Inversion Discussion for Dr. Tura's QI Class

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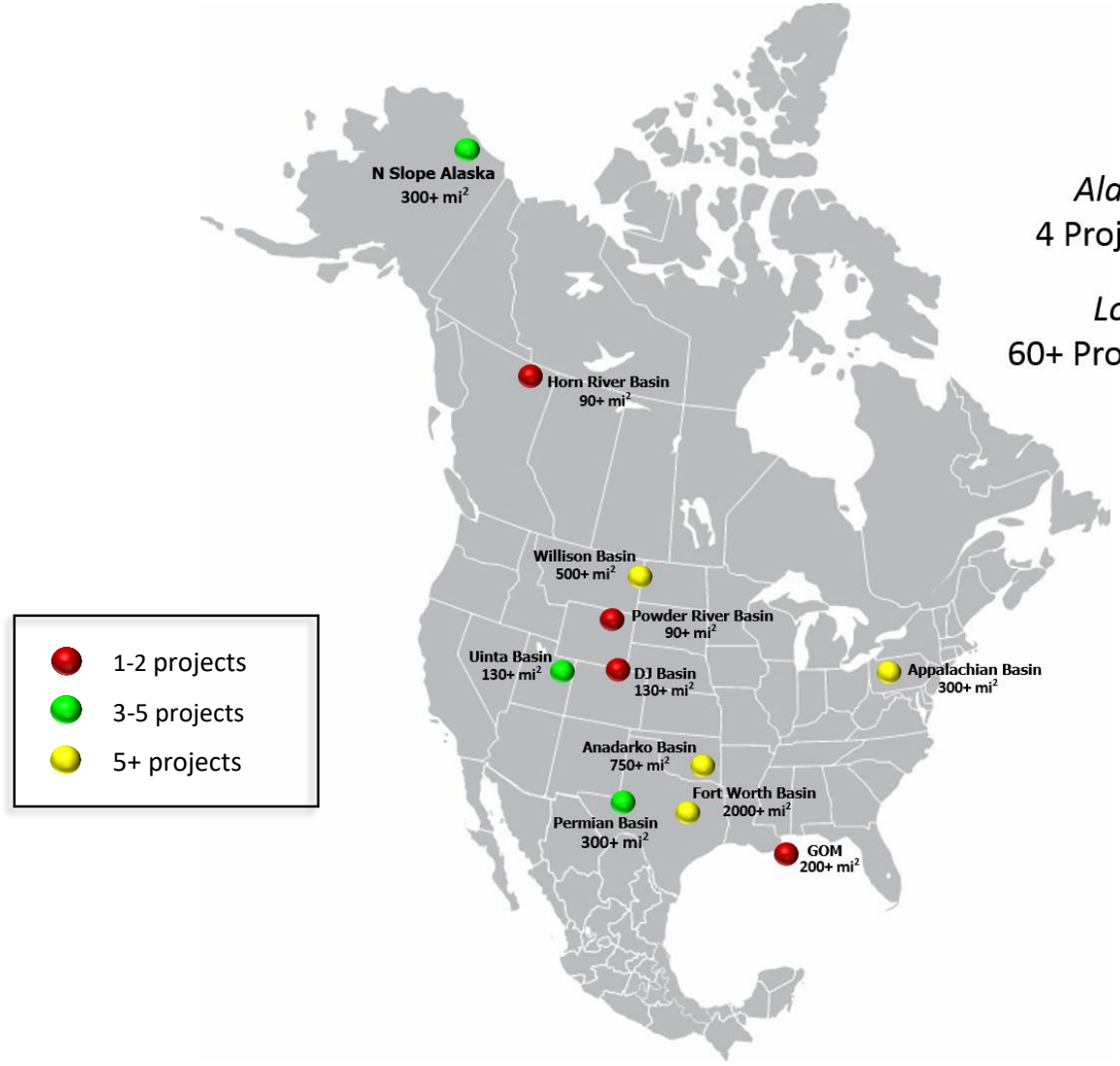
Today’s Discussion

- Workflow for building Simultaneous Elastic Inversion
- Data Examples and Pitfalls
- Applications
  - Rock Property Estimation
    - Geo-mechanical Brittleness
    - Density

North America Elastic Inversion Experience



Alaska-Canada
4 Projects; 400+ mi^2

Lower 48 US
60+ Projects; 5000+ mi^2

My History:

- BS in Geophysics from Bowling Green State University (Ohio)
- 18 years with Amoco Production Company (later BP)
  - Extensive classroom training at Amoco Training Center in Tulsa, OK.
  - Field trips to CA & Mexico (wrench faults), Nova Scotia (salt techtonics), Utah (clastic deposition), Turks & Caicos Islands (carbonate deposition), KT & TN (unconformities), Egypt's Sinai (extensional techtonics), . . .
  - Exploration and Field Development Assignments;
    - Permian Basin, West Texas (7 years)
    - North Sea – Netherlands and Norway (3 years)
    - Columbus Basin, Trinidad (3 years)
    - Gulf of Suez, Cairo, Egypt as Senior Geophysical Coordinator (5 years)
- MS in CIS at Regis University (Denver) – Database Technology and Object-Oriented Programming
- 10 years at seismic processing companies in Denver (GXT, ION, Neos)

Outline

- Overview of Inversion
- Review well data provided
- Low-Frequency Background Model
- Angle Gathers – what's available in the data
- Scaling the Angle Gathers based on Well Model
- Scaling the Inversion – x-plot analysis
- Results of Simultaneous Elastic Impedance Inversion
- Additional Volumes – Lame, Poisson's Ratio, Young's Modulus
- Predicting Lithology from LRM Cross-plots
- Comments & Conclusions

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Inversion

- Inversion is the process of extracting, from the seismic data, the underlying geology which gave rise to that seismic
- Originally, inversion was been applied to post-stack seismic data, with the aim of extracting acoustic impedance volumes
- More recently, inversion has been extended to pre-stack seismic data using AVO, with the aim of extracting both acoustic and shear impedance
- Another recent development is to use inversion results to predict lithologic parameters such as porosity, fluid saturation and brittleness
- We typically use a Model-based method, where Pre-stack angle gathers are inverted simultaneously for P and S-impedance and density

Modified from Hampson-Russell Inversion Primer 2004

Types of Inversion (available in Hampson-Russell)

Recursive:	Traditional bandlimited inversion
Model Based:	Iteratively updates a layered initial model
Sparse Spike:	Constrained to produce few events
Colored Inversion:	Modern derivative of Recursive Inversion
Elastic Impedance:	Enhancement for AVO data
Extended Elastic Impedance:	Uses EEI Cross-Plot to scale by angles up to +/-90°
LMR:	Enhancement for AVO data
Joint Inversion:	Pre-stack angle gathers are inverted simultaneously for P and S-impedance and density

Taken from Hampson-Russell Inversion Primer 2004

Non-Uniqueness in Inversion

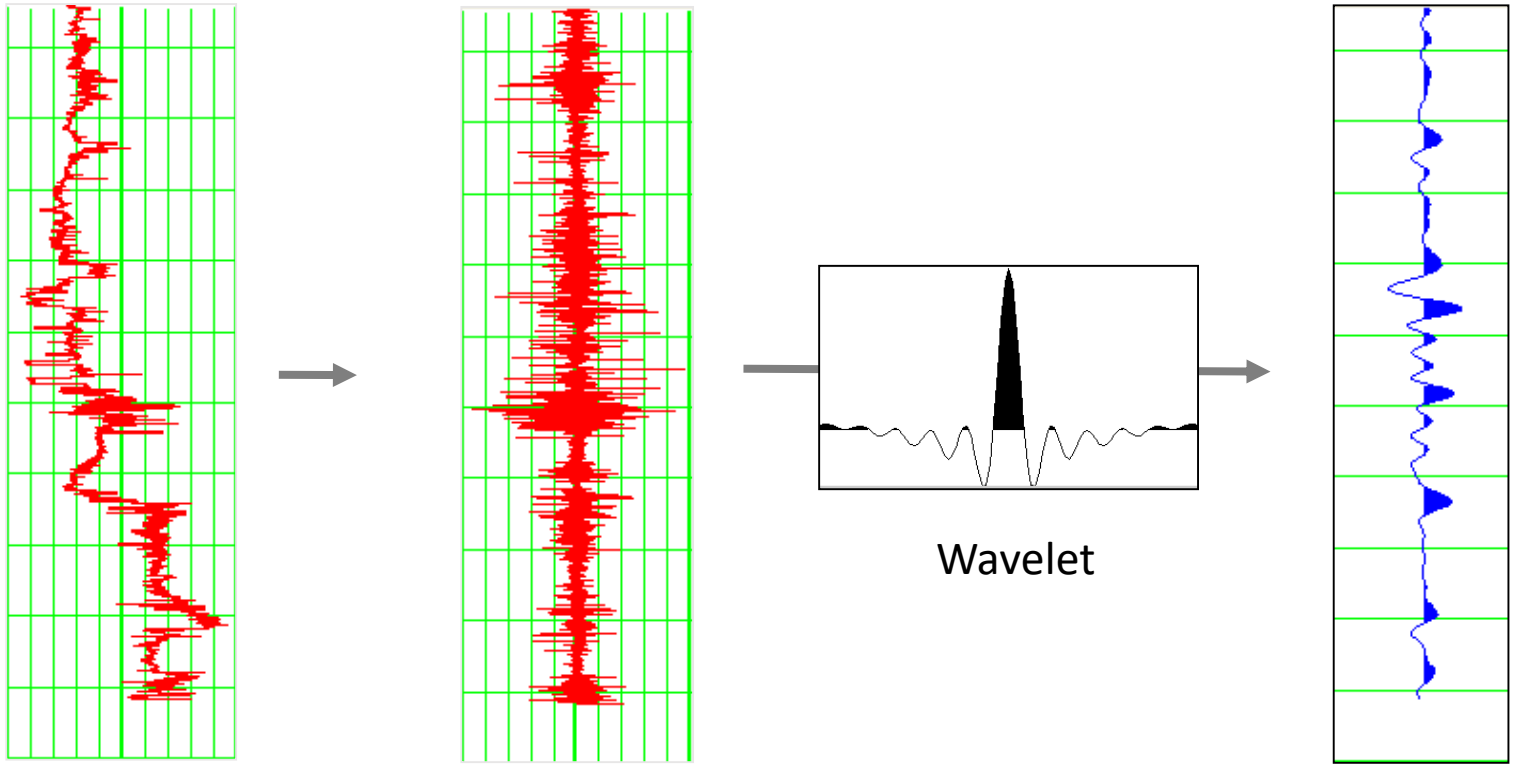
- All inversion algorithms suffer from “non-uniqueness”
- There is more than one possible geological model consistent with the seismic data. The only way to decide between the possibilities is to use other information, not present in the seismic data
- This other information is usually provided in two ways:
    - the initial guess model
    - constraints on how far the final result may deviate from the initial guess
- The final result always depends on the “other information” as well as the seismic data

Taken from Hampson-Russell Inversion Primer 2004

Newer Methods of Pre-Stack AVO Inversion

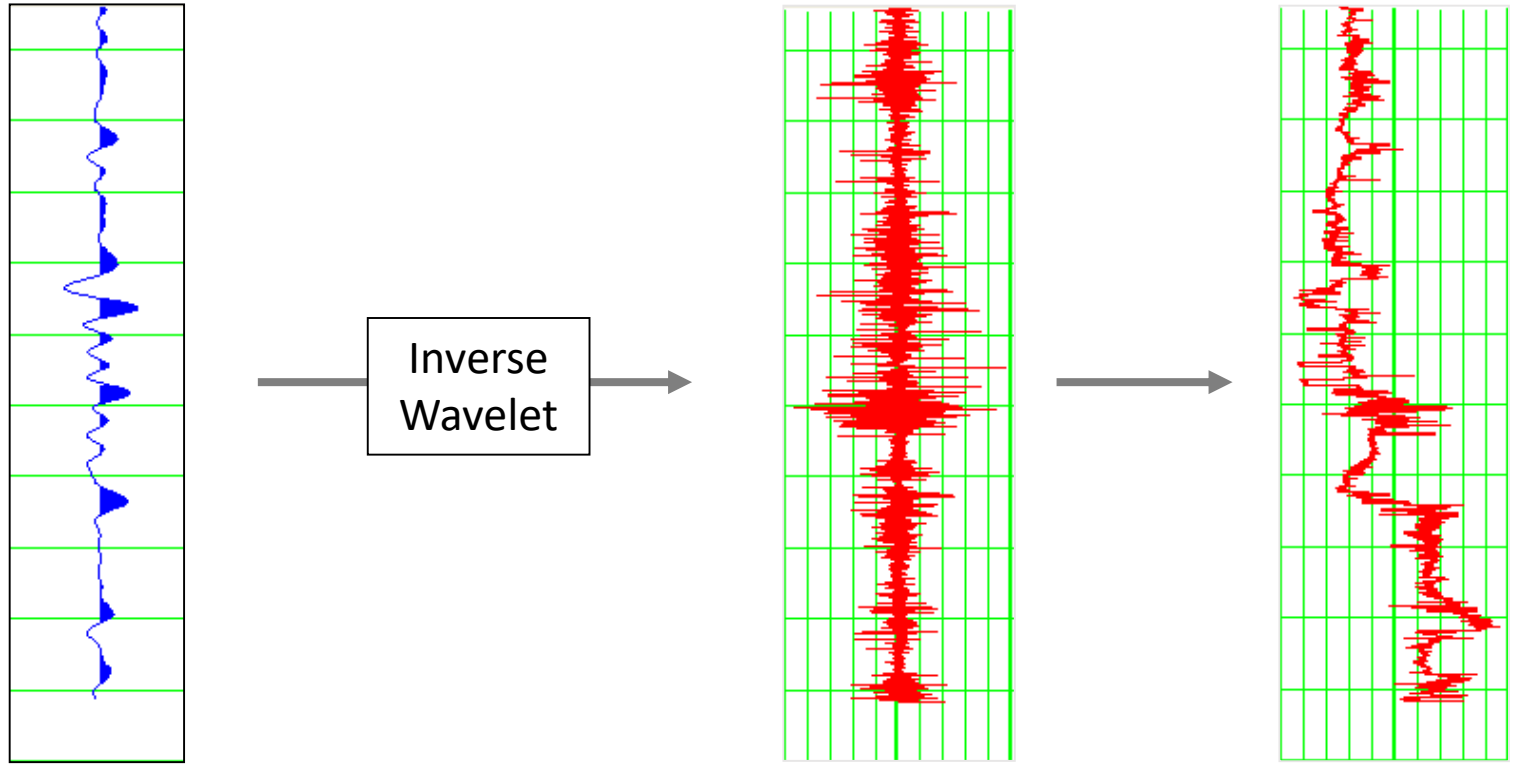
- Deterministic versus Stochastic Inversion – single vs range of solutions
- Joint Inversion – PP and PS data combined and inverted
- Azimuthal Inversion – directionally sectored stacks or gathers
- 4D Inversion – looks for changes of pressure and fluid saturation
- Geostatistical Inversion – Bayesian method using information of geology/stratigraphy, seismic horizons, deterministic inversion results, well logs, reservoir engineering combined with weighting functions and probability distribution functions (PDF's)

Forward Model for Inversion



Taken from Hampson-Russell Inversion Primer 2004

Inversion Simply Reverses the Procedure



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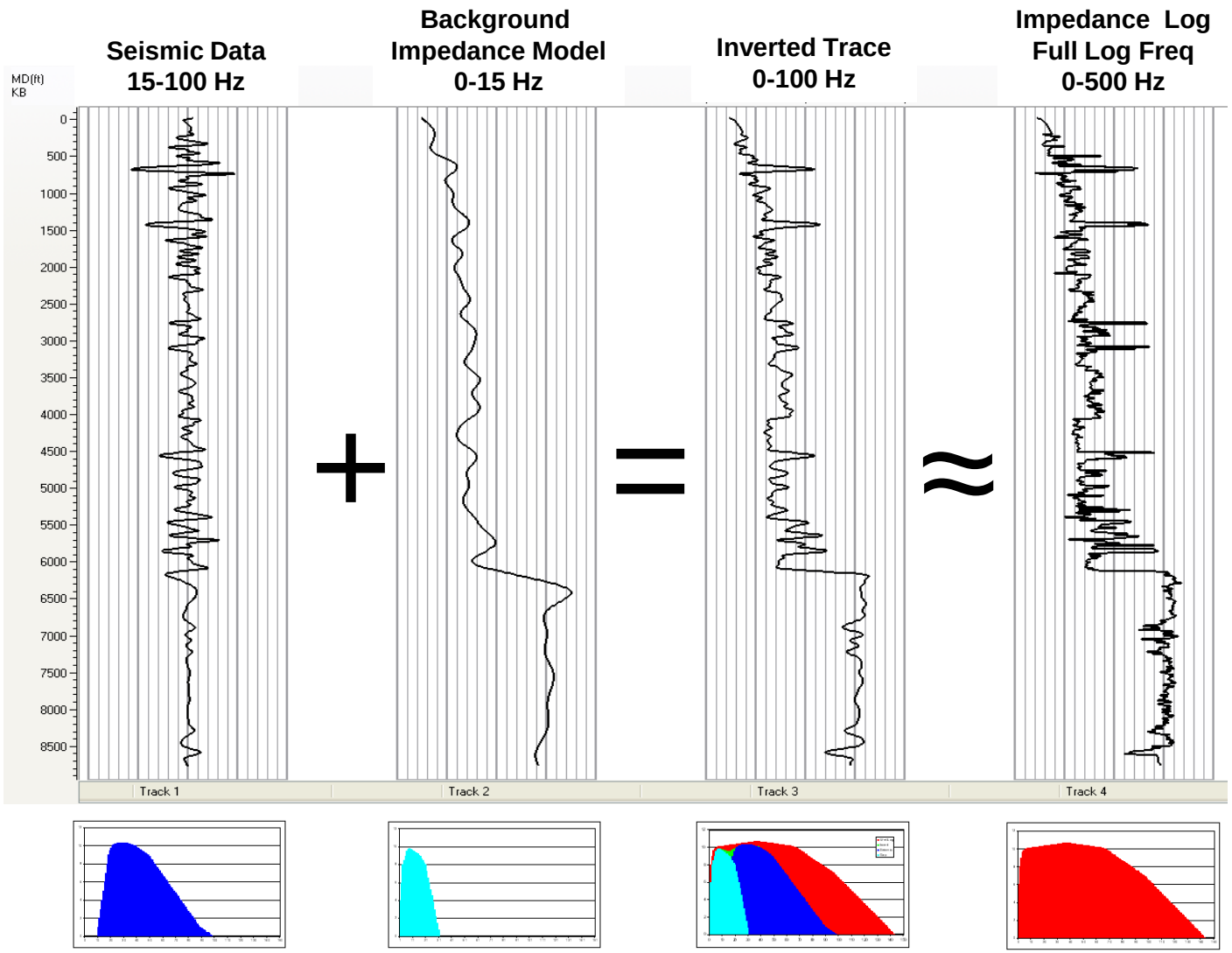
Inversion Schematic Diagram



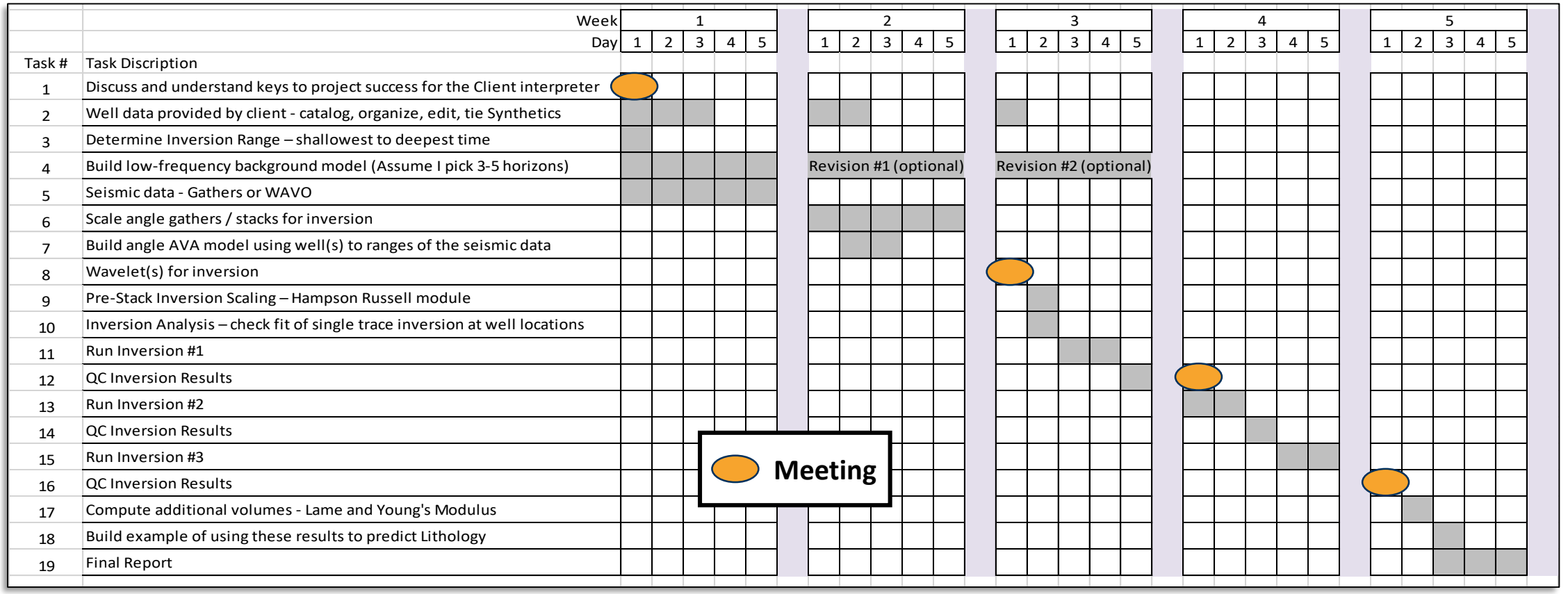
Group/Client Meetings

- Regular meetings at key milestones
- +/- 50 decisions to be made, including; wells, frequencies, wavelets, scaling, horizons, etc.
- We'll make a recommendation for each and show support for our reasoning
- Group/Client needs to understand each choice; and accept or modify my recommendation
- Discussion of effects of each decision

Typical Inversion Workflow

1. Discuss and understand keys to project success for the Team/Management/Client
2. Well data provided - catalog, organize, edit, tie synthetics
3. Determine Inversion Range – shallowest to deepest time
4. Build low-frequency background model (Assume you pick 3-5 horizons)
5. Seismic data – Stack and Gathers
6. Scale angle gathers / stacks for inversion
7. Build angle AVA model using well(s) to ranges of the seismic data
8. Wavelet(s) for inversion
9. Pre-Stack Inversion Scaling – Hampson Russell module
10. Inversion Analysis – check fit of single trace inversion at well locations
11. Run Inversion #1
12. QC Inversion Results
13. Run Inversion #2
14. QC Inversion Results
15. Run Inversion #3
16. QC Inversion Results
17. Compute additional volumes - Lame and Young's Modulus
18. Build example of using these results to predict Lithology
19. Final Report

Schematic Gantt Chart for Inversions



Big time considerations are:

- Survey Size
- Geologic complexity
- Number & quality of wells/logs – need DTC, DTS and RhoB
- Availability of horizons to guide background model

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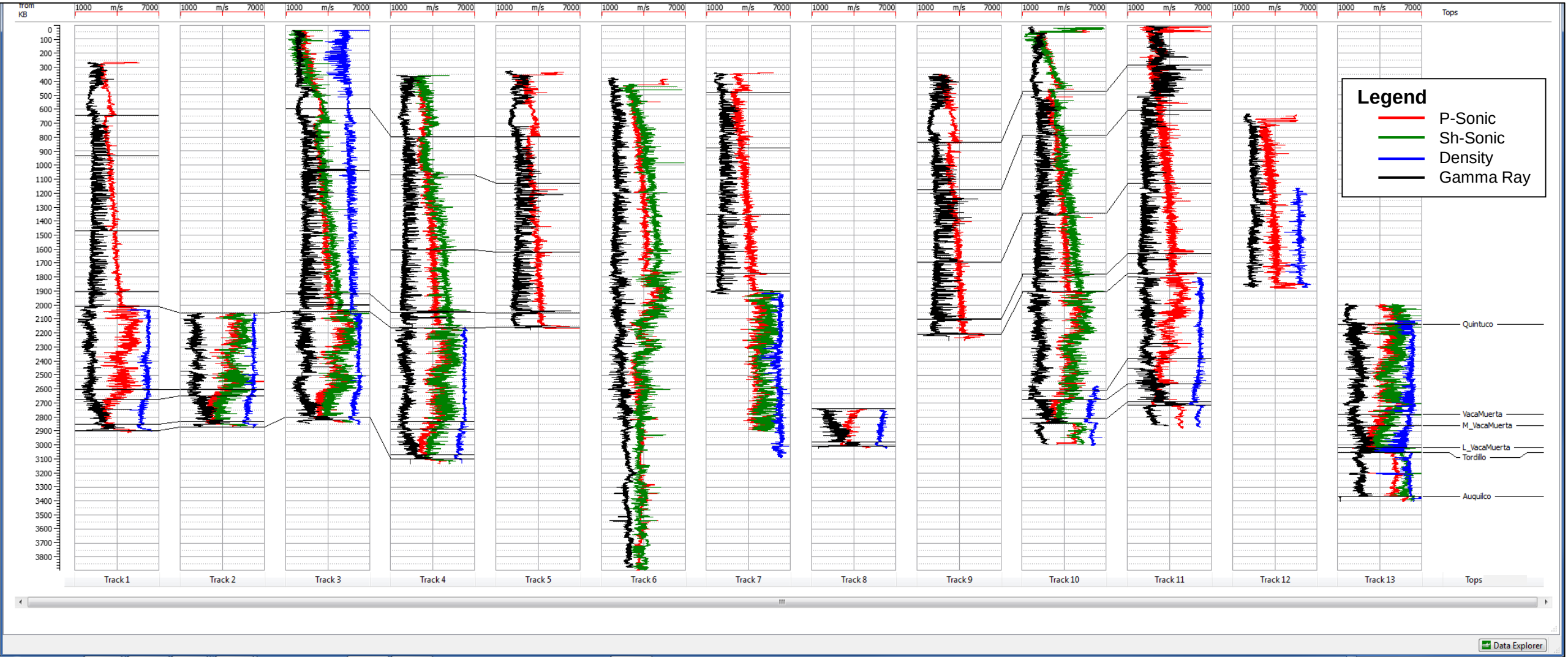
Well Data

This is all done before the inversion process starts as part of our typical processing/QC workflow

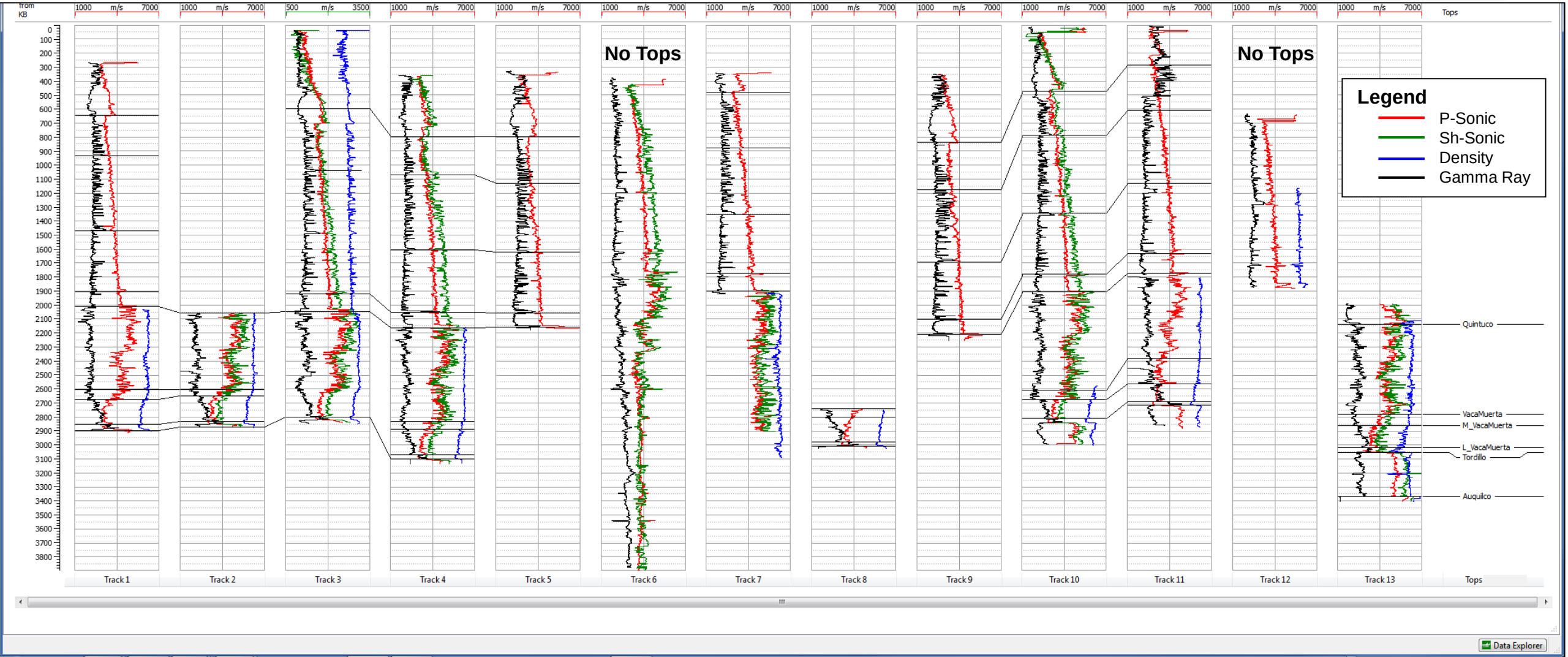
- Import & catalog all data: logs, surface location, deviation, formation tops
- Edit logs (DTC, DTS and RhoB), where needed
- Formation tops that include objective pay zones
- Determine wavelet to use for synthetic tie
- Tie synthetics to seismic
- Determine/correct seismic phase – correct to zero phase

13 well cross-section – raw logs



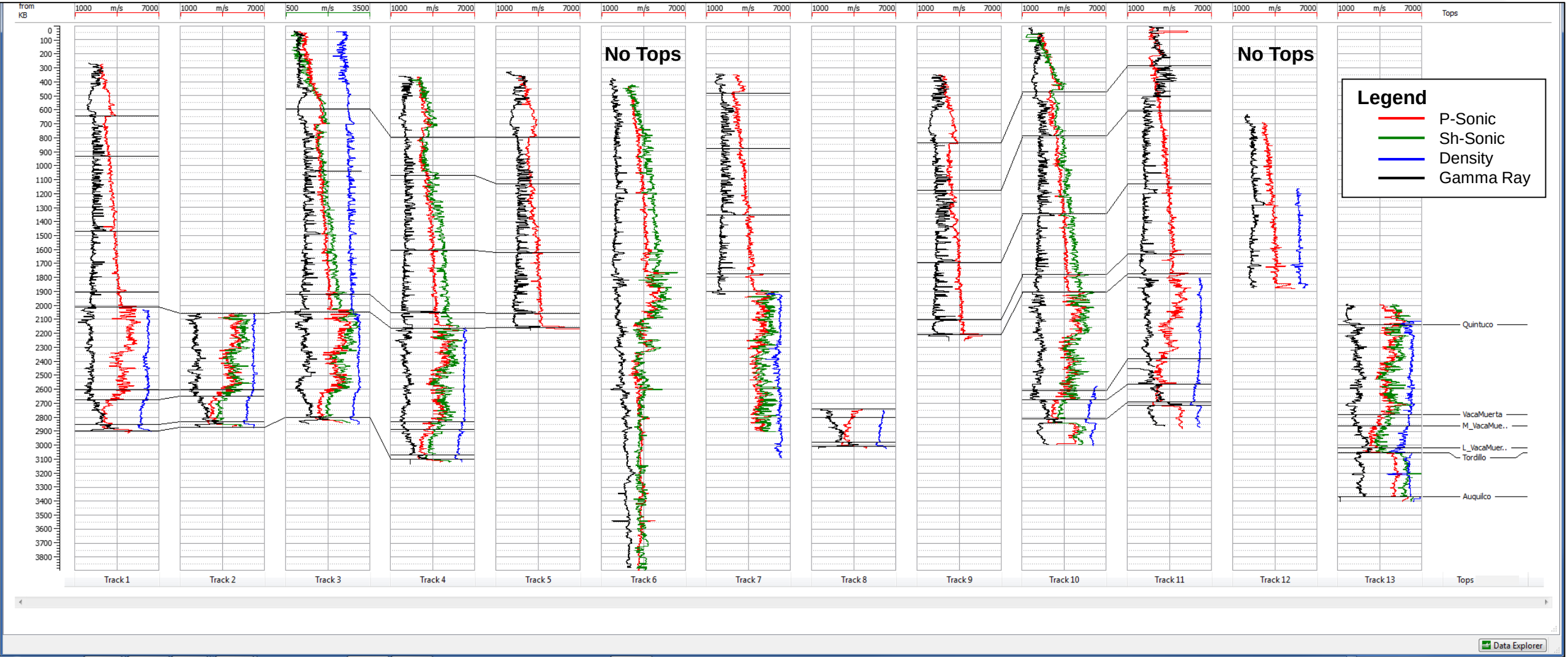
13 well cross-section – median filtered logs

31-point median filter applied to 0.5 ft sampled log data

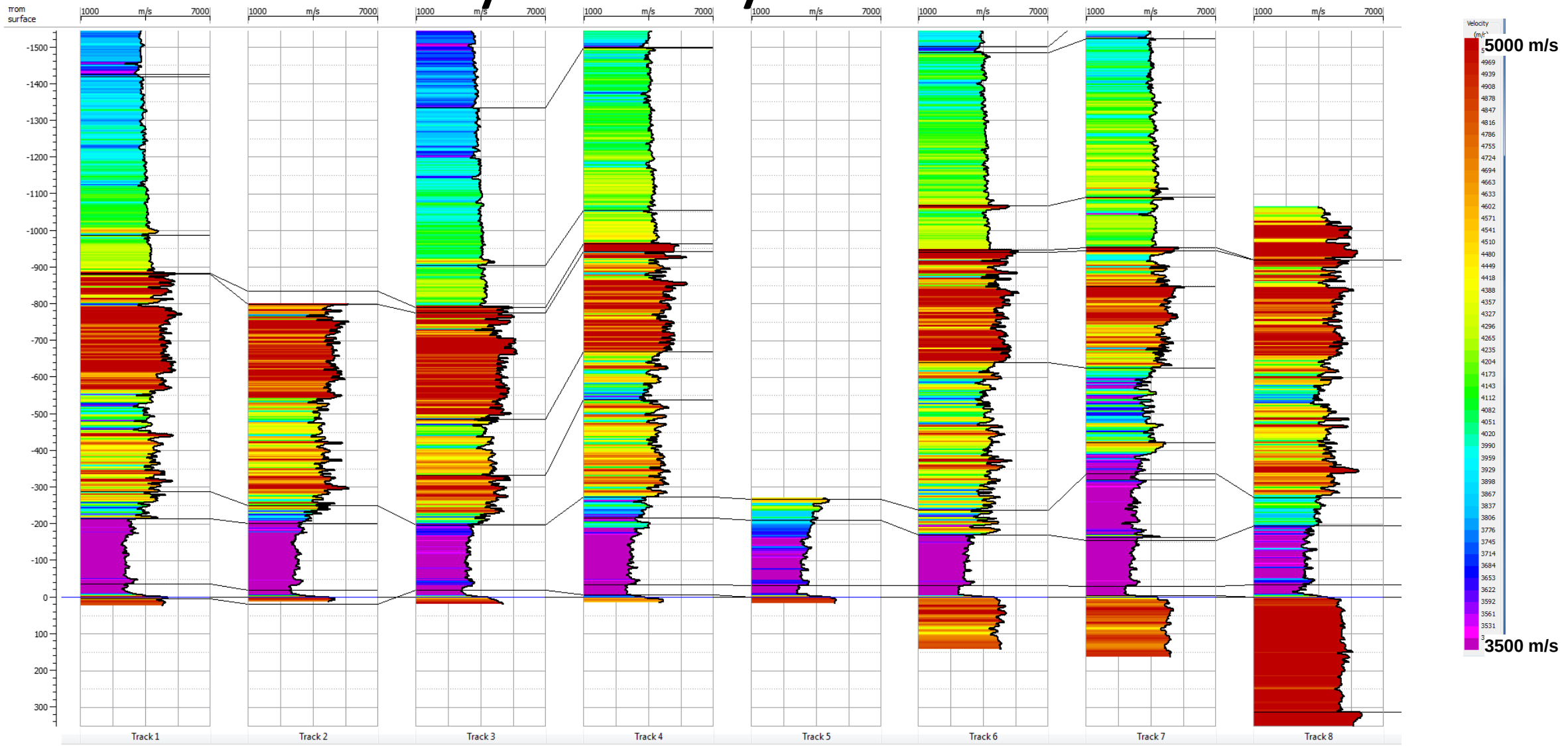


13 well cross-section – median filtered logs with hand-edits

31-point median filter applied to 0.5 ft sampled log data



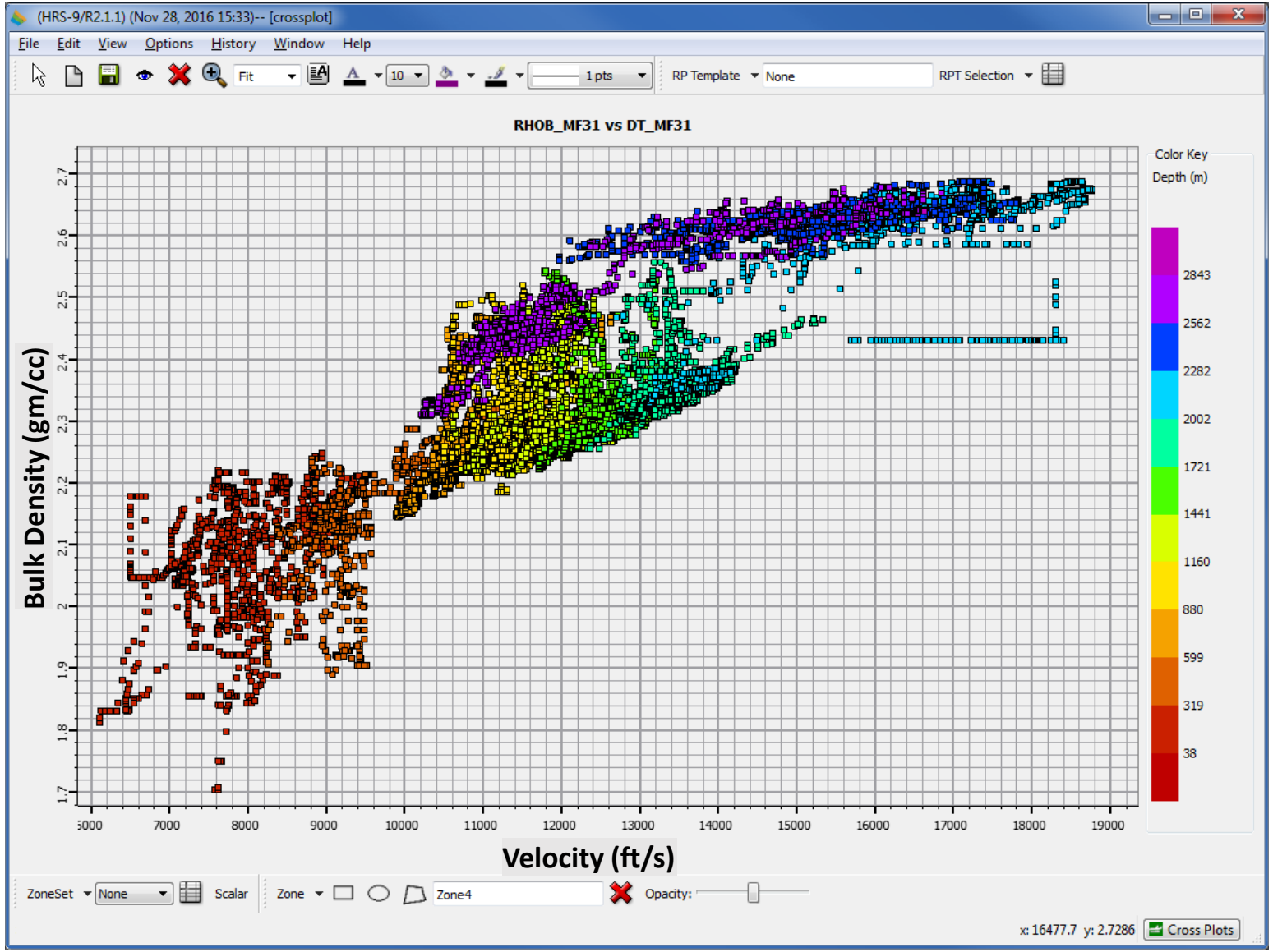
8 well cross-section – median filtered DT logs Color-filled by velocity



QC wells by x-plot

- Hampson-Russell tool
- Simple to use
- Ability to define zones on x-plot
- Immediately identify zones in logs
- Don’t need to be a petrophysicist to spot “bad data”

X-Plot; Sonic Velocity vs Density



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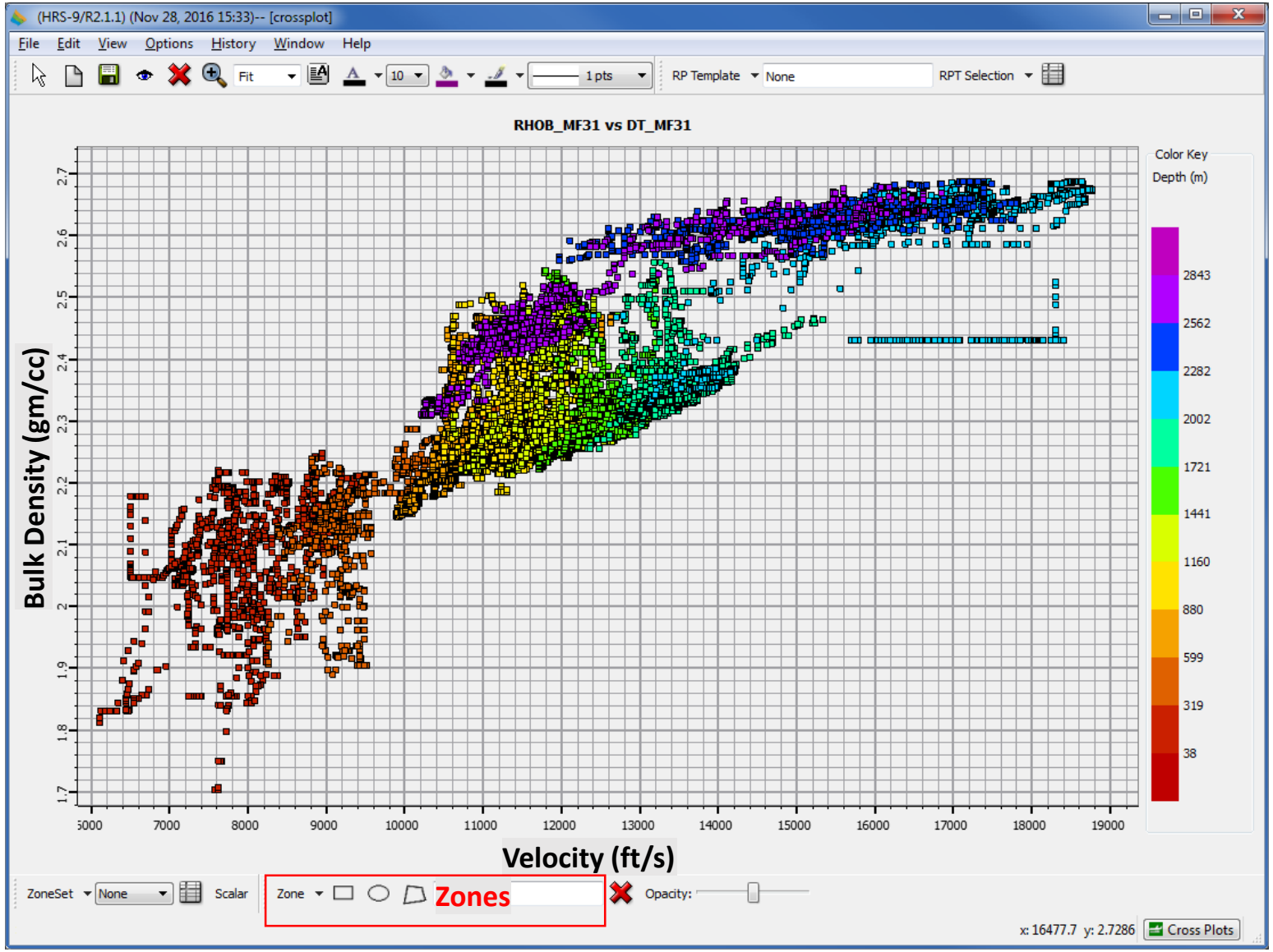

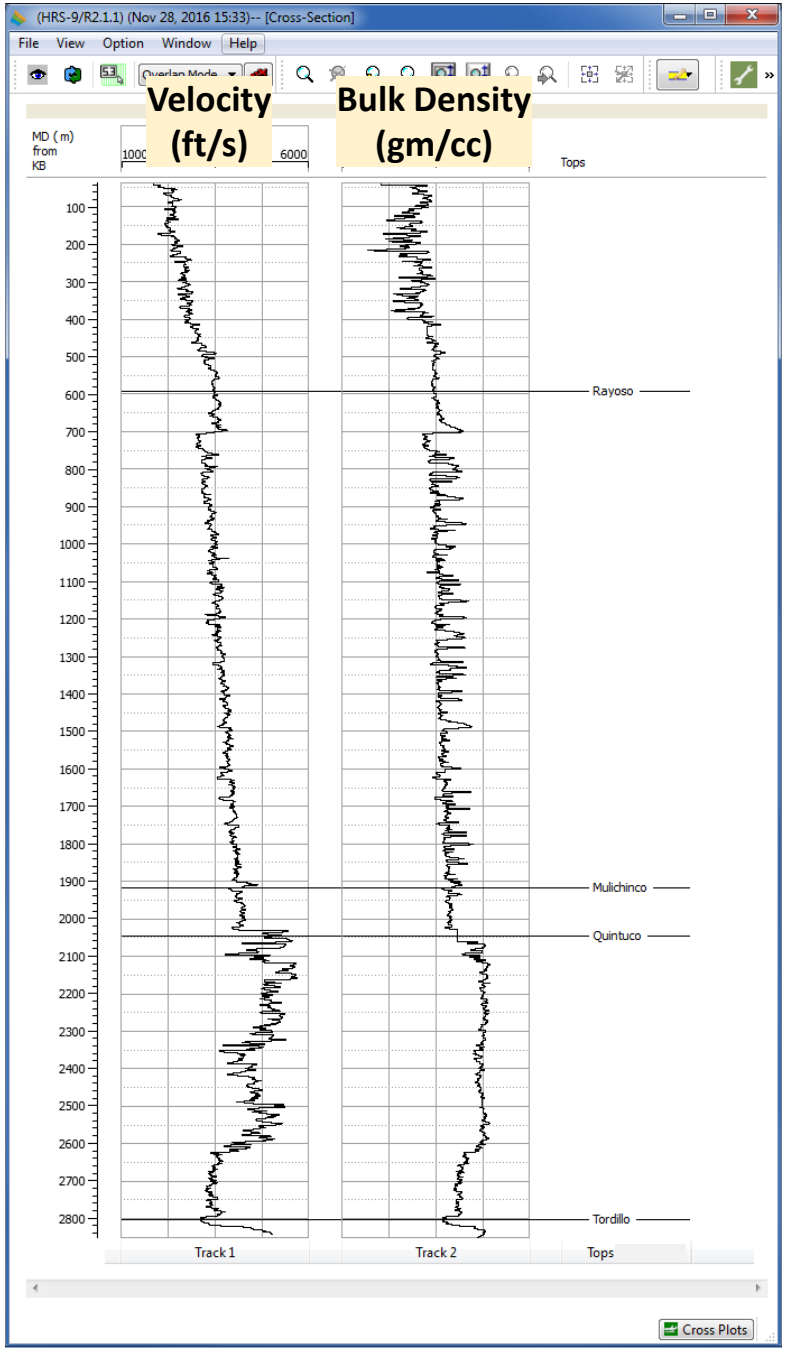

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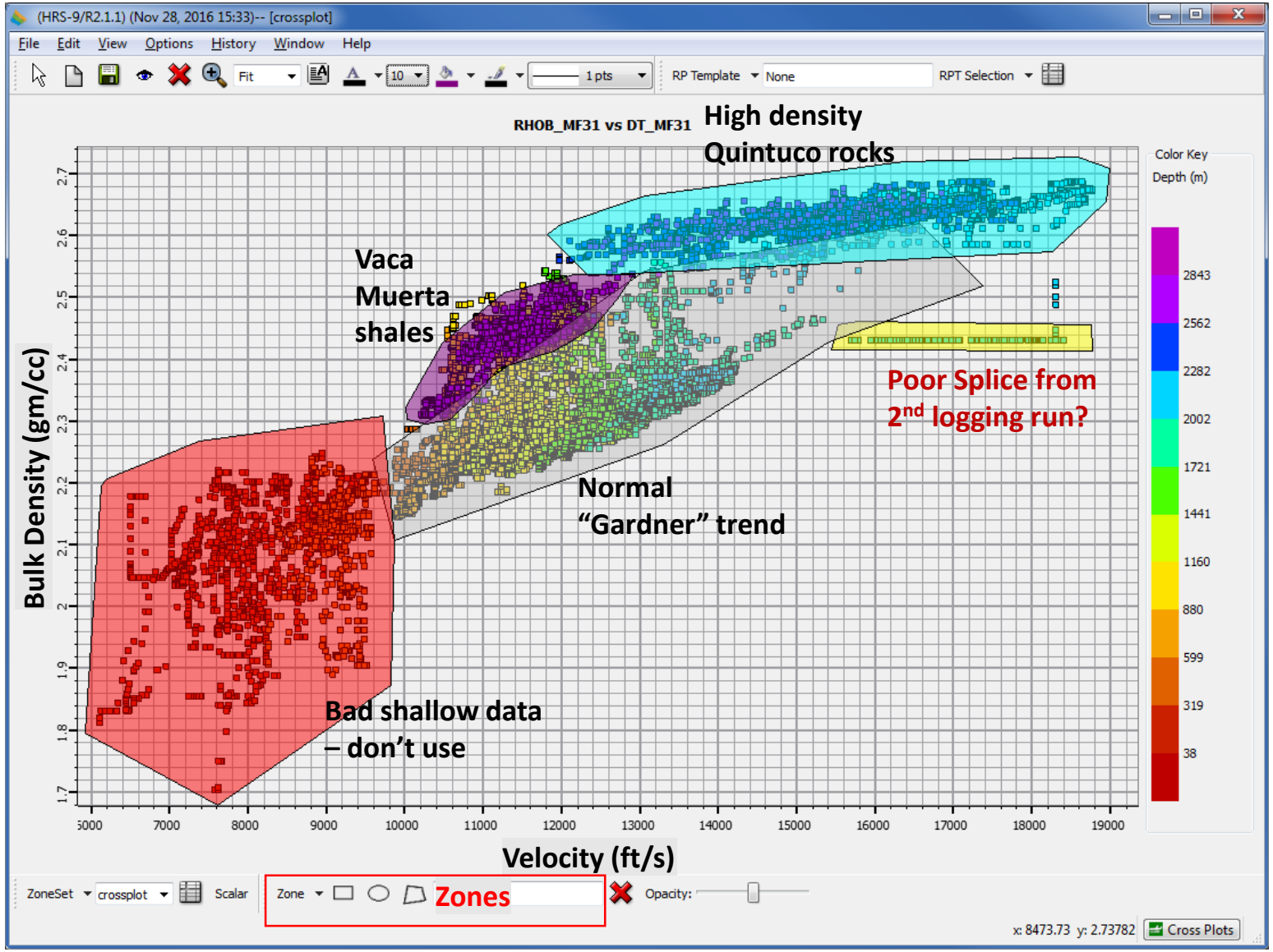
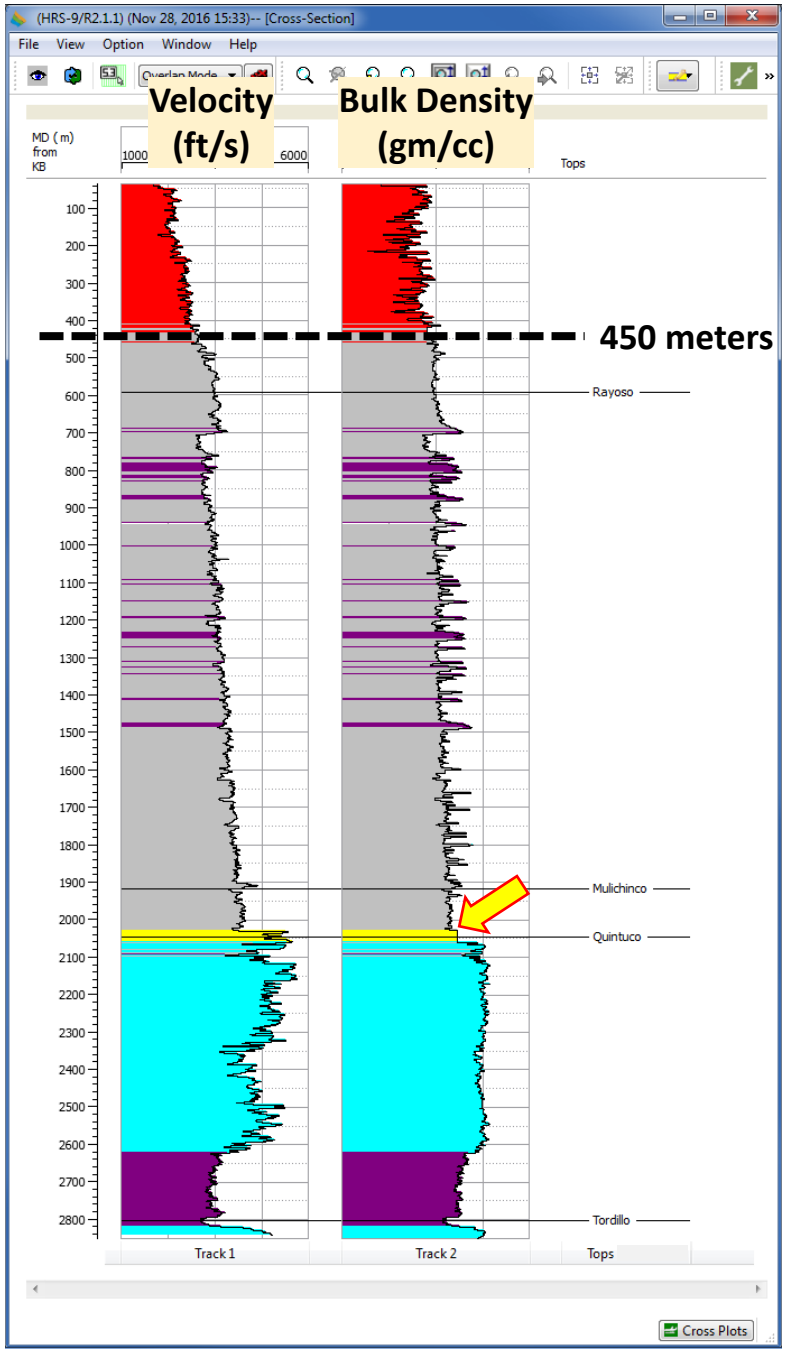
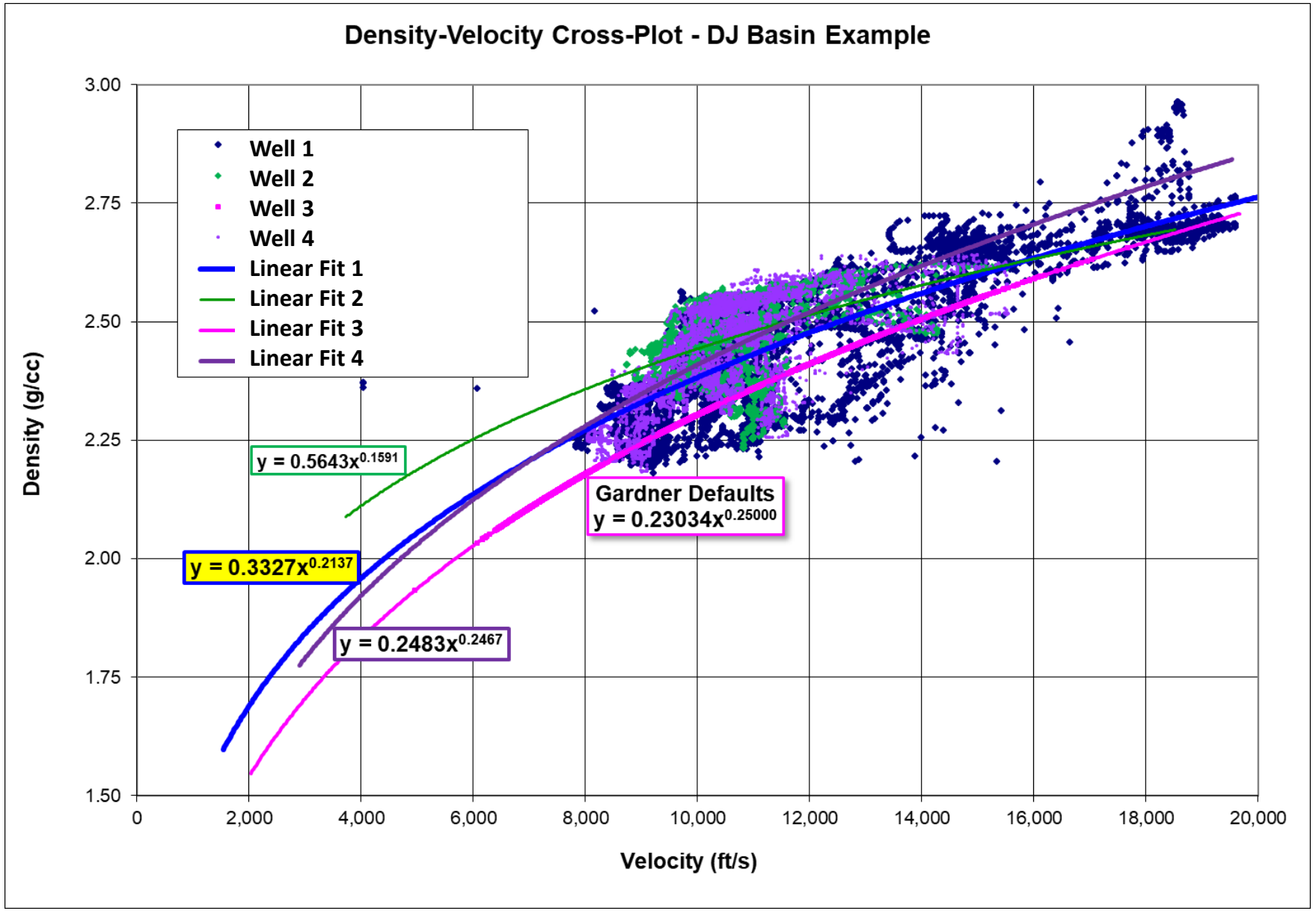




