# AVA, EEI and AVA Inversion Practicalities

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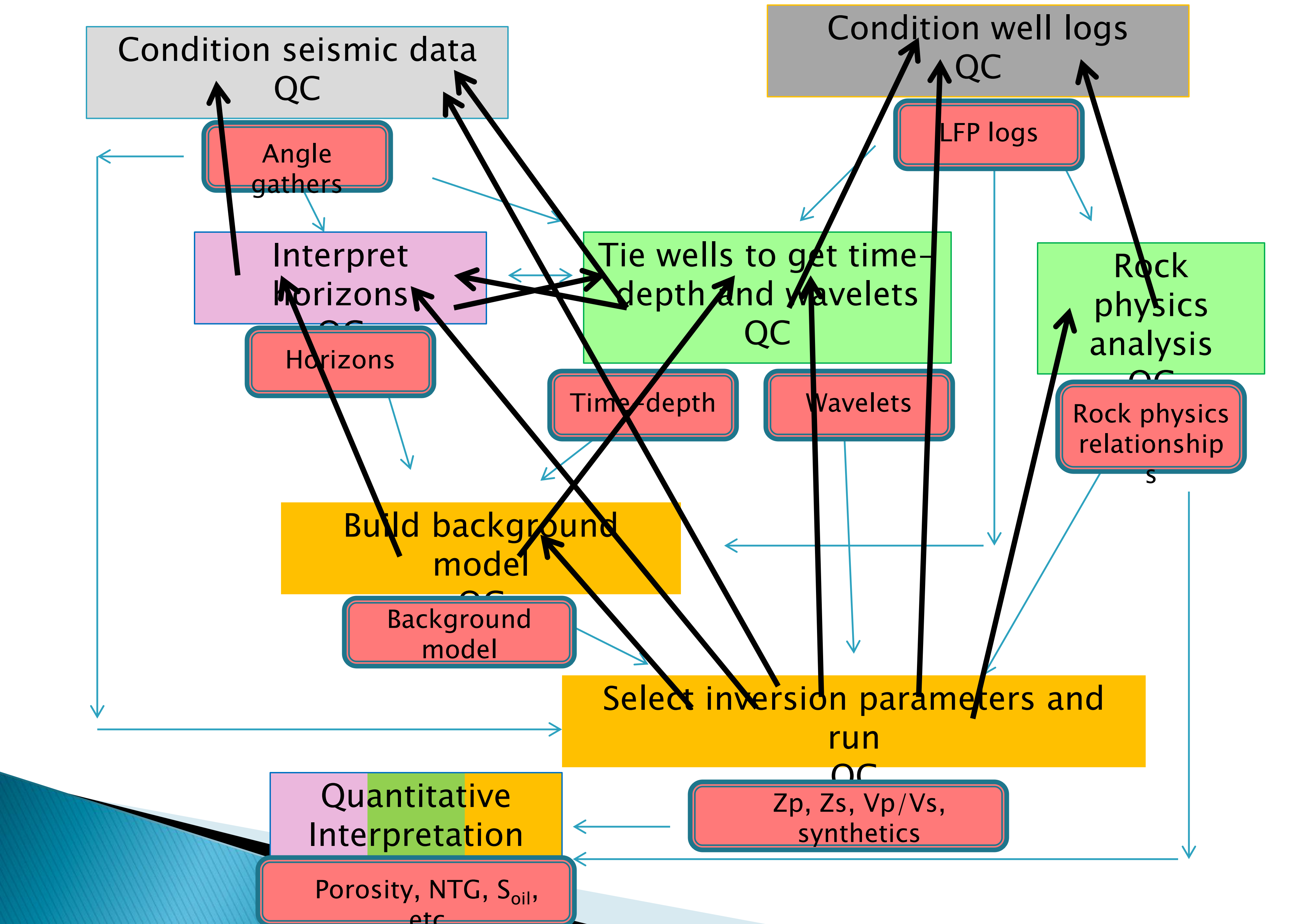
Deep Vision Ltd and Sharp Reflections

# Deterministic AVA Inversion Workflow



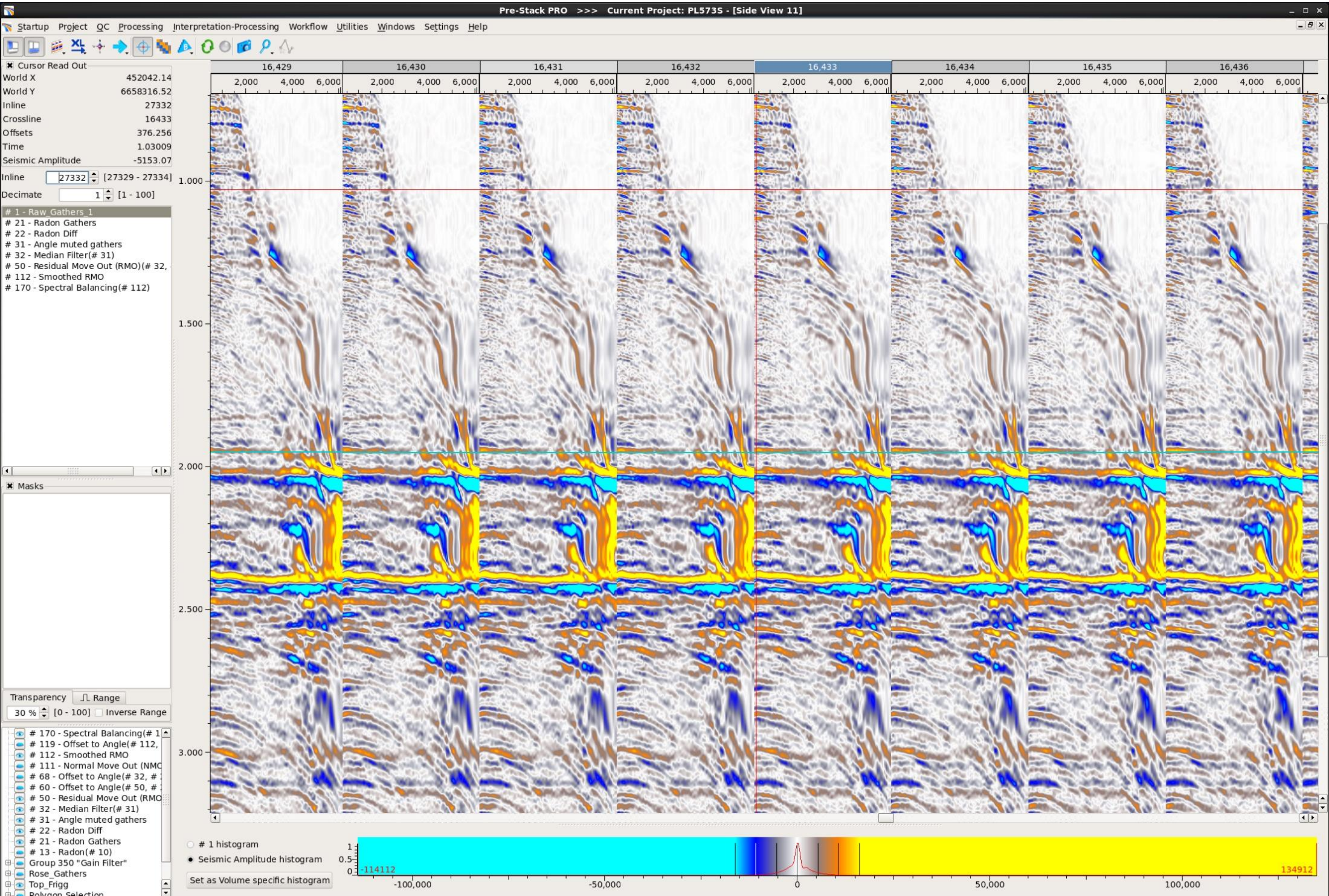
# Seismic data quality

Usually we start with time-migrated gathers ...

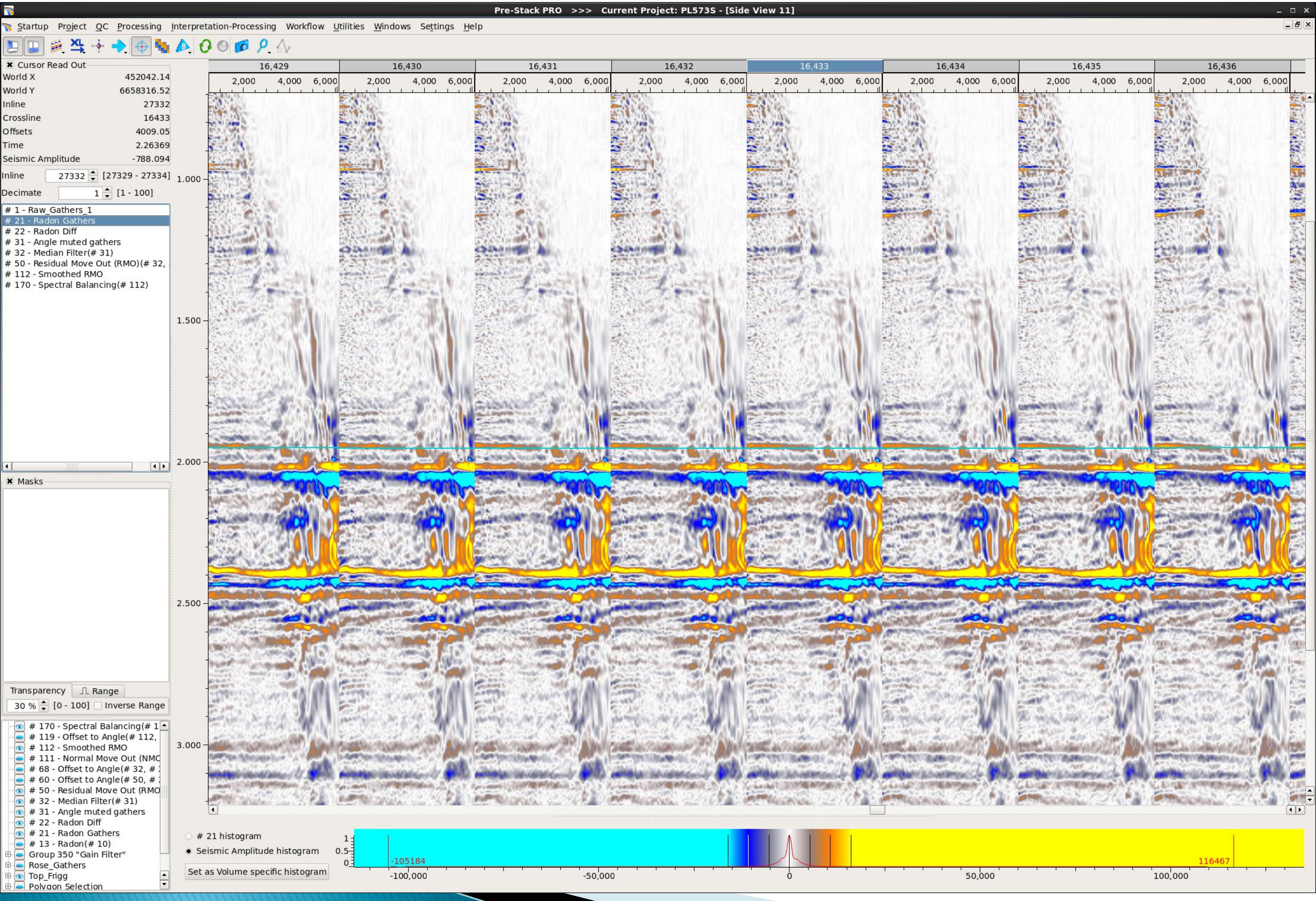
They are often sub-optimal for inversion

- Residual multiples
- Other types of noise
- Residual moveout
- Offset-dependent amplitude scaling

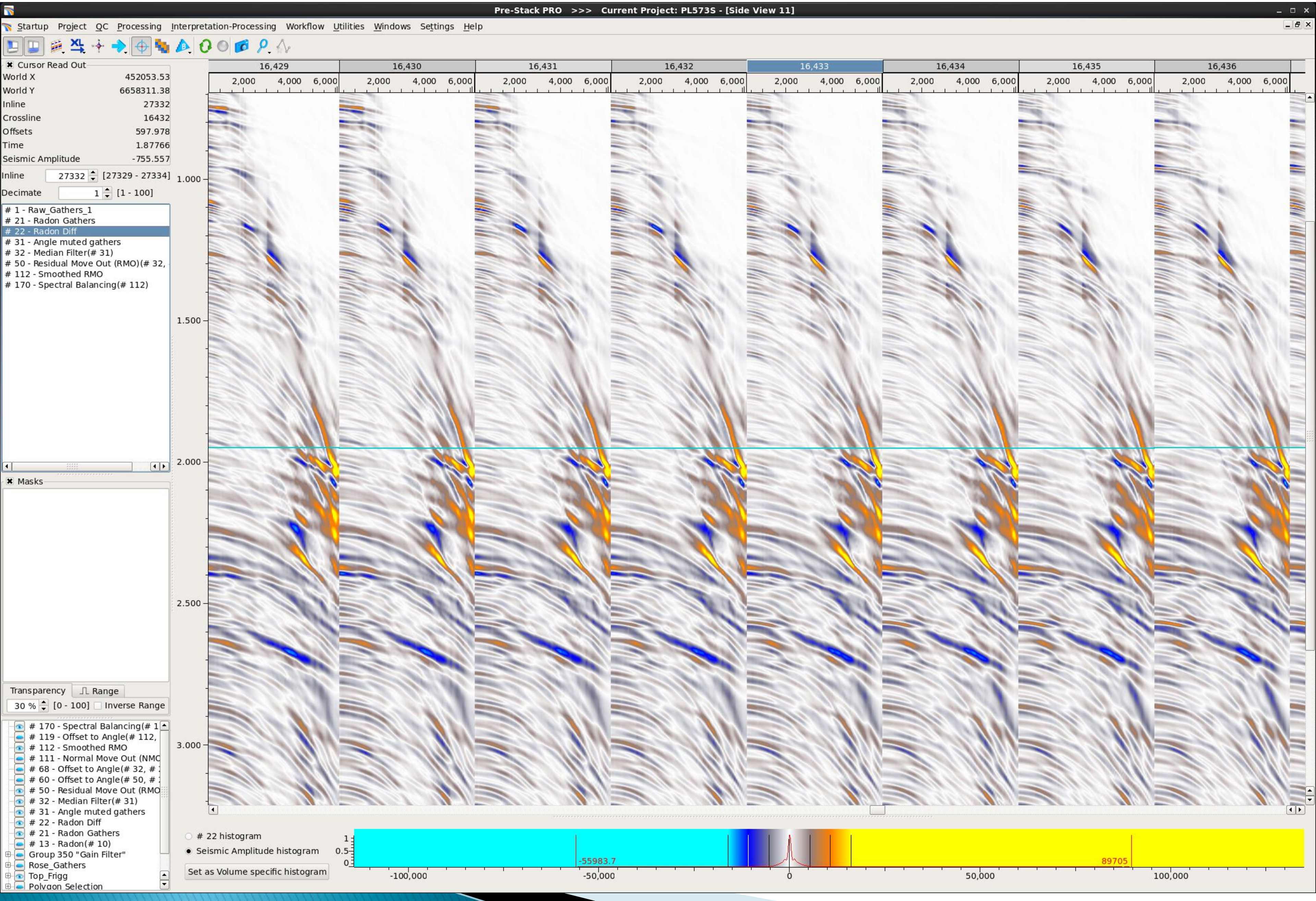
# Raw gathers (time mig, NMO corrected)



