Seismic calibration and low frequency modeling

The key to quantitative reservoir characterization

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Overview

- Seismic inversion
  - What is it?
  - How to QC lateral variations in wavelet amplitude
- Modeling the low frequencies
  - Inclusion of bodies
  - Estimation by sidelobes

Rock Properties → Reservoir Properties

Wireline Logs

Gamma Ray

Spontaneous Potential

Neutron

Density (ρ)

Resistivity (x5)

Acoustic Sonic (Vp)

Dipole Sonic (Vs)

Elastic parameters

P-impedance (AI) = Vp*ρ

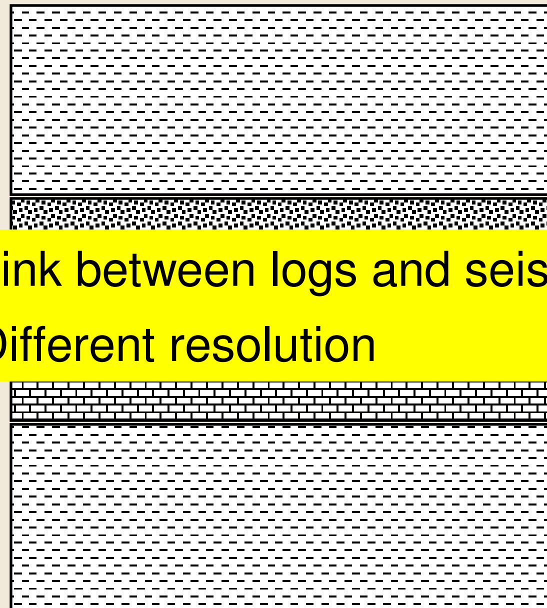
S-impdance (SI) = Vs*ρ

Vp/Vs

Poisson Ratio (σ) = $(Vp^2-2Vs^2)/2(Vp^2-Vs^2)$

Lambda Rho (λρ) = $(AI^2 - 2SI^2)$

Mu Rho (μρ) = SI^2



- Link between logs and seismic
- Different resolution

Seismic Data

P-impedance (AI)

S-impedance (SI)

Vp/Vs

Poisson Ratio (σ)

Lambda Rho (λρ)

Mu Rho (μρ)

Lithology

ϕ - Porosity

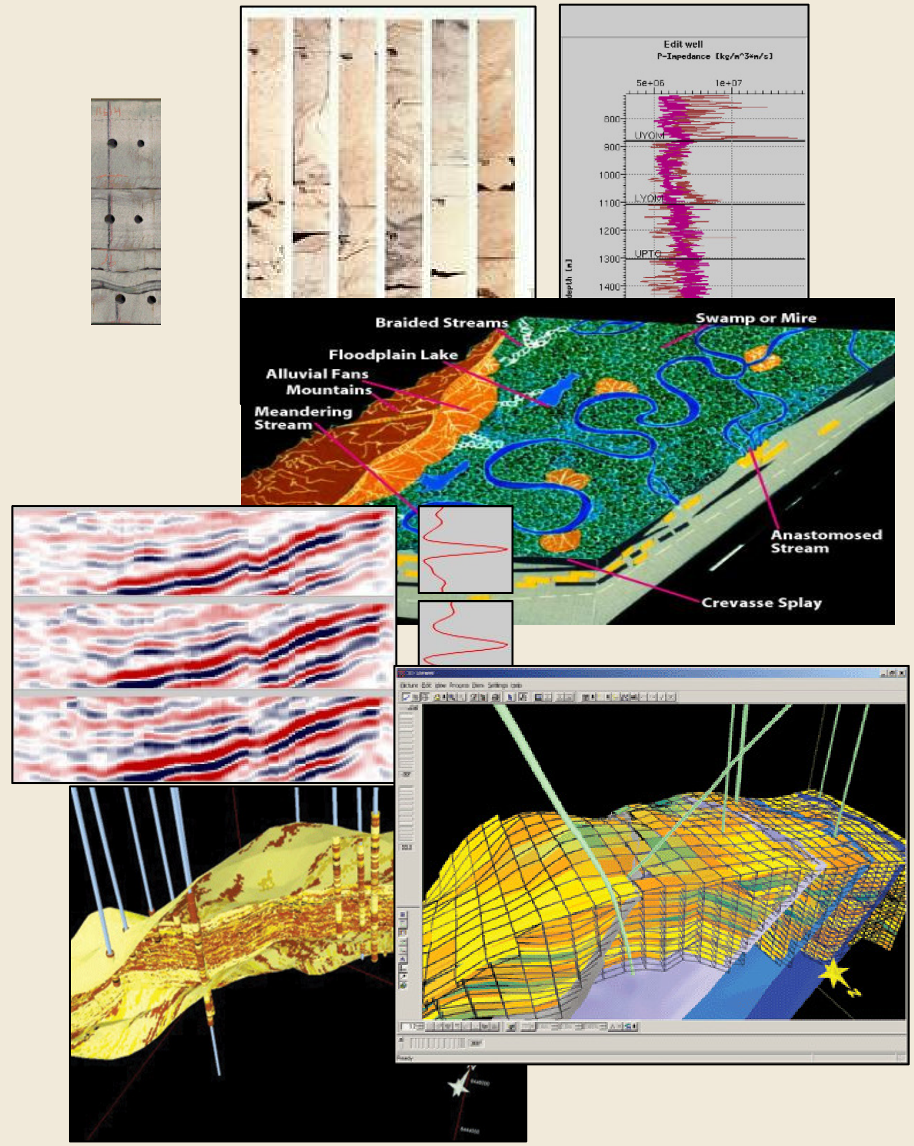
Fluid Type

Reservoir Geometry

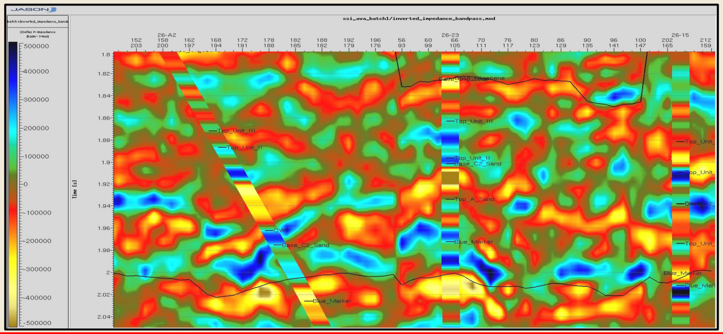
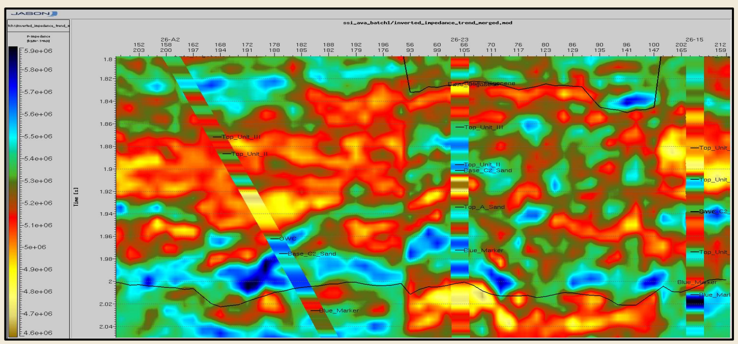
Reservoir Connectivity

Inversion integrates data from all disciplines

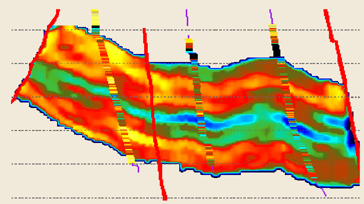
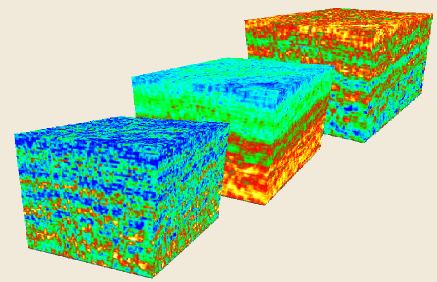
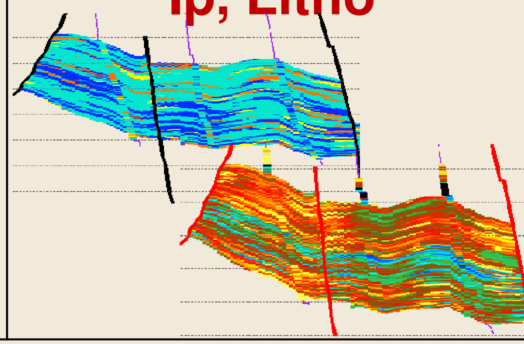
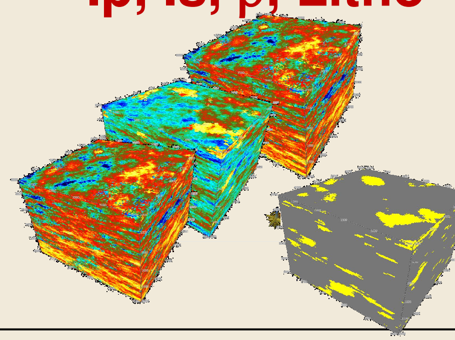
- Petrophysical Data
  - Understanding of the formations, the geology & the rock properties
- Geological Data
  - Structural models, property maps, reservoir size and shape
- Geophysical Data
  - Rock properties as seen by seismic data
- Engineering data
  - Property maps, fluid contacts, reservoir connectivity, flow simulation



Generating properties - key components

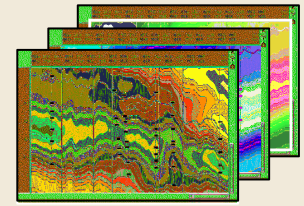
Workflow	Outputs
Relative impedance 	• Relative layer properties • Qualitative interpretation
Absolute impedance 	• Absolute layer properties • Qualitative and quantitative interpretation • Reduction of tuning

Inversion workflows – absolute impedance

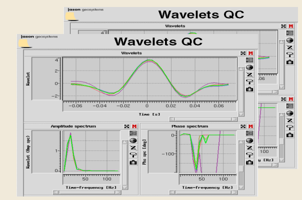
	Full stack	Partial stack
Seismic Detail → Deterministic (CSSI)	Ip 	Ip, Is, ρ 
Log Detail → Geostatistical (MCMC)	Ip, Litho 	Ip, Is, ρ, Litho 

Key Features of an Inversion Workflow

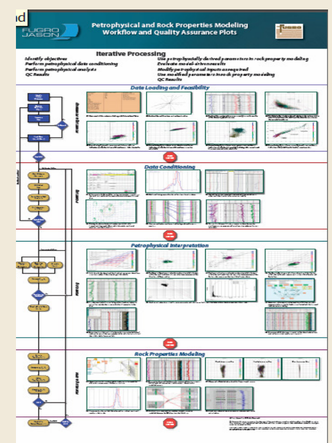
- Low frequency modeling
  - sophisticated interpolation: user-defined weighting functions, Multi-Attributes Well Interpolation



- Stable and accurate wavelet estimation
  - Both in full stack and partial stack mode
  - Changes in reflectivity with offset/angle are properly handled
  - Multi-well estimation



- Flexible QC options for selecting the best inversion parameters
  - QC parameter individually or by group
  - Systematically scan or optimization

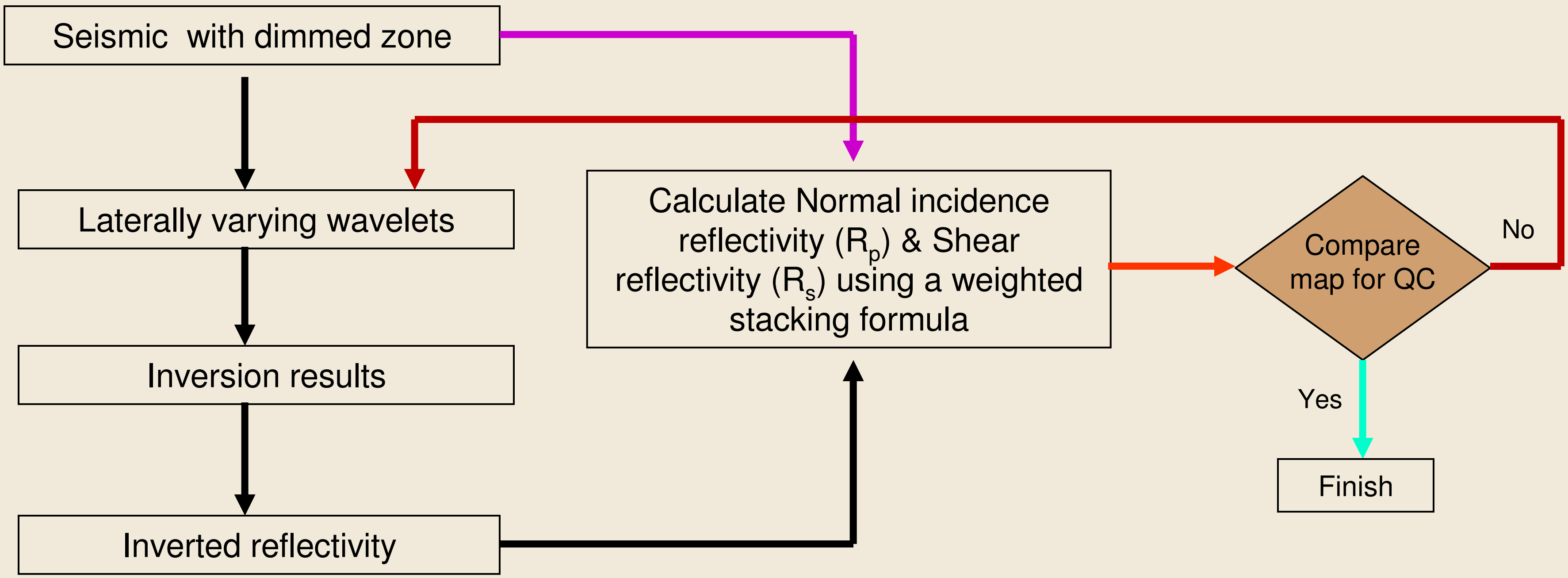


- Advanced options in simultaneous inversion
  - Laterally-varying wavelets
  - Vertically-varying wavelets: Q- and Scale-factors
  - NMO stretch