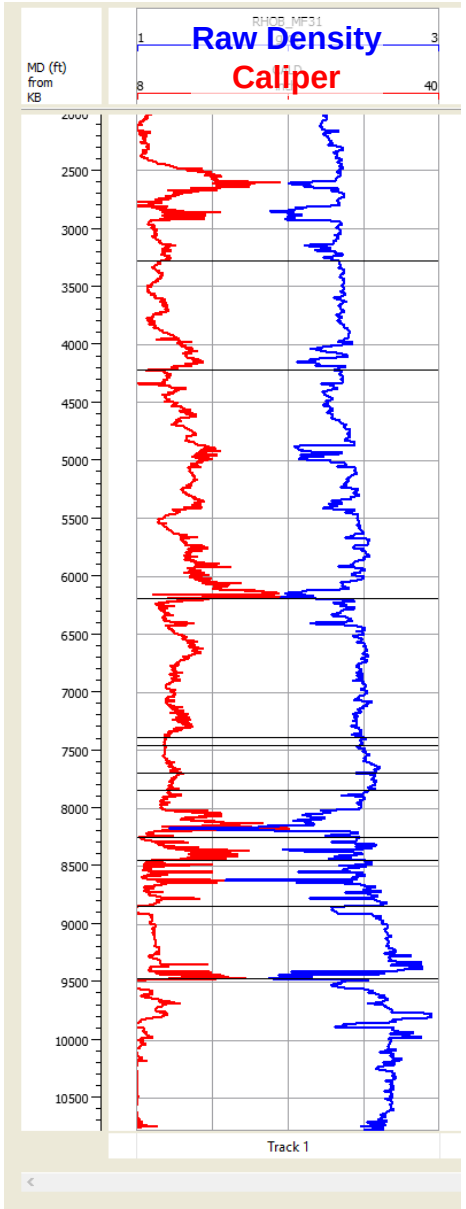
Estimating Missing/bad Density

- Uses Velocity/Density X-plot
- Uses wells with both sonic and density
- Establish an “Adjusted Gardner” trend

Estimating Missing/bad Density

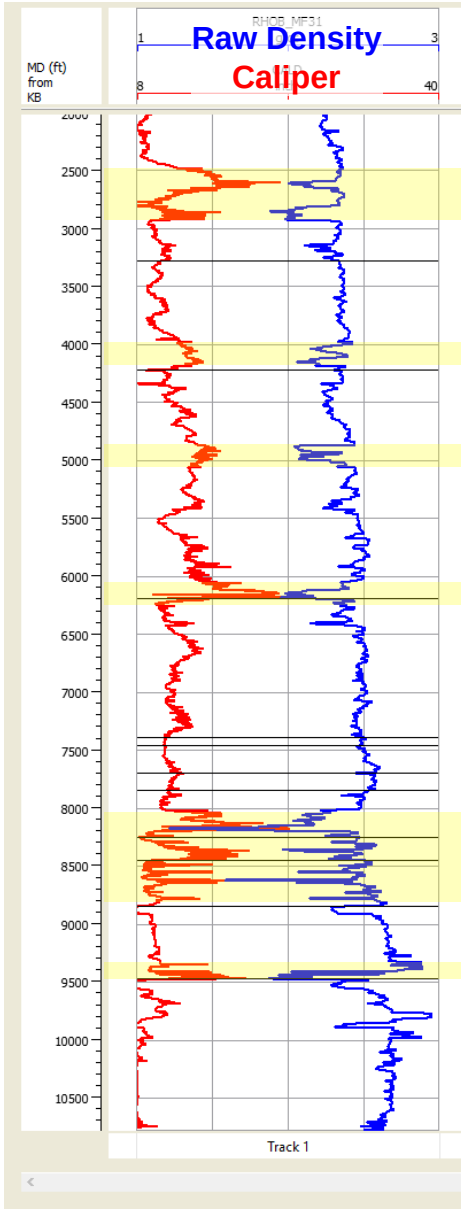


Estimating/Replacing Bad Density



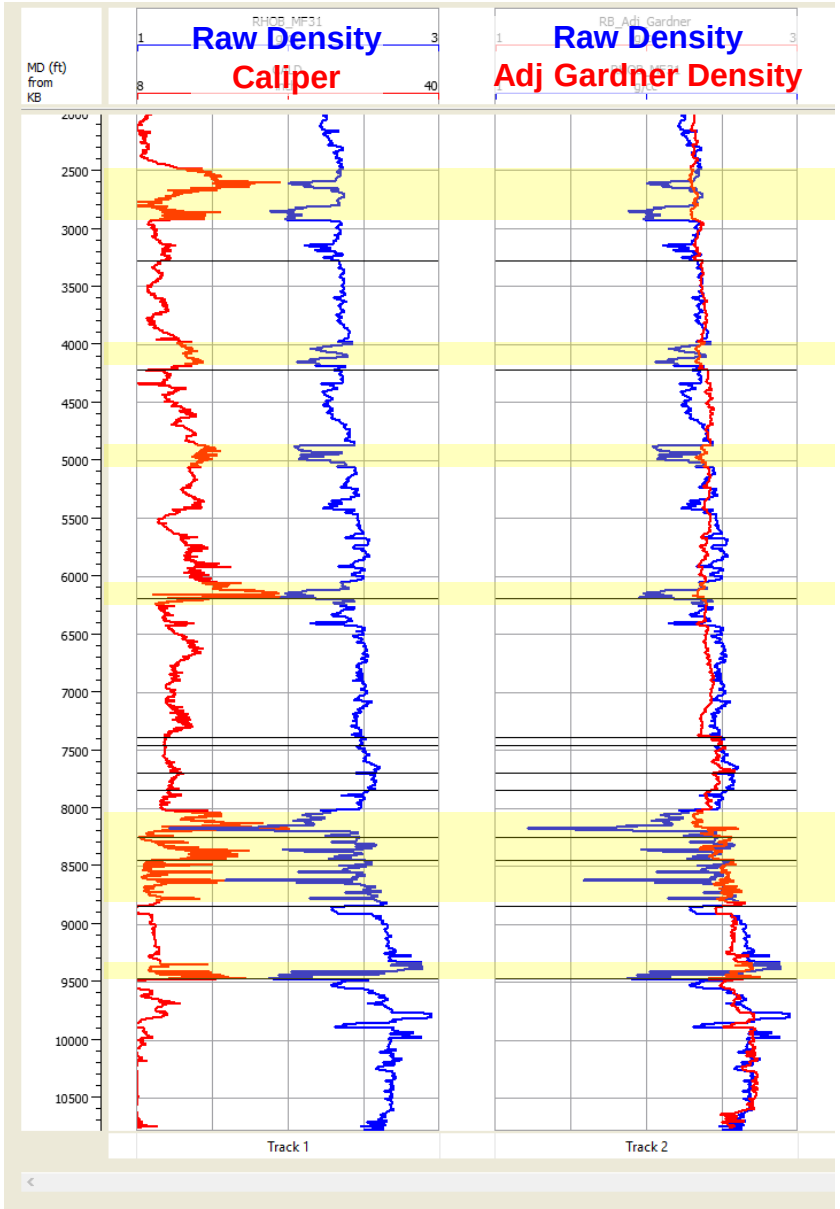
Step 1 – Identify wash-outs based on Caliper Log

Estimating/Replacing Bad Density



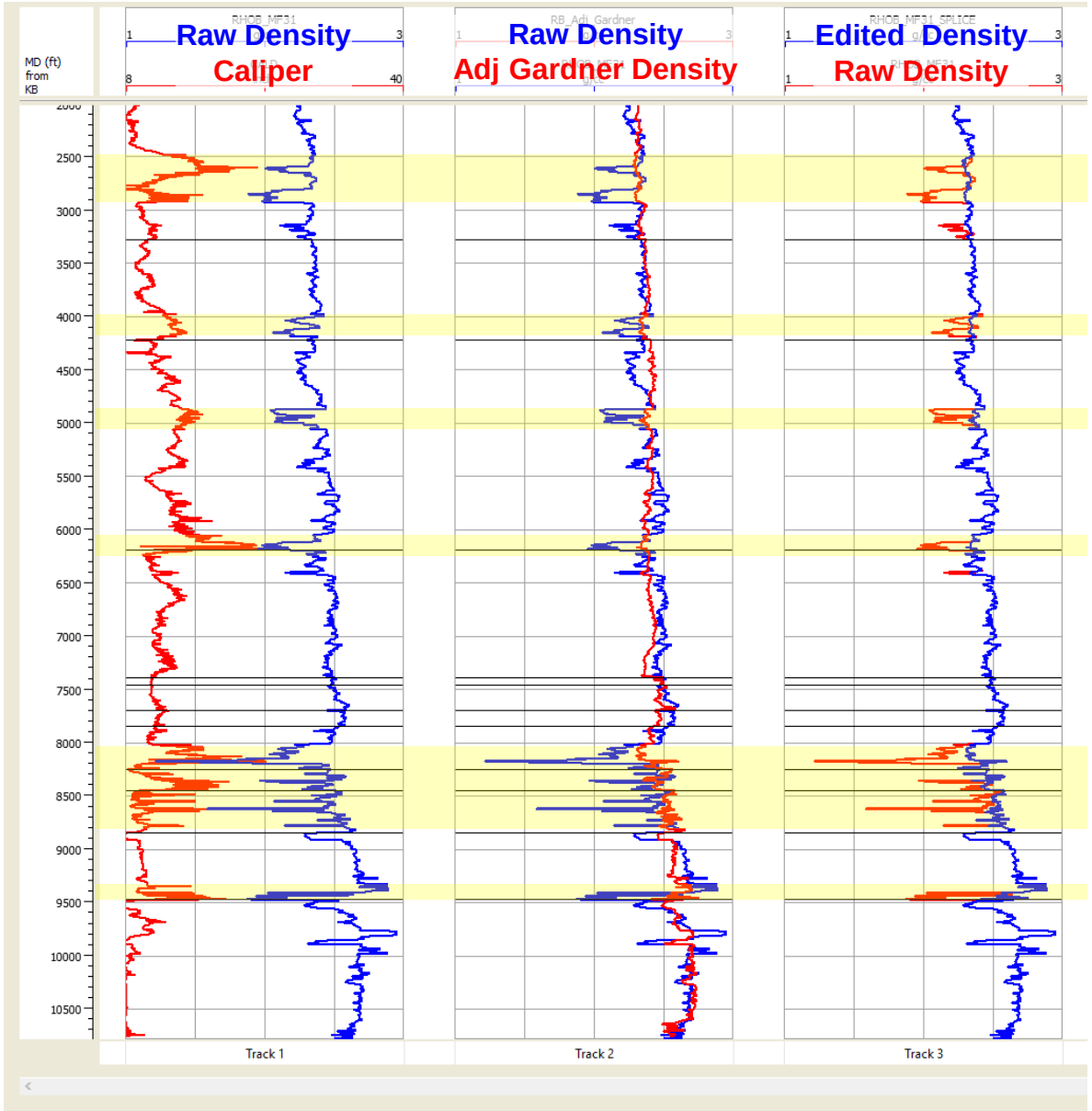
Step 1 – Identify wash-outs based on Caliper Log
Step 2 – Use X-plot to calculate Adj. Gardner Log

Estimating/Replacing Bad Density



Step 1 – Identify wash-outs based on Caliper Log
Step 2 – Use X-plot to calculate Adj. Gardner Log
Step 3 – Replace “Bad” density with estimated density

Estimating/Replacing Bad Density



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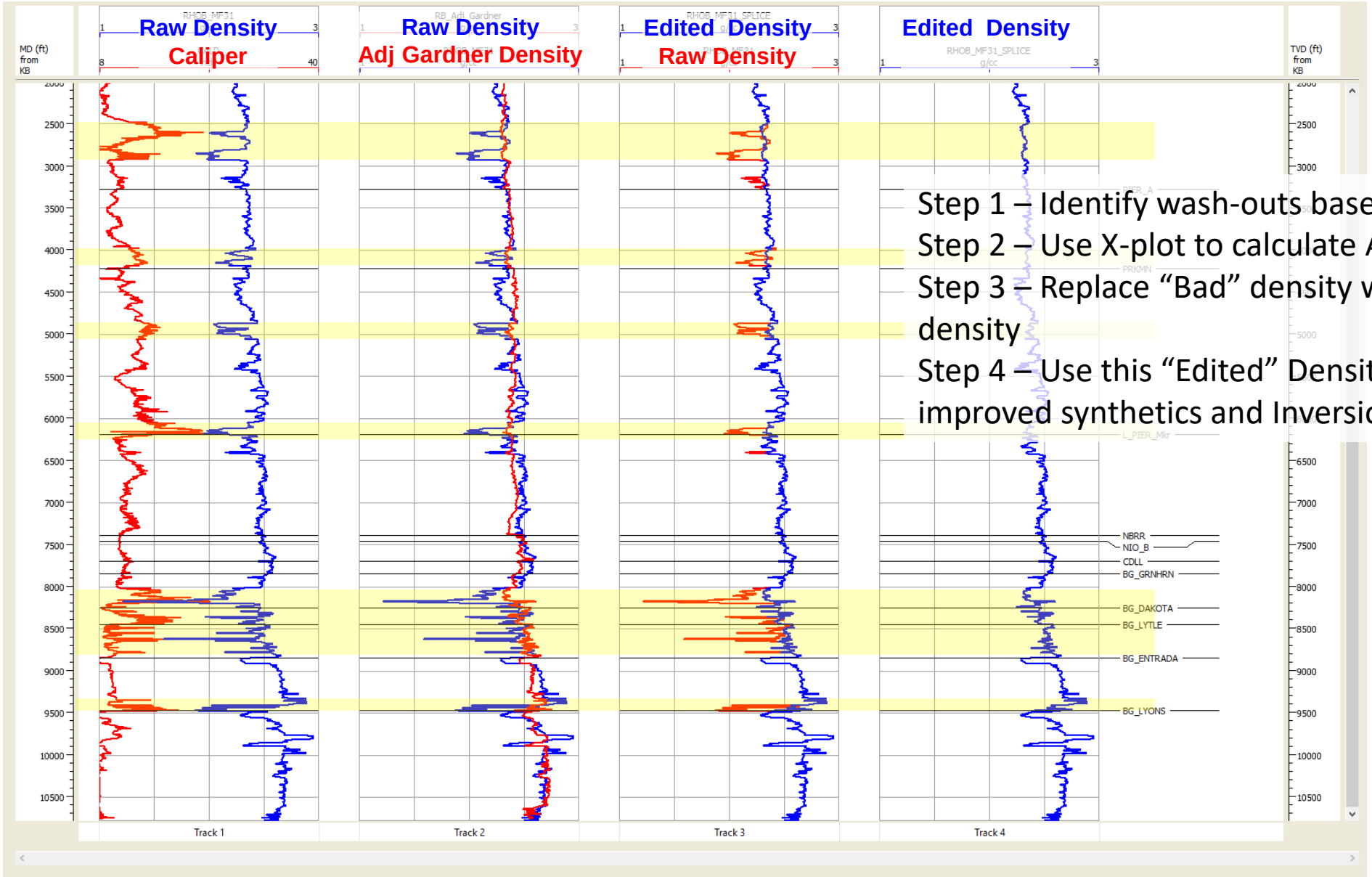


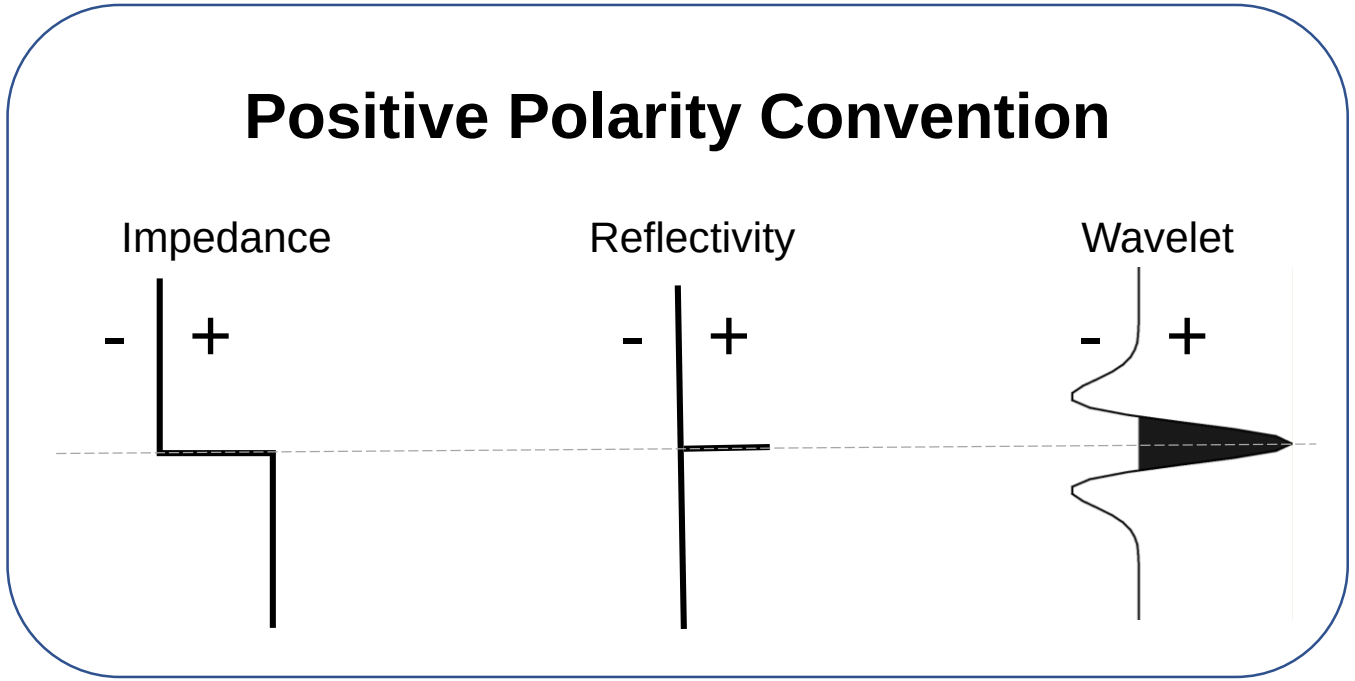
Step 1 – Identify wash-outs based on Caliper Log
Step 2 – Use X-plot to calculate Adj. Gardner Log
Step 3 – Replace “Bad” density with estimated density
Step 4 – Use this “Edited” Density log for improved synthetics and Inversion work

Tie Wells to Seismic

- Hampson-Russell tools
- Simple to use
- Extract statistical wavelet from stack (over objective zone)
- Correlate synthetic over large time window first
- Bulk shift to give best correlation
- Apply “reasonable” stretch-squeeze, if needed
- Determine optimum wavelet phase – button in H-R
- Best to do this to several wells and apply average phase correction

Polarity Convention

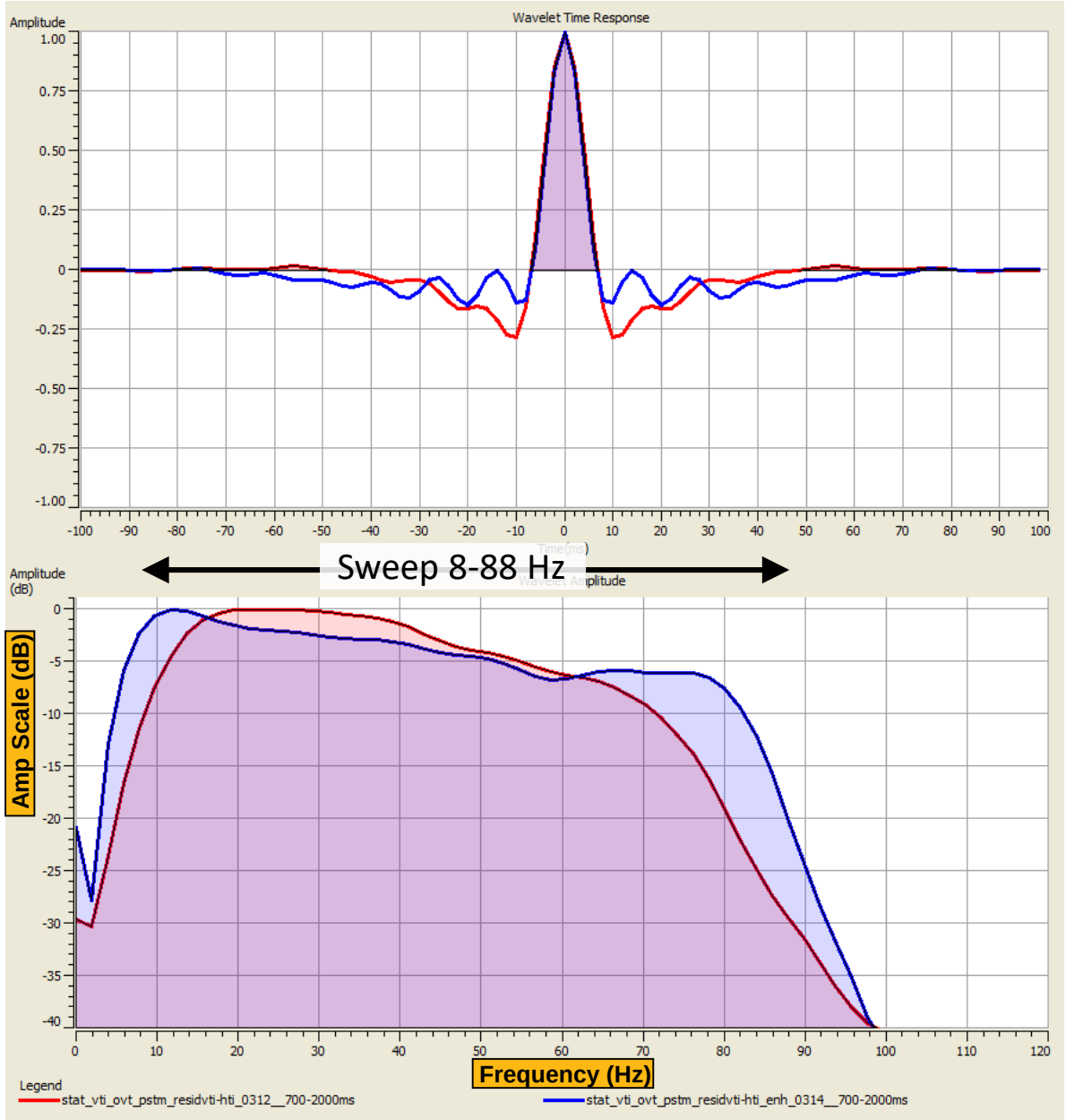
- The displays are presented in “Positive Polarity”:
  - An increase of impedance with depth is represented by a Positive sample – a PEAK on displays



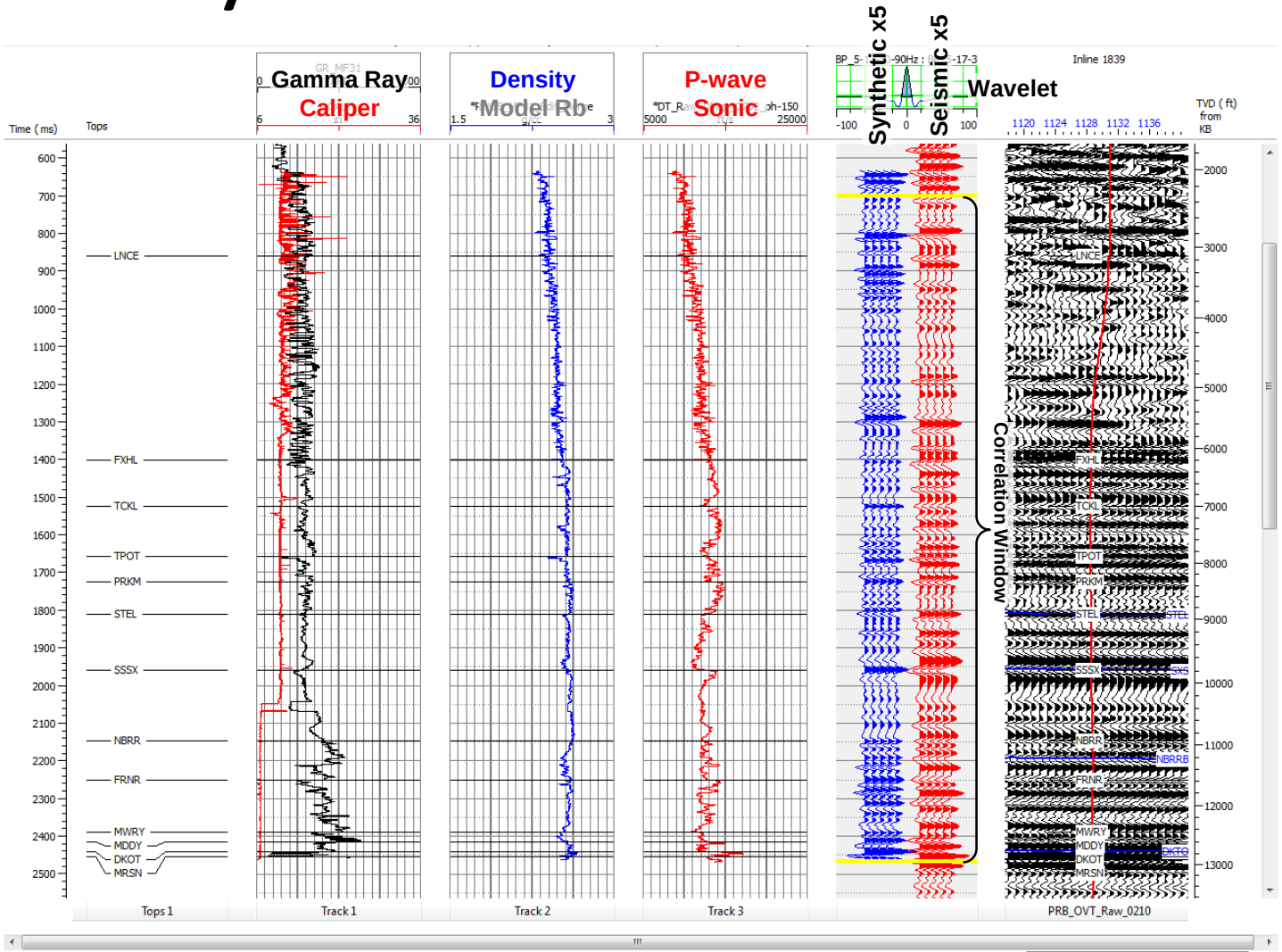
Statistical Wavelet from PSTM

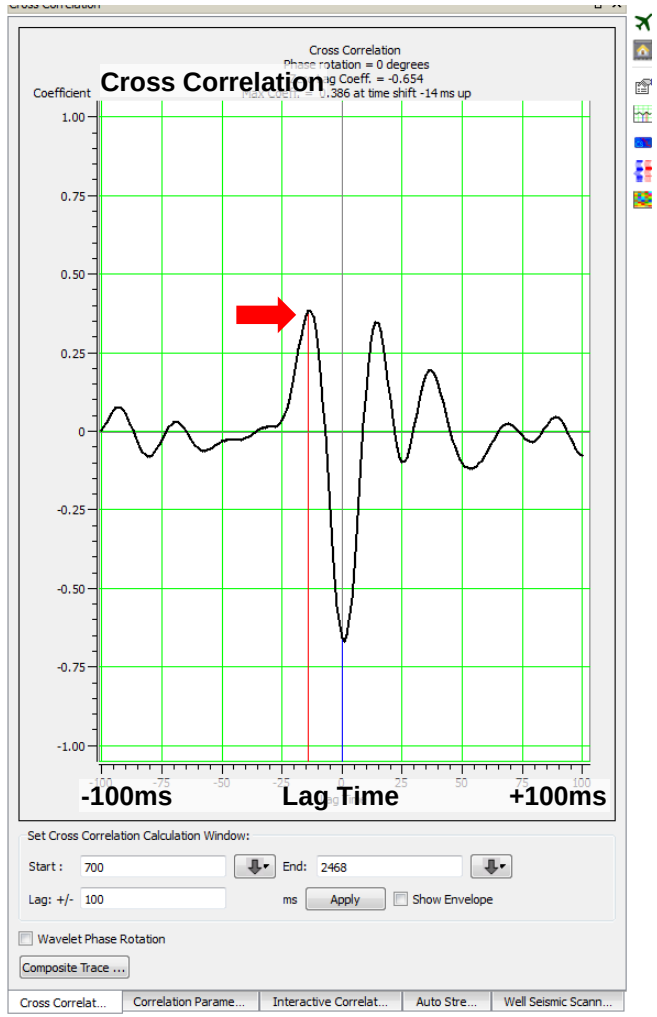
Parameters
Dataset: Pre-Stack Migration
Time: 700-2000 ms
Inline: every 10th trace
Xline: every 10th trace
Wavelet Length: 200 ms
Taper: 50 ms
Phase: Constant
Phase Rotation: 0 degrees

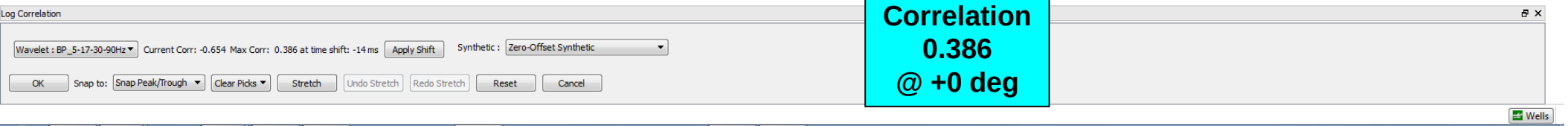
PSTM_raw
PSTM_enh



Synthetic tied to PSTM

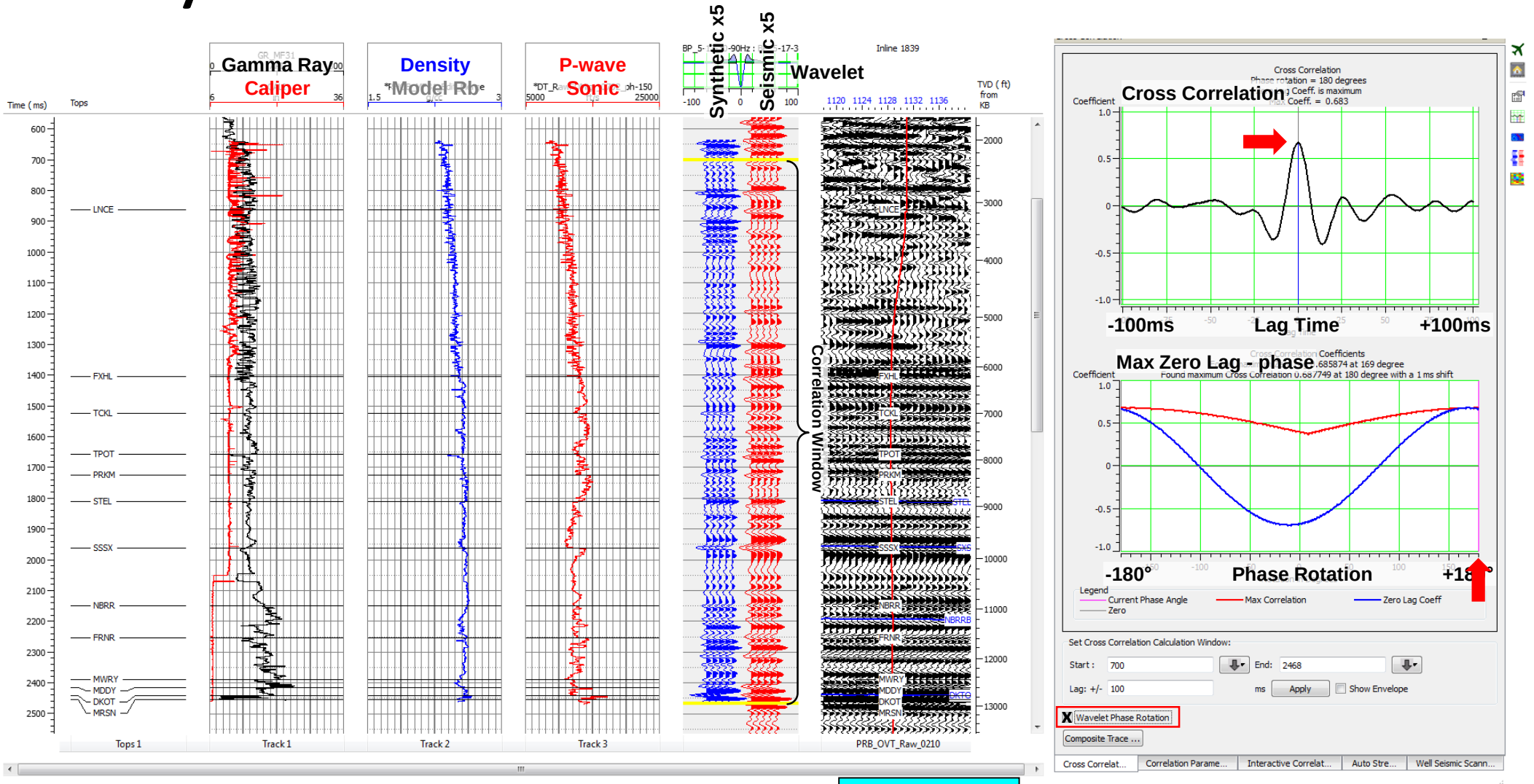


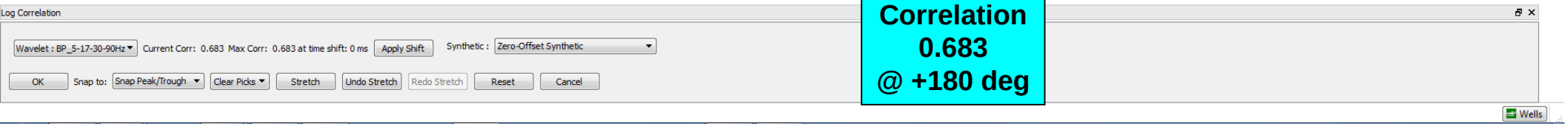




Correlation 0.386 @ +0 deg

Synthetic tied to PSTM





Correlation 0.683 @ +180 deg

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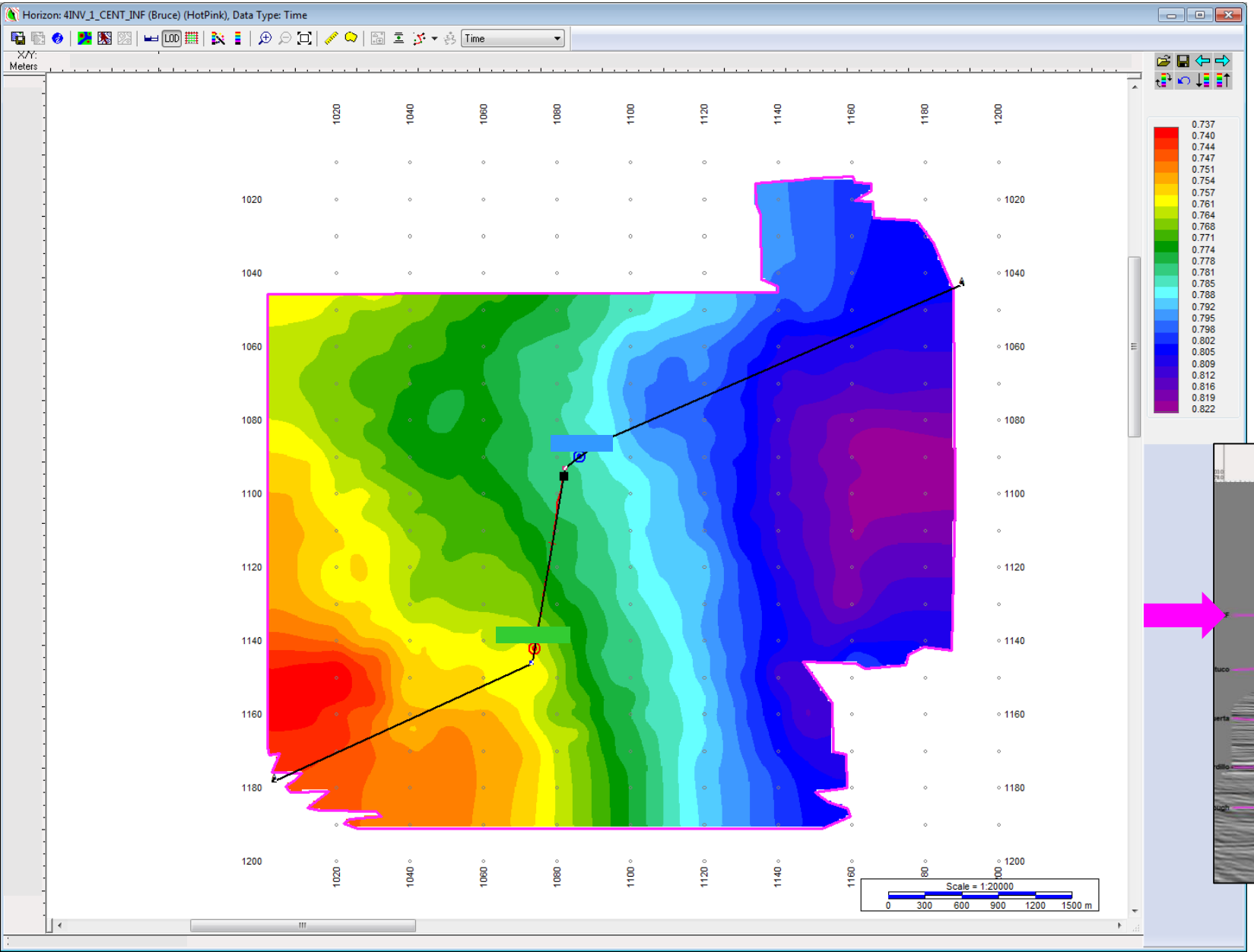
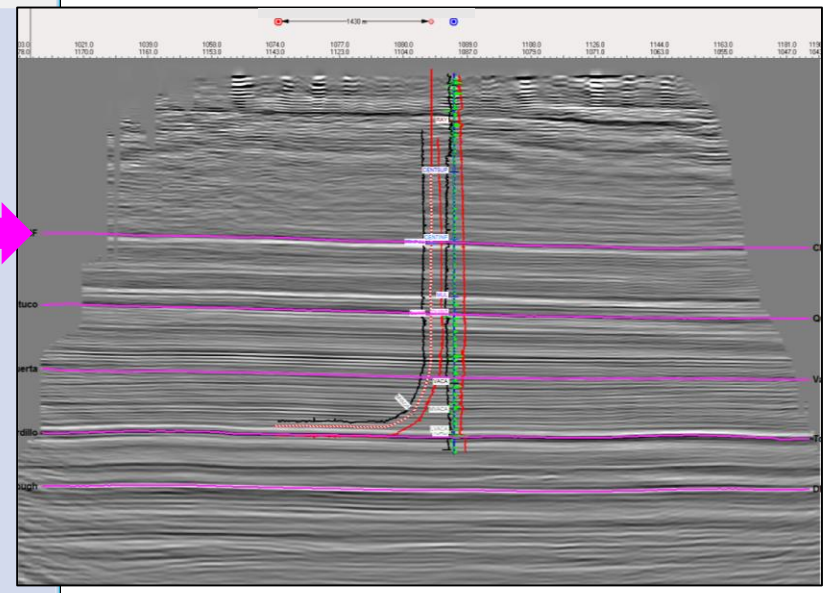
Low-Frequency Background Model (LFBGM)

- Built from **Horizons** and **Well Logs**, to fill-in low **Frequencies**
- **Horizons** – need to decide:
  - How many and where
  - Who picks them
- **Well Logs** – need to decide:
  - How many wells to use (simple is usually better)
  - How to estimate missing logs (DTC, DTS, RhoB)
  - How to correct bad logs (typically DTS or RhoB)
- **Frequency** needed to “fill the gap”:
  - Analyze seismic data over time range of objective
  - Determine filter for model

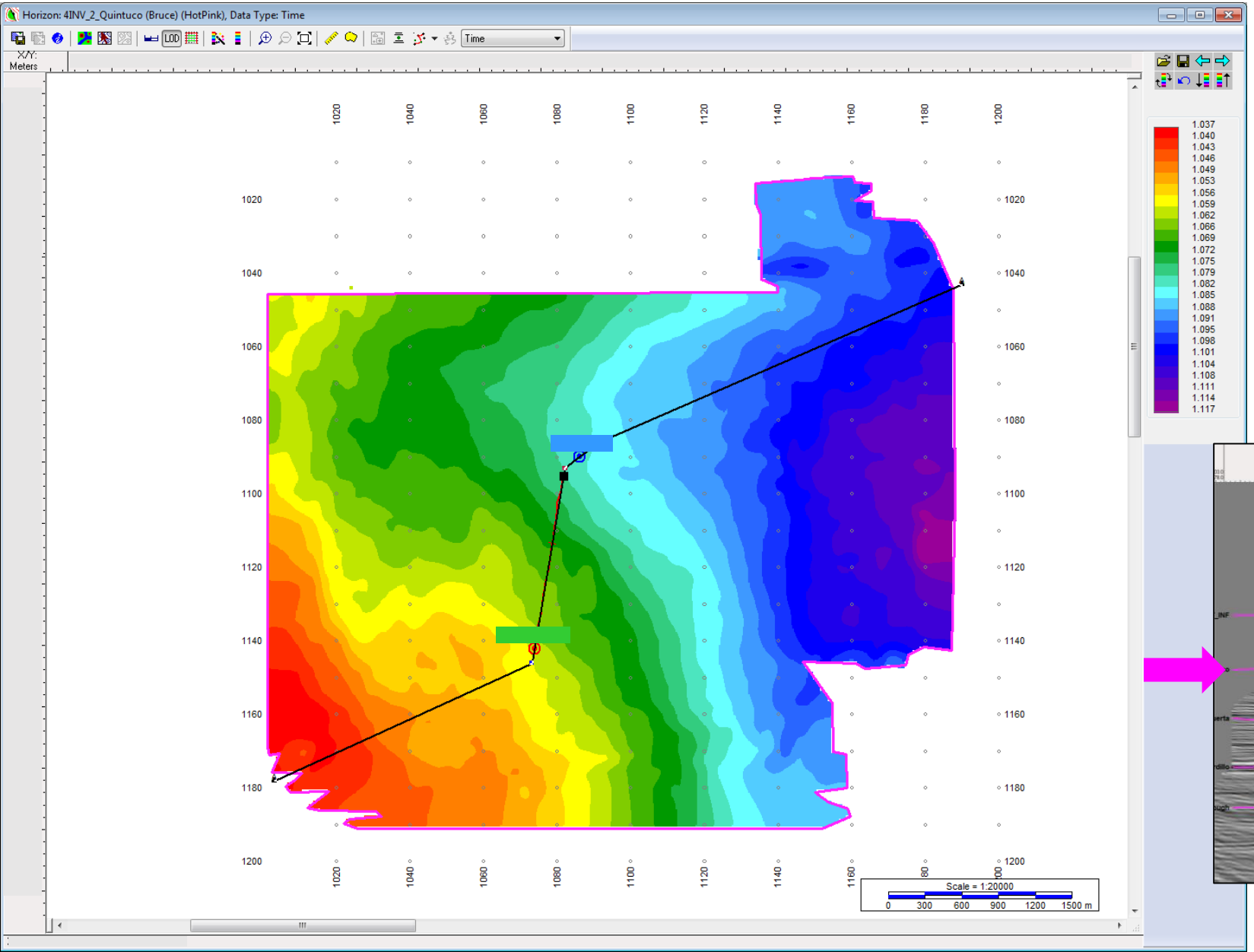
Horizon 1



Note:
1) The horizons must extend the full extent of the deepest horizon to be inverted
2) There can't be gaps (nulls) in the horizons



Horizon 2



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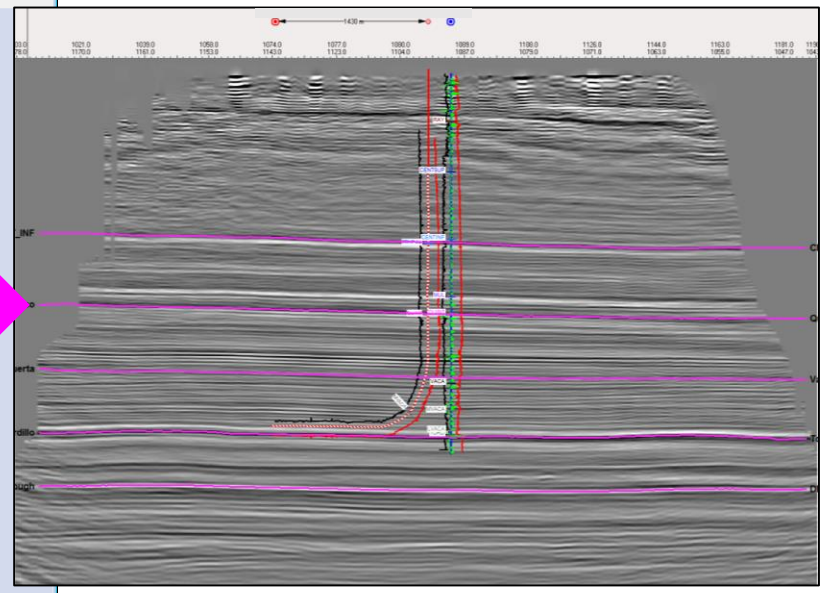
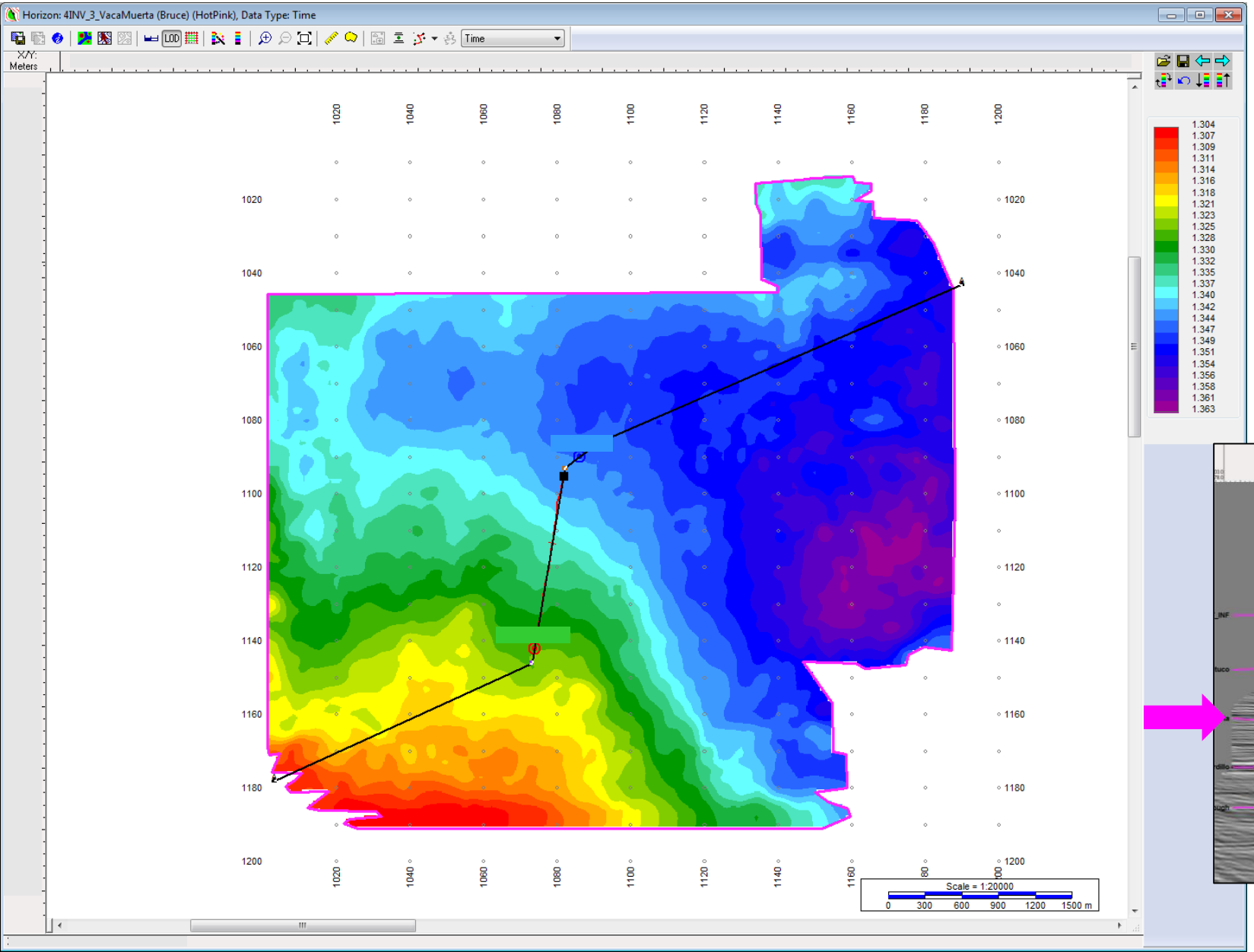