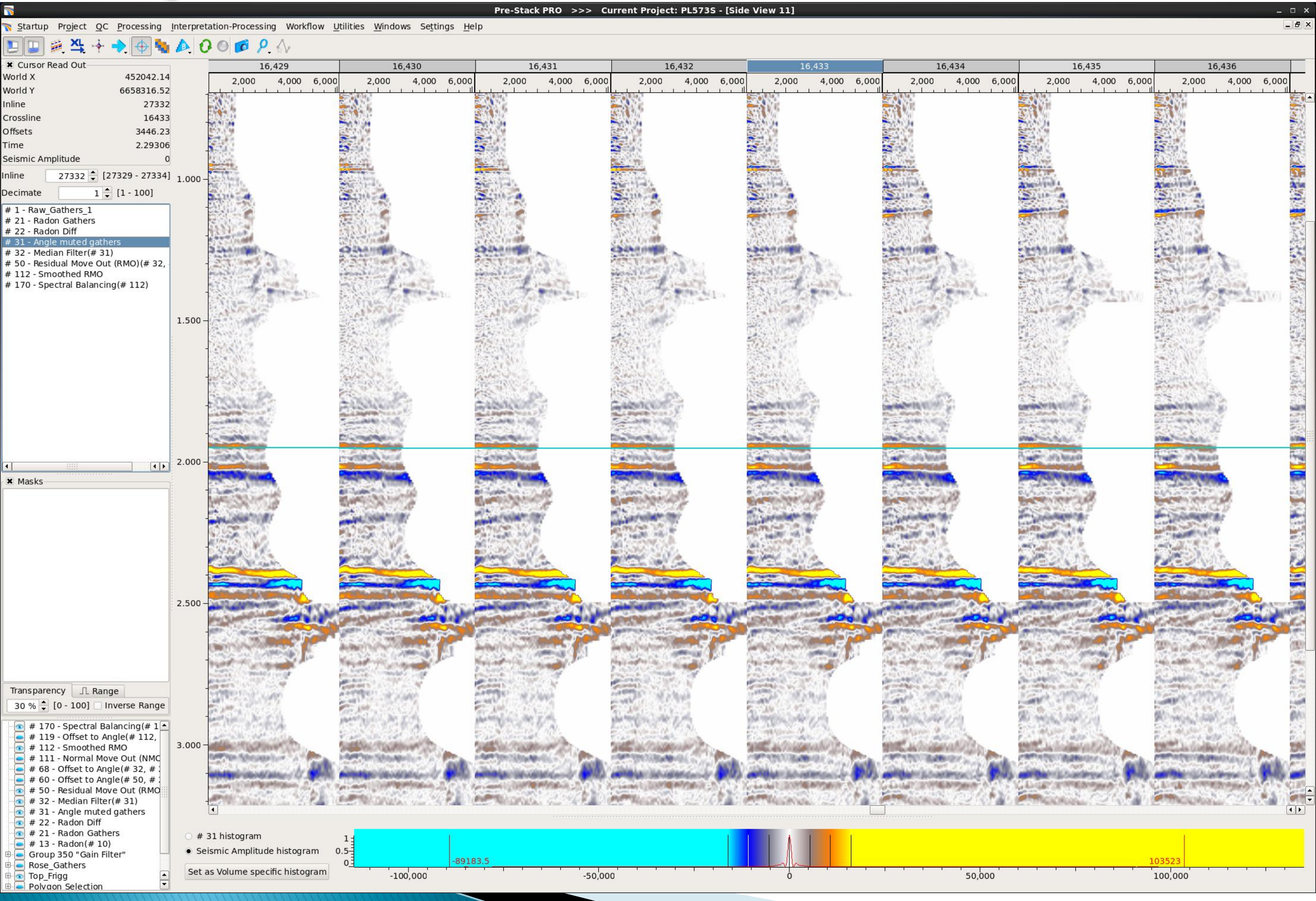
# Radon demultiple



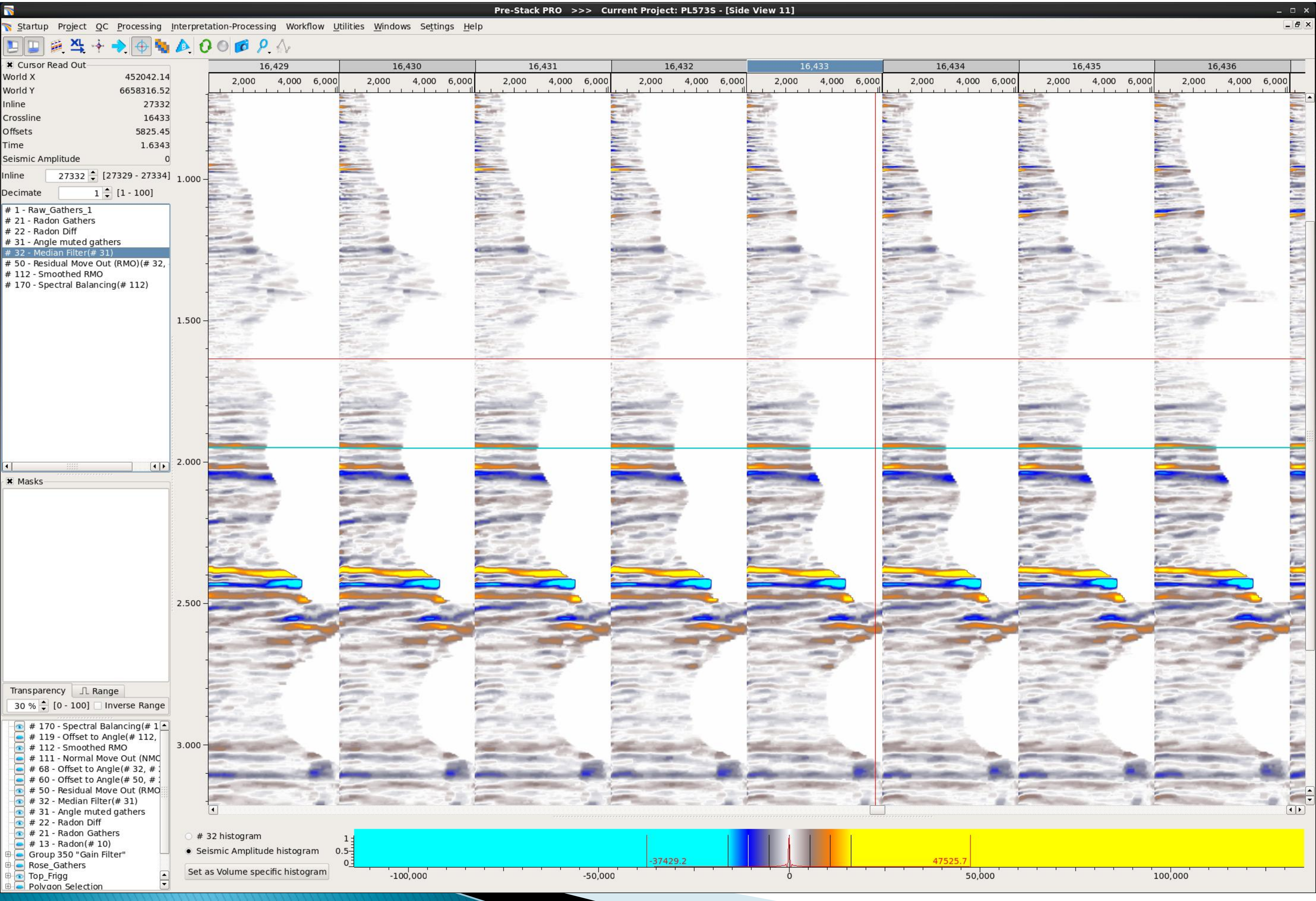
# Removed multiple energy



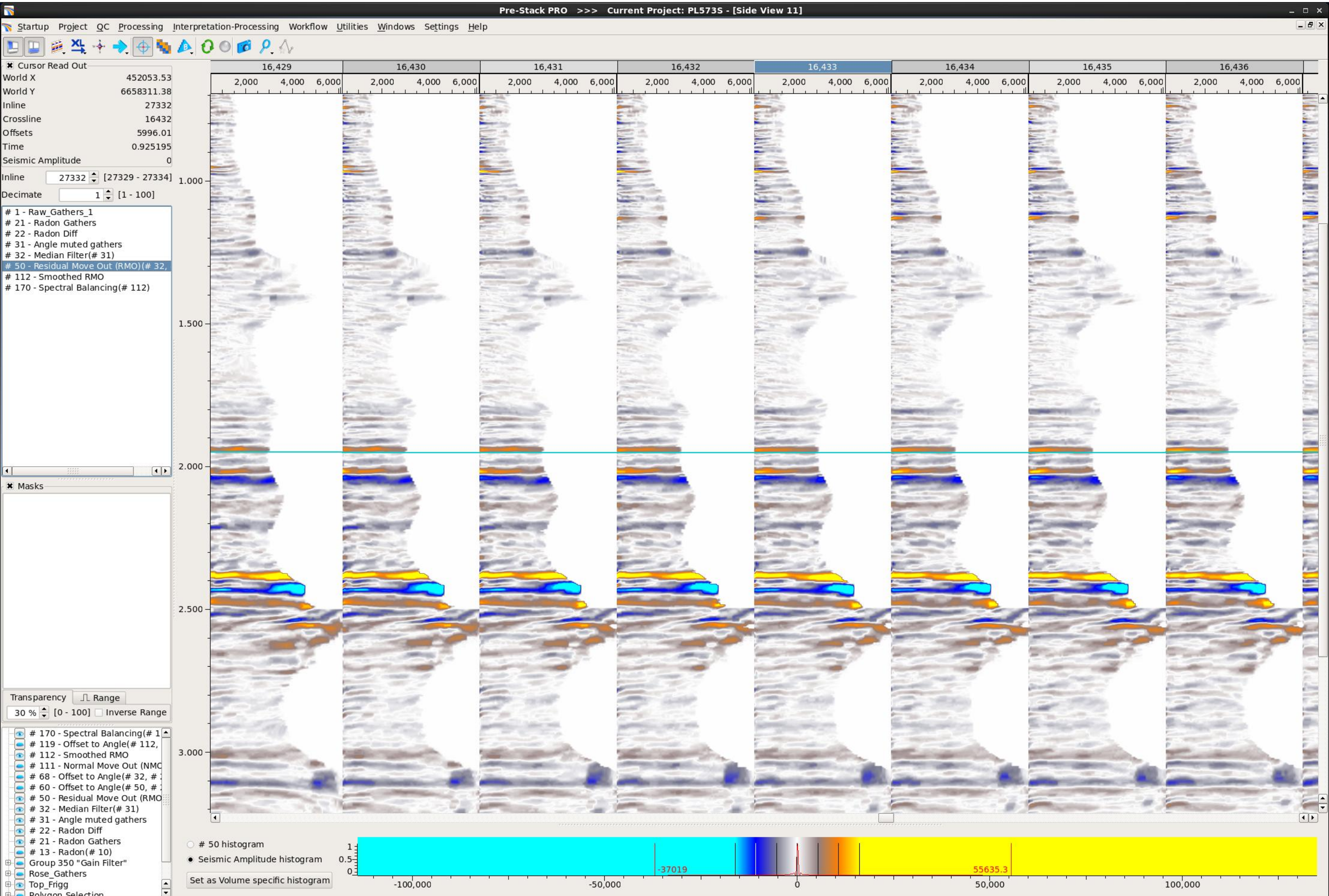
# Angle muted 50°



# Random noise reduction

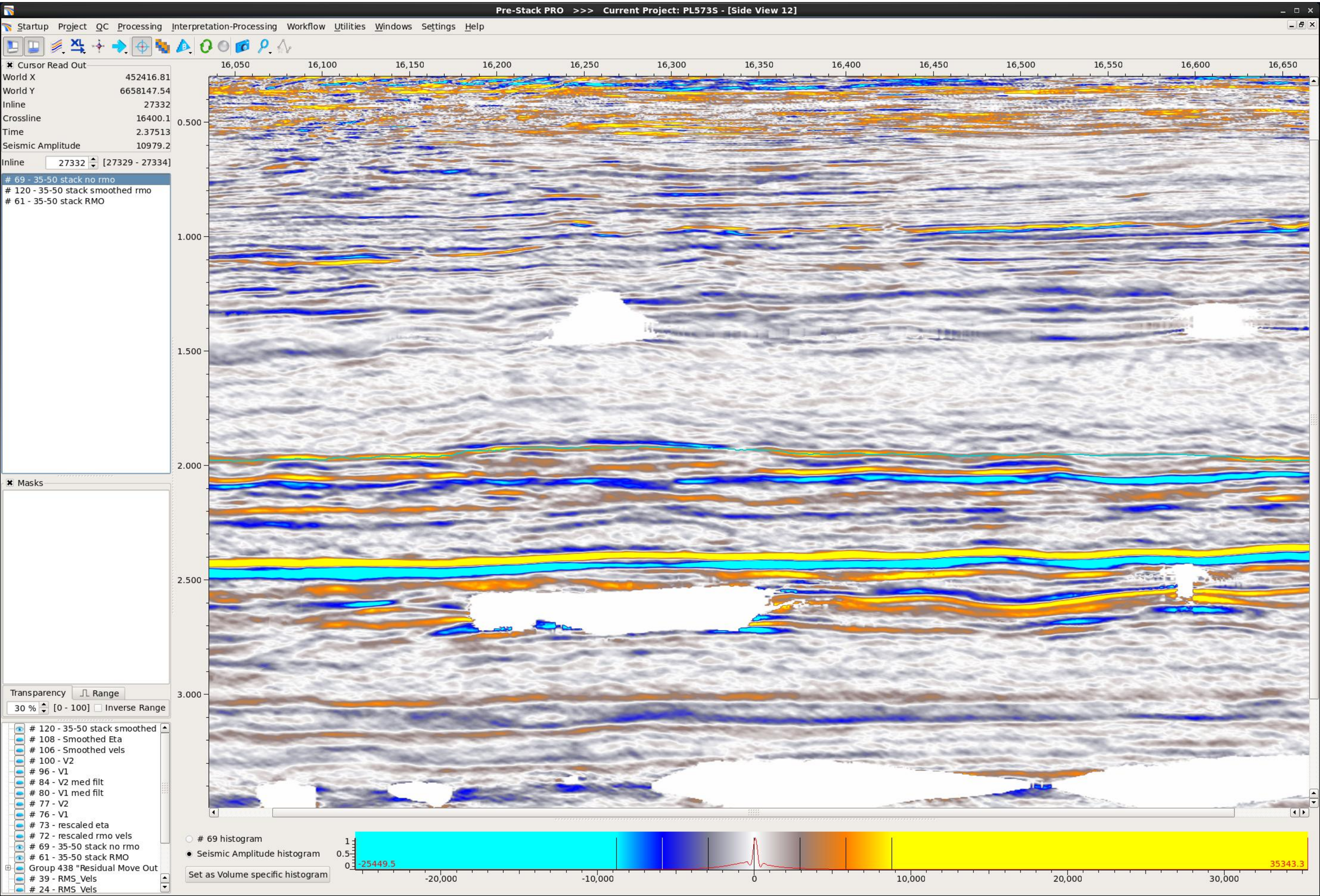


# RMO

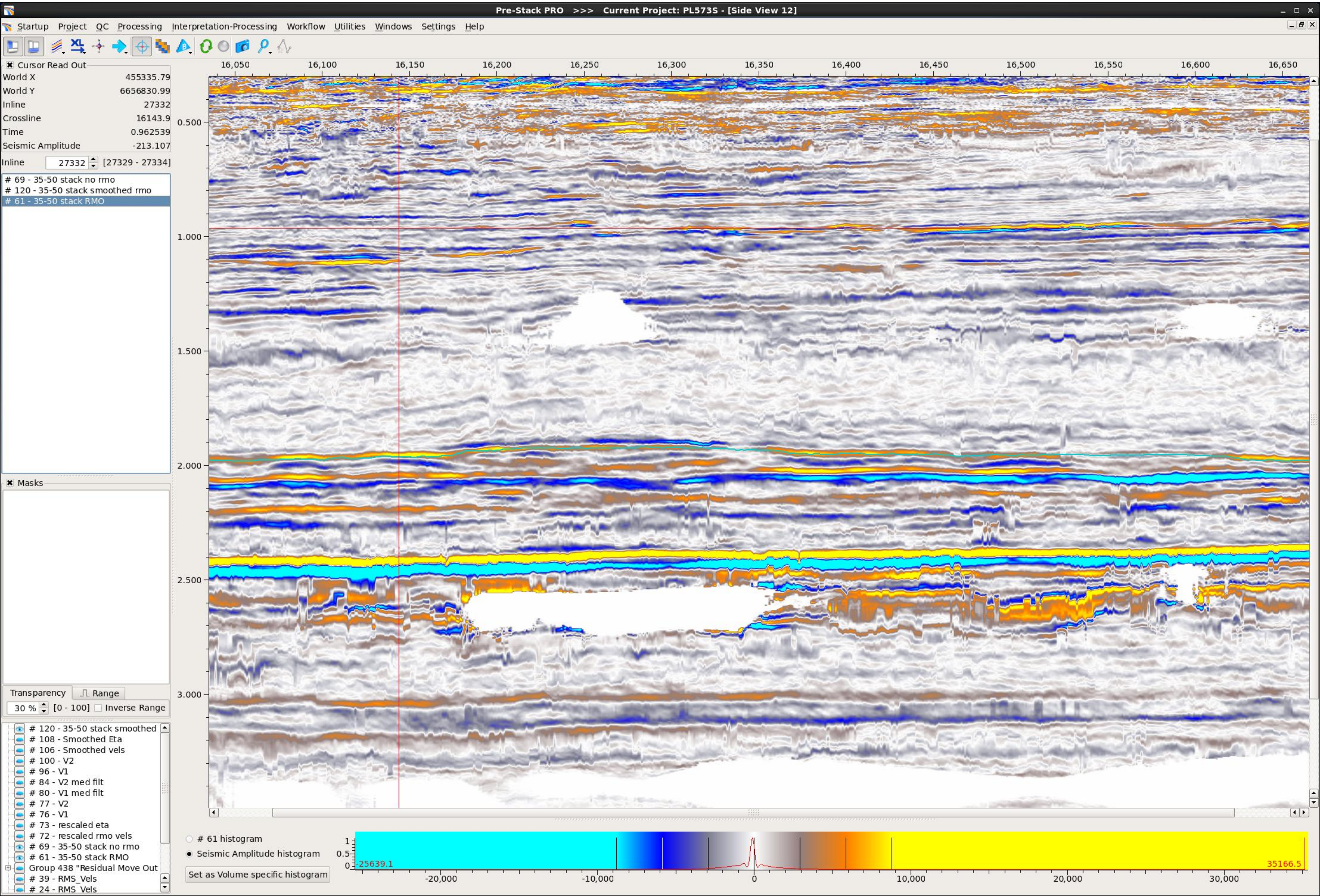


Pre-Stack PRO >>> Current Project: PL573S - [Side View 11]
Startup Project QC Processing Interpretation-Processing Workflow Utilities Windows Settings Help
Cursor Read Out
World X 452053.53
World Y 6658311.38
Inline 27332
Crossline 16432
Offsets 5996.01
Time 0.925195
Seismic Amplitude 0
Inline 27332 [27329 - 27334]
Decimate 1 [1 - 100]
# 1 - Raw_Gathers_1
# 21 - Radon Gathers
# 22 - Radon Diff
# 31 - Angle muted gathers
# 32 - Median Filter(# 31)
# 50 - Residual Move Out (RMO)(# 32,
# 112 - Smoothed RMO
# 170 - Spectral Balancing(# 112)
Masks
Transparency
Range
30 % [0 - 100] Inverse Range
# 170 - Spectral Balancing(# 1
# 119 - Offset to Angle(# 112,
# 112 - Smoothed RMO
# 111 - Normal Move Out (NMC
# 68 - Offset to Angle(# 32, #
# 60 - Offset to Angle(# 50, #
# 50 - Residual Move Out (RMO
# 32 - Median Filter(# 31)
# 31 - Angle muted gathers
# 22 - Radon Diff
# 21 - Radon Gathers
# 13 - Radon(# 10)
Group 350 "Gain Filter"
Rose_Gathers
Top_Frigg
Polygon Selection
16,429
16,430
16,431
16,432
16,433
16,434
16,435
16,436
2,000 4,000 6,000
1.000
1.500
2.000
2.500
3.000
# 50 histogram
Seismic Amplitude histogram
Set as Volume specific histogram
-37019
55635.3
-100,000
-50,000
0
50,000
100,000

