Cascadia 2D

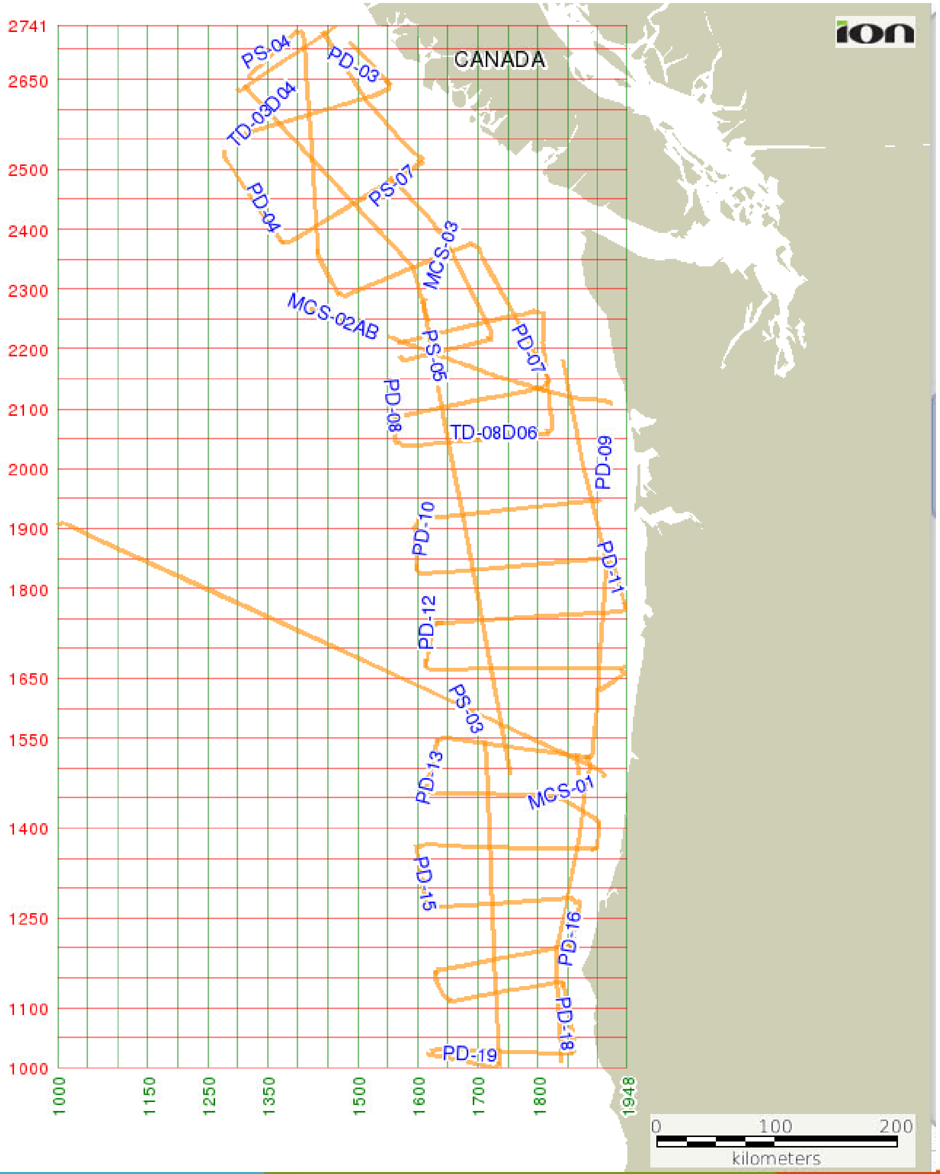
Data Processing Report

ION Data Processing

August 2022

- Data Acquisition
  - Line layout and acquisition specifications
- Pre-processing
  - Flow and data examples
- Pre-stack Depth Migration (PSDM)
  - Flow and data examples
  - Potential fields modeling
- Post Processing
  - PSDM

Survey Program Map



2012 Survey Parameters

- **<u>For all lines except MCS-01 and NTMCS-01:</u>**
  - OFFSET (increment) : 195-8070m (@75m)
  - CDP Interval : 12.5m
  - Record Length : 12300ms
  - Fold : 106

- **<u>For MCS-01 only:</u>**
  - OFFSET (increment) : 300-8175m (@75m)
  - CDP Interval : 12.5m
  - Record Length : 12300ms
  - Fold : 106

- **<u>For NTMCS-01 only:</u>**
  - OFFSET (increment) : 300-8175m (@75m)
  - CDP Interval : 12.5m
  - Record Length : 12300ms
  - Fold : 80

2021 Survey Parameters

- **For first 11 lines shown in the table:**
  – OFFSET (increment) : 225-15150m (@75m)
  – CDP Interval : 12.5m
  – Record Length : 15000ms
  – Fold : 200

MGL2104PD09
MGL2104TD09D10
MGL2104PD10
MGL2104TD10D11
MGL2104PD11
MGL2104TD11D12
MGL2104PD12
MGL2104TD12S01
MGL2104PS01A
MGL2104TEST2
MGL2104PS01B

- **For rest of the lines in the 2021 survey**
  – OFFSET (increment) : 225-12150m (@75m)
  – CDP Interval : 12.5m
  – Record Length : 15000ms
  – Fold : 160

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  - Flow and data examples
- Pre-stack Depth Migration (PSDM)
  - Flow and data examples
  - Potential fields modeling
- Post Processing
  - PSDM