Horizon 3



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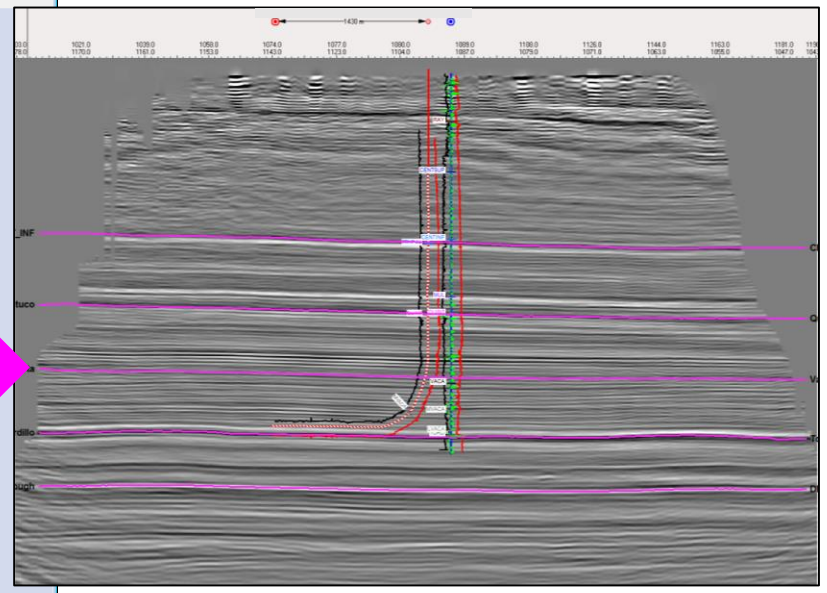
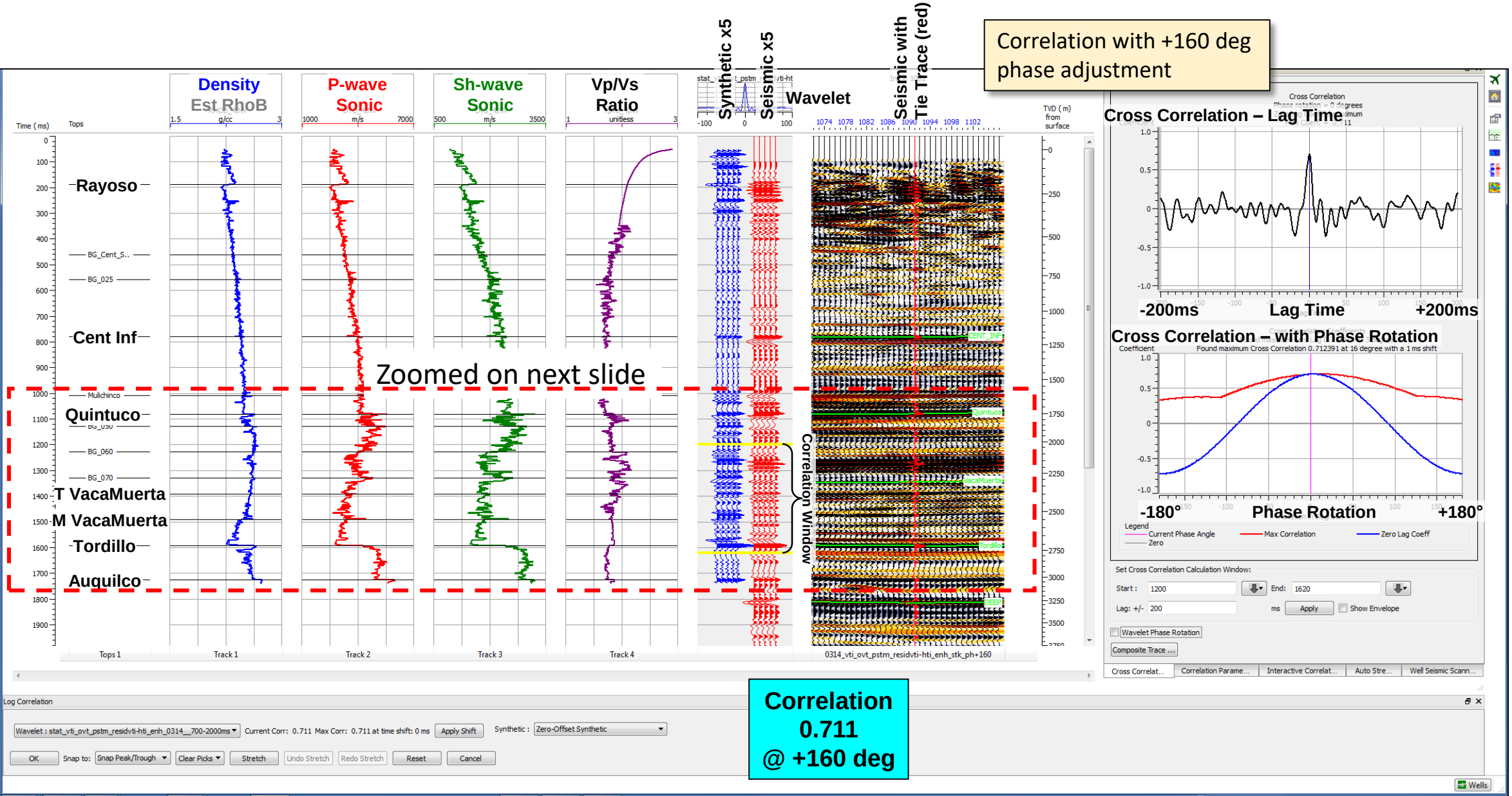


Well logs to be used in inversion (4INV)



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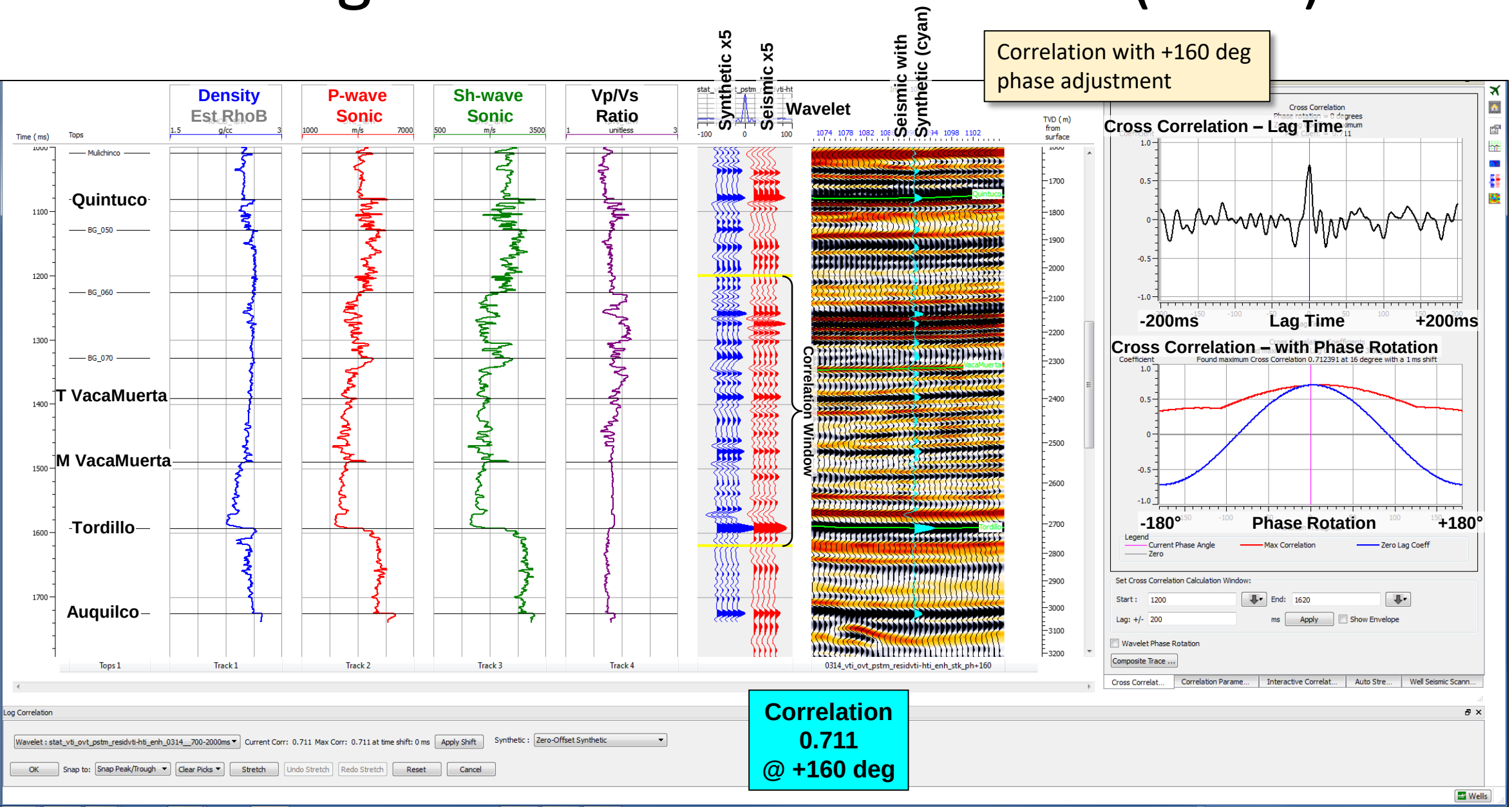
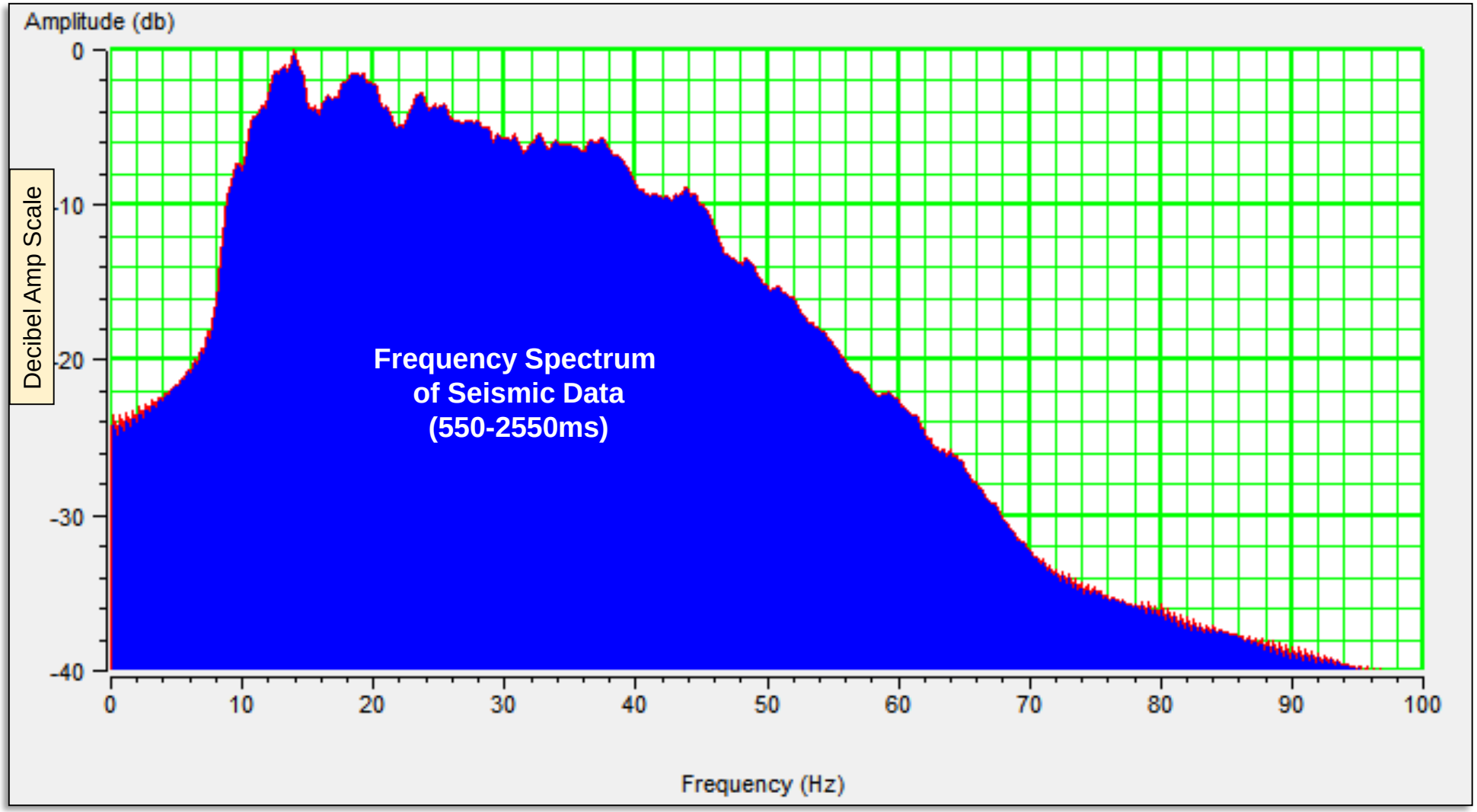


Schematic Diagram of Frequencies Used to Achieve Final Impedance Model



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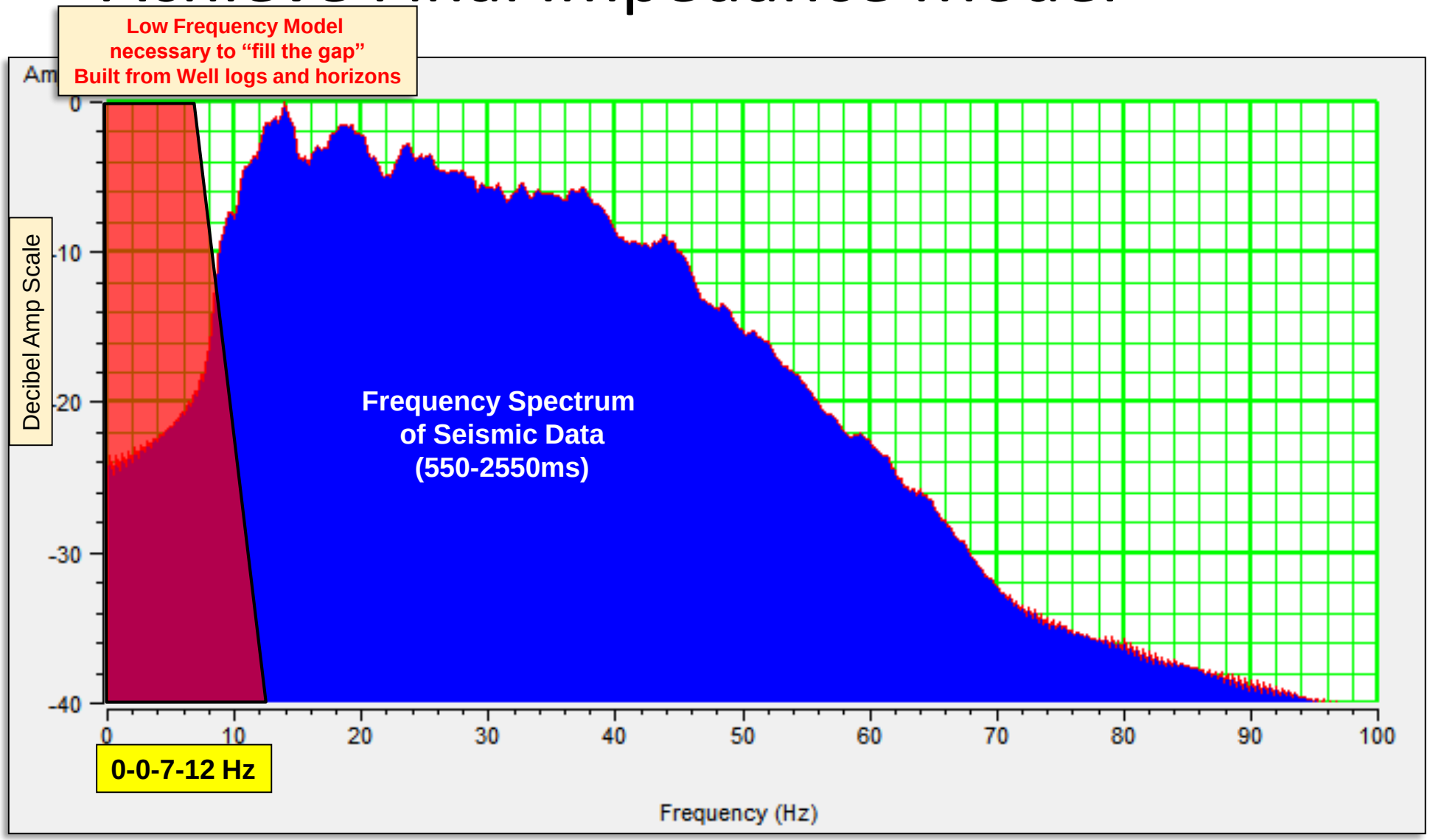

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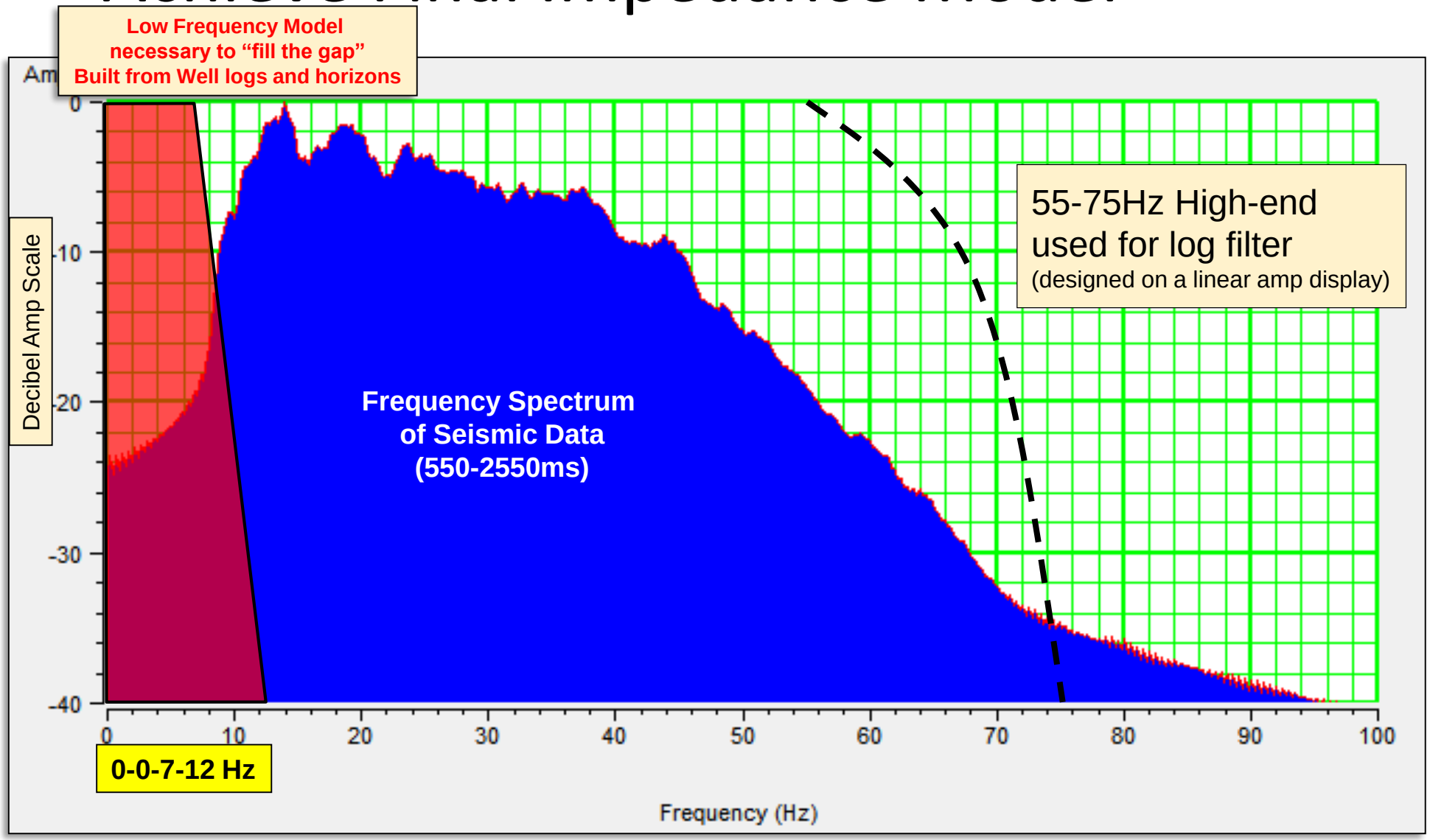
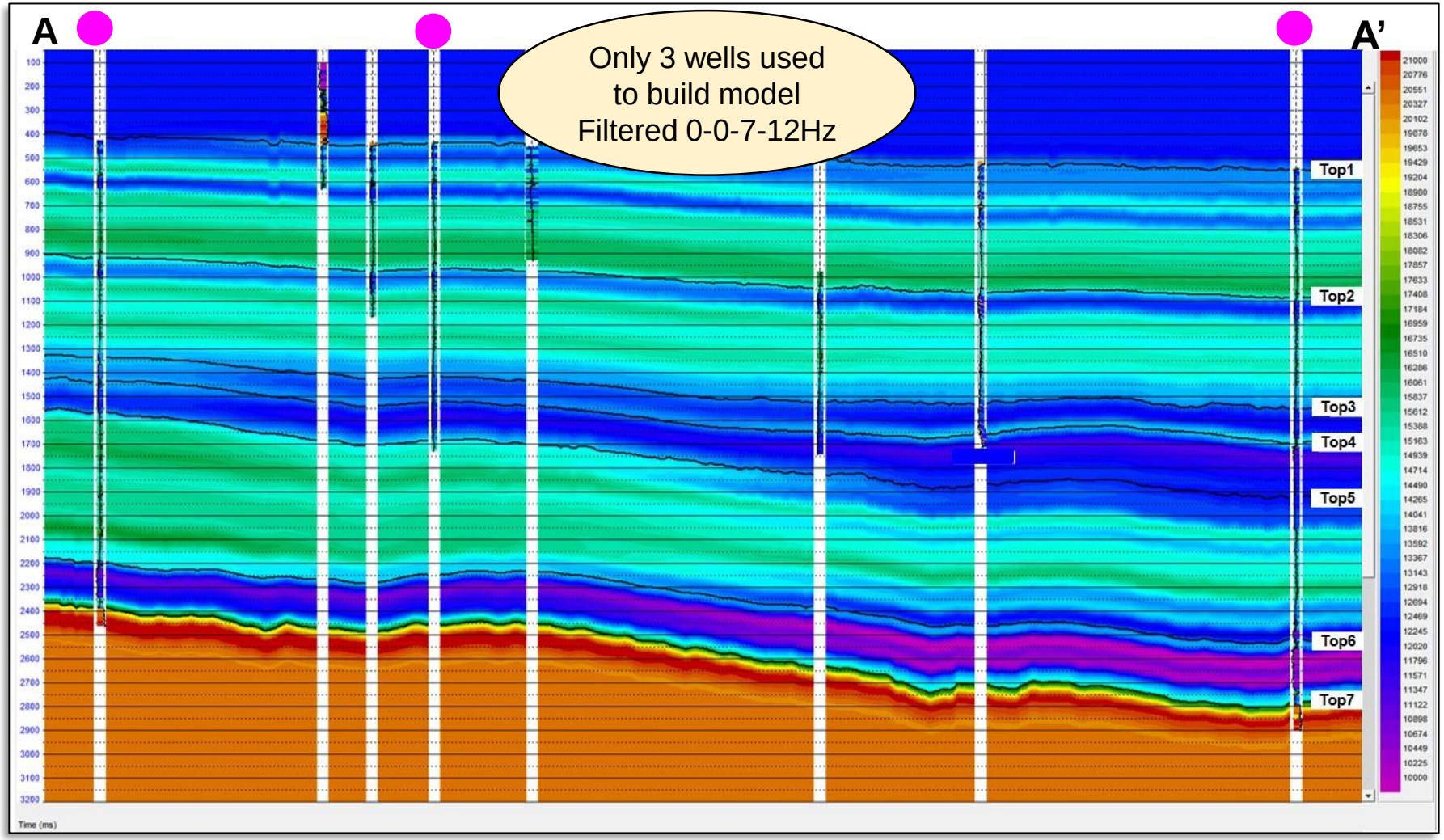
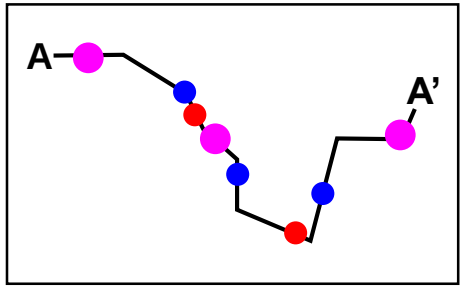


Arb Line through wells with digital log and 7 horizons Background Model – P-Velocity (ft/s)





Low-Frequency Background Model (LFBGM)

- Built from **Horizons** and **Well Logs**, to fill-in low **Frequencies**
- **Horizons** – need to decide:
  - How many and where
  - Who picks them
- **Well Logs** – need to decide:
  - How many wells to use (simple is usually better)
  - How to estimate missing logs (DTC, DTS, RhoB)
  - How to correct bad logs (typically DTS or RhoB)
- **Frequency** needed to “fill the gap”:
  - Analyze seismic data over time range of objective
  - Determine filter for model

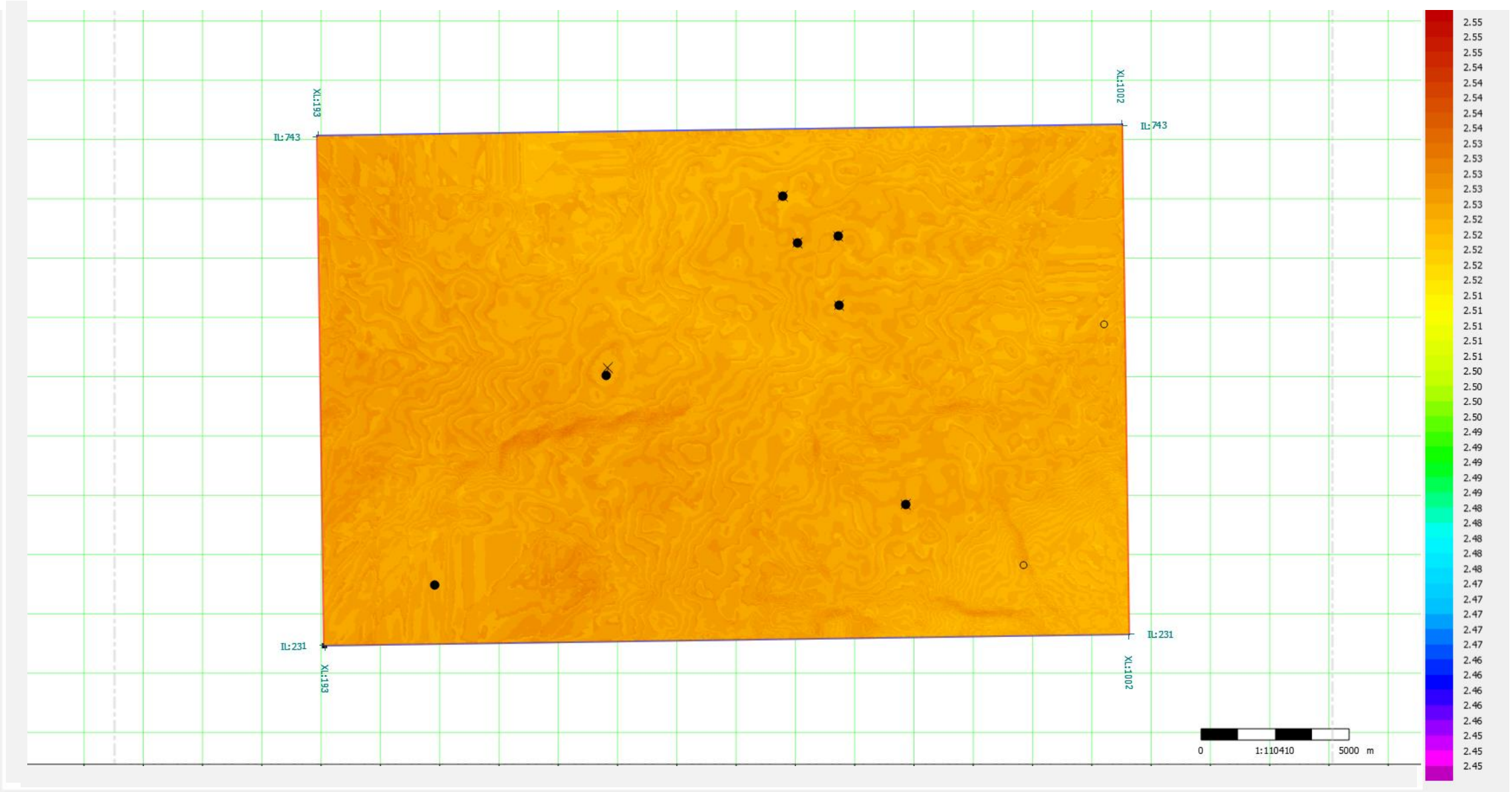
Well to Use in Background Model

- We usually recommend using **just one well** to build the low-frequency background model, and here are the “pros” and “cons”

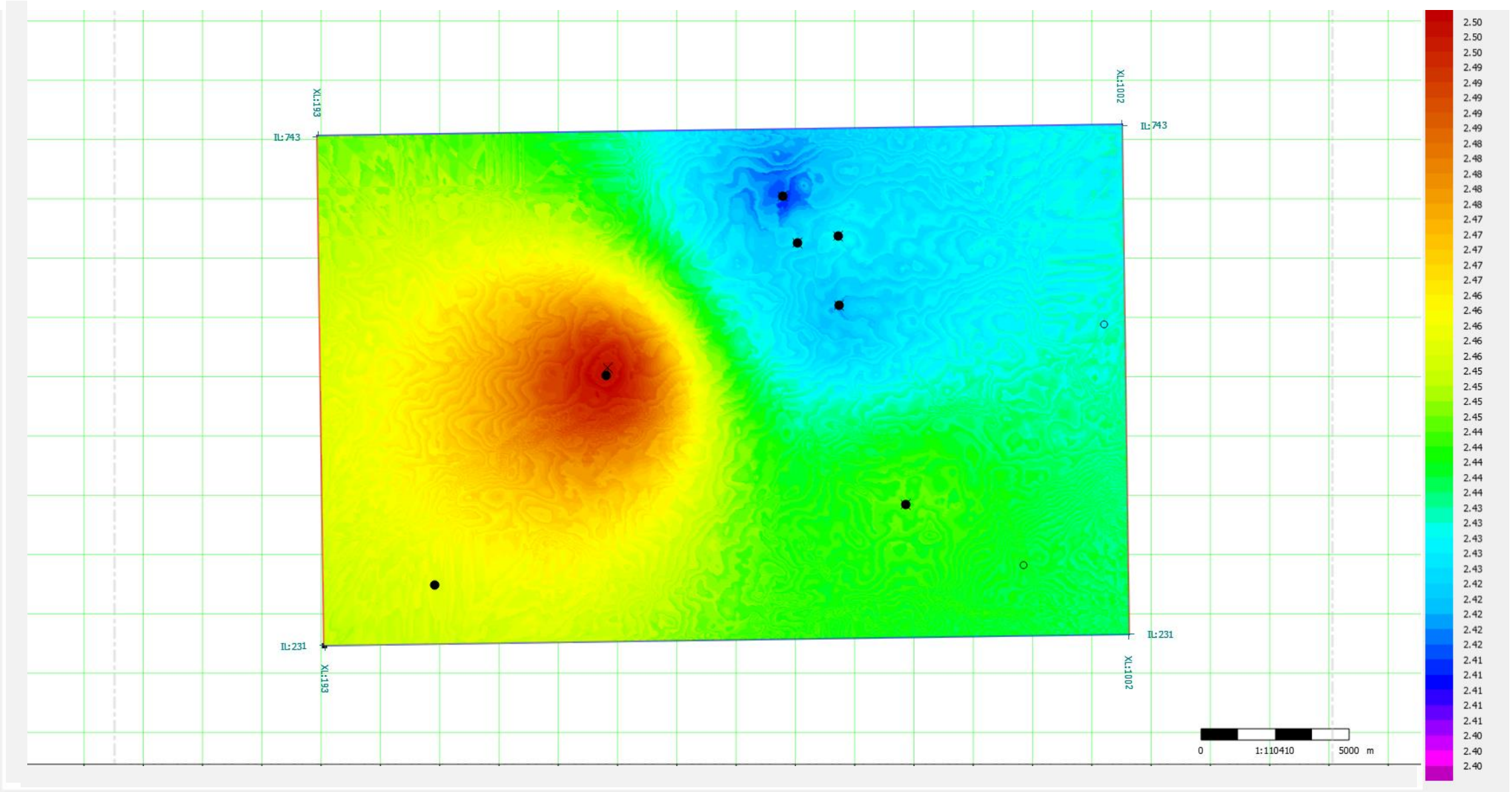
- **Pros**
  - Simple to construct
  - Rock properties are constant across model
  - Changes in inversion are a result of changes in seismic amplitudes
  - Avoids questions of interpolation

- **Cons**
  - Assumes rock velocity and density changes – and you have enough wells to model the geologic changes accurately
  - Changes in inversion are a combined result of changes in the background model and seismic amplitudes
  - Raises questions of interpolation

Hrz Slice; Density Model – 1-well



Hrz Slice; Density Model – 6-wells



Low-Frequency Background Model (LFBGM)

- Built from **Horizons** and **Well Logs**, to fill-in low **Frequencies**

- **QC** is ***Critical*** to success
- Look closely at each volume; Vp, RhoB, Zp, Vs, Zs and Vp/Vs Ratio
- Look vertically (Arb Line) through wells
- Look at Horizon Slices – something like 20ms above/below objective, averaged over 10ms

- Look for bulls-eyes, null values, interpolations that are non-geological

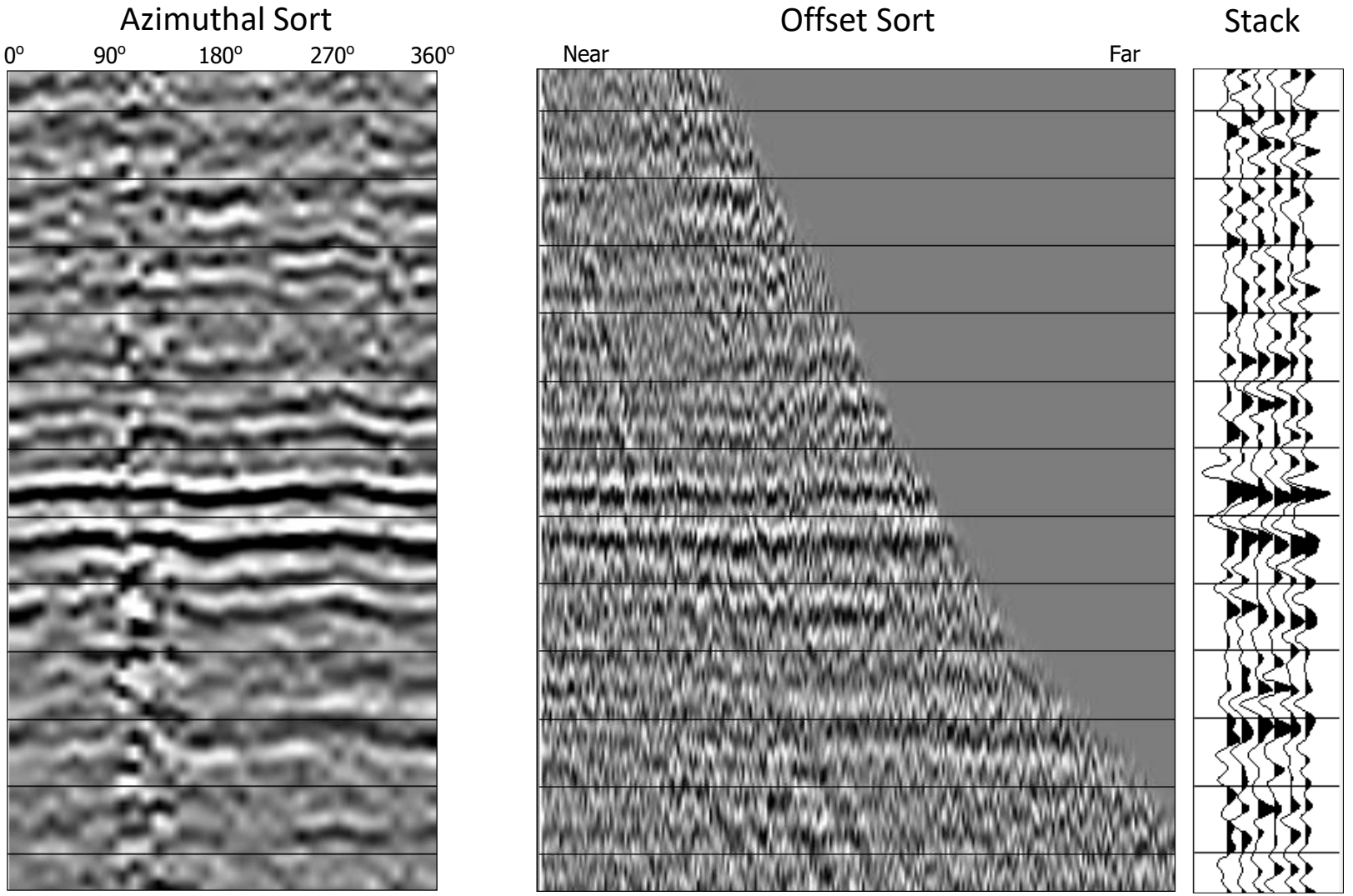
Outline

- Overview of Inversion
- Review well data provided
- Low-Frequency Background Model
- Angle Gathers – what's available in the data
- Scaling the Angle Gathers based on Well Model
- Scaling the Inversion – x-plot analysis
- Results of Simultaneous Elastic Impedance Inversion
- Additional Volumes – Lame, Poisson's Ratio, Young's Modulus
- Predicting Lithology from LRM Cross-plots
- Comments & Conclusions

Gathers for Inversion

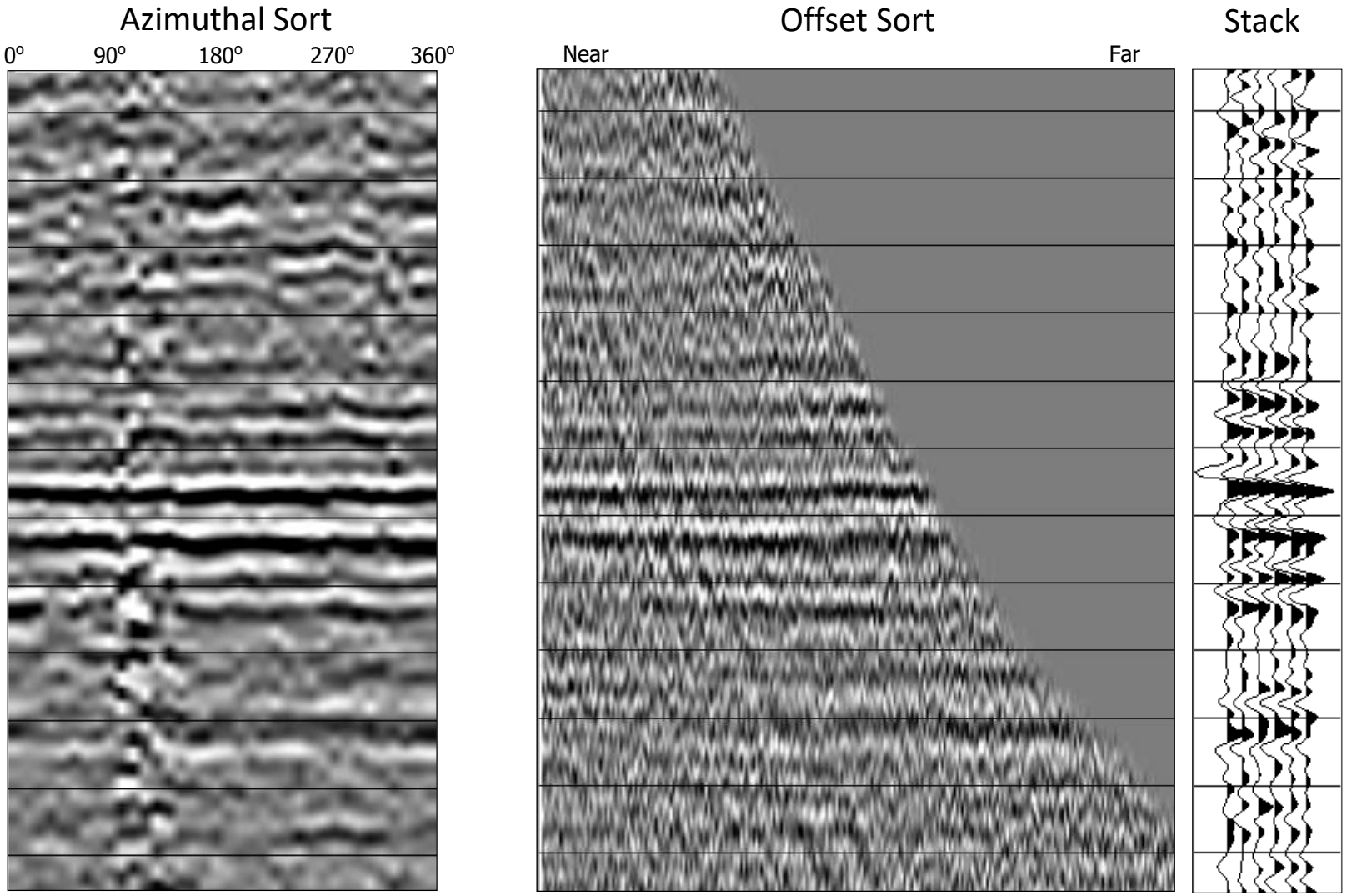
- Lot’s of things to consider here . . .
- Pre-Stack Time migrated gathers
- OVT-PSTM gathers are needed if you’re looking azimuthally
- Corrected for Vertical Transverse Isotropy (VTI – Hockey stick)
- Corrected for Horizontal Transverse Isotropy (HTI – Sinusoid)
- Scaling is Critical – must retain AVO (no short-window AGC)
- Need to QC the gathers closely

Example of HTI Corrections



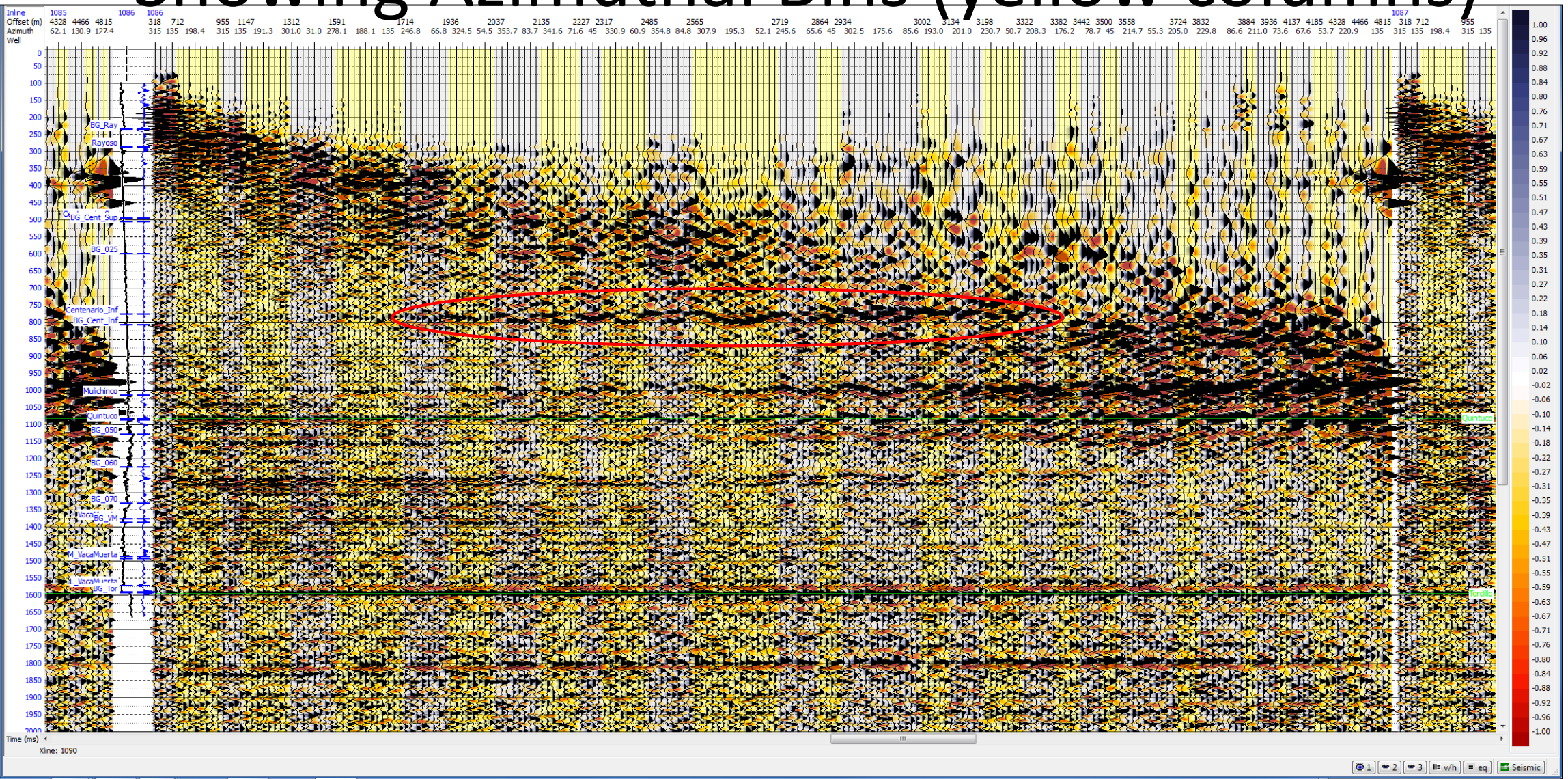
After Isotropic NMO Correction Only

Example of HTI Corrections

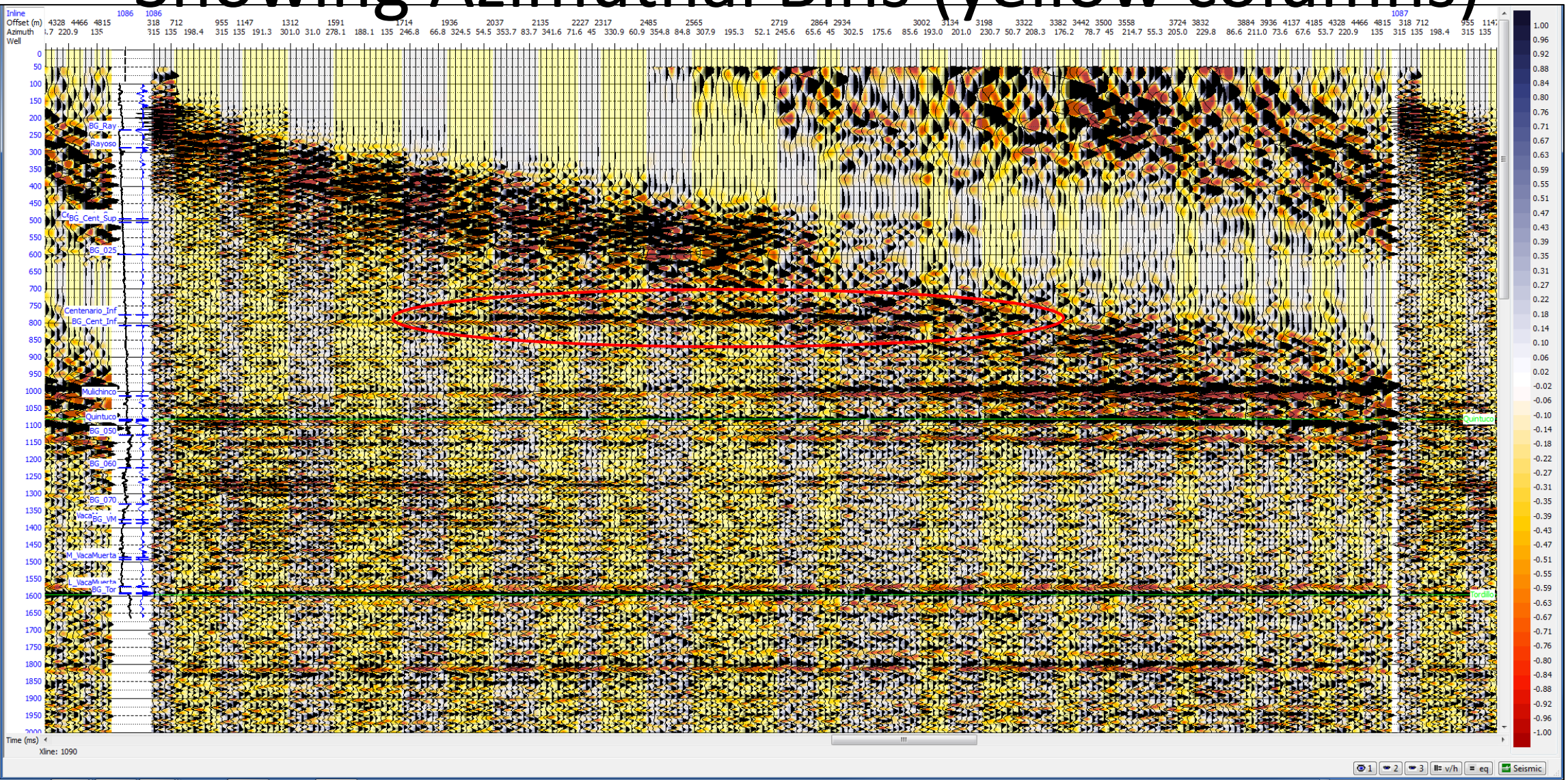


After Azimuthal NMO Correction

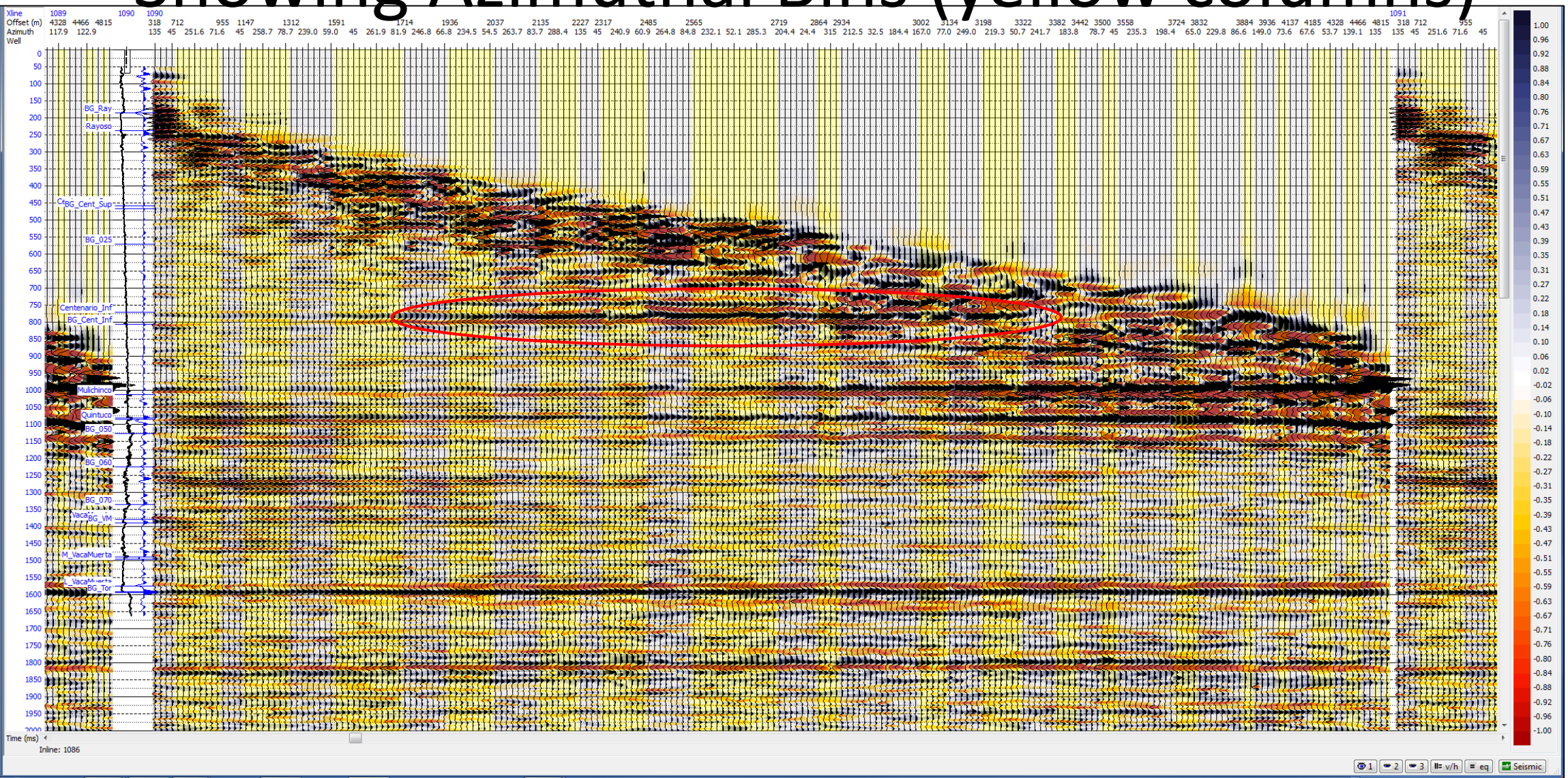
OVT-PSTM Gather with VTI Correction Showing Azimuthal Bins (yellow columns)