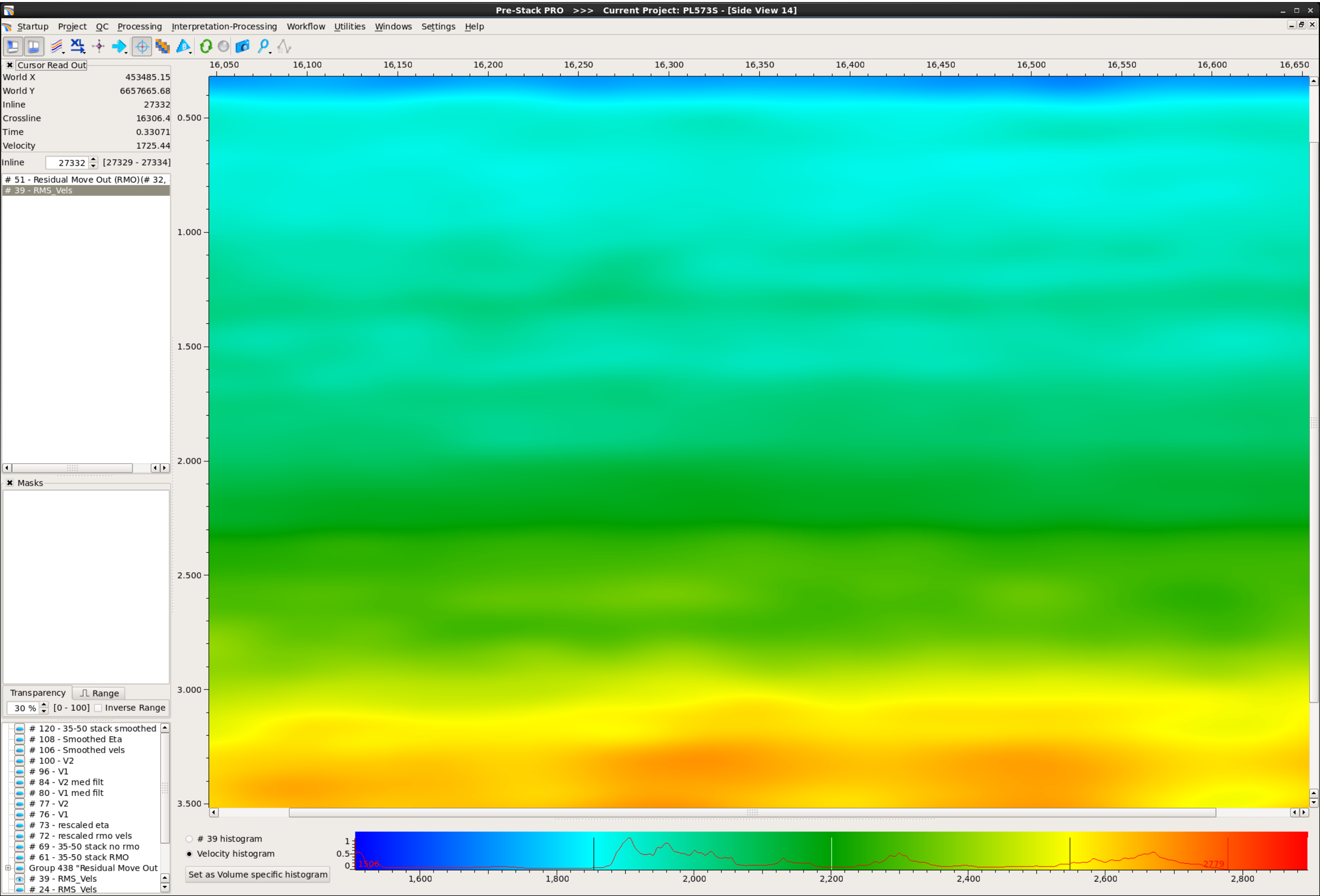
# Far stack before RMO



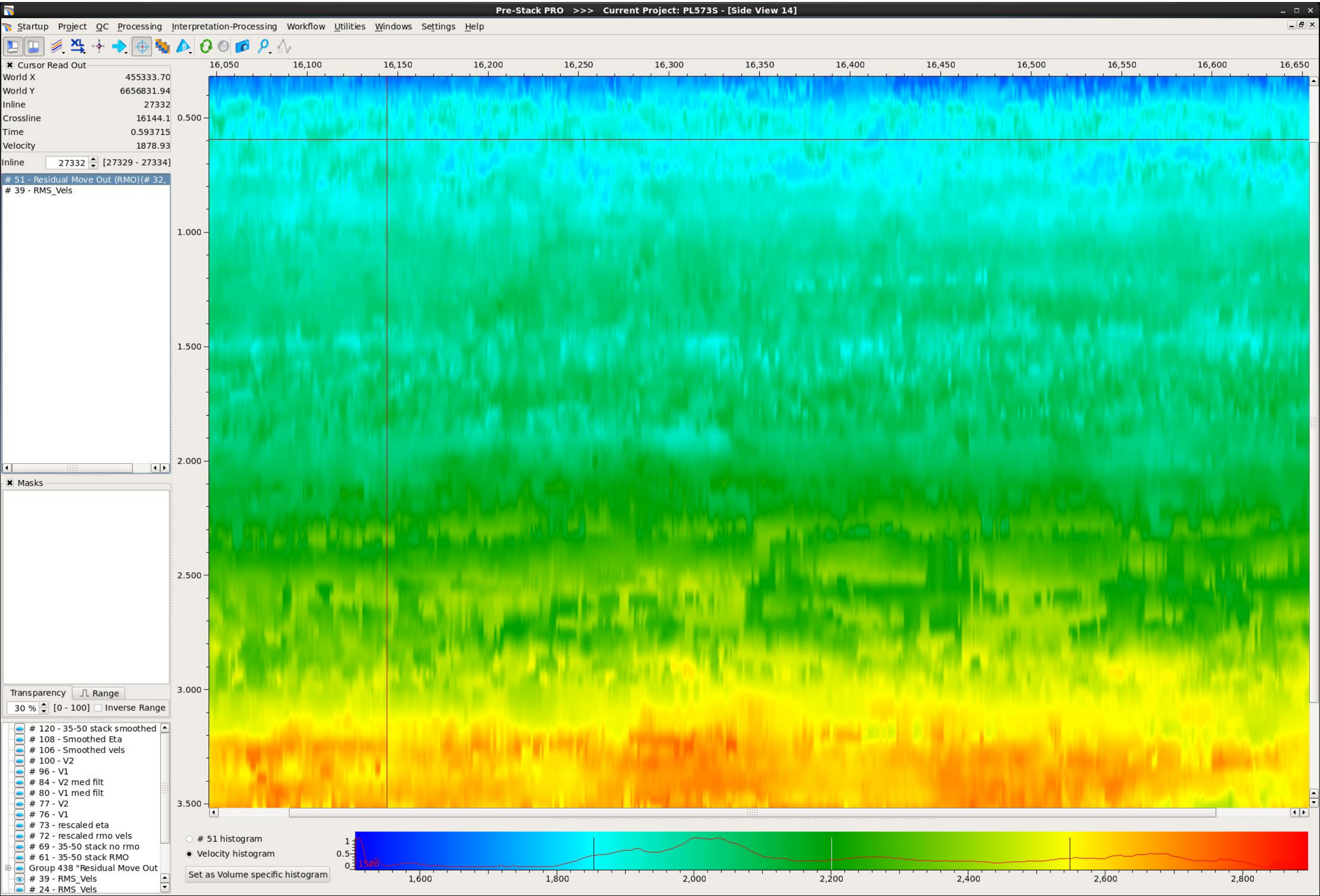
# Far stack after RMO



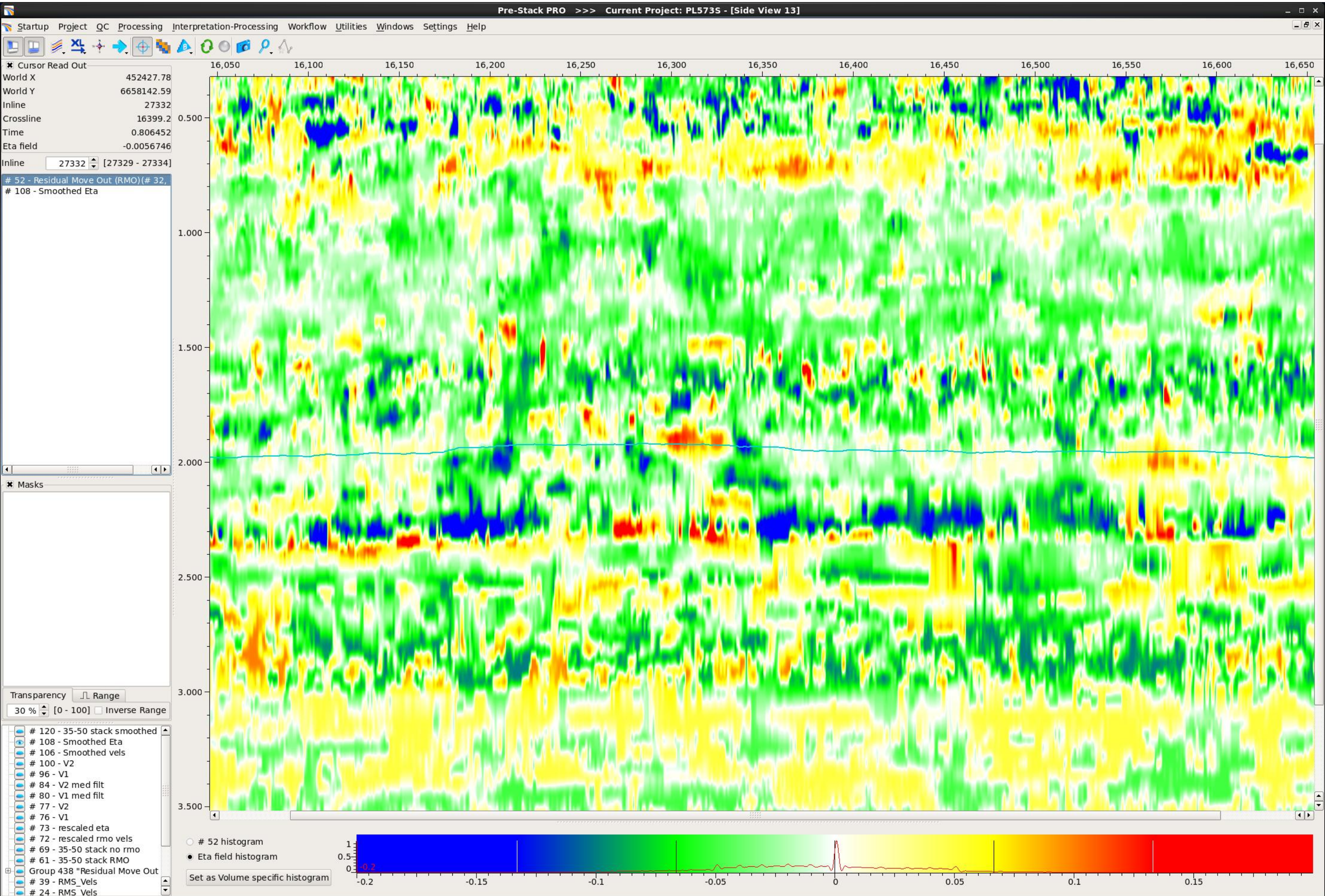
# Stacking velocities



# Updated velocities

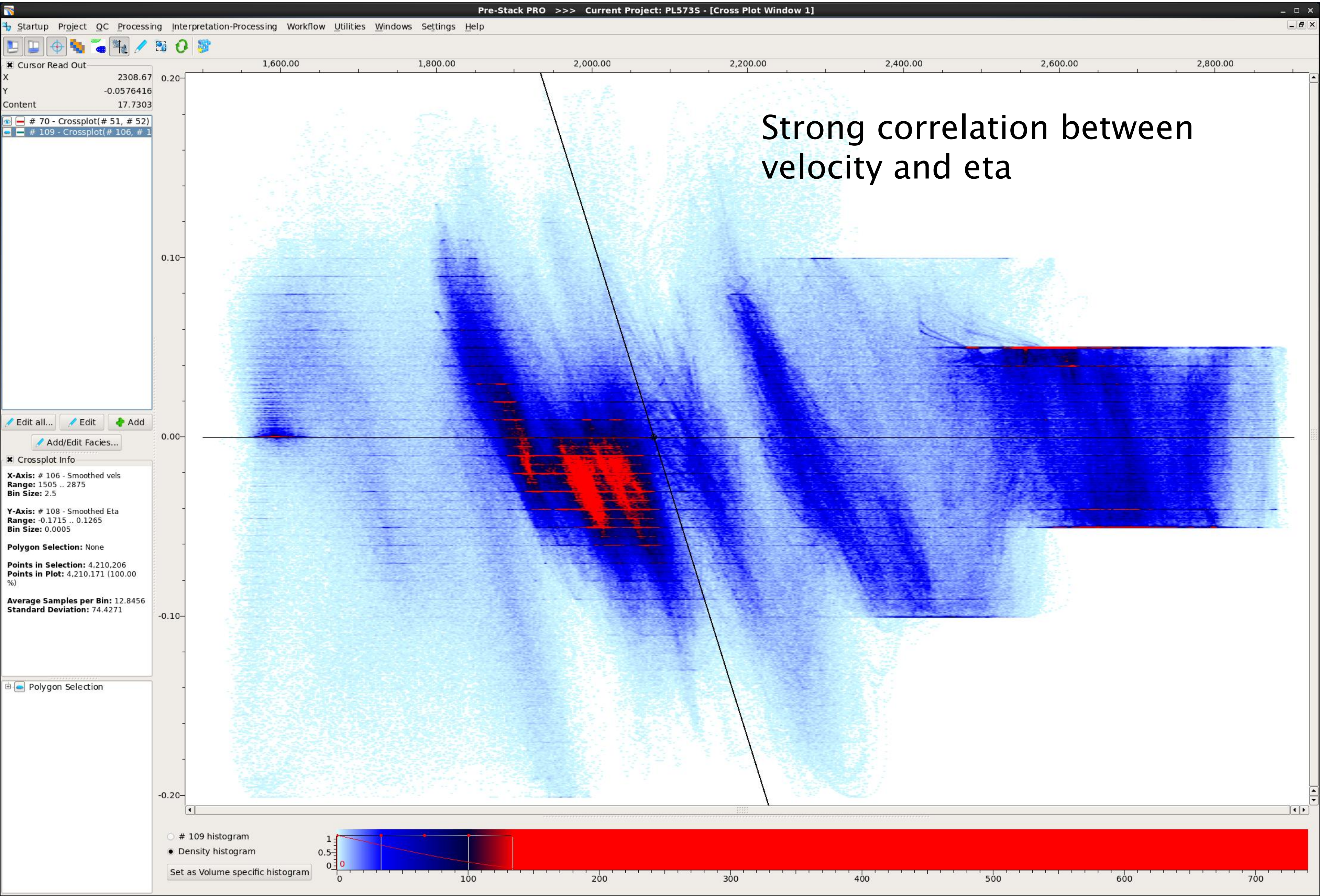


# Updated eta

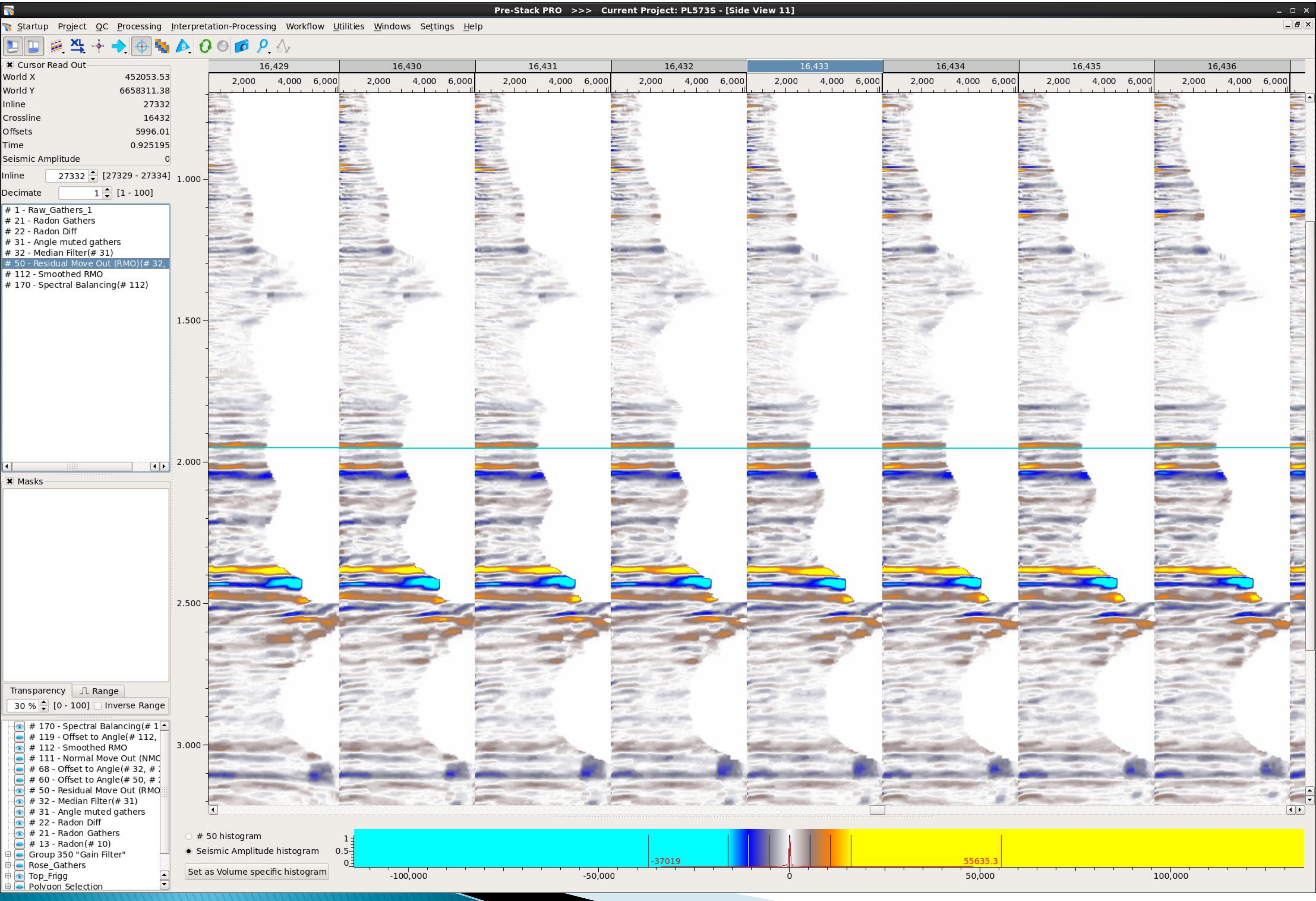


Pre-Stack PRO >>> Current Project: PL573S - [Side View 13]
Startup Project QC Processing Interpretation-Processing Workflow Utilities Windows Settings Help
Cursor Read Out
World X 452427.78
World Y 6658142.59
Inline 27332
Crossline 16399.2
Time 0.806452
Eta field -0.0056746
Inline 27332 [27329 - 27334]
# 52 - Residual Move Out (RMO)(# 32,
# 108 - Smoothed Eta
Masks
Transparency
Range
30 % [0 - 100] Inverse Range
# 120 - 35-50 stack smoothed
# 108 - Smoothed Eta
# 106 - Smoothed vels
# 100 - V2
# 96 - V1
# 84 - V2 med filt
# 80 - V1 med filt
# 77 - V2
# 76 - V1
# 73 - rescaled eta
# 72 - rescaled rmo vels
# 69 - 35-50 stack no rmo
# 61 - 35-50 stack RMO
Group 438 "Residual Move Out
# 39 - RMS_Vels
# 24 - RMS_Vels
16,050 16,100 16,150 16,200 16,250 16,300 16,350 16,400 16,450 16,500 16,550 16,600 16,650
0.500 1.000 1.500 2.000 2.500 3.000 3.500
# 52 histogram
Eta field histogram
Set as Volume specific histogram
1 0.5 0
-0.2 -0.15 -0.1 -0.05 0 0.05 0.1 0.15

