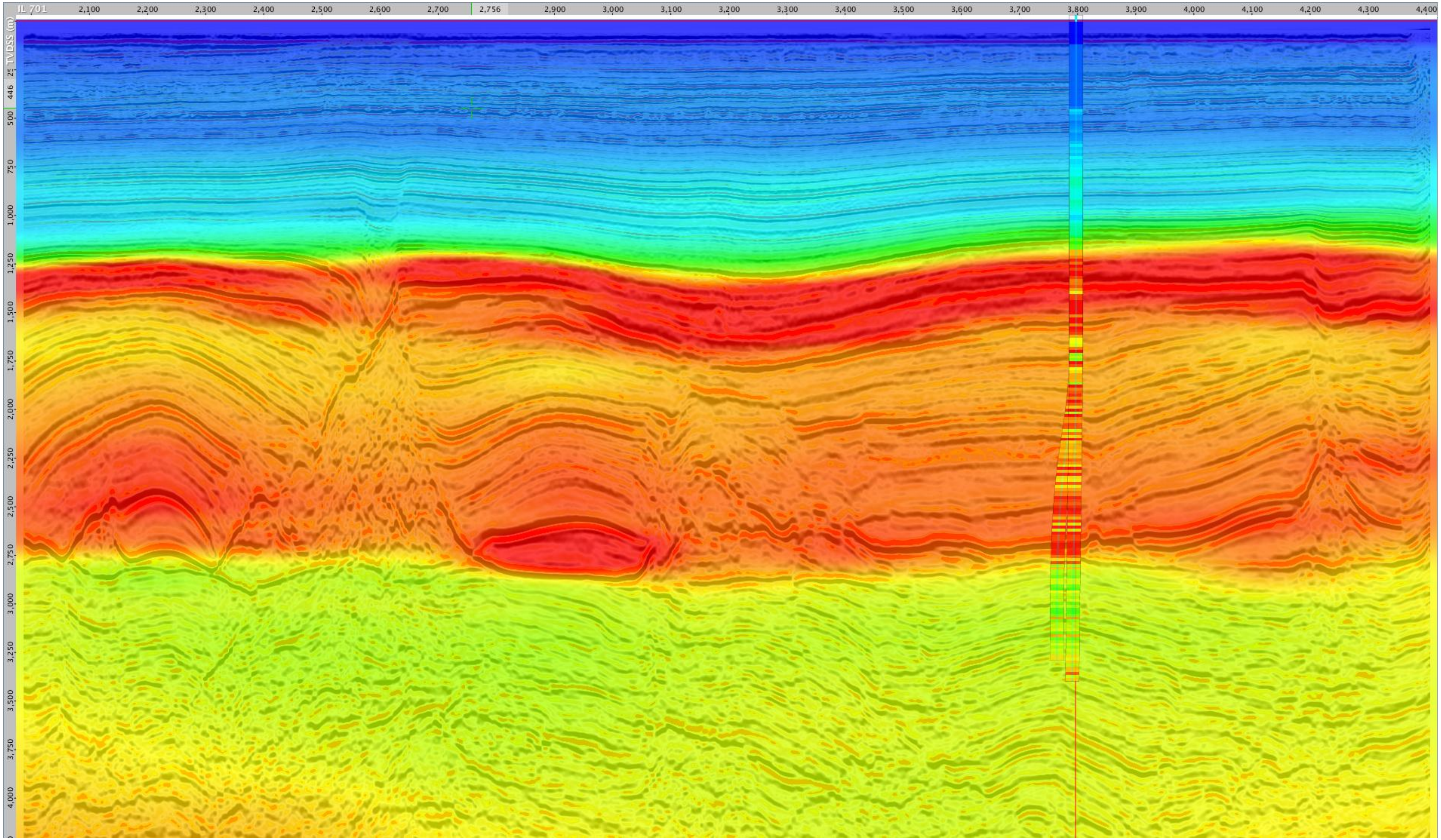
Initial model & mig



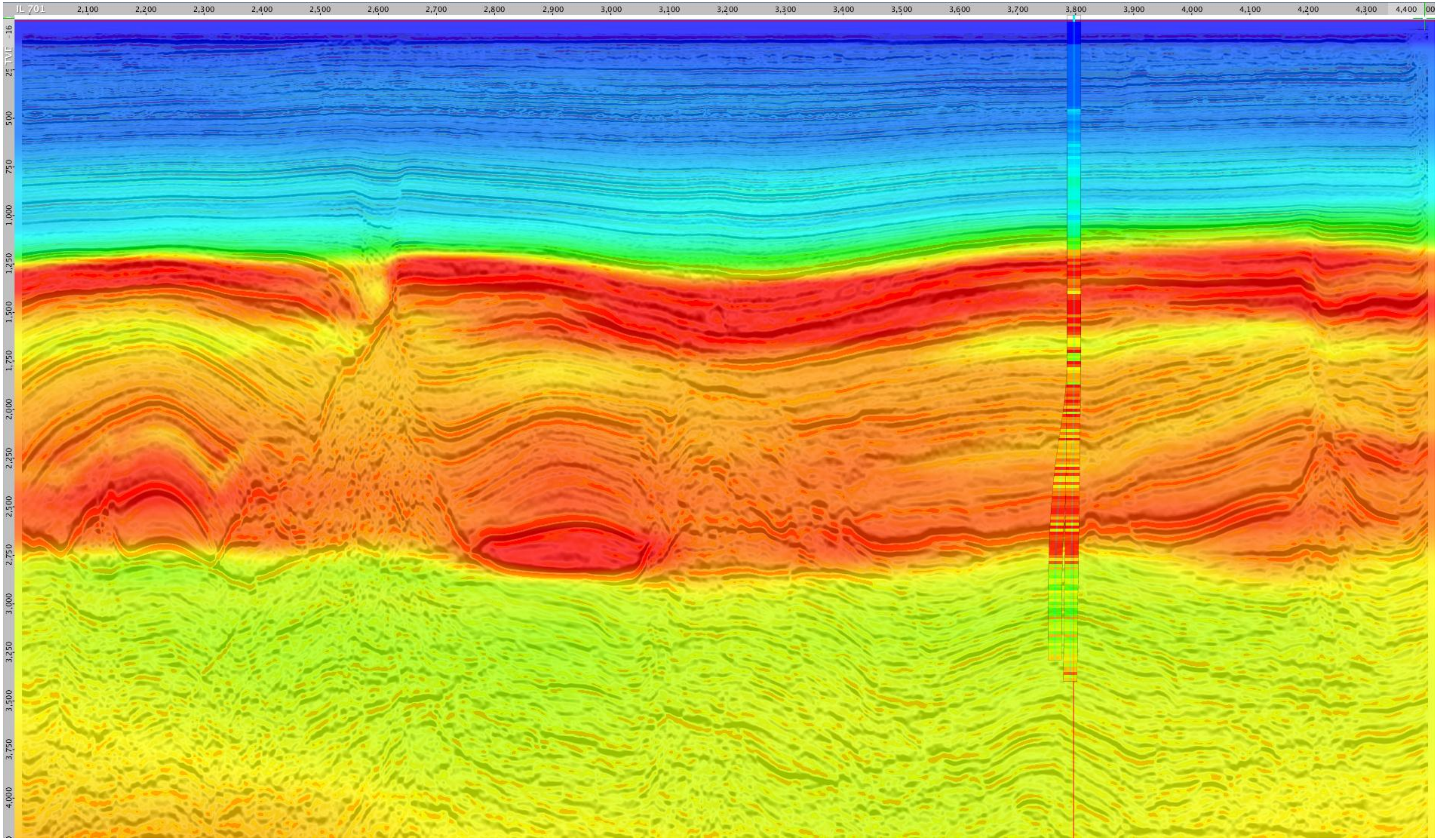
Iteration 1, anisotropic tomo & mig



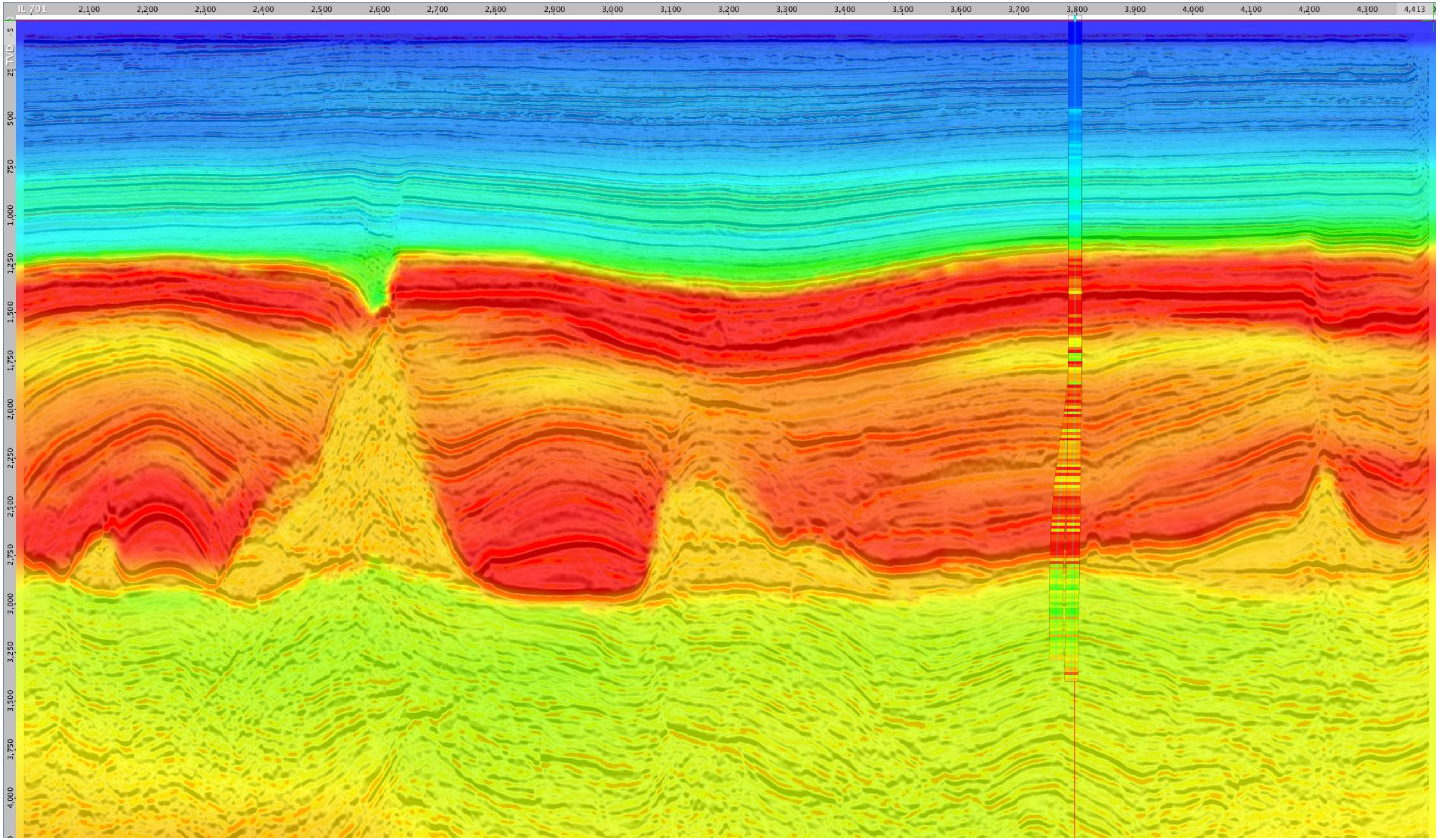
Iteration 2, anisotropic tomo & mig



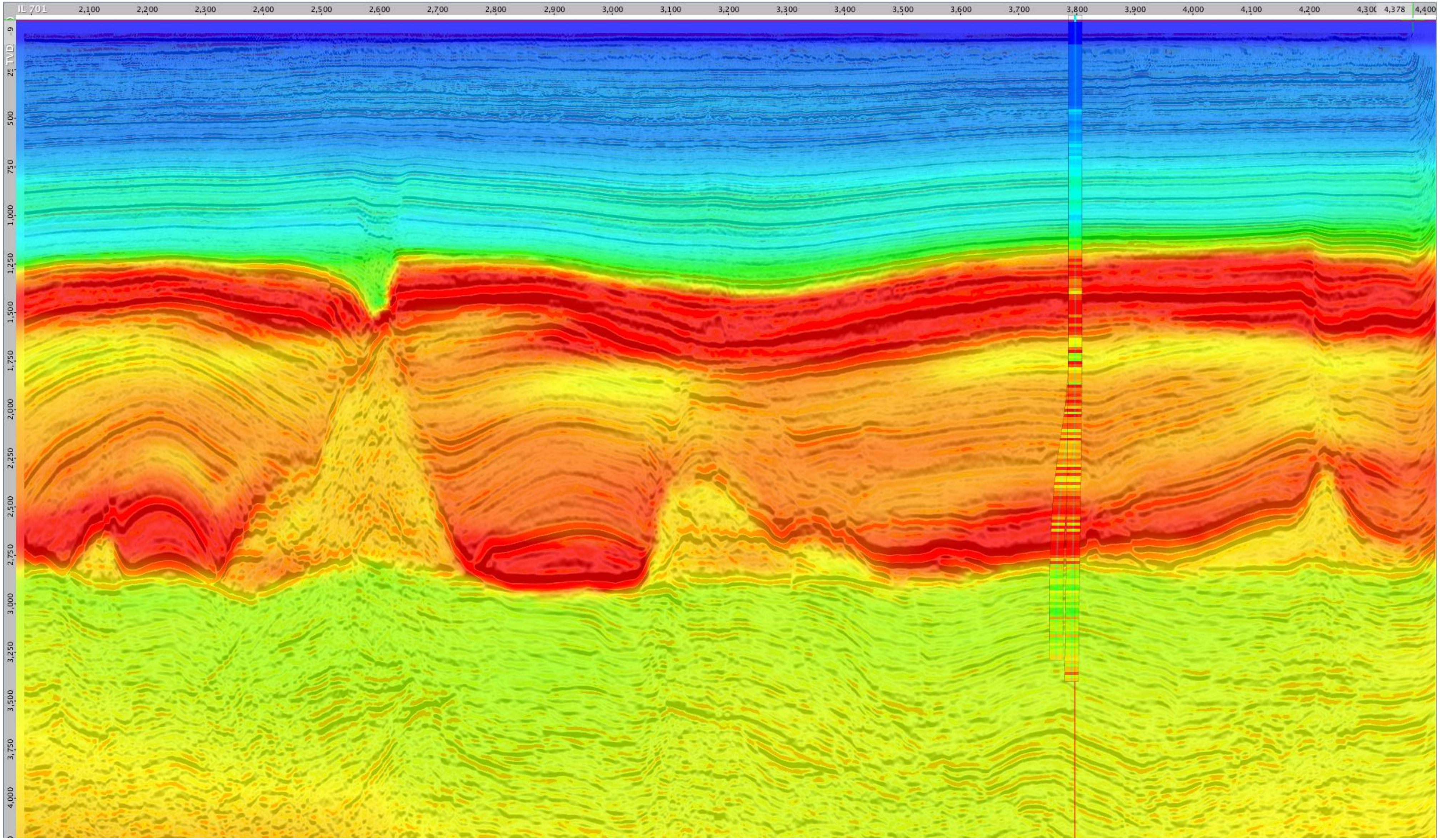
Iteration 3, anisotropic tomo & mig



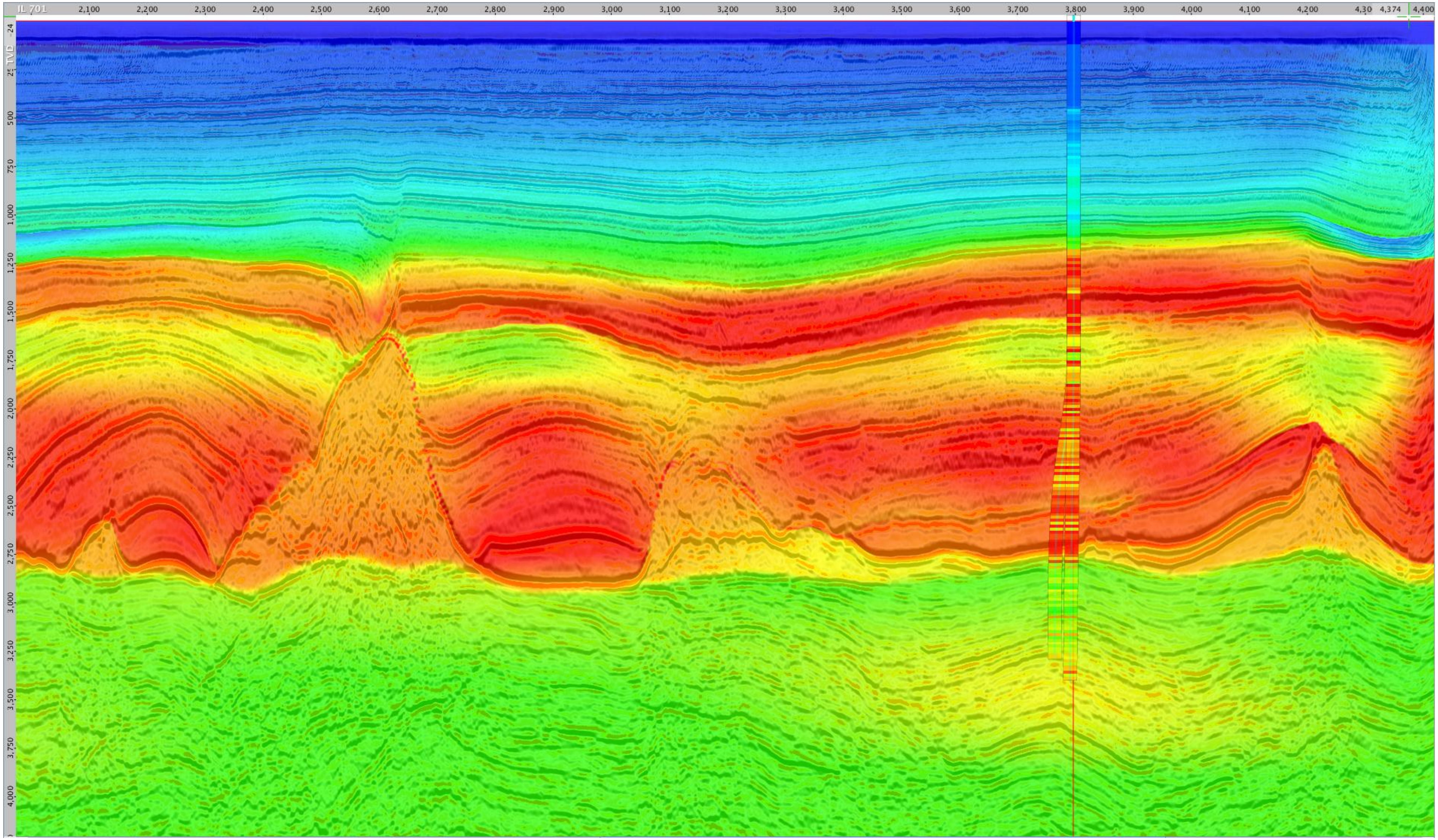
Iteration 4, anisotropic tomo & mig



Iteration 5, anisotropic tomo & mig



Previous PreSDM