General Pre-processing Workflow

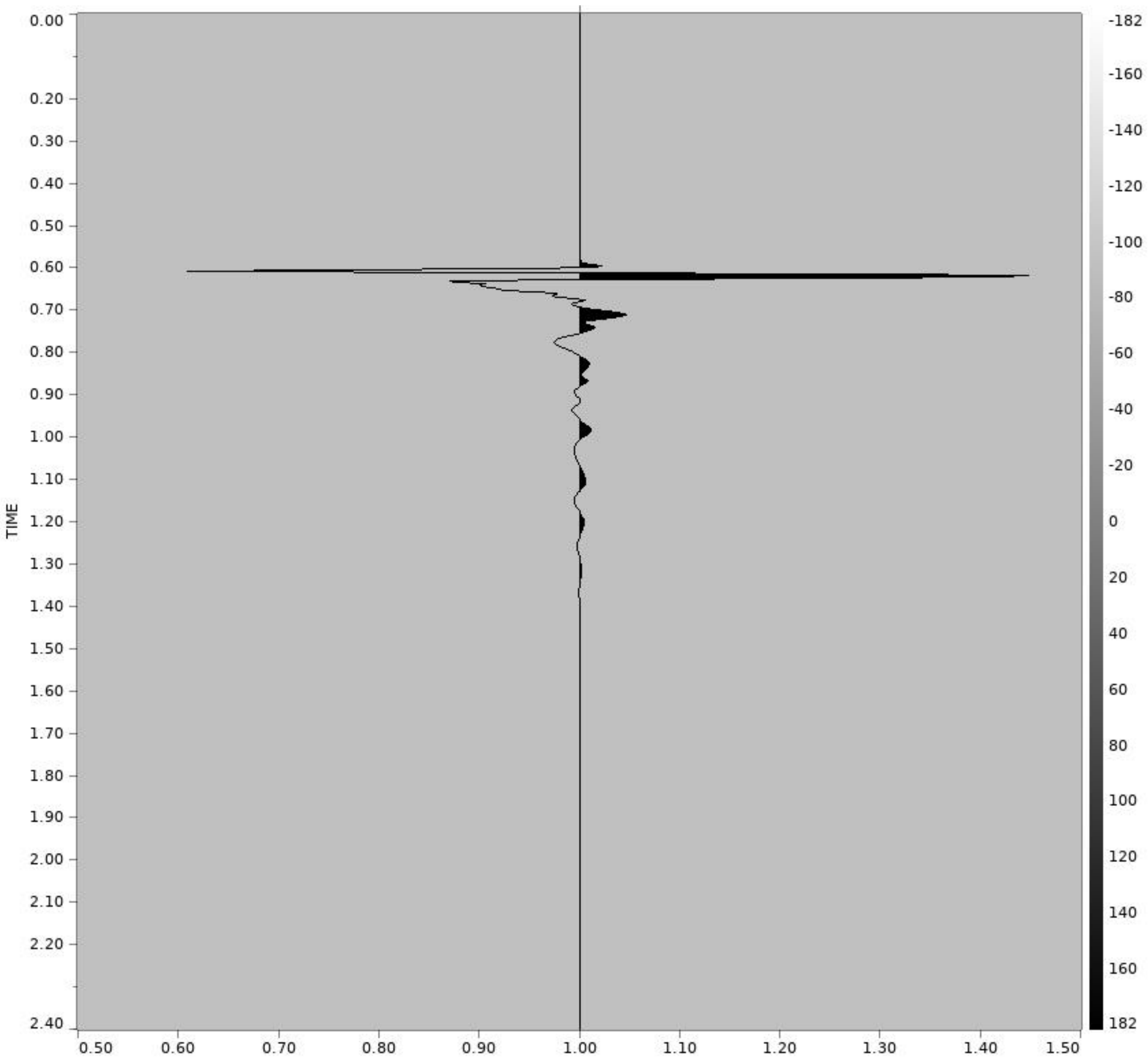
- Reformat SEG-D to Internal format
- Geometry merge and QC
- Geometrical spreading correction
- Debias and De-bubble Filter
- Noise attenuation
  - Swell noise attenuation
  - Seismic interference attenuation
  - Radial filter for residual noise attenuation
- Acquisition Footprint Removal
- De-ghosting, Residual De-bubble
- Guided Wave Removal - Shallow data only
- Multiple attenuation
  - SPMA (Short Period Multiple Attenuation) - Shallow data only
  - SRME (Free Surface Related Multiple Elimination)
- Zero Phase Operator
- Resample to 4ms and Trace Decimation (as needed) with Spatial anti-aliasing
- Merge line segments
- High resolution parabolic radon de-multiple
- Apex-shifted multiple attenuation (ASMA)
- Residual noise attenuation, Phase only Q, and TVF
- Geometrical spreading correction removed
- Pre-stack time and depth migration
- Post processing

De-bubble Filter

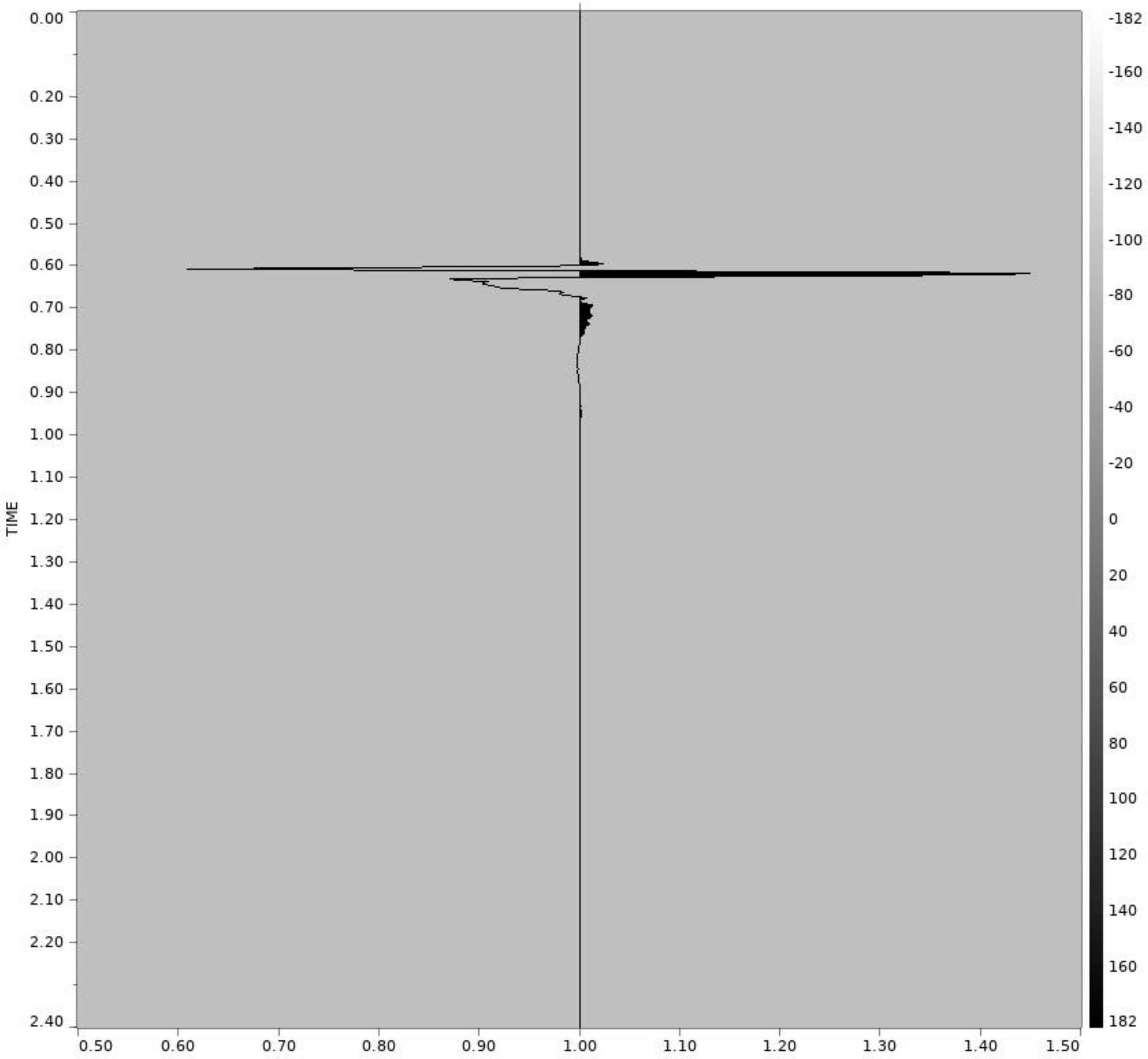
- The aim of debubble is to remove the bubble train from the acquired wavelet.
- An input signature was derived from the data by flattening and stacking nearest offset small angle traces at the water-bottom. Geology stacked out well, and a good representation of the signal resulted, containing the real ghost notches and bubble energy
- A gapped deconvolutional operator was designed and optimized and an operator obtained which removed the bubble train present in the wavelet.
- The periodic bubble train in the wavelet was successfully deconvolved, leaving minimal residual bubble energy in the seismic.