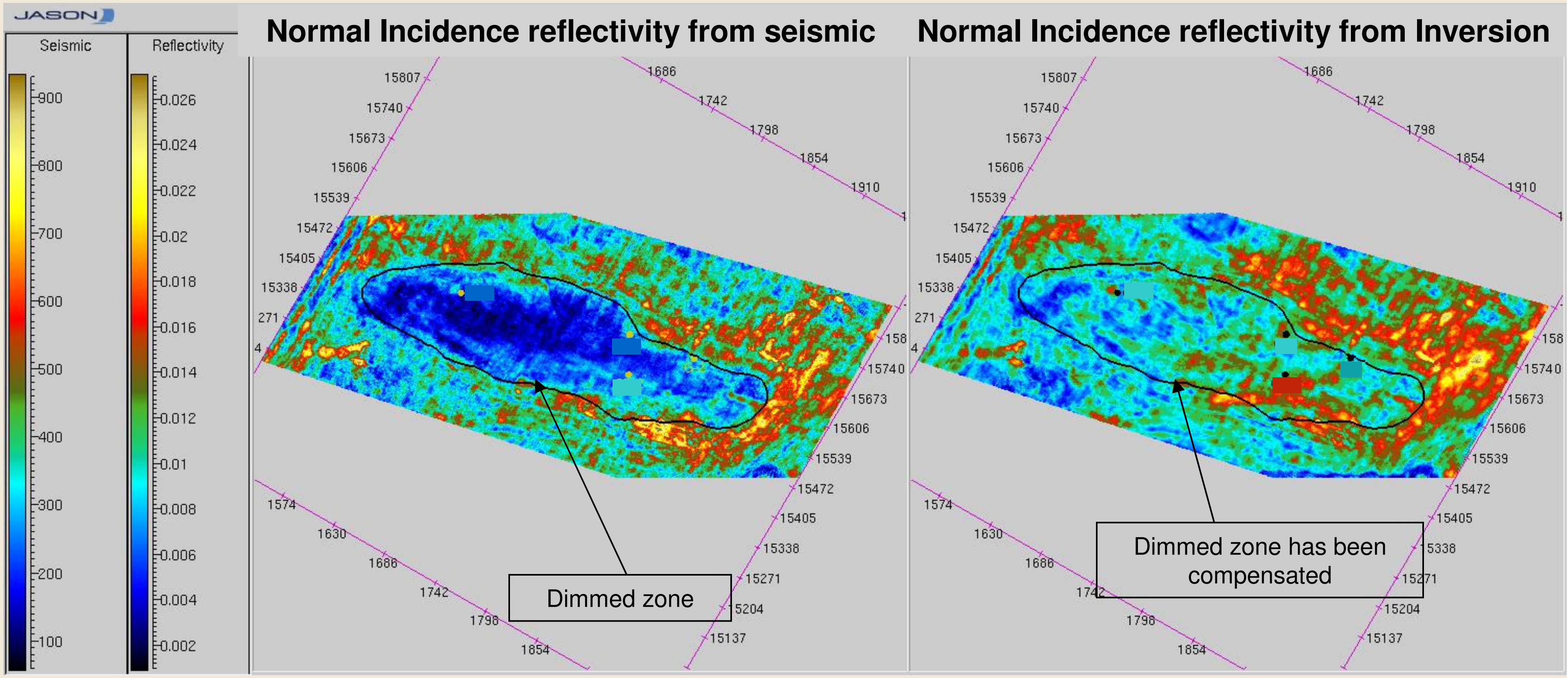
Laterally varying seismic amplitude and phase

- Due to overburden effects
  - Gas cloud
  - Salt or shale diapir
  - Chalk
- Varies with position and offset
- Needs to be compensated with laterally varying wavelets
- Careful QC to avoid false amplitude or AVO

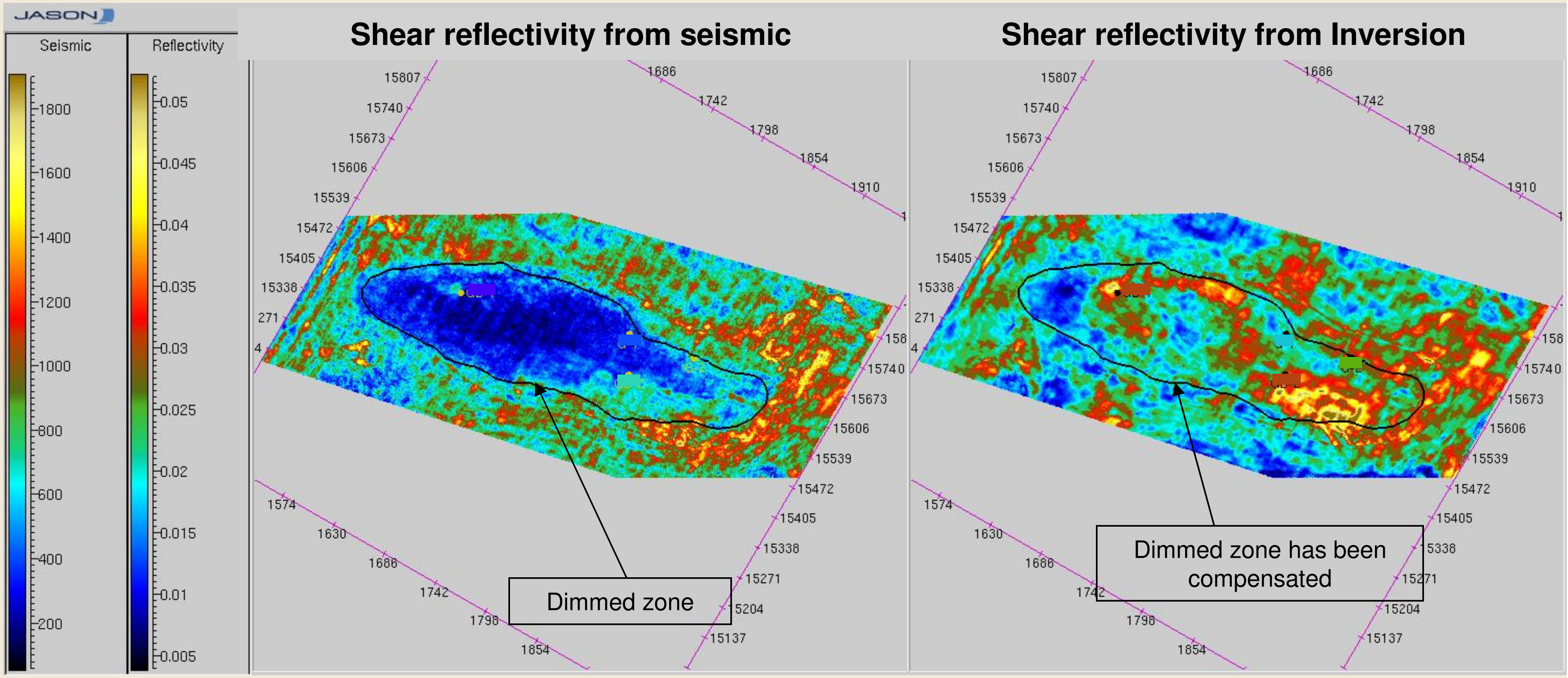
Use inversion to QC laterally varying wavelets



Normal incidence reflectivity RMS map



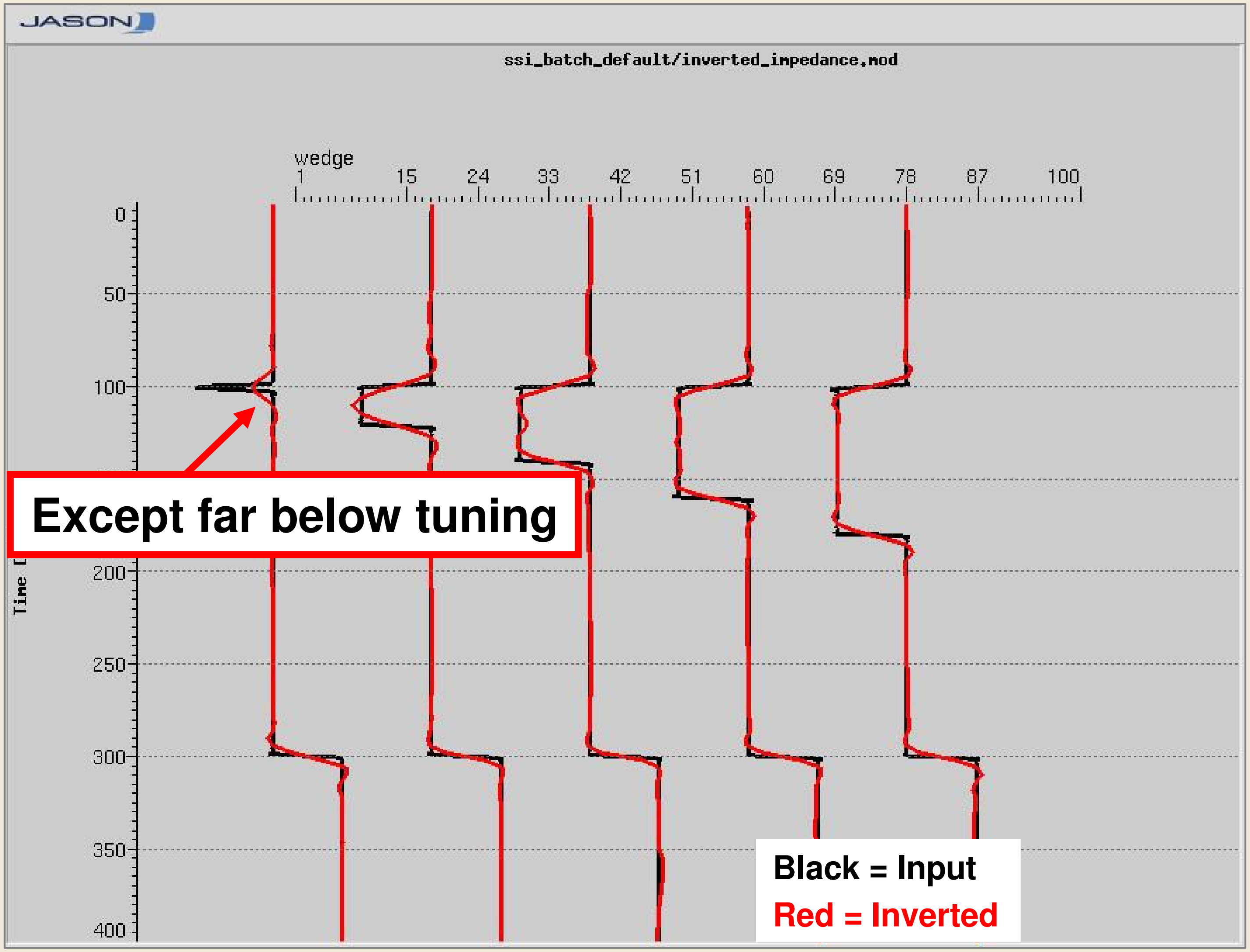
Shear reflectivity RMS map



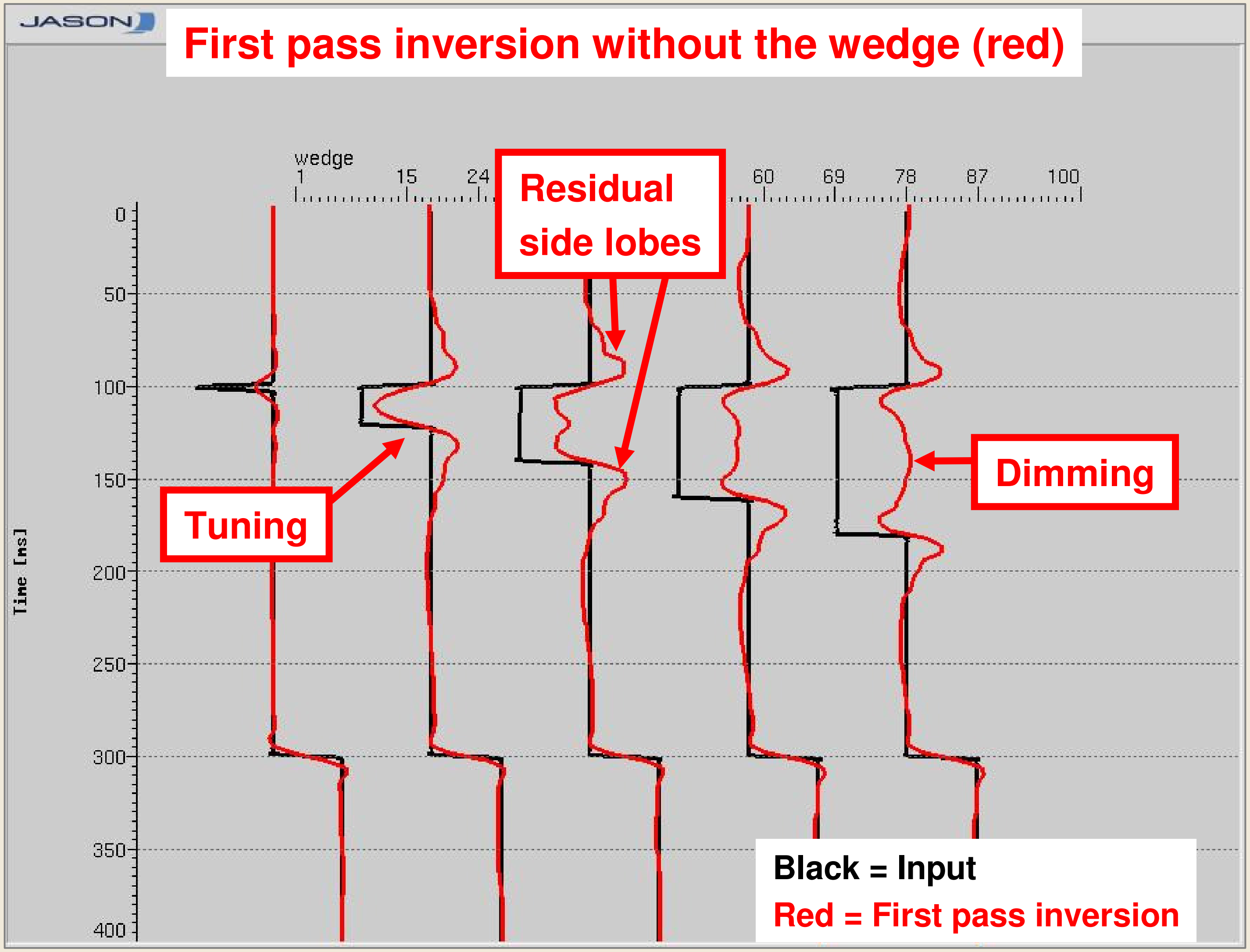
Modeling the low frequencies: How?