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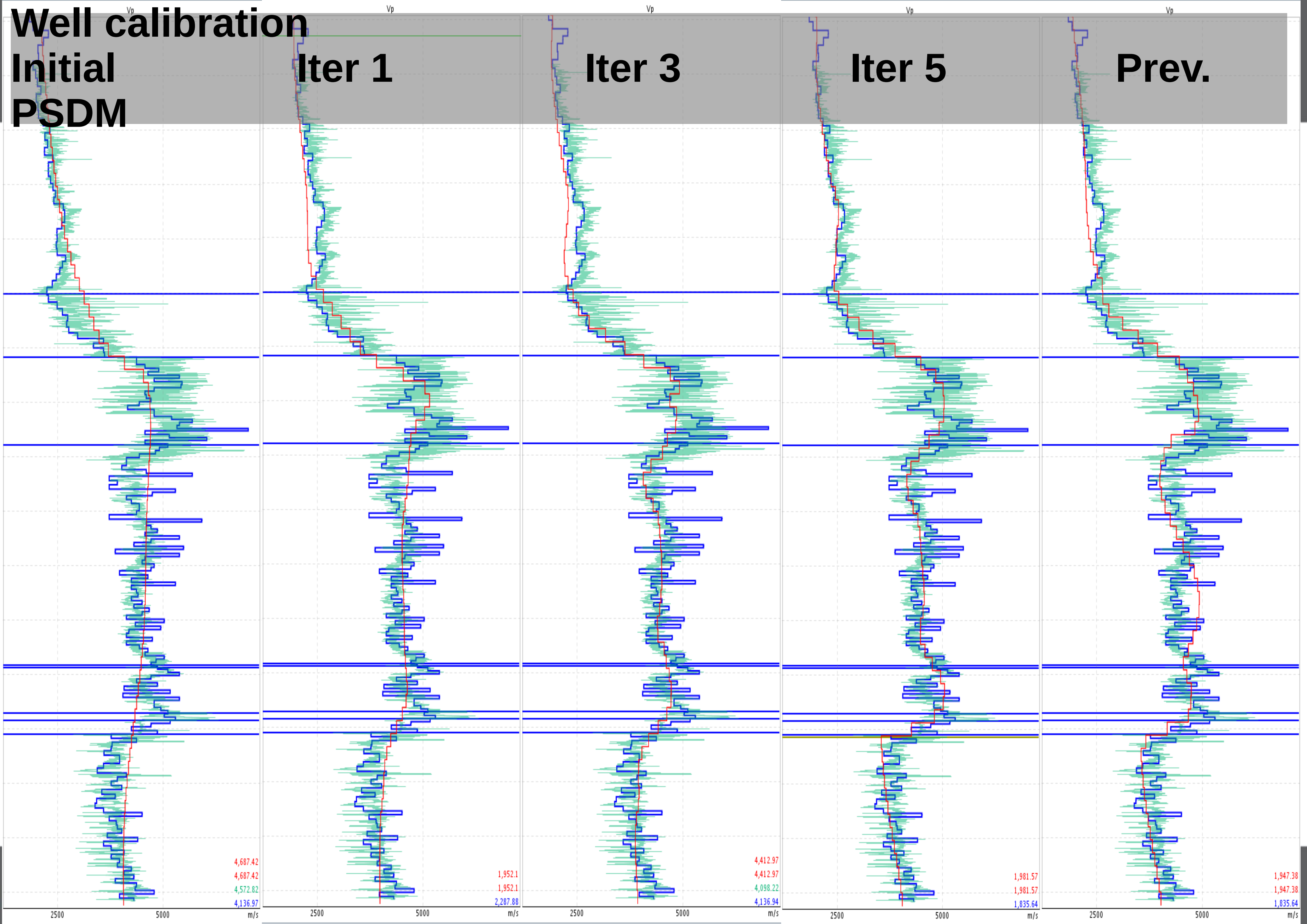
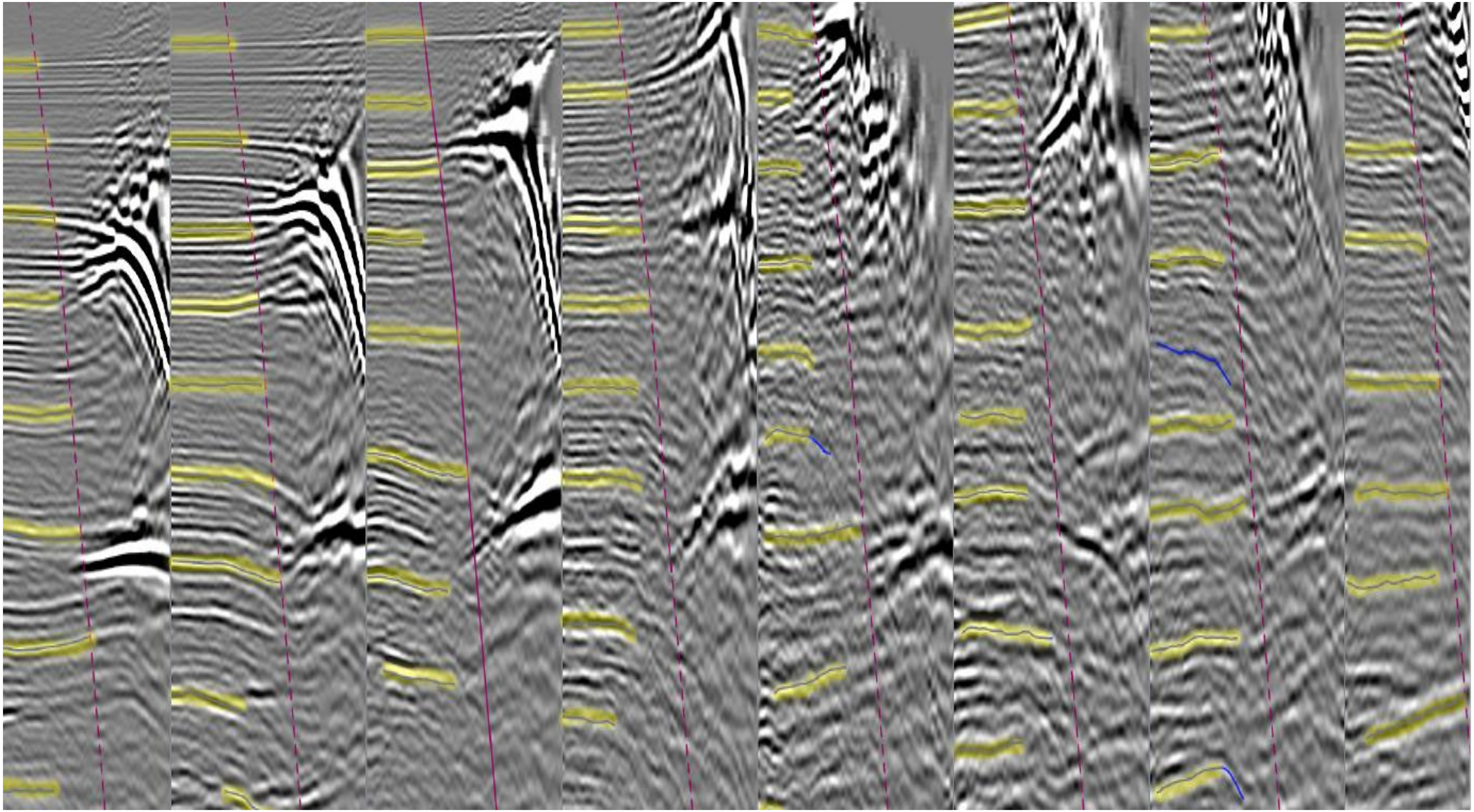
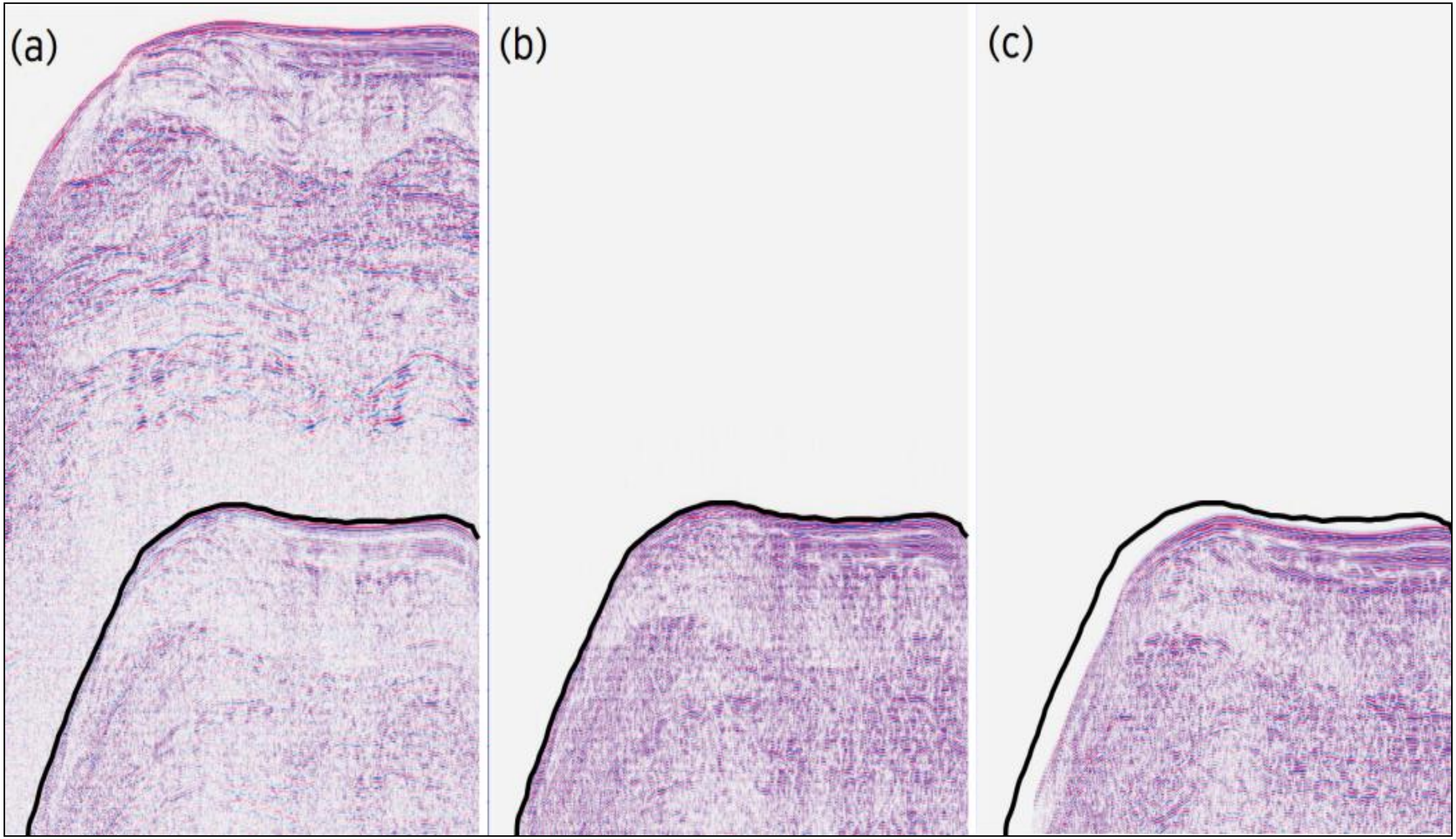
Well calibration



Non parabolic picking in DUG Insight

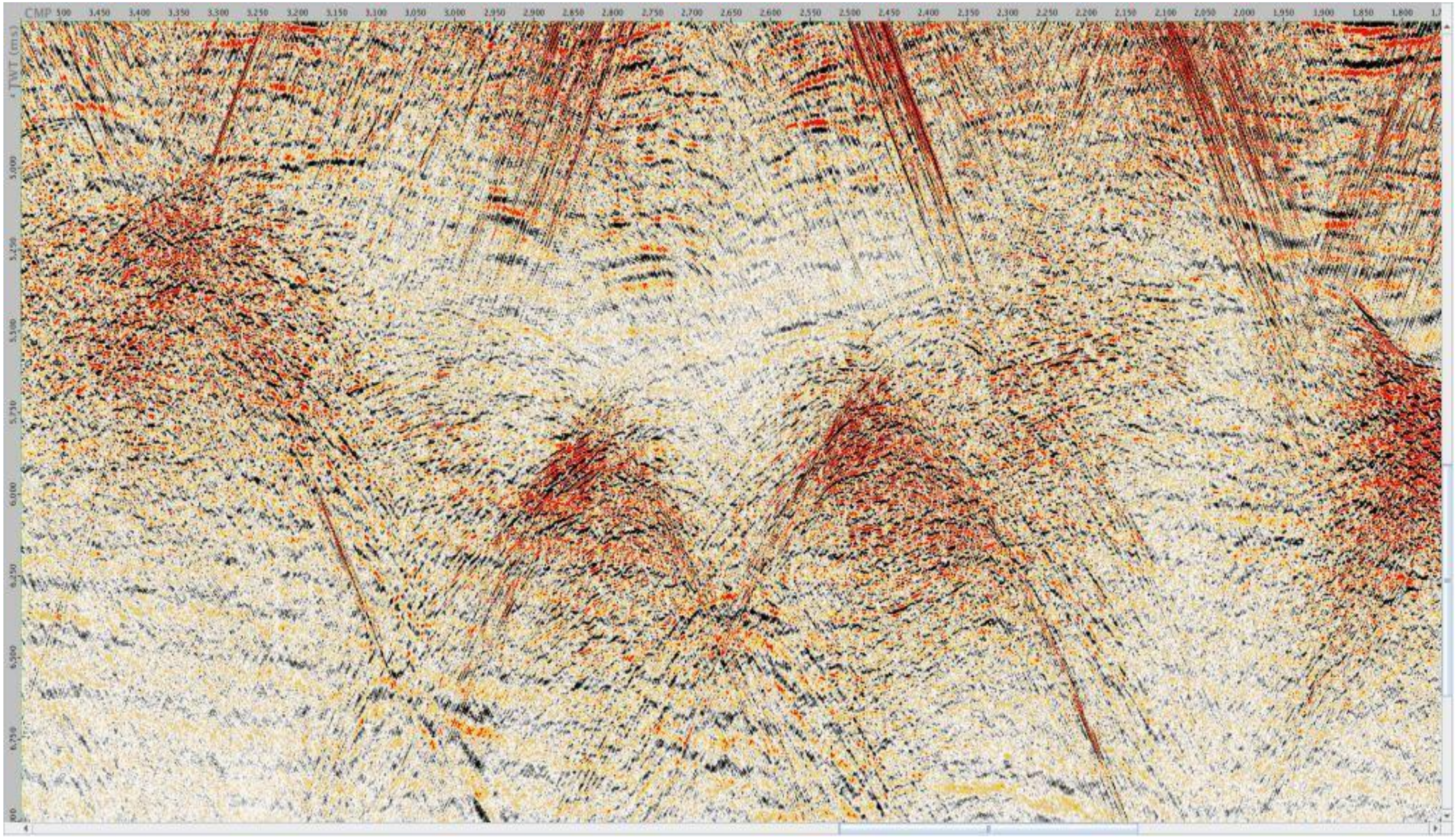


DUG 3D SRME over conventional 2D SRME

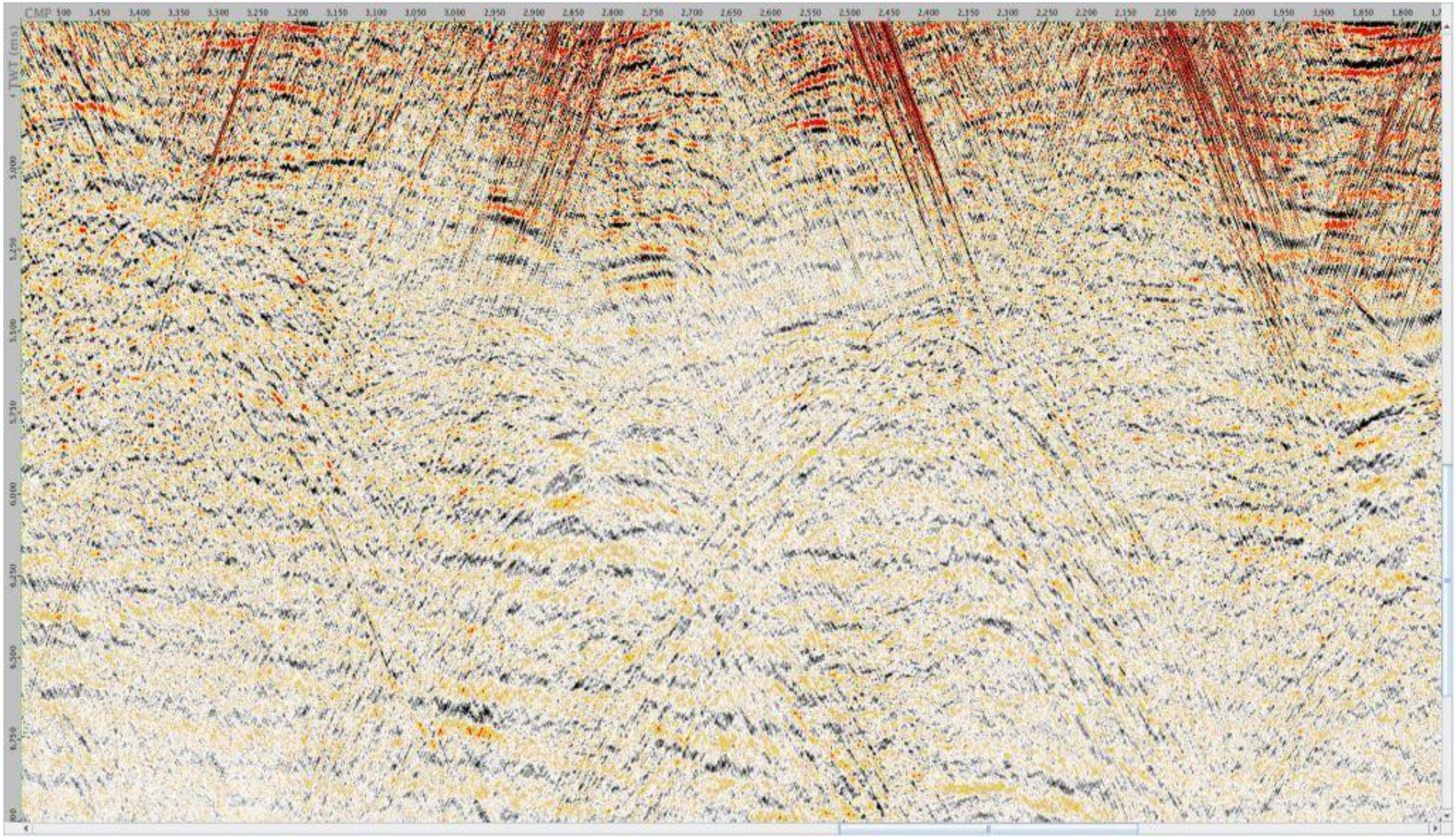


(a) Multiple picked on offset plane (b) 3D multiple prediction (c) 2D multiple prediction