- One signature for entire 2021 survey is derived from the near offset data (0-500m)
- Initial De-bubble filter was derived from data driven signature
- Bubble energy was found to be present up to 40-45Hz
- Final de-bubble filter was derived to work on the frequency range of 3-5-40-45Hz only

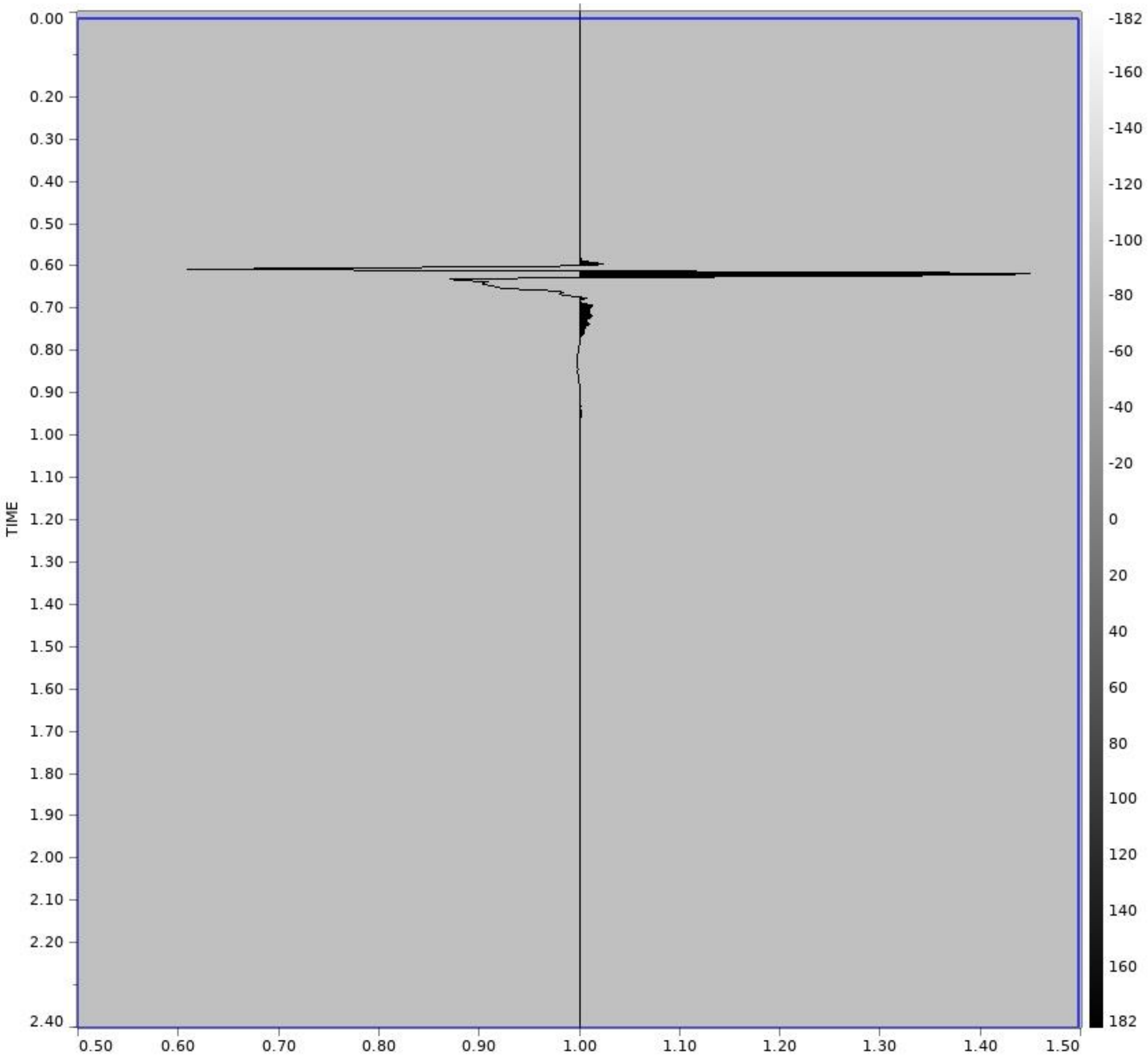
MGL2104 survey: Data Derived Signature before De-bubble



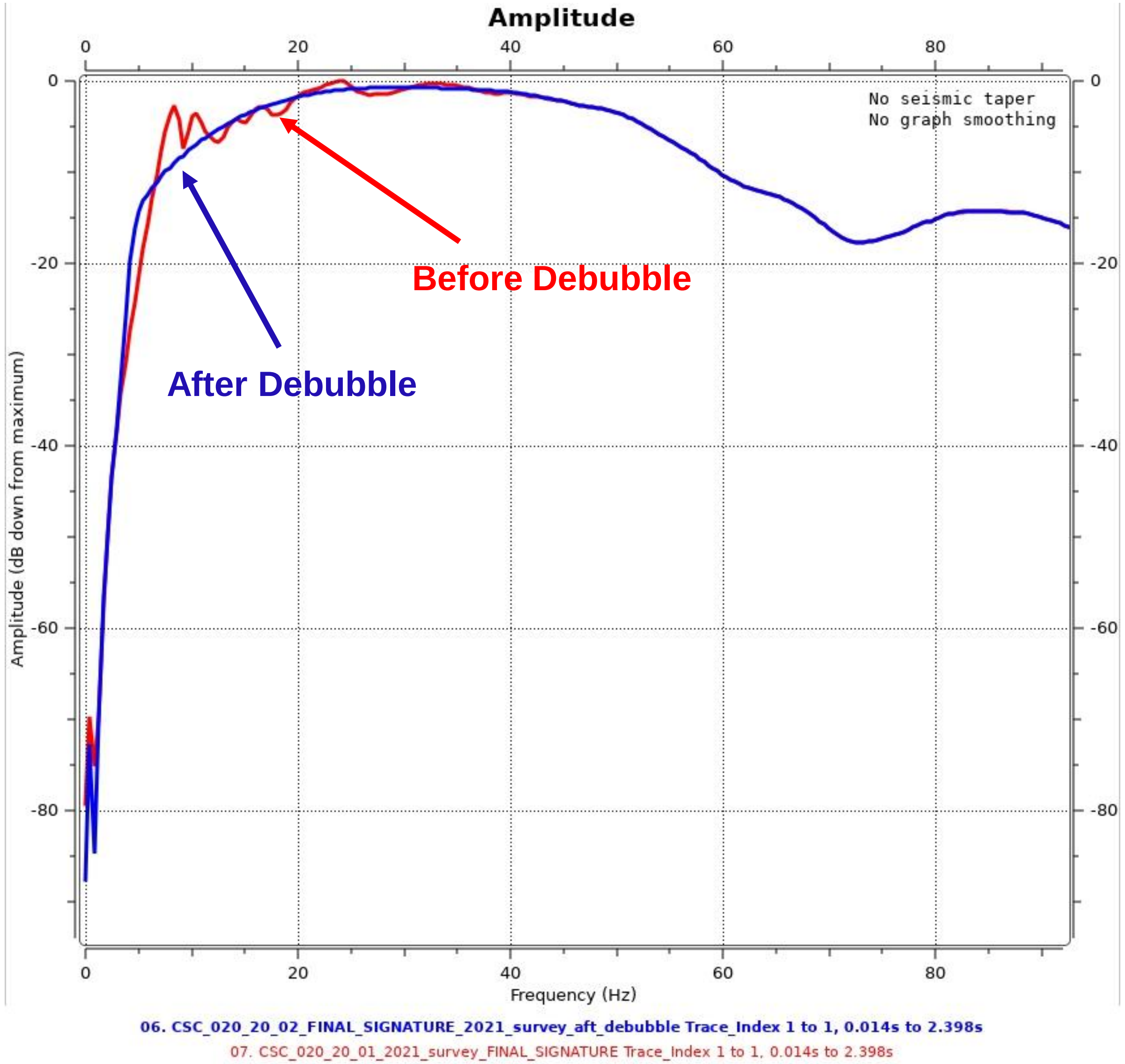
MGL2104 survey: Data Derived Signature after De-bubble