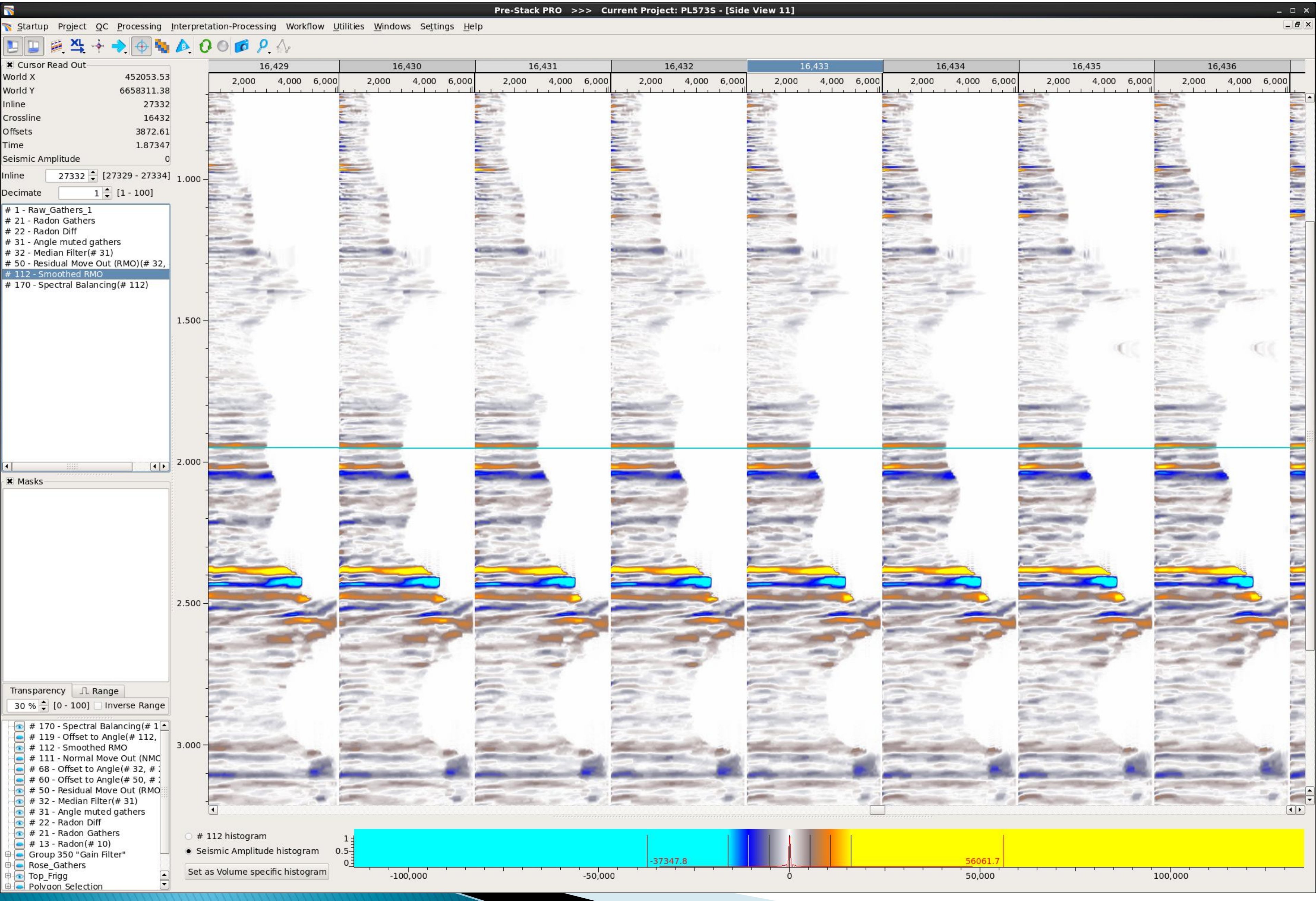
# Cross plot eta v velocity



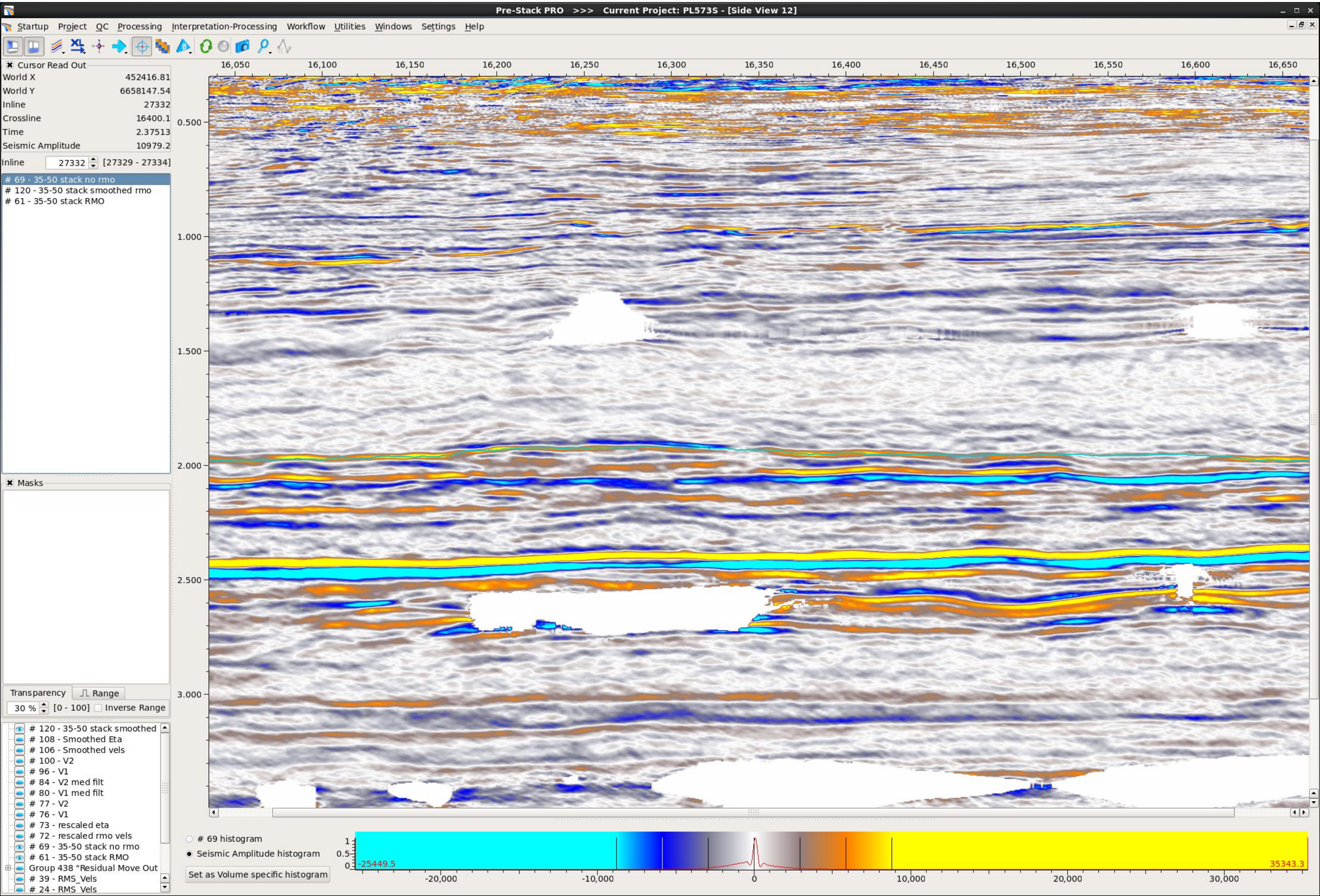
# Original RMO



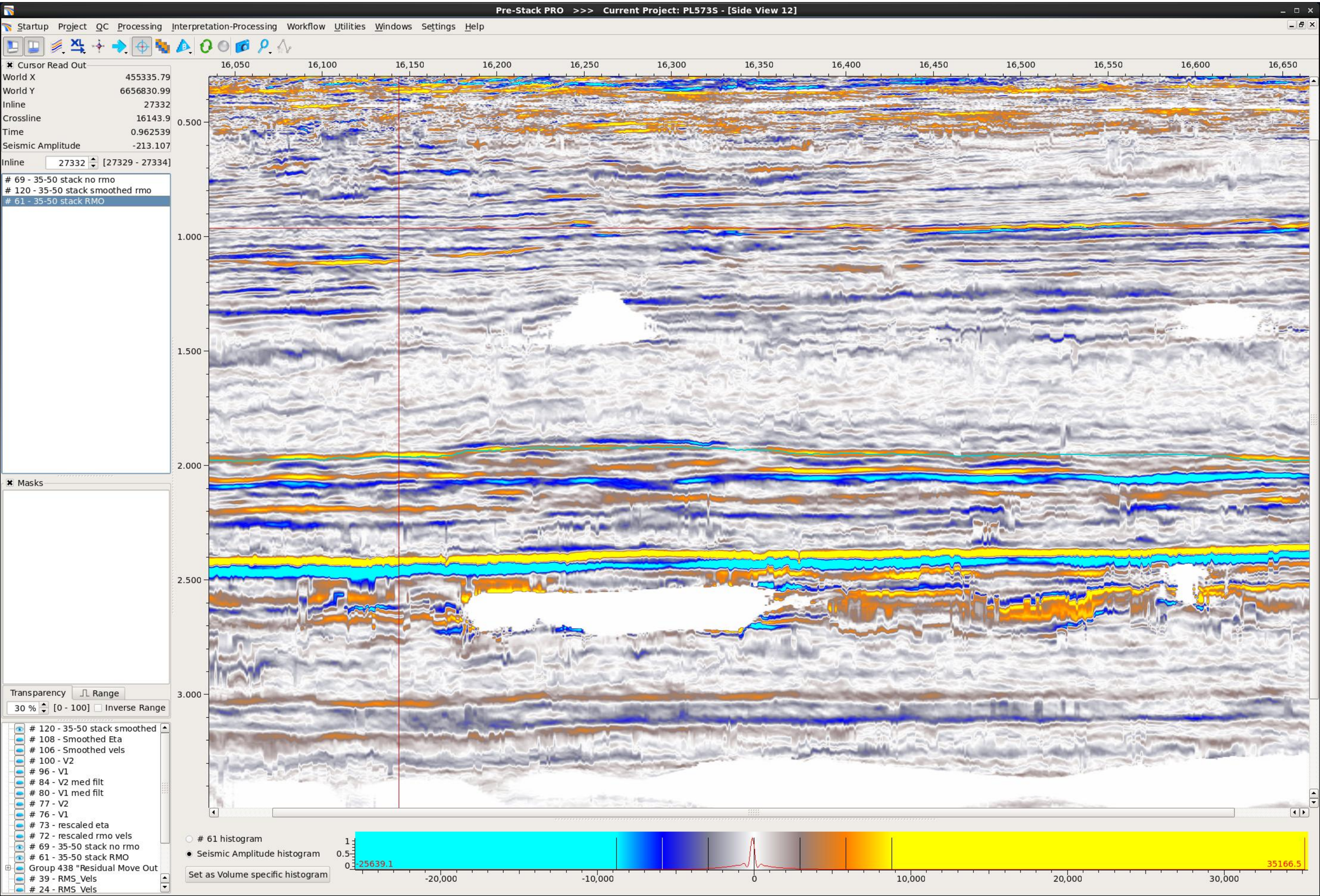
# RMO with smoothed velocity & eta



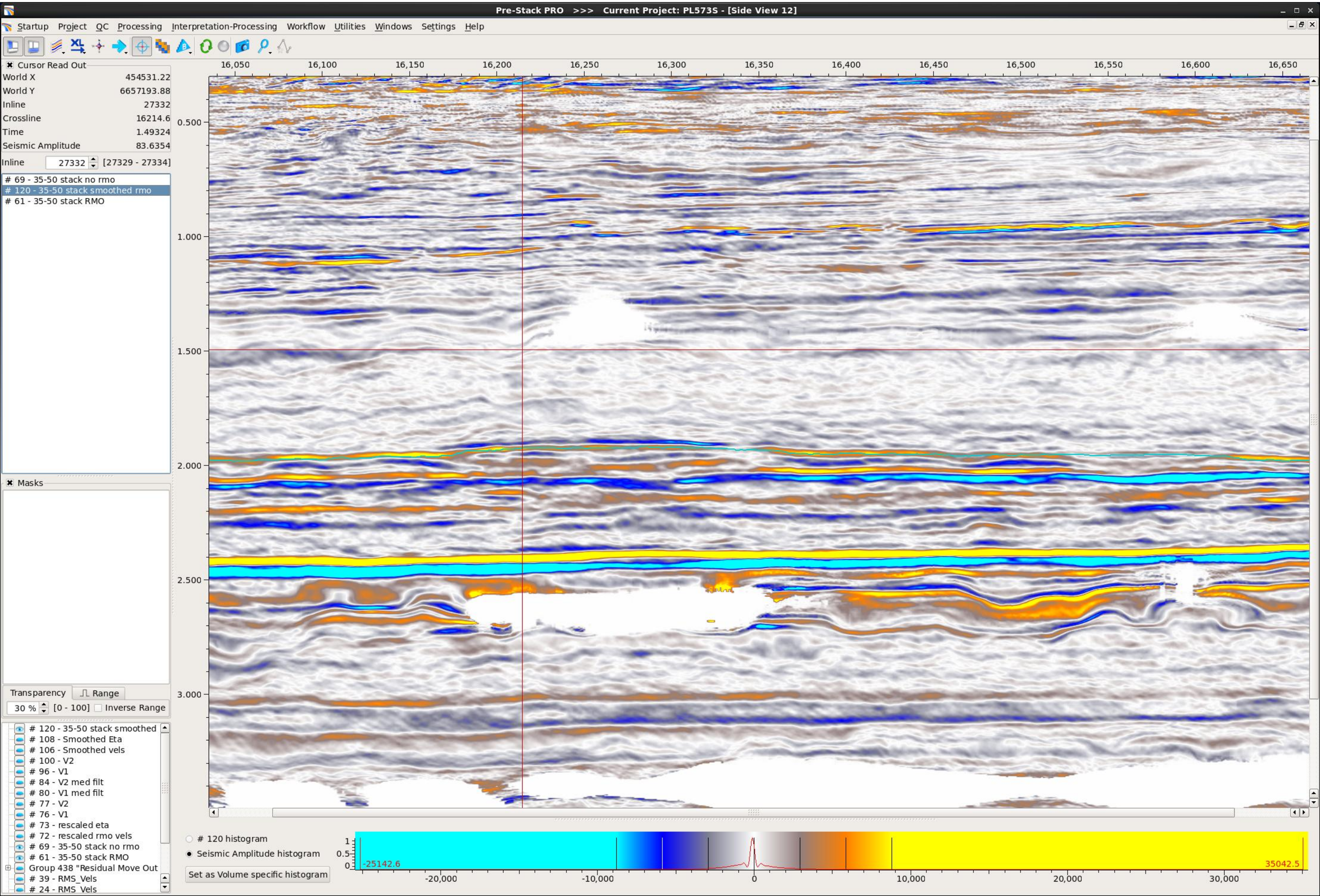
# Far stack before RMO



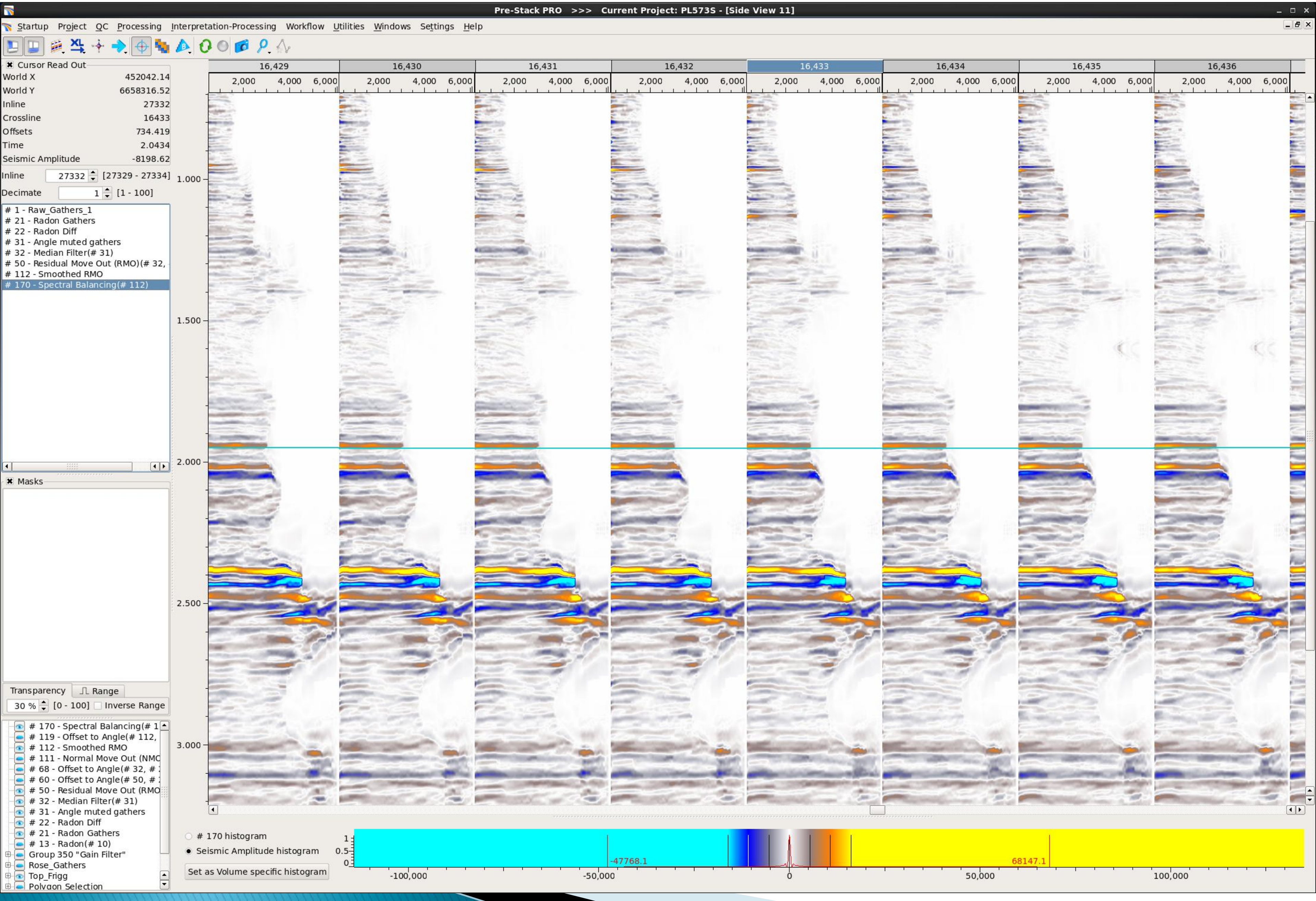
# Far stack after original RMO



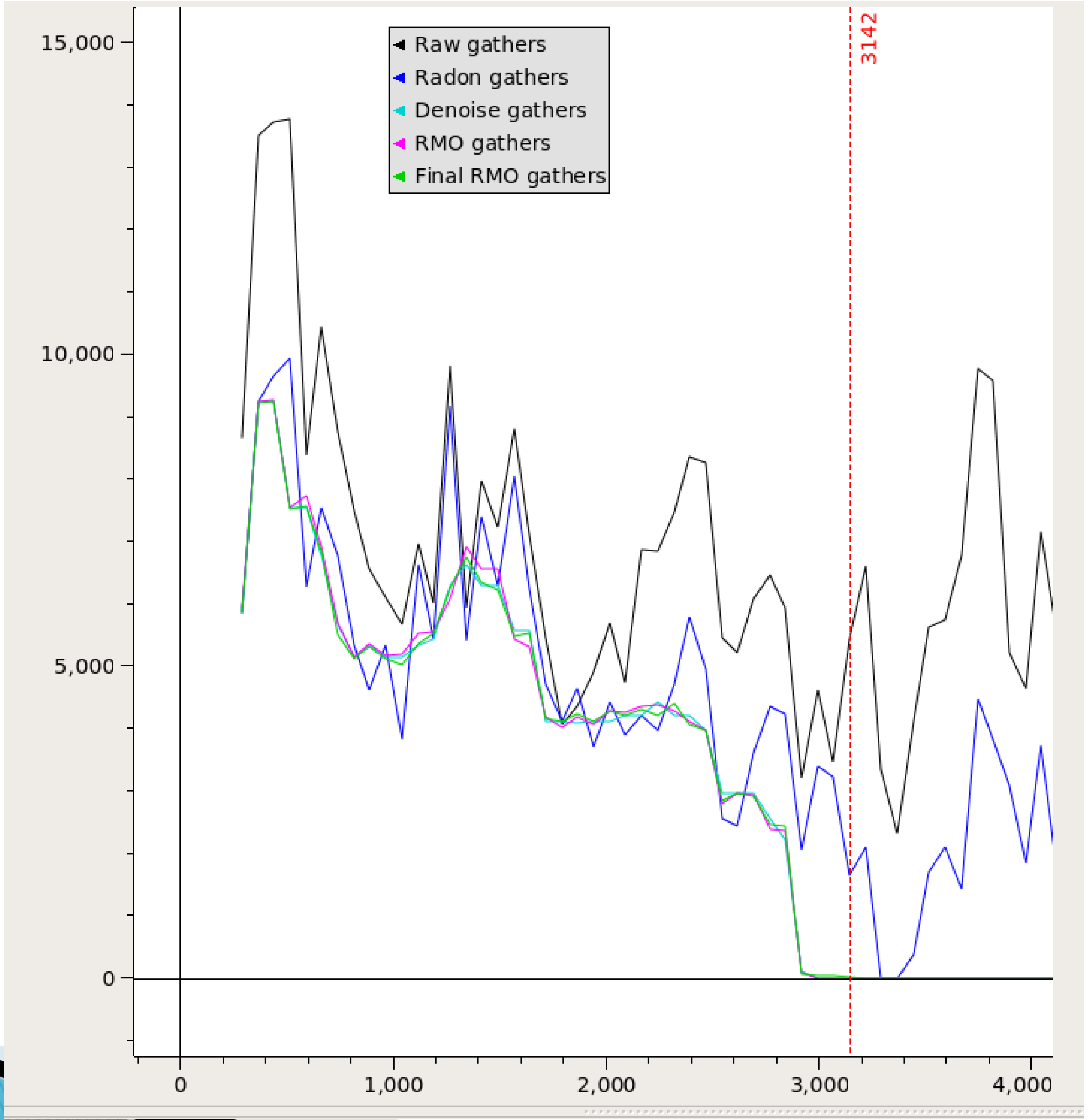
# Far stack after RMO with smoothed fields



# Final: spectral balancing across offsets



# Evolution of Top Frigg AVO response



# Seismic data quality

Multiples