OVT-PSTM Gather with VTI+HTI Correction Showing Azimuthal Bins (yellow columns)



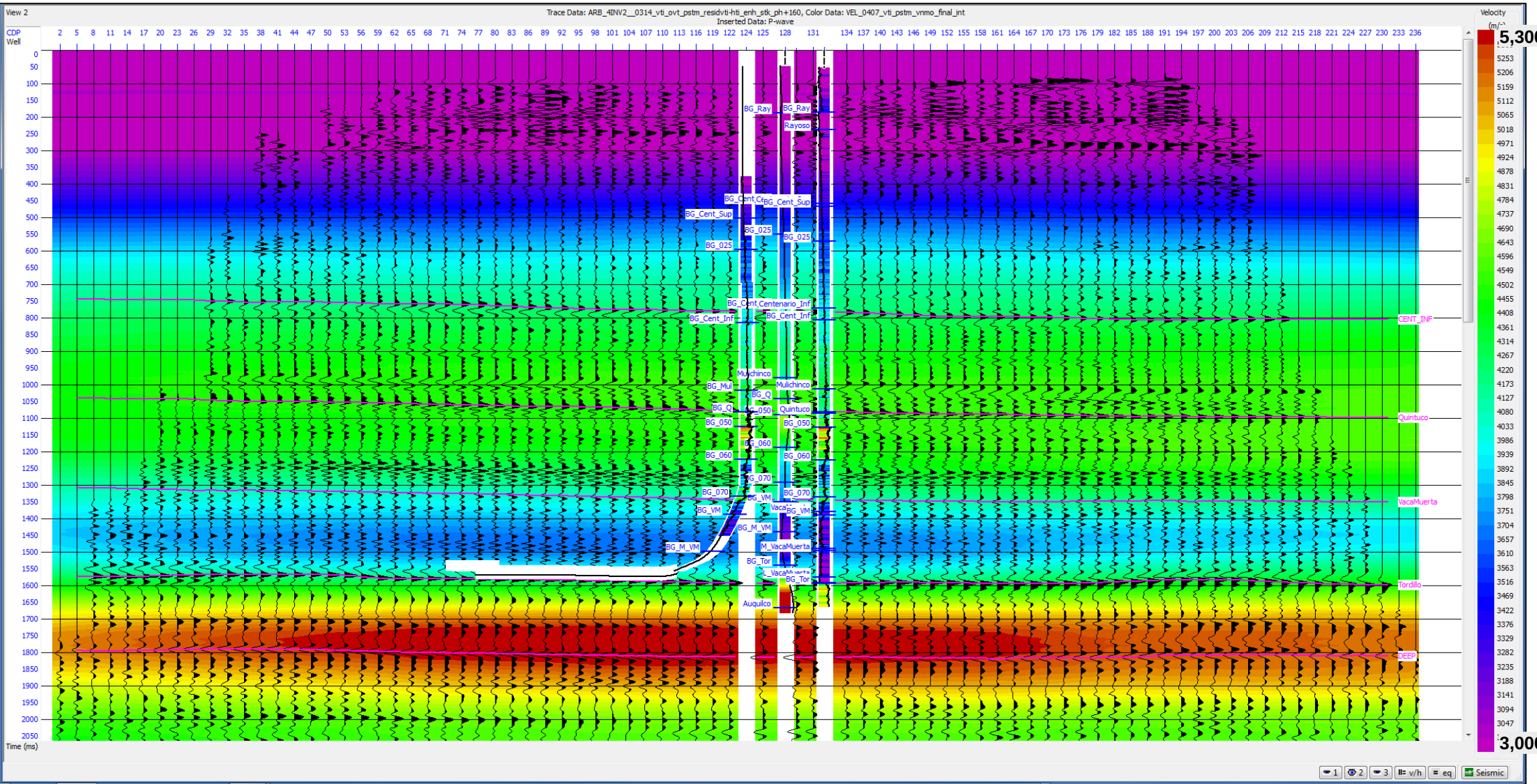
OVT-PSTM Gather with VTI+HTI+Conditioning Showing Azimuthal Bins (yellow columns)



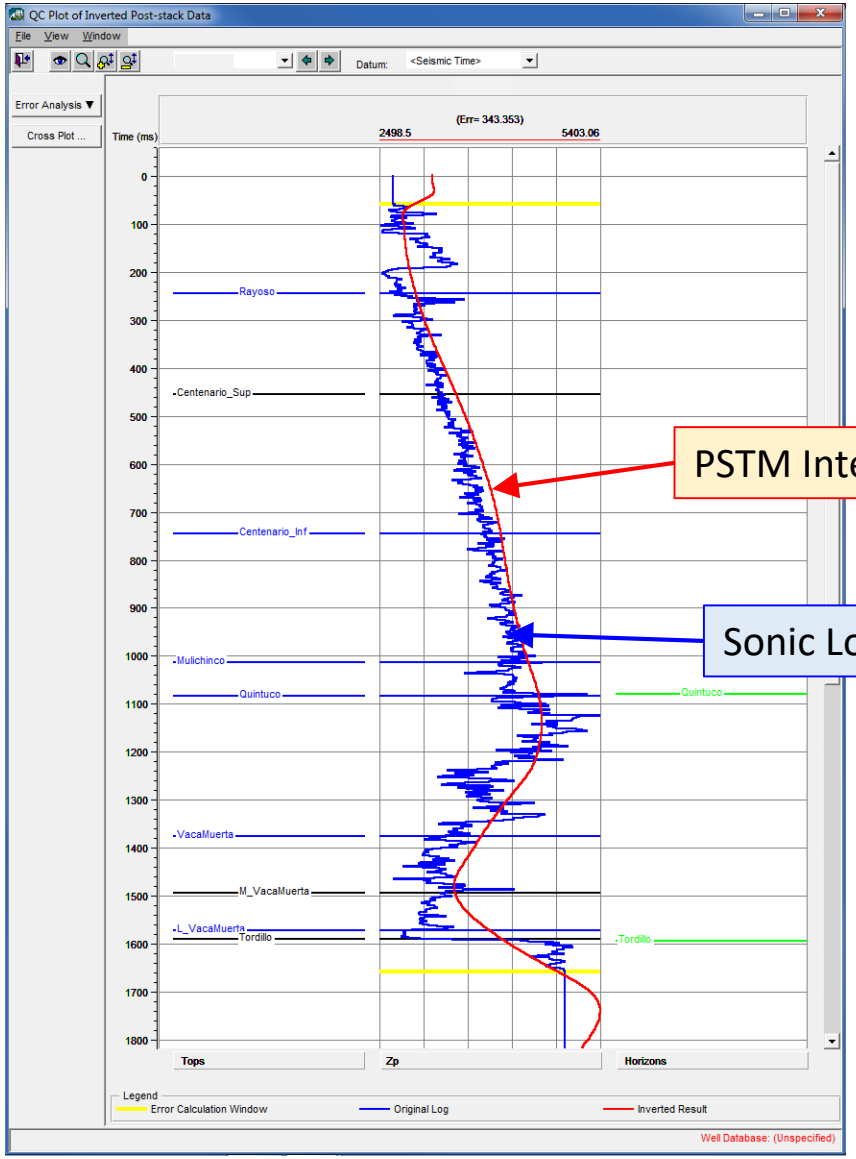
Velocity for Angle Gathers and Stacks

- Inversions are typically run from angle-stacks
- In order to create angle gathers or angle stacks, a velocity is required
- We typically use the PSTM velocity field, converted from RMS to interval velocity
- The HTI-corrected velocity field is sometimes an improvement, so we look at that as well
- Well velocities can be used – but need to be smoothed vertically

Interval Velocity from PSTM (color)

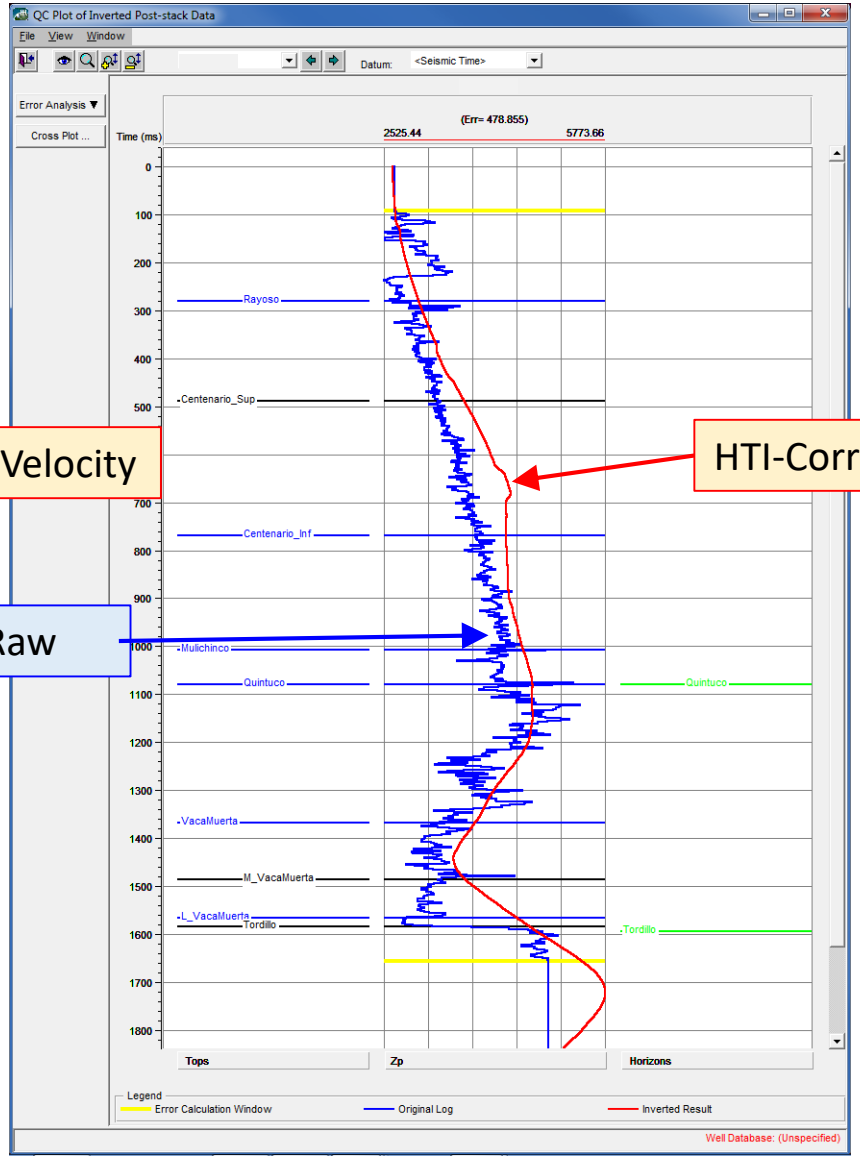


PSTM Velocity Compared with Well Sonic



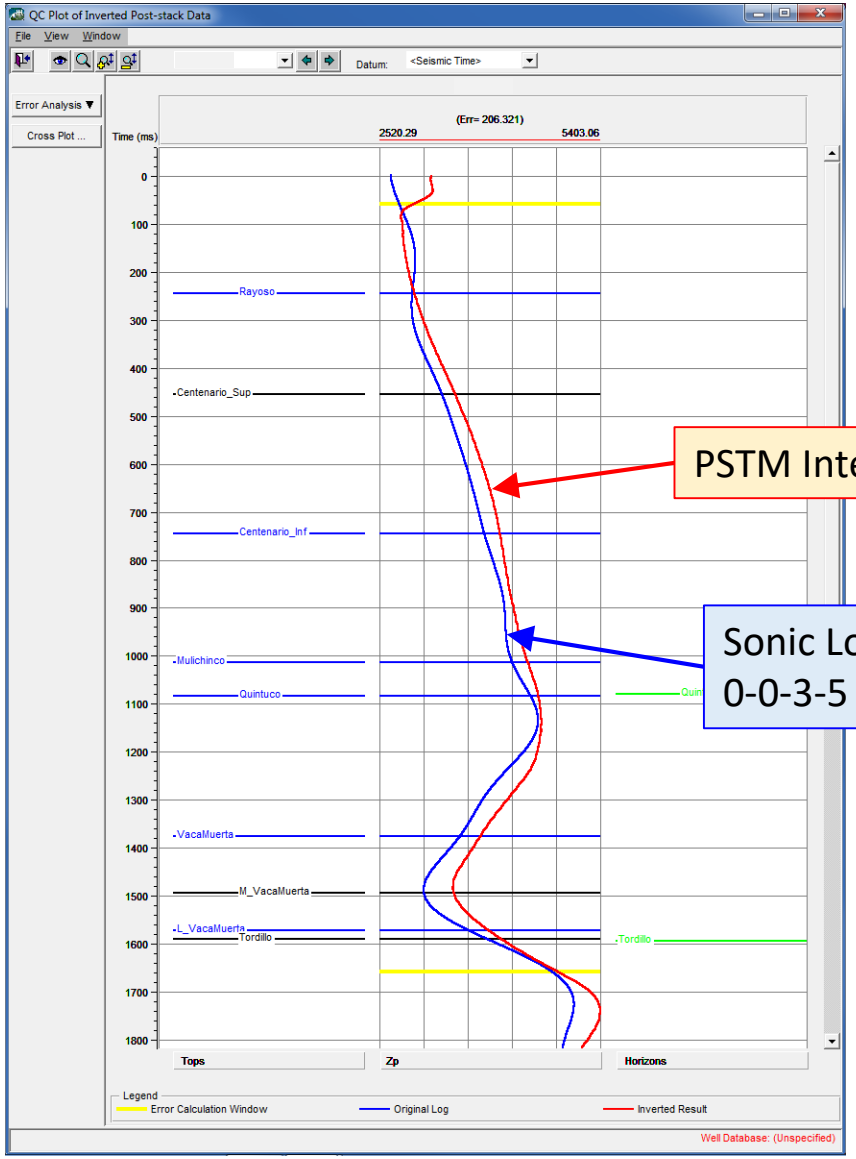
PSTM Interval Velocity

Sonic Log – Raw



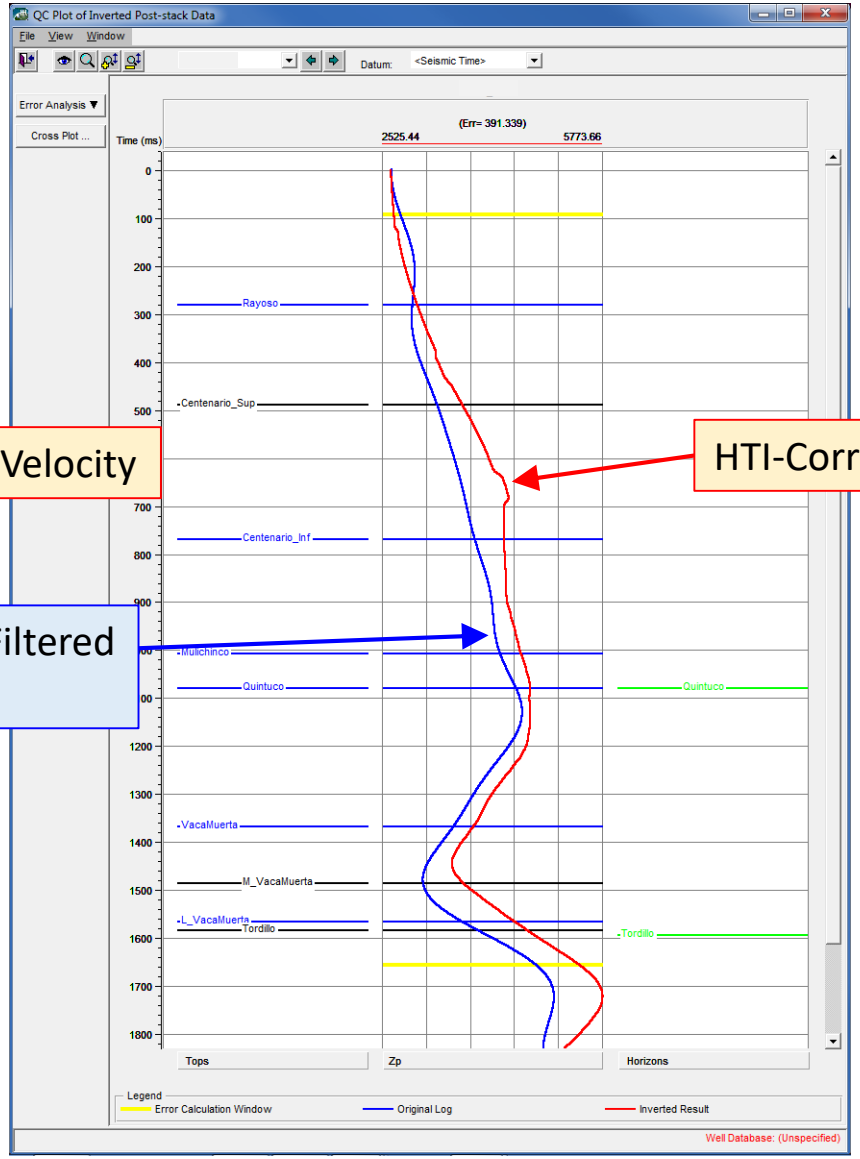
HTI-Corrected INT_Vfast

PSTM Velocity Compared with Well Sonic



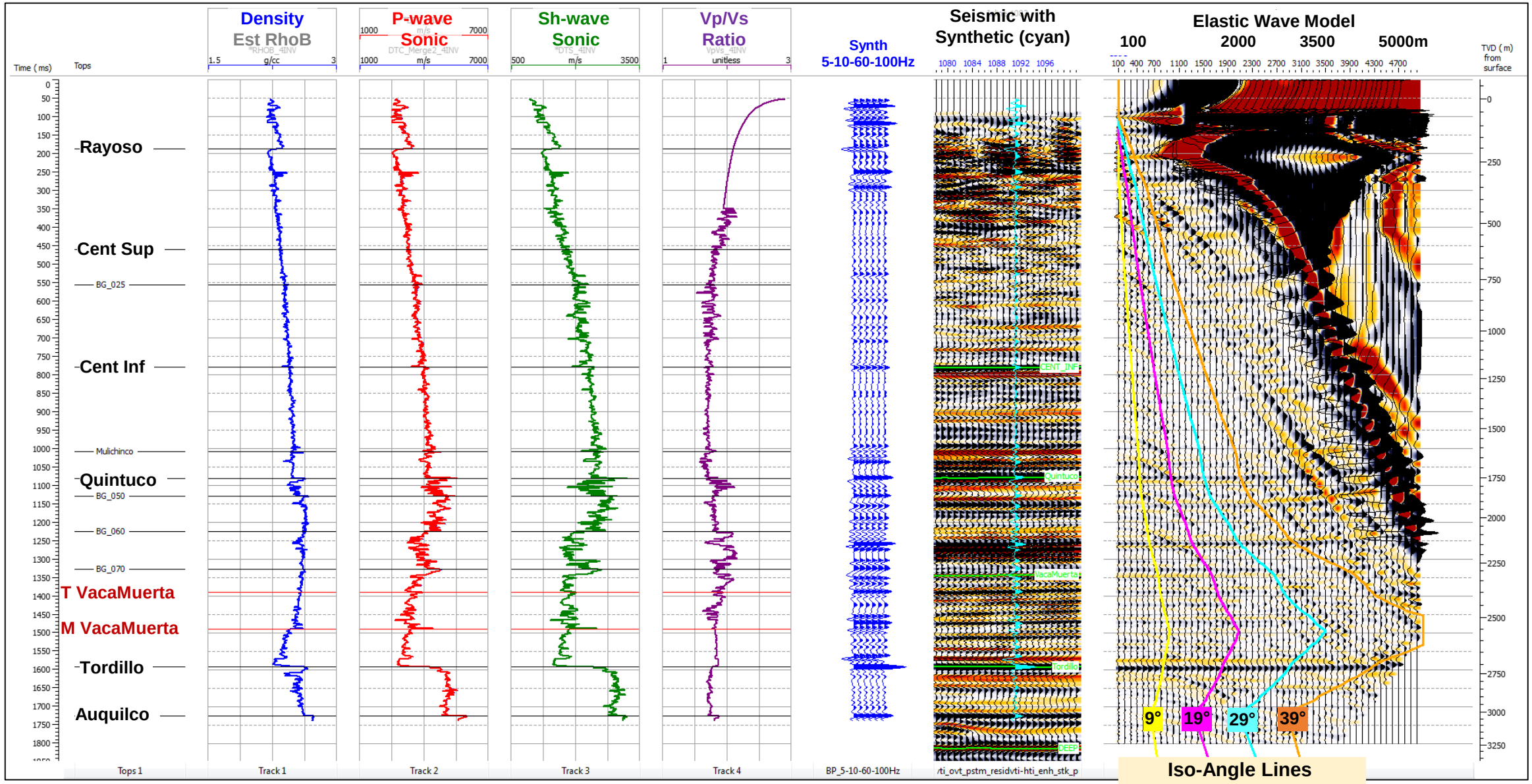
PSTM Interval Velocity

Sonic Log – Filtered
0-0-3-5 Hz

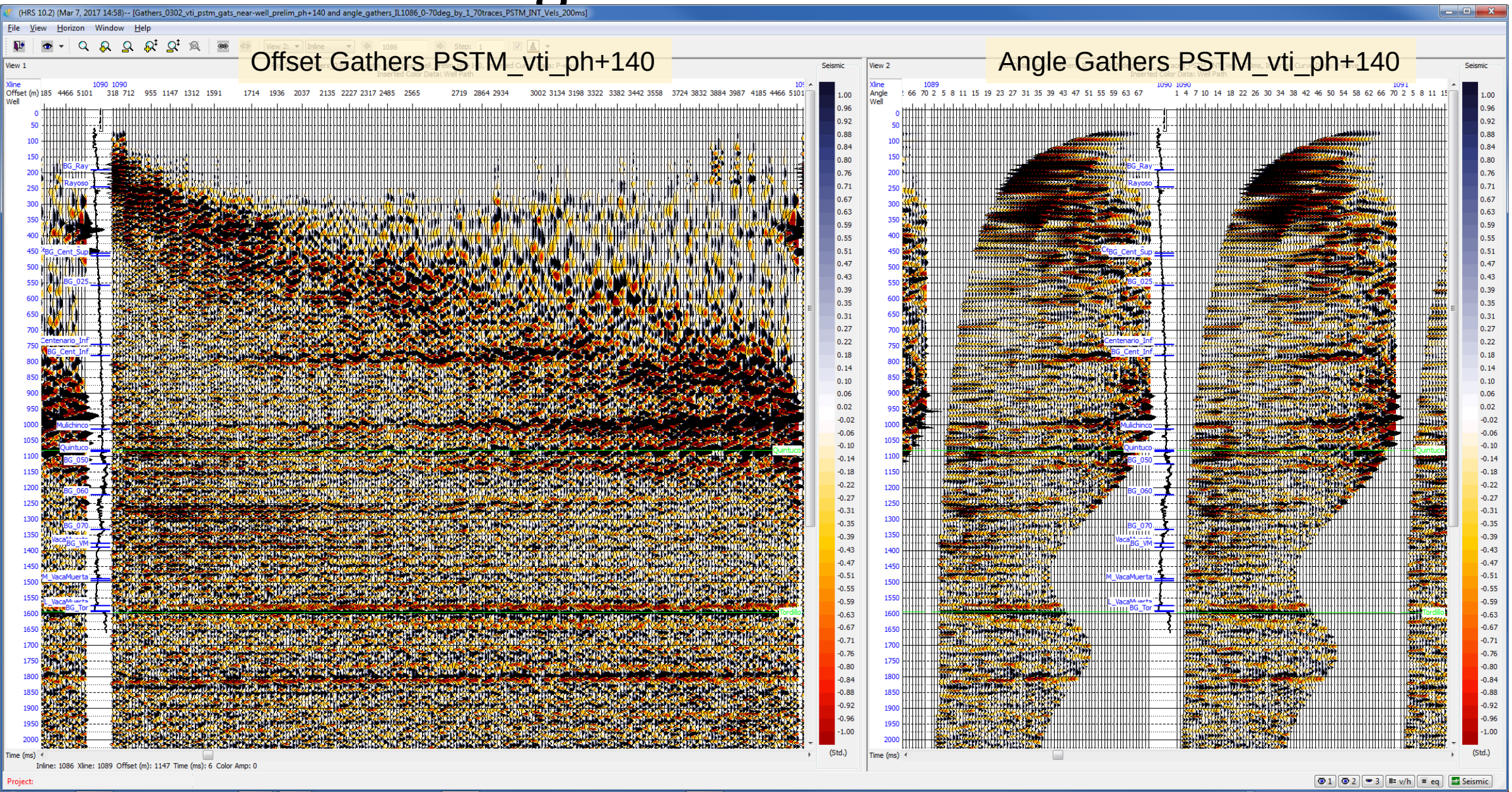


HTI-Corrected INT_Vfast

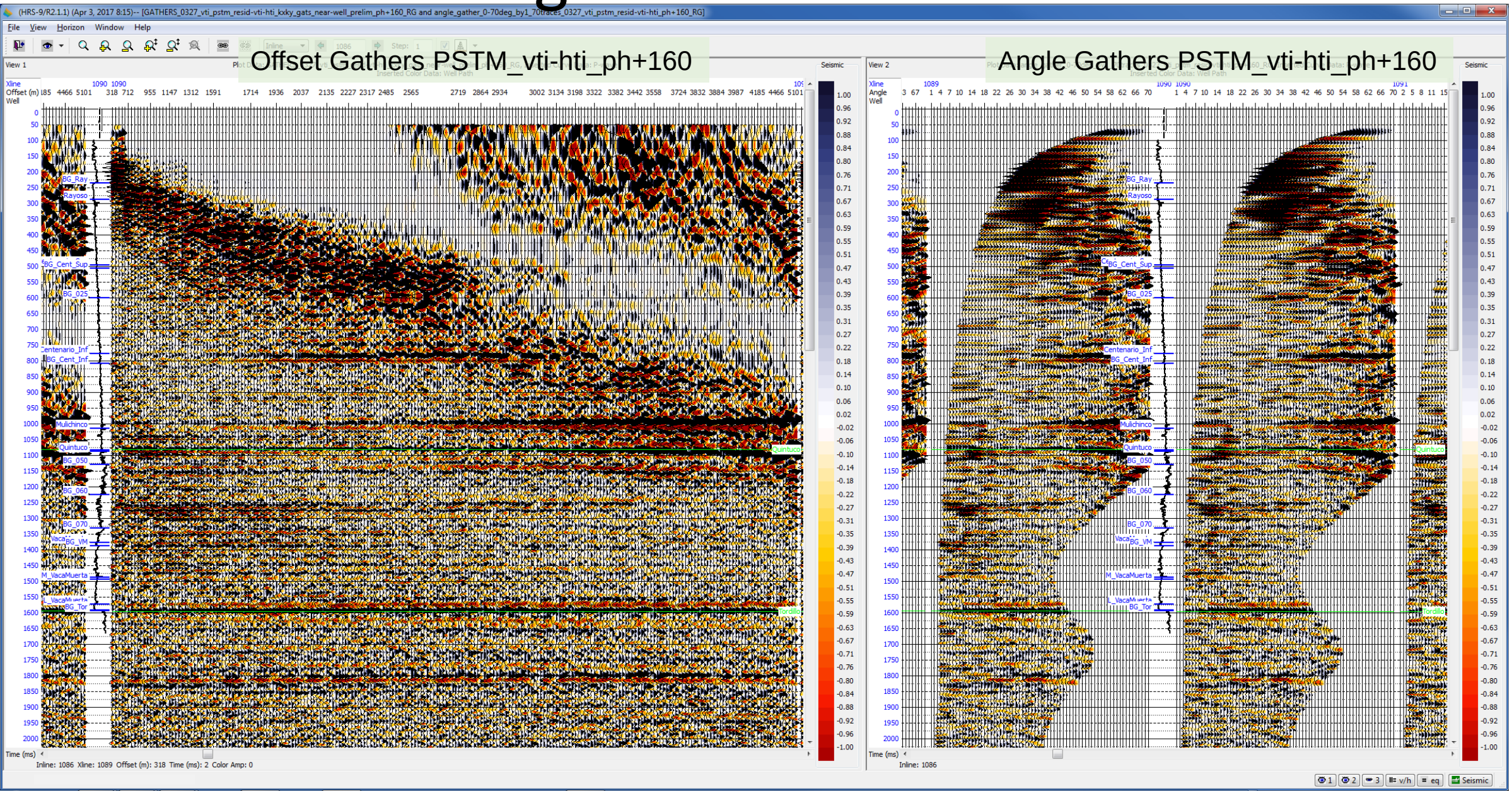
Final Well Model – with Iso-Angles



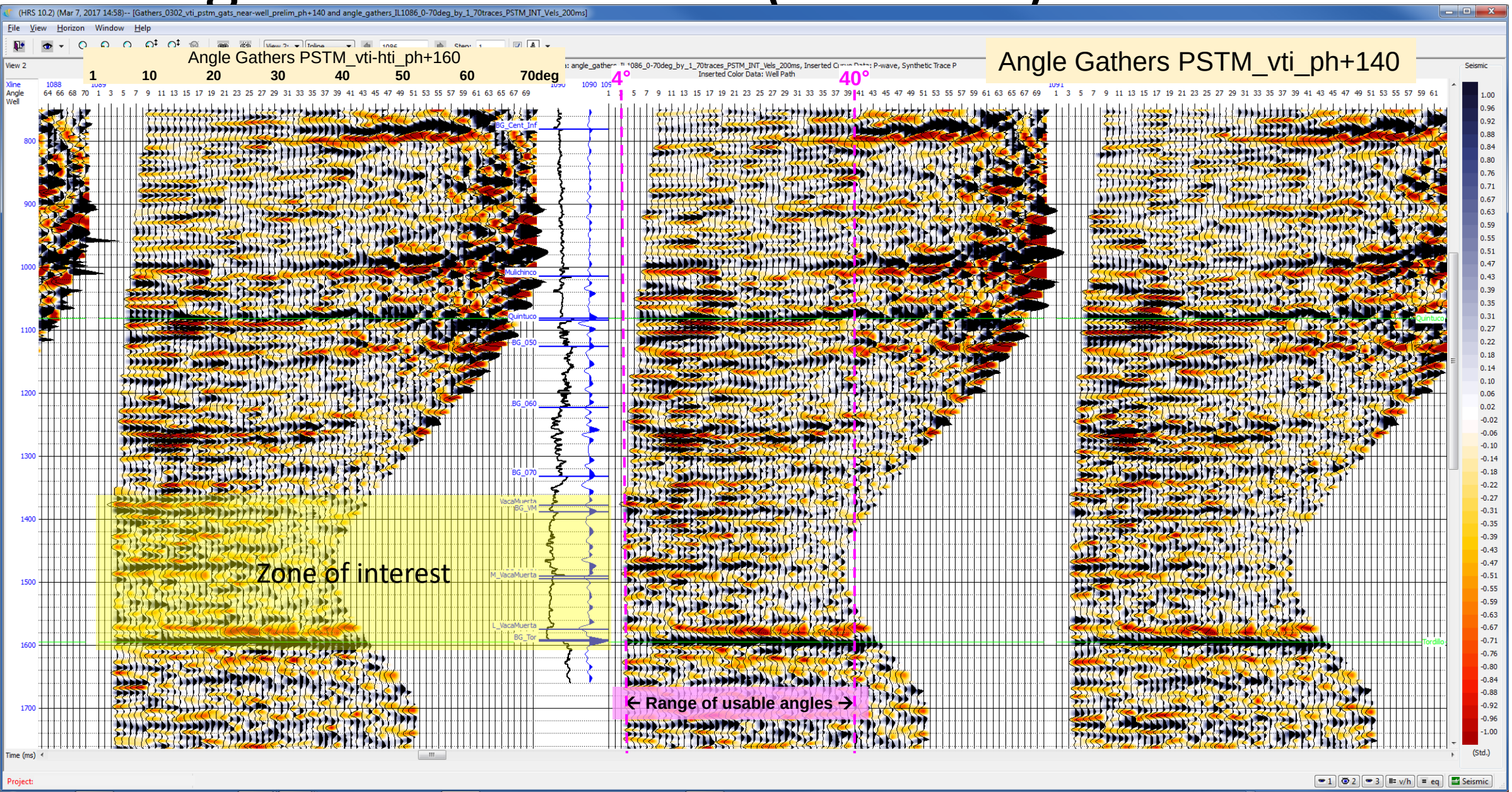
Offset and Angle Gathers



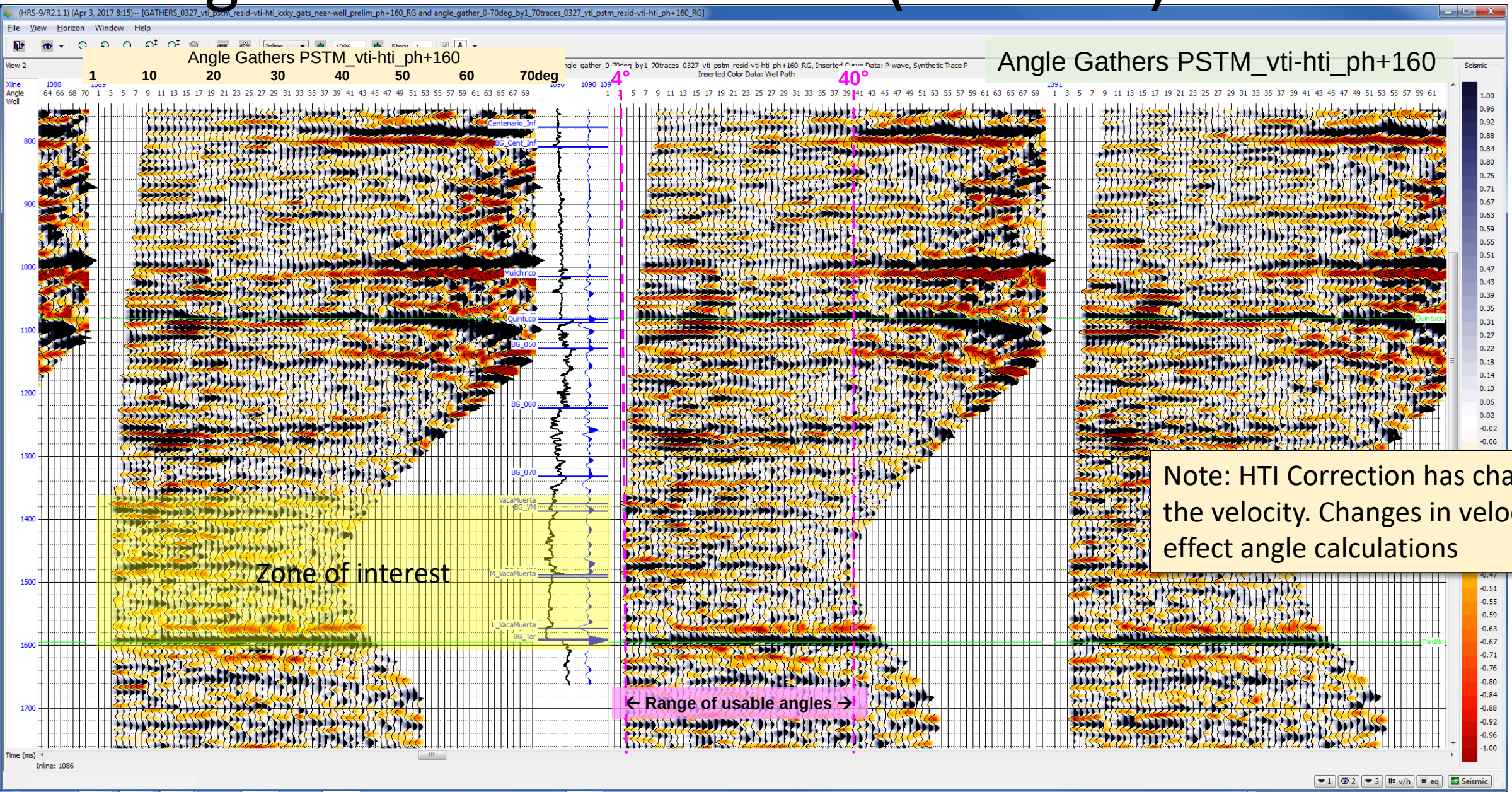
Offset and Angle Gathers



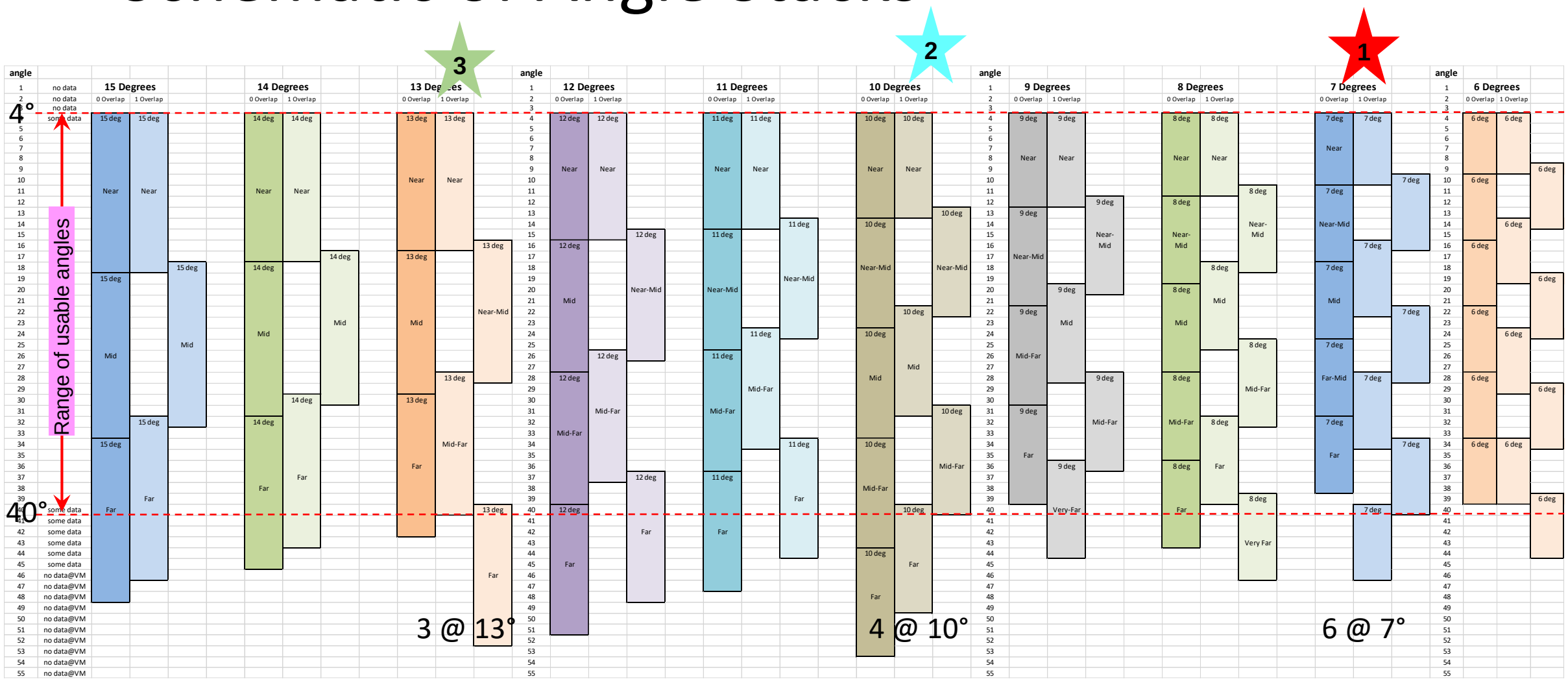
Angle Gathers – Raw (zoomed)



Angle Gathers – with HTI (zoomed)

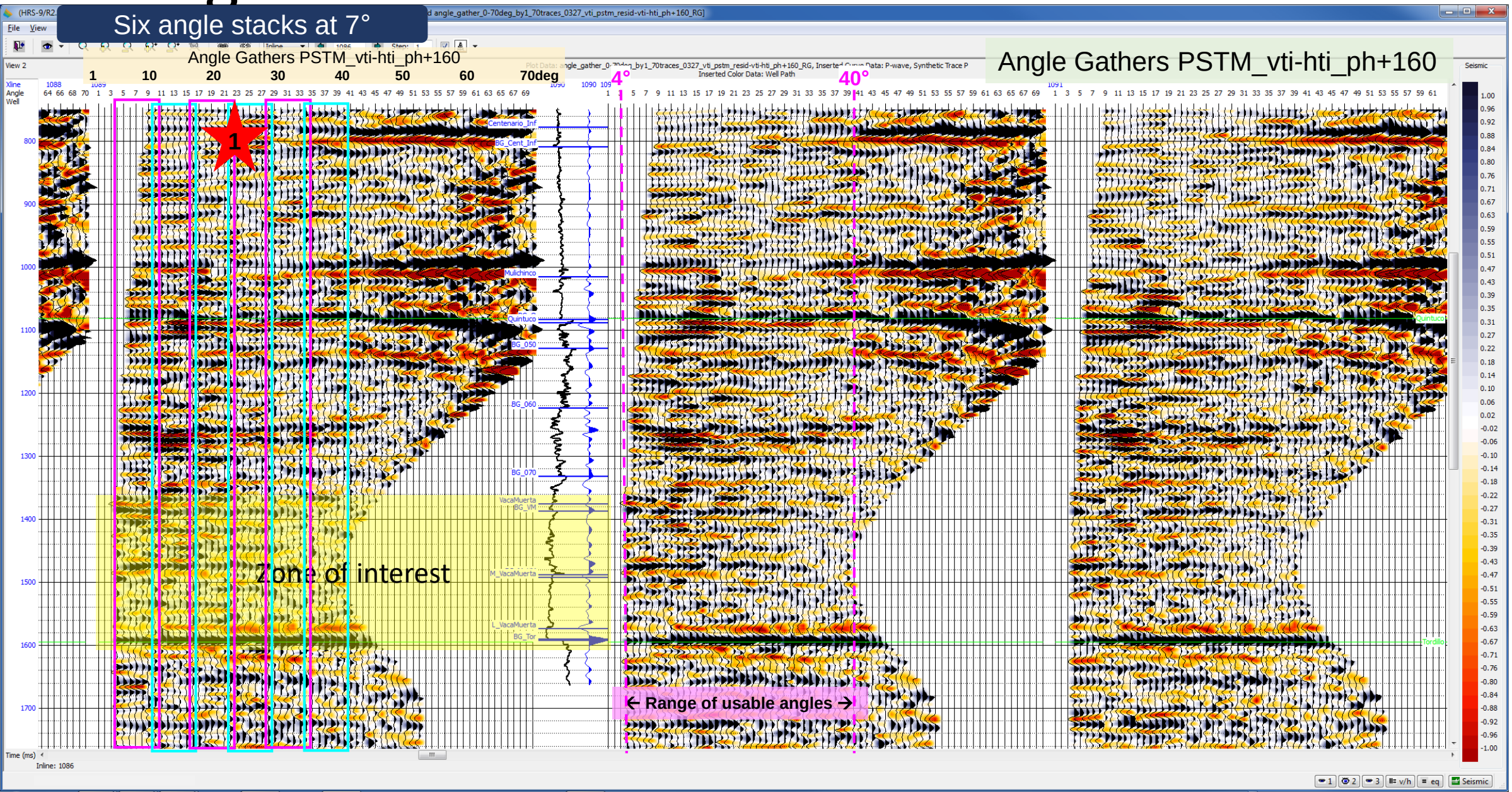


Schematic of Angle Stacks



How do you decide?
Look at gathers, consider AVO near objective, discuss with client

Angle Gathers - zoomed



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- Predicting Lithology from LRM Cross-plots
- Comments & Conclusions

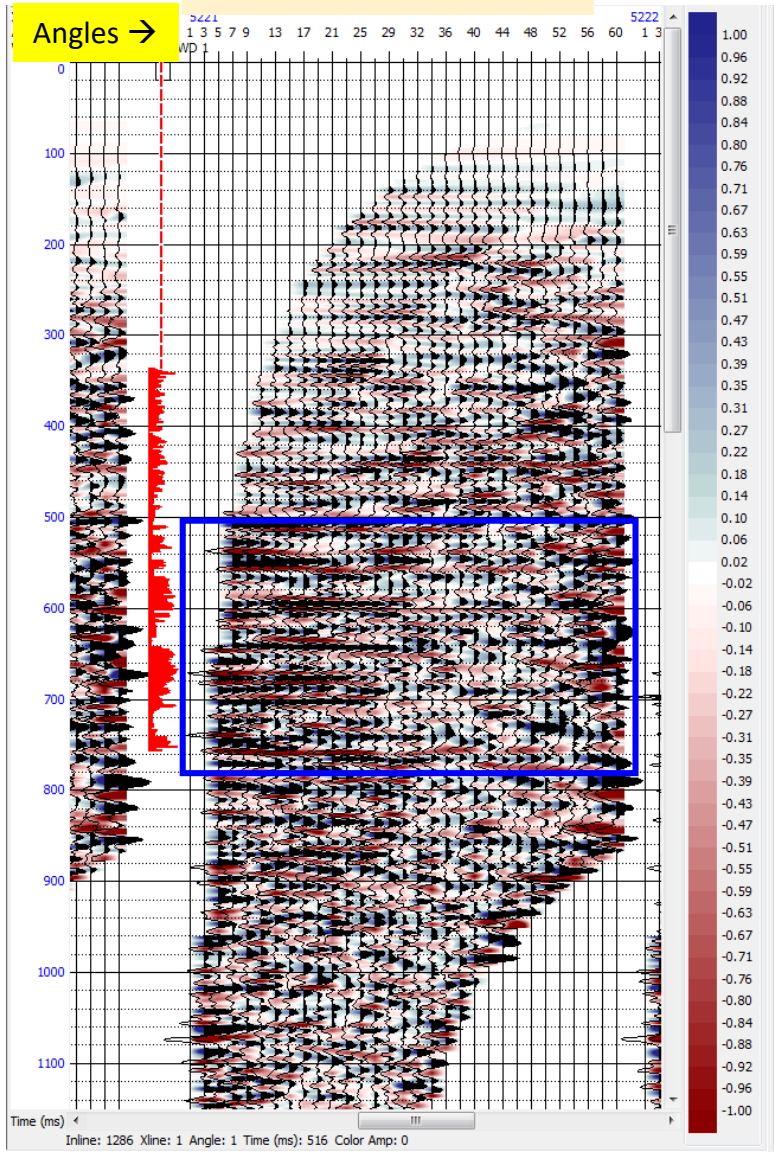
AVO Scaling Analysis

- Build offset/angle Models based on well logs
- Build the Model to match the seismic – offsets, trace distance, etc.
- Compare Model to AVO/AVA seen in gathers
- Can correct AVO/AVA based on well average over a long RMS window