- Well interpolation
  - Interpolation concurrent to deposition and structure
  - Preferential location of wells causes bias
  - Over-imprint of good reservoir
- Iterative modeling using body capturing from first pass inversion
- Iterative modeling using the side lobes from a first pass inversion

Full bandwidth inversion is quantitative

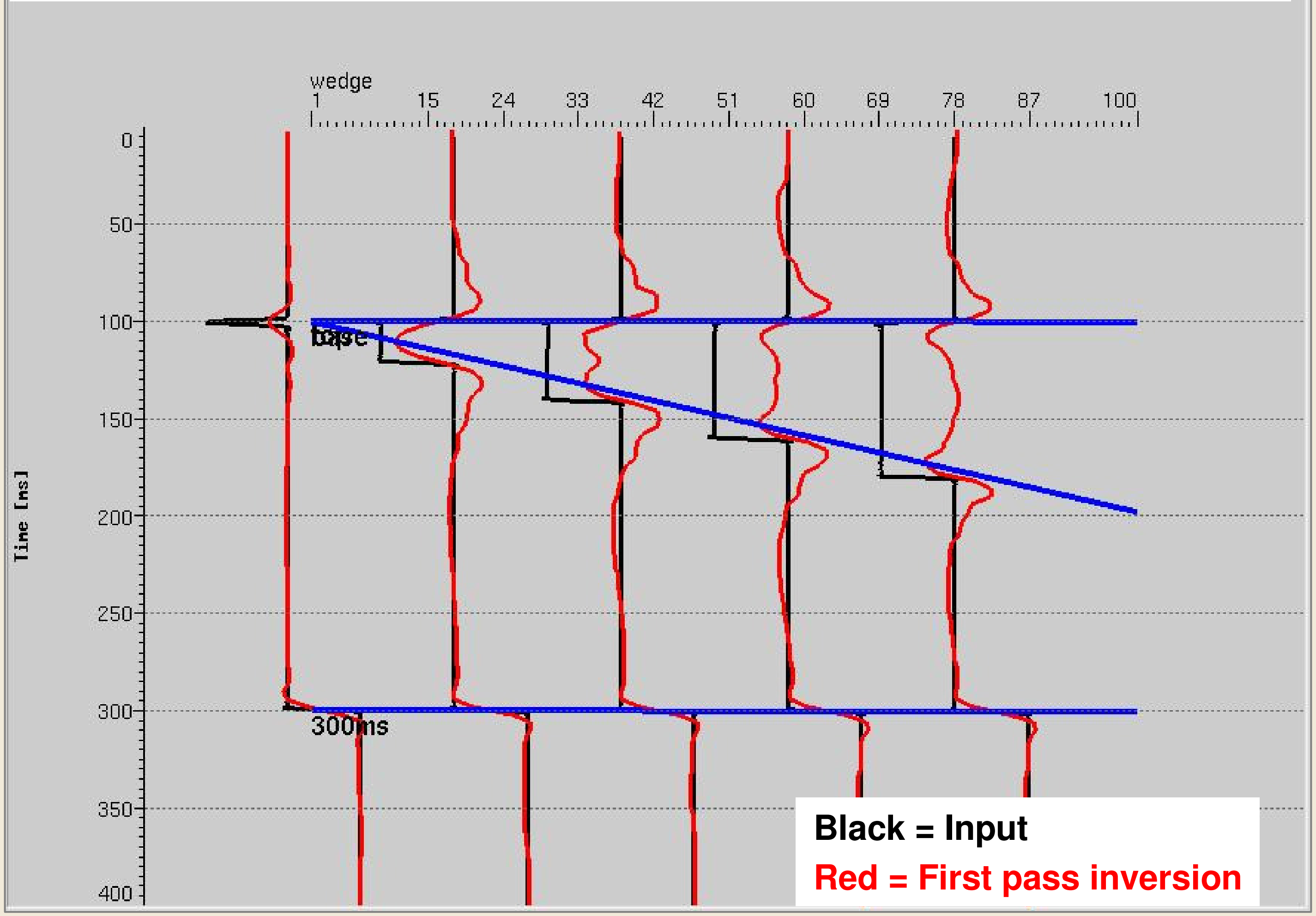


What if layer is not included in low frequency?



What if layer is not included in low frequency?

Interpret and add to the EarthModel in a second pass



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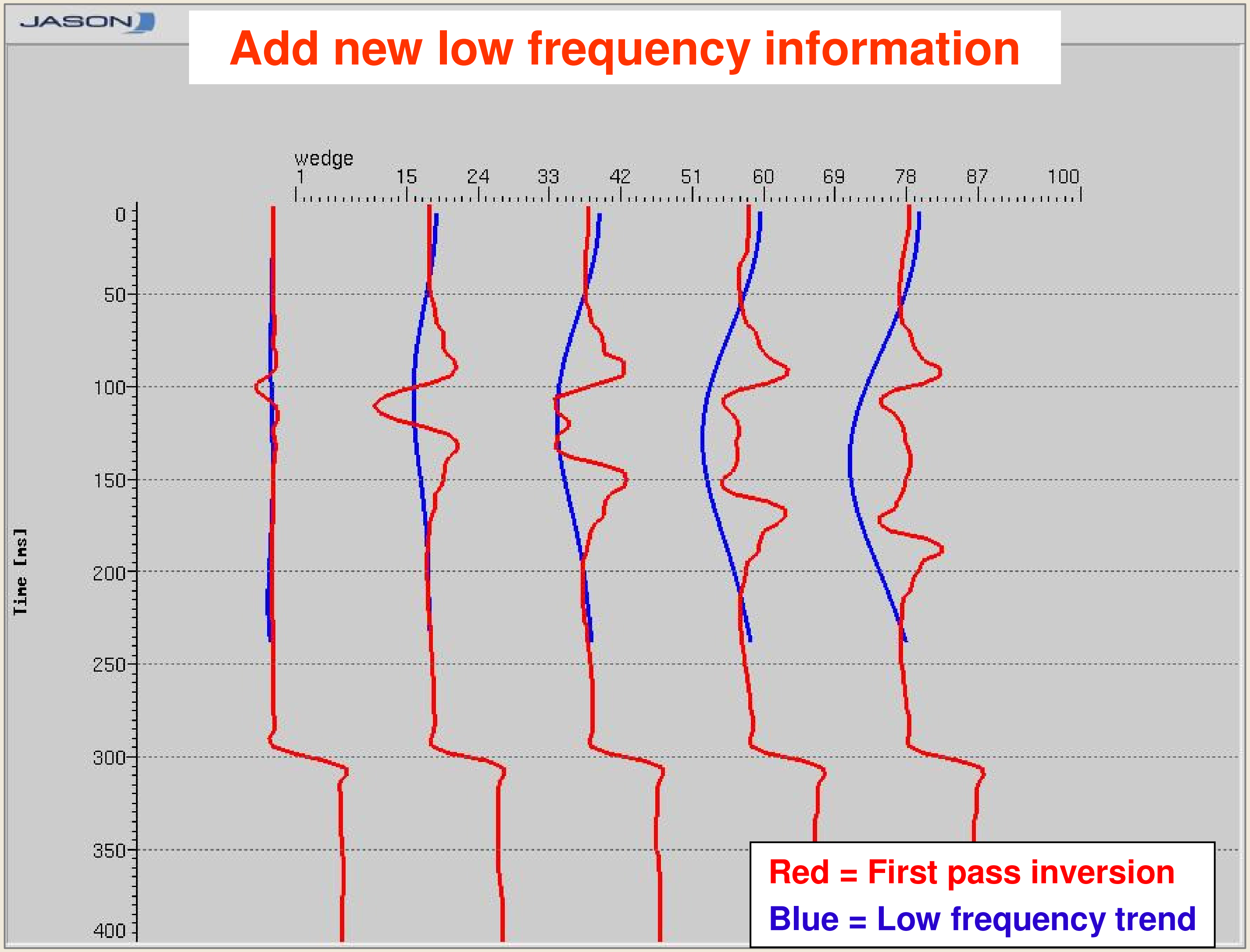

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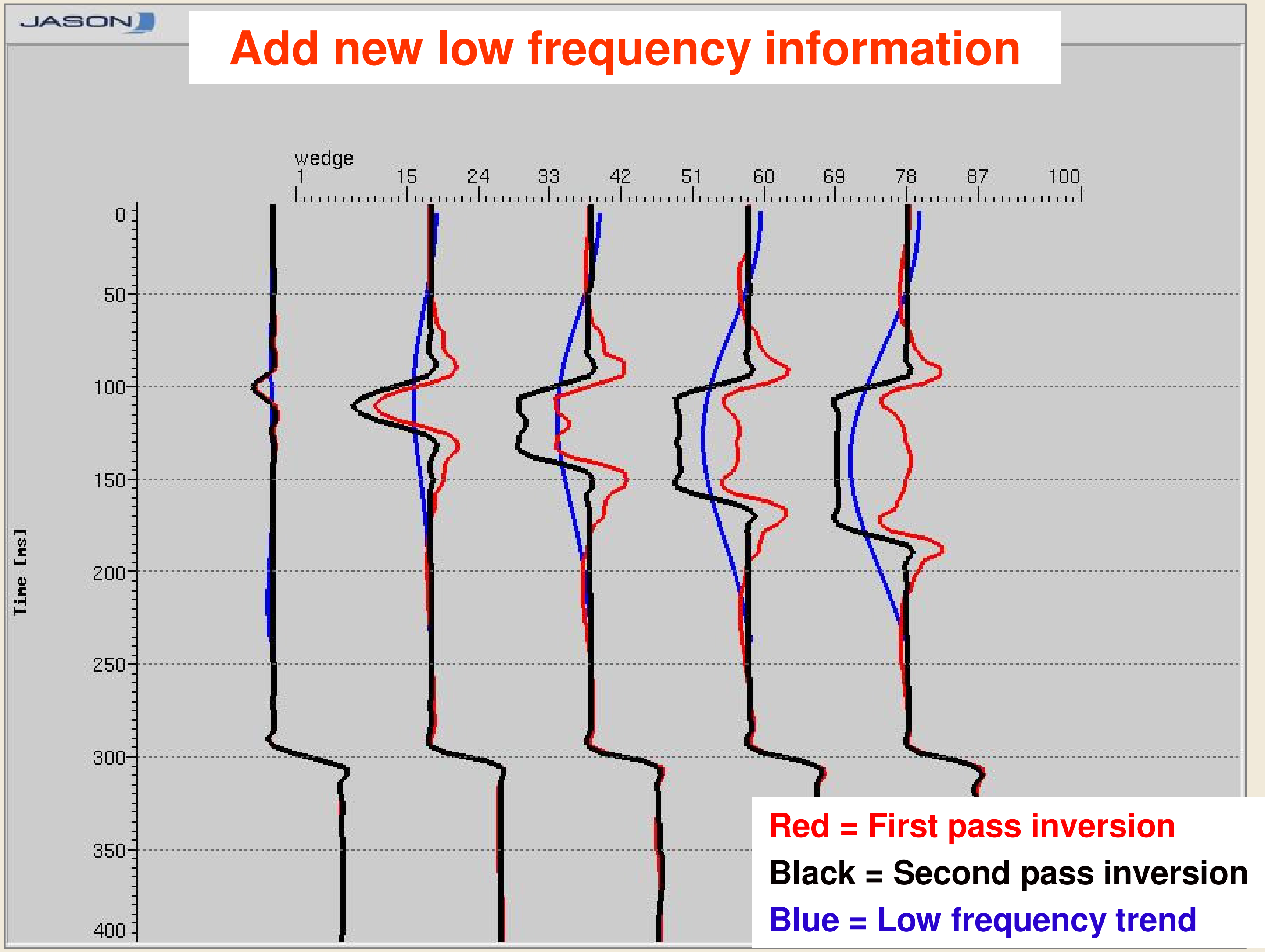
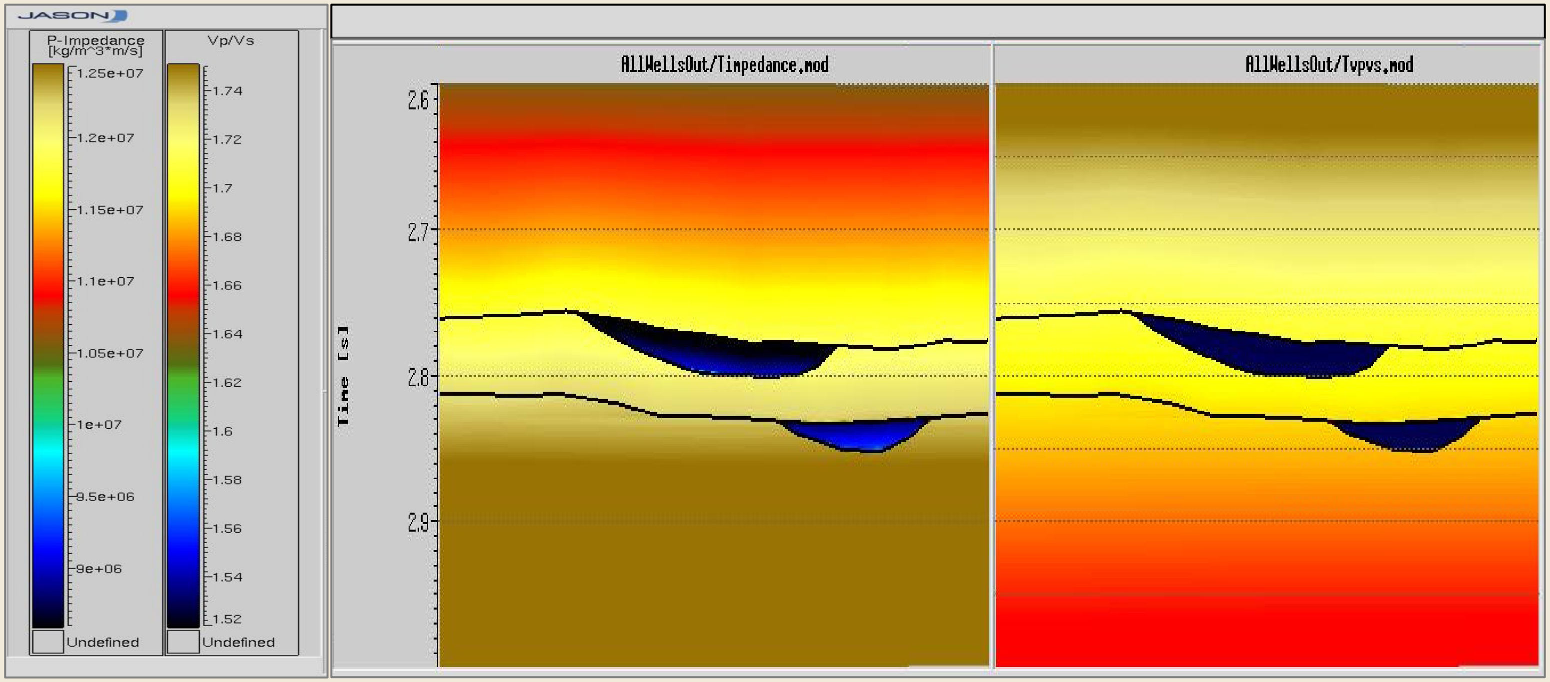