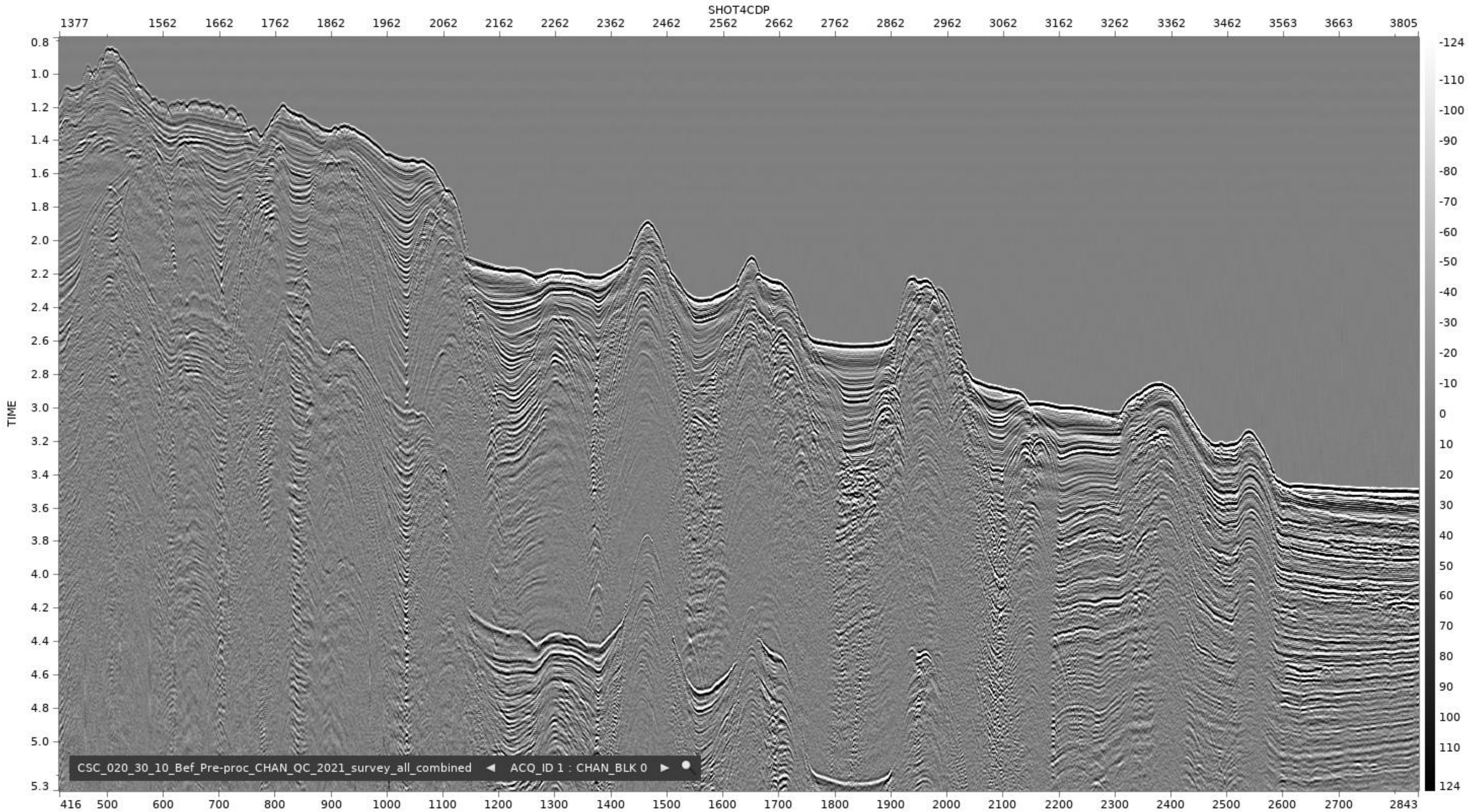
Amplitude Spectra Analysis Window (blue box)