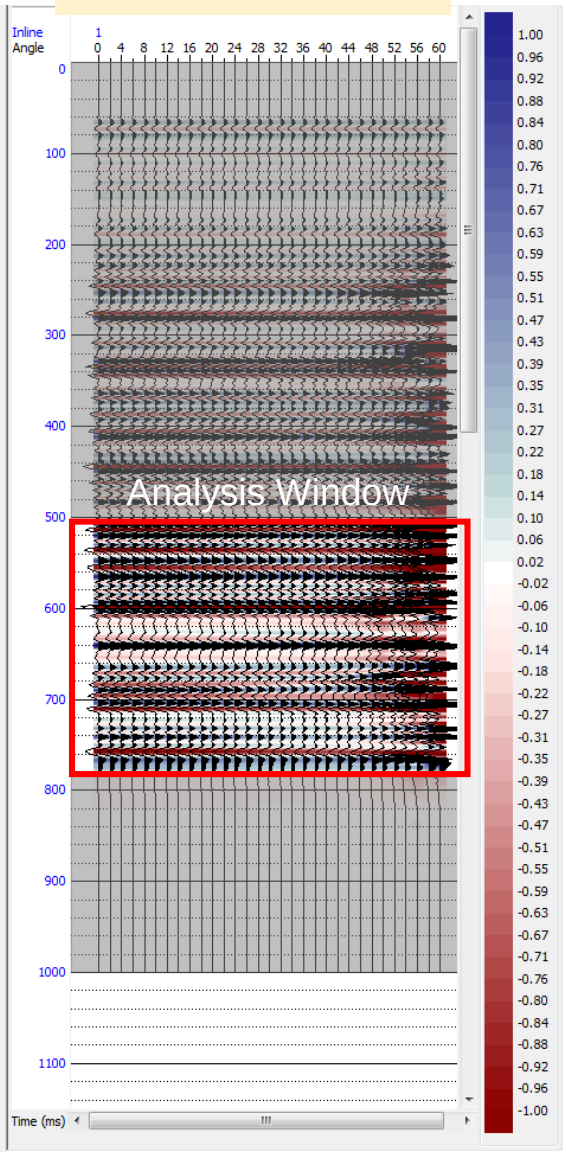
AVA Analysis Tool – Raw Gathers

Example #1

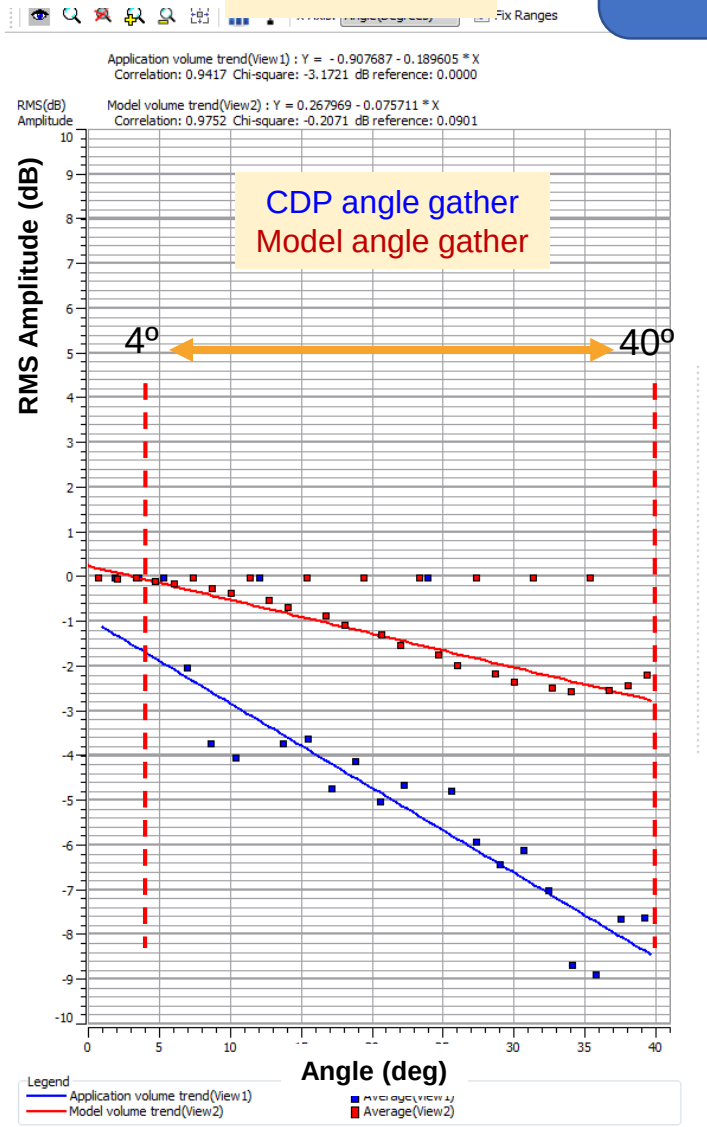
Raw Angle Gather



Well Angle Model



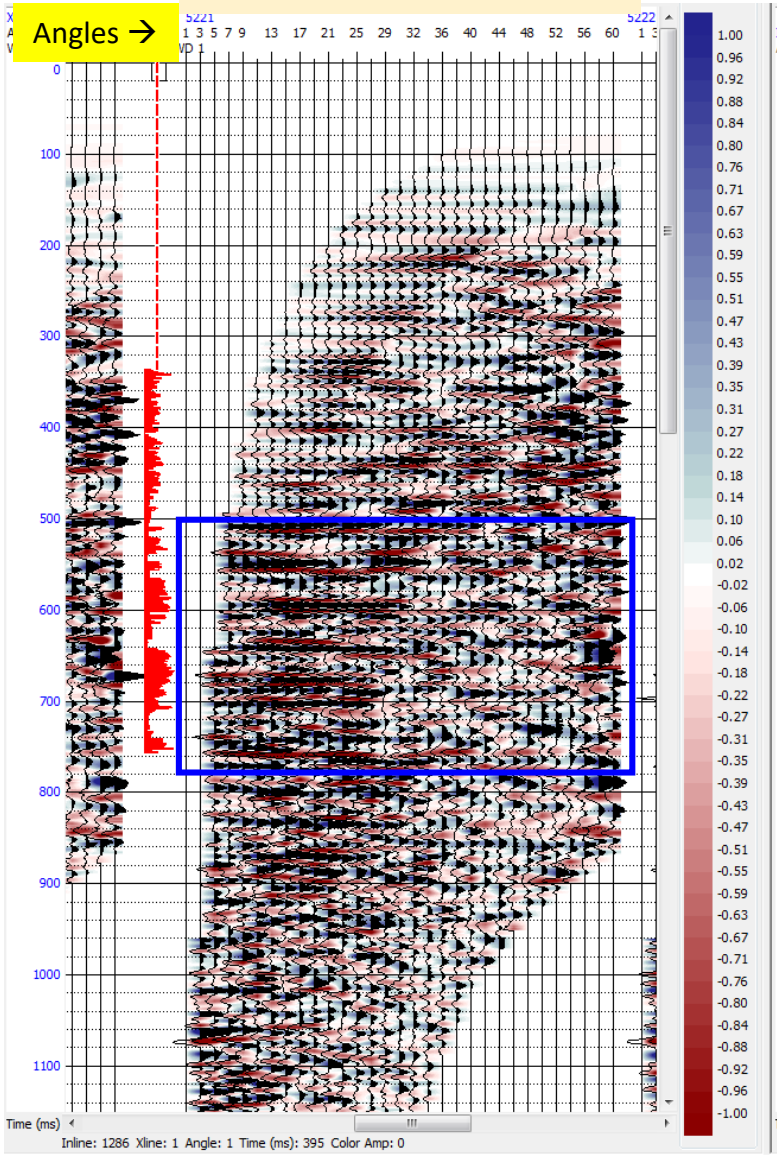
AVA Graph



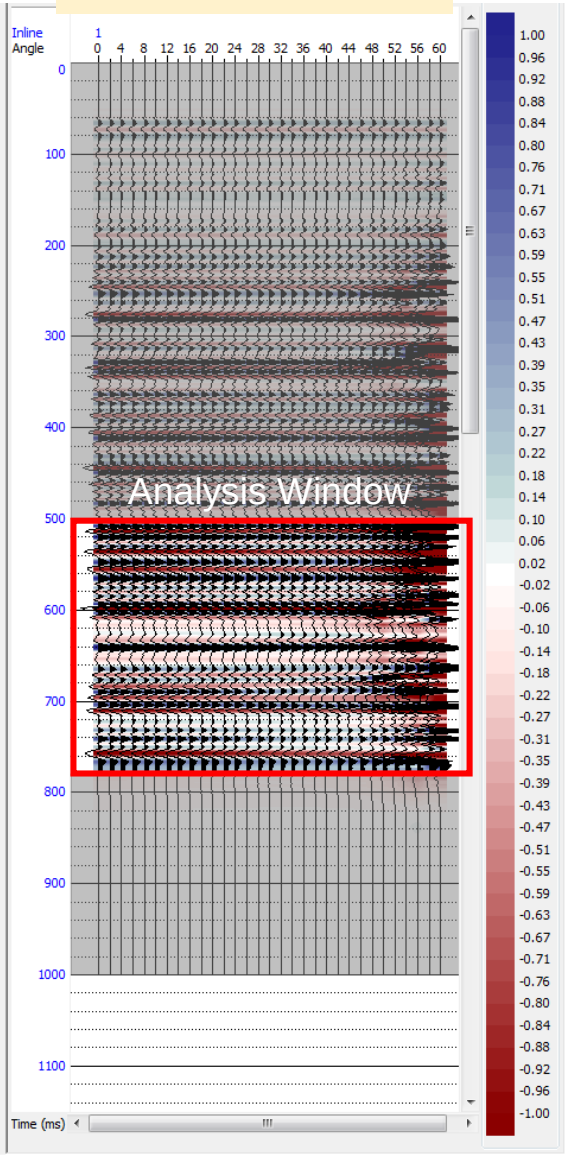
AVA Analysis Tool – Scaled Gathers

Example #1

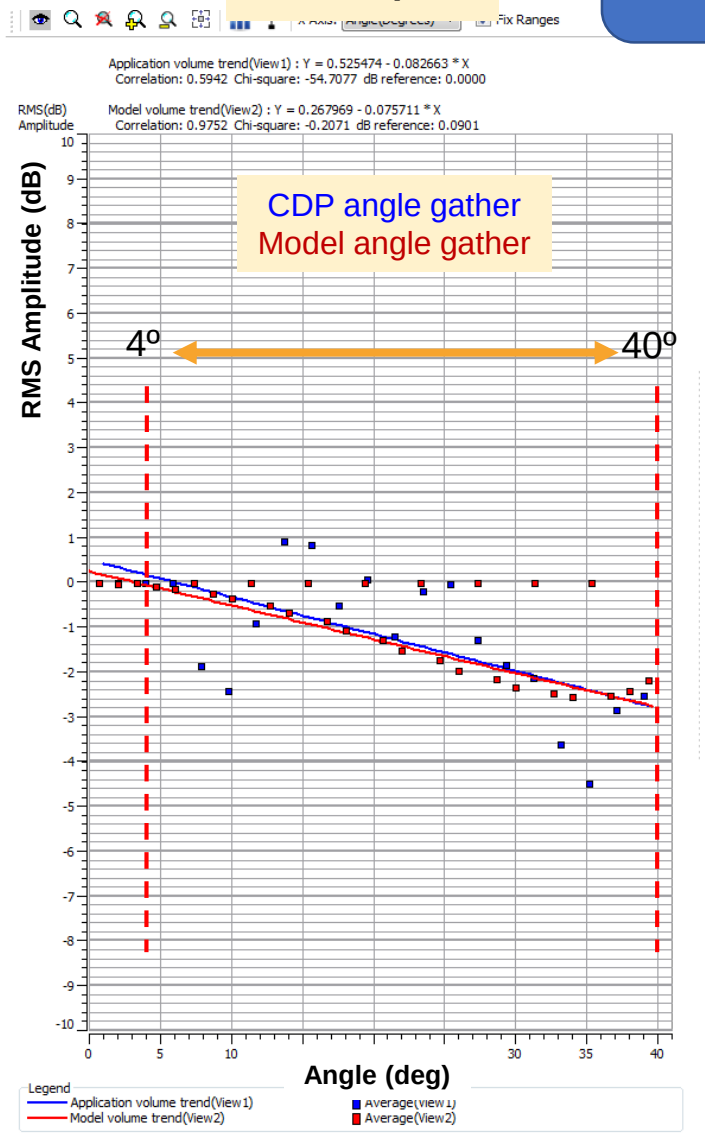
Scaled Angle Gather



Well Angle Model



AVA Graph



AVO Scaling Analysis

- Build offset/angle models based on well logs
- Compare to AVO/AVA seen in gathers
- Can correct AVO/AVA based on well average over a long RMS window

- Offset Vector Tiles (OVT) can improve migration by making azimuthal corrections possible after migration
- But tiling reduces near trace spacing – often critical for inversion
- Processors often use a technique called “¼ Tiling” to improve this

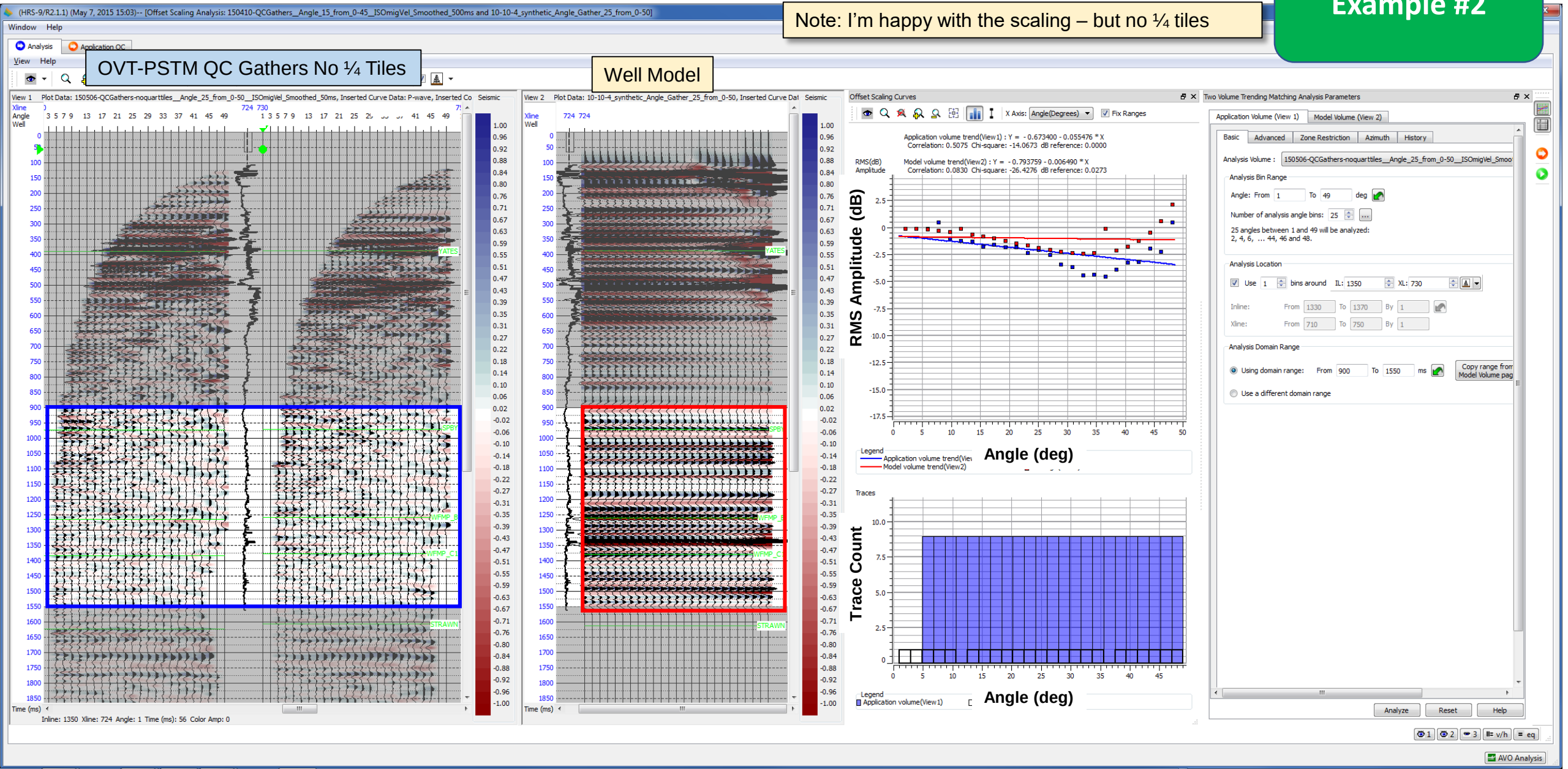
OVT-PSTM Gathers - Raw

Example #2

Note: I'm happy with the scaling – but no ¼ tiles

OVT-PSTM QC Gathers No ¼ Tiles

Well Model



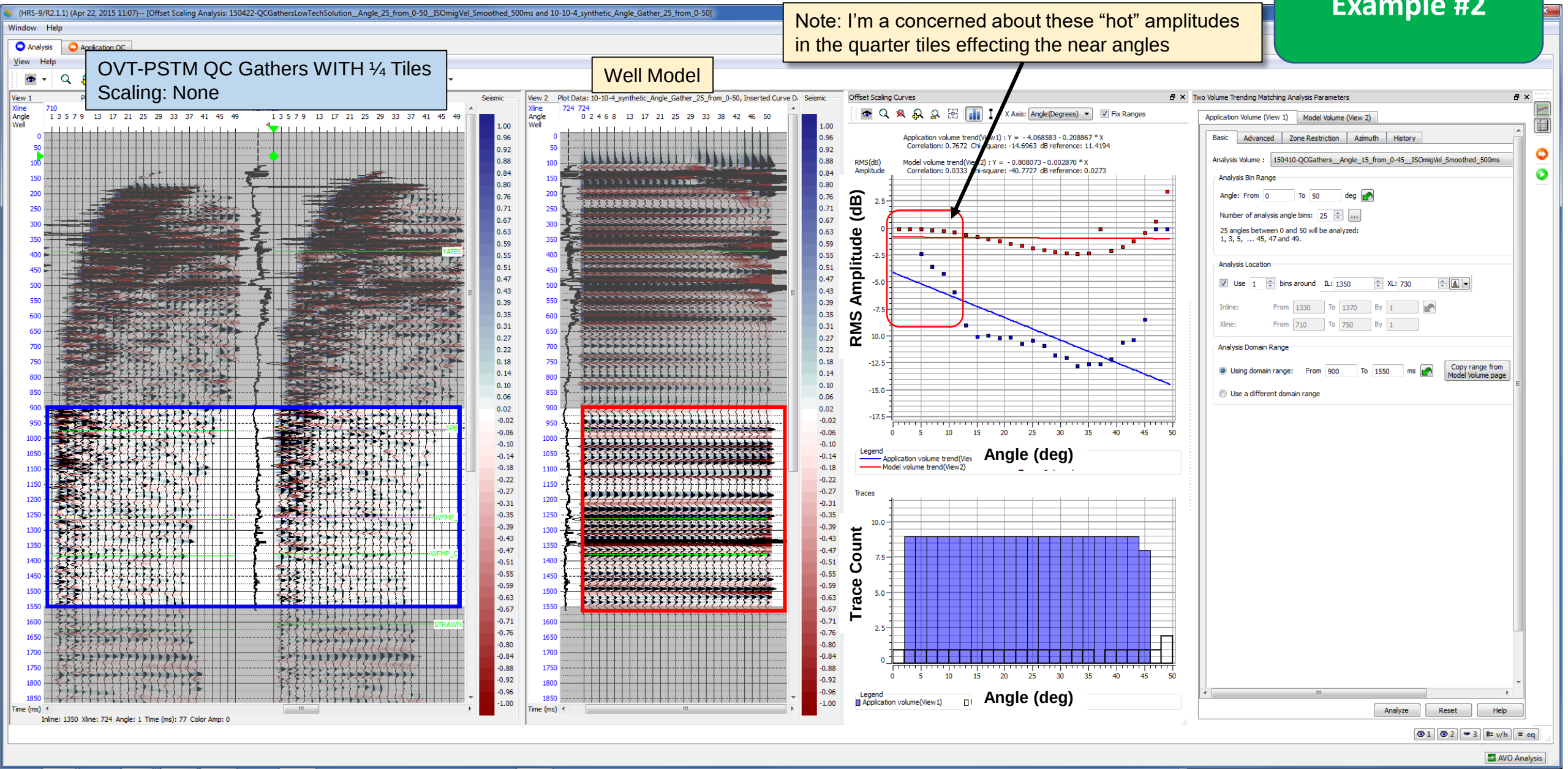
OVT-PSTM Gathers – With ¼ Tiles

Example #2

OVT-PSTM QC Gathers WITH ¼ Tiles
Scaling: None

Well Model

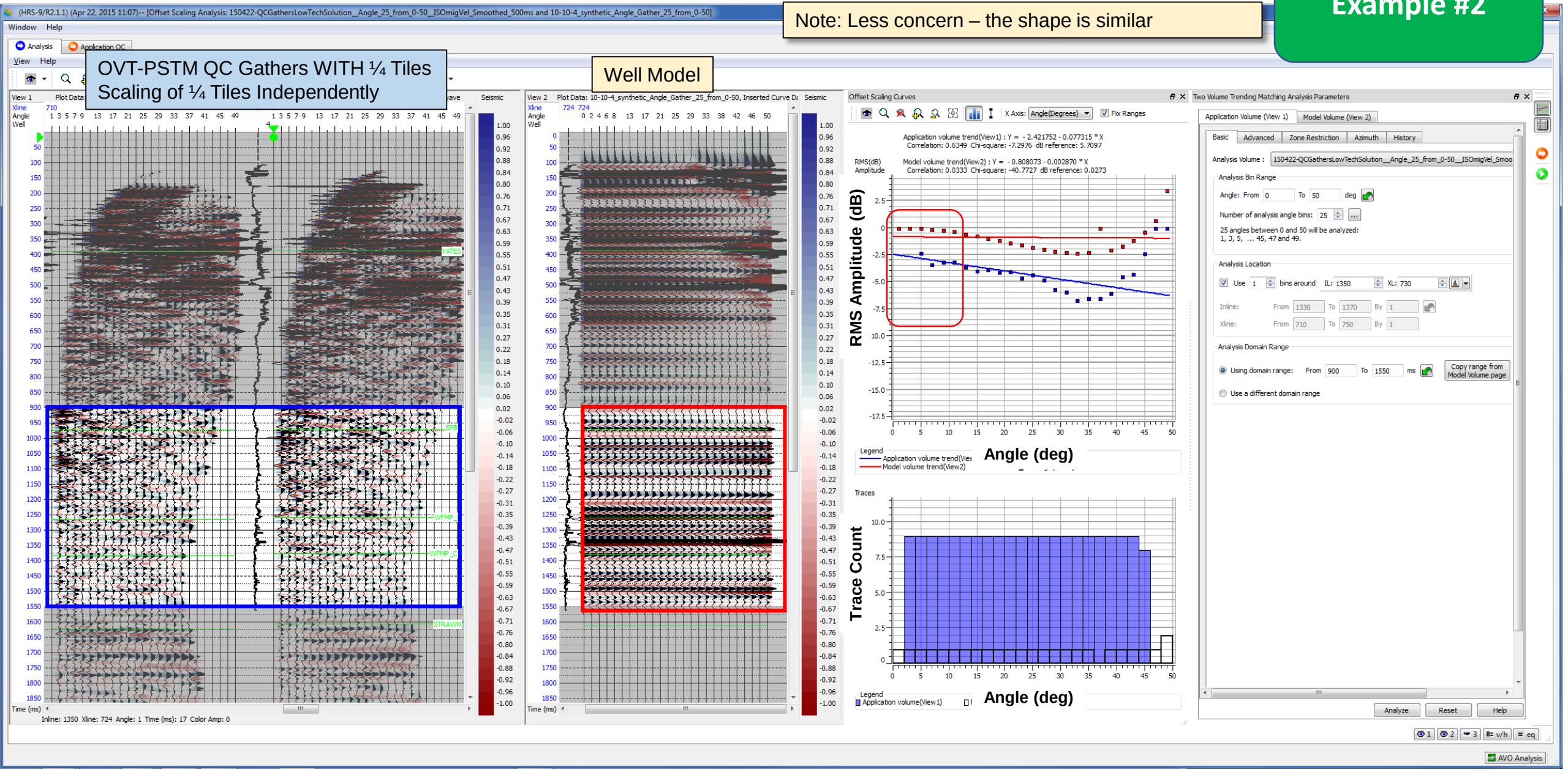
Note: I'm a concerned about these "hot" amplitudes in the quarter tiles effecting the near angles



OVT-PSTM Gathers – With ¼ Tiles

Note: Less concern – the shape is similar

Example #2



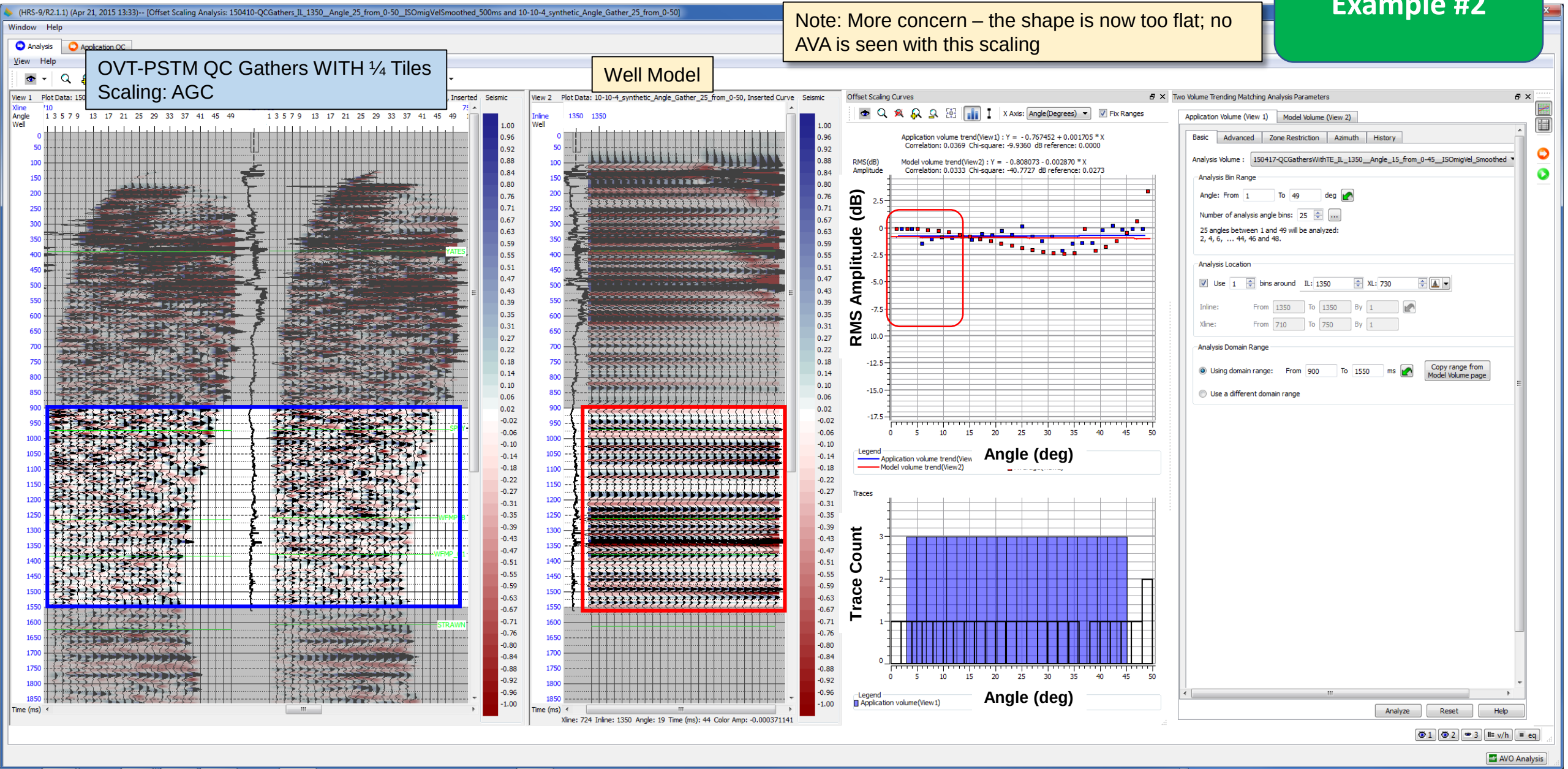
OVT-PSTM Gathers – With ¼ Tiles

Example #2

Note: More concern – the shape is now too flat; no AVA is seen with this scaling

OVT-PSTM QC Gathers WITH ¼ Tiles
Scaling: AGC

Well Model



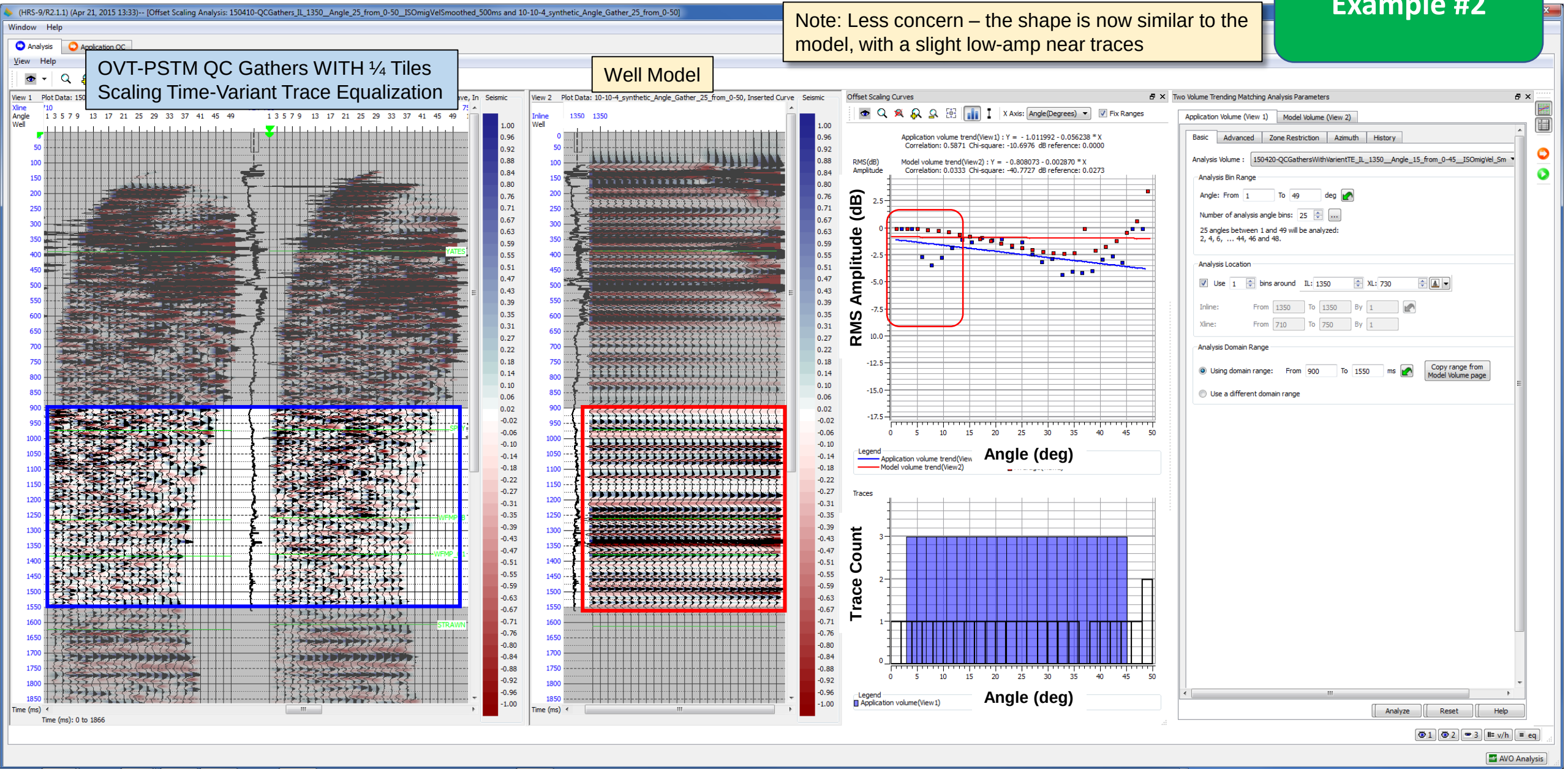
OVT-PSTM Gathers – With ¼ Tiles

Note: Less concern – the shape is now similar to the model, with a slight low-amp near traces

Example #2

OVT-PSTM QC Gathers WITH ¼ Tiles
Scaling Time-Variant Trace Equalization

Well Model



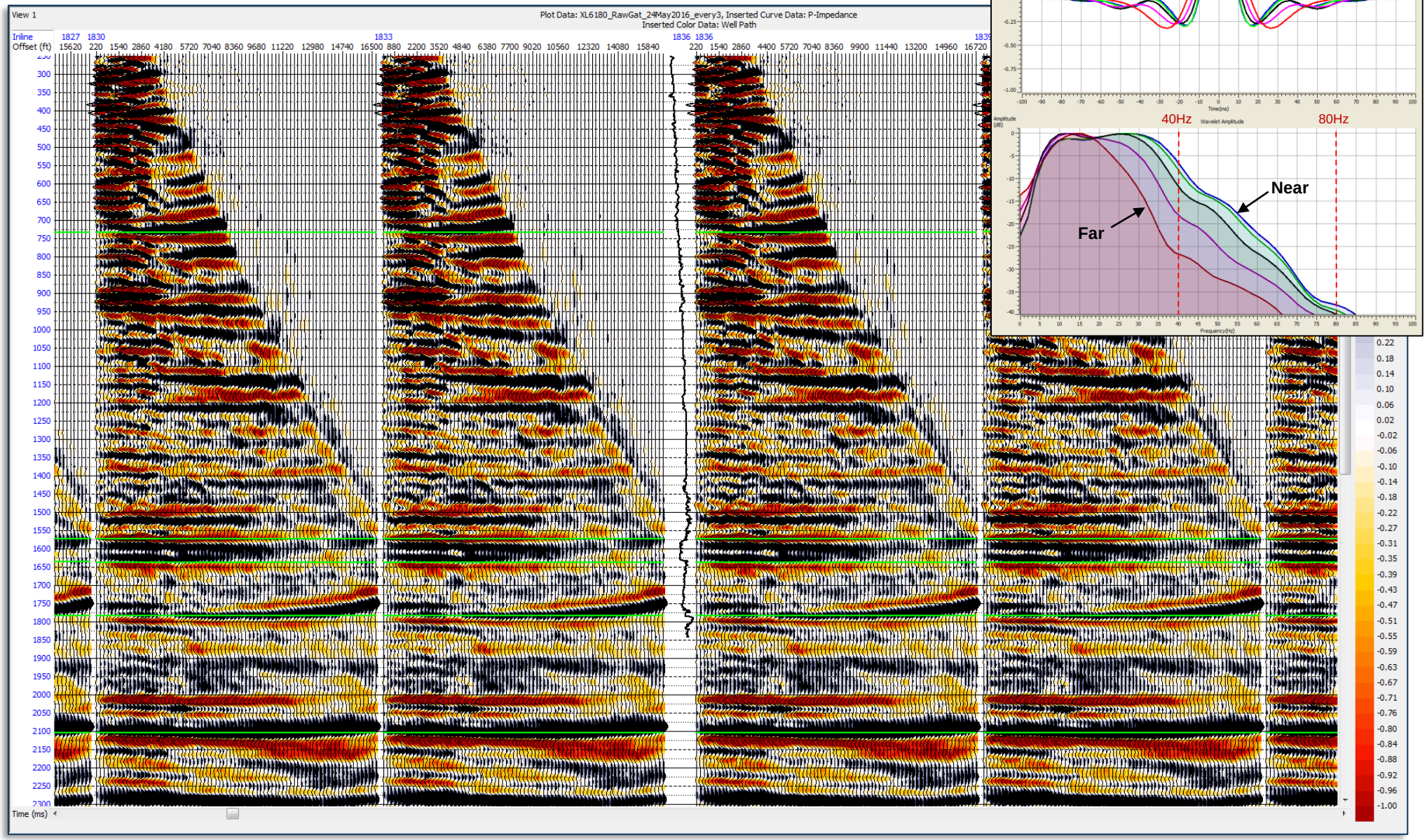
Enhancements to Gathers – and Wavelets

- Done typically by processing shop
- Several S/N and frequency enhancements available
- “Conditioning” can mean FXY, mix, Trim, Radon, Bi-lateral filter, etc.
- “Whitening” is frequency enhancement, spectral shaping, blueing

Why do we care?

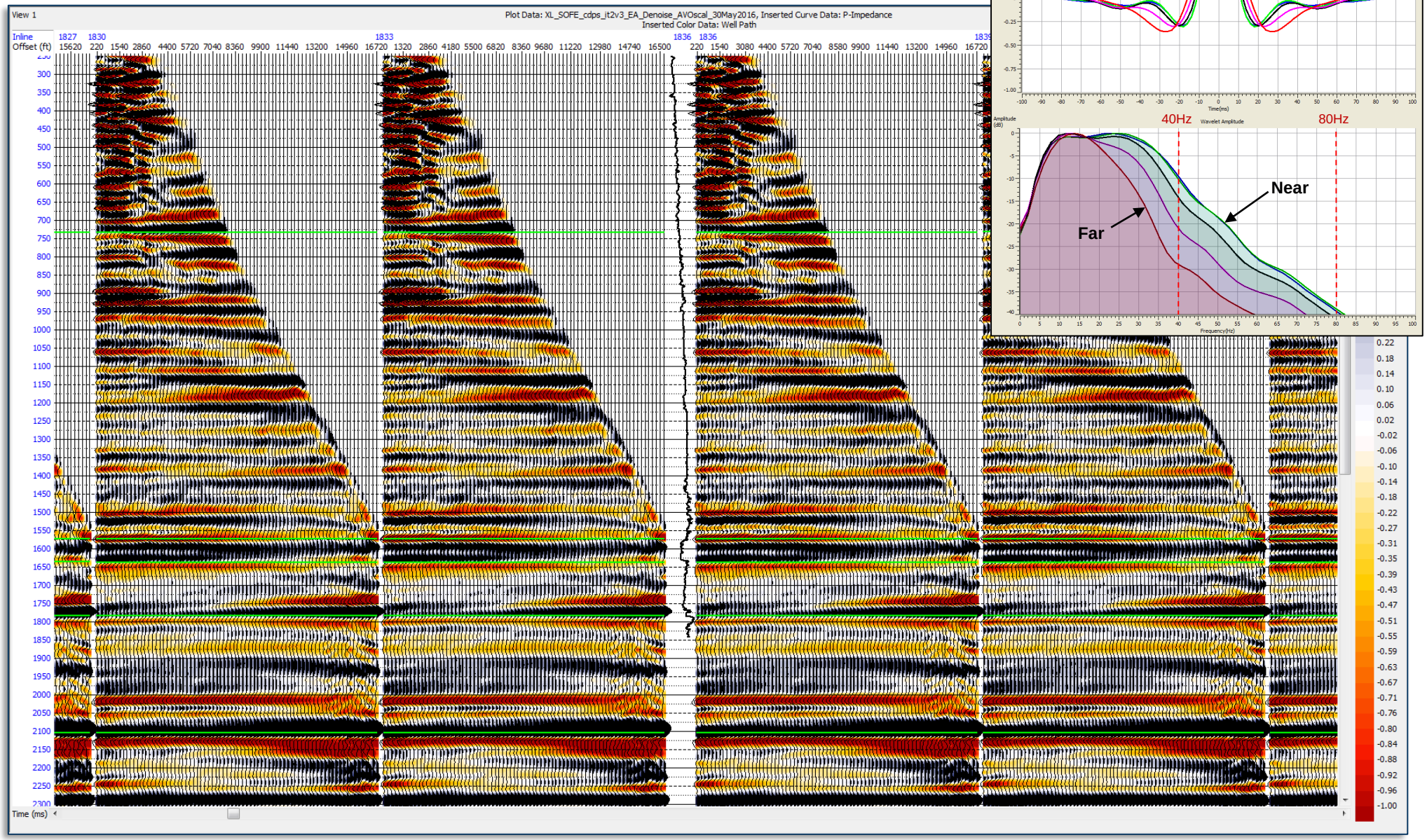
- For inversion we use separate wavelets for each angle/offset
- After whitening, wavelets are more “frequency normalized”
- Effect: very little, but should be tested

Raw Offset Gathers



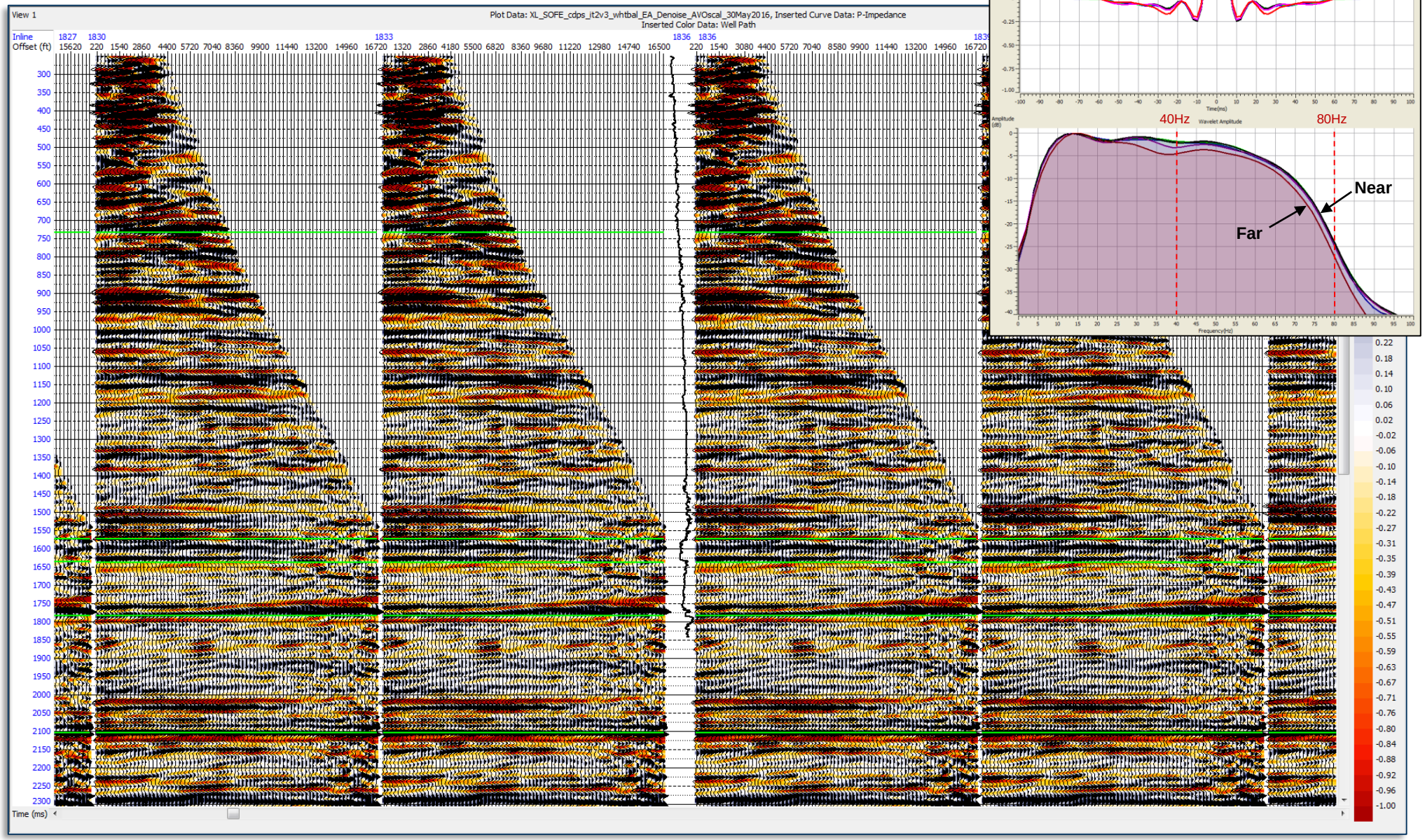
Note: You'll need 4 wavelets; one for each angle stack

Conditioned Offset Gathers



Note: You'll need 4 wavelets; one for each angle stack

Whitened Offset Gathers



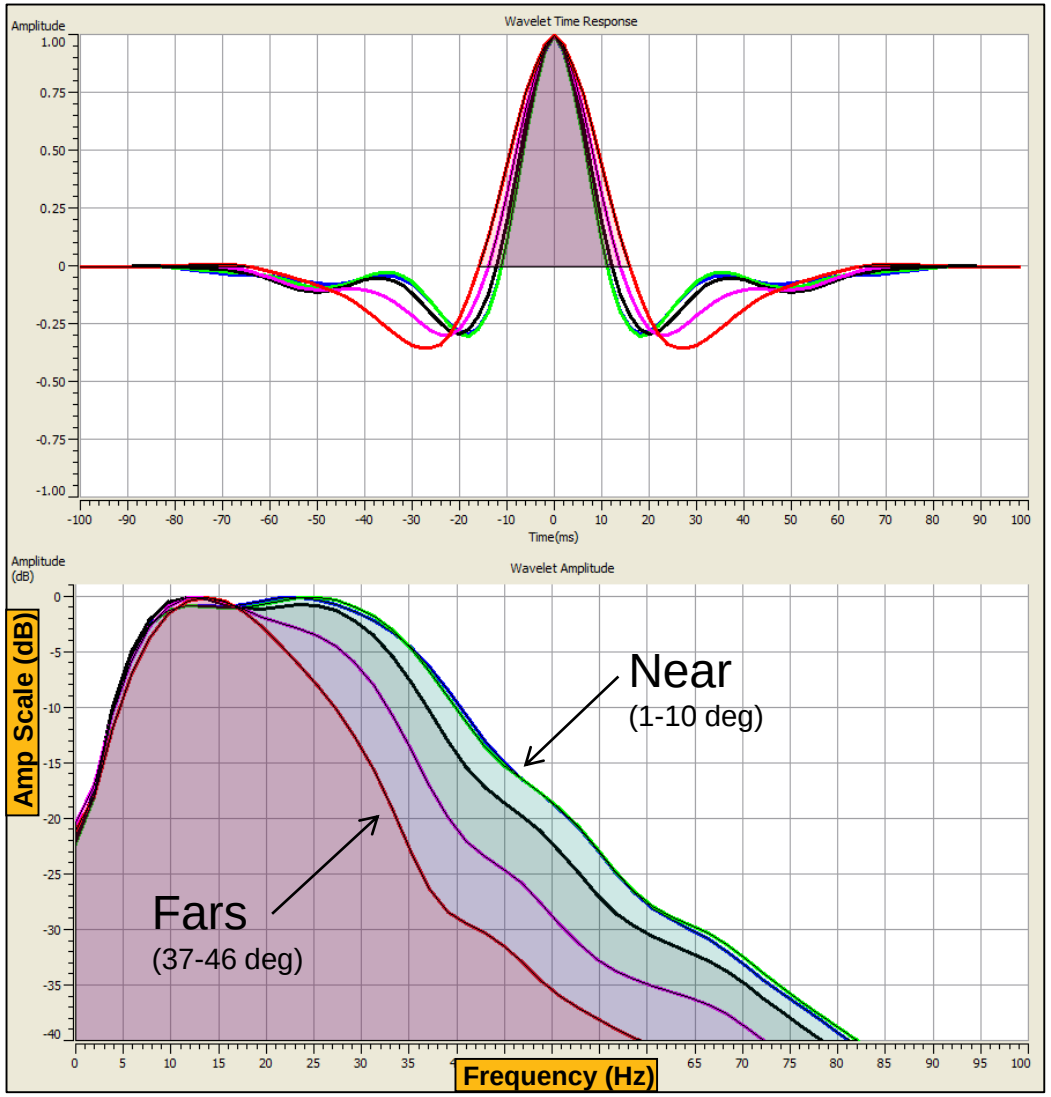
Note: You'll need only one wavelet

Wavelet(s) for Inversion

- You must determine what wavelets to use
- Typically use a different wavelet for each angle stack
- Use statistical wavelets taken at the time range of the objective
- QC the wavelets – do they make sense?
- If gathers/partial stacks are whitened, you may only need one wavelet

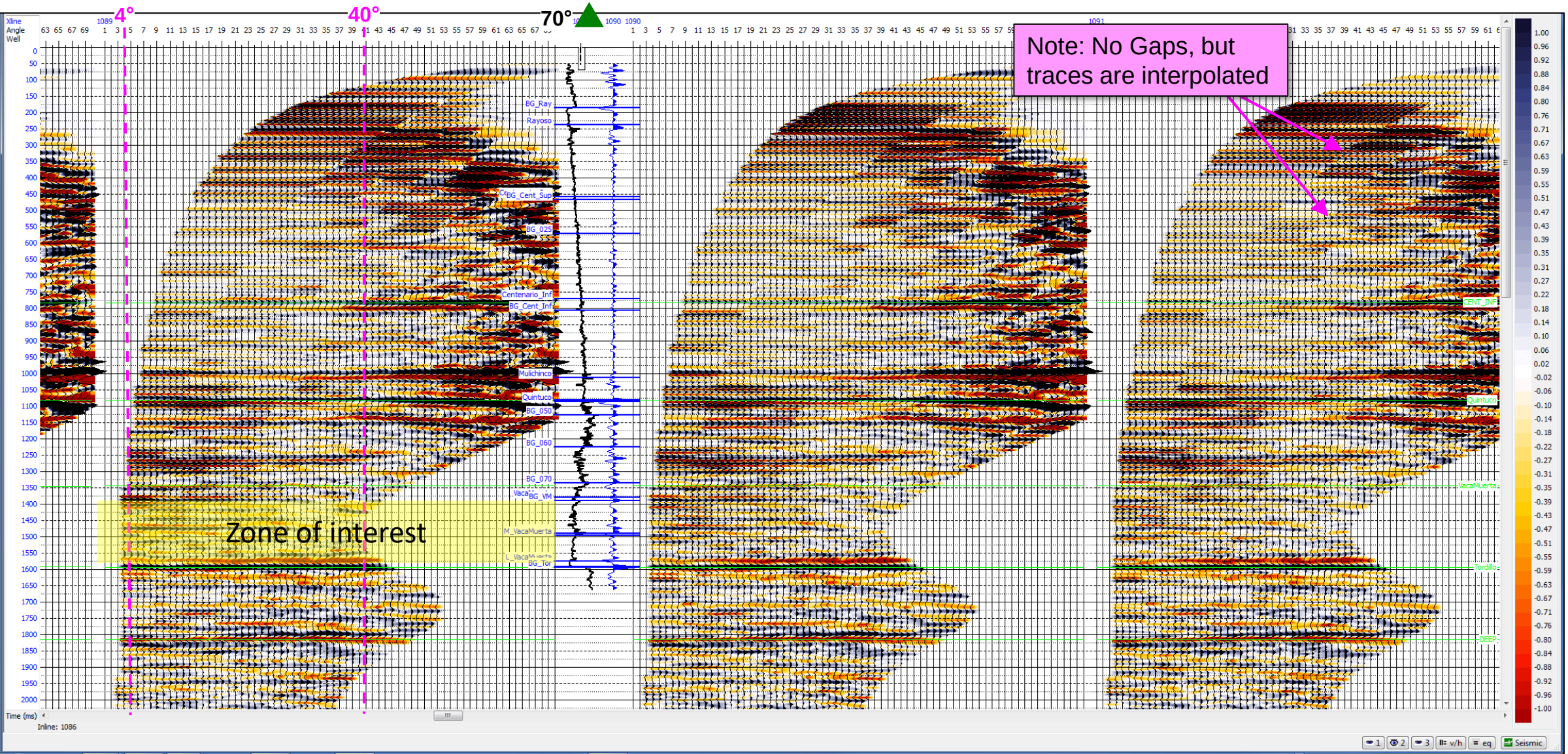
Statistical Wavelets from Angle Stacks – from Raw Gathers

Near	(1-10, center 6)
Near-Mid	(10-19, center 15)
Mids	(19-28, center 24)
Mid-Fars	(28-37, center 33)
Fars	(37-46, center 42)