Diffracted Noise Attenuation – Stack before

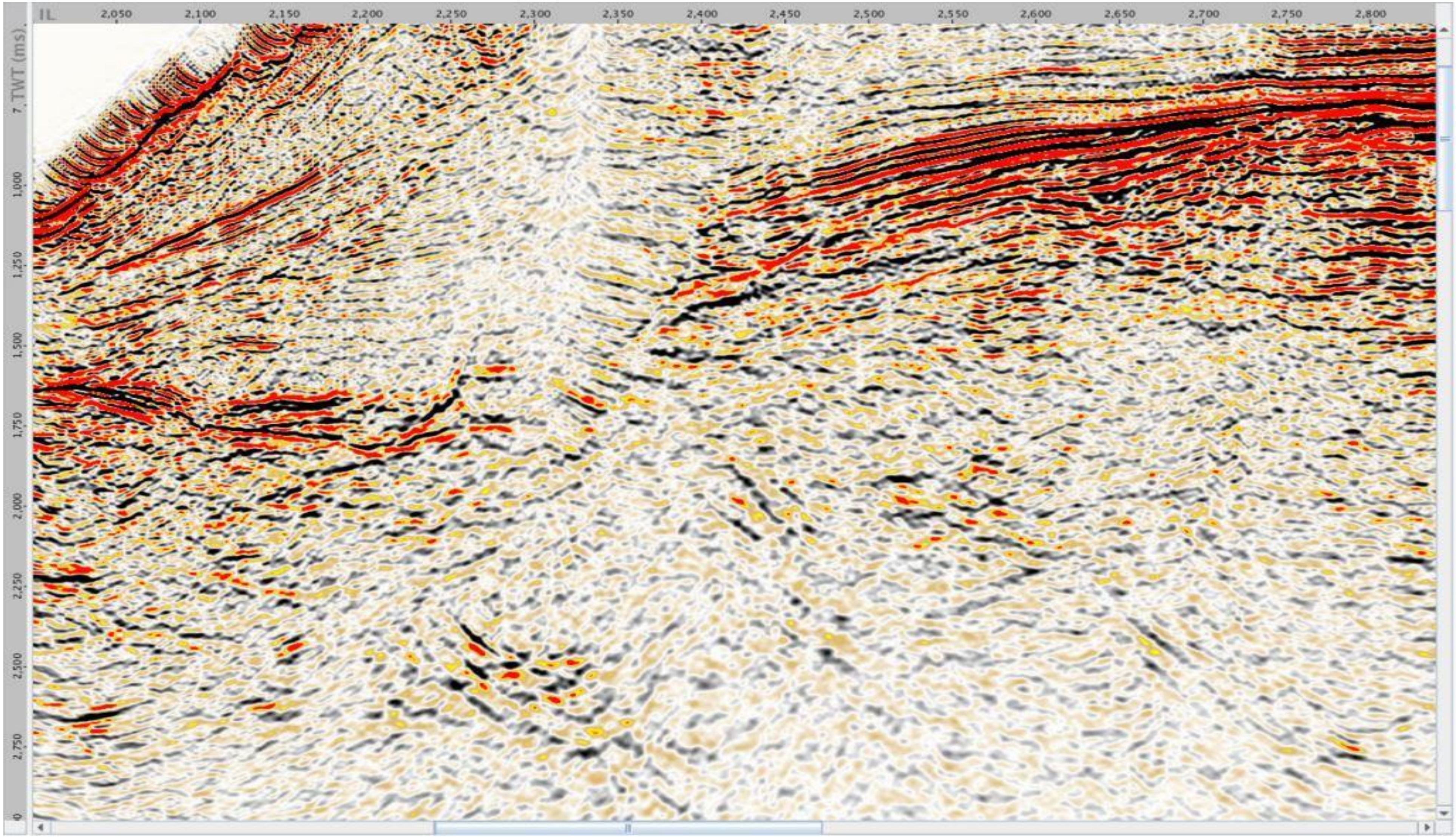


Stack after

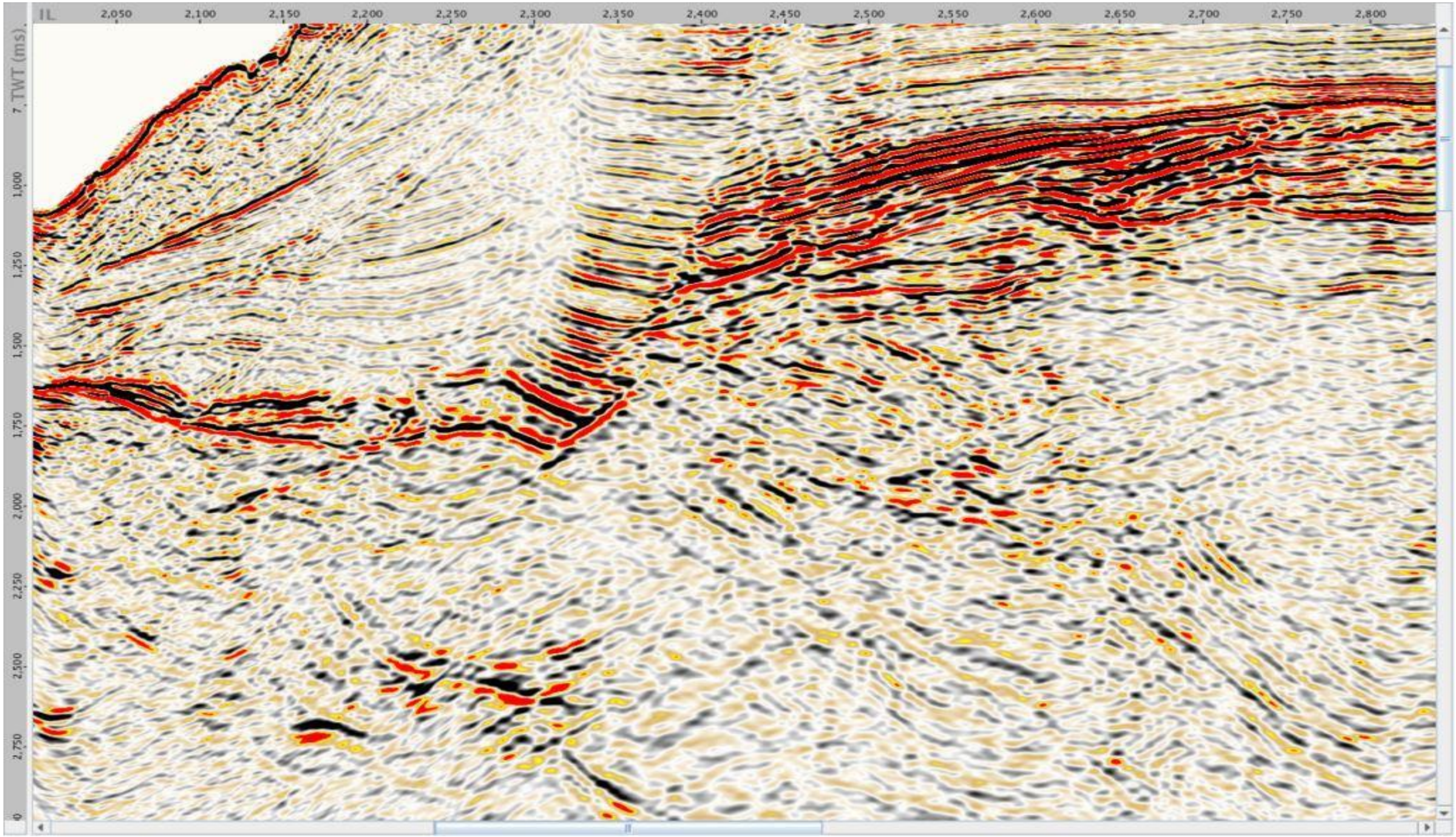


DownUnder GeoSolutions

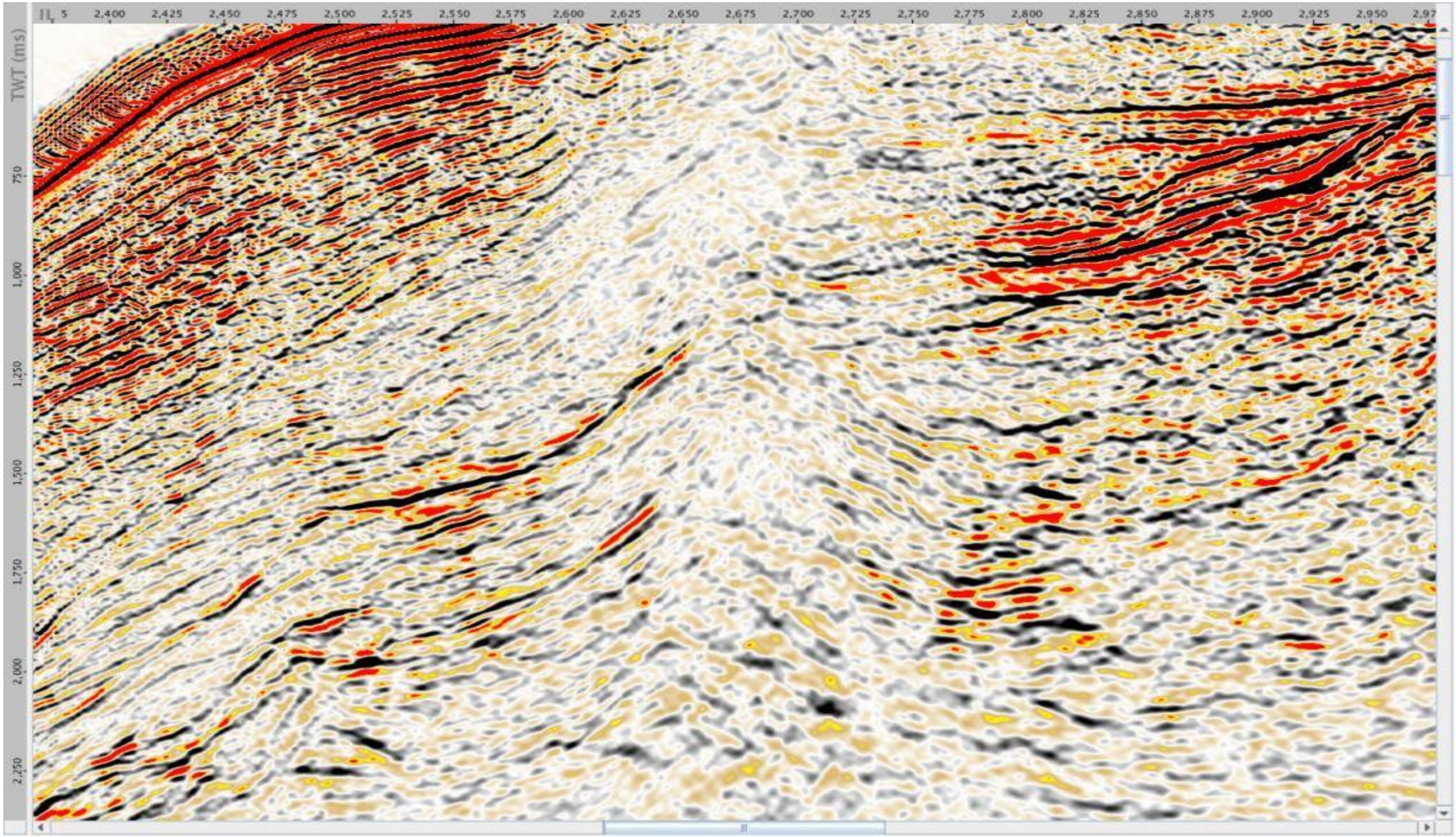
“Major Contractor” processing 2011 result



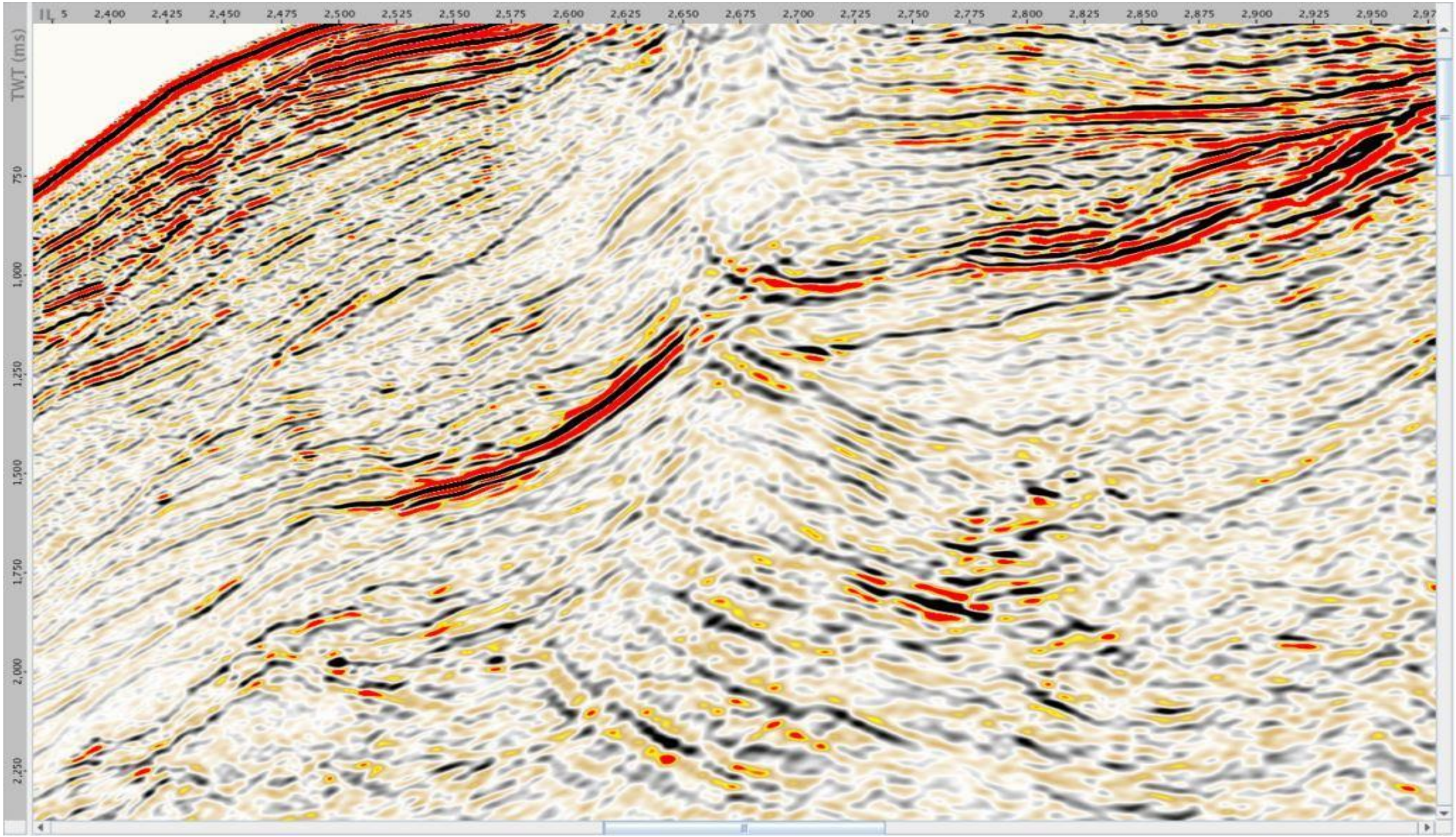
Dugeo 2011/12 reprocessing



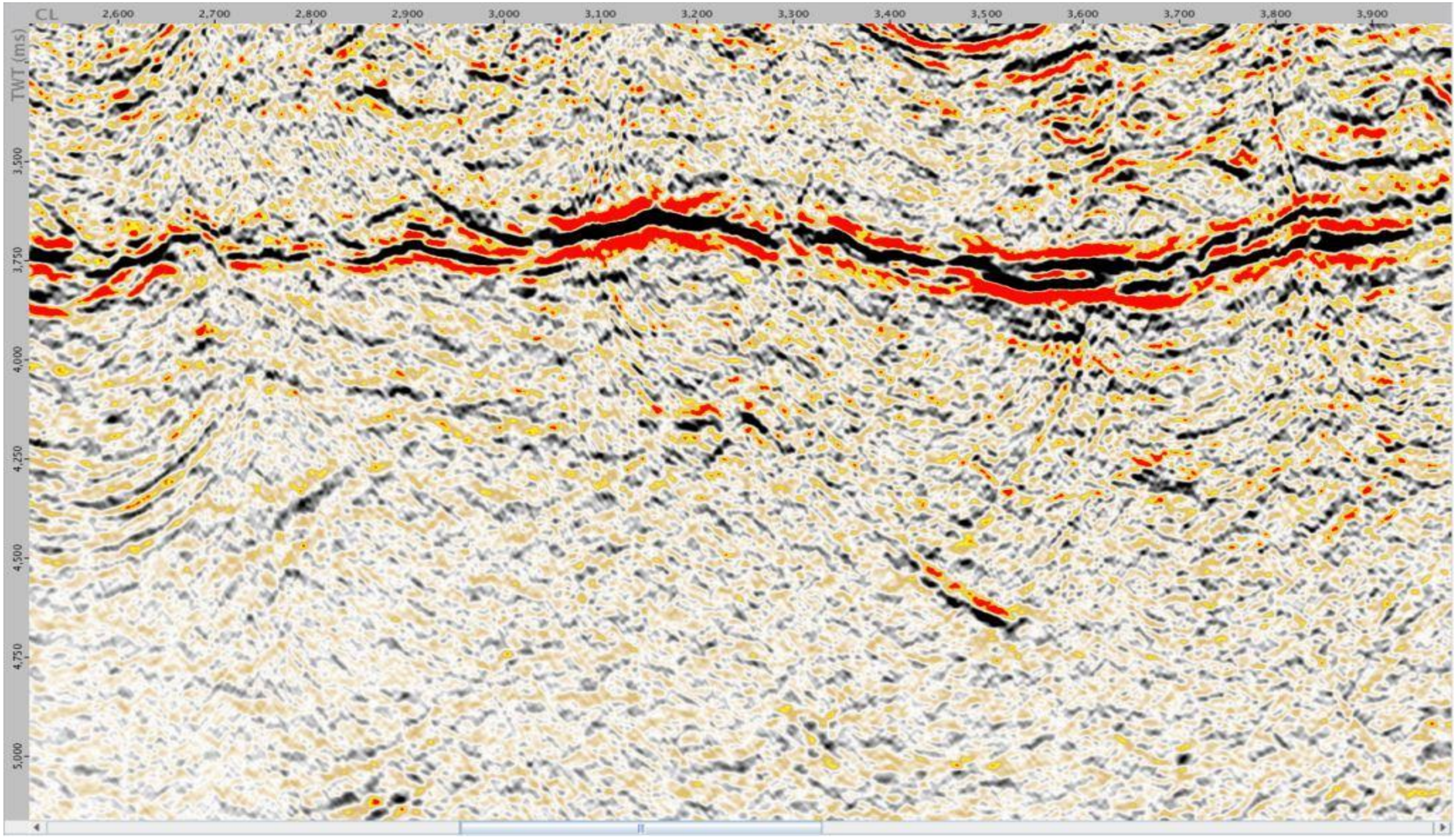
“Major contractor” processing 2011 results



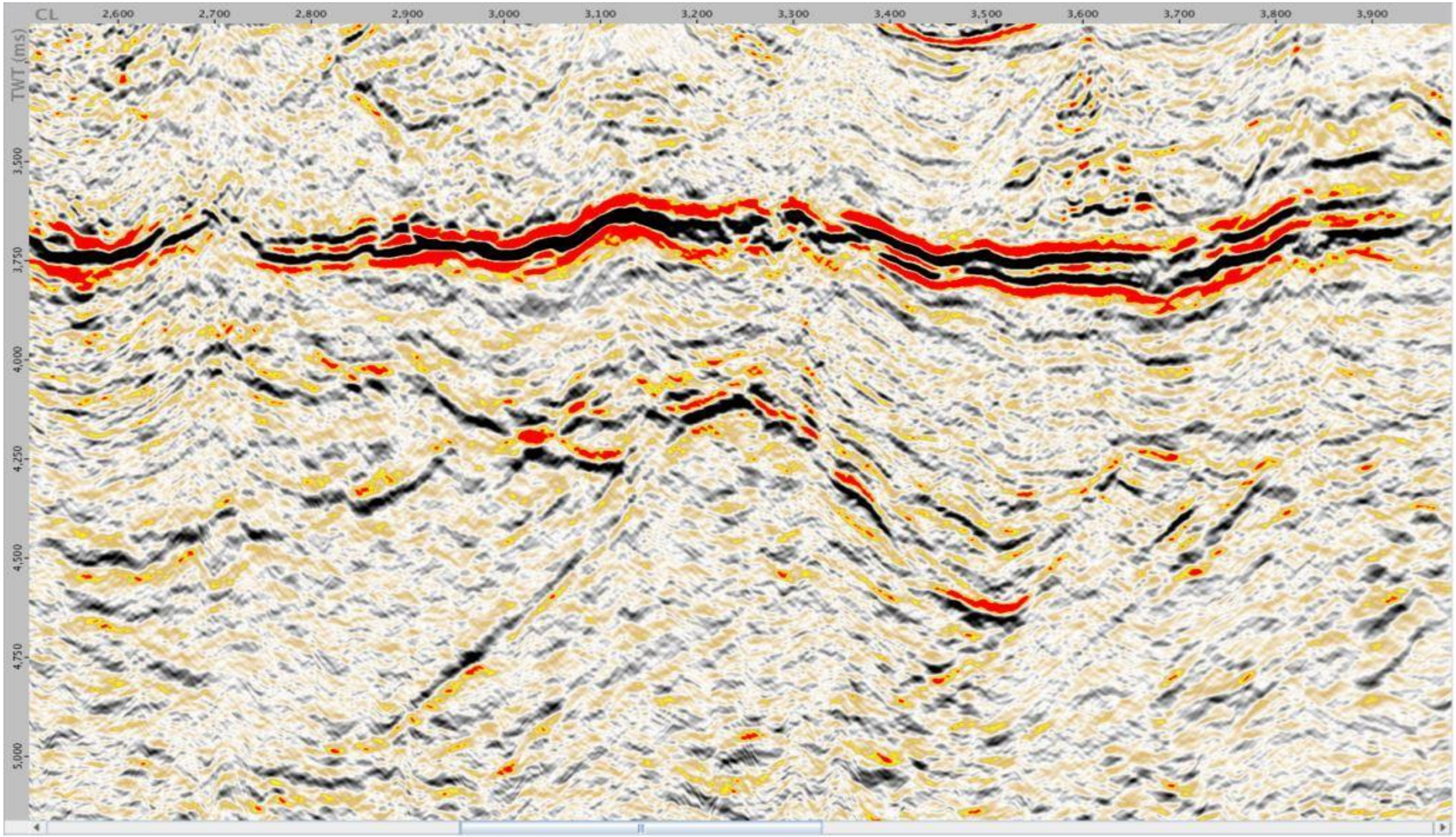
Dugeo 2011/12 reprocessing



"Major contractor" processing 2011 results



Dugeo 2011/12 reprocessing



Quantitative Interpretation

- Predicting rocks and fluids using quantitative analysis of seismic amplitudes
- Identify leads and help risking of prospects
- Quantitatively integrate information from multiple disciplines
- For business impact it must be distilled in a form that can be digested by the decision makers
- Independent sources of information have value on their own, but add non linearly – the whole is more valuable than the sum of its parts