Sand channels in a shale background

- A synthetic model based on real data:
  - Two channel sands in a shale

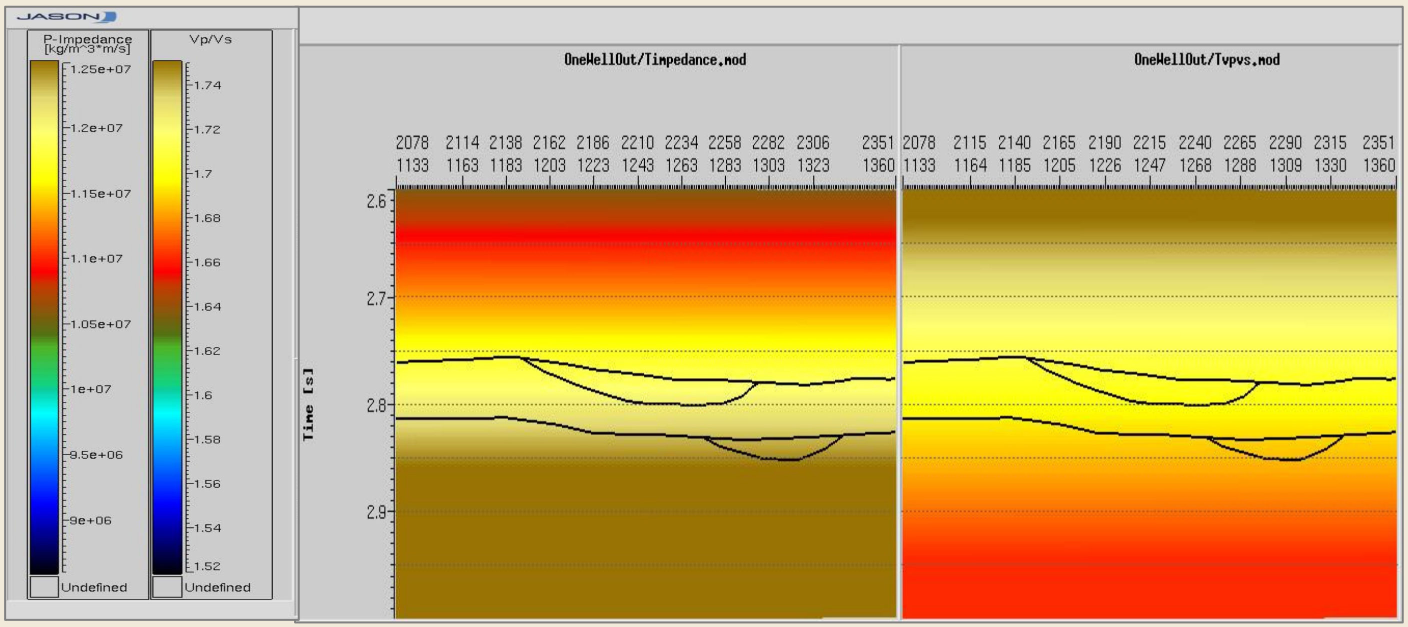


LF modeling workflow

- Run an inversion with a simple trend model
- Capture the lithology based on the first pass inversion results
- Update the low frequency model based on
  - Captured bodies and trend or
  - Captured bodies and rock physics information
- Run a new inversion with the updated trend model

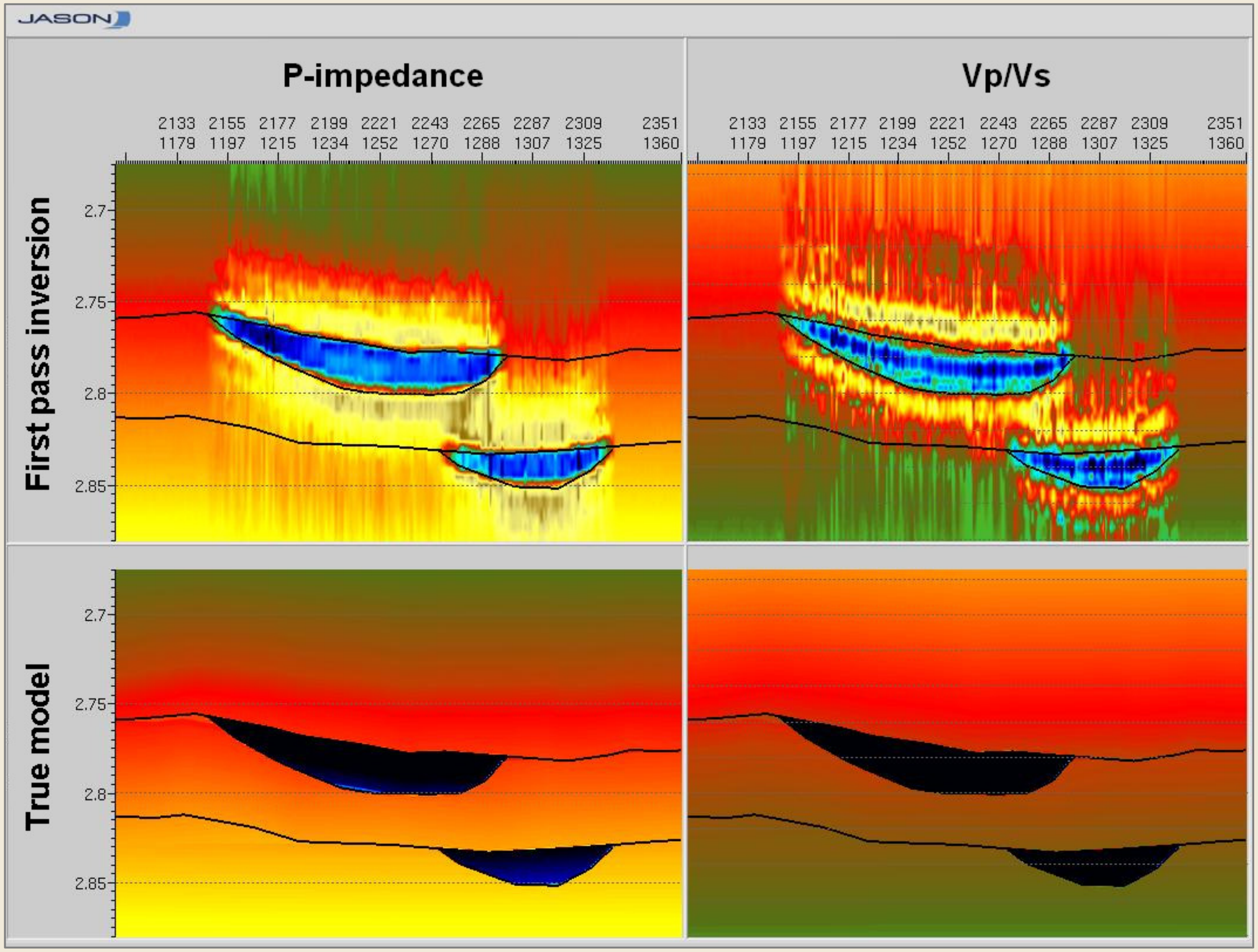
Simple trend model

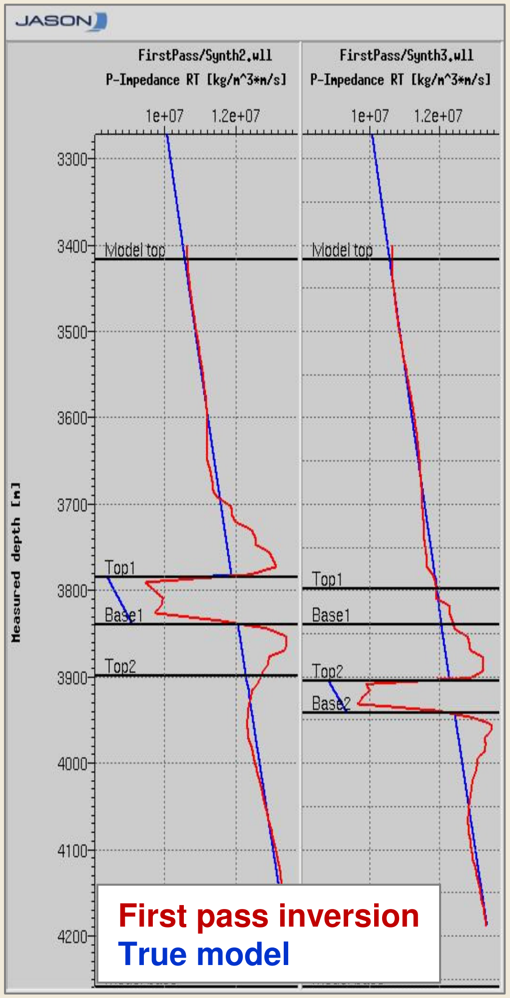
- A simple trend model:
  - Shale trend used for first pass inversion



First pass inversion results

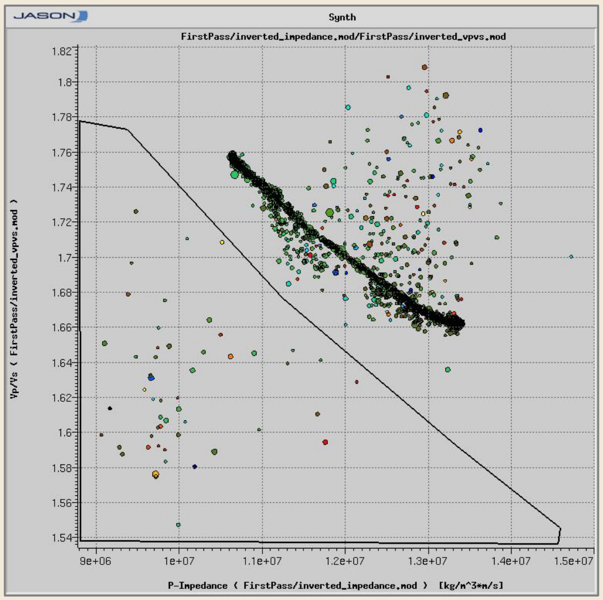
- Shale trend is used for first pass inversion