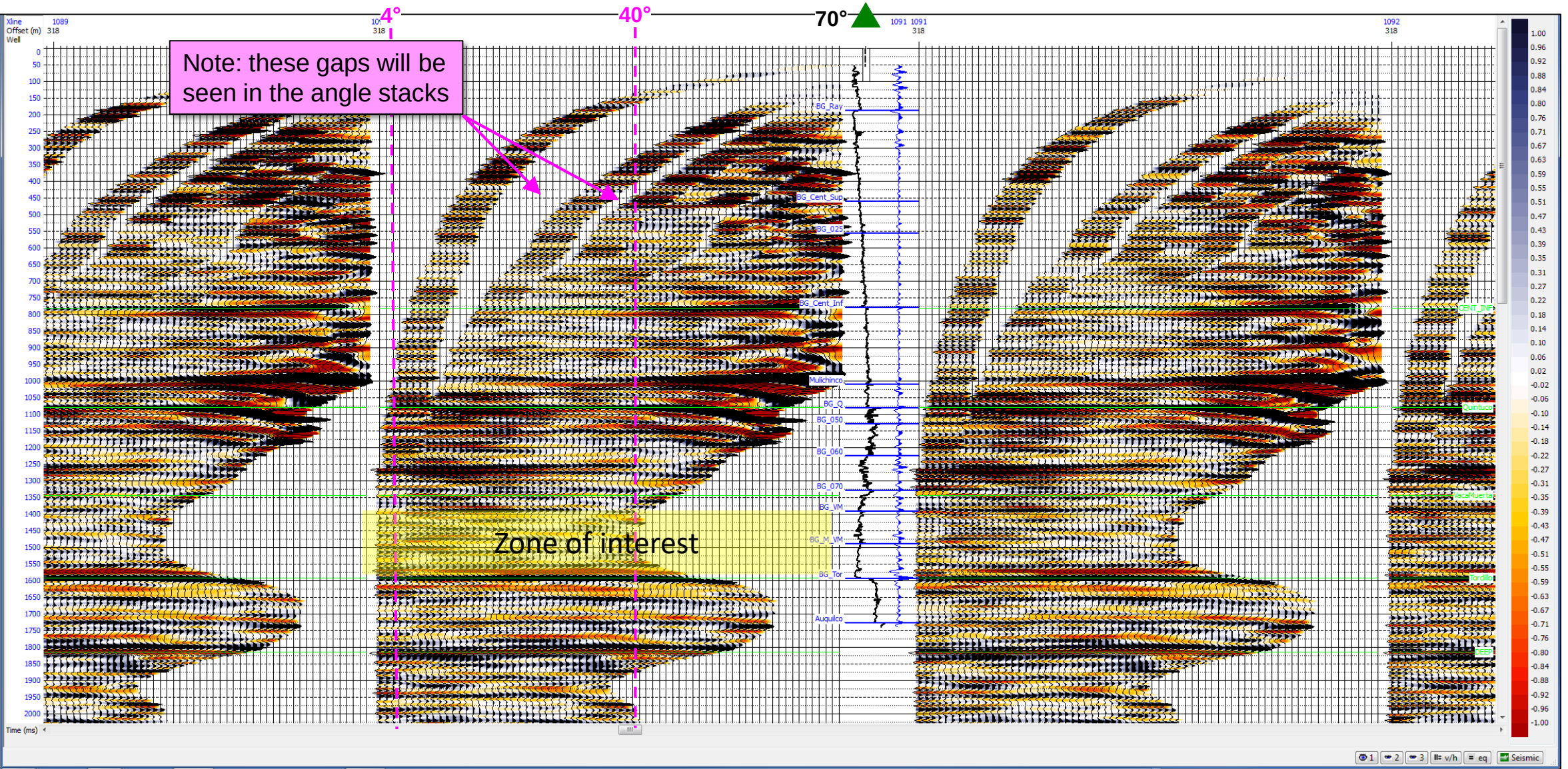
Angle Stacks – Hampson-Russell

Angle Gathers made in Hampson-Russell



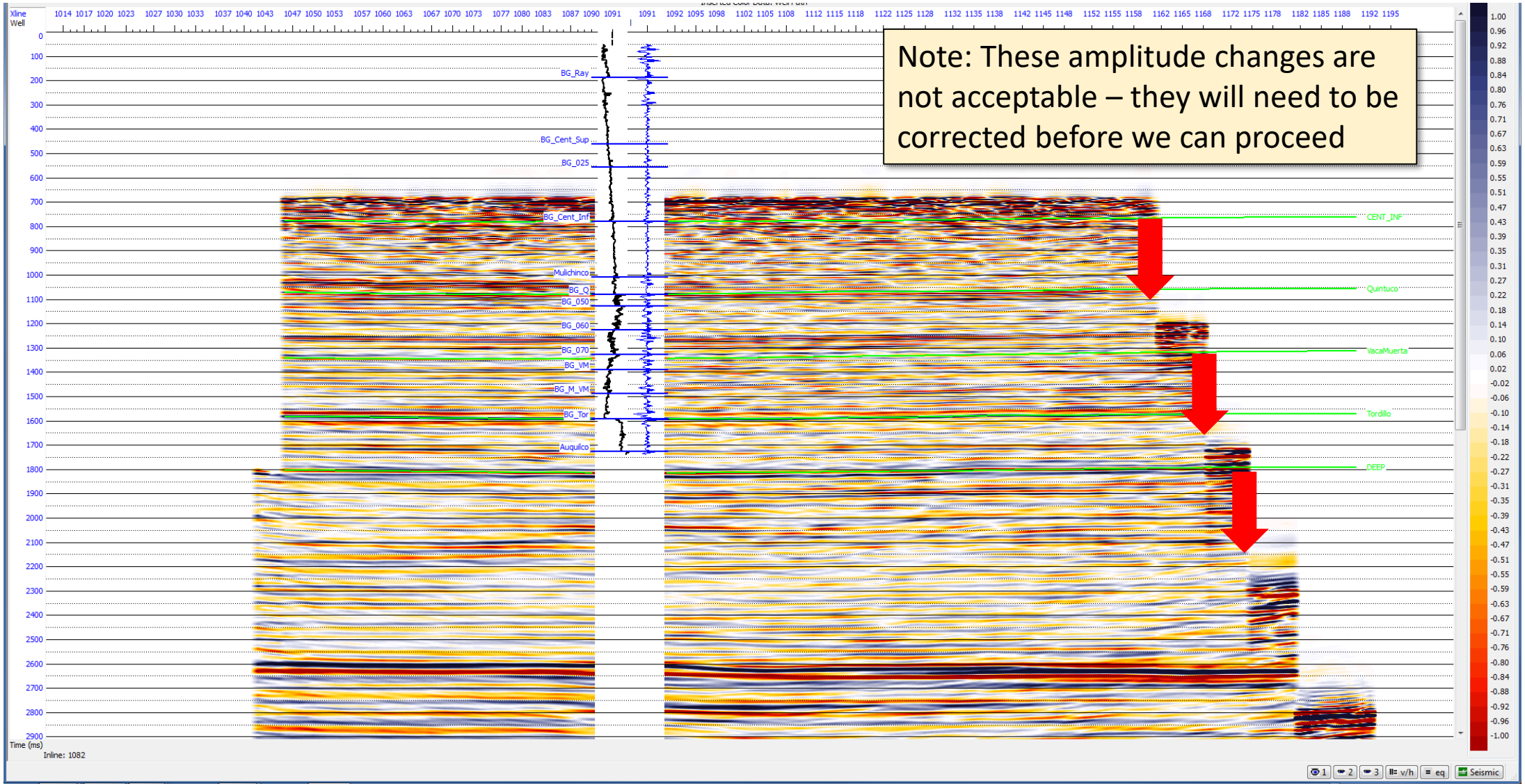
Angle Stacks – ProMax

Angle Gathers made in Landmark's ProMax



Angle Stacks - ProMax

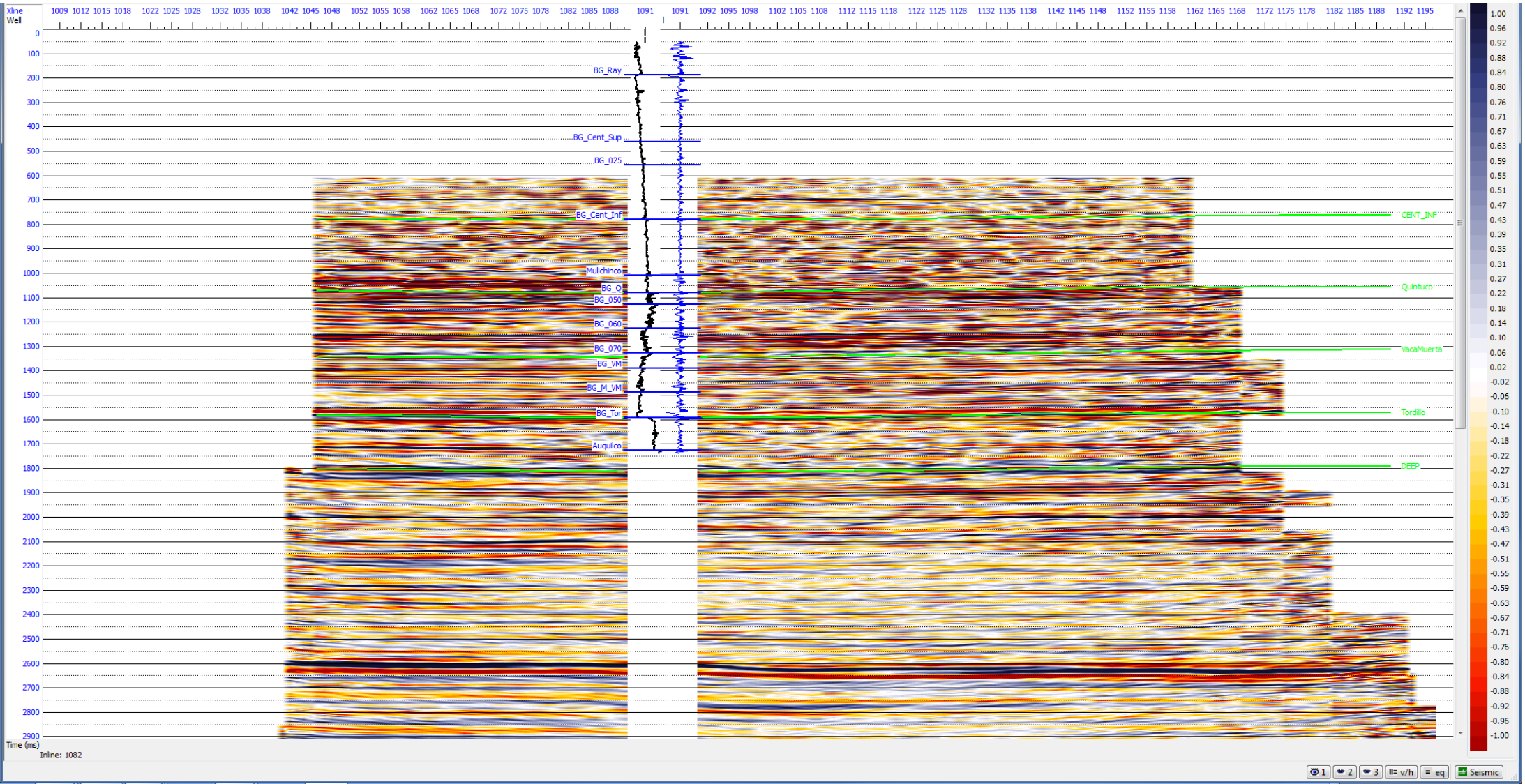
Angles: 4-10°



Note: These amplitude changes are not acceptable – they will need to be corrected before we can proceed

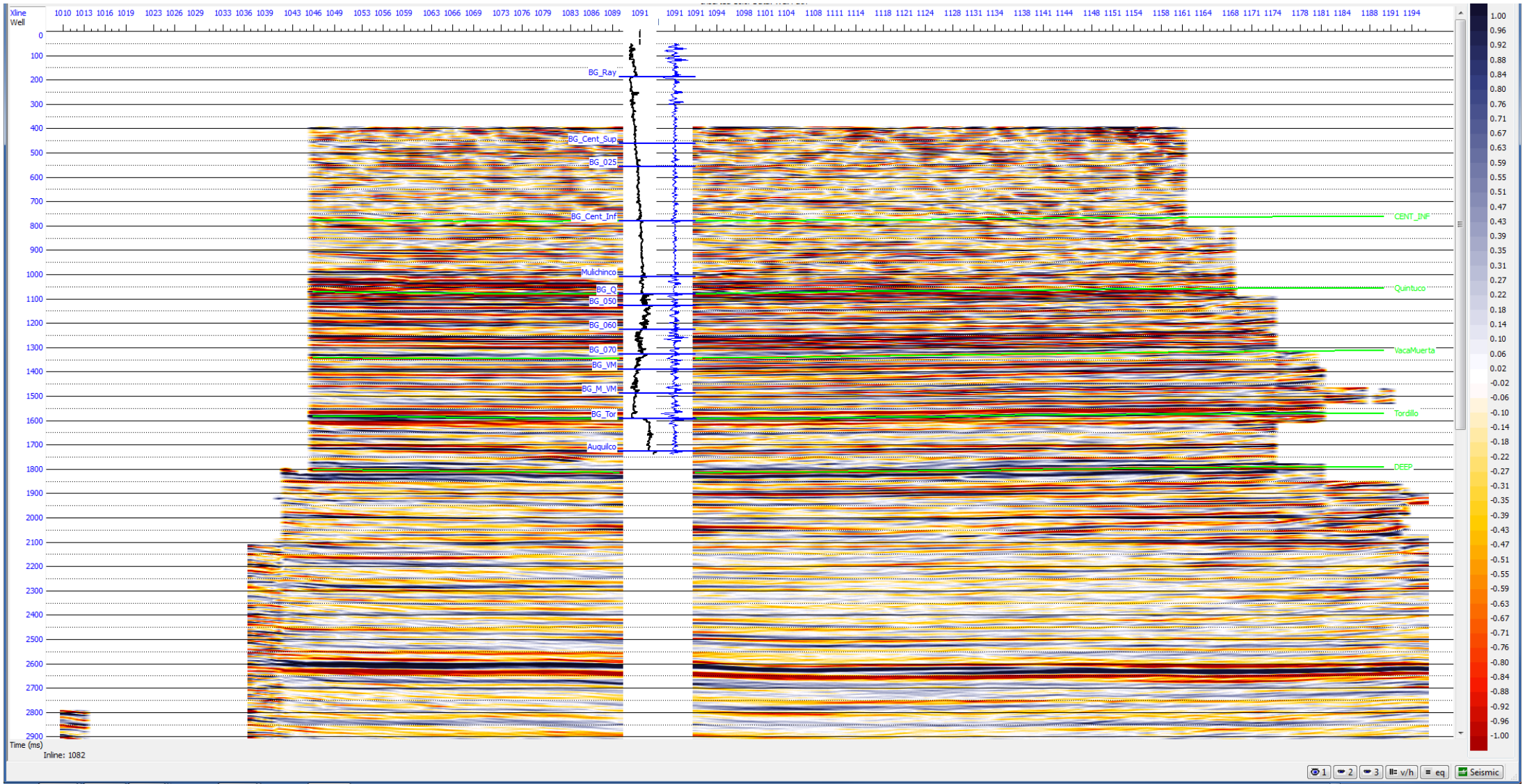
Angle Stacks - ProMax

Angles: 4-10°



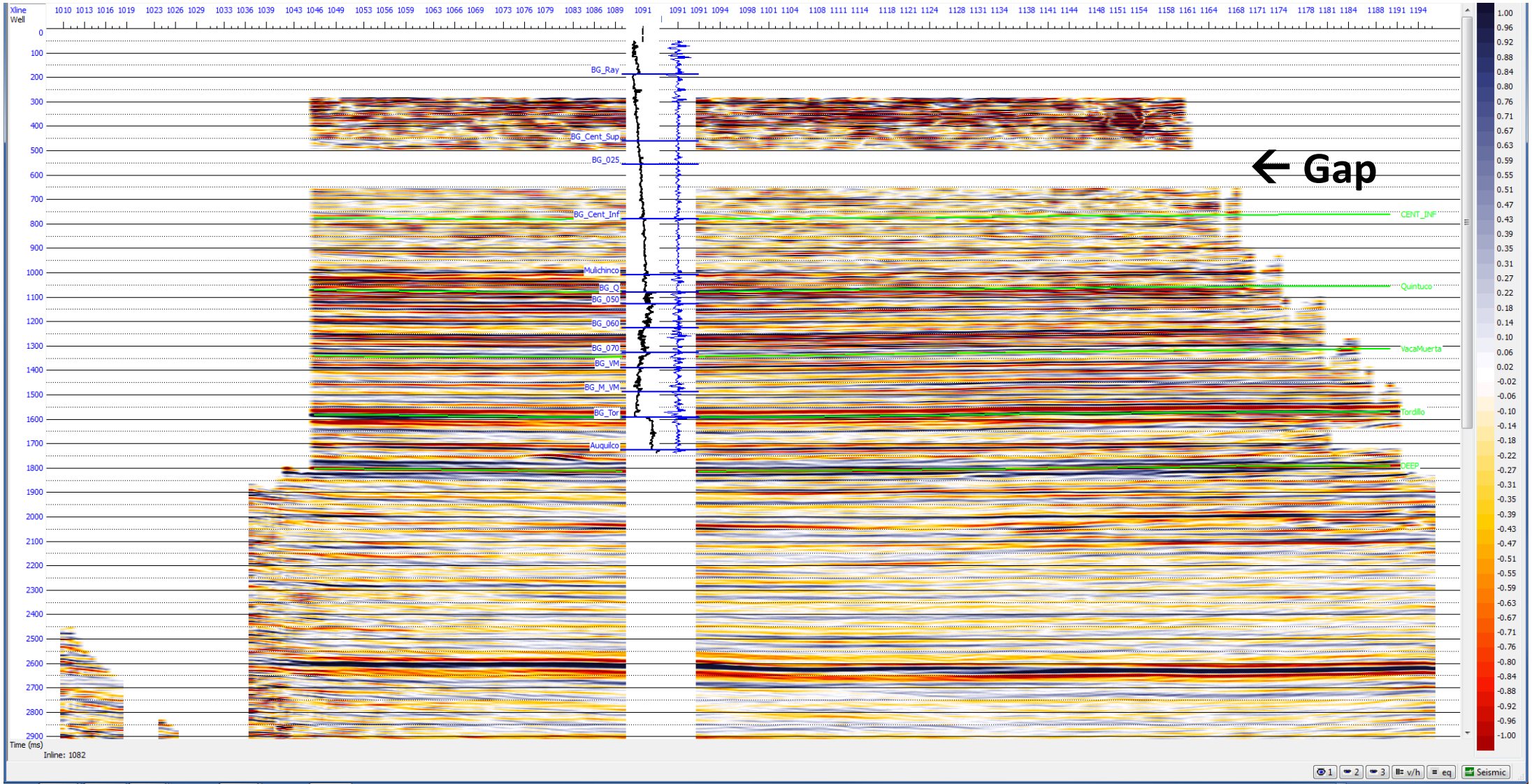
Angle Stacks - ProMax

Angles: 10-16°



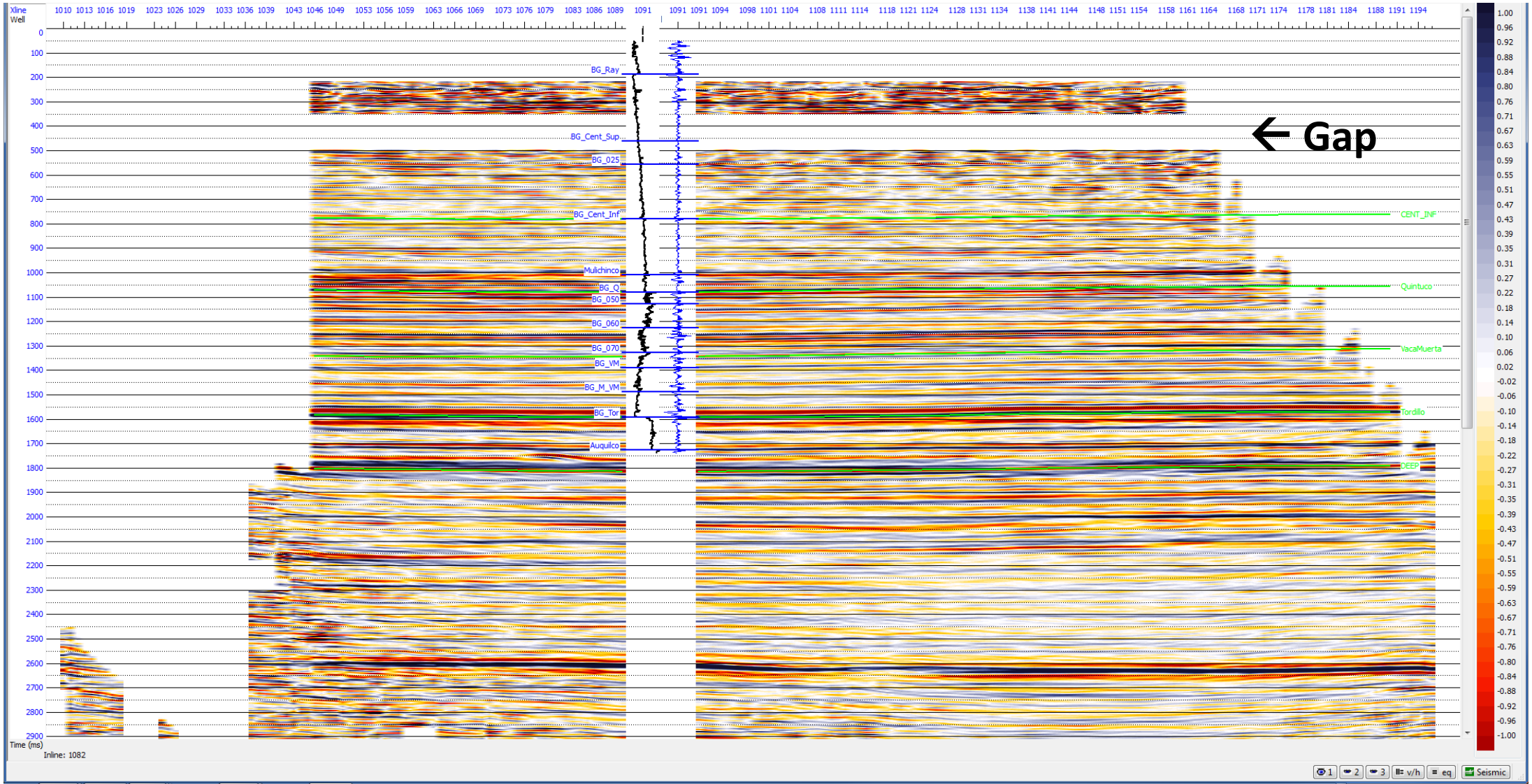
Angle Stacks - ProMax

Angles: 16-22°



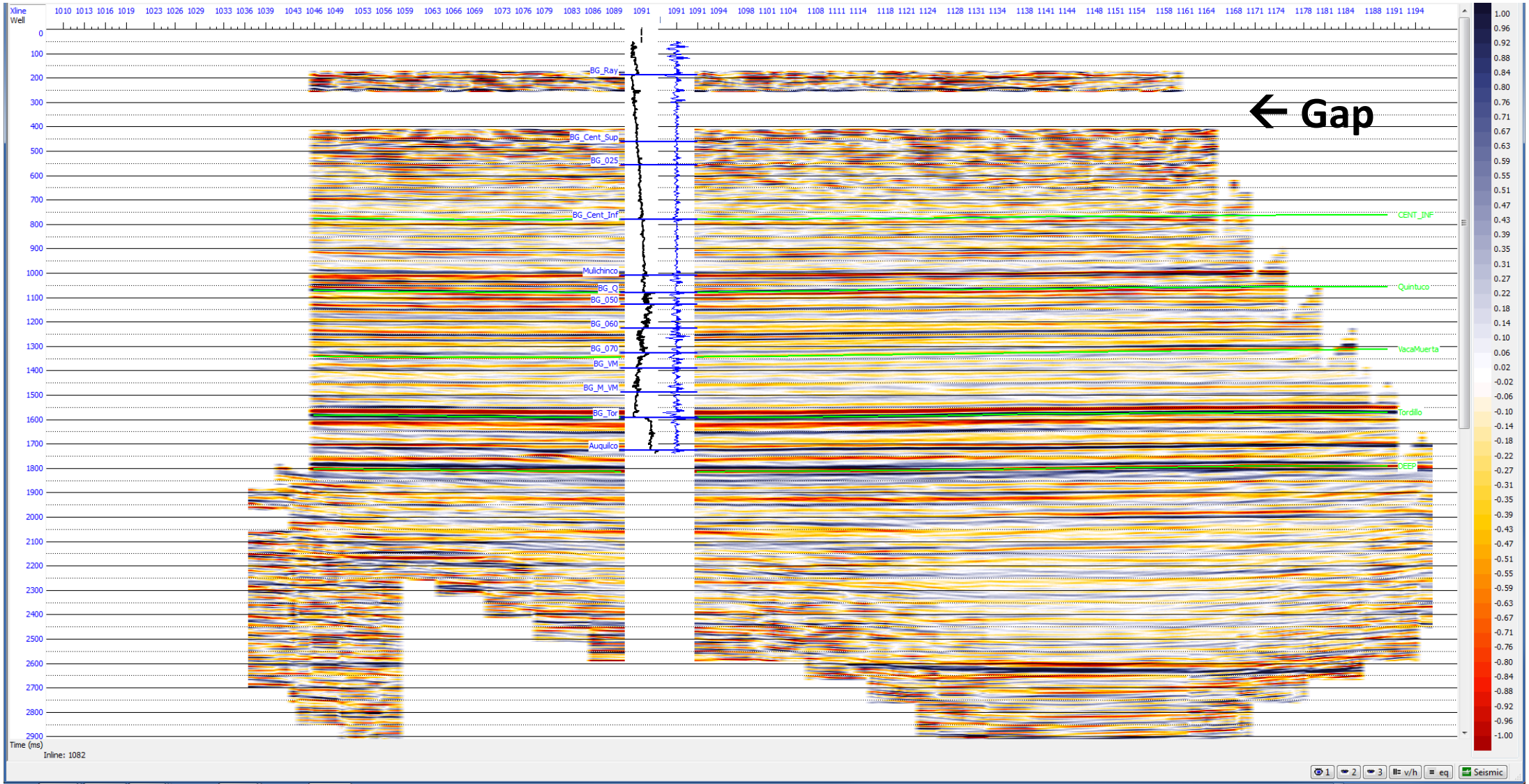
Angle Stacks - ProMax

Angles: 22-28°



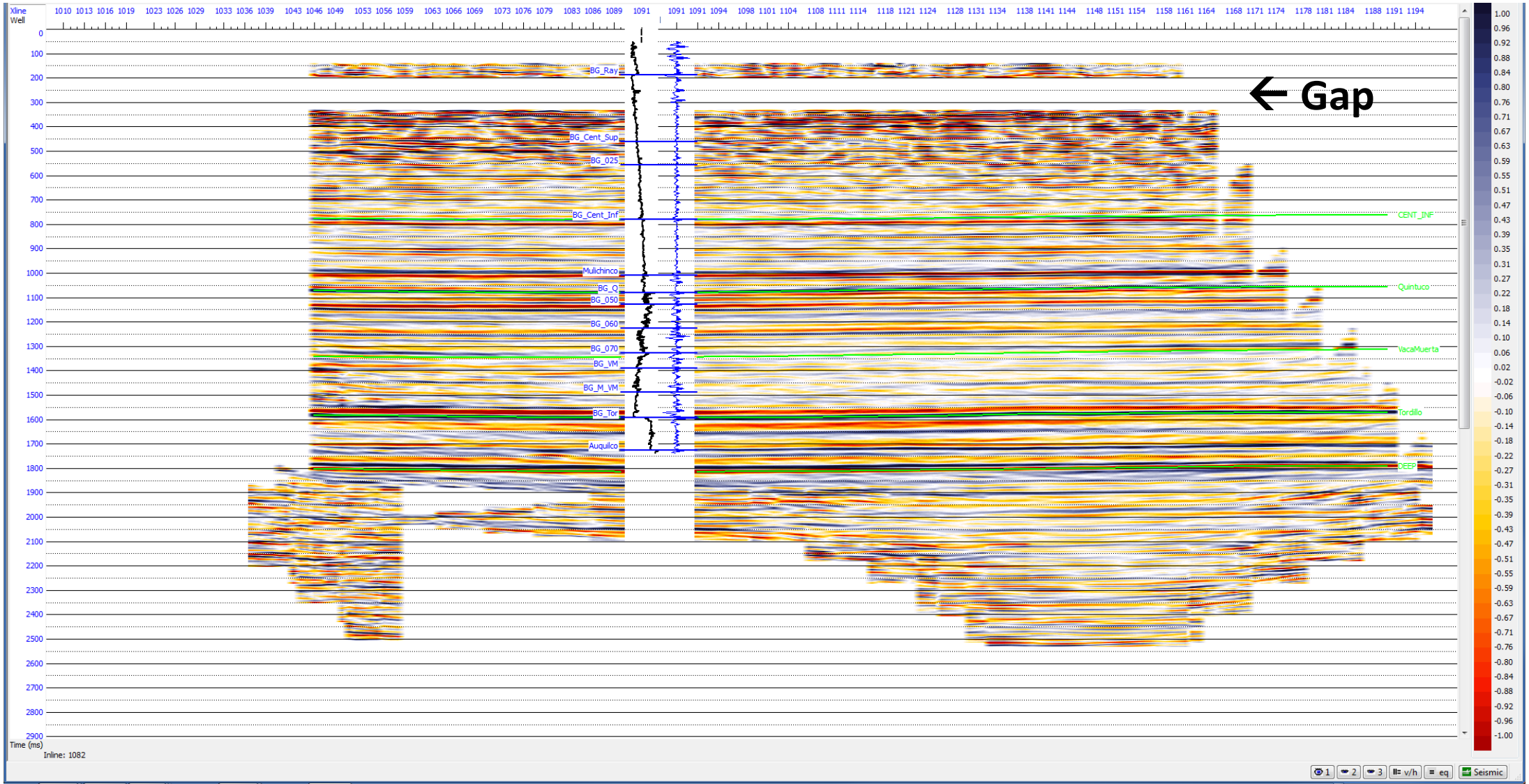
Angle Stacks - ProMax

Angles: 28-34°



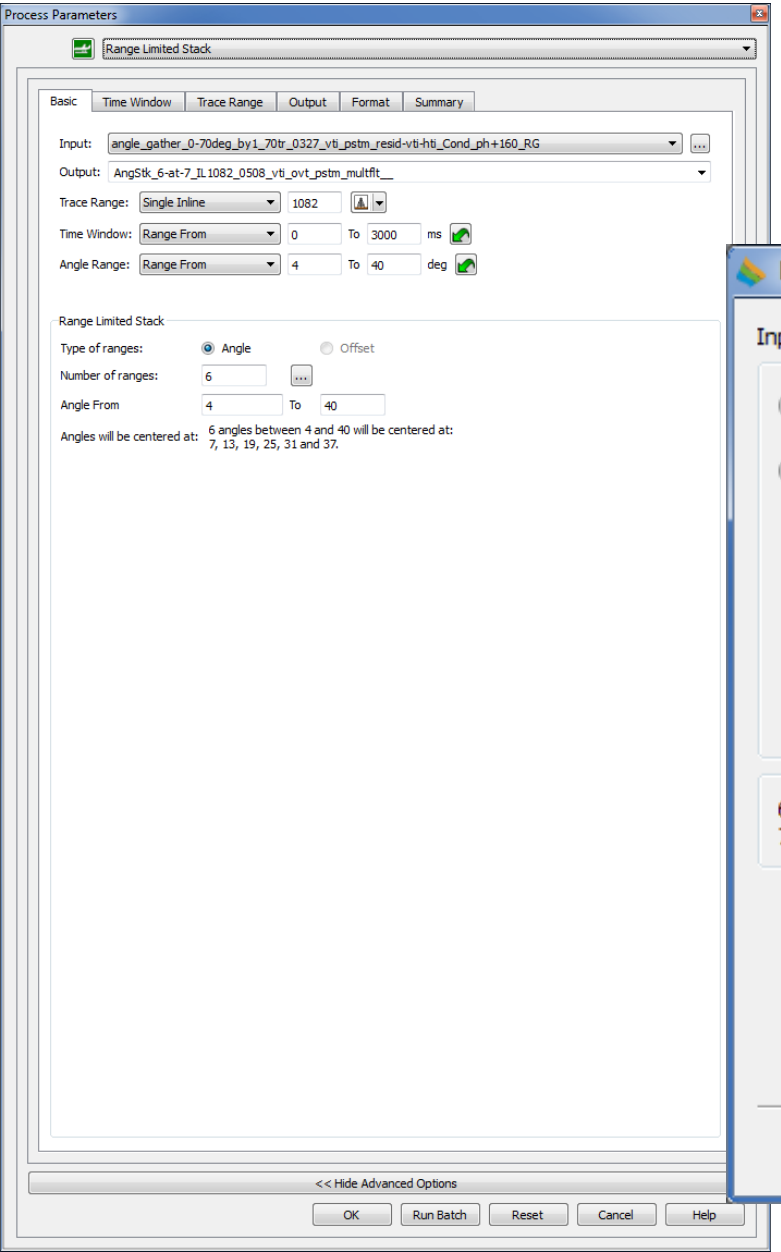
Angle Stacks - ProMax

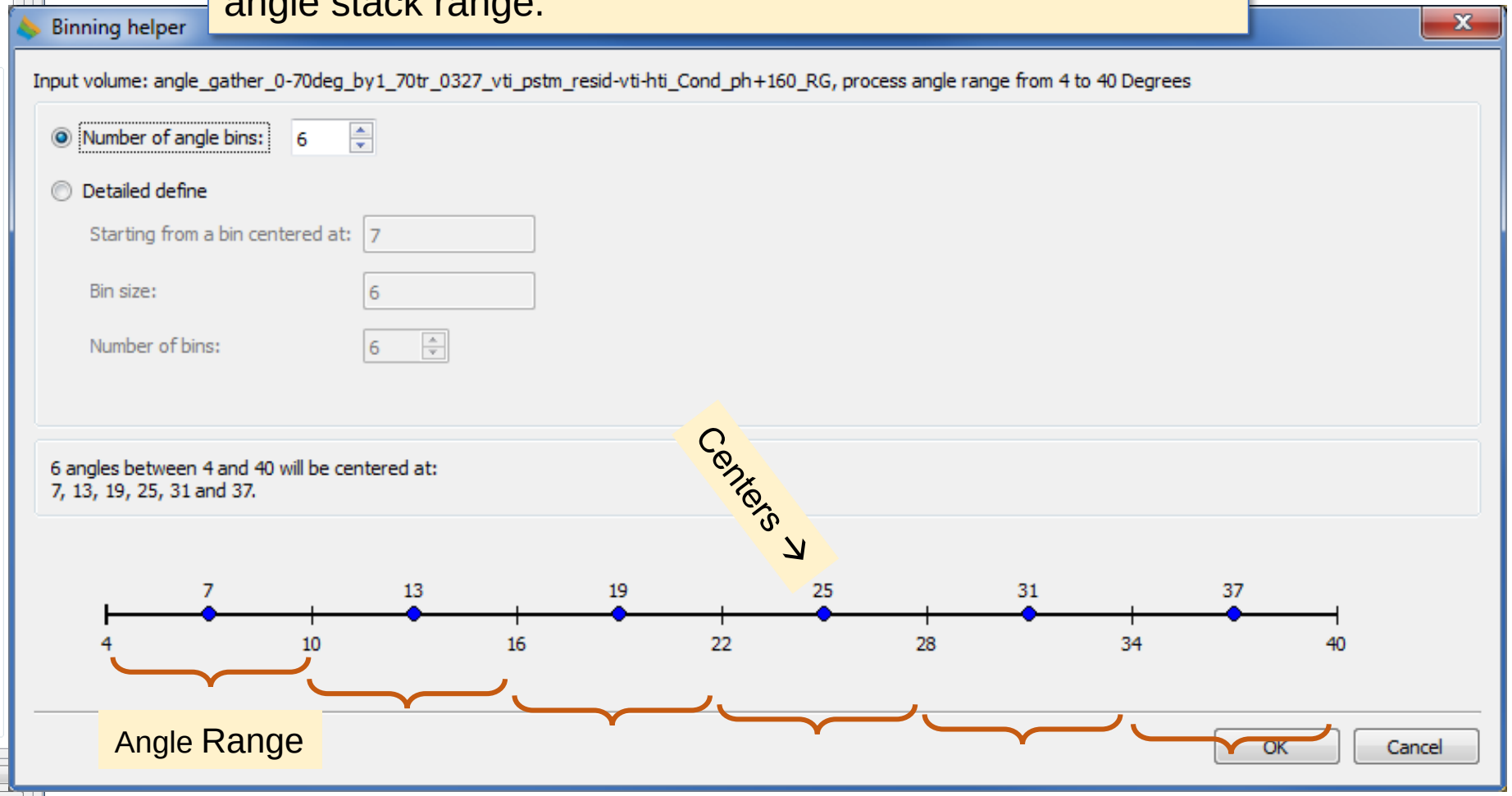
Angles: 34-40°



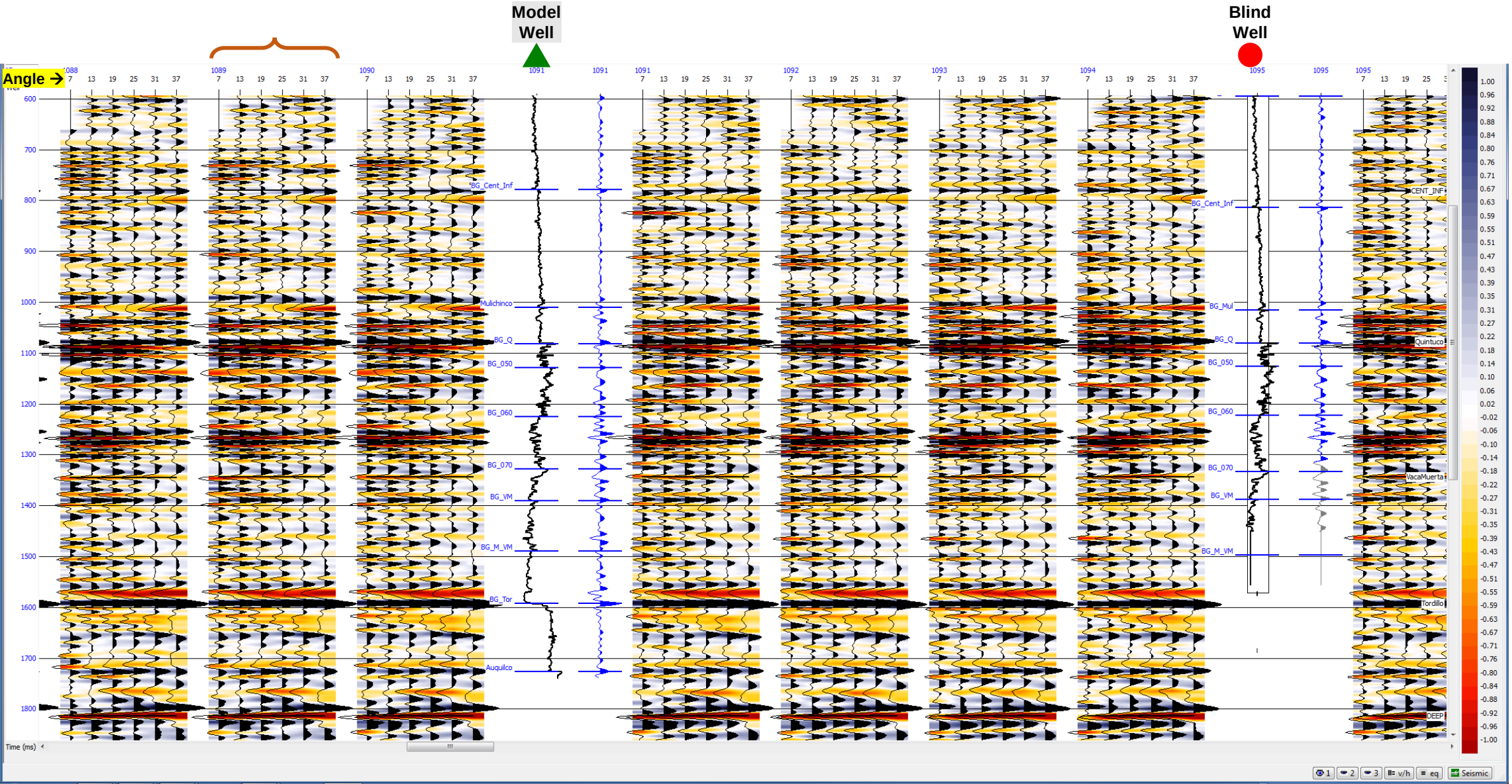
Build “Gathers” from Stacked Volumes

We need to use the individual Angle Stacks to build a set of “Gathers” with six traces at each IL/XL bin.
The traces are assigned the angle of the middle of the angle stack range.

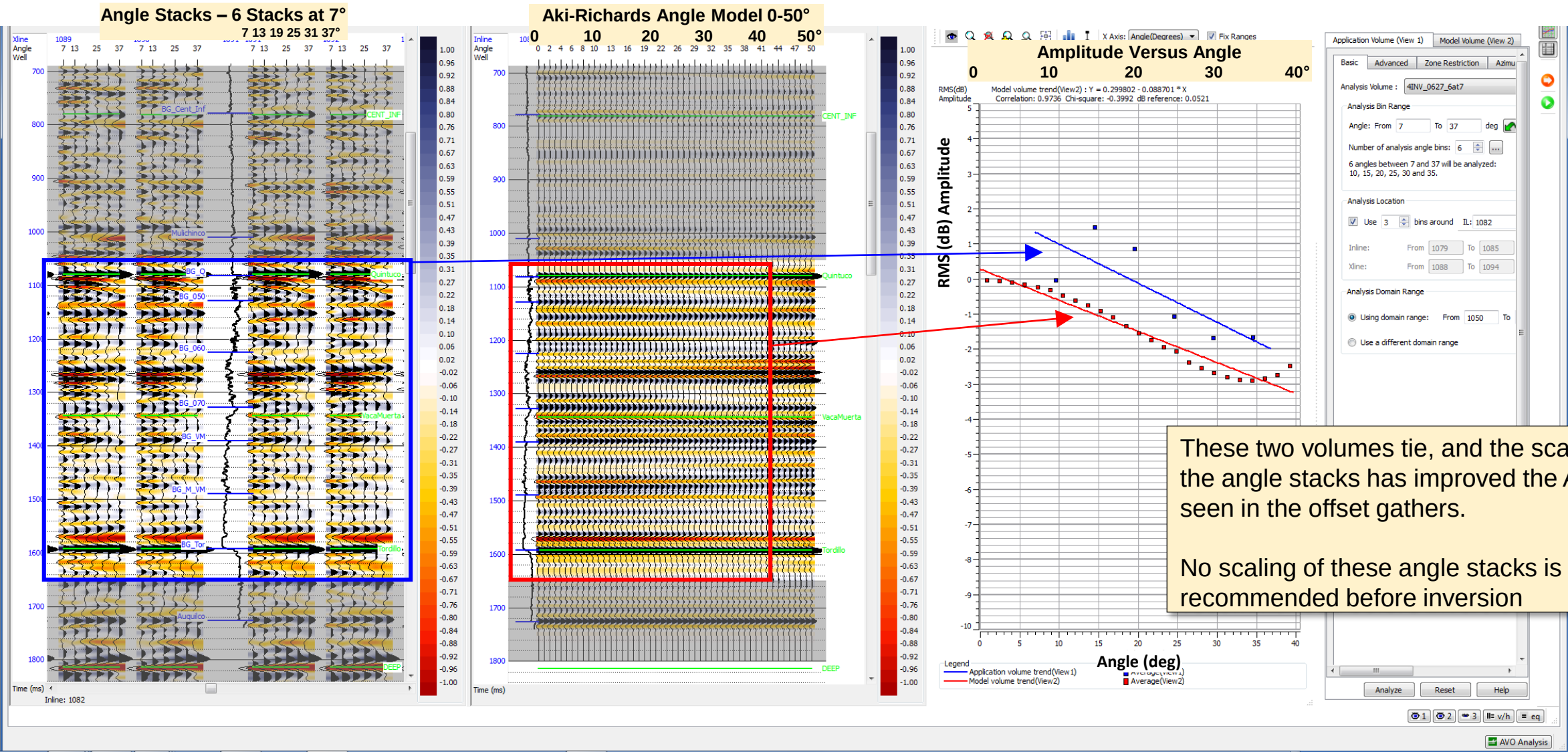




“Gathers” from Angle Stacked Volumes



Final AVA Comparison – Angle Stacks vs Model



These two volumes tie, and the scaling on the angle stacks has improved the AVO seen in the offset gathers.

No scaling of these angle stacks is recommended before inversion

Outline

- Overview of Inversion
- Review well data provided
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- Scaling the Inversion – x-plot analysis
- Results of Simultaneous Elastic Impedance Inversion
- Additional Volumes – Lame, Poisson's Ratio, Young's Modulus
- Predicting Lithology from LRM Cross-plots
- Comments & Conclusions

Inversion Analysis

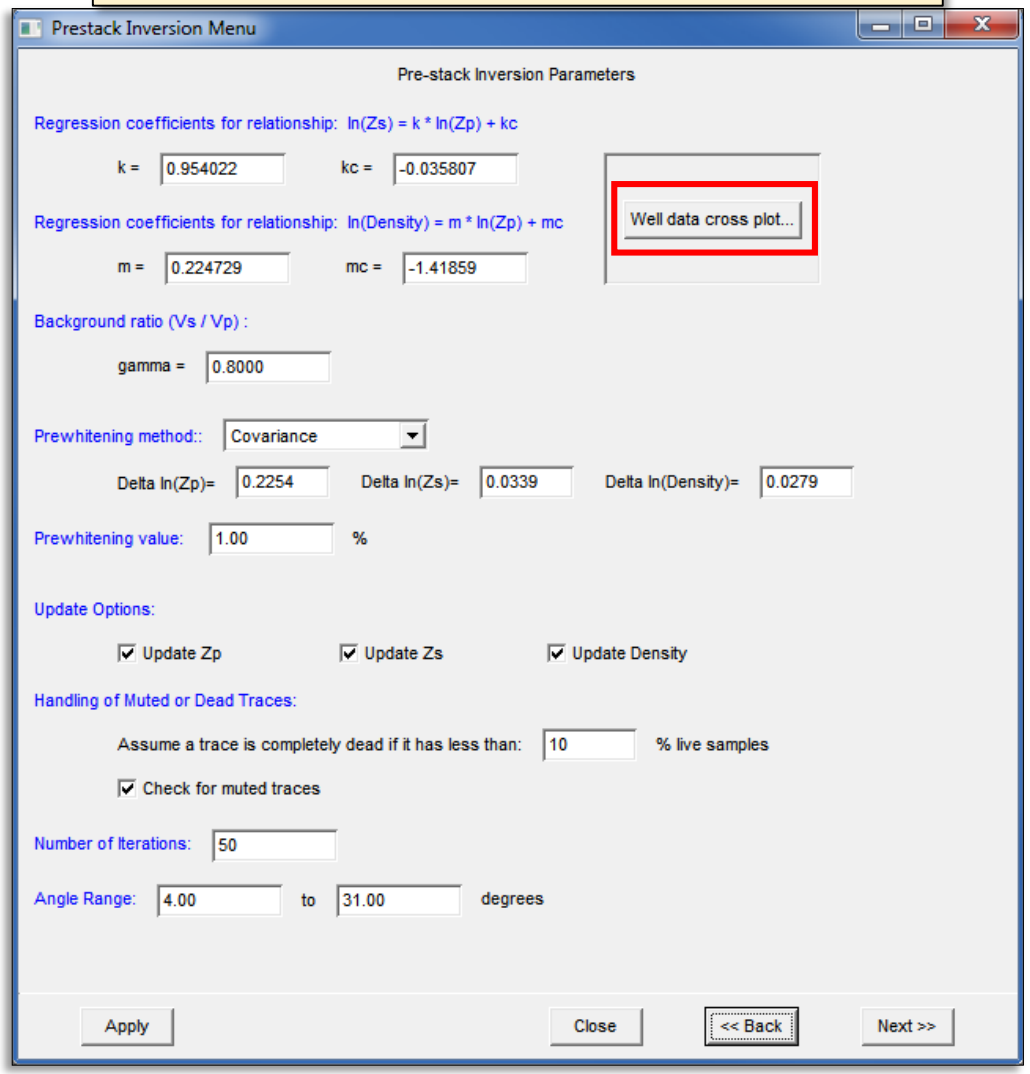
You need to decide:

- Which well(s) to use to perform scaling?
- Over what time zones to scale inversion? Target zone?
- Default regressions – cross plots of natural logs (ln)
  - What zones (depth or time) to use for X-plots
  - Zp versus Zs is usually good fit (>0.8)
  - Zp versus Dn is usually fair-to-poor fit (<0.3)

Inversion Analysis

Example #1

We would start with the default fits
then consult with client on alternatives



Inversion Analysis

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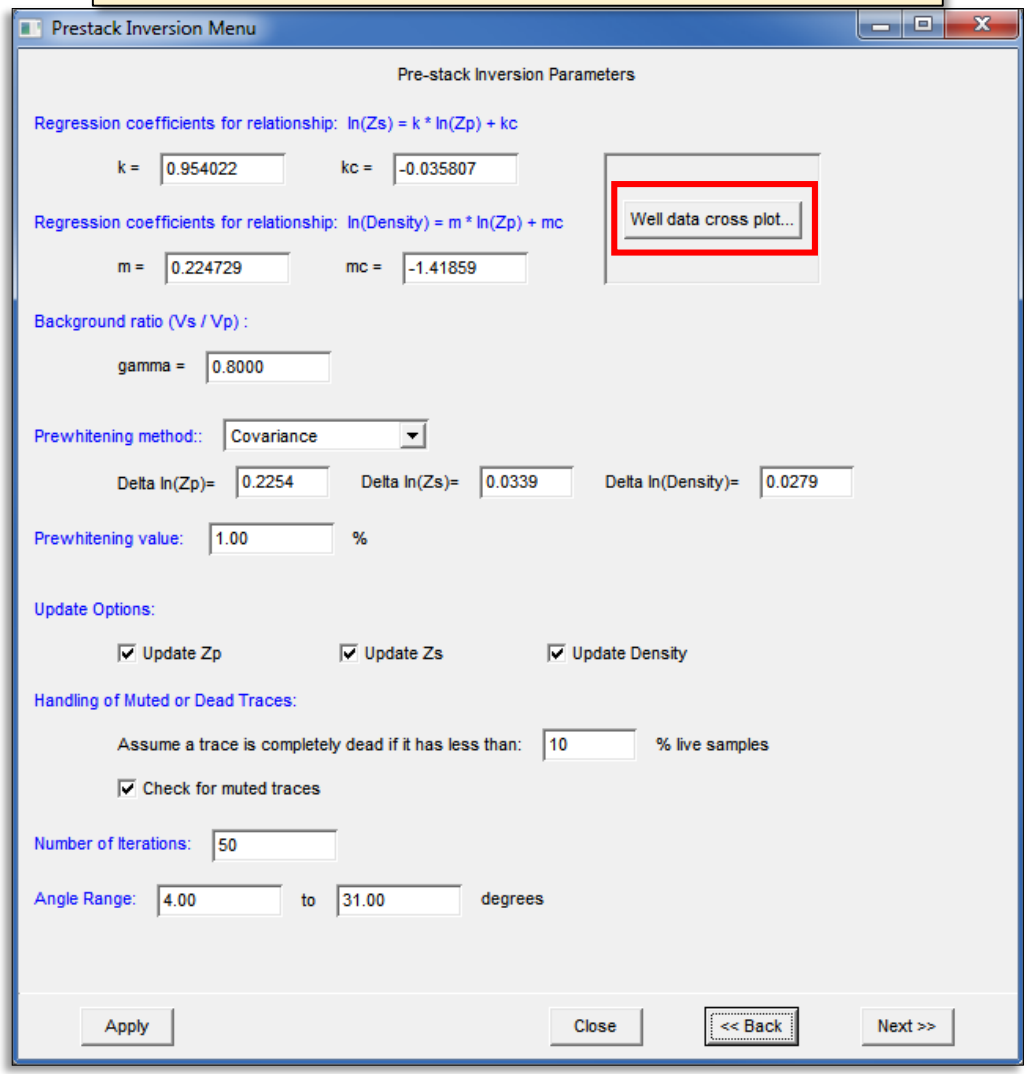
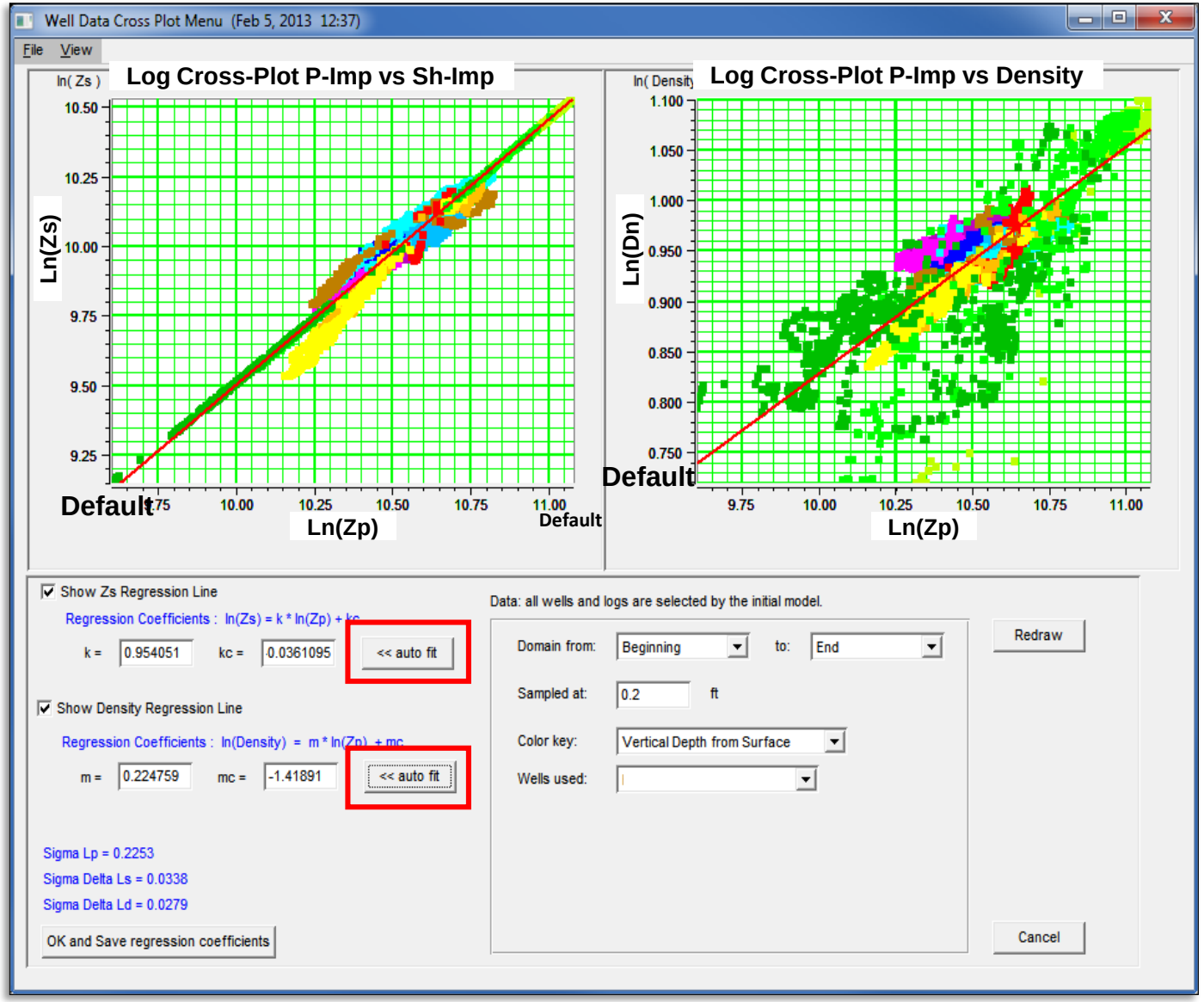
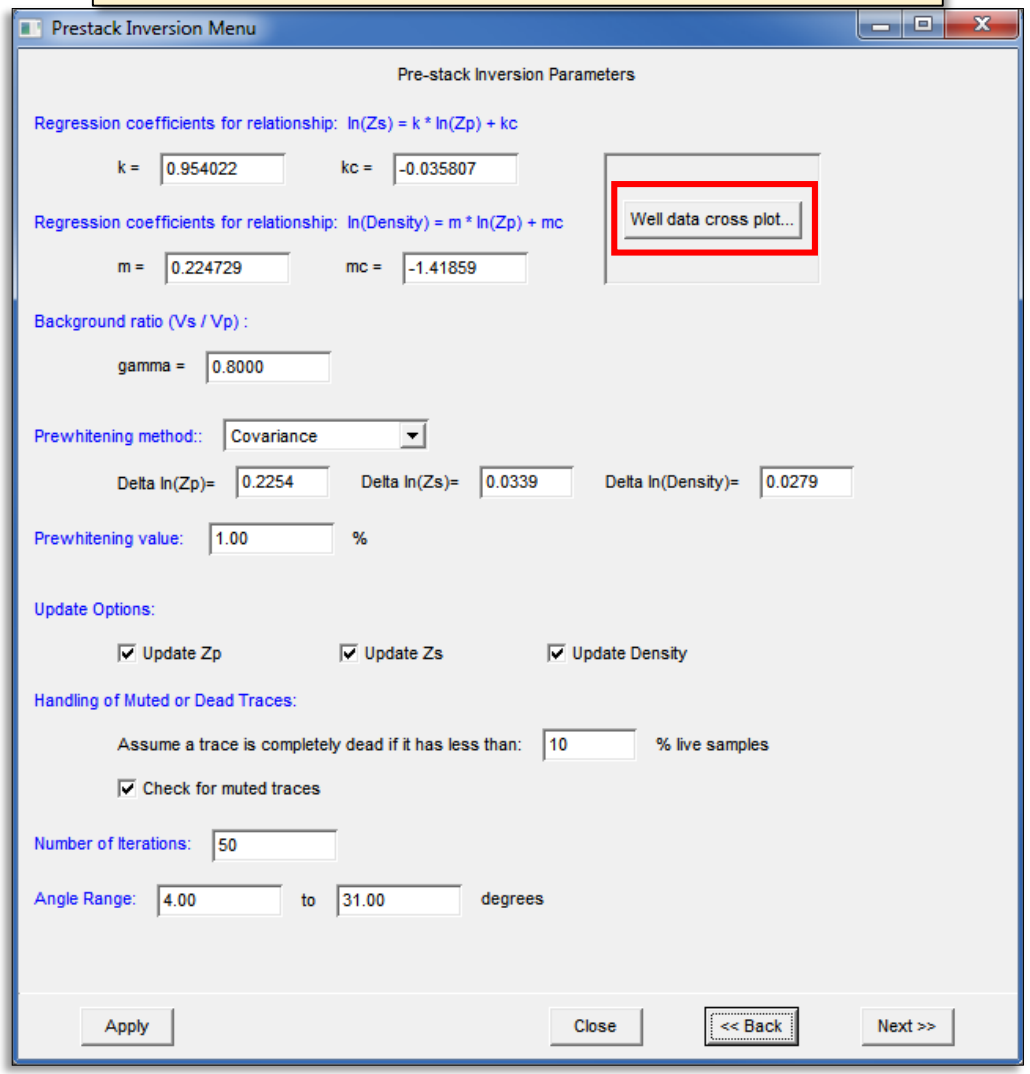