High level road map

Increasing well control

More quantitative

1.) **Reconnaissance -** *No well control within the seismic*

A) No regional wells exist

- **AVA attributes and AVA stack rotations (EEI equivalent)**

B) Relevant regional wells exist

- **Statistical rock physics**
- **AVA attributes and calibrated stack rotations**

AVA attribute based

2.) **Exploration and appraisal -** *Well control within the seismic volume*

- **Statistical rock physics**

A) Limited well control

- **Relative simultaneous (AVA) inversion and impedance rotations**
- **Map based probabilistic lithology and fluid prediction**

B) Well control

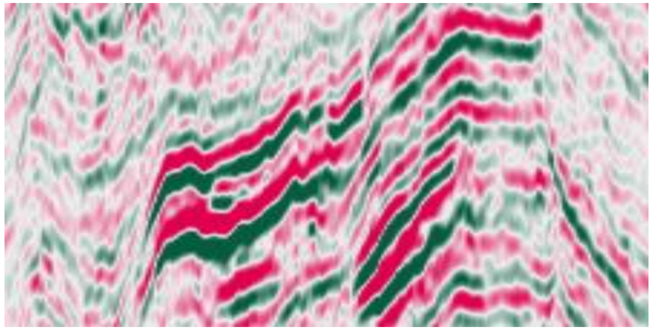
- **Absolute simultaneous (AVA) inversion**
- **Volume based probabilistic lithology and fluid prediction**

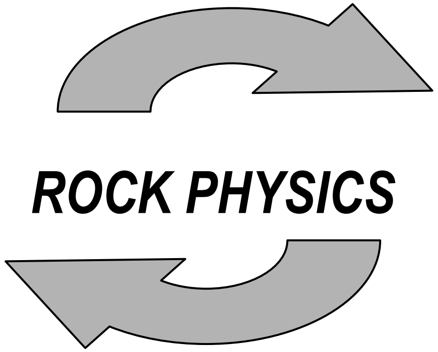
3.) **Focussed reservoir characterisation -** *Well control within the field*

- Understand the uncertainties in key reservoir parameters
  - **Statistical rock physics**
  - **Stochastic inversion**
  - **Reservoir focussed probabilistic lithology and fluid prediction**

AVA inversion based

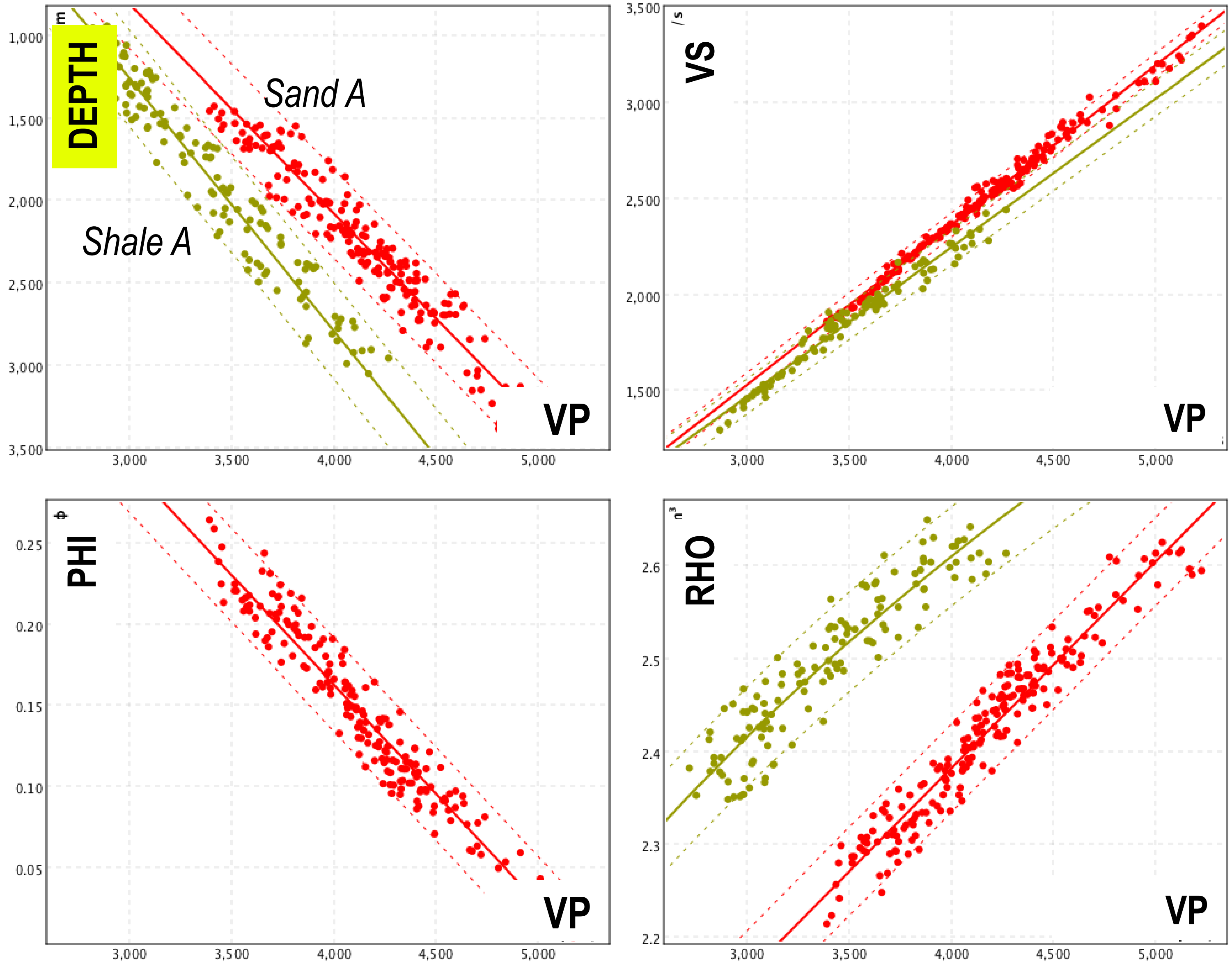
Before Inversion → Rock Physics





- The link between seismic (or seismic derivatives) and rock properties.
- Quantify the geophysical signatures of “all” rock and fluid properties.
- Allows us to play the *“ what if ? ”* game and to extrapolate.
- Statistical rock physics – capture uncertainty, population behaviour, possible variations.
- Interpretation model for seismic / derivatives / seismic reservoir characterisation
  - Attributes
  - Impedance

Statistical Rock Physics Model



Depth dependent end-member trends

Interpretation

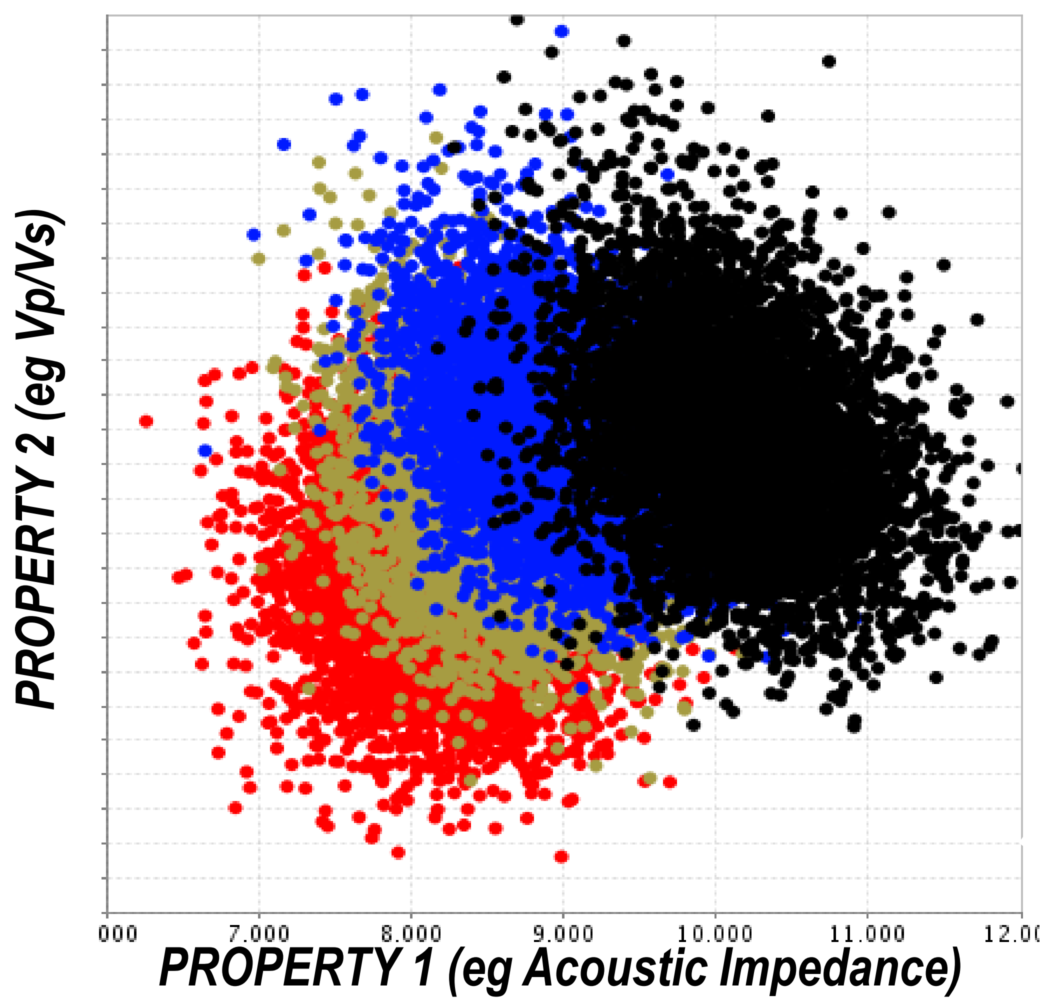
Captures inherent scatter

Elastic properties of all rocks

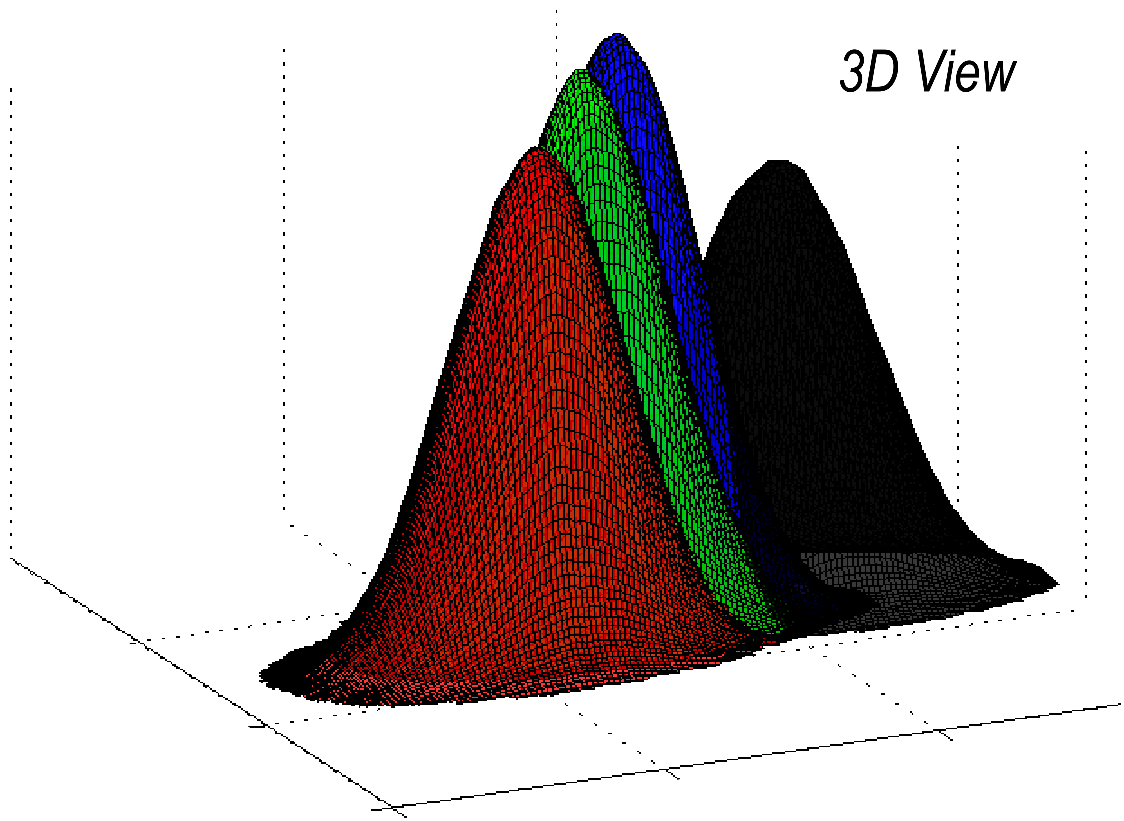
Normally distributed at any given point

Stochastic Forward Modelling

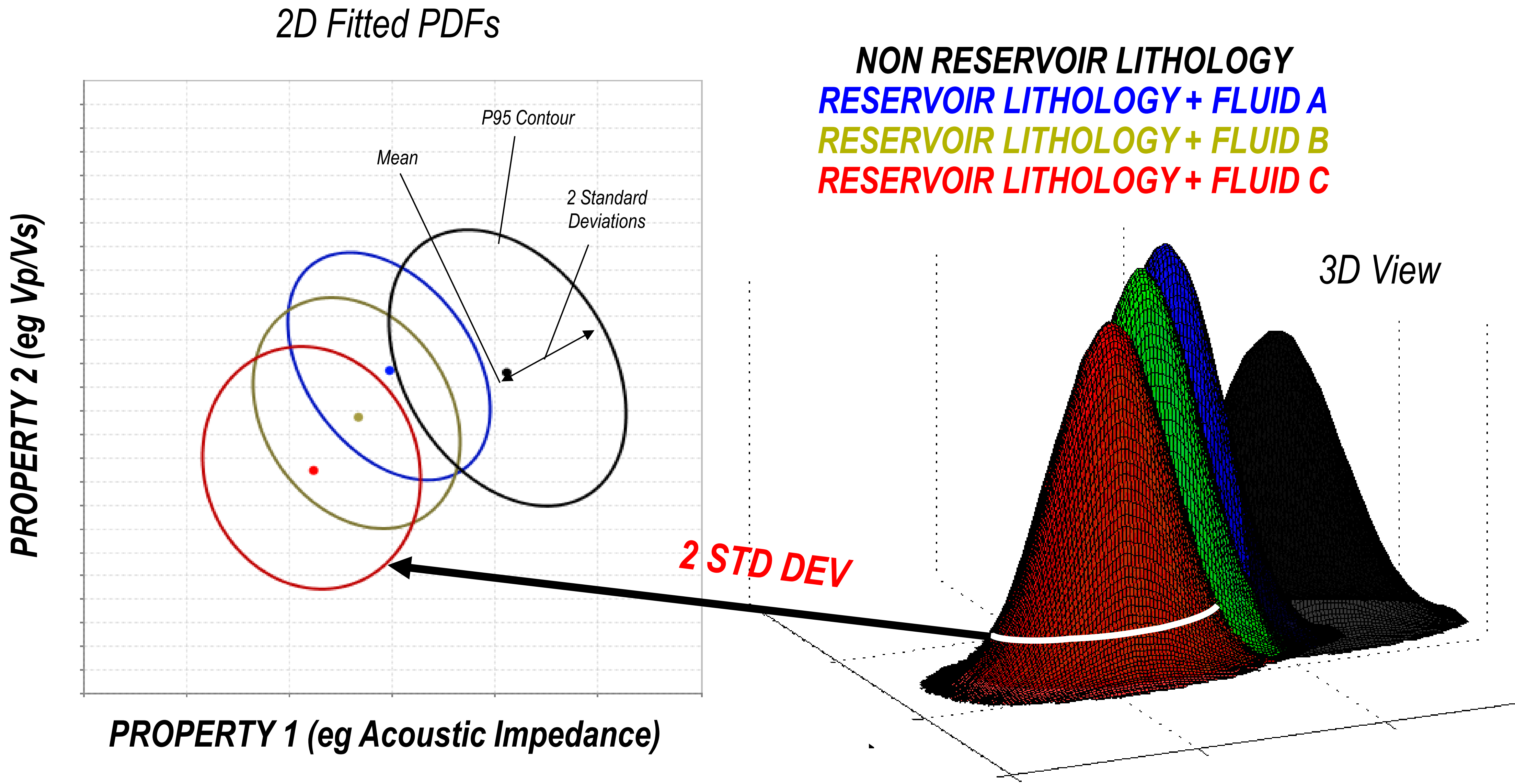
2D scatter plot of individual realisations



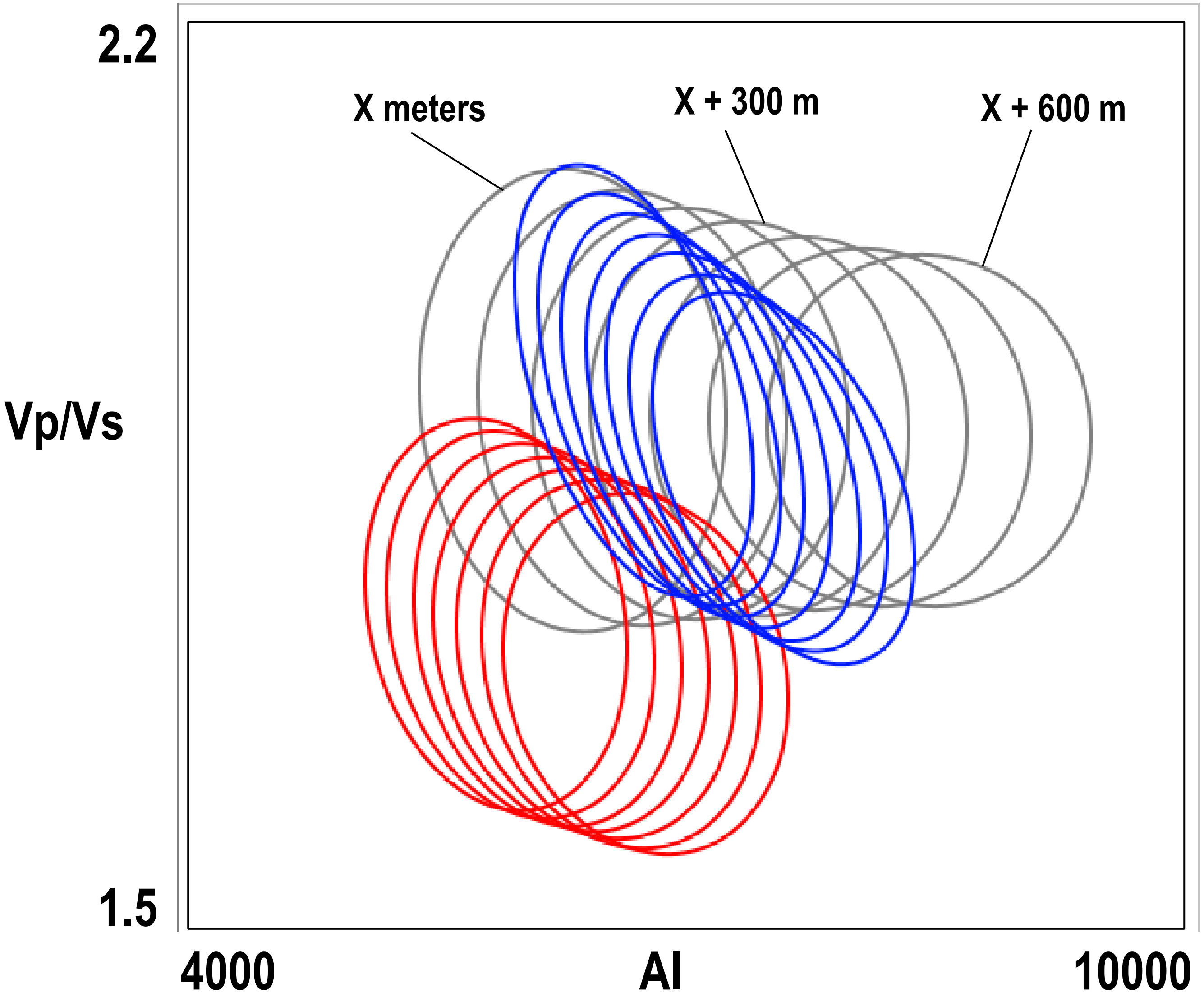
NON RESERVOIR LITHOLOGY
RESERVOIR LITHOLOGY + FLUID A
RESERVOIR LITHOLOGY + FLUID B
RESERVOIR LITHOLOGY + FLUID C