Contractors are often conservative.
Modern high-resolution Radon transforms can get away with surprisingly tight mutes.

Lots of modern methods for coherent and incoherent noise in different domains

- Prediction methods
- Transform methods

# Seismic data quality

Residual moveout

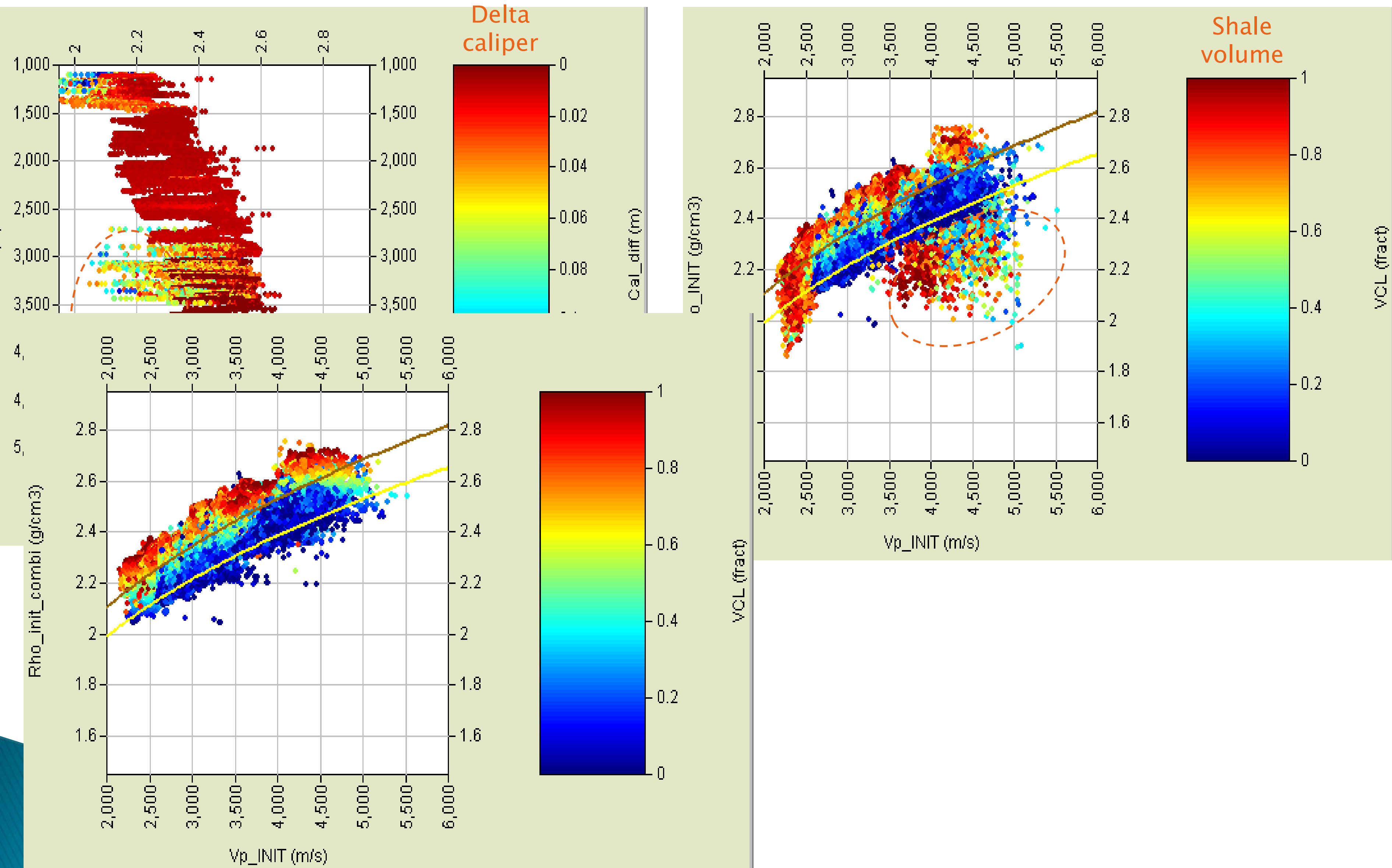
Sparse velocity picking grids give rise to interpolation errors and mispicks.
Dense, automatic methods don’t recover from mispicks in guide function.

How flat is flat??

Velocity and $\eta$ are negatively correlated.