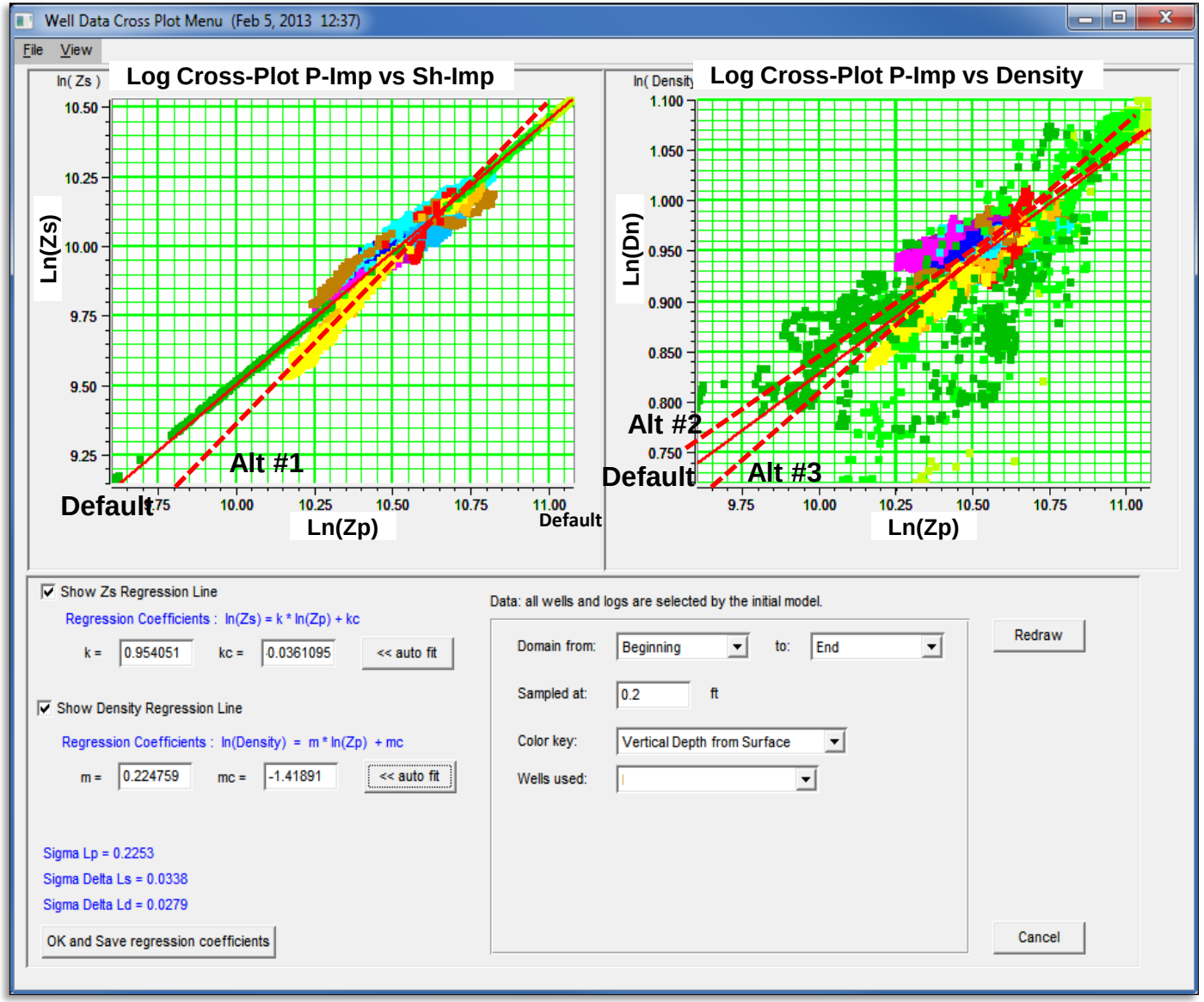


Inversion Analysis

We would start with the default fits
then consult with client on alternatives

Example #1





Inversion Analysis

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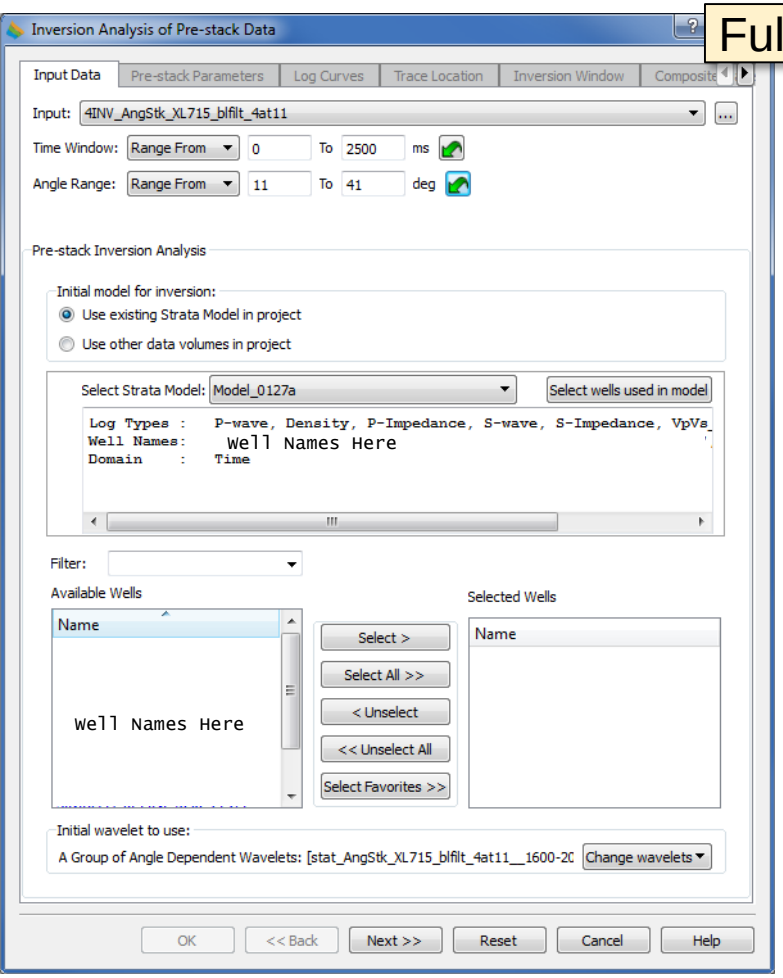
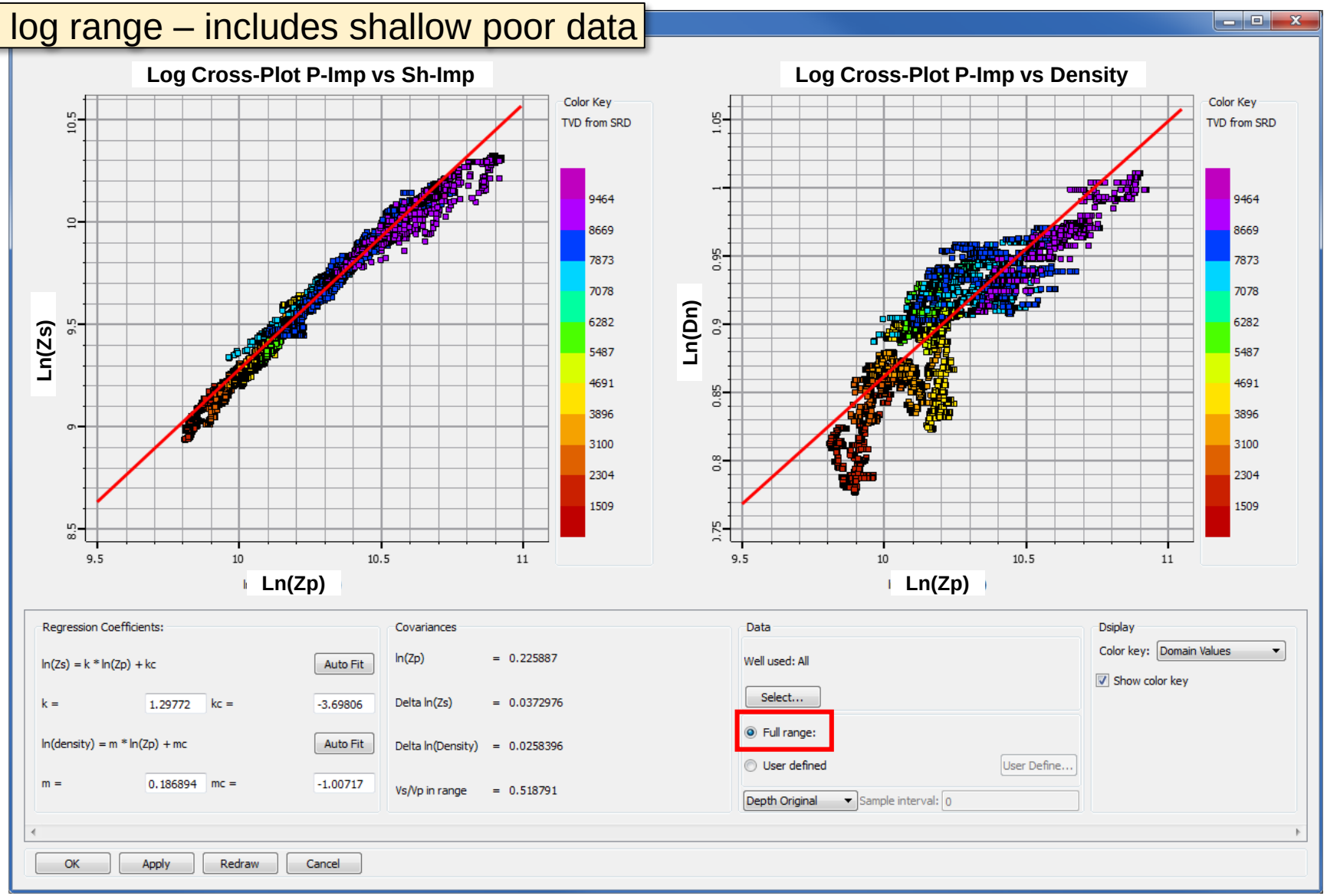
  - Zp versus Dn is usually fair-to-poor fit (<0.3)

Inversion Analysis

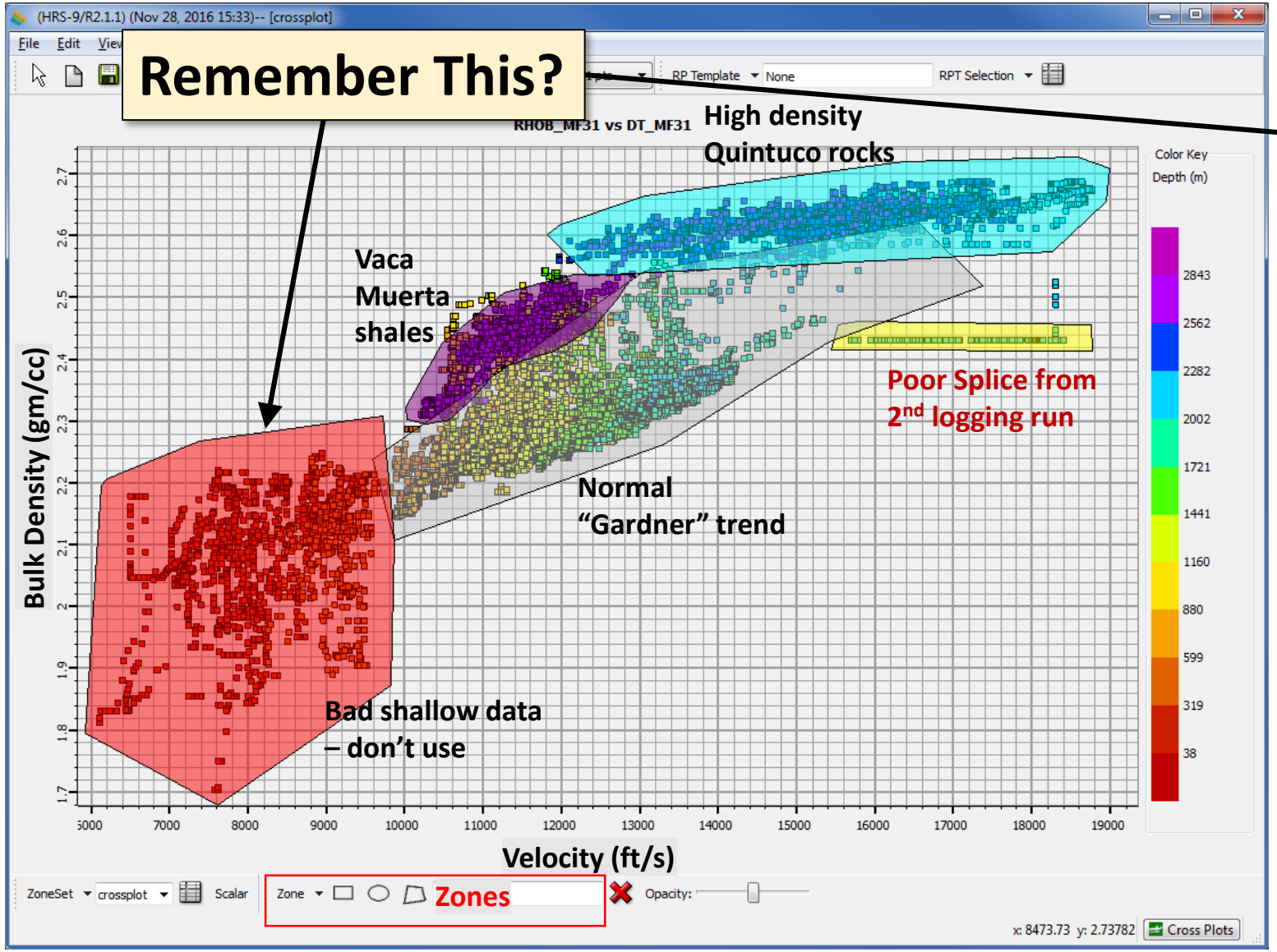
Example #2

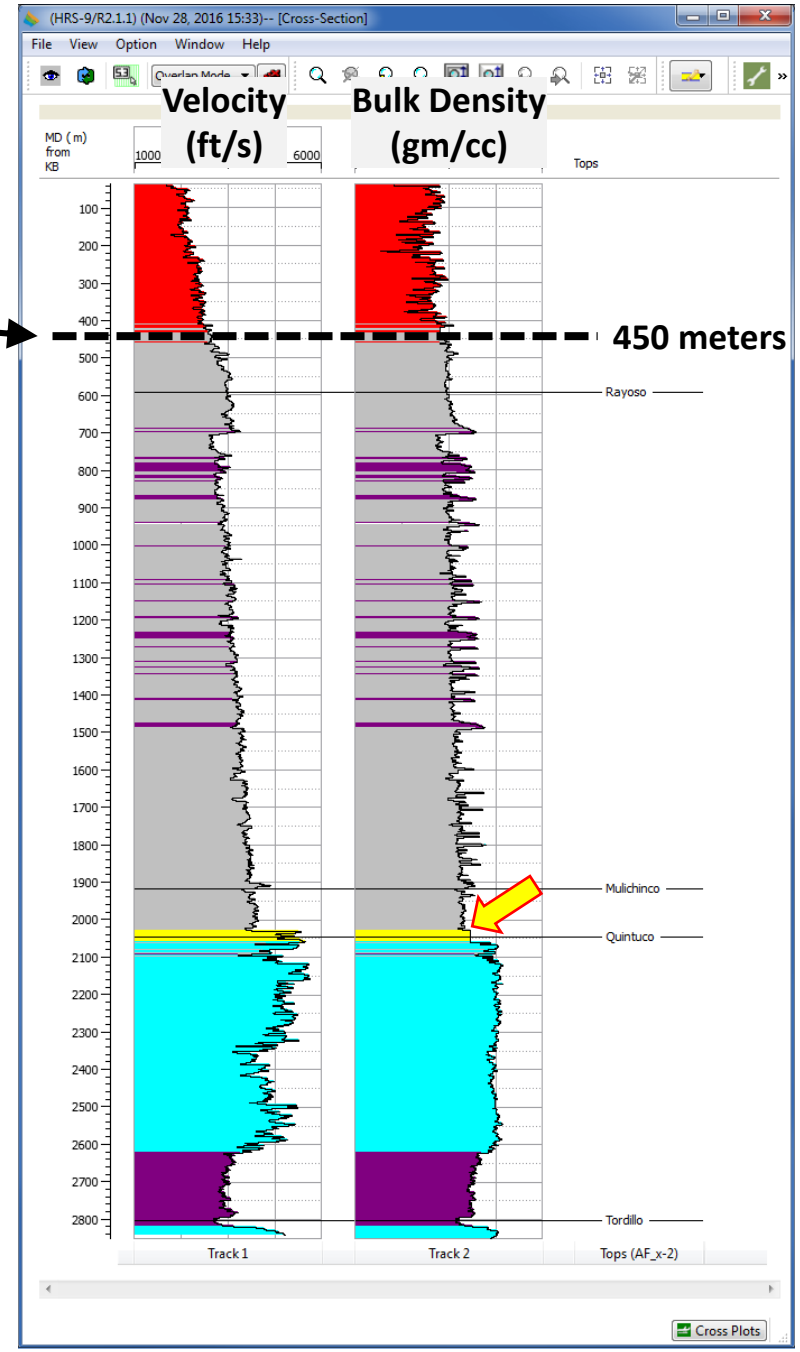
Full log range – includes shallow poor data