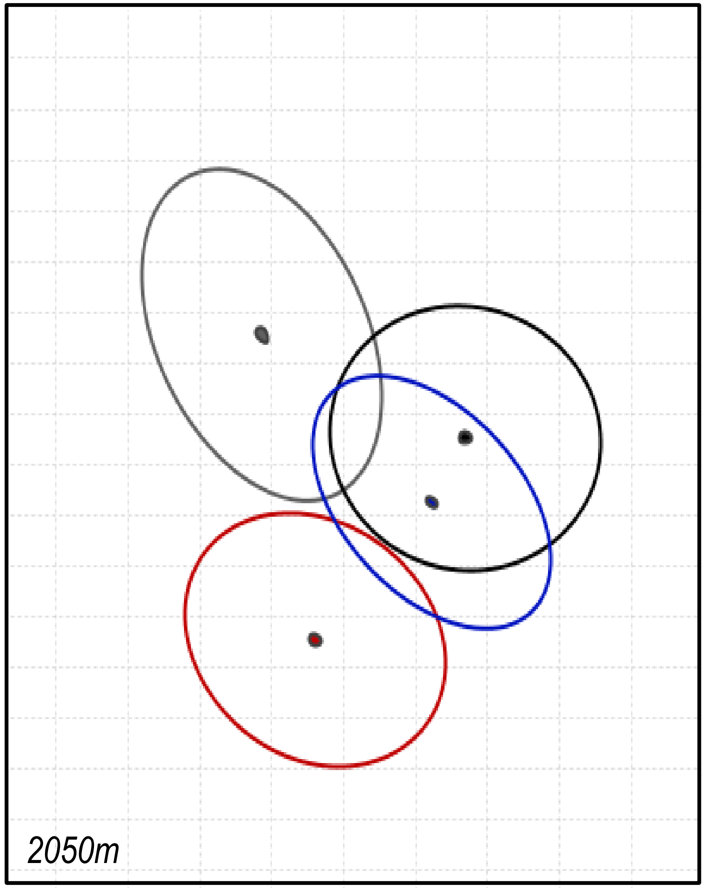
Stochastic Forward Modelling



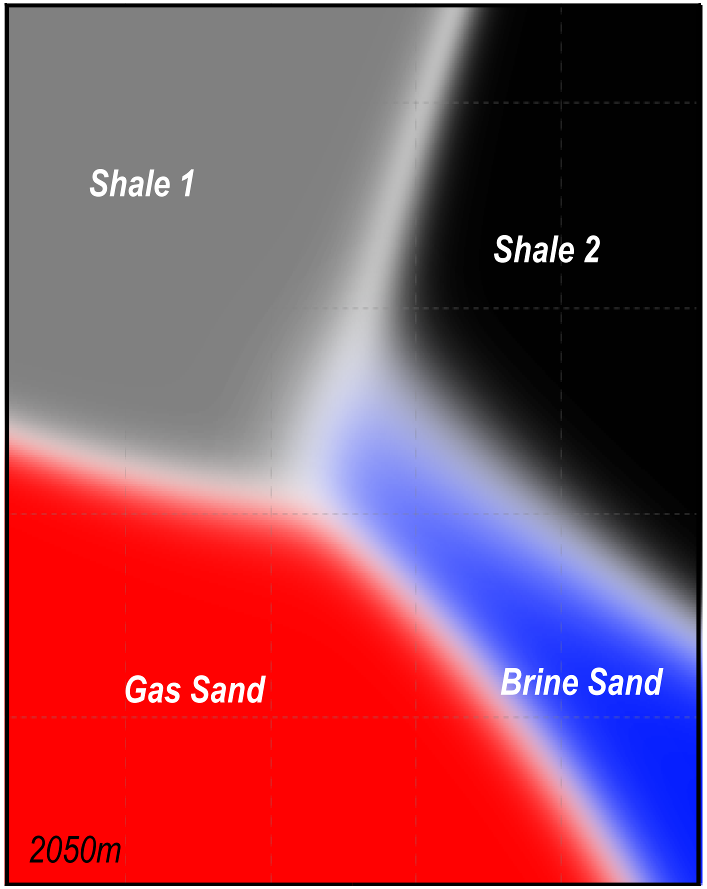
Depth Dependent Modelling



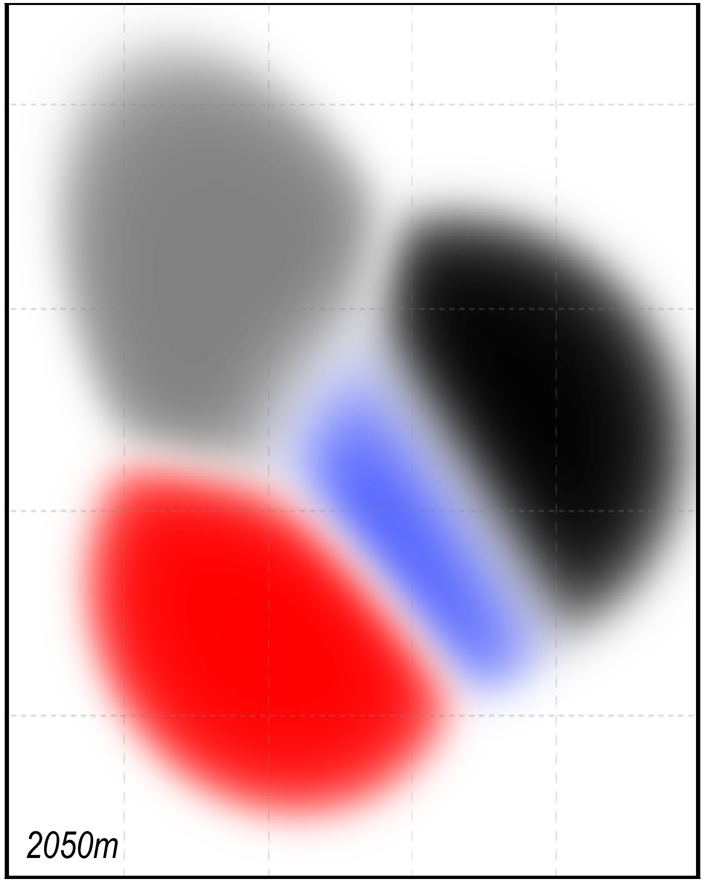
Know what you don't know too!



Rock Property PDFs



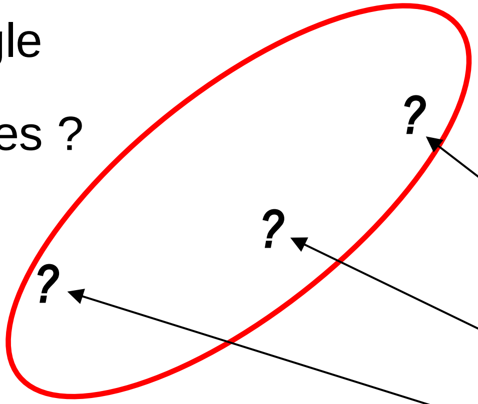
Posterior Probabilities



Posterior Probabilities
(accounting for unknowns)

Statistical vs Deterministic

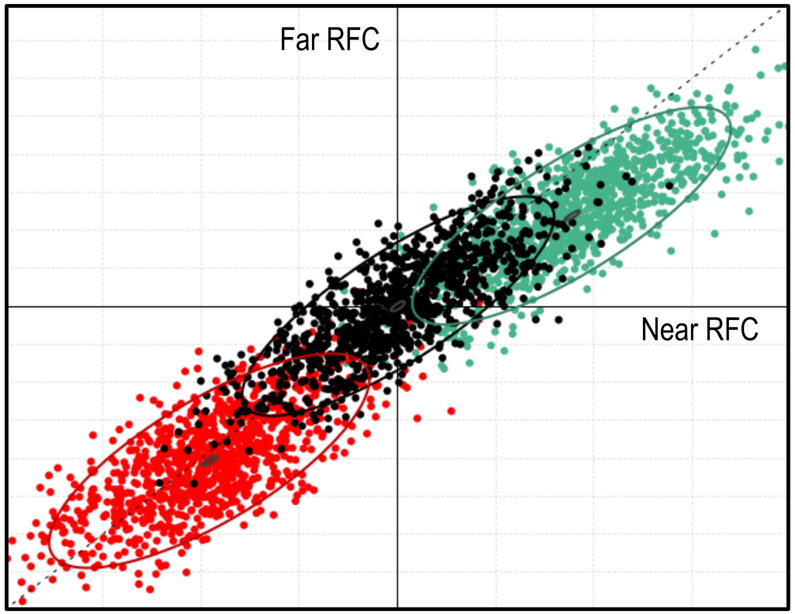
Where does that single point sit within the continuum of possibilities ?

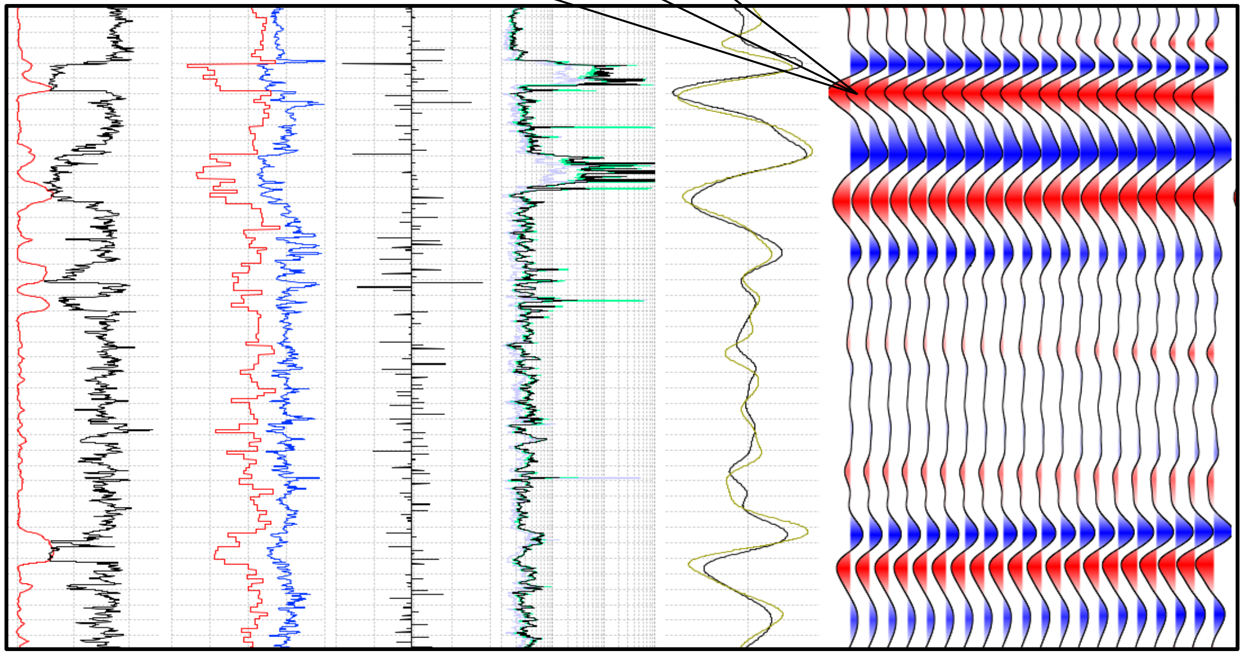


Ellipse represents the 2 std contour of the fitted PDF

Captures the behaviour at a single point

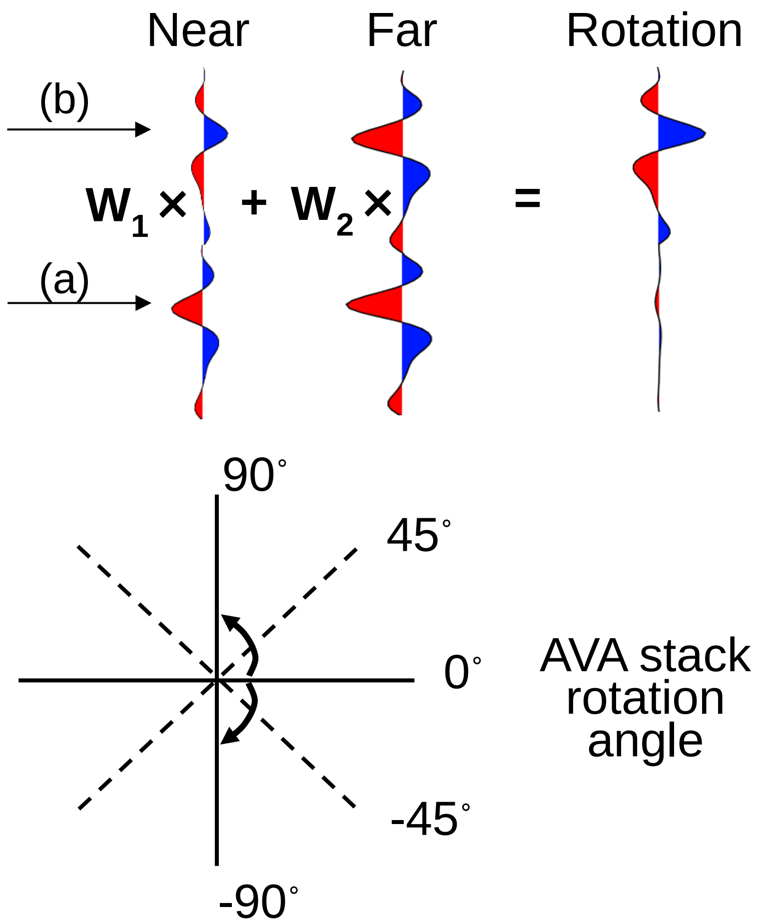
Captures the population behaviour

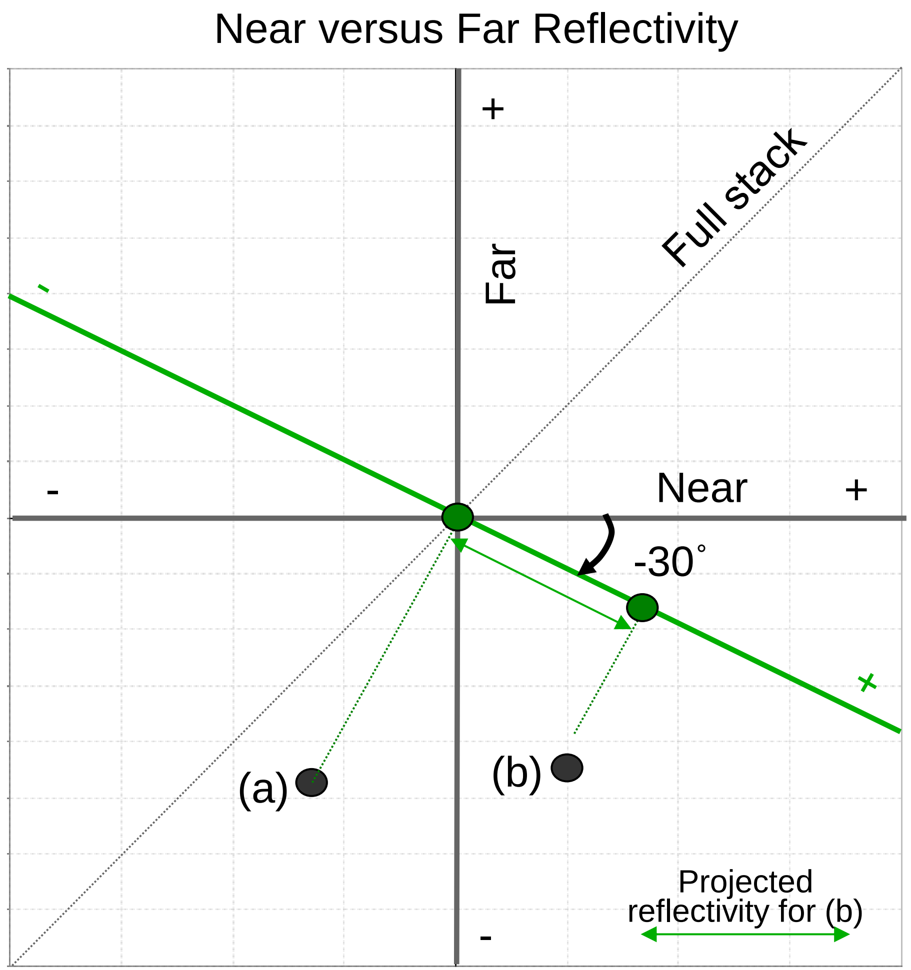




AVA Stack Rotations

Introduction





An AVA stack rotation is a weighted stack of AVA attributes - for example near and far angle stacks. The weights (W_1 and W_2) are defined by the stack rotation angle which varies between -90° and 90°. This can be thought of as a constant angle projection. In the example above, a stack rotation angle of -30° defines a projection (green line) which tends to suppress the Class 3 AVA event (a) and enhance the polarity flipping Class 1 event (b).

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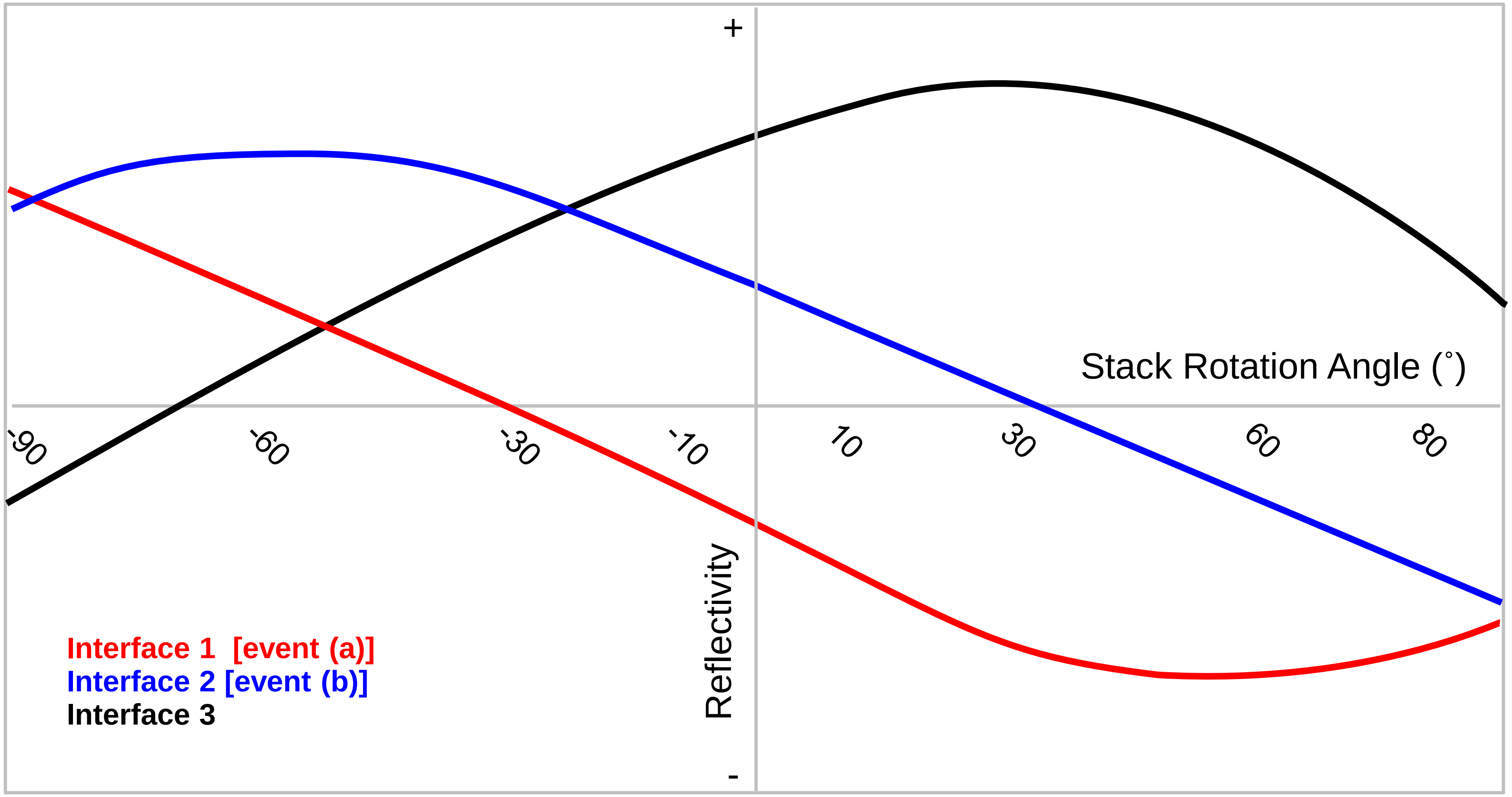
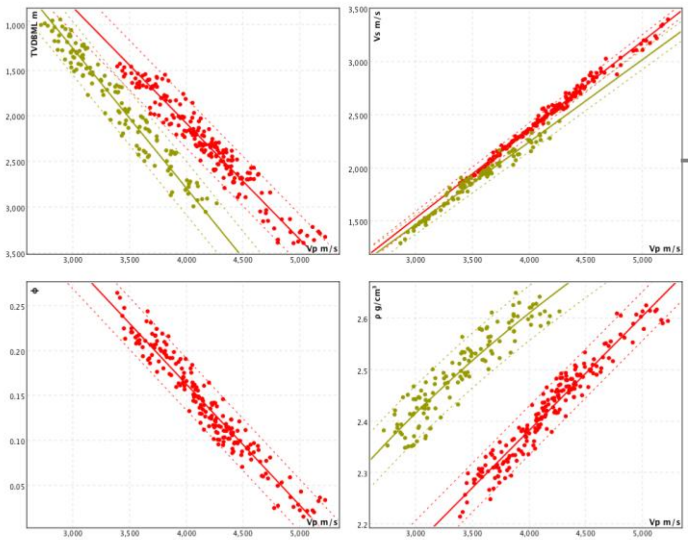
AVA Stack Rotations