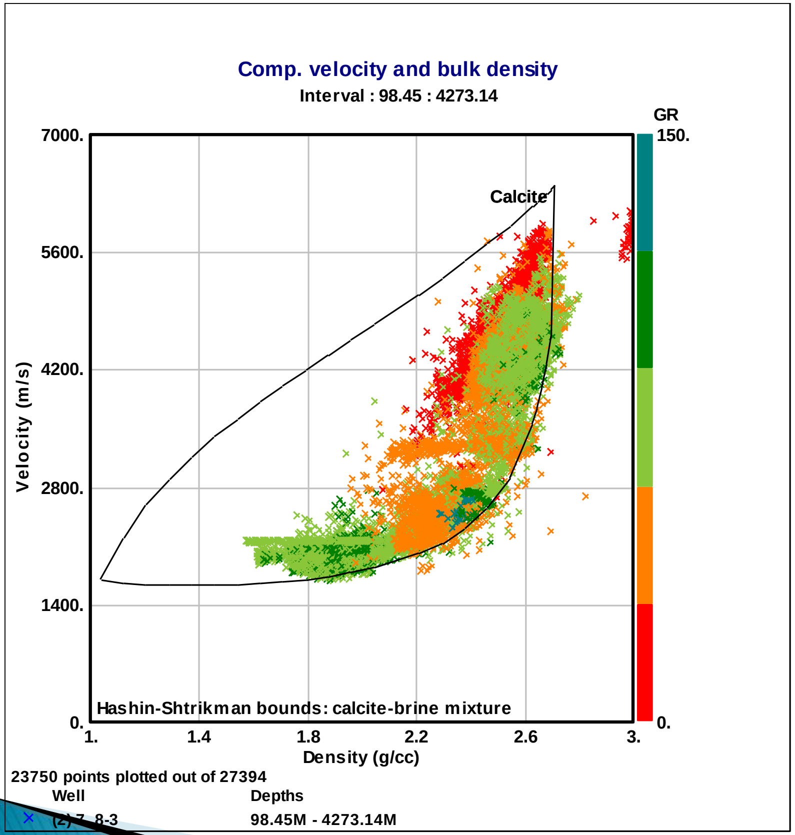
# Well log quality

What to look for: are logs fit for purpose?

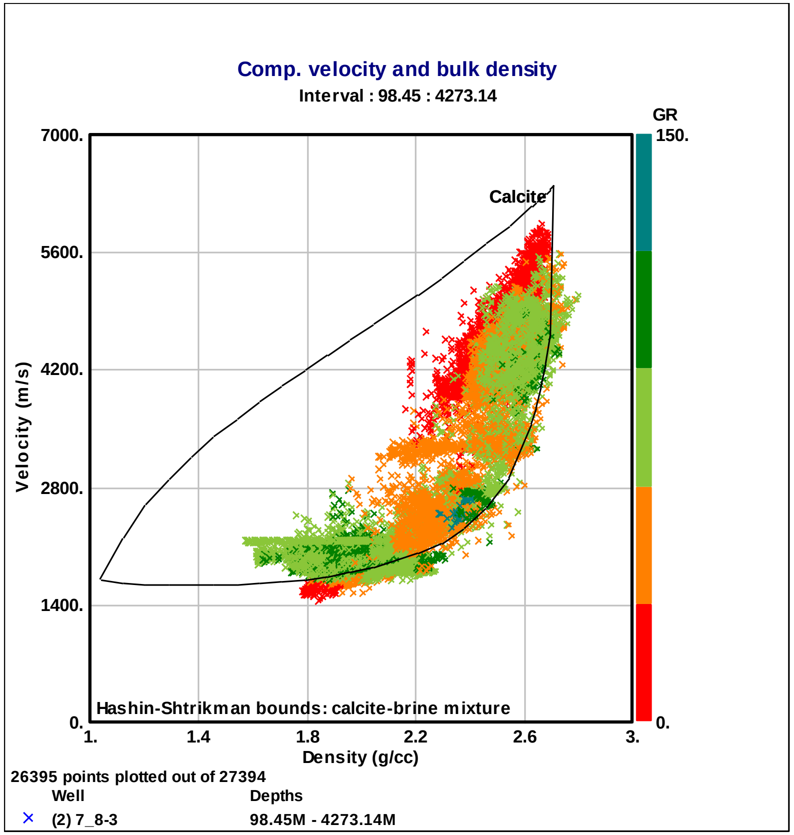


# Well log quality

- Provided

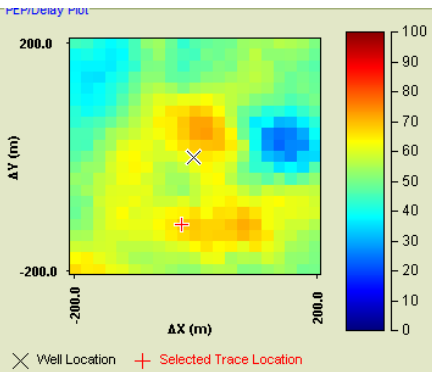


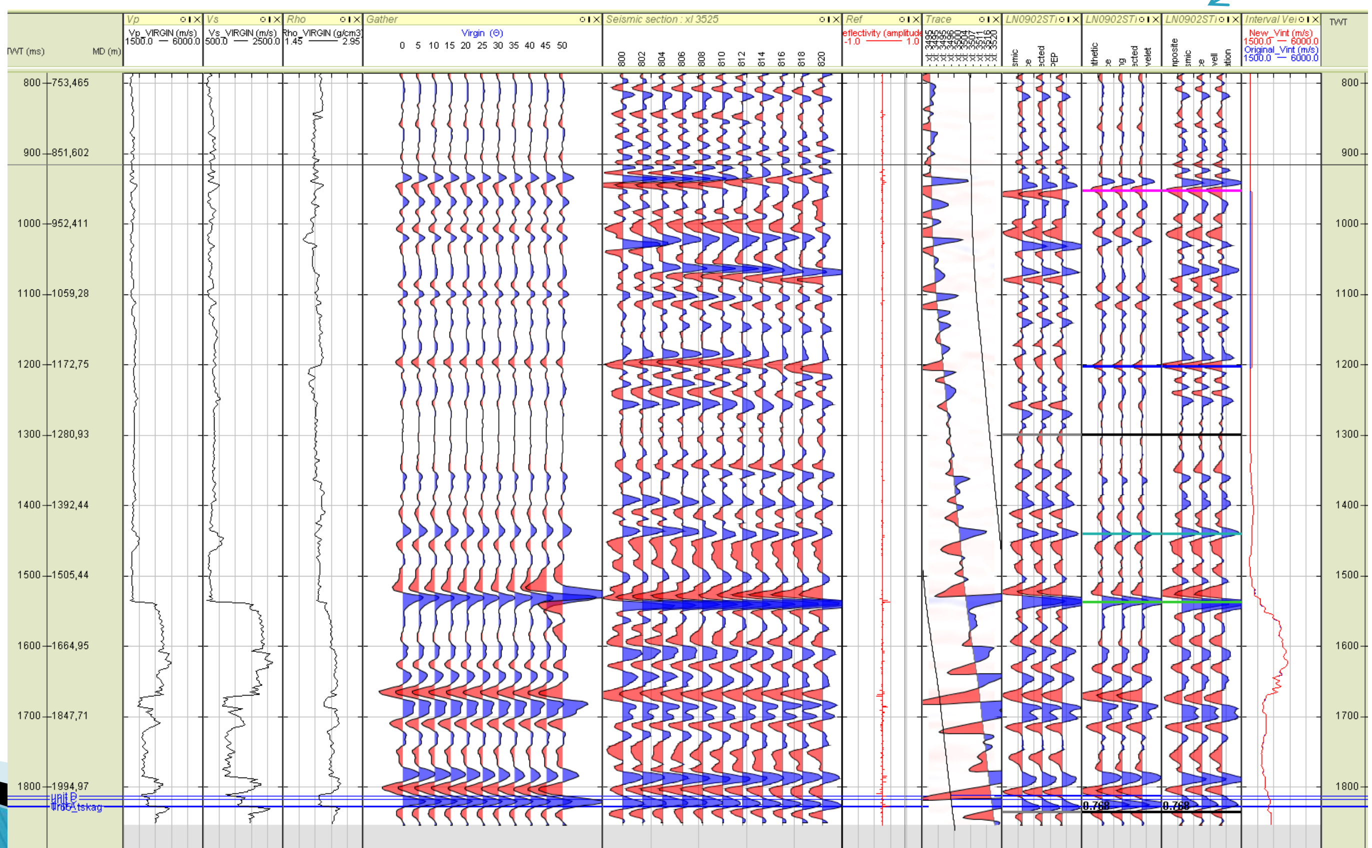

- Edited



# Well tie

There are plenty of packages out there .... Are they any good?



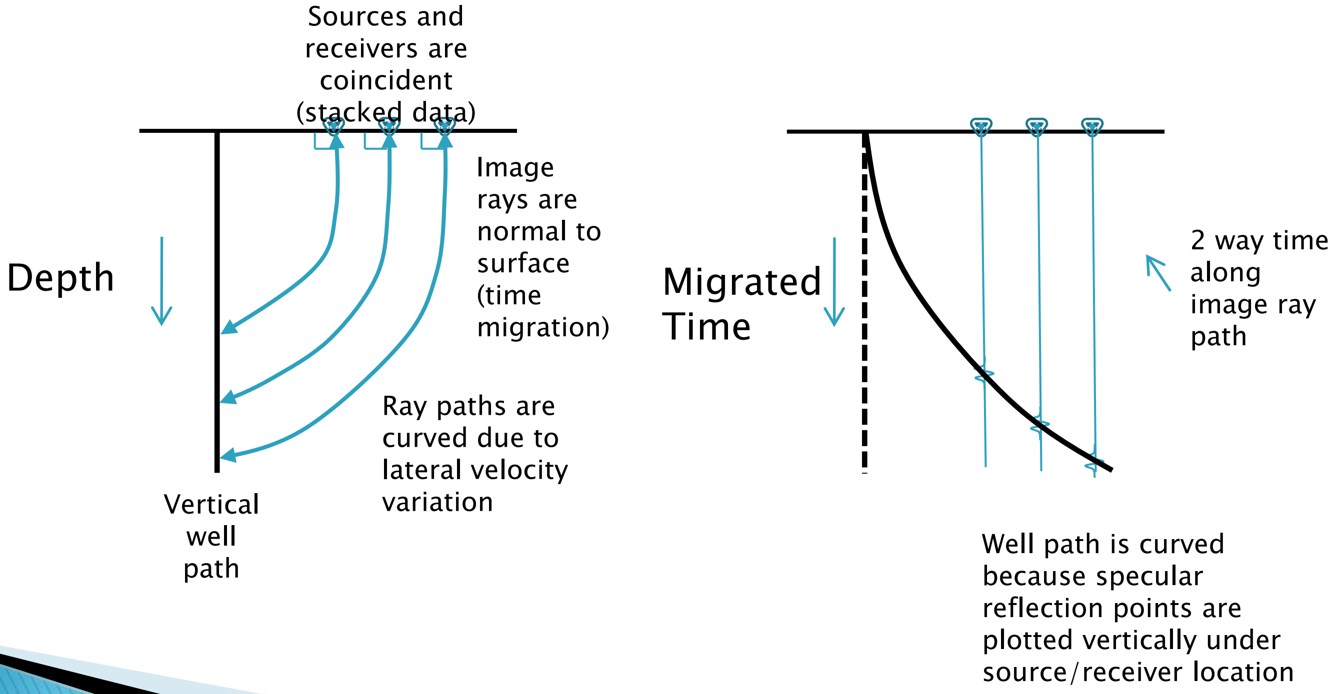
# Well tie

There are plenty of packages out there .... Are they any good?

Edit checkshot to get time-depth curve

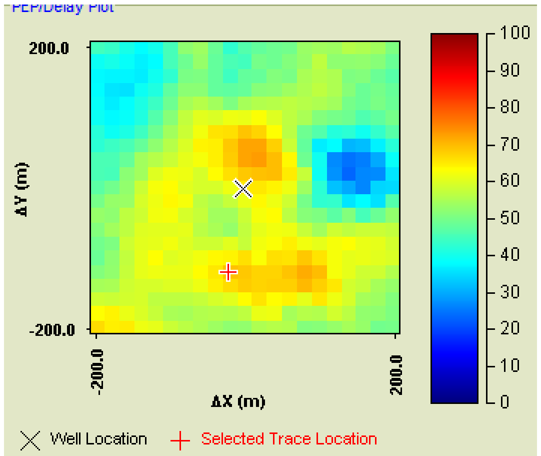
- Want to see synthetics for all angles
- Want to see wavelets for all angles

Spatial scanning for the best match is essential

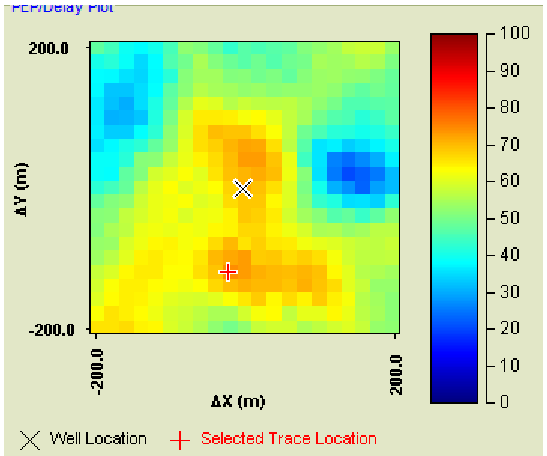


# Well tie

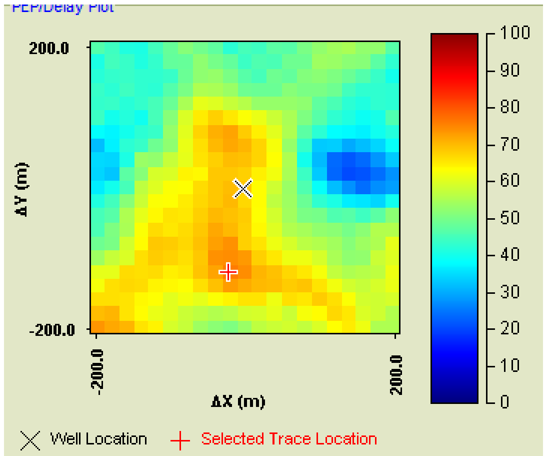
3° –8°

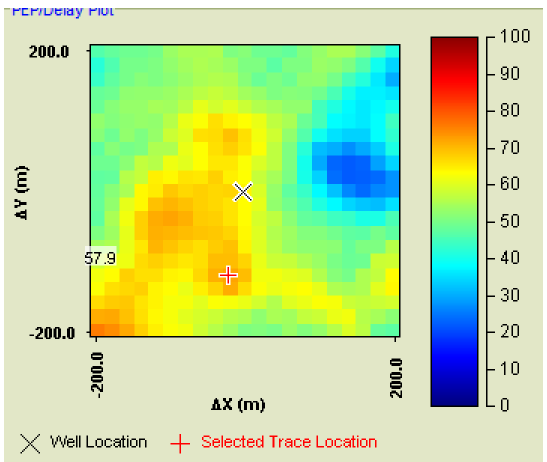



8° –16°

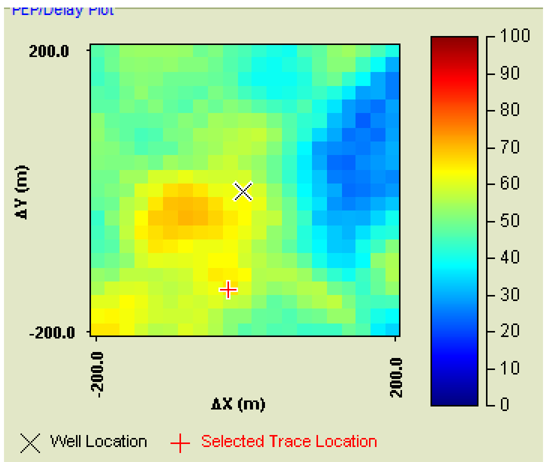



15° –23°

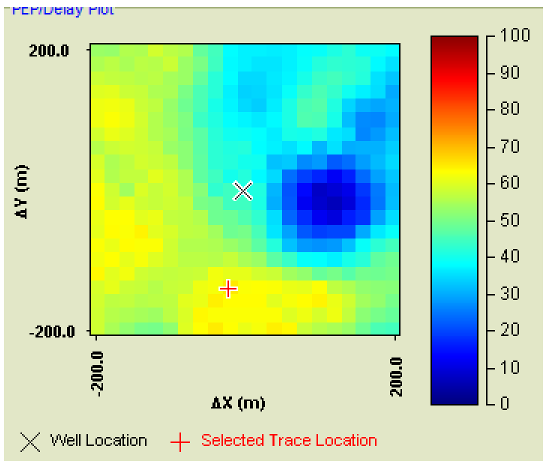



22° –30°




29° –37°




36° –43°

# Noise and resolution

- Tuning, interference, and thin beds
- Resolution
- Scattering

One of the results from a Google search for ”seismic tuning” ...