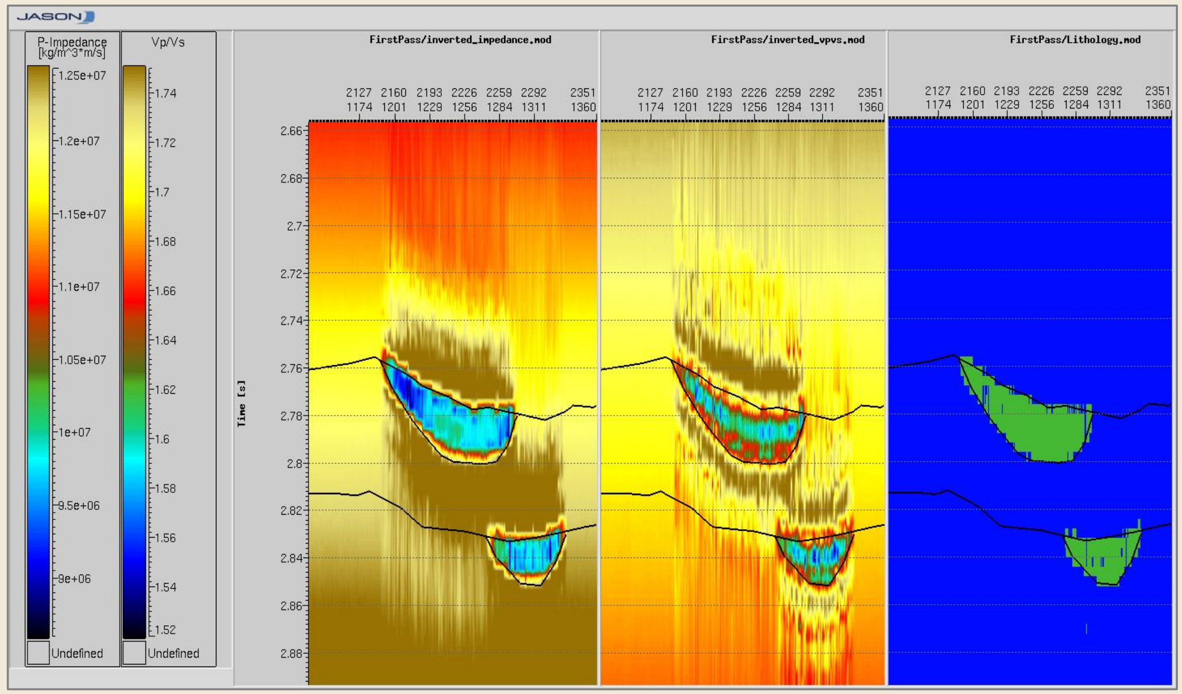




Body capture

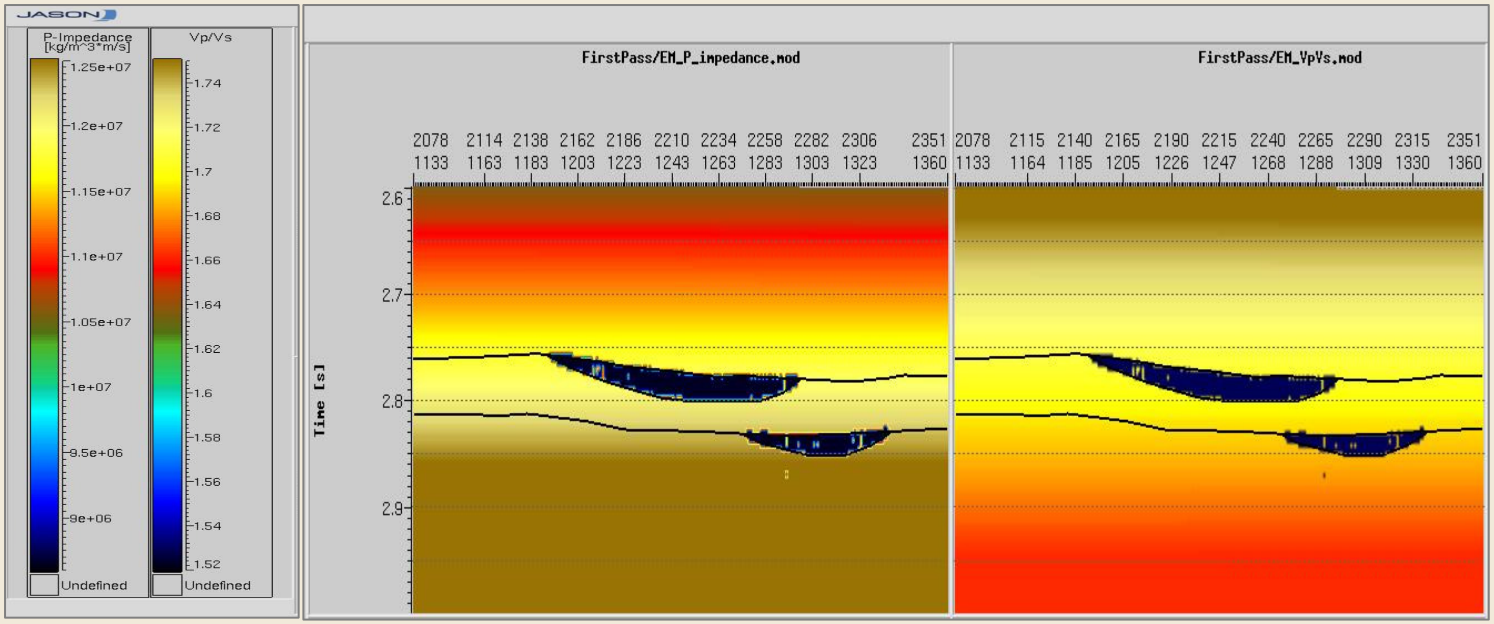
- Potential sands are captured from first pass inversion results



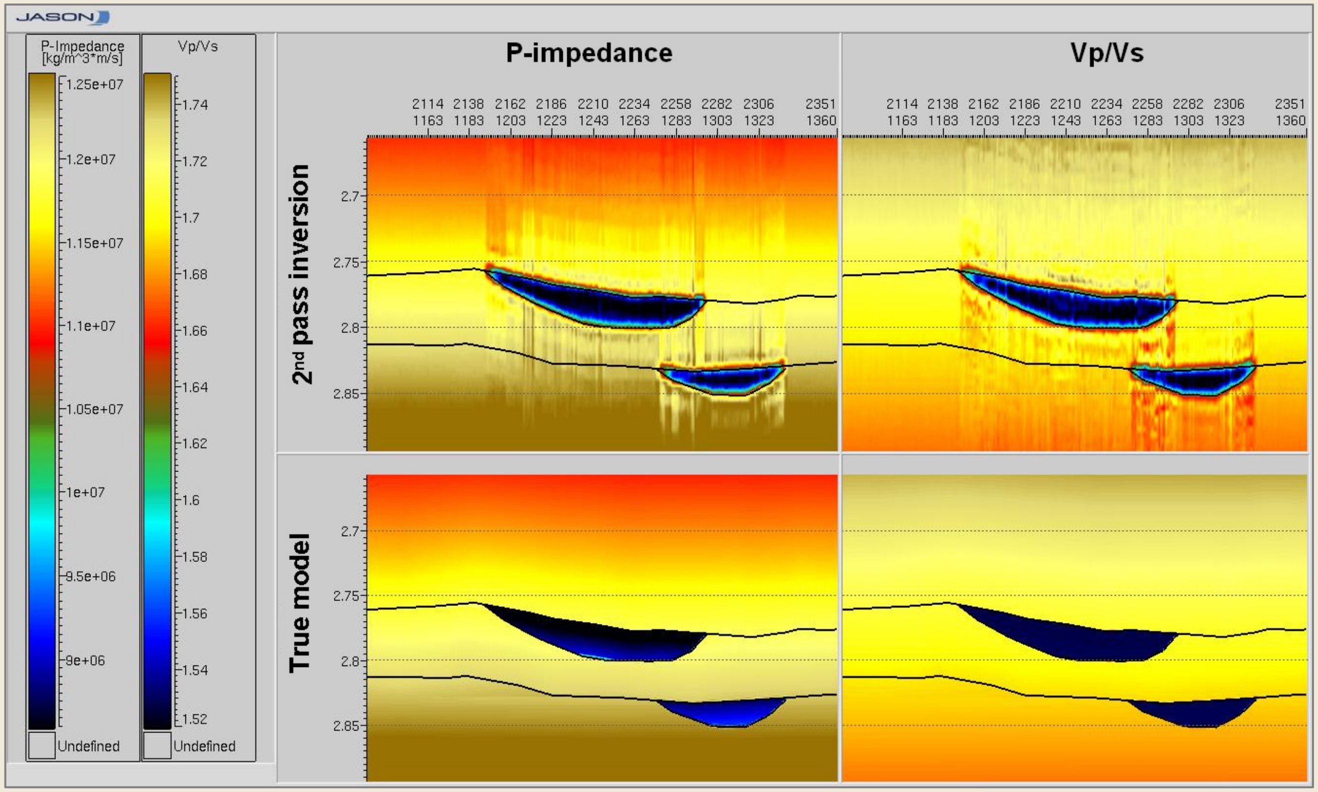


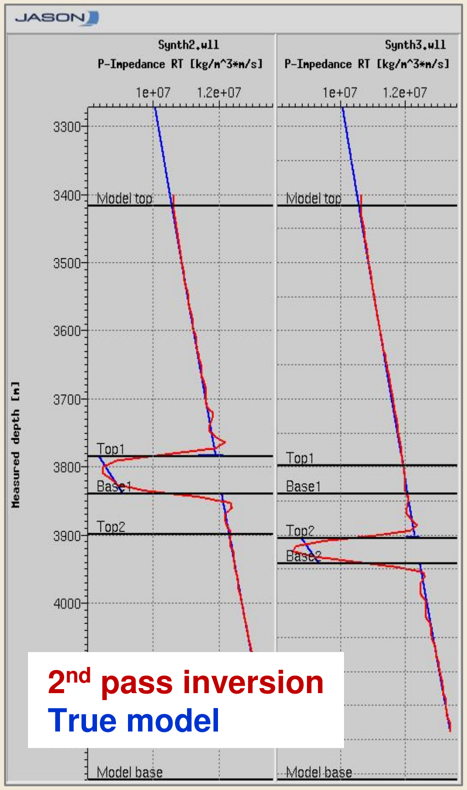
LF model for the second pass of inversion