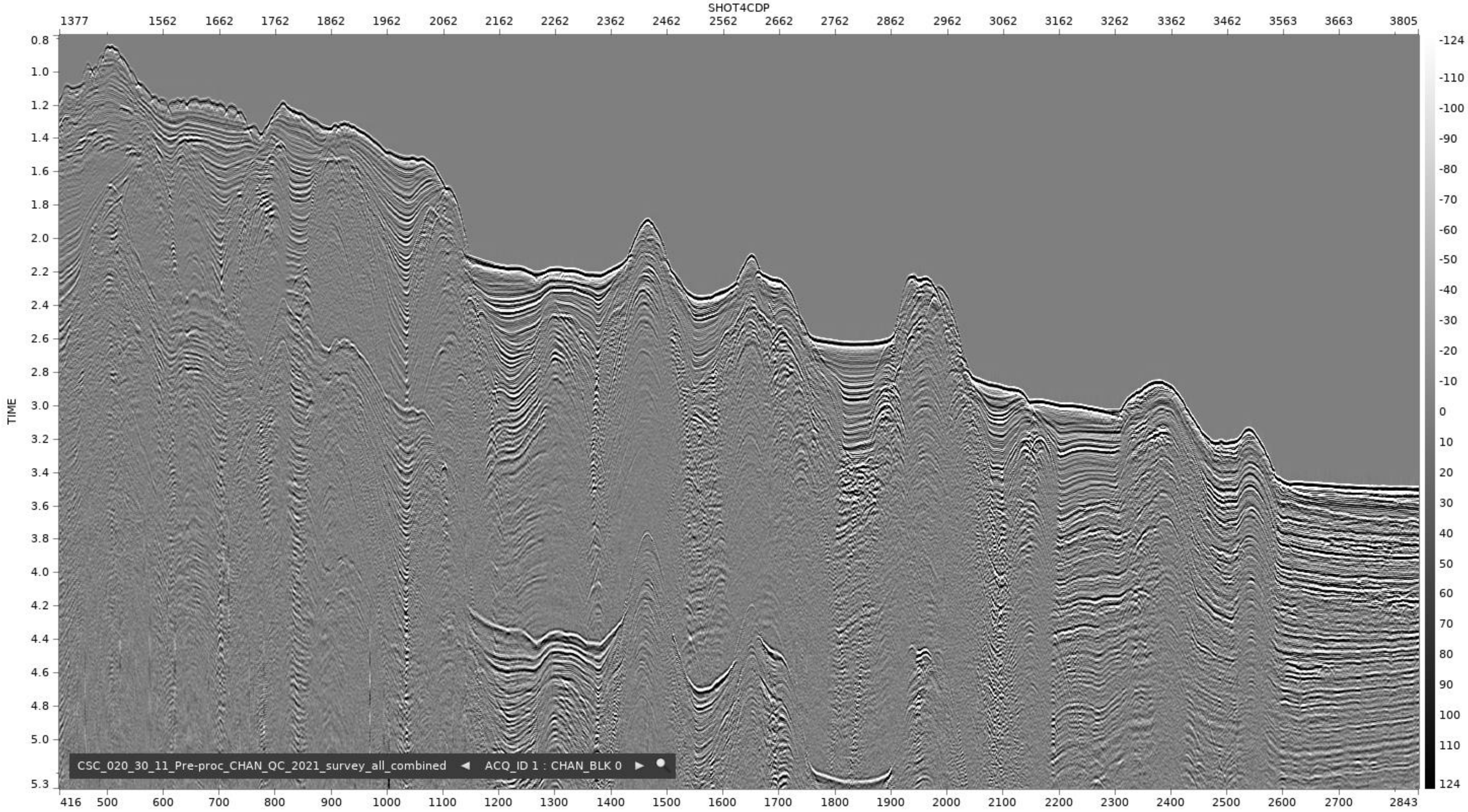
Amplitude Spectra



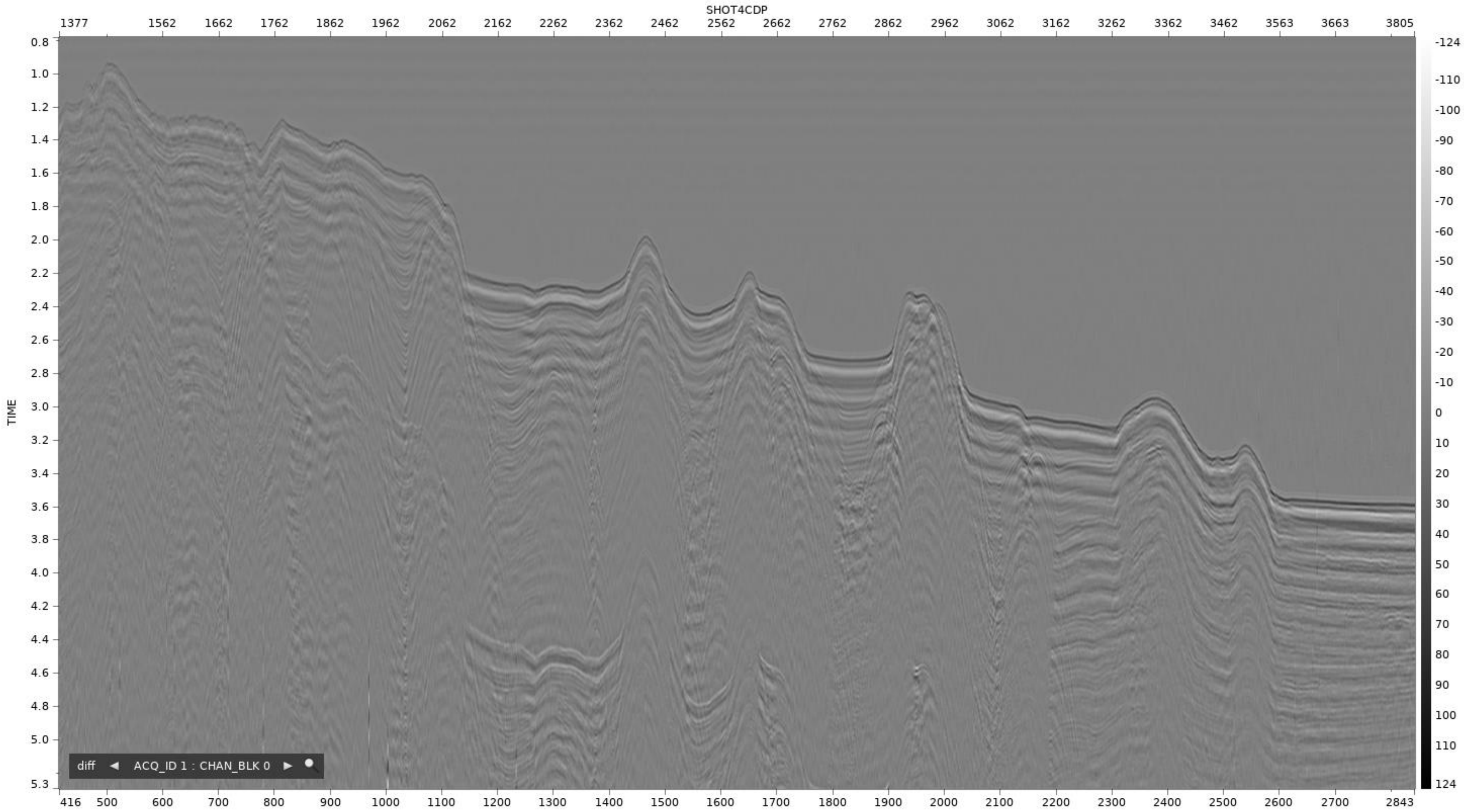
MGL2104PD09 : CHAN 1 before De-bubble



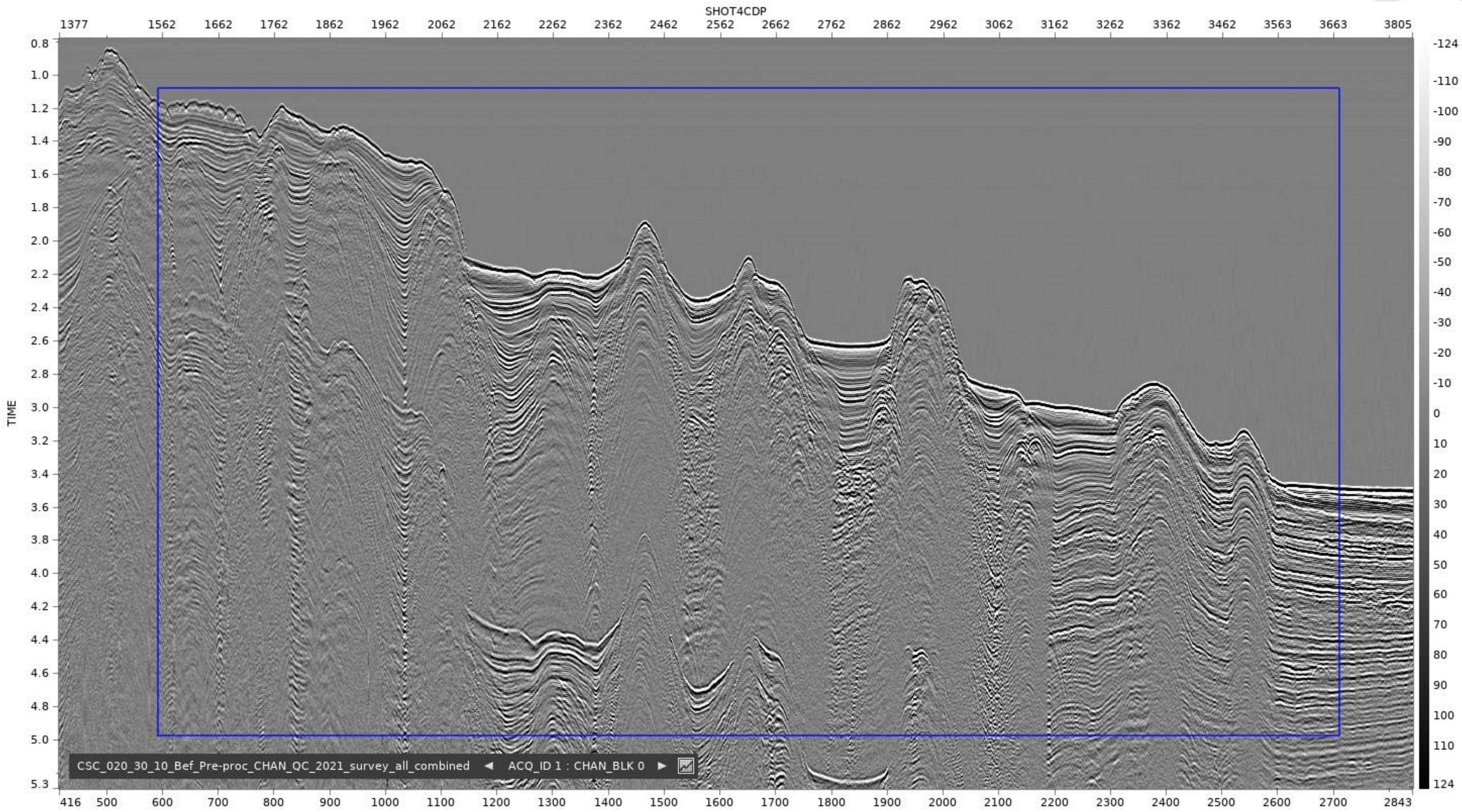
MGL2104PD09 : CHAN 1 after De-bubble



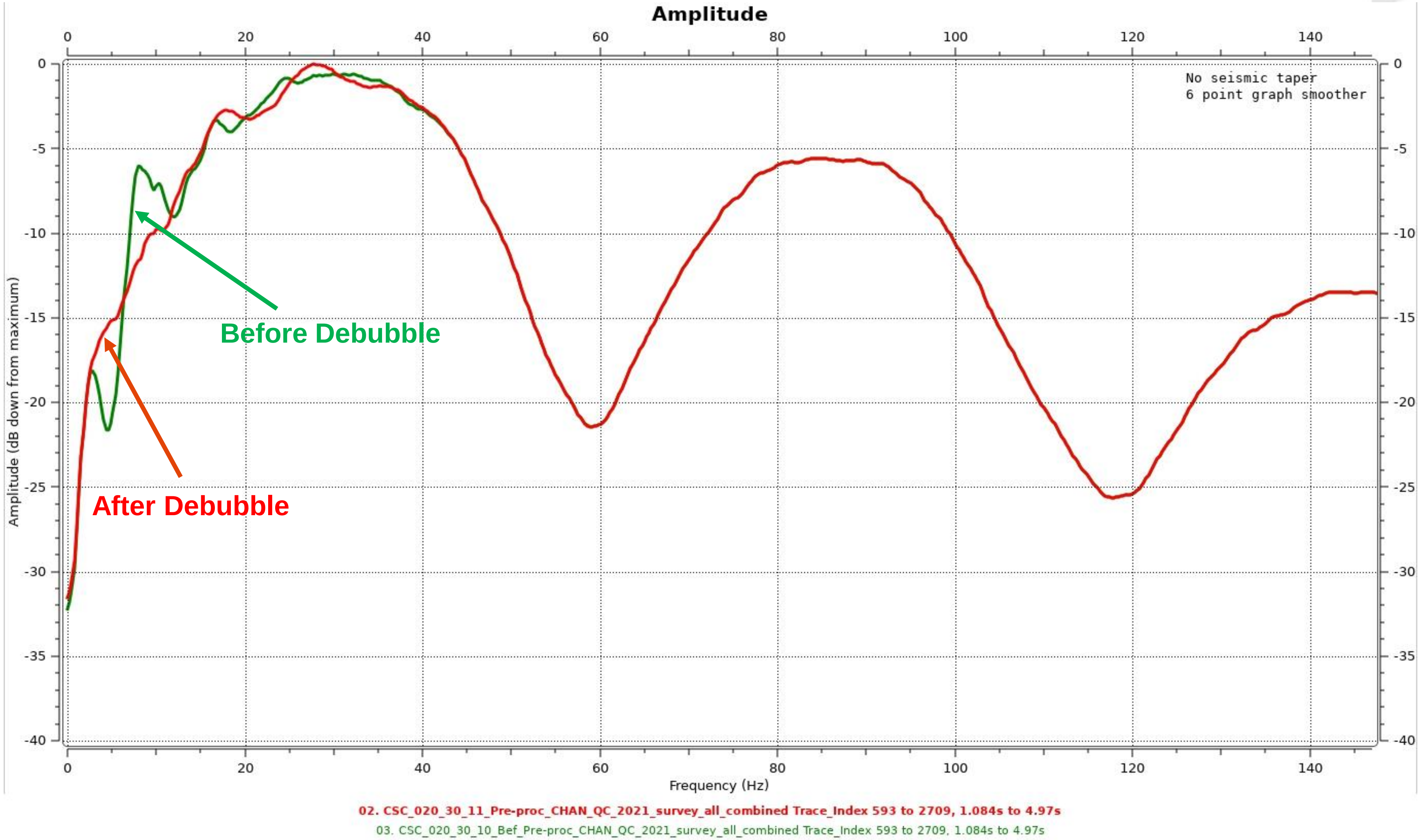
MGL2104PD09 : CHAN 1 difference De-bubble



MGL2104PD09 : Amplitude Spectra Analysis Window (blue box)



MGL2104PD09 : Amplitude Spectra



Noise Attenuation

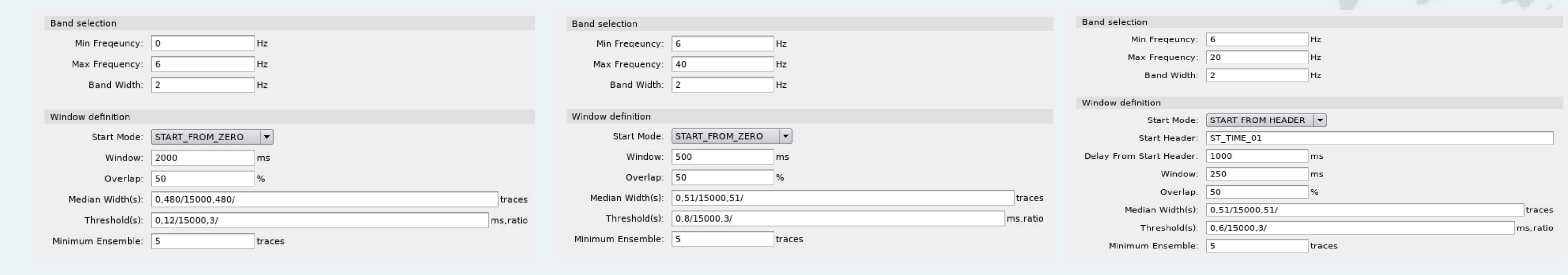
- **Swell noise attenuation:**
  - Input data is sorted into different domains (gathers, shots, channels).There are user specified frequency bands, and temporal and spatial windows tested for each survey. Each window is analyzed for each frequency band, and the median amplitude is calculated within that window. The program takes the ratio of the median trace to all other traces within that window and if the ratio of any trace in that window exceeds the user specified threshold it will get attenuated.

- **Strum and linear noise attenuation**:
  - Radial Domain filter is used to address strum noise.