Illustrative example

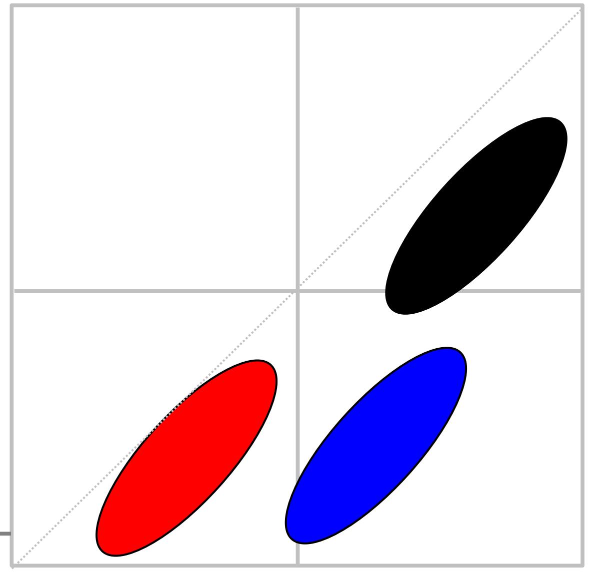


The variation in (projected) reflectivity as a function of stack rotation angle can be forward modelled to determine if optimal rotation angles exist for fluid and/or lithology discrimination. In this case, a rotation angle of approximately -30˚ should highlight event (b) while suppressing the Class 3 event (a). Alternatively a rotation angle around 30 degrees will tend to suppress event (b). Ideally rotation angles which leave a target of interest relatively bright while suppressing other reflections are desired.

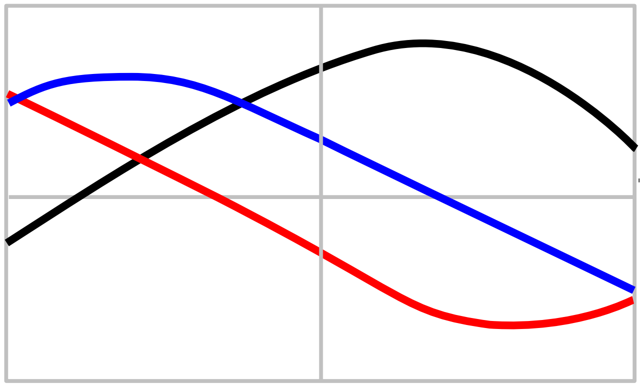
AVA stack rotation workflow



(1) Statistical rock physics model building.

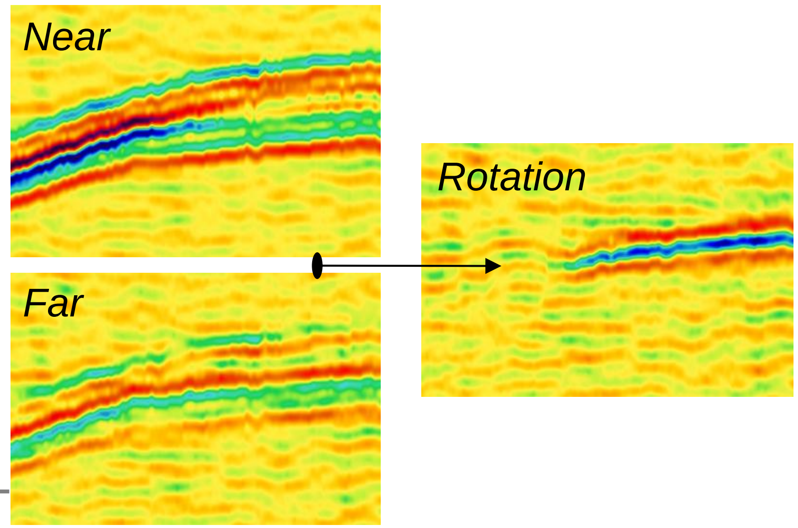


(2) Stochastic modelling of amplitude and AVA for relevant lithology and fluid combinations in near-far space.

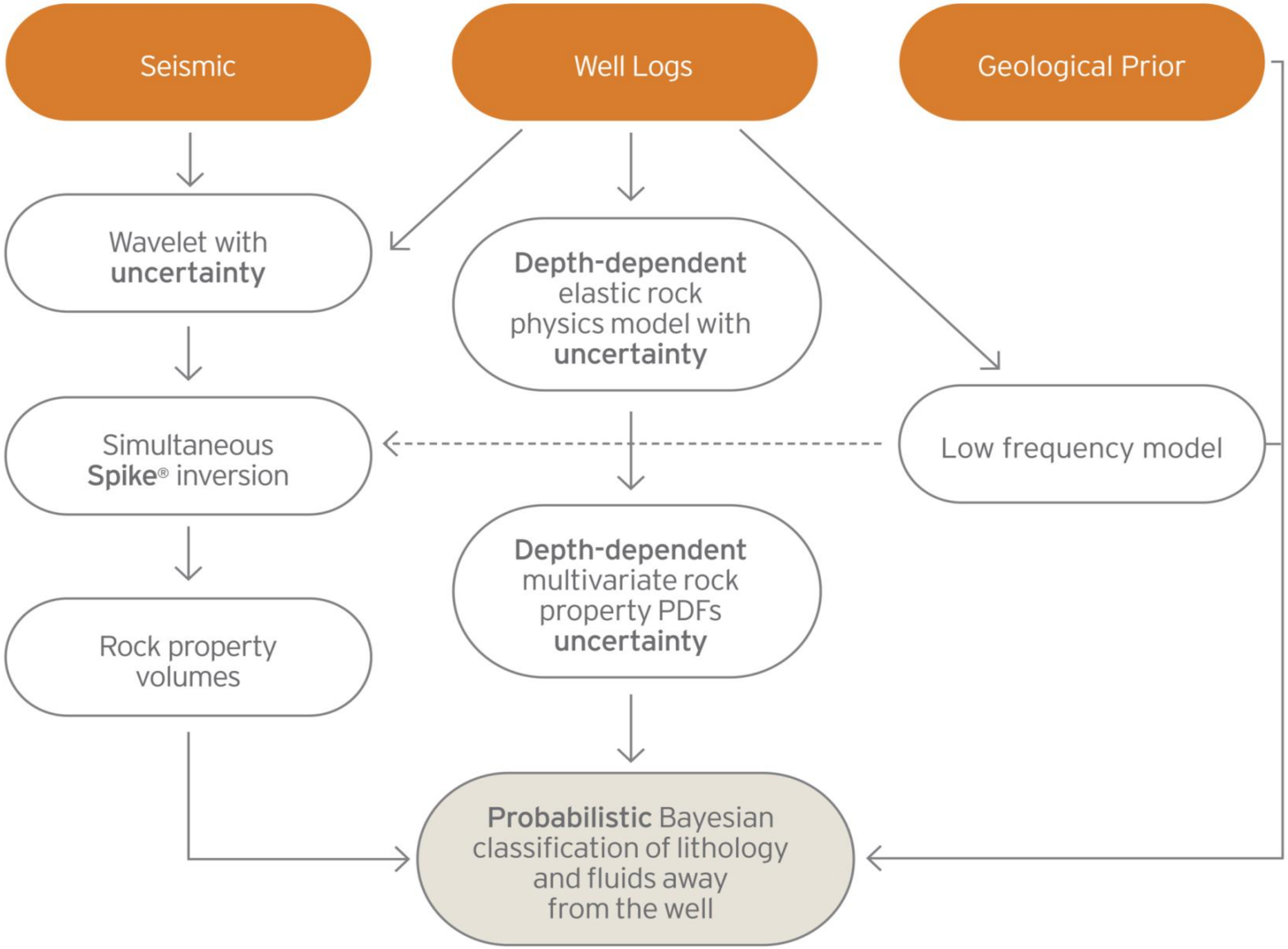


(3) Model the AVA stack rotation responses. Interpret optimal rotation angles.

(4) Apply to seismic data and interpret the results.



QI Workflow


Seismic
Well Logs
Geological Prior
Wavelet with uncertainty
Depth-dependent elastic rock physics model with uncertainty
Simultaneous Spike® inversion
Low frequency model
Rock property volumes
Depth-dependent multivariate rock property PDFs uncertainty
Probabilistic Bayesian classification of lithology and fluids away from the well

DUG Spike® - Constrained Simultaneous Inversion

Absolute

P and S impedance and Density

Low frequency models

Relative

Intercept, Gradient and Curvature

NO Low frequency models

Pre and post stack / 1D, 2D and 3D / Any number of angle stacks

4 dimensional wavelet field

A constrained non-linear optimisation is solved at every trace location

3 fundamental constraints

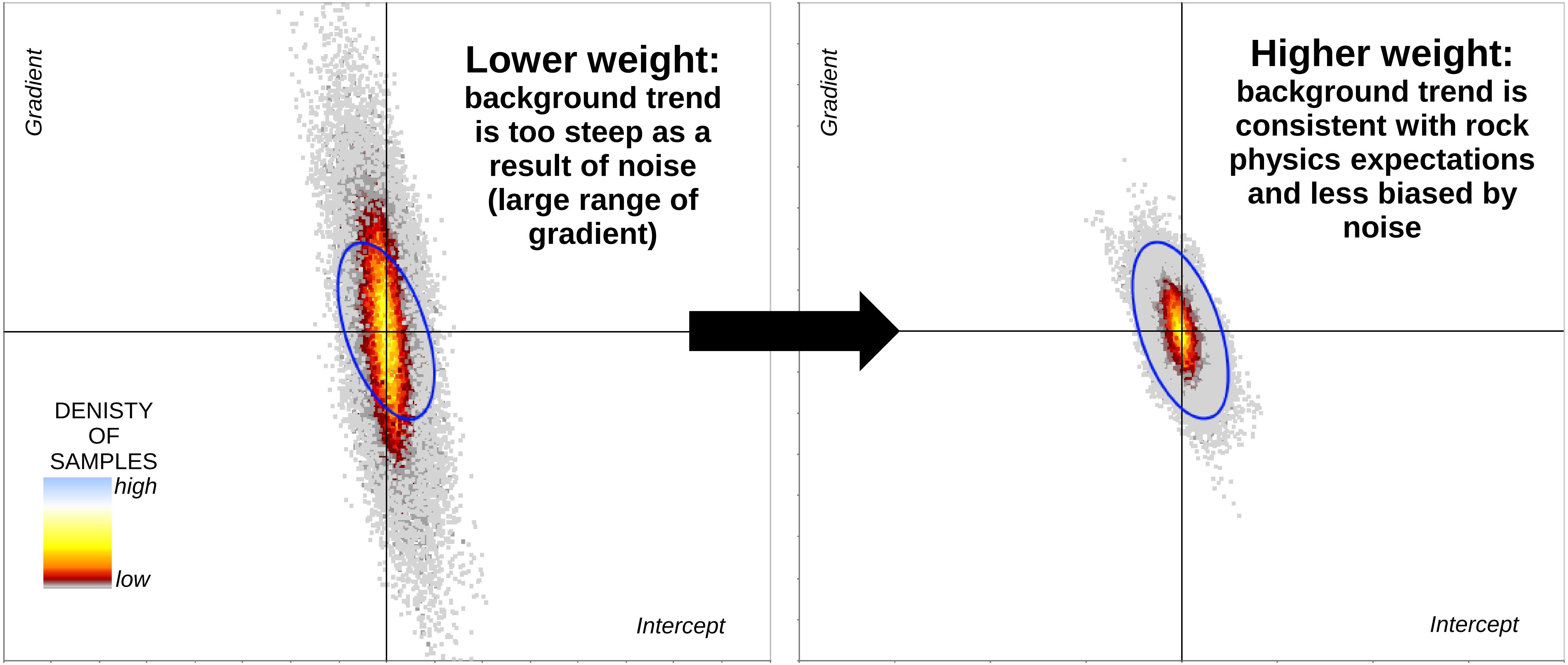
Seismic matcher

High frequency damper

Low frequency damper

Other constraints including **Rock Physics AVA Covariance** on reflectivity

DUG Spike® - Constrained Simultaneous Inversion



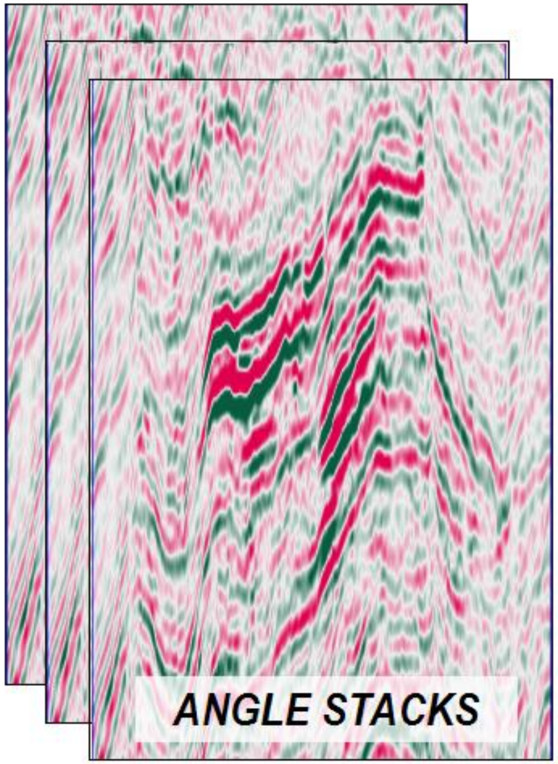
Cross-plot inverted of intercept vs gradient reflectivity showing the effect of increasing weight on the rock physics AVA covariance constraint. The shape of the expected distribution is shown by the blue ellipse.