- Composed of Shale trend and constant values for captured sands

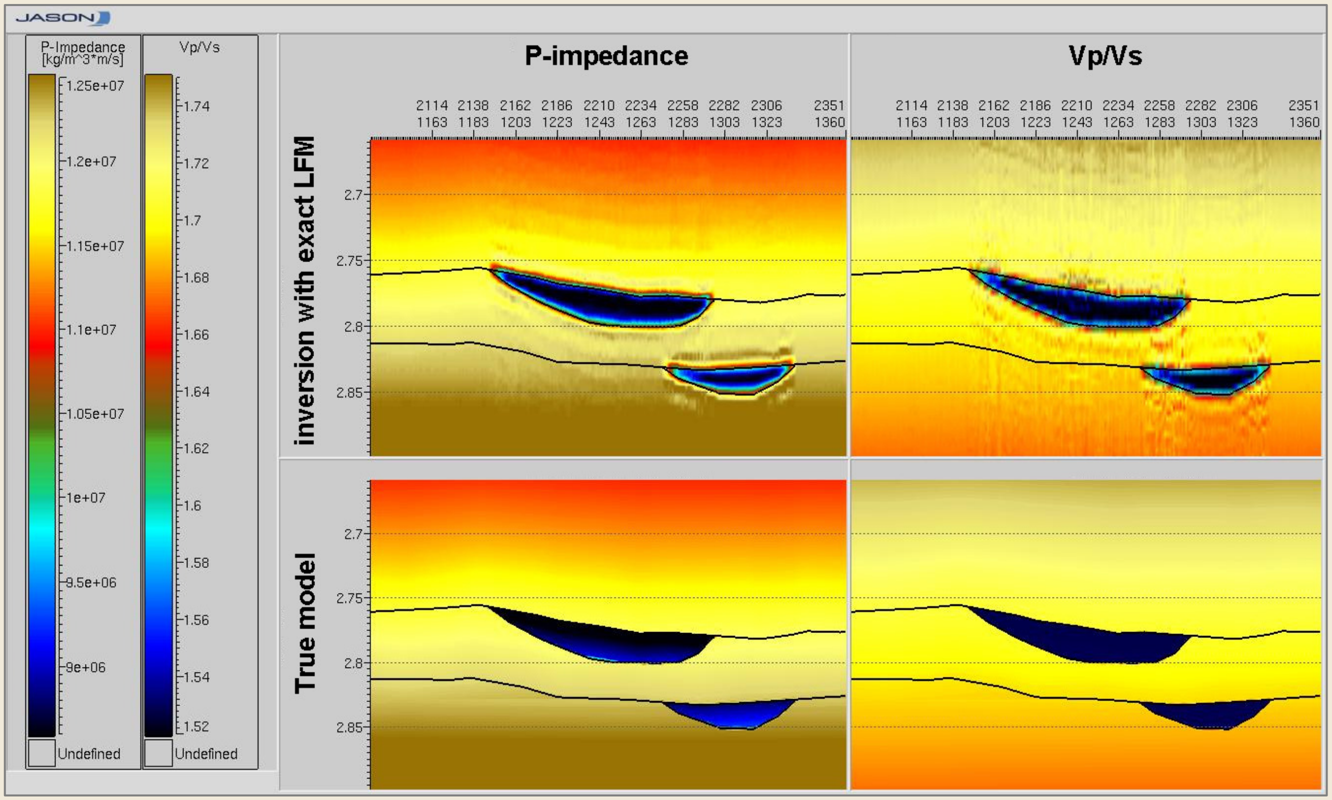


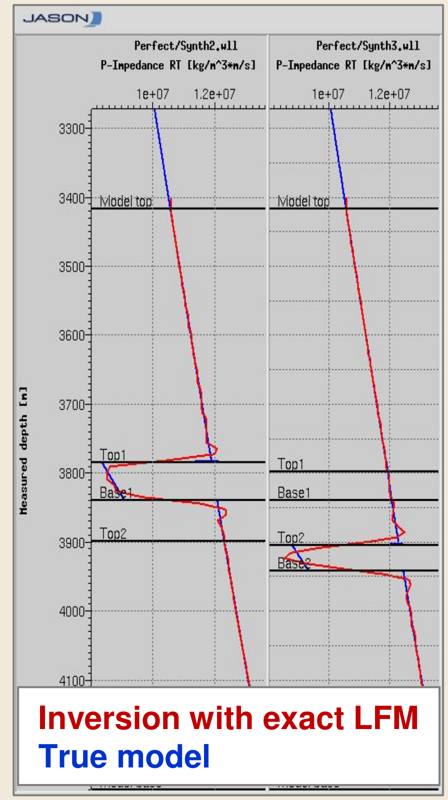
Second pass inversion results



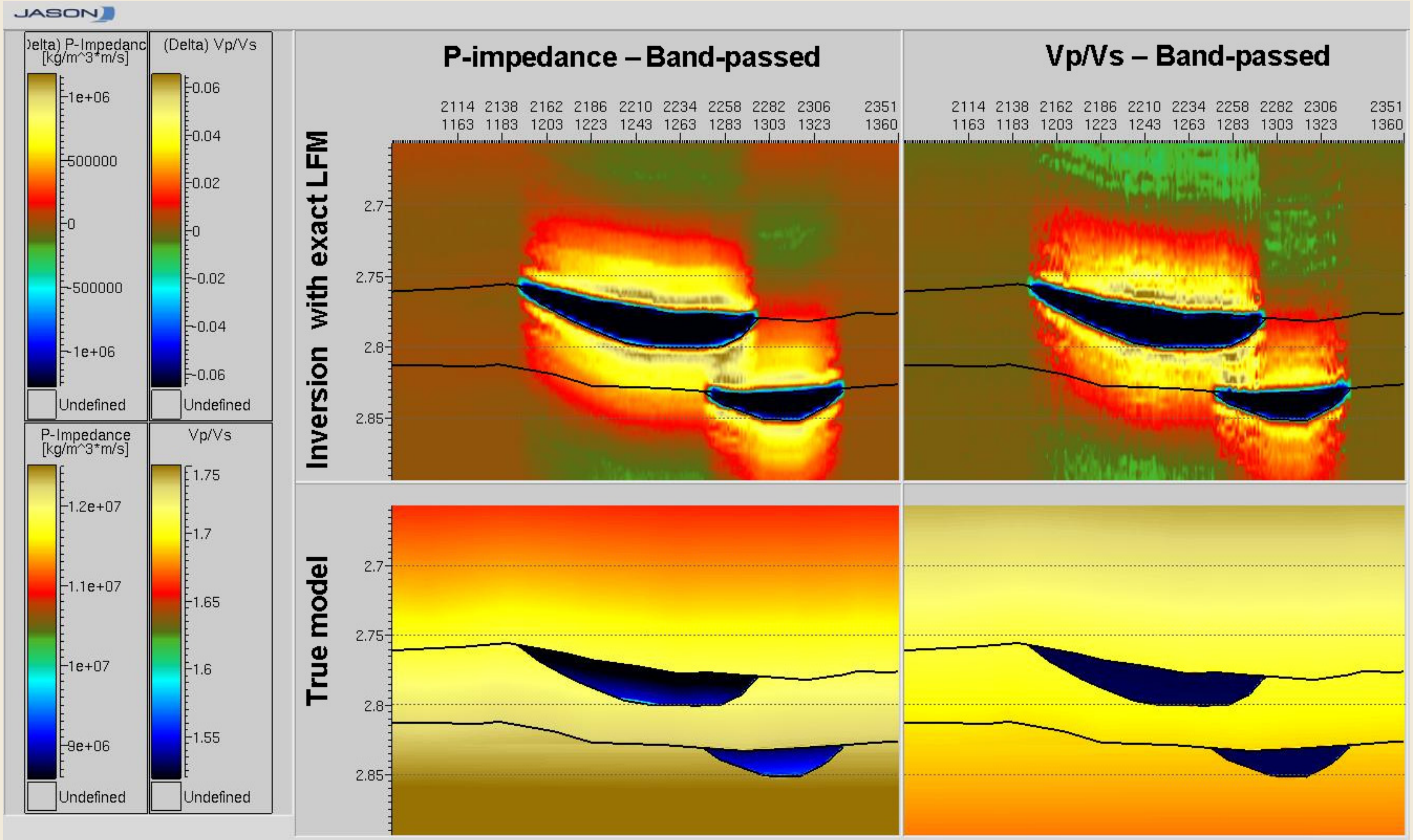


Inversion using correct low frequency trend





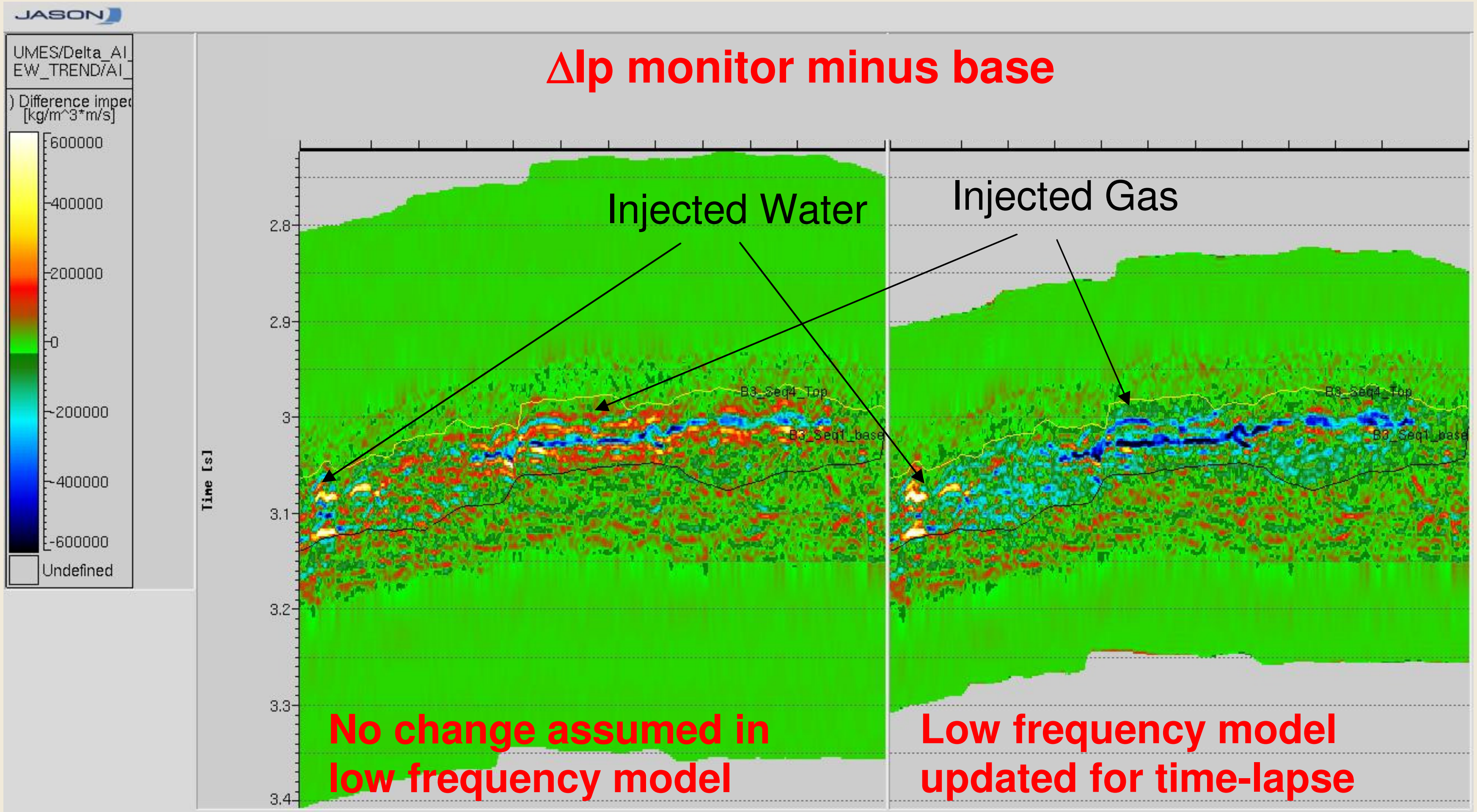
Inversion using correct LF trend band-pass results



Conclusions

- Low frequency model can be updated within reservoirs using a sand trend model
- For thicker packages manual interpretation is required to map sand bodies
- Side lobe effects are highly reduced using updated low frequency model
- Sand trends may be adjusted for various fluid scenarios
- Concept relatively simple and fast to implement

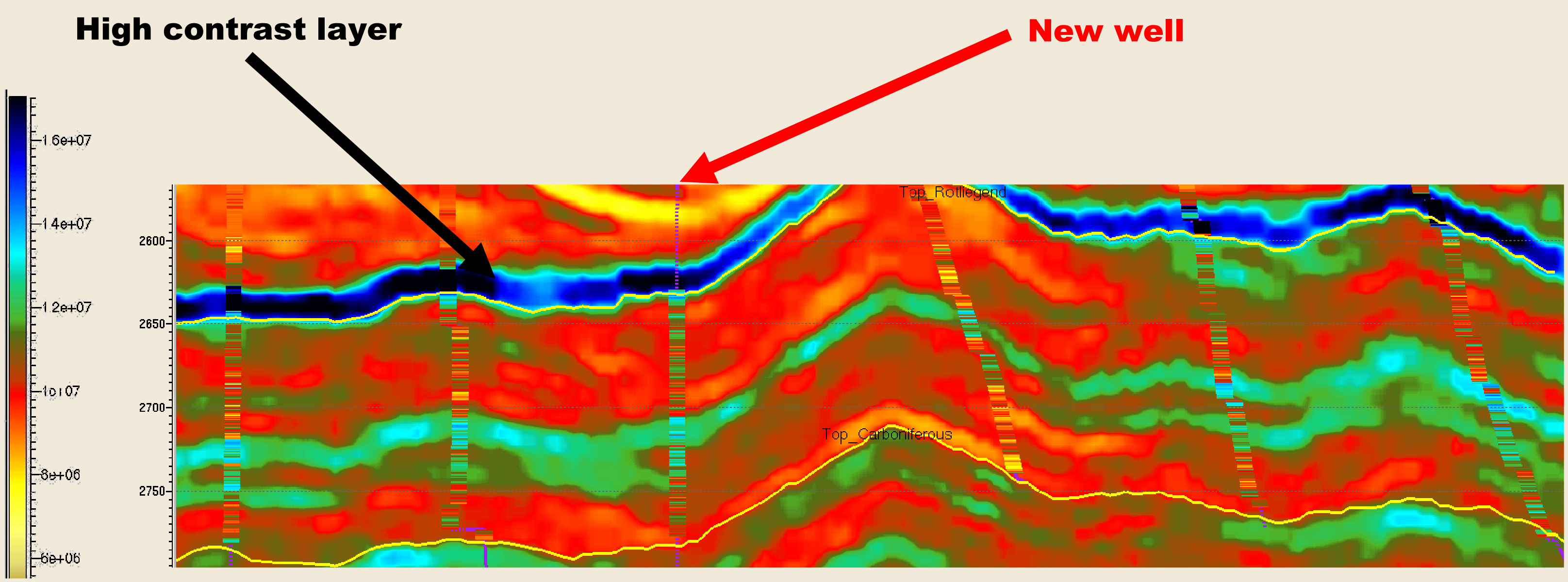
Example with time lapse signal*



***From Girassol 2004 study by Fugro-Jason**

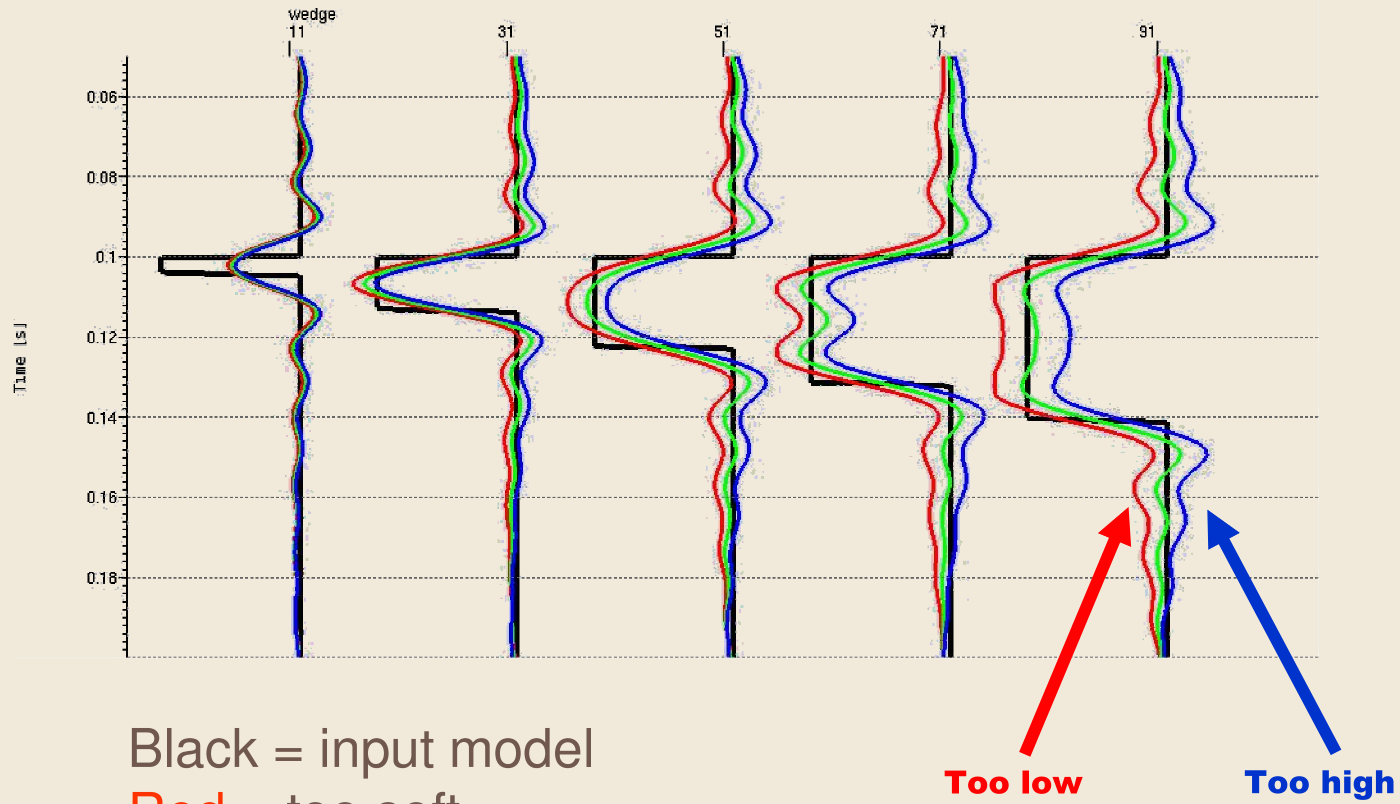
A typical Zechstein problem

- High lateral variability of contrast between Zechstein and Rotliegend
- Well coverage is not sufficient to capture the lateral variability of the high contrast layer in the low frequency model



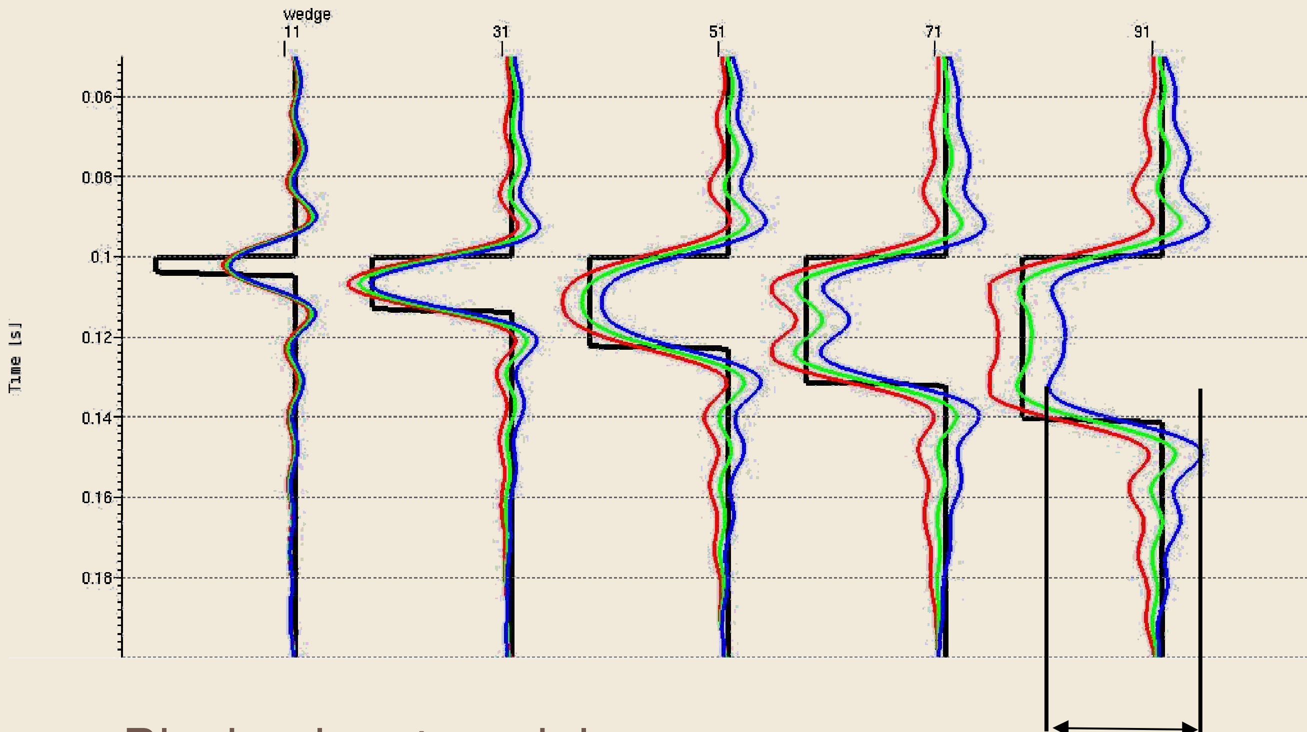
Predicted average P-Impedance in Rotliegend reservoir too low

What value to use as a trend between the wells?