J Comp Physiol A (1991) 169:241–248

Journal of Comparative Physiology A Sensory, Neural, and Behavioral Physiology



**Seismic and auditory tuning curves from bullfrog saccular and amphibian papillar axons**

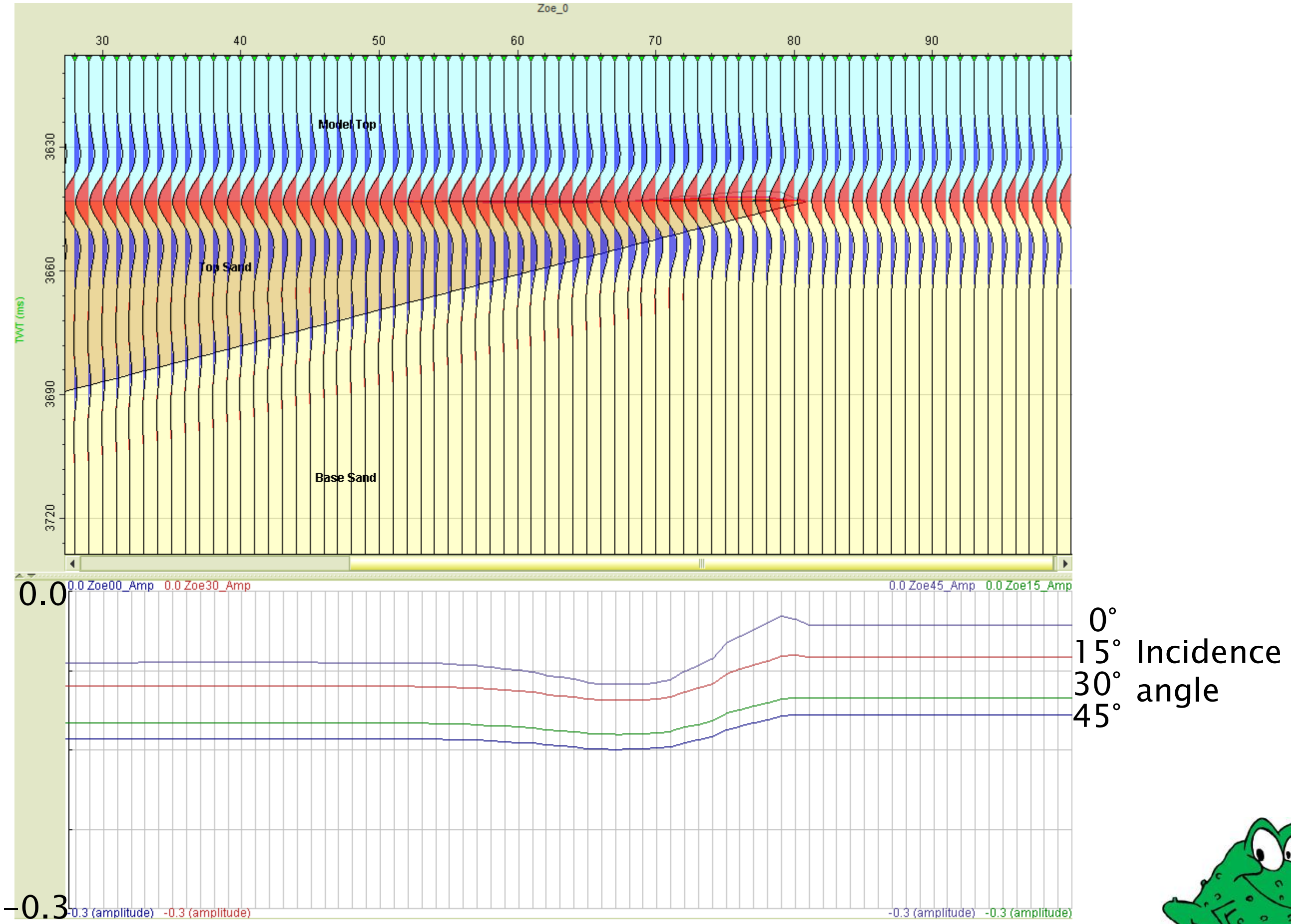
Xiaolong Yu, Edwin R. Lewis* and David Feld

Department of Electrical Engineering and Computer Sciences, 263 Cory Hall, University of California, Berkeley, CA 94720, USA

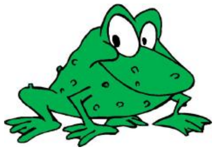
Accepted January 7, 1991

# Tuning

Wedge models are the standard method of understanding tuning and vertical resolution. They usually assume plane-layering.

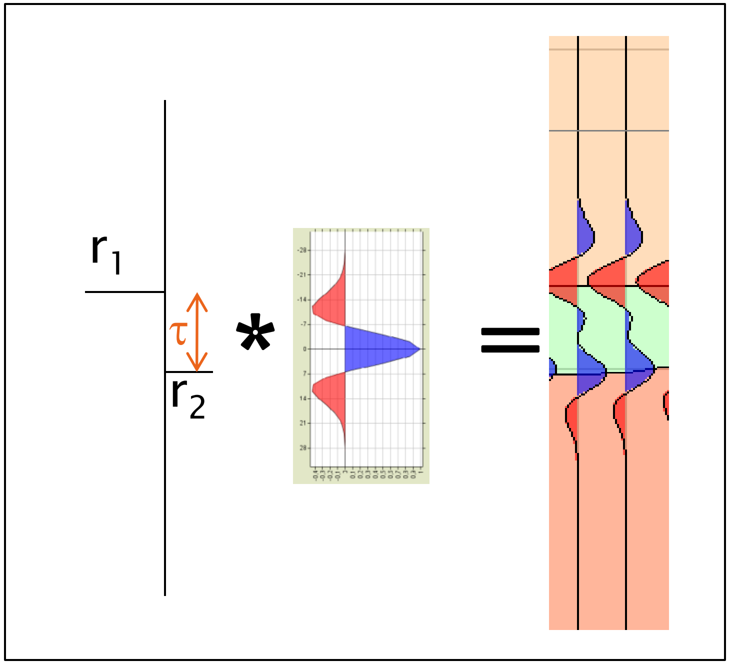



Trough amplitude at upper reflector



# Tuning

Convolutional model ...




Power spectrum is

$$W(f)\left[r_1^2 + r_2^2 + 2r_1r_2\cos(2\pi f\tau)\right]$$

f: frequency
W(f): spectrum of wavelet
$r_1$, $r_2$: reflection coefficients
$\tau$: time separation of the reflections

# Noise and resolution

Rayleigh: resolution of two point diffractors
Widess: How thin is a thin bed?

Don’t account for noise!

Can beat the Rayleigh criterion using super-resolution methods.

“Super-resolution requires super signal to noise ratios” (Roy White)

How many reflection coefficients?
Where are they?
How big is each one?

# Noise and resolution

Formulate a simpler problem: one reflection coefficient or two?

Hypothesis test

$$H_0 : x(t) = c\,h(t) * \delta(t) + w(t)$$

$$H_1 : x(t) = a\,h(t) * \delta(t - d/2) + b\,h(t) * \delta(t + d/2) + w(t)$$

h is the wavelet, a, b, c are reflection coefficients, d is the separation between them, w is zero-mean Gaussian noise.
Assume data are sampled at $\Delta t = 1/2B$ , then d = 1 is the Rayleigh limit and we are interested in d < 1.

Make a choice between the hypotheses by a generalised likelihood ratio test: choose $H_1$ if

$$L_G(x) = \frac{p(x; \hat{a}, \hat{b}, \hat{d}, H_1)}{p(x; \hat{c}, H_0)} > \gamma$$

$\gamma$ is determined from the acceptable probability of making an error by deciding $H_1$ when in fact $H_0$ is true.

# Noise and resolution

Formulate a simpler problem: one reflection coefficient or two?

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Based on Kay, Fundamentals of Statistical Signal Processing, Prentice Hall.

# Noise and resolution

$$L_G(x) = \frac{p(x;\hat{a},\hat{b},\hat{d},H_1)}{p(x;\hat{c},H_0)} > \gamma$$

Assume Gaussian errors and take logarithms, rearrange and write in terms of vectors:

$$x^T(\hat{s}_1 - \hat{s}_0) - \frac{1}{2}\|\hat{s}_1\|^2 > \sigma^2 \log\gamma - \frac{1}{2}\|\hat{s}_0\|^2$$

$\hat{s}_k$ is the model of the data using maximum likelihood estimates of a,b,c,d under the appropriate hypothesis.

Note that all the dependence on d is in $\hat{s}_1$ .
At the limit of detection the two sides are equal:

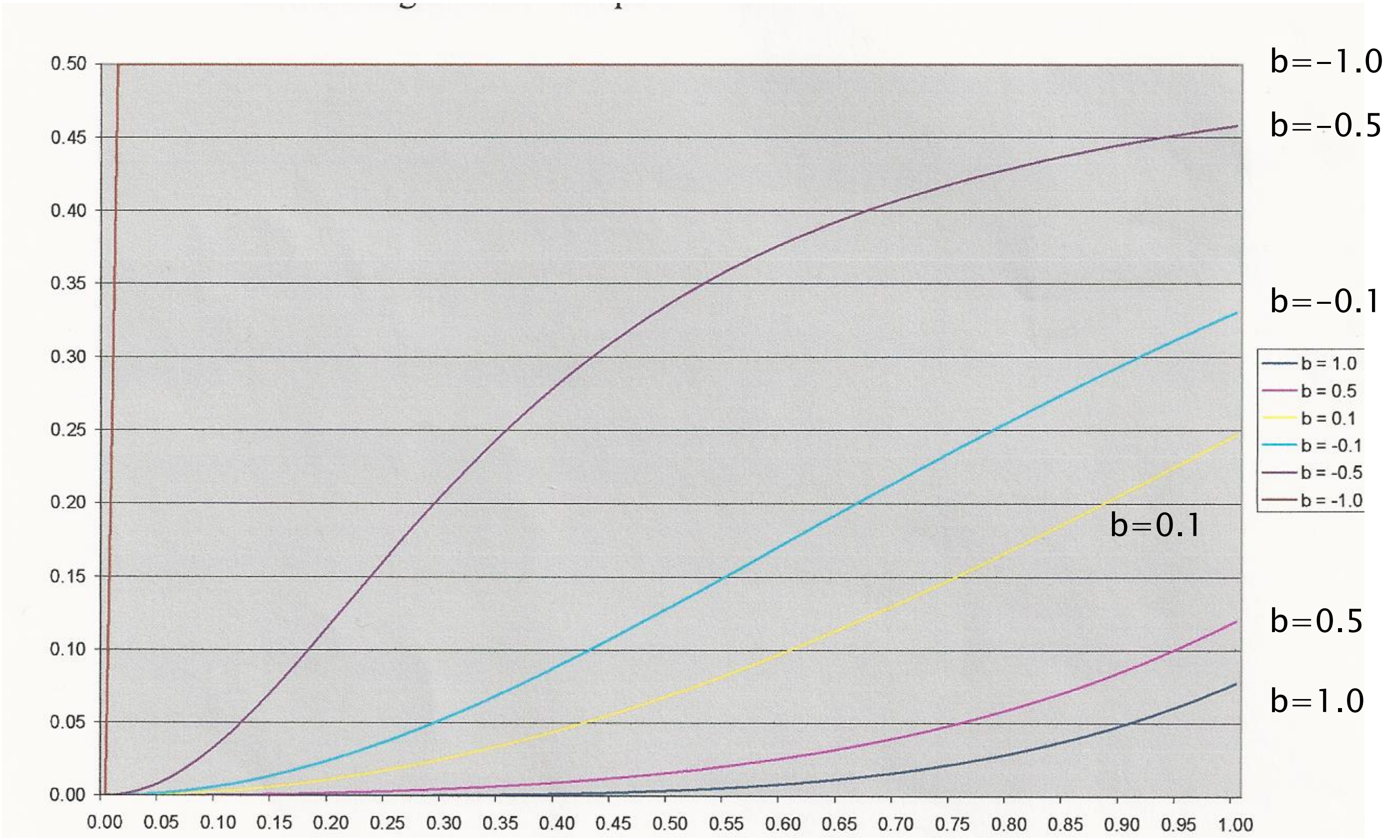
$$f_1(\hat{a},\hat{b},\hat{c},\hat{d}) = f_2(\hat{c},\sigma^2,\gamma)$$

Can interpret this equation as giving a minimum detectable d for particular reflection coefficients & noise level, or a maximum noise level for a desired separation, or mimimum magnitude of resolvable reflection coefficients for given noise and separation ...

# Noise and resolution

Noise to signal ratio

$$\frac{1}{\|\hat{s}_1\|^2}\left(x^T(\hat{s}_1-\hat{s}_0)-\frac{1}{2}\|\hat{s}_1\|^2+\frac{1}{2}\|\hat{s}_0\|^2\right)>\frac{\sigma^2}{\|\hat{s}_1\|^2}\log\gamma$$



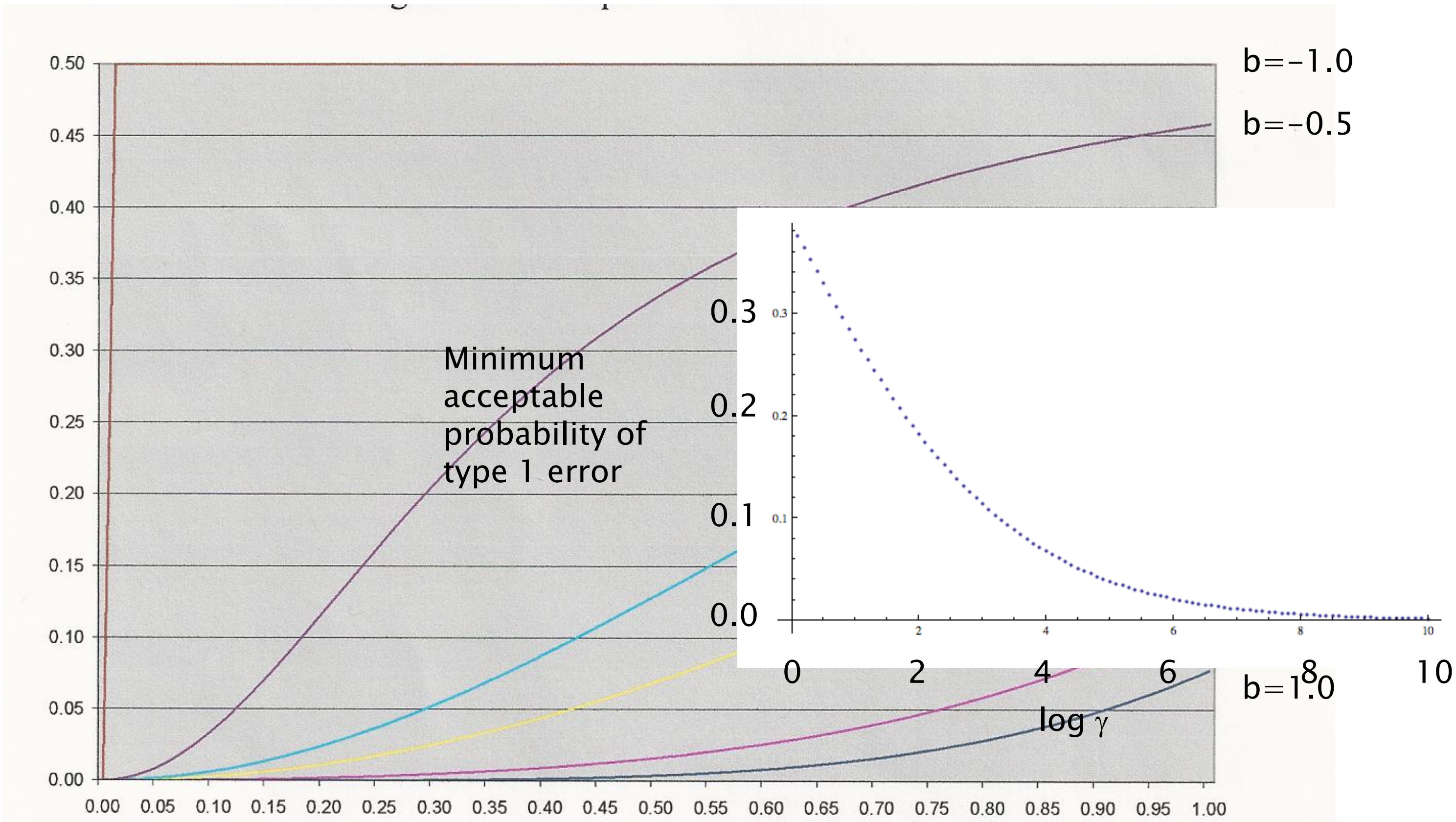

Separation, d

a=1 in all curves.
The curves for any a,b pair lie inbetween b=1 and b=−1.