  - Shot records were mapped into the radial domain at user specified velocity dips. The choice of dip velocities was the key focus of the testing. A high cut 'filter' was then applied in radial domain, retaining any very low 'apparent frequency' events, which corresponded to linear dipping noise in shot domain with the specified velocity. Finally, this noise model was subtracted in *x-t* domain.
  - Radial filtering proved extremely effective at attenuating low frequency, low velocity noise while preserving under-lying primary signal. Note: The process was parameterized with dip velocities slower than water velocity to safely ensure that no primary would be damaged.

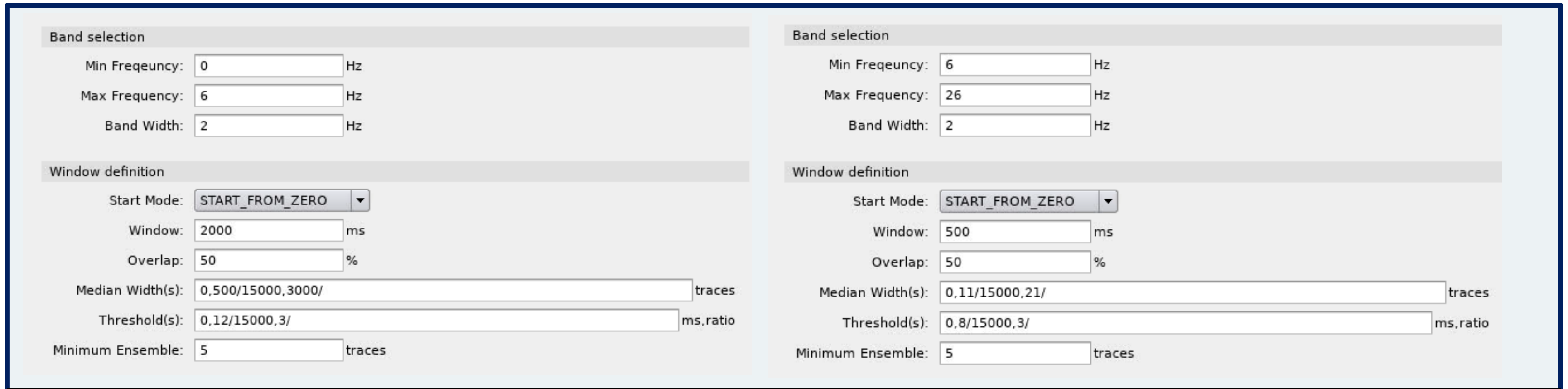
Noise Attenuation

- Denoise flow is comprised of the following:
  - De-spike to remove large spikes
  - SHOT domain denoise - 3 passes – Low, Mid and High frequency targeted
  - CHAN domain denoise - 2 passes – Low, Mid and High frequency targeted
  - Linear noise attenuation with Radial filter to address Strum noise
  - Dips used in linear noise modelling **(m/s) – 100, 300, 500, 700, 900, 1100, 1300, 1370**