Simultaneous Inversion

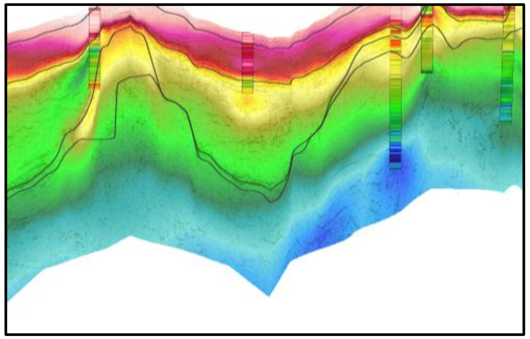
Inversion Products

Simultaneous Inversion

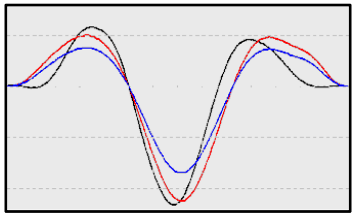
Seismic

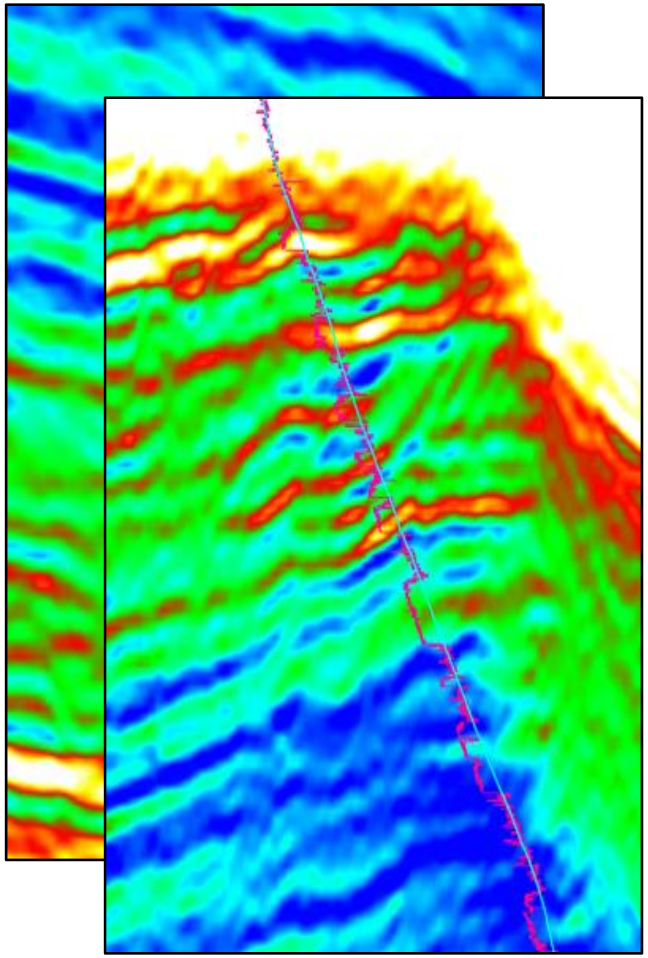


LF Models

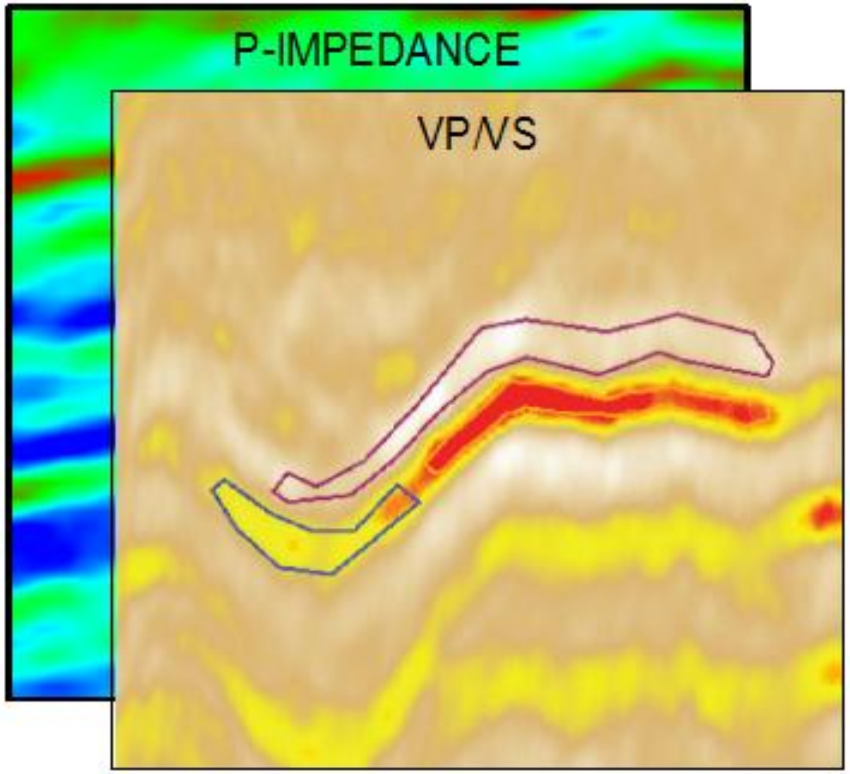


Wavelet Field

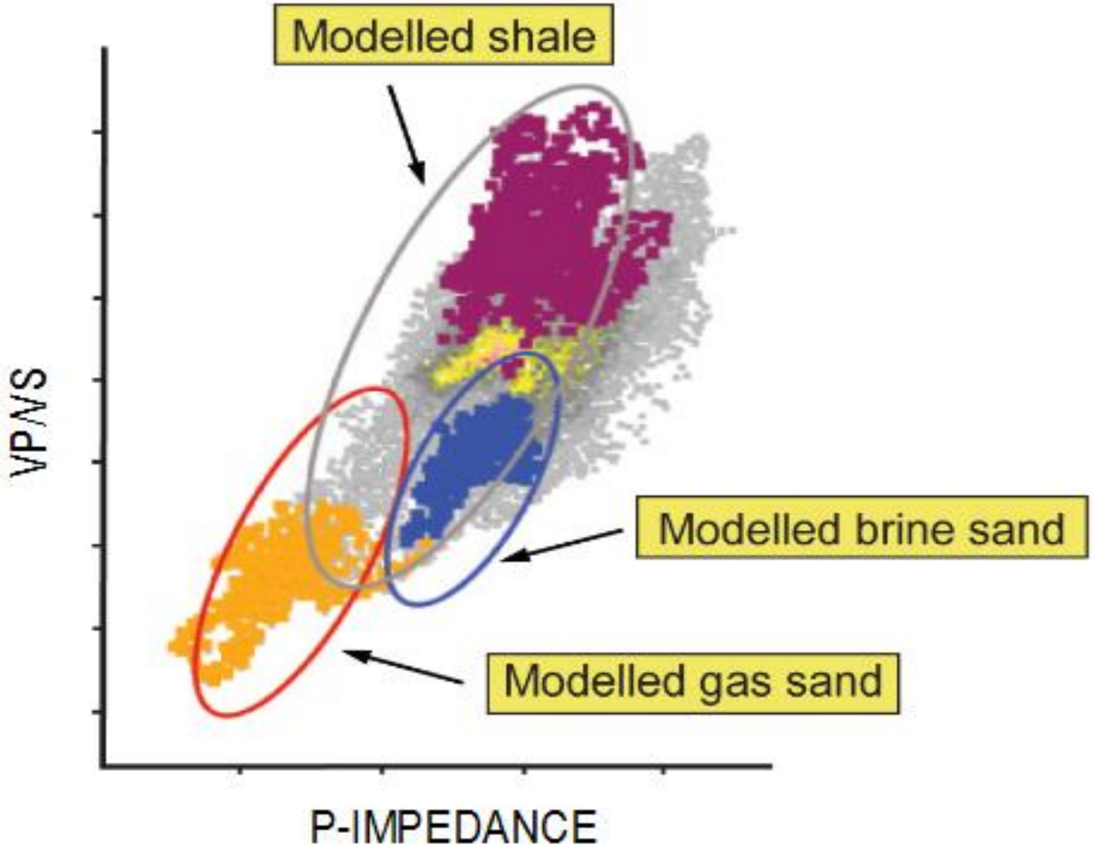




Lithology and Fluid Prediction



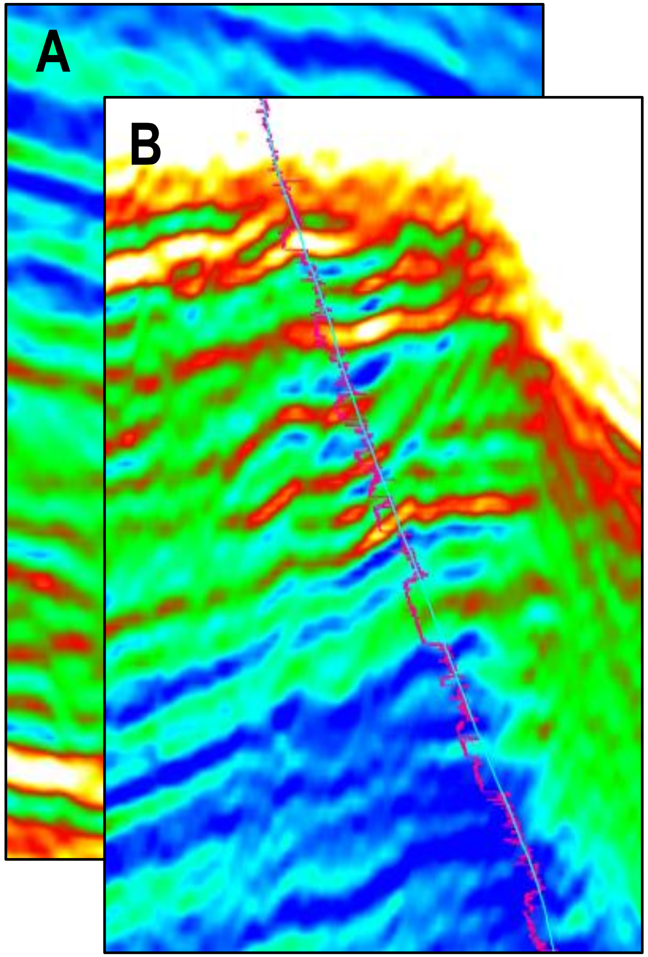
Inverted Rock Properties

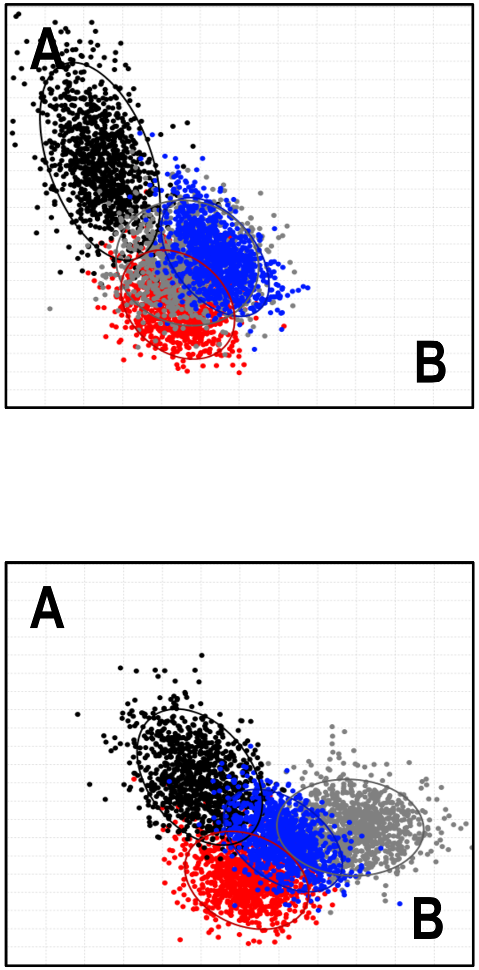


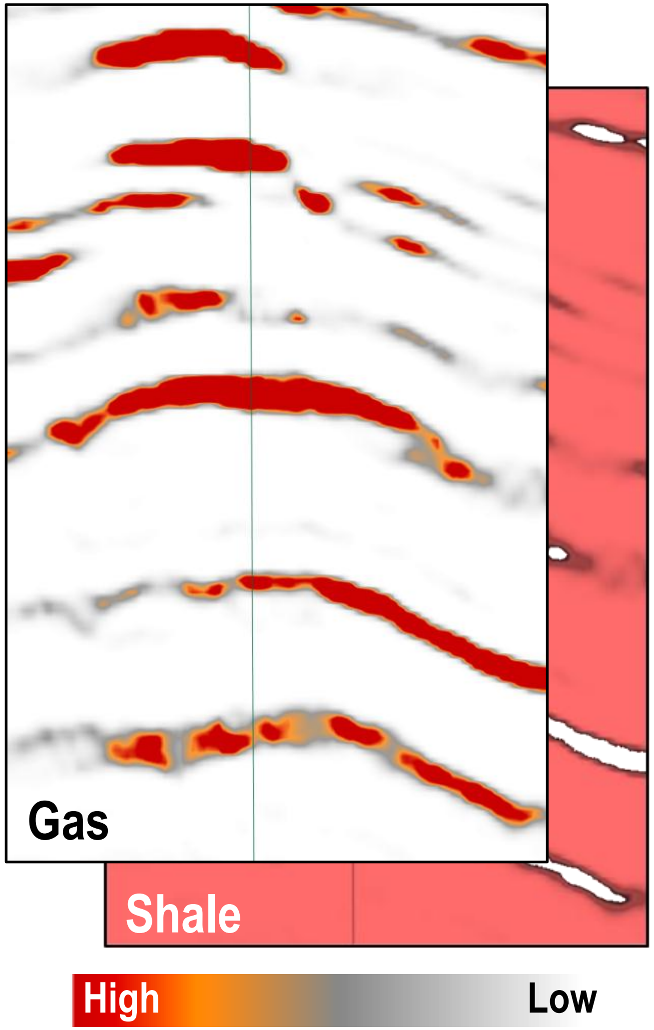
Bayesian Classification

Lithology and Fluid Prediction

Inversion Products ➕ Depth Dependent Rock Physics = Probability Volumes

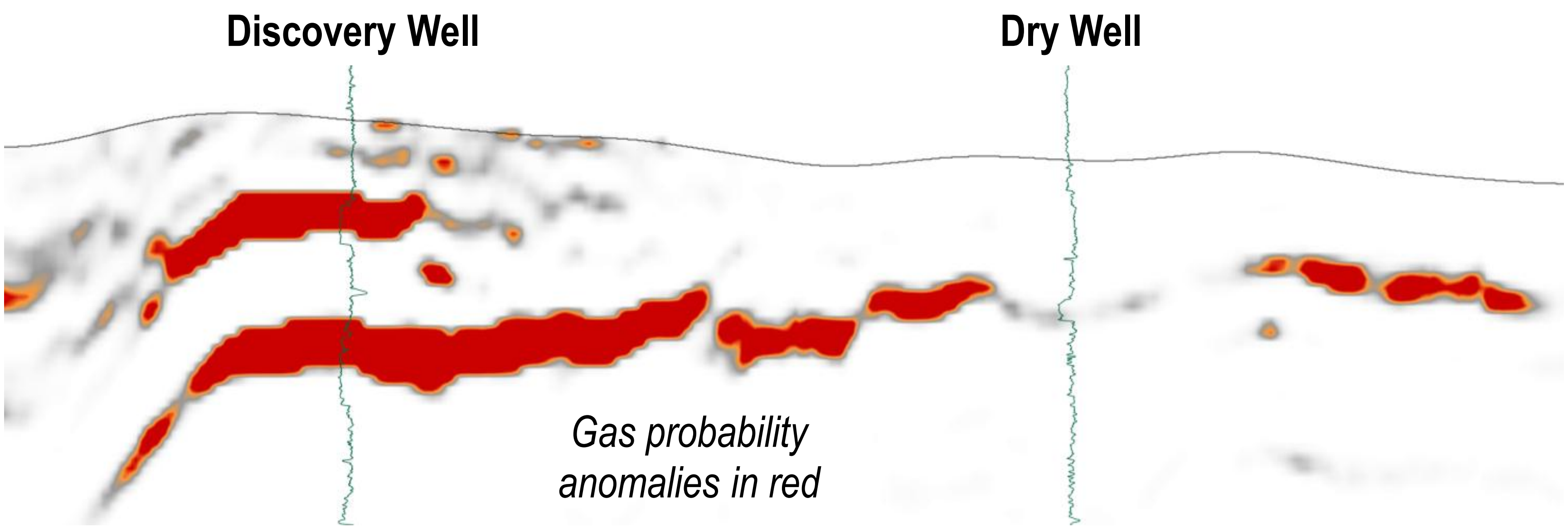






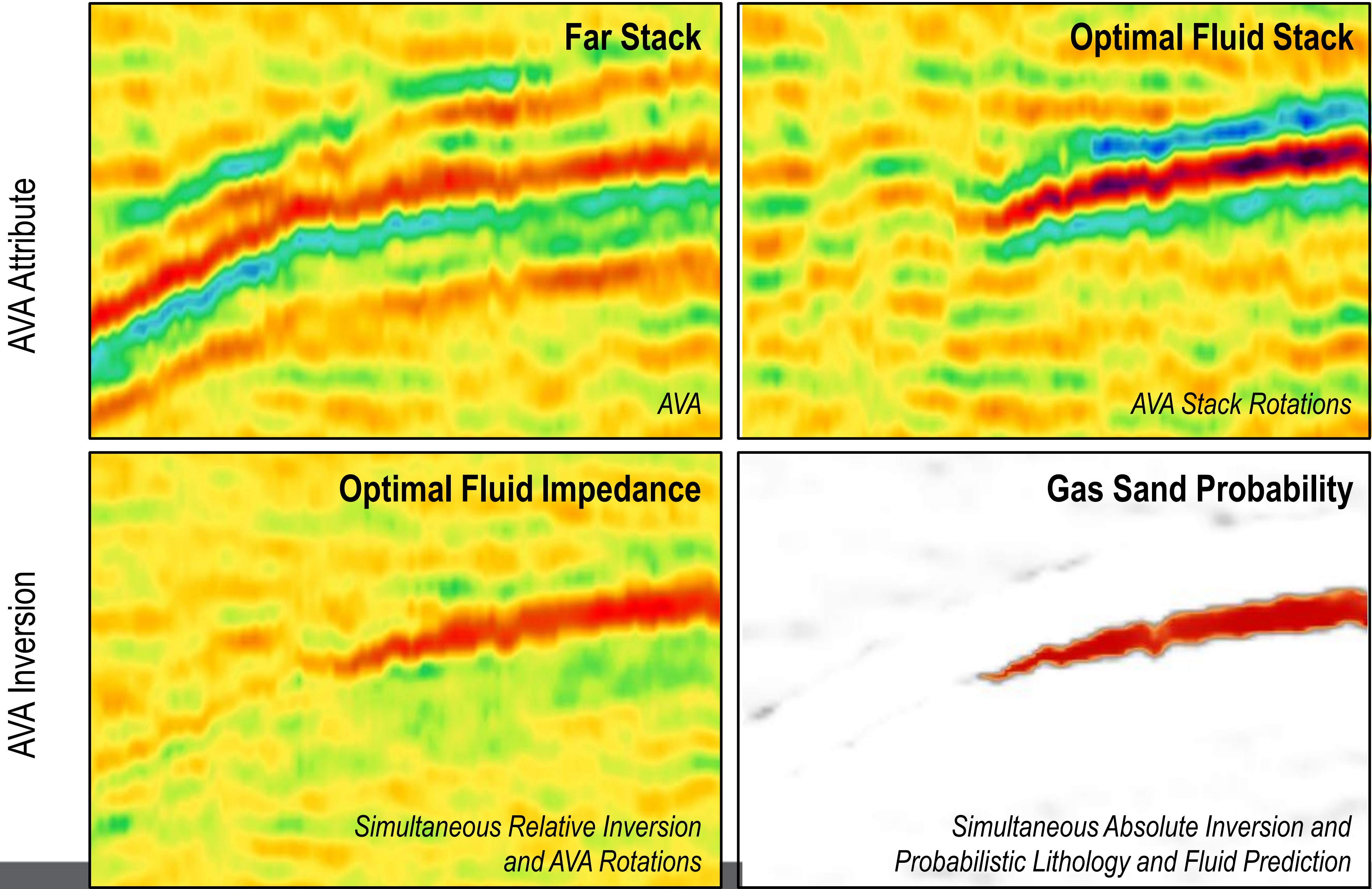
Adding Value with Inversion

Inversion and seismic reservoir characterisation provided confidence to drill downdip of a dry well → the first of over a dozen successful new discovery and appraisal wells in this block.

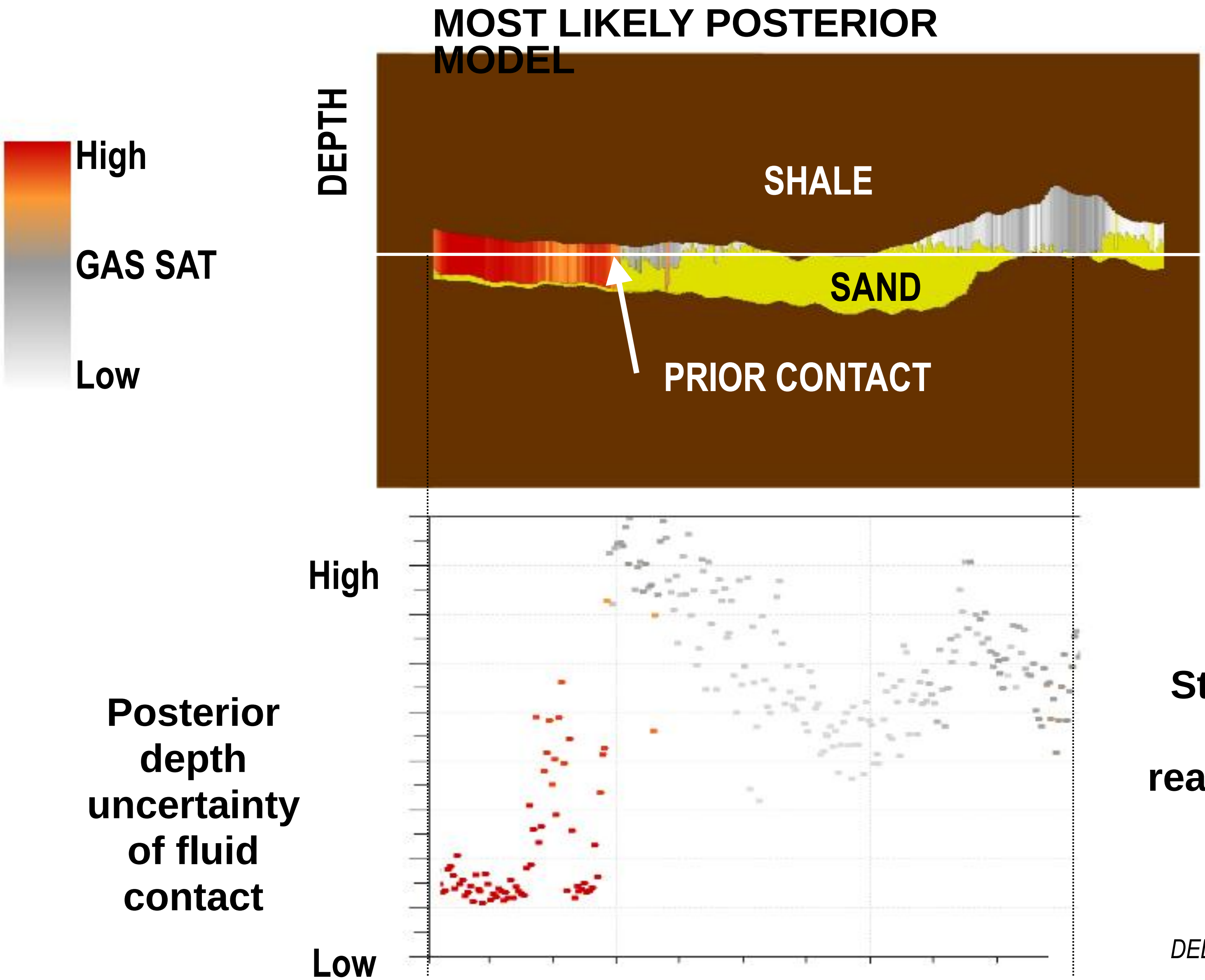


Simultaneous Absolute Inversion and Probabilistic Lithology and Fluid Prediction

Different Workflows



Bayesian Model Based (Stochastic) Inversion (Delivery)



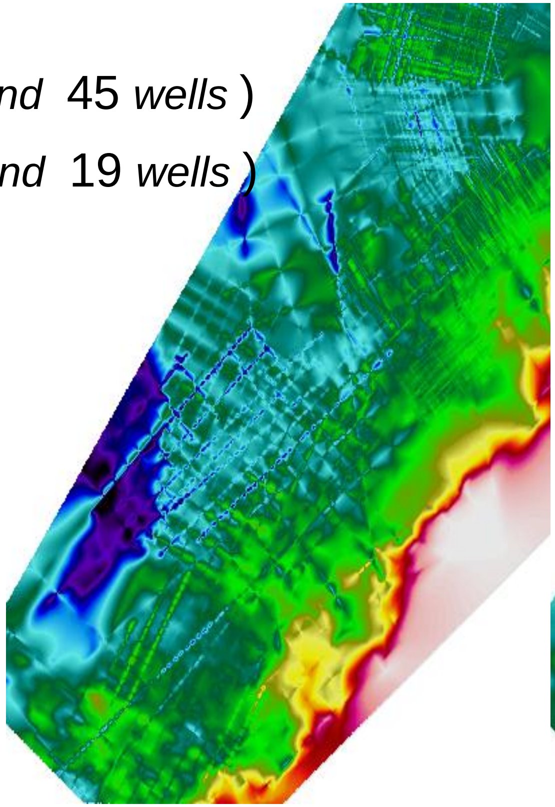
Posterior depth uncertainty of fluid contact