# Noise and resolution

Noise to signal ratio

$$\frac{1}{\|\hat{s}_1\|^2}\left(x^T(\hat{s}_1-\hat{s}_0)-\frac{1}{2}\|\hat{s}_1\|^2+\frac{1}{2}\|\hat{s}_0\|^2\right)>\frac{\sigma^2}{\|\hat{s}_1\|^2}\log\gamma$$

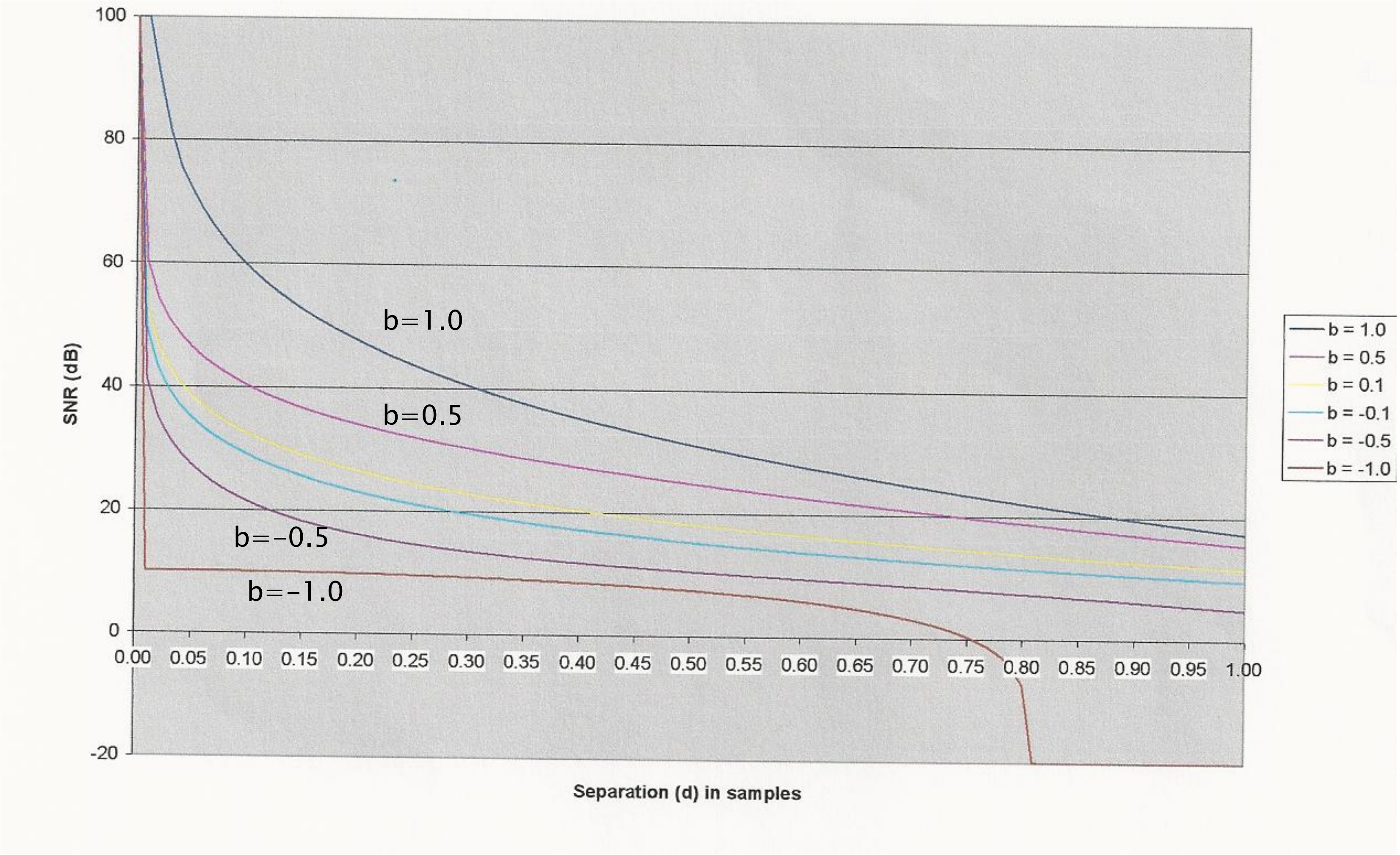



Separation, d

a=1 in all curves.
The curves for any a,b pair lie inbetween b=1 and b=−1.

# Noise and resolution

Minimum SNR (dB) required to resolve reflection coefficients for P(type 1 error) = 0.05




a=1 in all curves.

# Noise and resolution

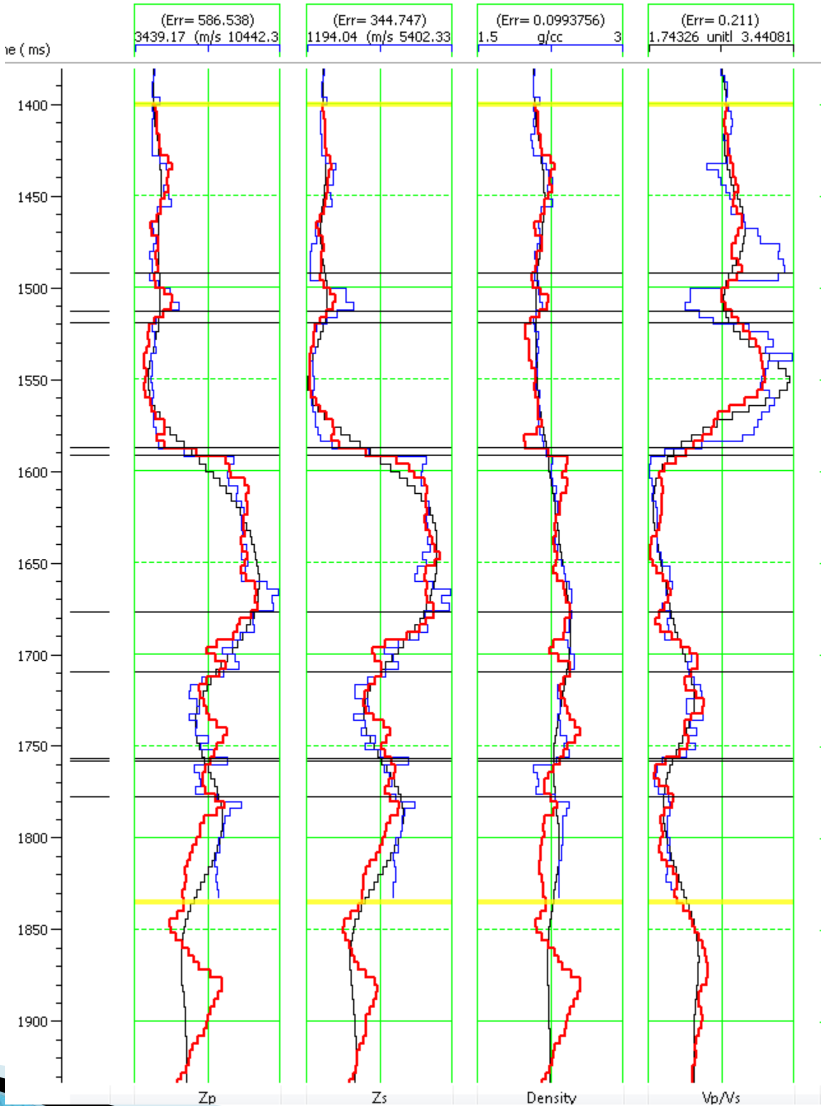
Resolution depends on

- Bandwidth
- Signal to noise ratio
- Size of reflection coefficients
- Acceptable probability of error

The results are optimistic! They assume

- The wavelet is known
- We know that there are exactly one or two reflection coefficients within the time interval analysed

# Noise and resolution




Blue curve: blocked logs,
Black curve: initial model
Red curve: Inversion result

# Can we obtain density?

NO (from linearised AVA analysis)

- 3 term fit is very unstable
- Very high correlation between density and Zp
- Can try rock physics constraints but they may not be valid globally

YES (from non-linear high-angle analysis)

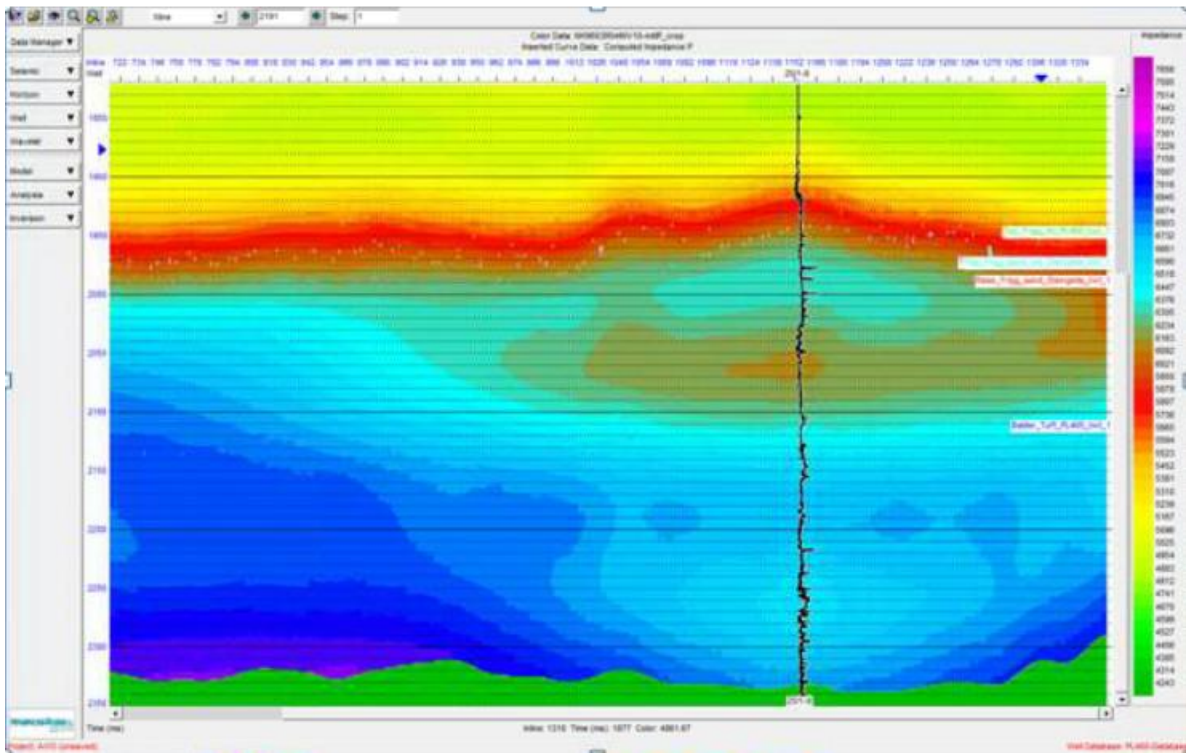
Downton, Kabir, Skopintseva

- How to preprocess data near/beyond the critical angle?

# Initial models

Trying to fill the low frequency gap

Use smoothed well-logs and interpolate along horizons between wells.



Need a lot of QC: horizons, length of logged interval, interpolation methods.

Background model building

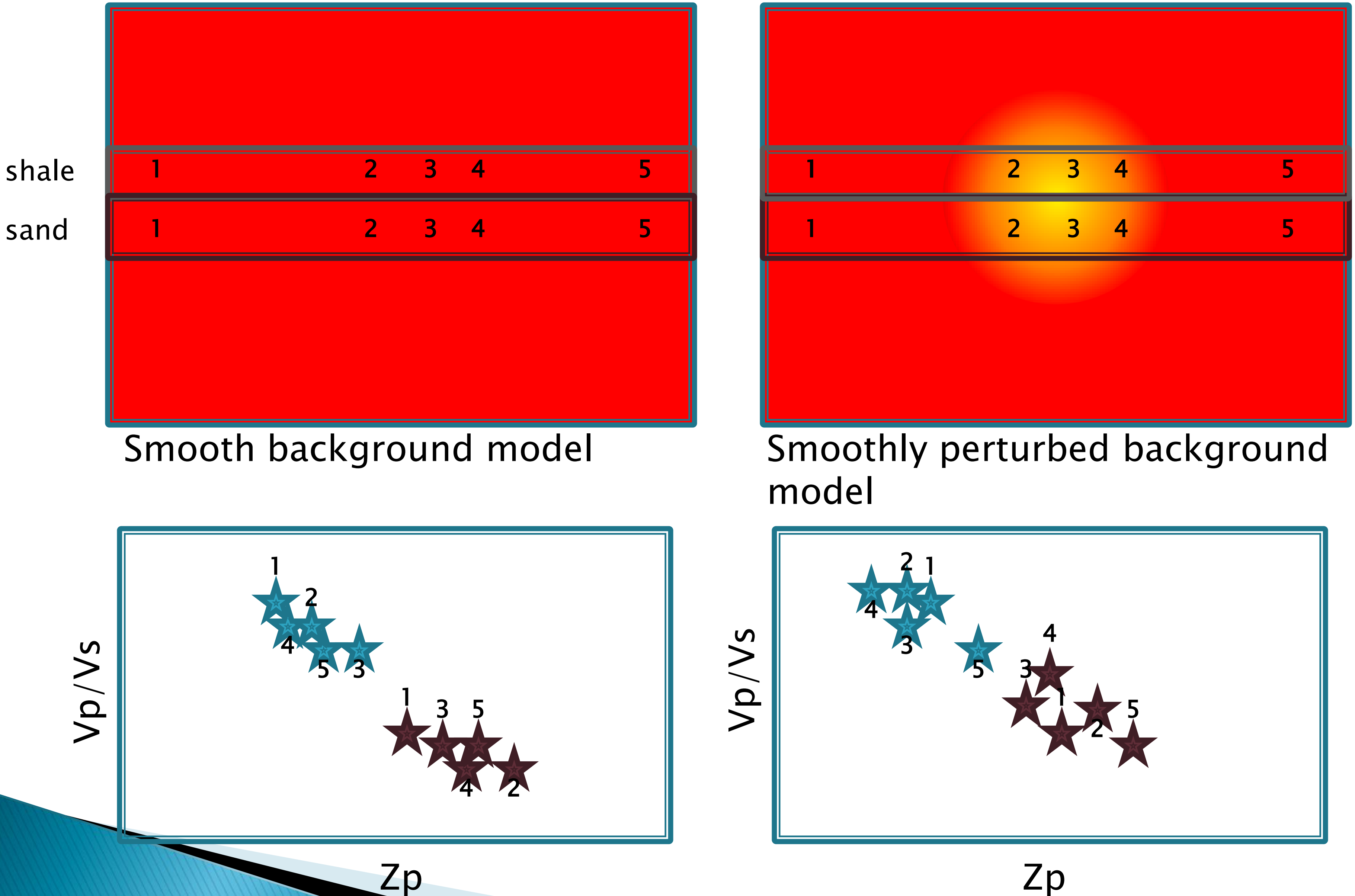
Simple inverse distance-weighted interpolation along horizons
Cokriging along horizons (seismic velocities or other attributes)
Etc

Interpreters don’t know the requirements for a good horizon!

- Don’t need all the fine detail of the target (we will smooth the horizon anyway)
- Should cover the full inversion area if possible (regional horizons)
- Horizons which come too close together cause interpolation artefacts
- Cycle skips can introduce false “faults” in the inversion results (but real faults should be preserved)
- Auto-track busts in bad data areas have to be fixed. These are often found towards the edges of the inversion area away from the prospect, so the interpreter didn’t notice or didn’t care.
- We do best with 4 – 6 horizons surrounding the zone of interest, hopefully none too close to it.

Errors in background models often go un-noticed until after the inversion is run. Good QC tools are essential!

# Crossplot warping due to background model




Smooth background model

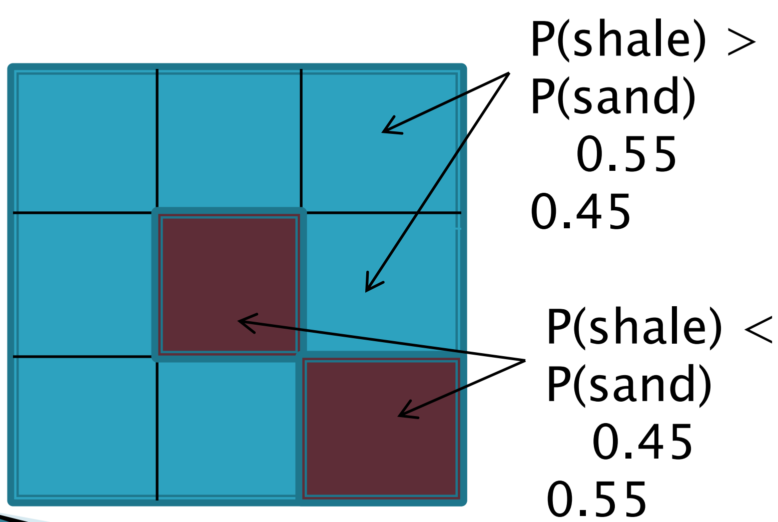
Smoothly perturbed background model

# Spatial Smoothness and Geological Consistency

No spatial constraints: smoothness comes from background model

What happens if some region has prior probabilities 50% shale, 50% sand? Most likely lithology in neighbouring voxels could switch between sand & shale if there is overlap in crossplot space.

Could add Markov random field term. Neighbouring voxels are more likely to be similar lithology. Can make it dip-steered, and respect faults. Could make it a post-processing step after PCUBE or include in inversion.




Markov random field:
P(sand) in the middle voxel depends on the PCUBE results (data) and the classification of neighbouring voxels (MRF).
Use Bayes theorem to update classification.
MCMC, simulated annealing, or other algorithms can be used: expensive!

Can help to resolve areas where classes overlap in crossplot