Black = input model
Red = too soft
Green = correct
Blue = too hard

What value to use as a trend between the wells?



Black = input model
Red = too soft
Green = correct
Blue = too hard

Contrast is independent of actual value

Two-pass inversion

First-pass P-impedance inversion

⇩

Re-interpret of top and base of high contrast layer on first pass inversion

⇩

Extract Contrast and Update LFM

⇩

Re-run P-impedance inversion

Updated LFM

First-pass P-impedance inversion

↓

Re-interpret of top and base of high contrast layer on first pass inversion

↓

Extract Contrast and Update LFM

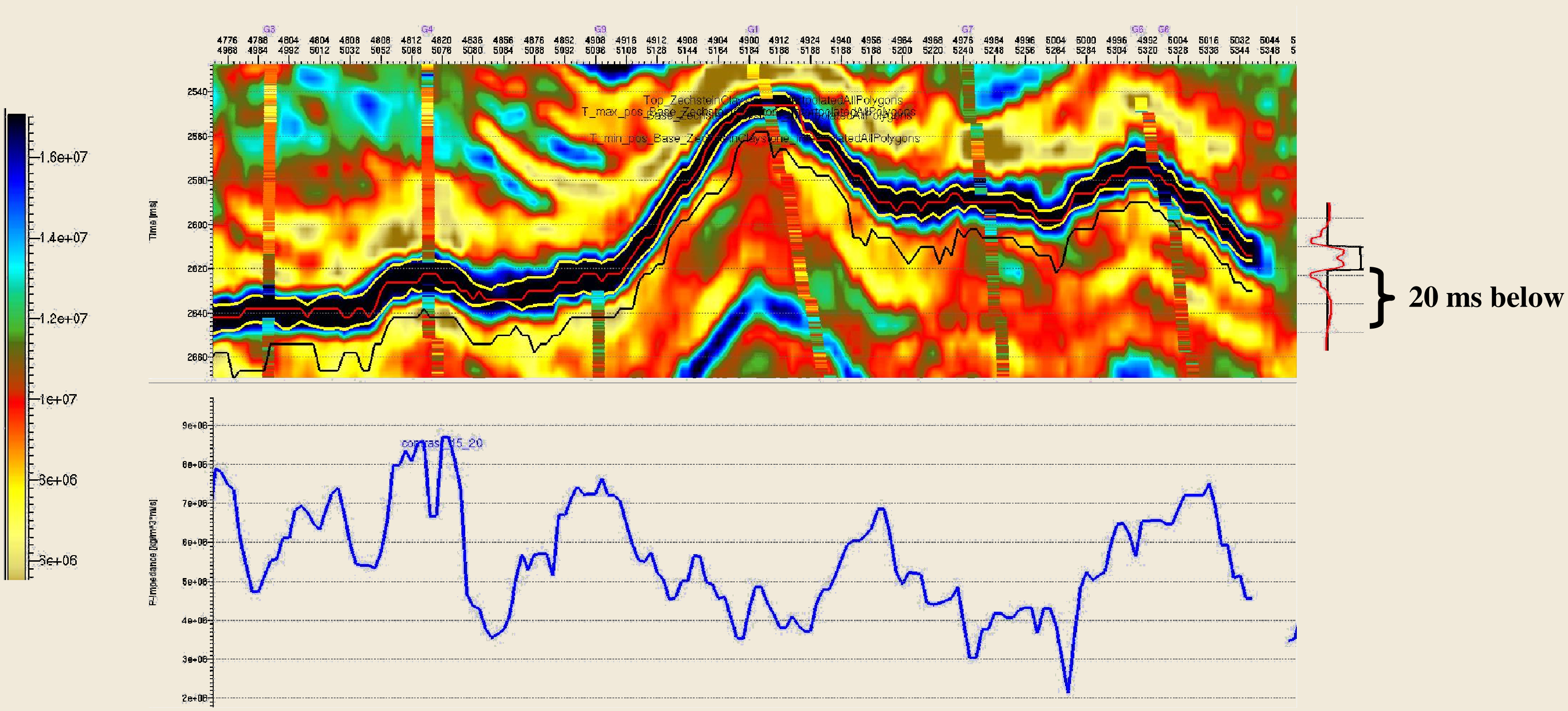
↓

Re-run P-impedance inversion

Updating the low frequency model

- Step 1: Calculate the bandlimited P-Impedance contrast over the Top Rotliegend

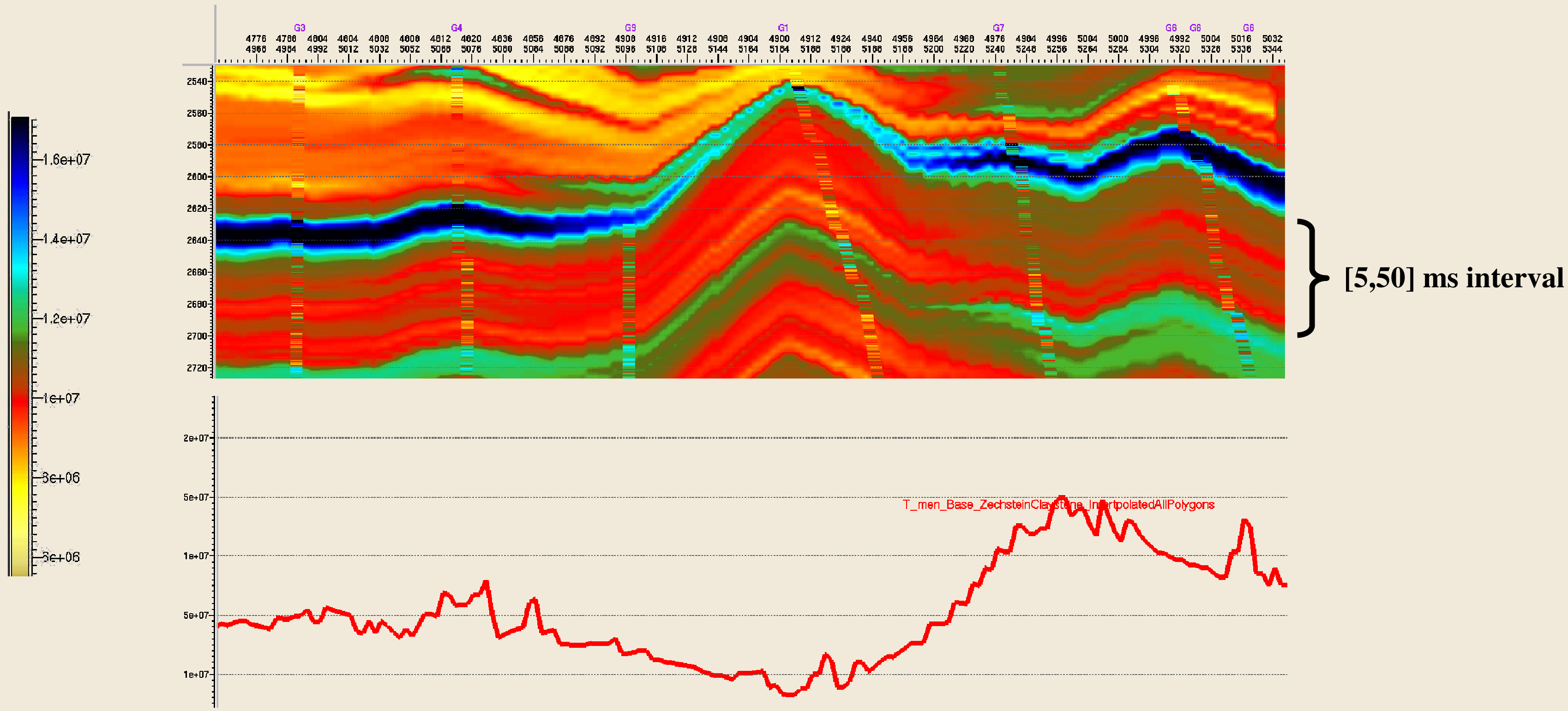
The minimum P-Impedance directly below the interpreted horizon is subtracted from the maximum P-Impedance directly above the interpreted horizon



Upper panel: Bandpass P-Impedance section with P-Impedance logs in overlay
Lower panel: P-Impedance contrast over the Top Rotliegend interpretation

Updating the low frequency model

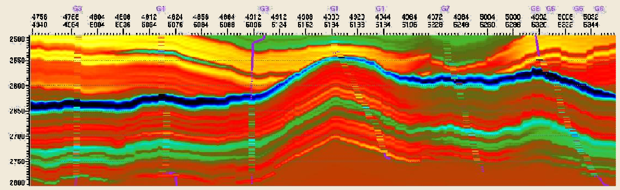
- Step 2: Extract the average P-Impedance from Rotliegend in the original LFM

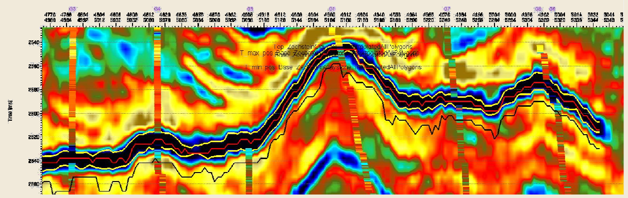


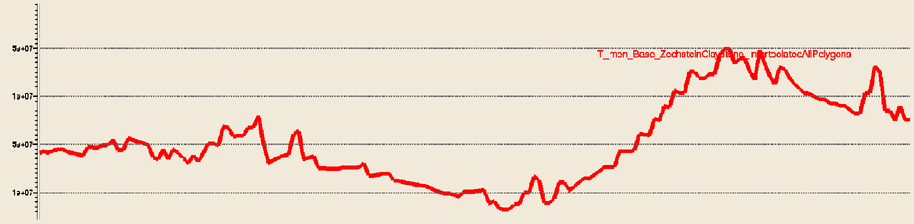
Upper panel: P- Impedance trend model
Lower panel: mean P-Impedance extracted from the Rotliegend in the top panel

Updating the low frequency model

- Step 3: Add the P-Impedance contrast to the LFM Rotliegend P-Impedance







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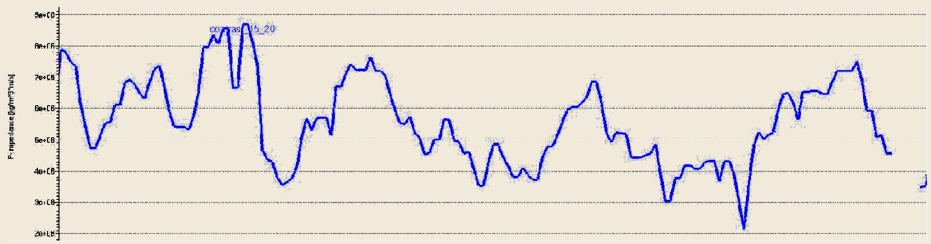
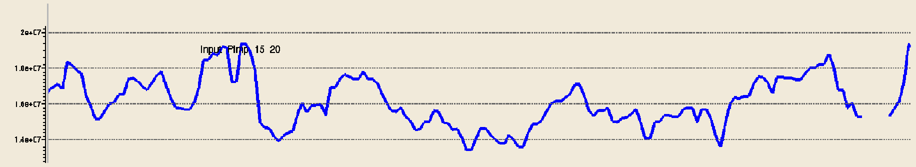
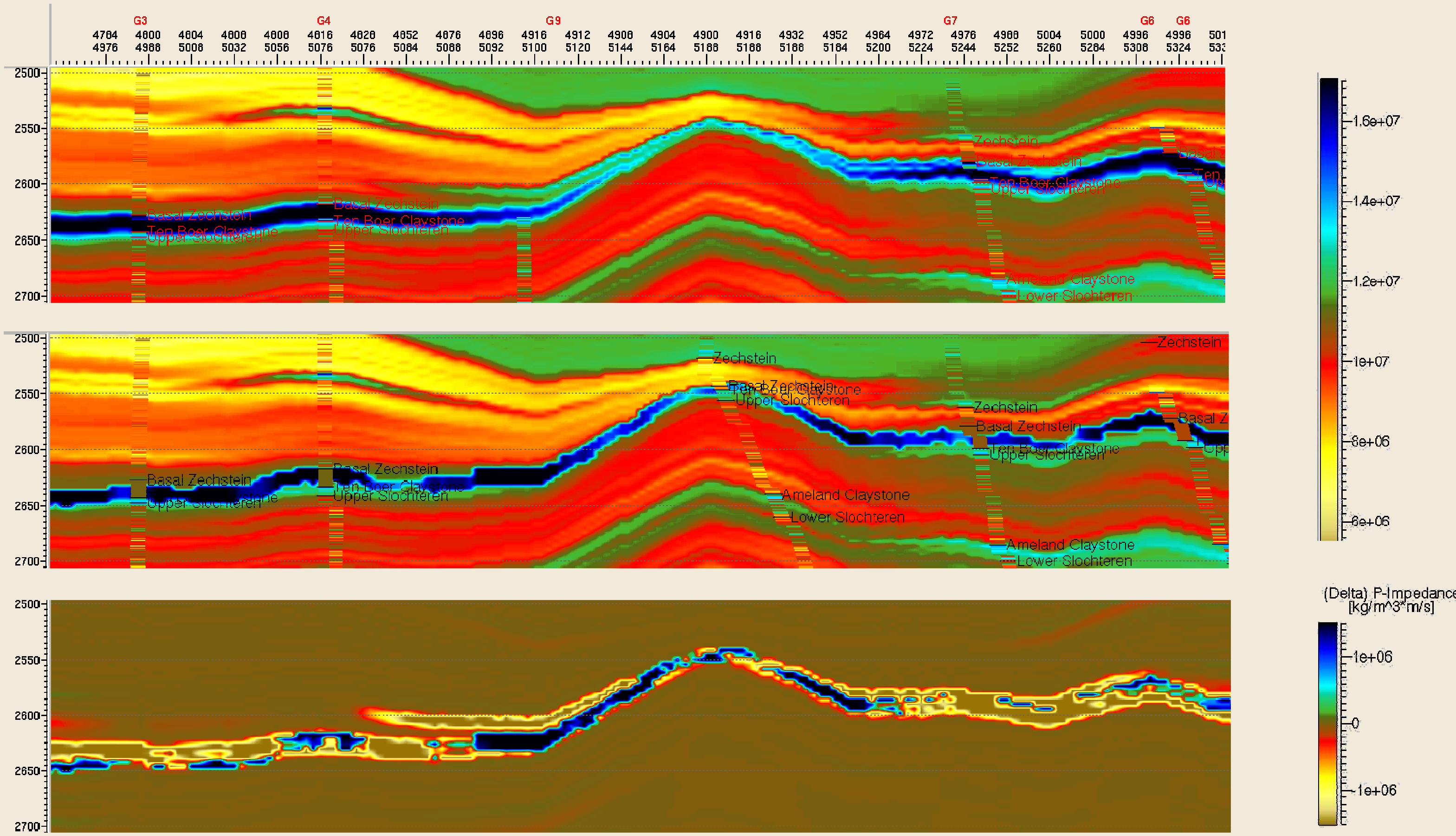