Shot and Channel domain denoise pass parameters



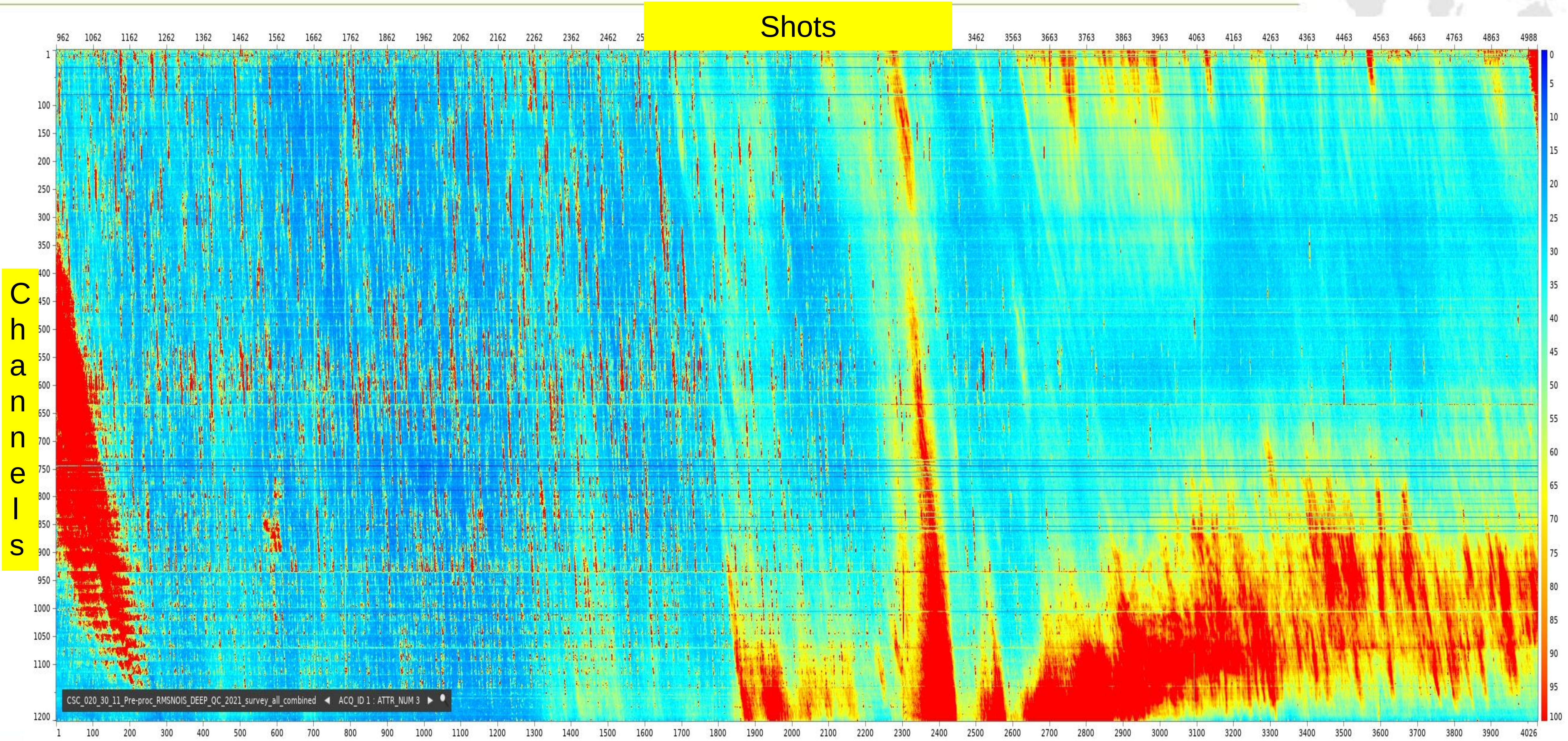
Shot domain denoise pass 1,2 & 3



Channel domain denoise pass 1,2

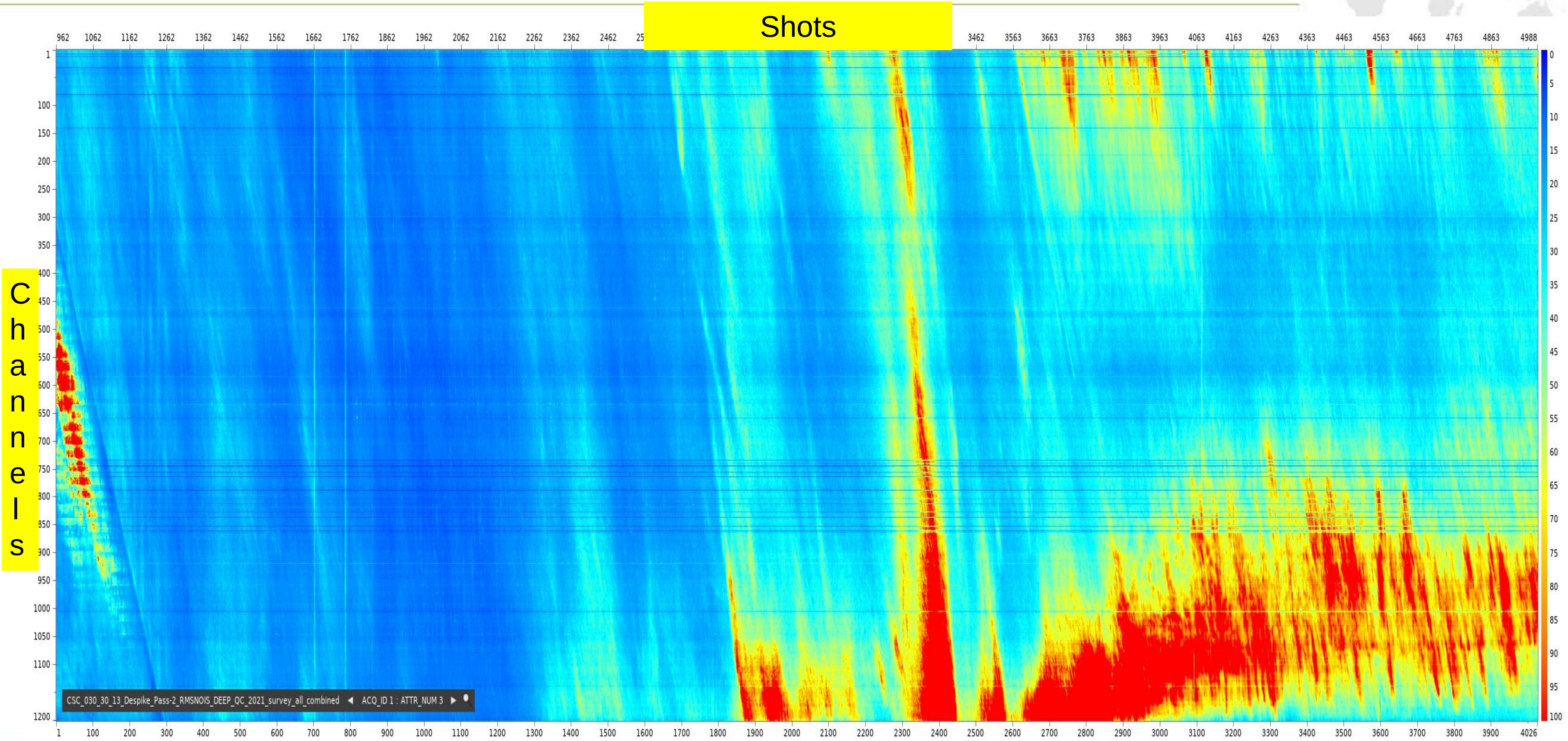
MGL2104PD09 : RMS Amplitude Deep Window (14300-14800ms)