X-Plot; Sonic Velocity vs Density

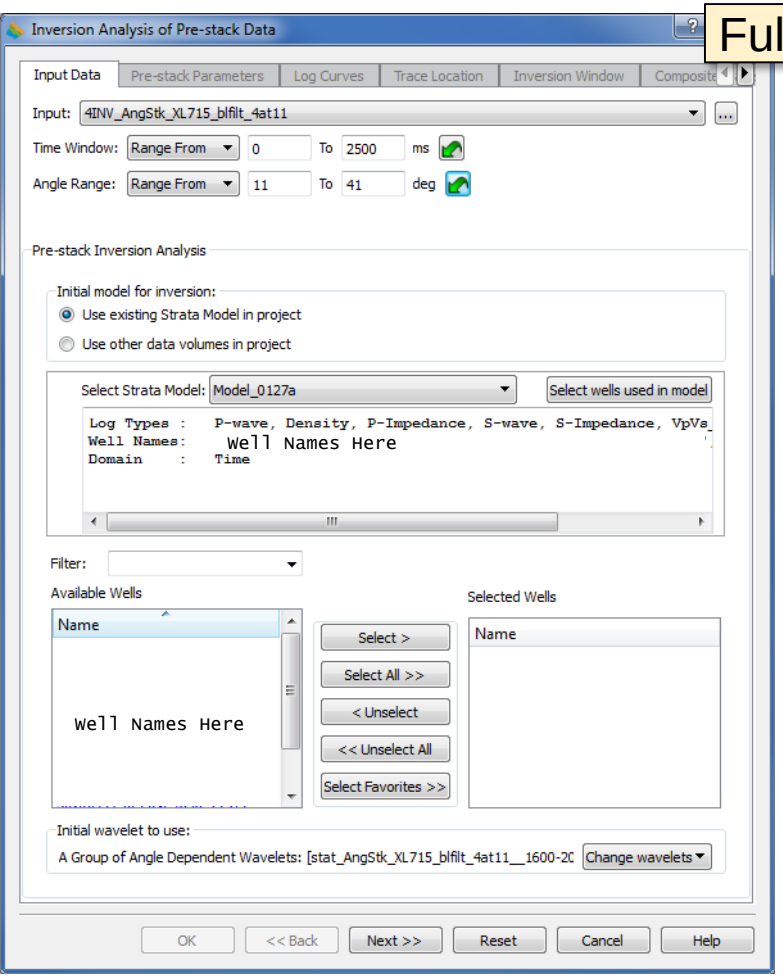


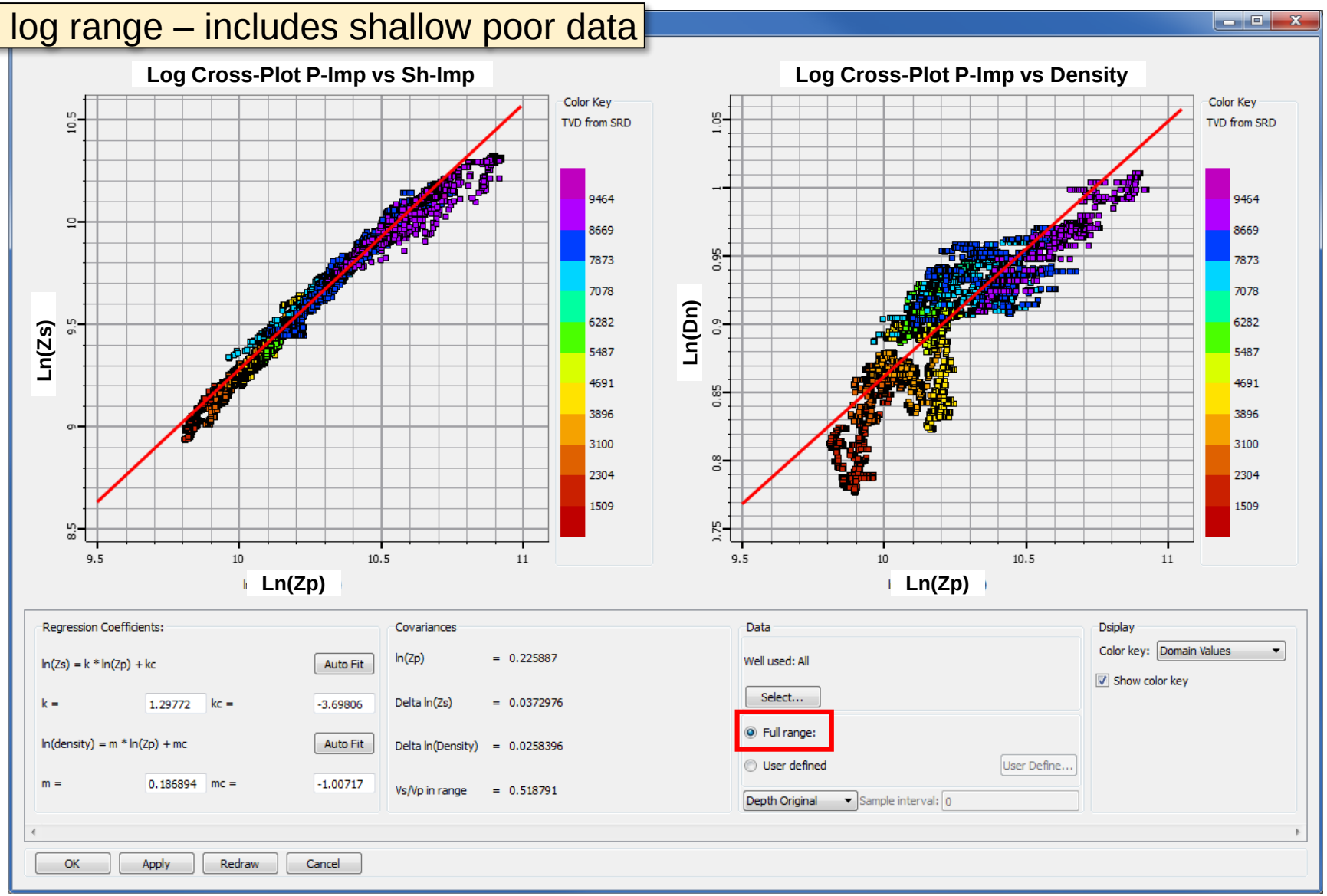


Inversion Analysis

Example #2

Full log range – includes shallow poor data

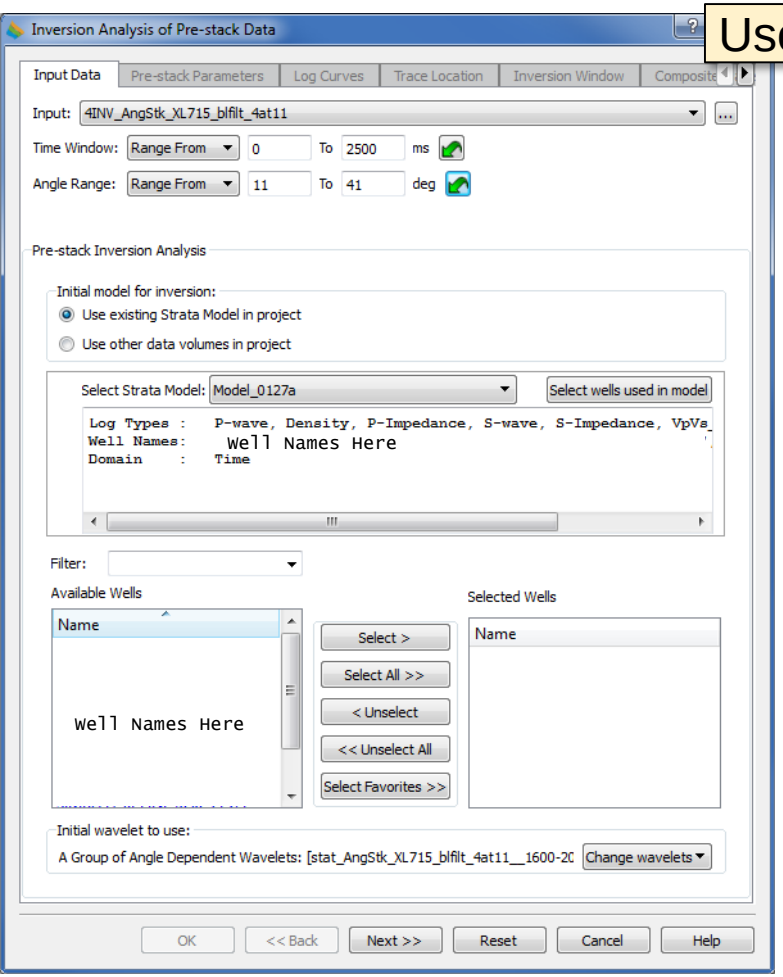


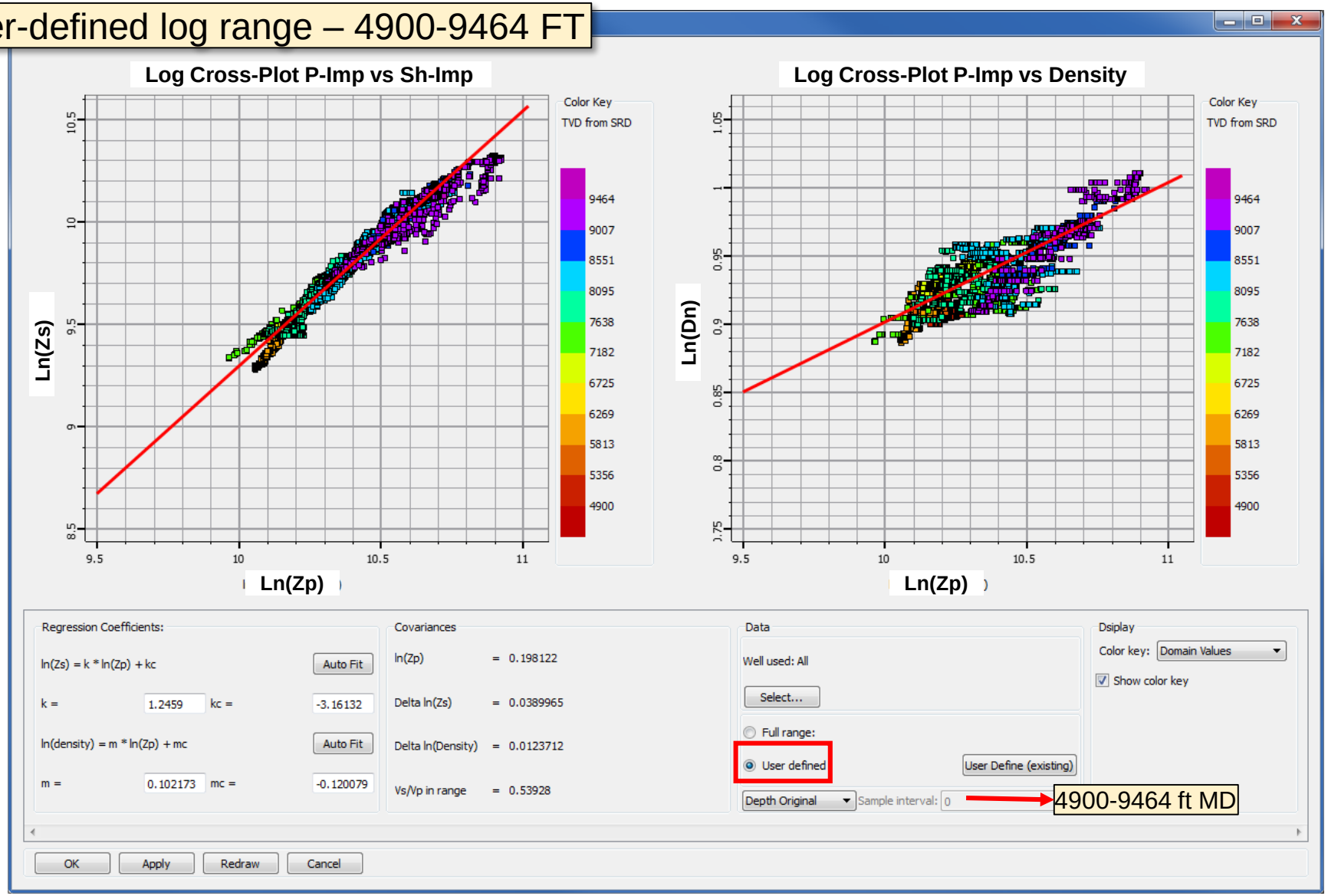


Inversion Analysis

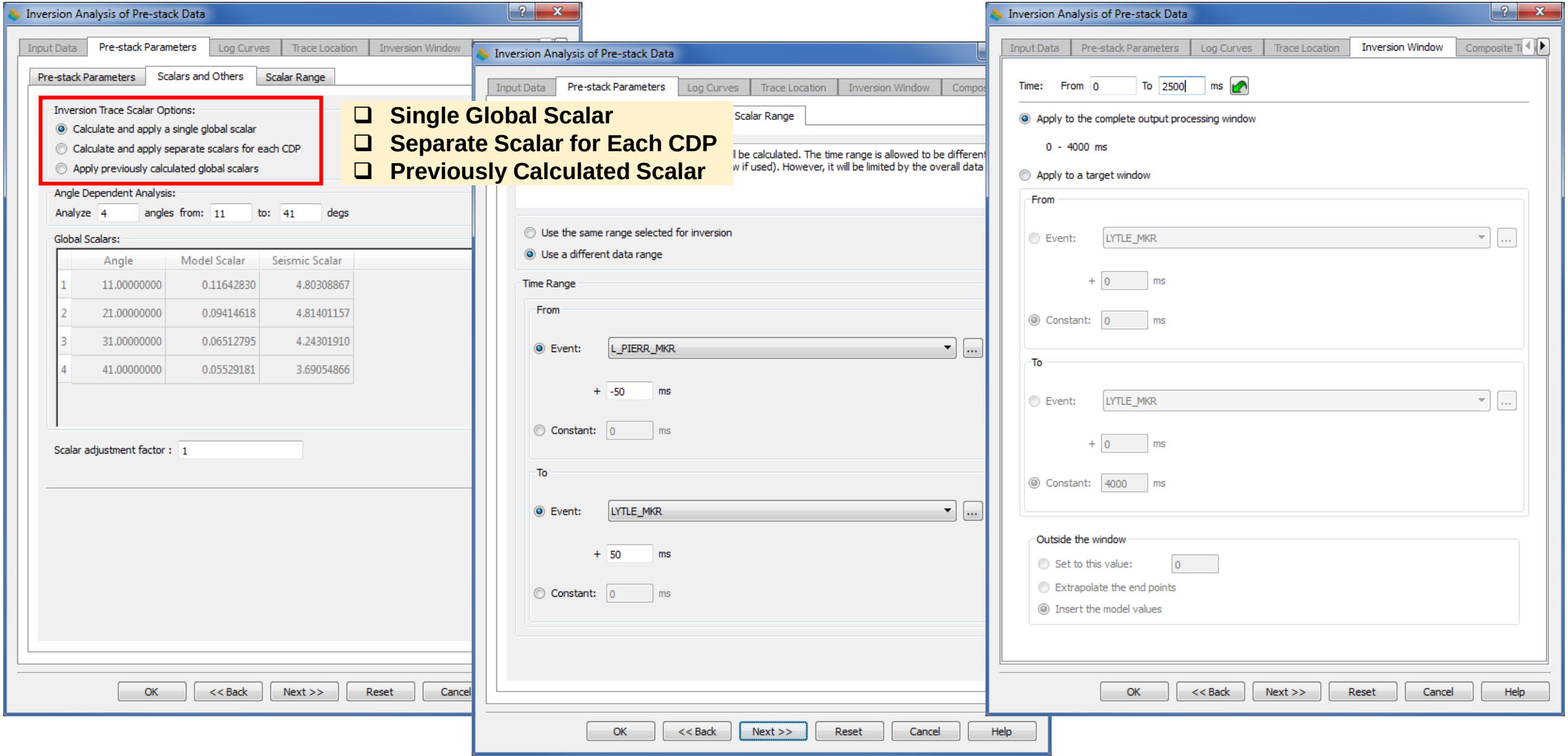
Example #2

User-defined log range – 4900-9464 FT

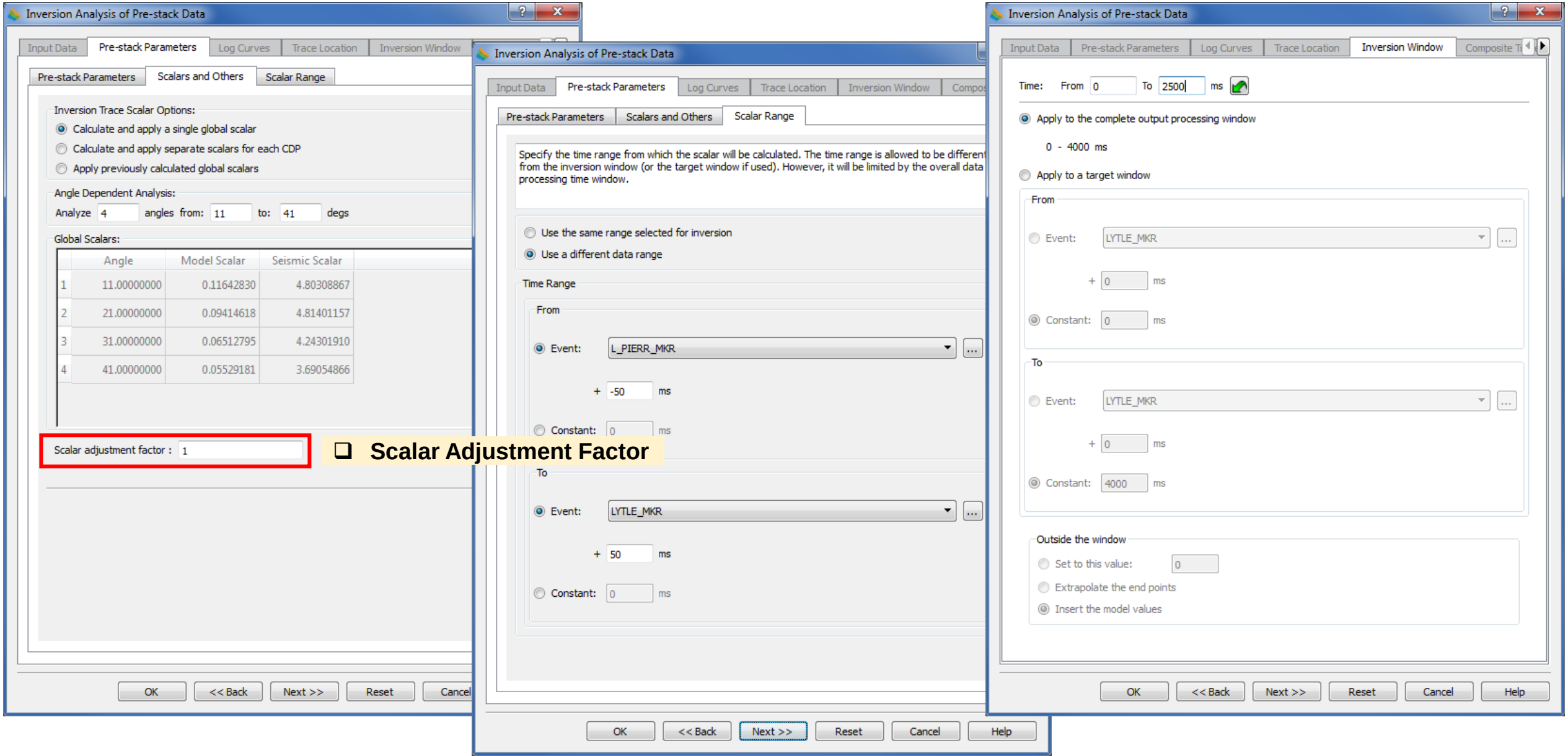




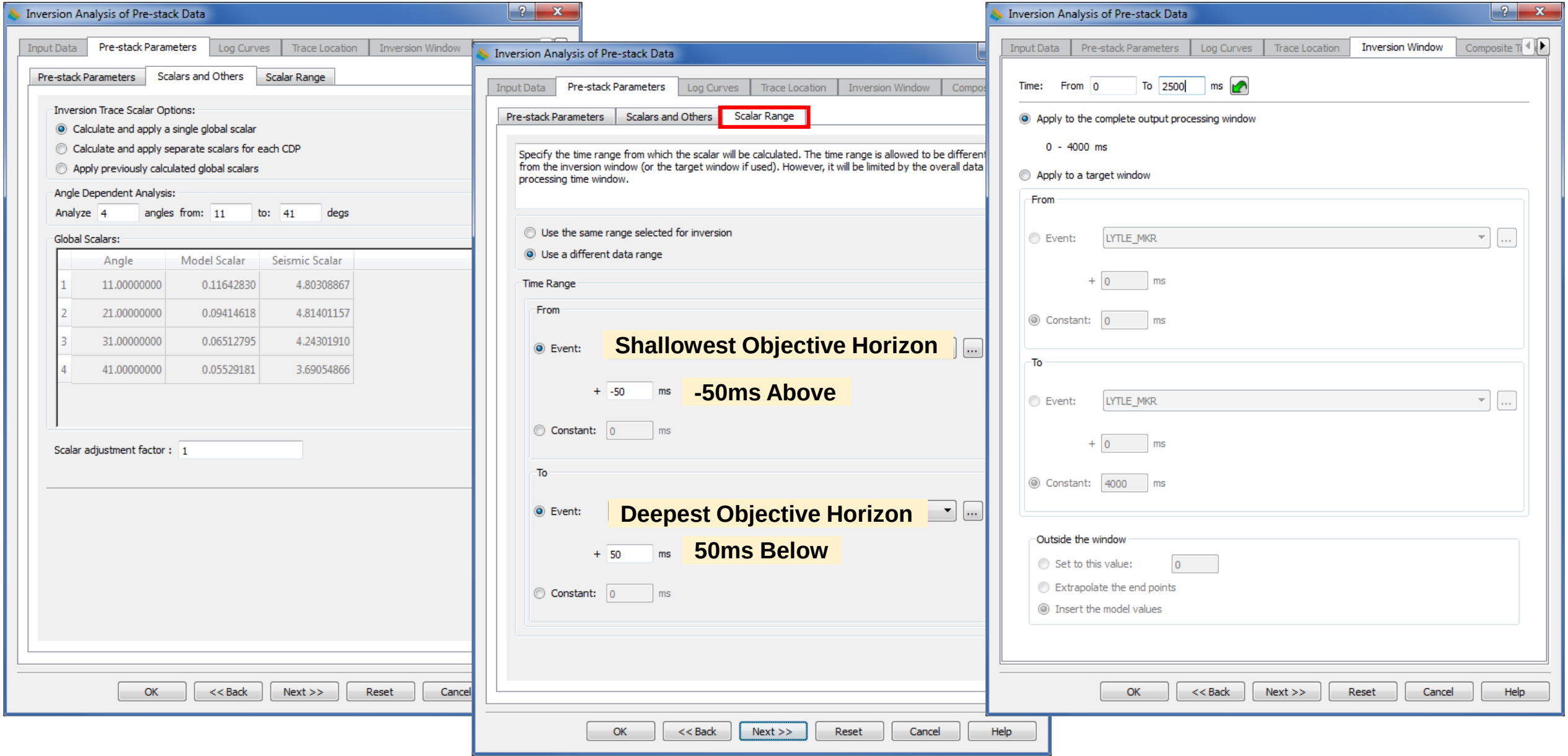
Inversion Analysis - Menus



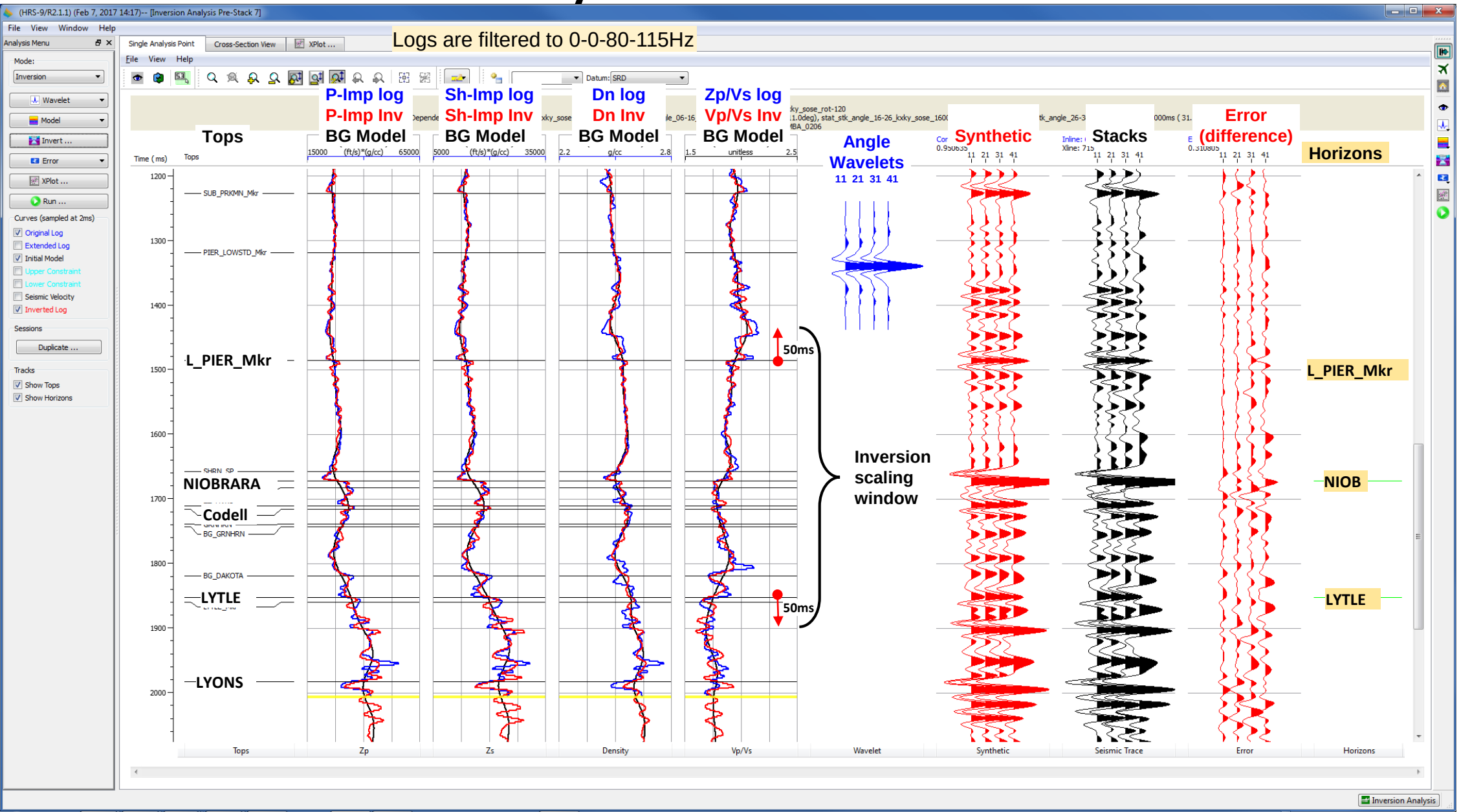
Inversion Analysis - Menus



Inversion Analysis - Menus



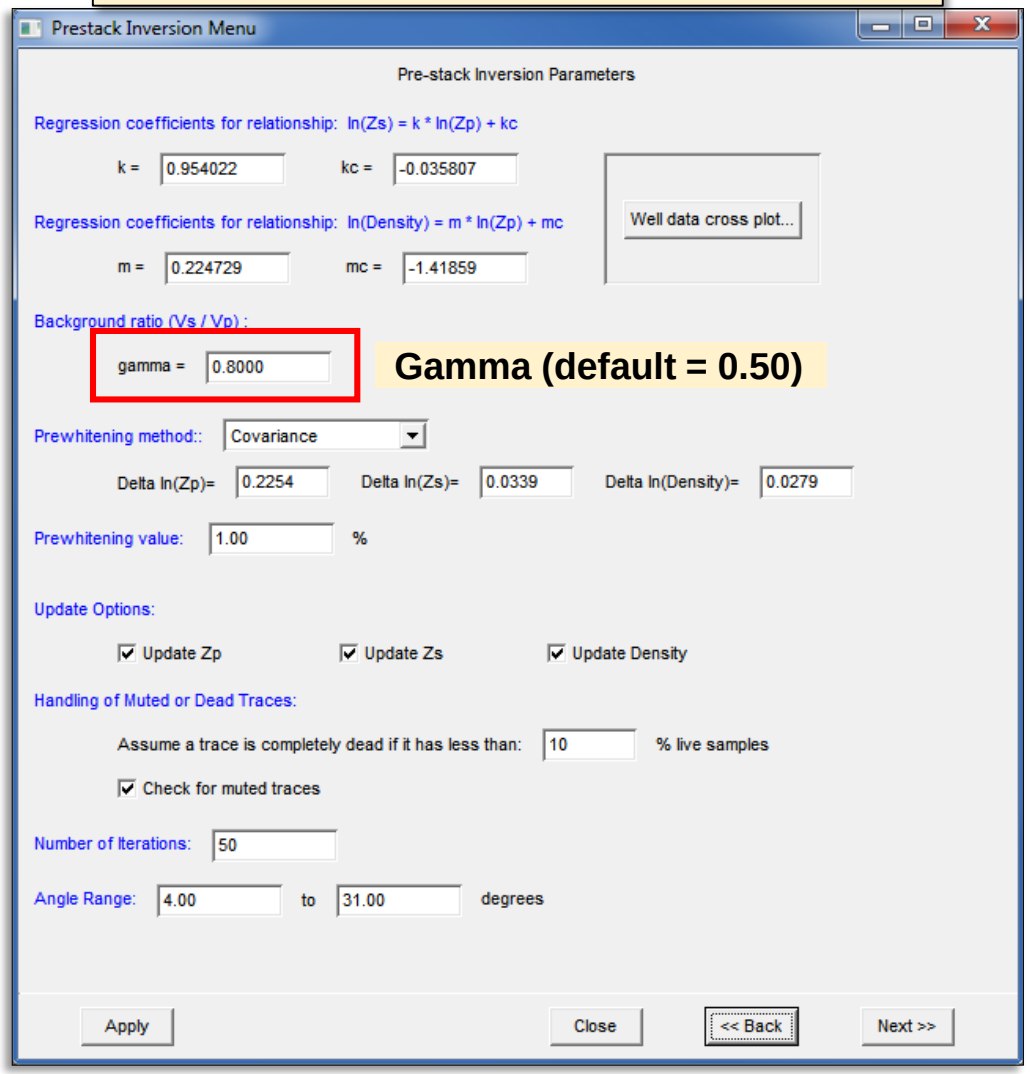
Inversion Analysis – 1-Trace Inversion

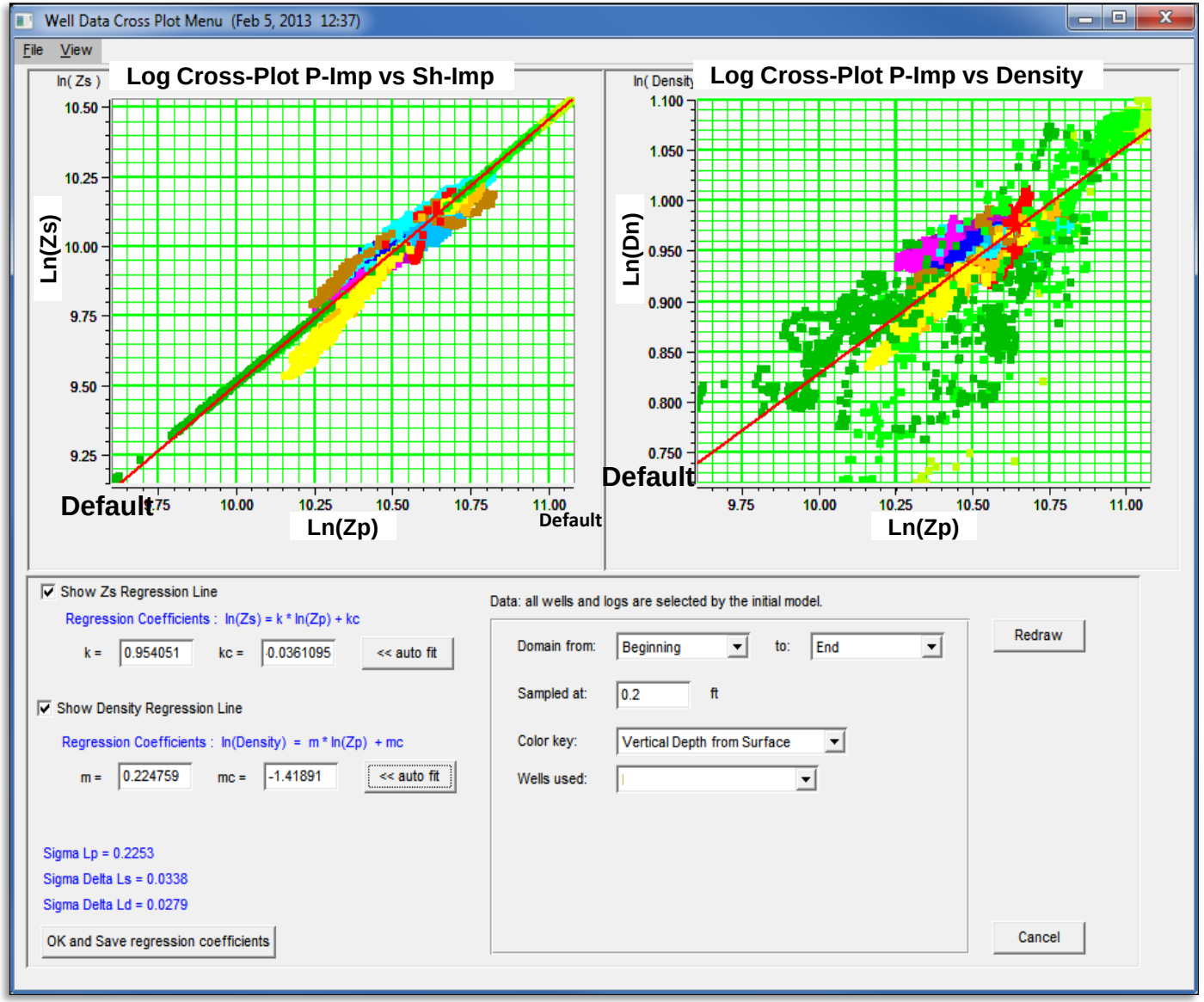


Inversion Analysis - Gamma

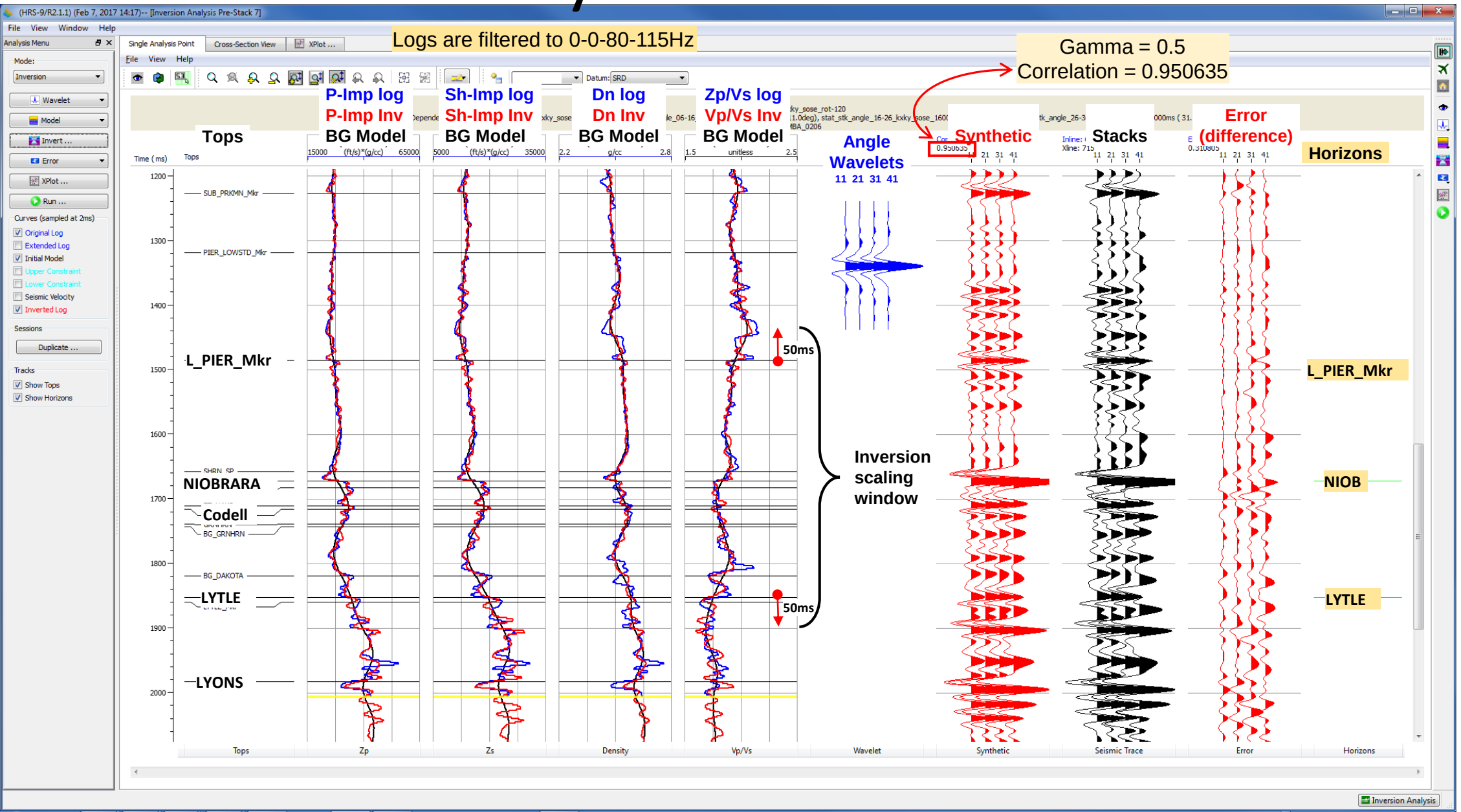
Example #1

We would start with the default fits
then consult with client 0n alternatives

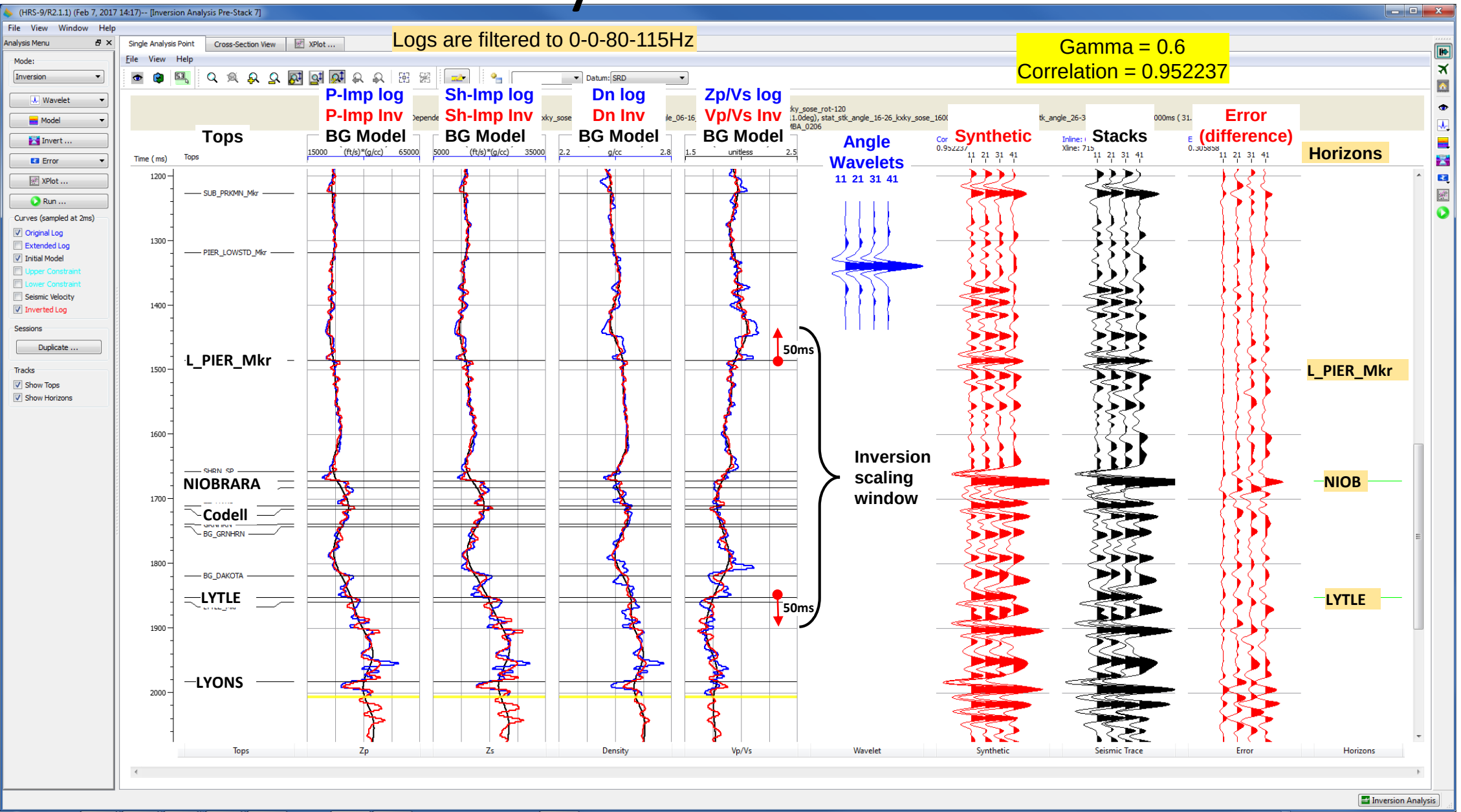




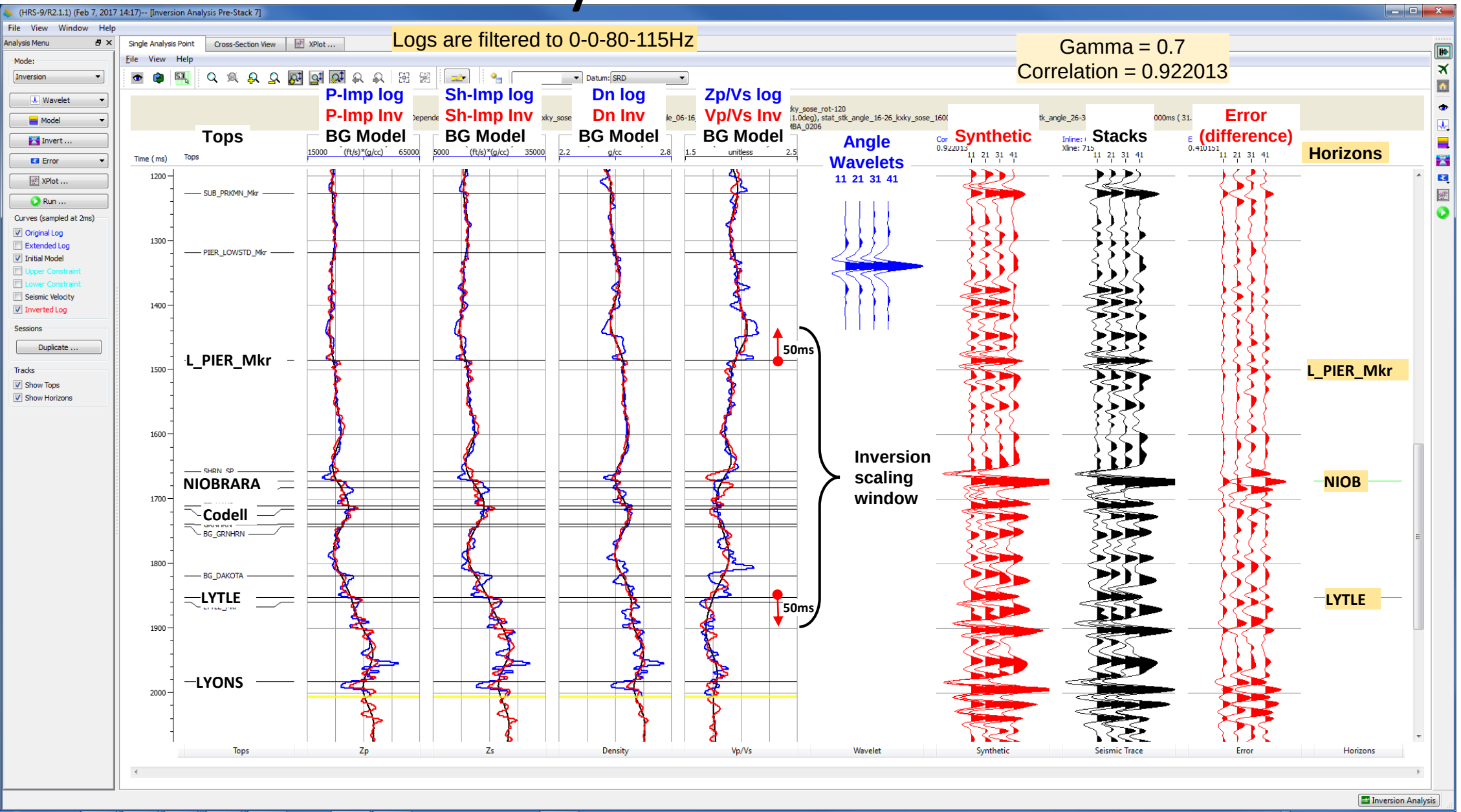
Inversion Analysis – 1-Trace Inversion



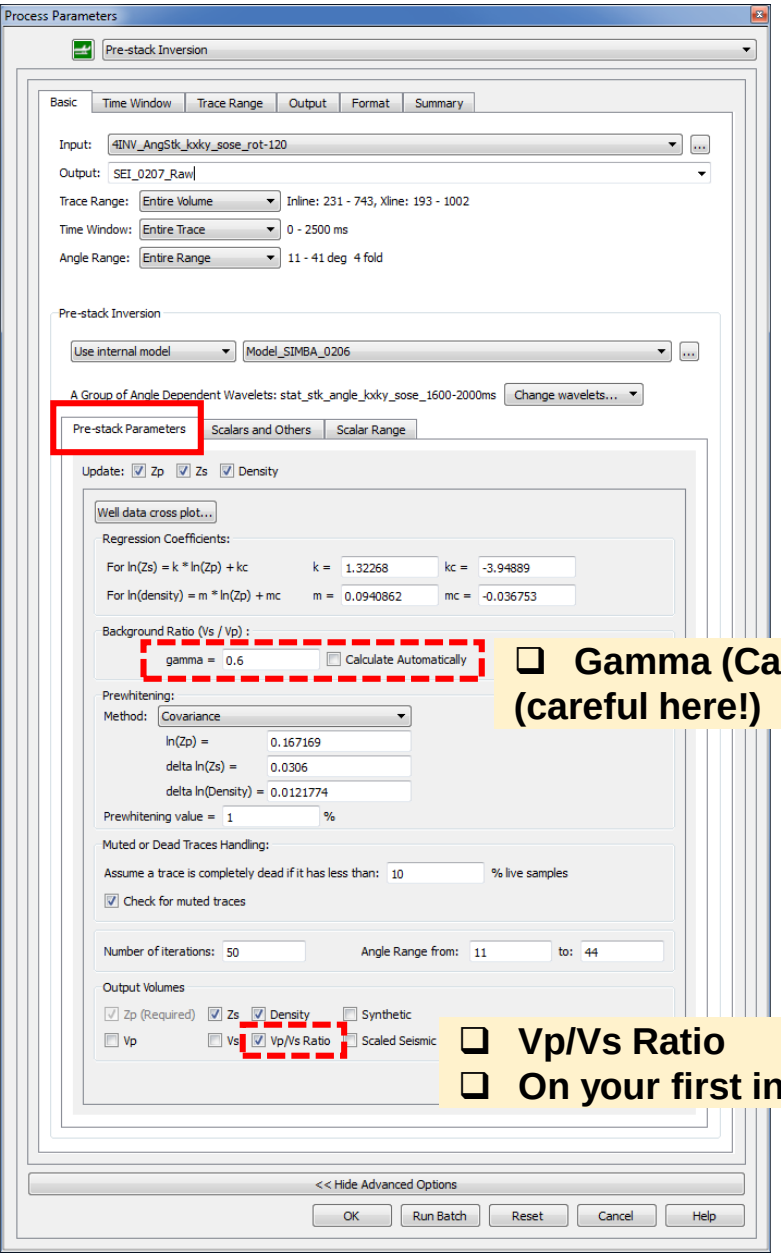
Inversion Analysis – 1-Trace Inversion

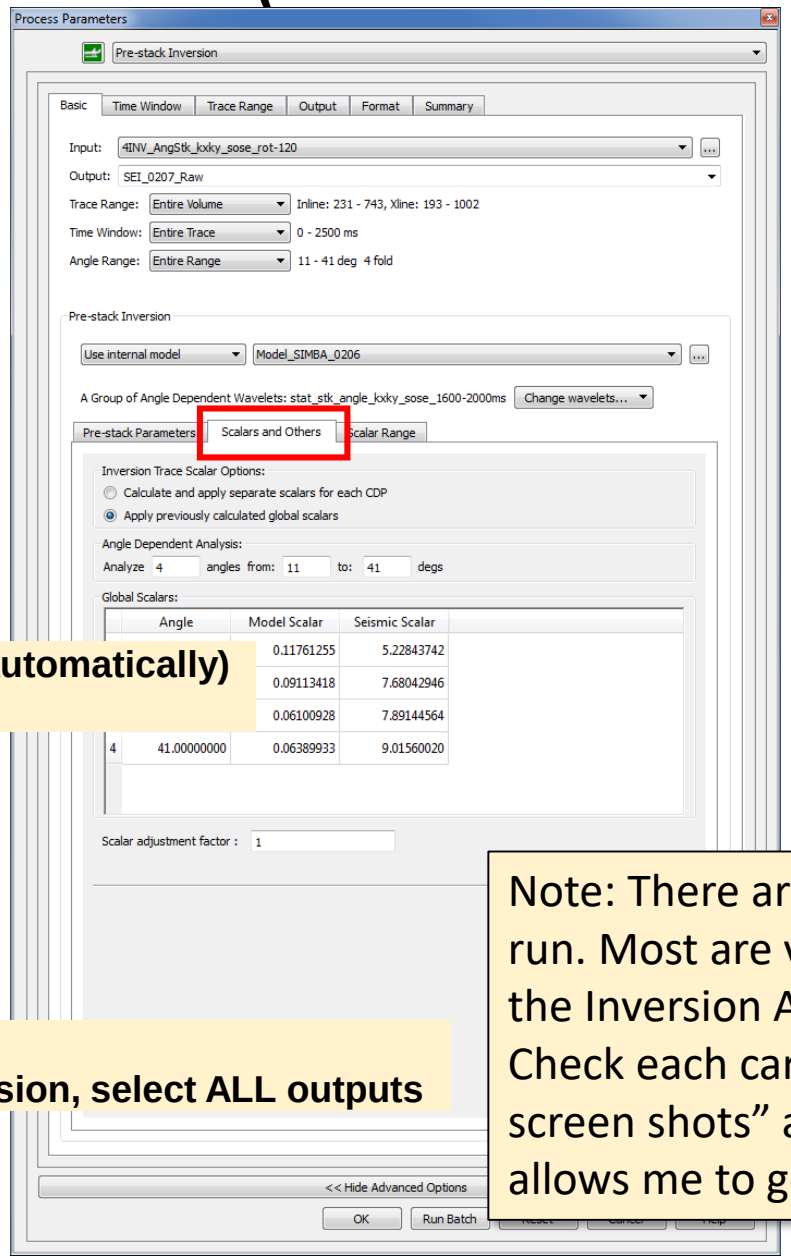


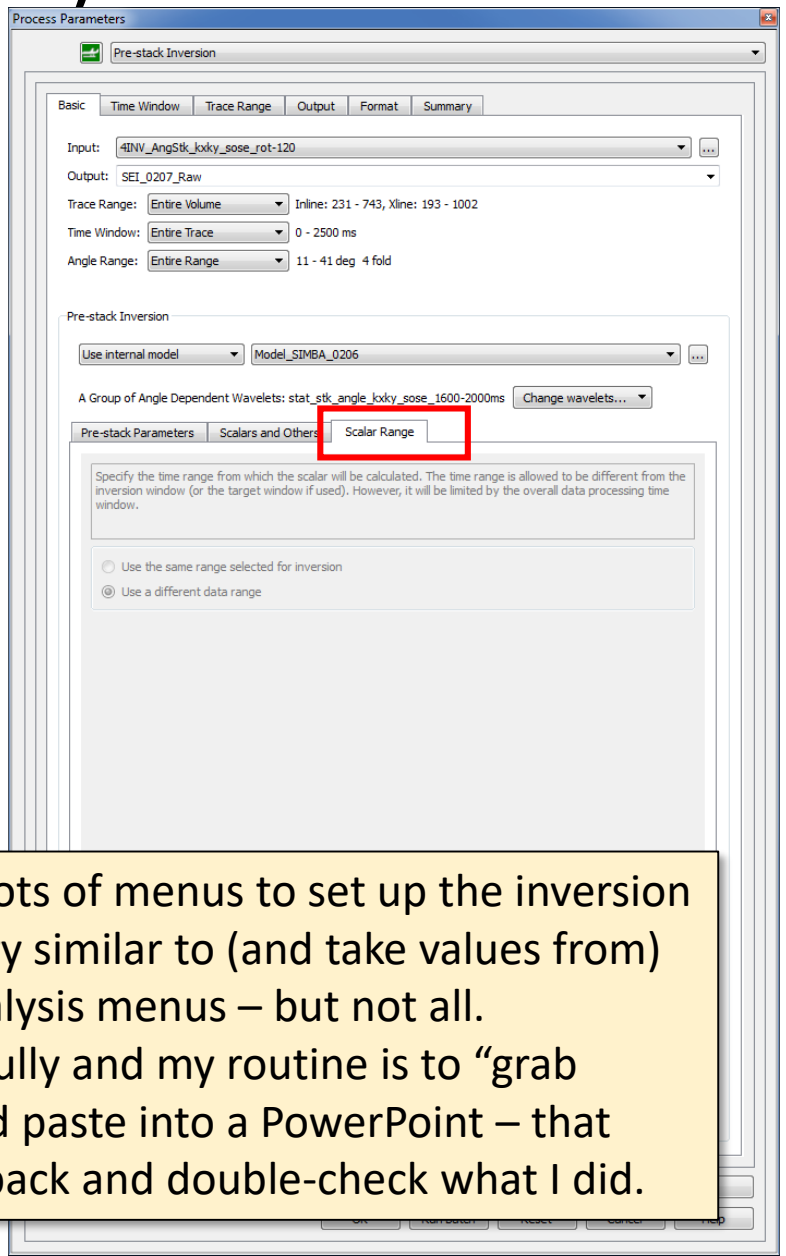
Inversion Analysis – 1-Trace Inversion



Inversion – Menus (tabs inside tabs!)







- **Gamma (Calc Automatically) (careful here!)**
- **Vp/Vs Ratio**
- **On your first inversion, select ALL outputs**

Note: There are lots of menus to set up the inversion run. Most are very similar to (and take values from) the Inversion Analysis menus – but not all.
Check each carefully and my routine is to "grab screen shots" and paste into a PowerPoint – that allows me to go back and double-check what I did.

Inversion Analysis – To Do's

- Check fit of single trace inversion at each well location
- Check the Inverted Result of DTC, DTS, RhoB and Vp/Vs Ratio logs
- See synthetic versus seismic, and error traces for each angle stack
- Determine correlation coefficient at each well
- Special attention to objective horizon
- Capture screen shots of menus – you're likely to run several inversions before you get it "just right"
- Name inversion runs with date – eg. SEI_0228

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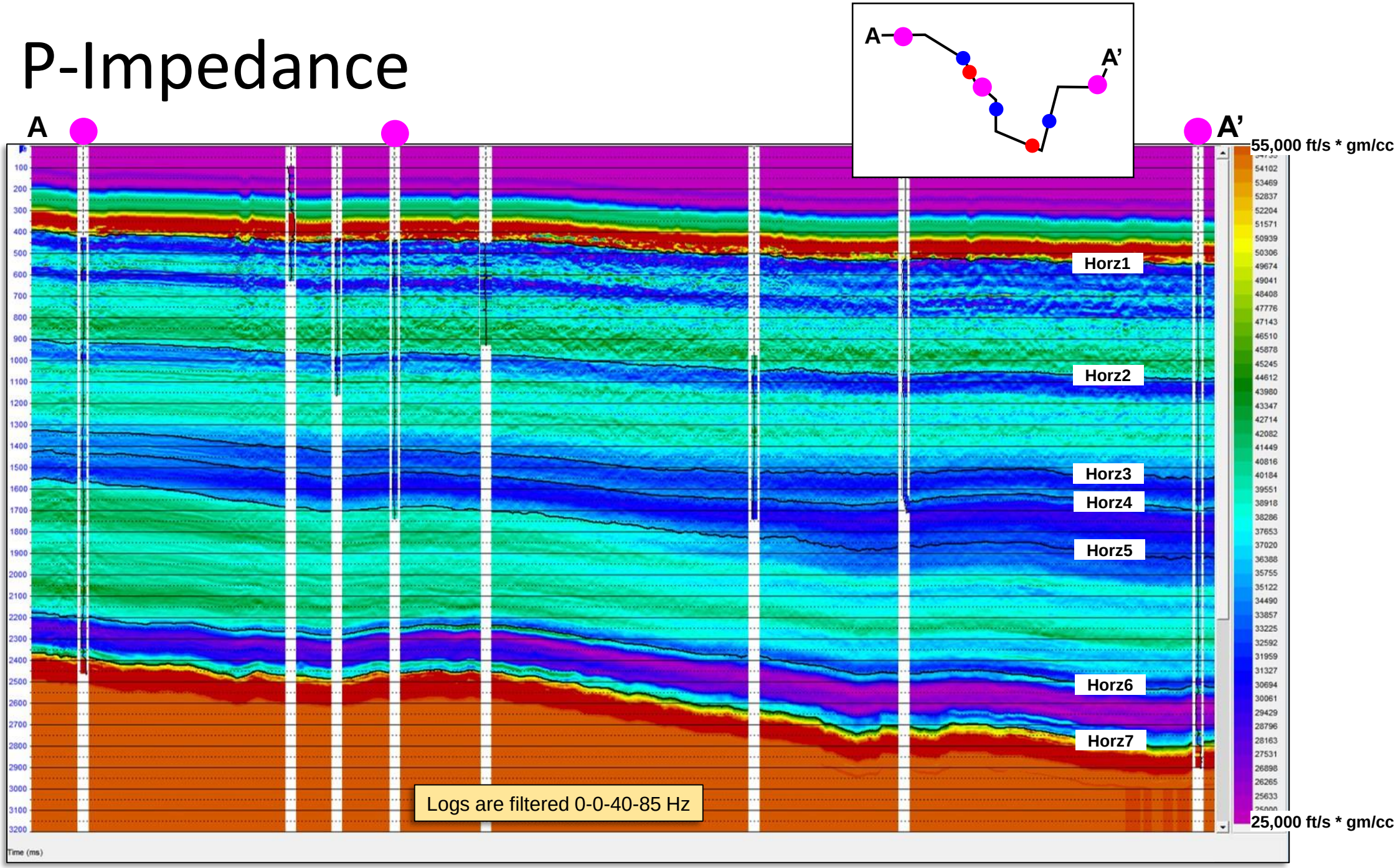
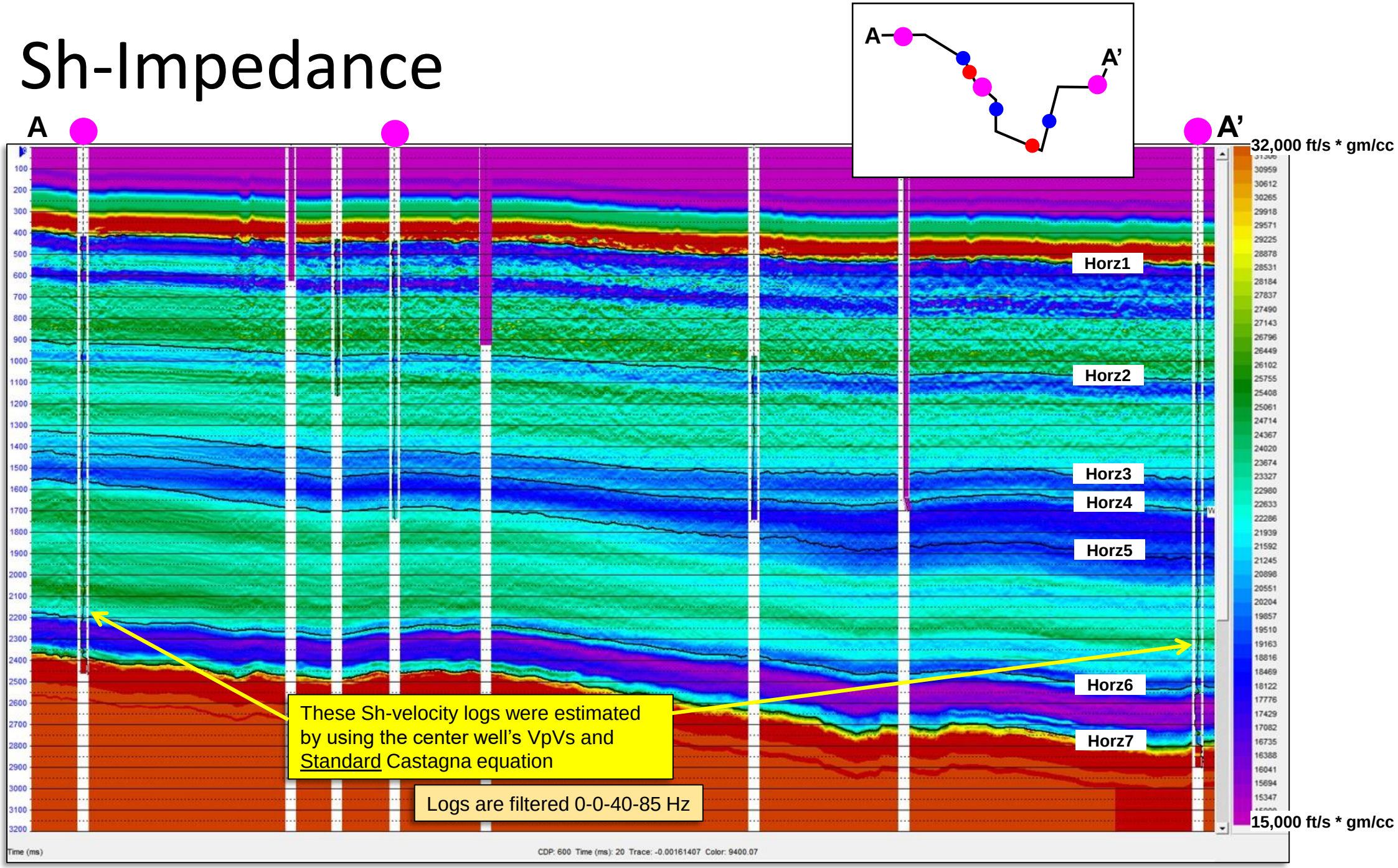
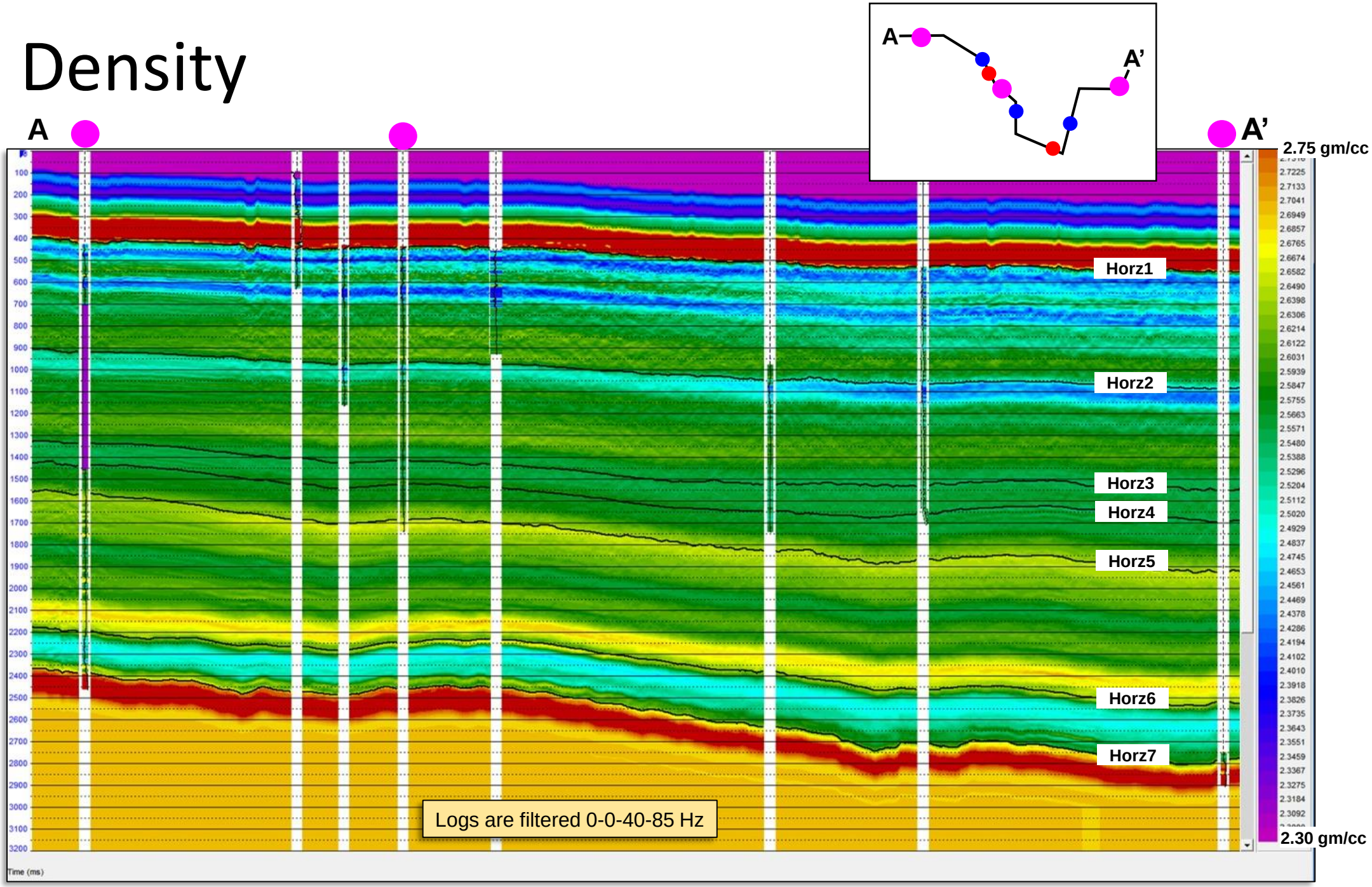
P-Impedance


A
A'
A
A'
55,000 ft/s * gm/cc
54102
53469
52837
52204
51571
50939
50306
49674
49041
48408
47776
47143
46510
45878
45245
44612
43980
43347
42714
42082
41449
40816
40184
39551
38918
38286
37653
37020
36388
35755
35122
34490
33857
33225
32592
31959
31327
30694
30061
29429
28796
28163
27531
26898
26265
25633
25000
25,000 ft/s * gm/cc
Horz1
Horz2
Horz3
Horz4
Horz5
Horz6
Horz7
Logs are filtered 0-0-40-85 Hz
Time (ms)

Sh-Impedance



Density

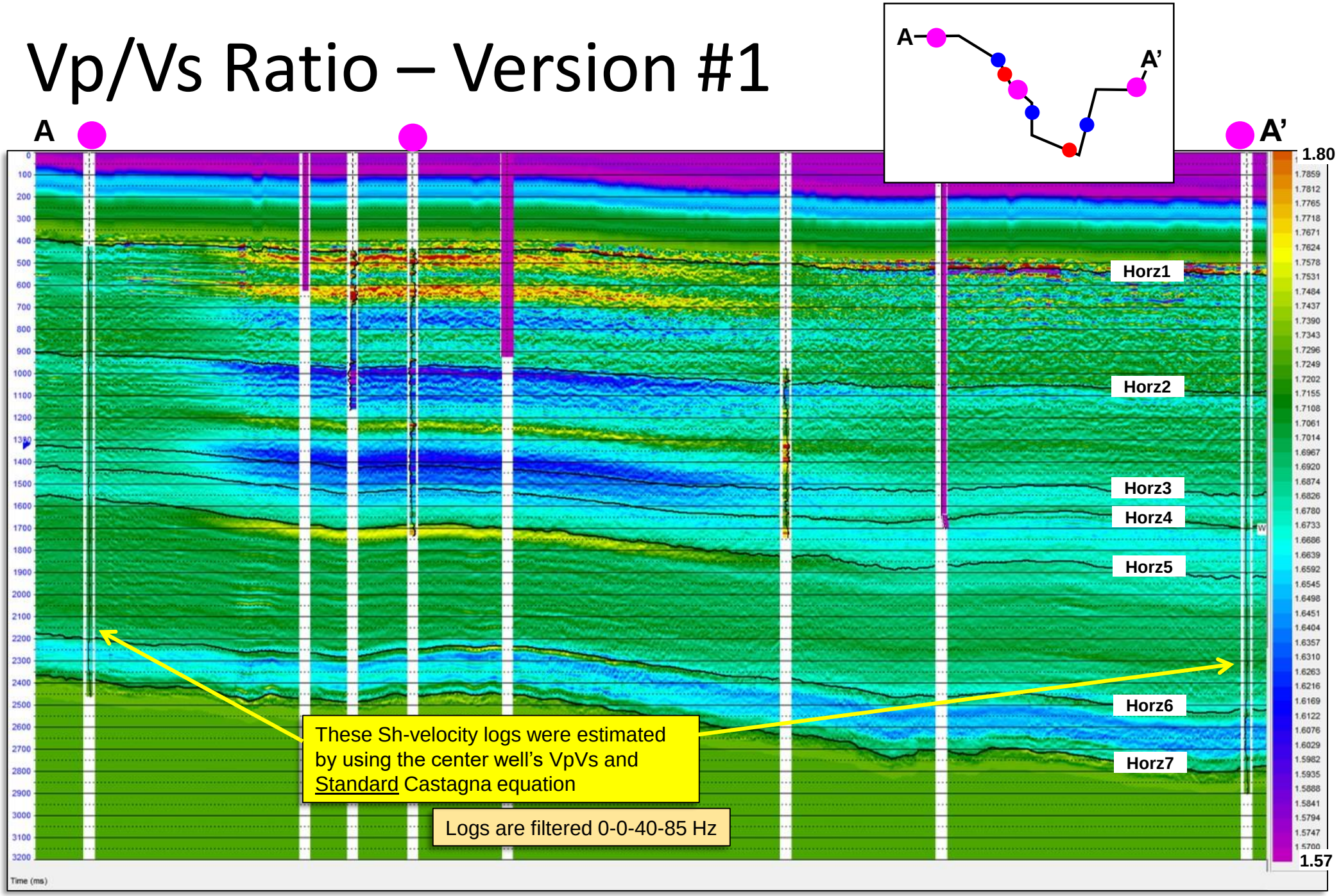

A
A'
A
A'
2.75 gm/cc
2.30 gm/cc
Horz1
Horz2
Horz3
Horz4
Horz5
Horz6
Horz7
Logs are filtered 0-0-40-85 Hz
Time (ms)

QC Results of Inversion

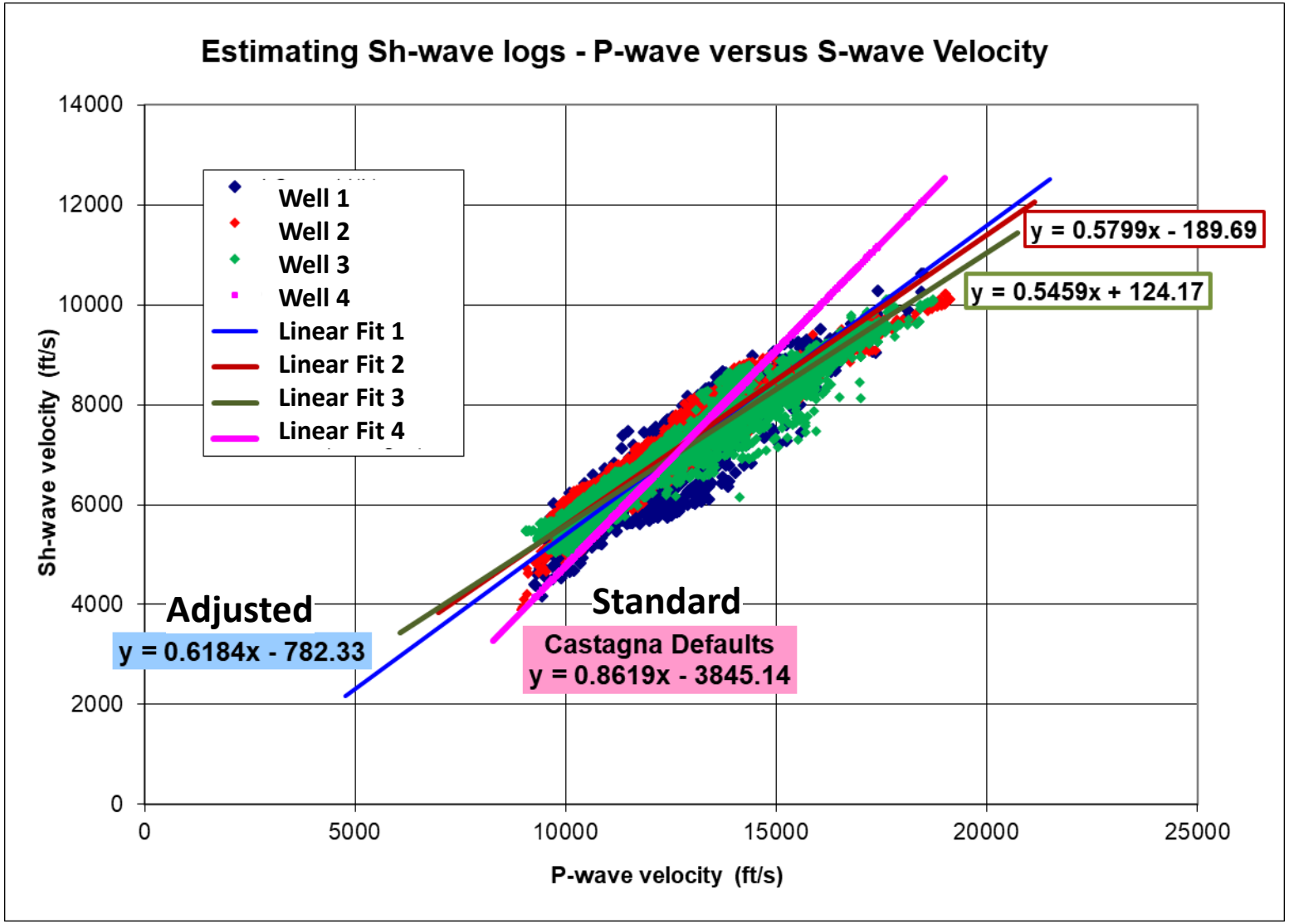
- P-Impedance (Zp)
- Sh-Impedance (Zs)
- Density (Dn)

- Don’t forget to look at Vp/Vs Ratio – it’s the most sensitive!

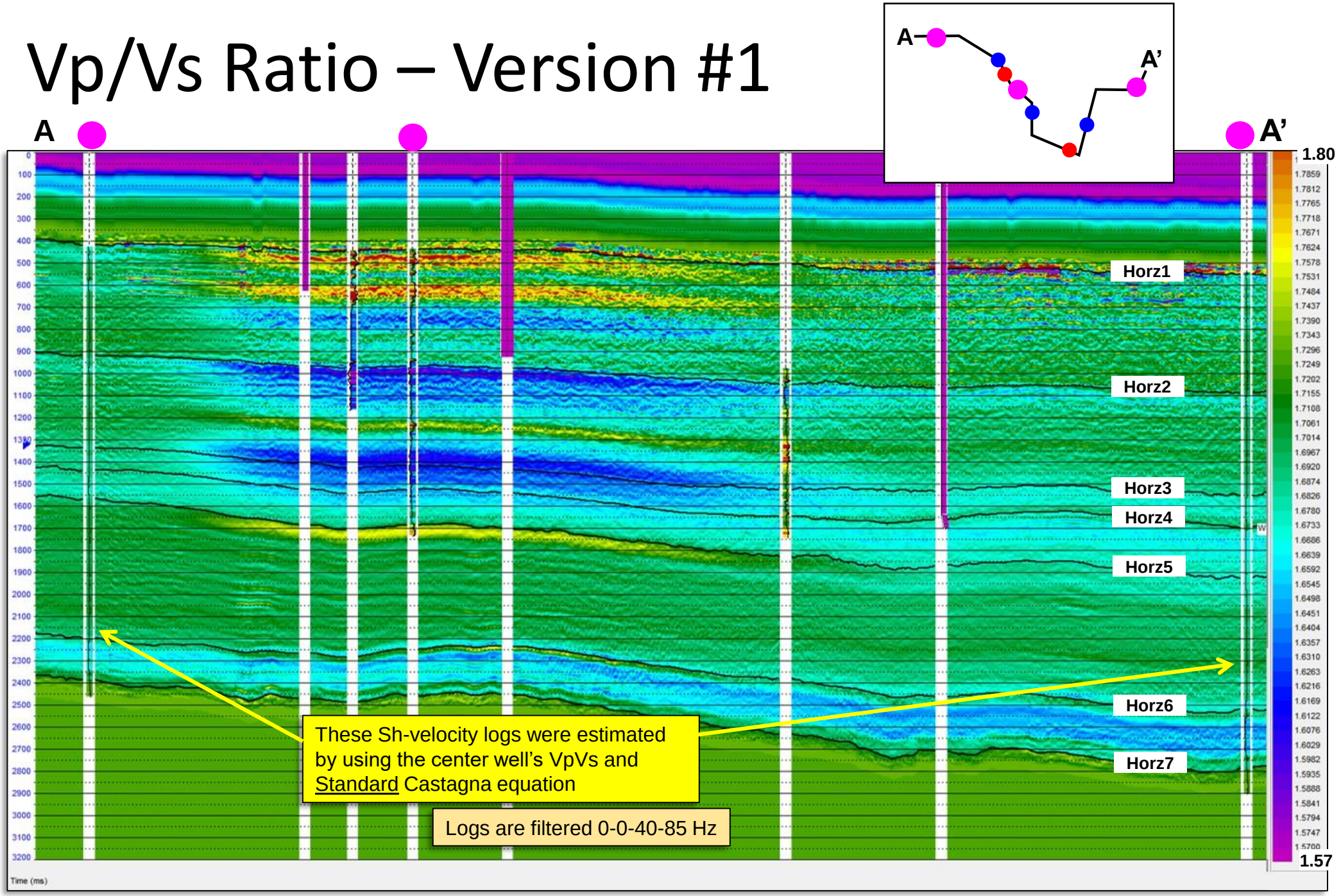
Vp/Vs Ratio – Version #1



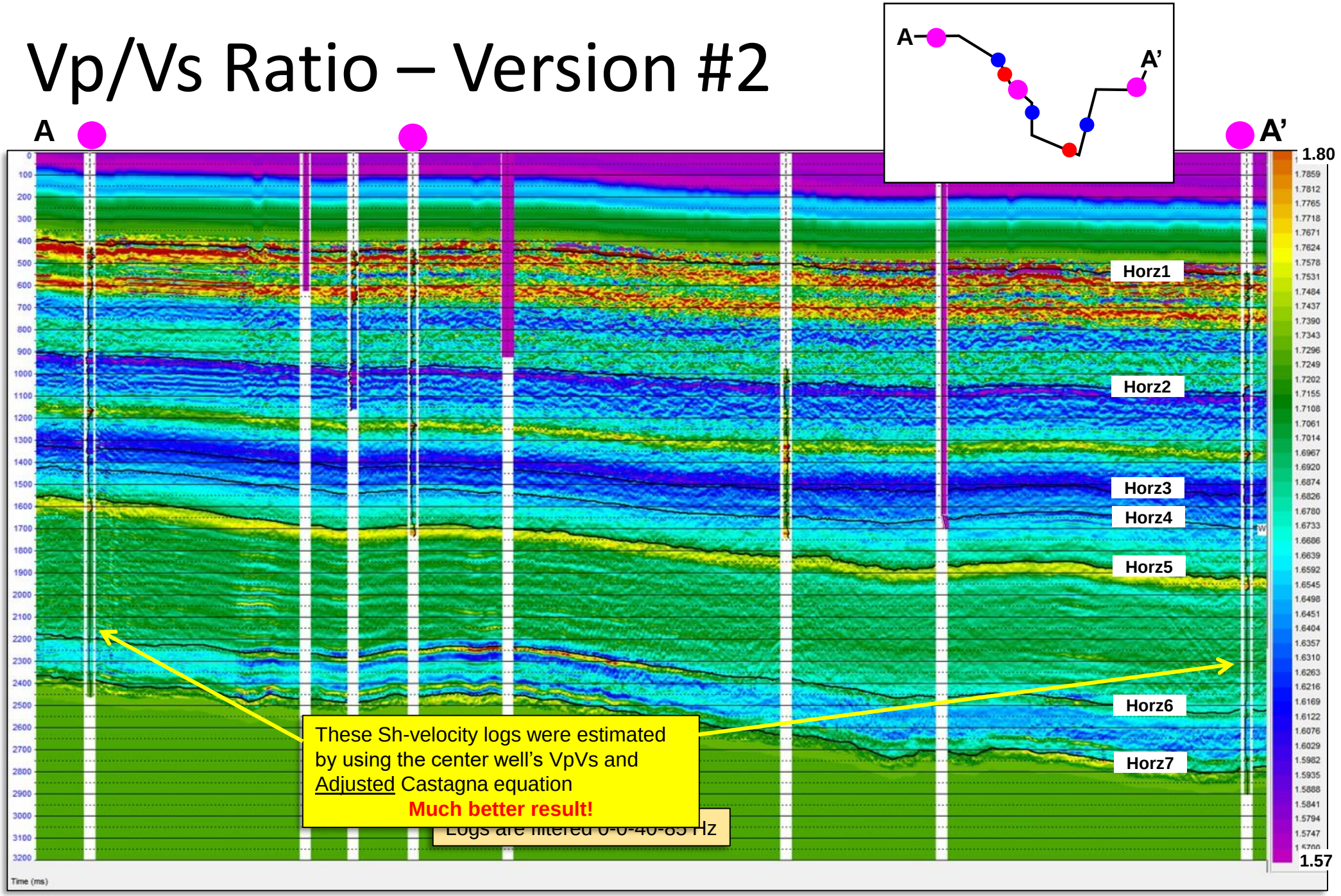
Estimating Sh-wave velocity from P-wave



Vp/Vs Ratio – Version #1



Vp/Vs Ratio – Version #2



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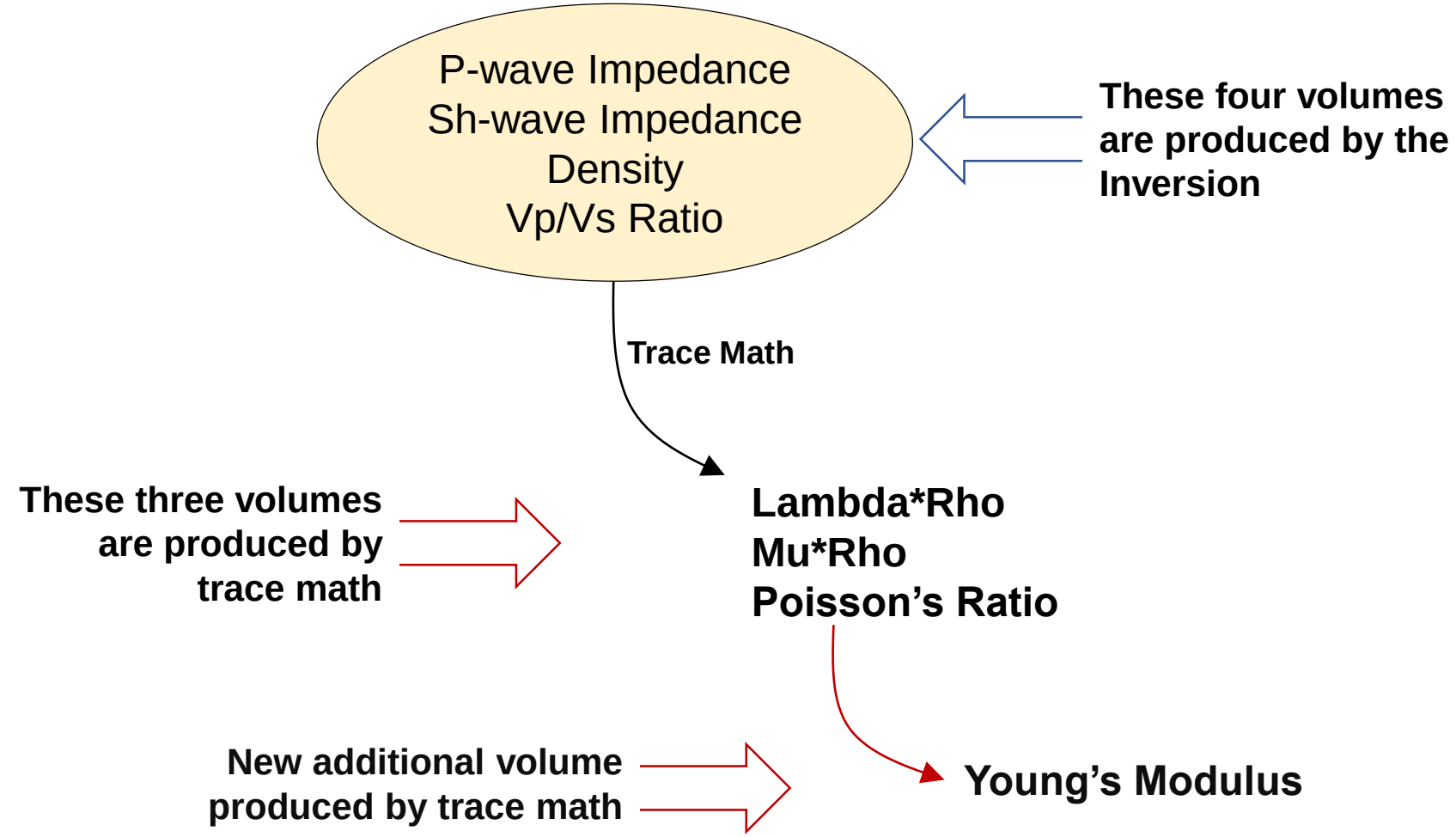
Additional Volumes

8 Volumes Delivered in Total



LMR Transforms

1. **P-wave Impedance Inversion** (Zp)
2. **Sh-wave Impedance Inversion** (Zs)
3. **Density from Inversion** (Dn)
4. **Vp/Vs Ratio from Inversion** (Zp / Zs)
5. **Lambda*Rho** $(Zp^2 – c*Zs^2)$
   c of 2.0 was used for this dataset
6. **Mu*Rho** (Zs^2)
7. **Poisson's Ratio (PR)** $$\frac{(Vp/Vs)^2 – 2}{2(Vp/Vs)^2 – 1}$$
8. **Young's modulus** 2*[(Mu*Rho / Dn)*(1 + PR)]

Questions?

Contact me at:

Bruce Golob

Discovery Resources, LLC.

bgolob27@gmail.com