New input horizon

Updating the low frequency model

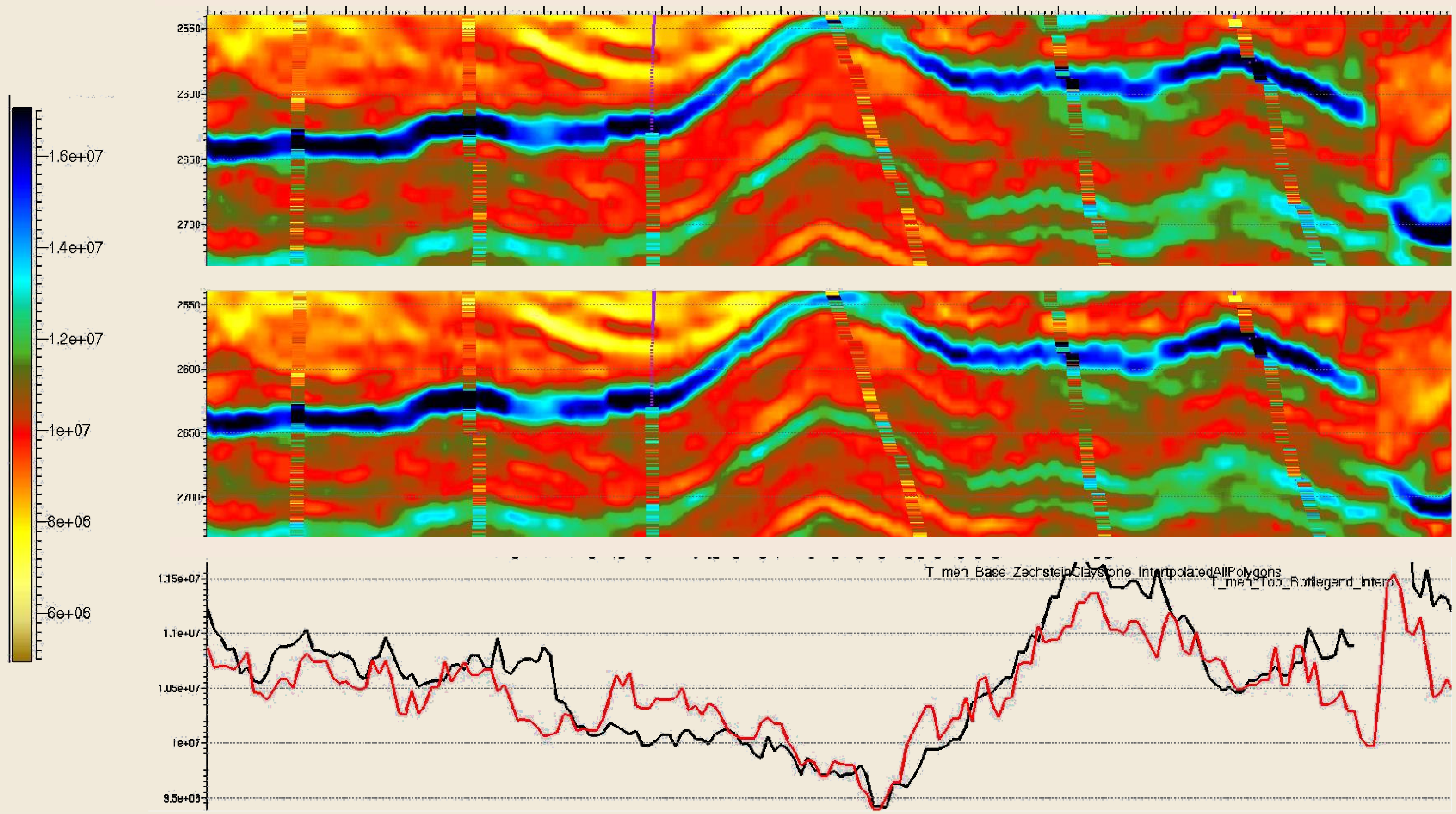
- Step 4: Replace the new Zechstein P-Impedance in the original LFM



Top: original FT LFM. Middle: updated LFM. Bottom: difference.

Inversion results and QC

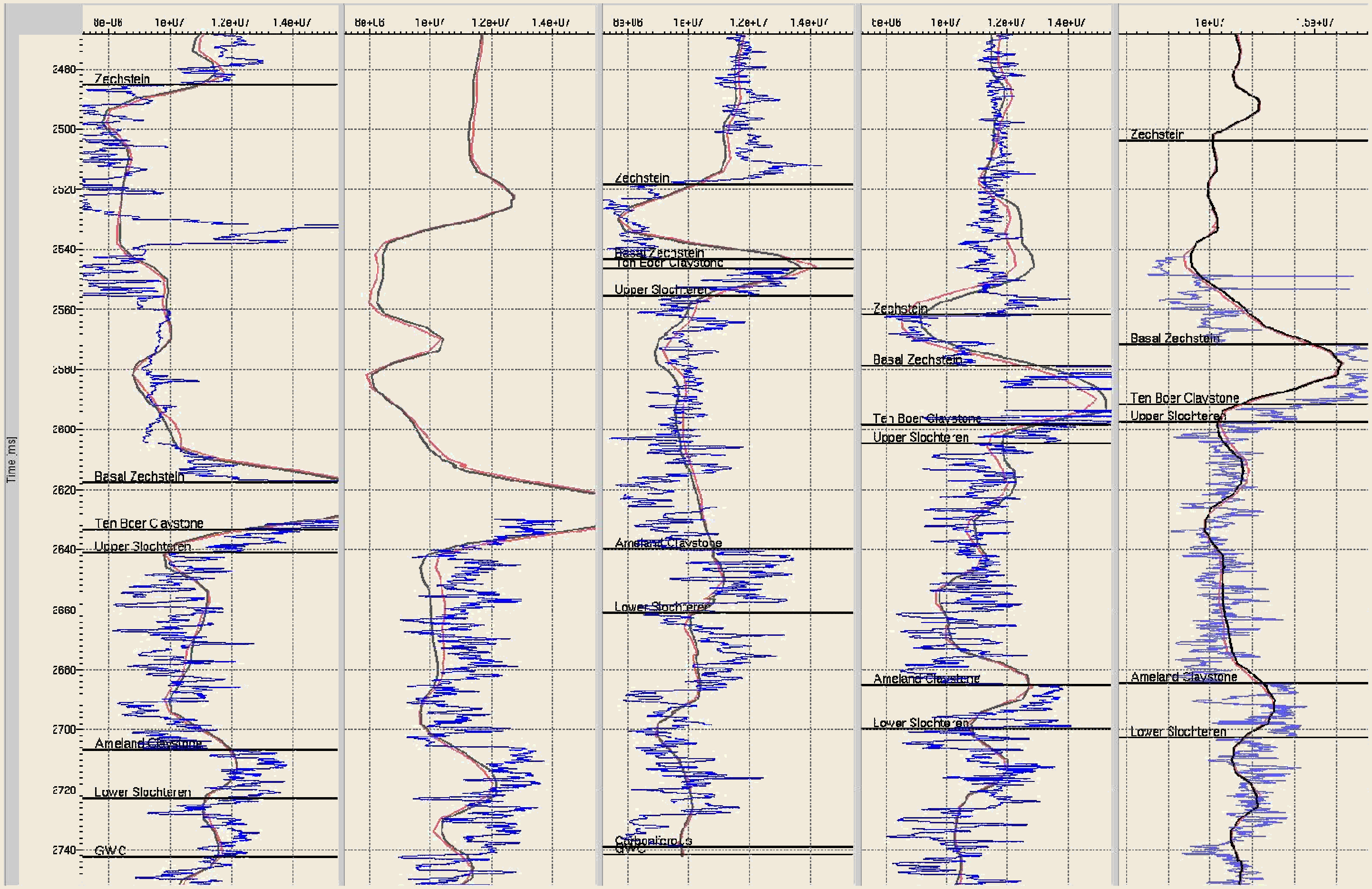
- Extracted mean P-Impedance from Upper Slochteren sandstone



Upper panel: Original RockTrace P-Impedance; Middle panel: Newly merged P-impedance
Lower panel: mean P-Impedance. Original is in black

Inversion results and QC

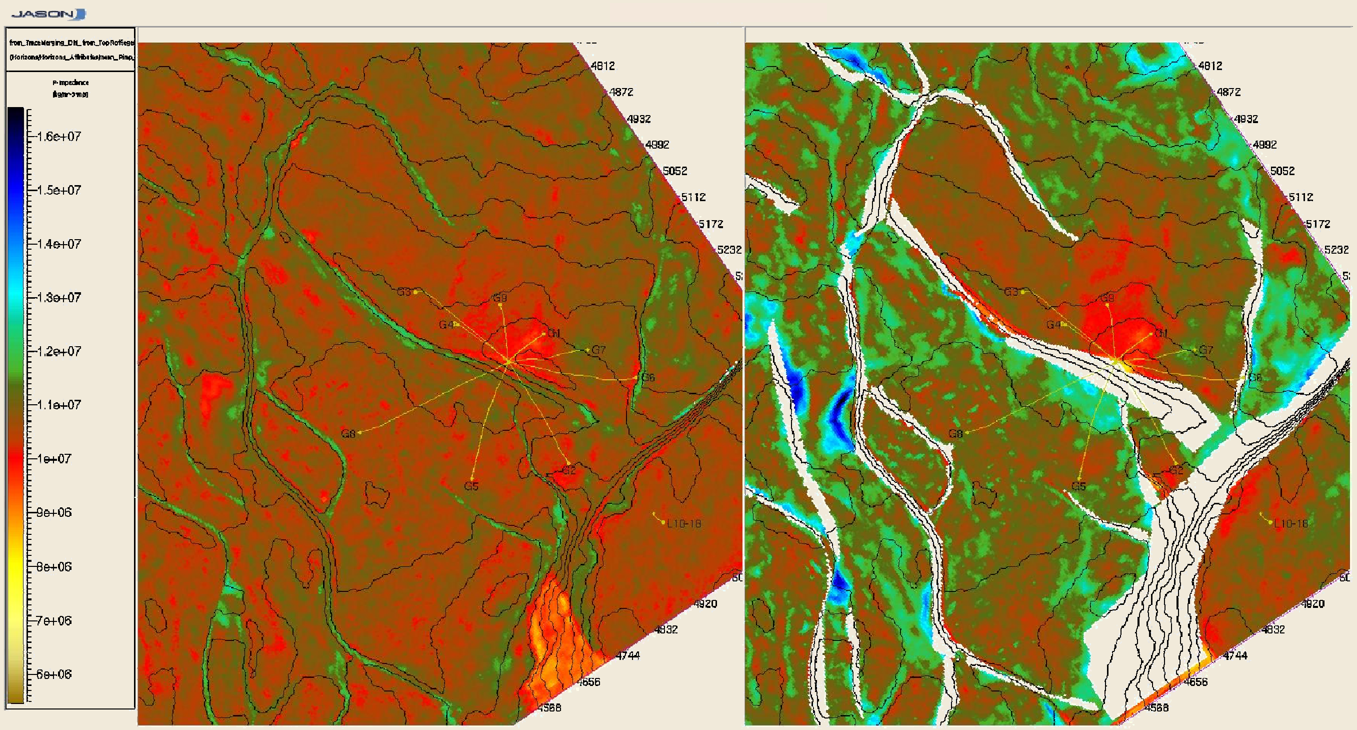
- P-impedance (pseudo) logs



Blue = well data; Black = from original inversion; Red = from newly merged model

Inversion results and QC

- Map of average P-Impedance of the upper Slochteren sandstone



Mean P-impedance extracted from 5 to 50 ms below the Top Rotliegend horizon. Left panel: from newly merged P-impedance. Right panel: from the original inversion. The contours are from the Top Rotliegend time representation

Conclusions

- Imprecise information in the LFM about high contrast layers causes residual sidelobes in neighboring layers
- Adding contrast information to the LFM helps alleviating sidelobe effects

Acknowledgement

- Thanks to co-authors and GdF Suez Production Netherlands BV