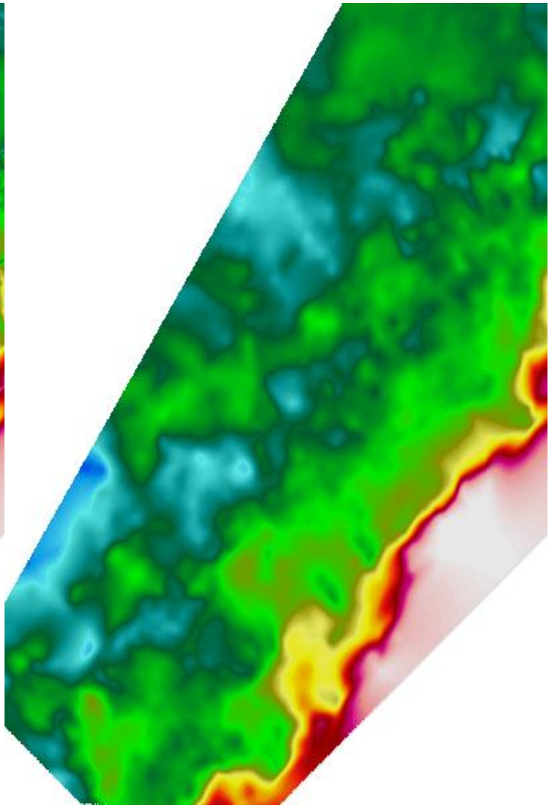
Statistics based on 1000 posterior realisations (statistical significance)

DELIVERY, Gunning and Glinsky, Computers & Geosciences, 30, 2004

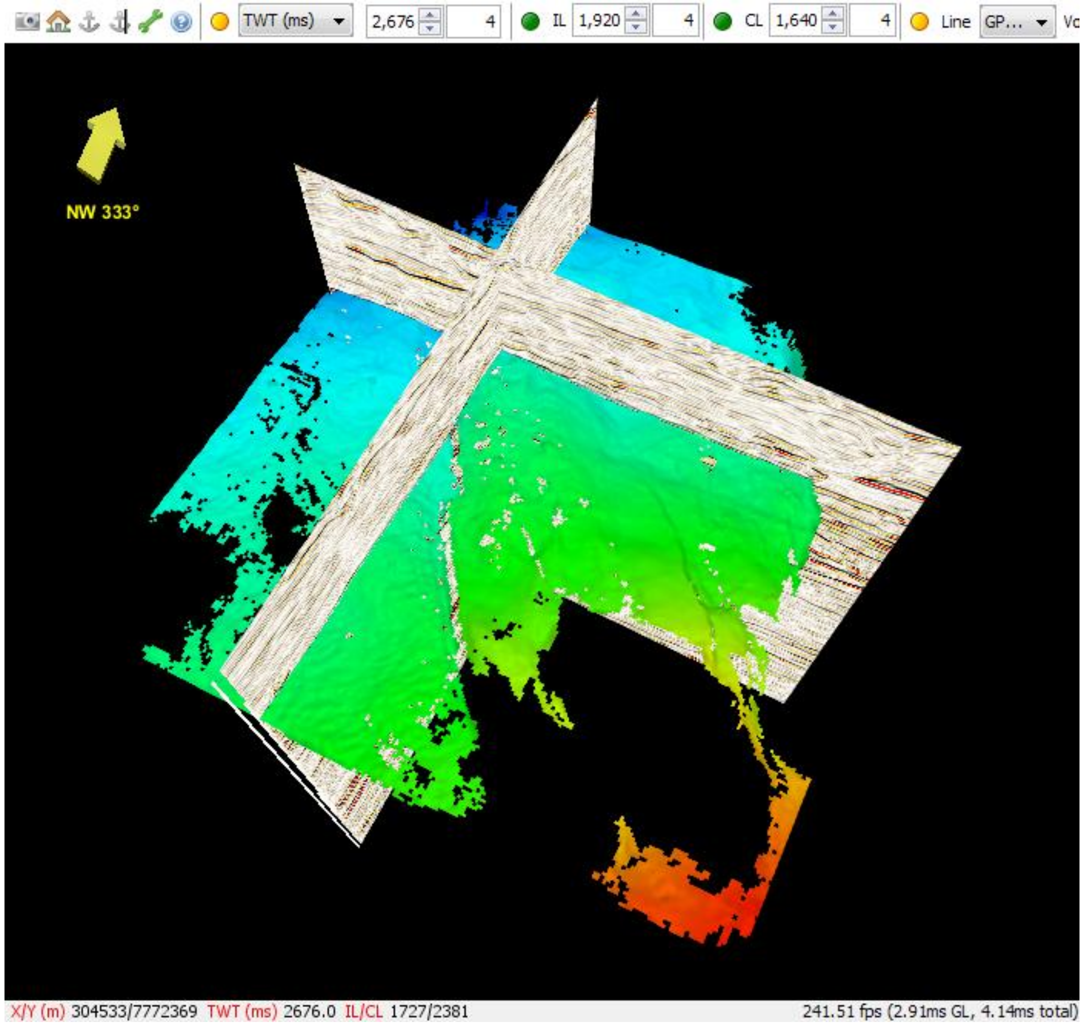
Velocity Conditioning

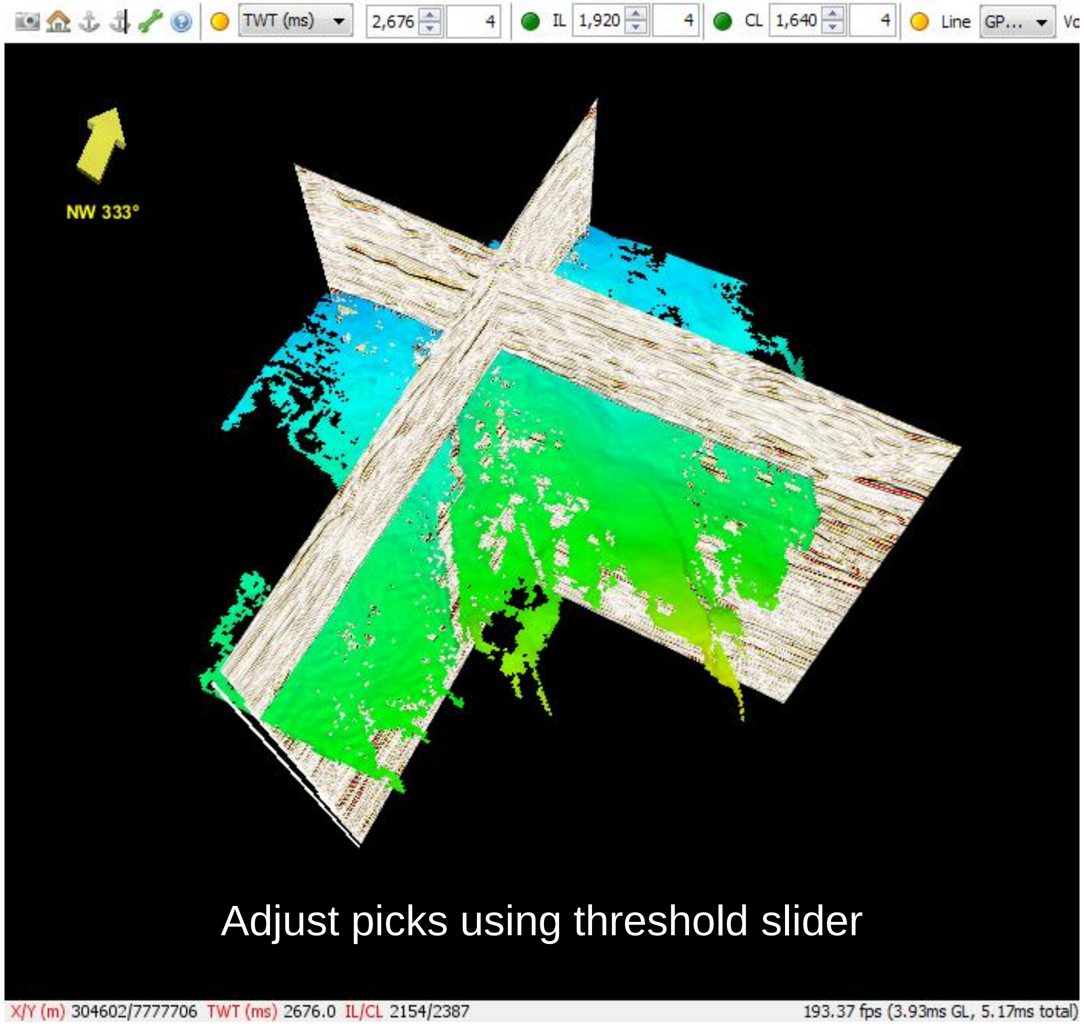
- Multi-survey 2D and 3D
- Conversion/Editing/Smoothing/Reconciling/Interp/Extrap/Merging
- Geostatistical scaling to tie wells
- Horizon consistent
- Recent projects
  - 132,000 km^2 (18 *3D /* 45 *2D surveys and* 45 *wells*)
  - 127,000 km^2 (1 *3D /* 14 *2D surveys and* 19 *wells*)
  - Carnarvon multiclient:
    - 134,000 km^2
    - 50+ *3D surveys*
    - 30+ *2D surveys*
    - 80+ *wells*)



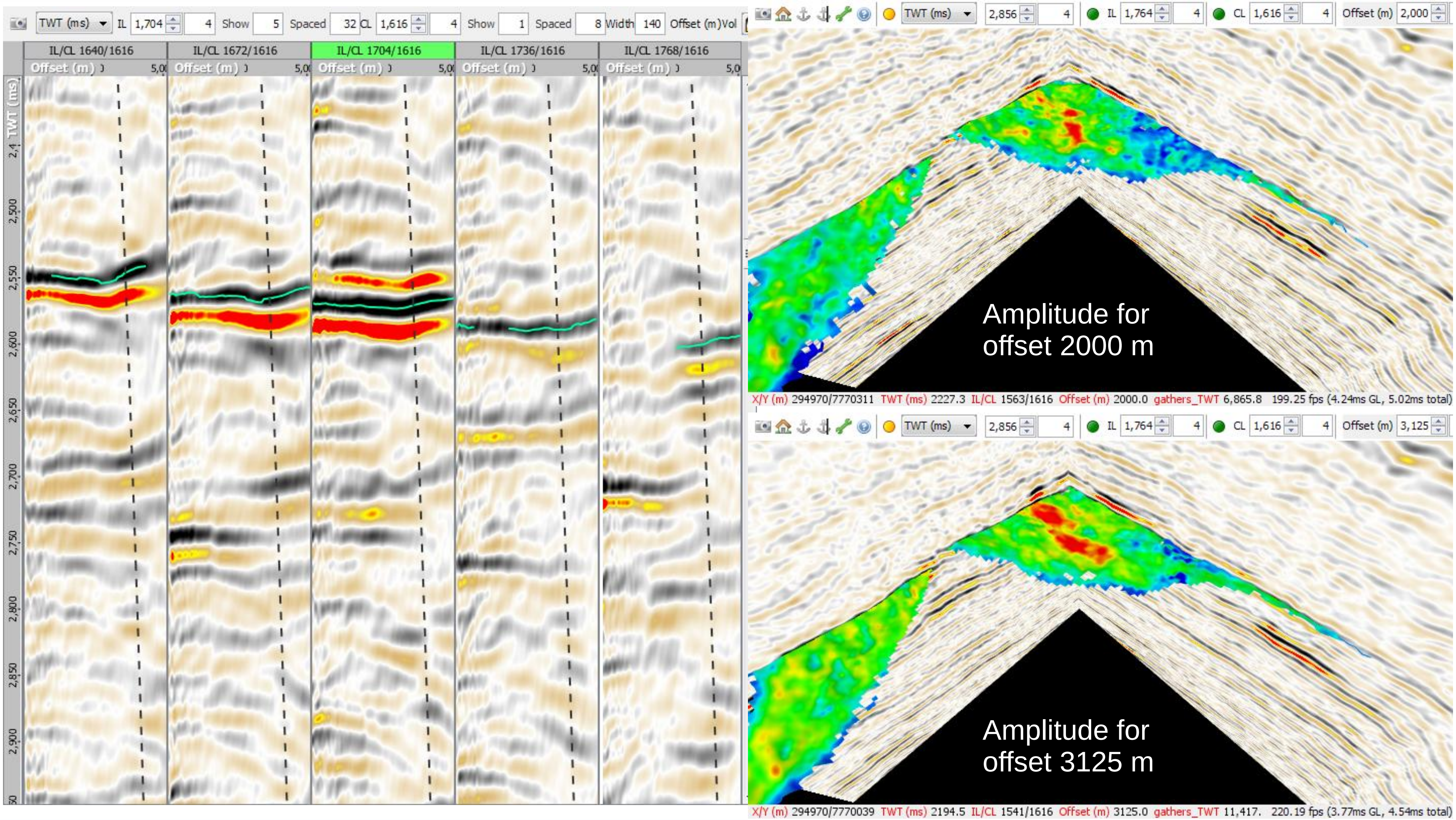


Waveform propagation

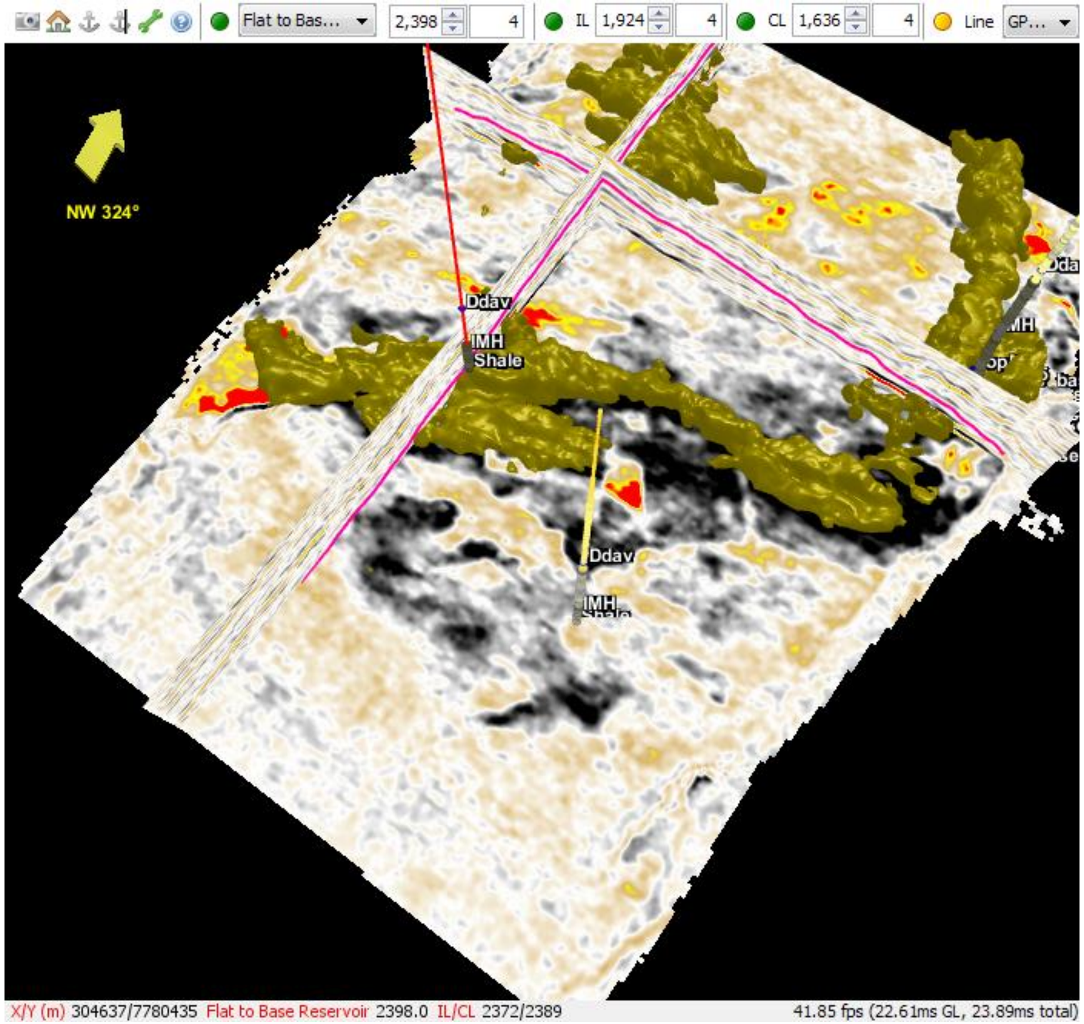


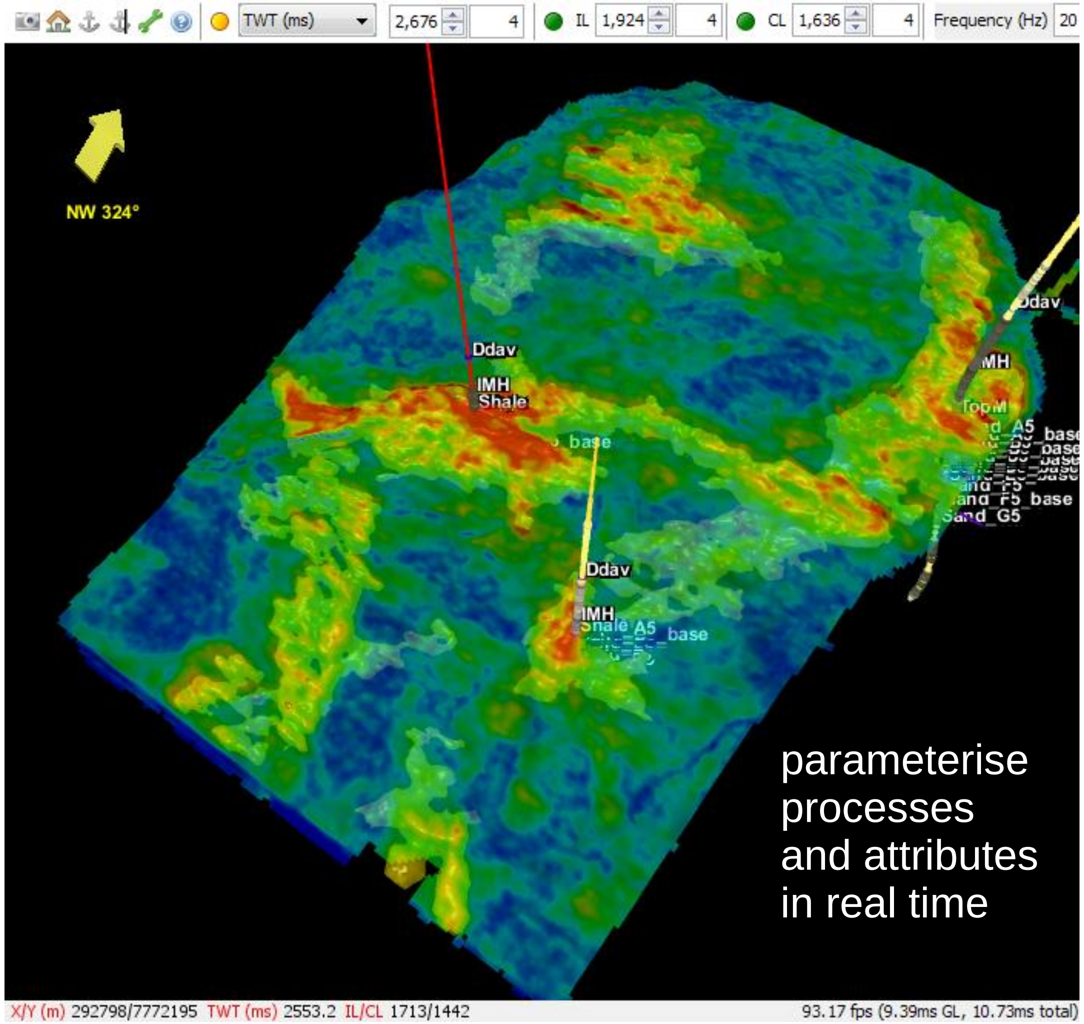


Pre stack interpretation



On the fly processes





parameterise processes and attributes in real time