Before De-noise

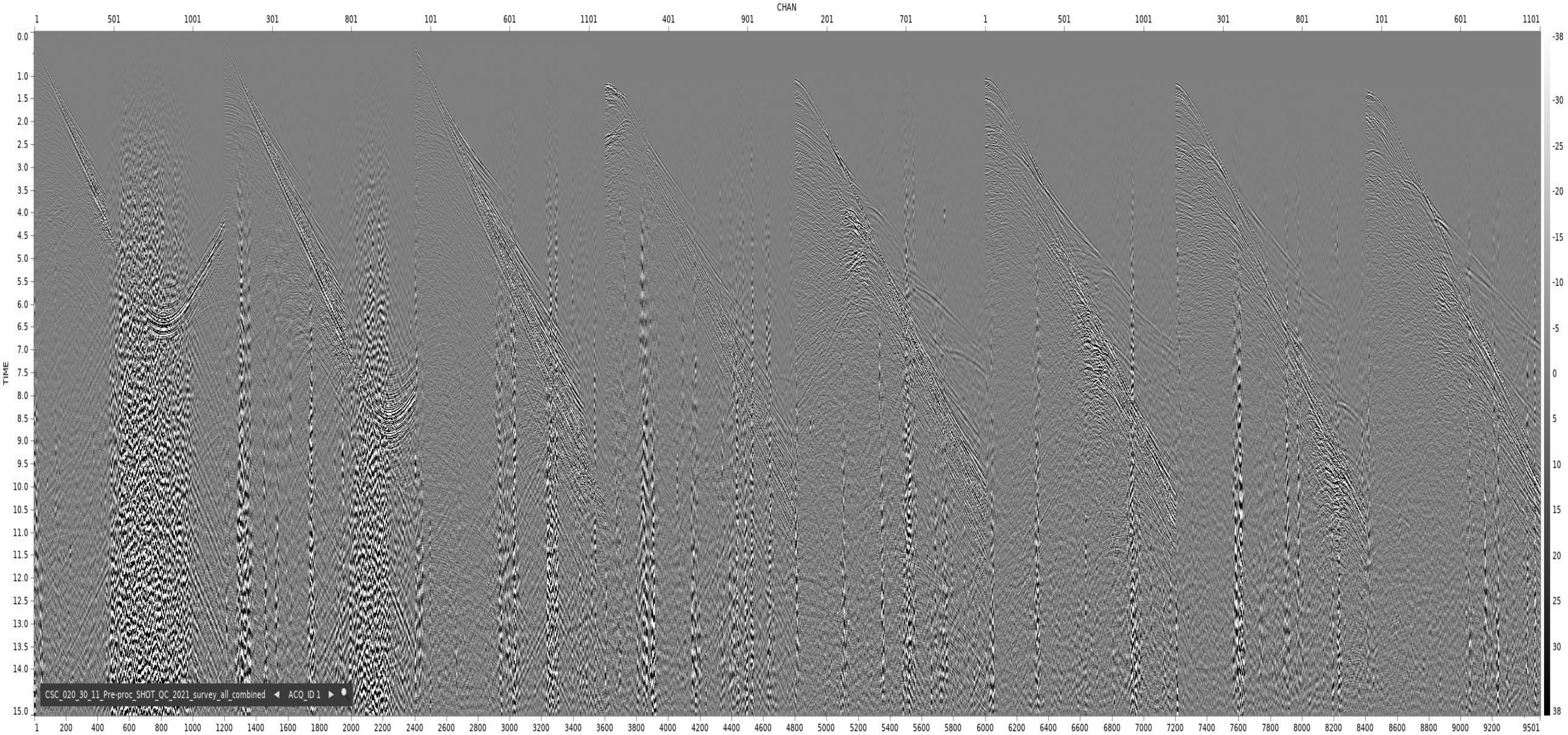


MGL2104PD09 : RMS Amplitude Deep Window (14300-14800ms)

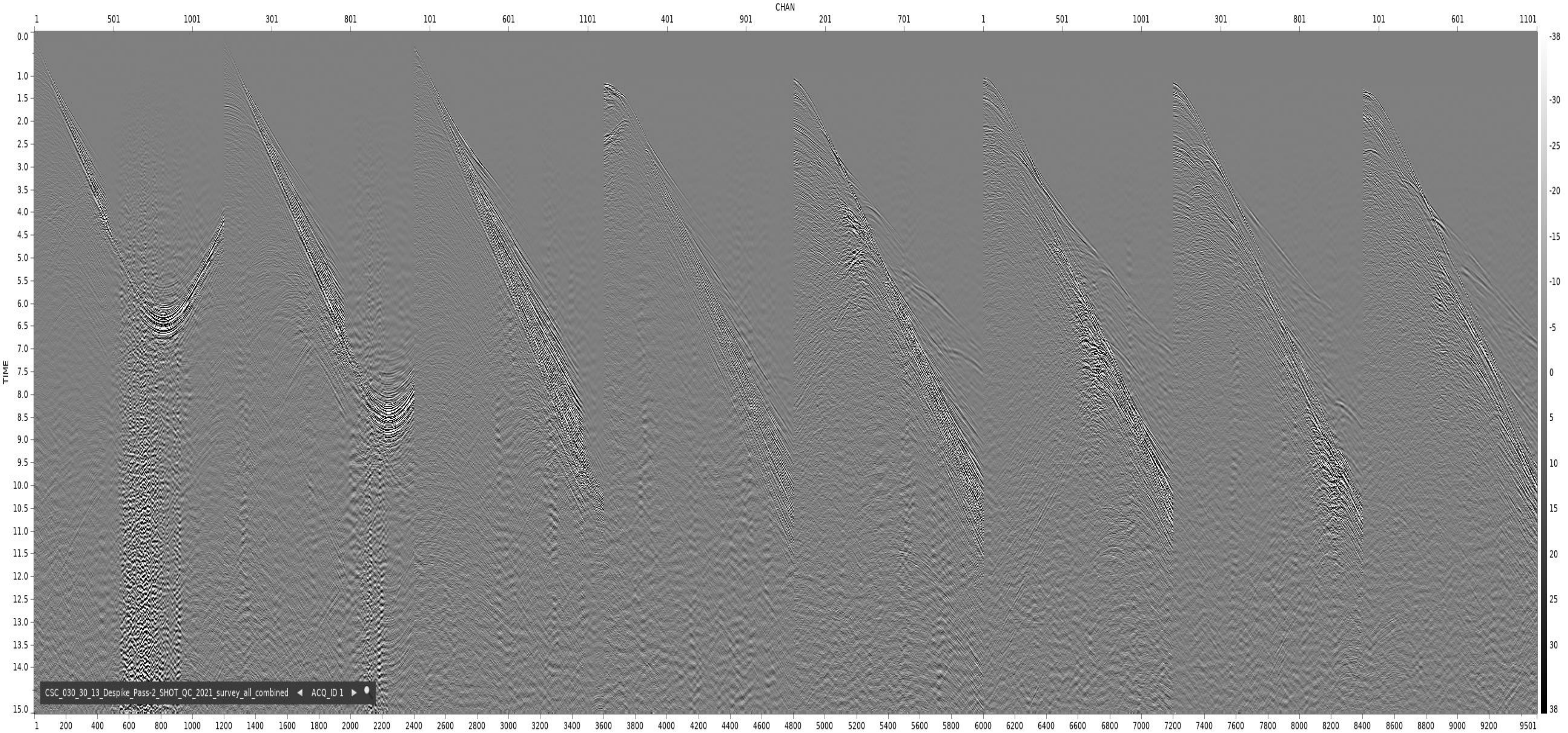
After De-noise



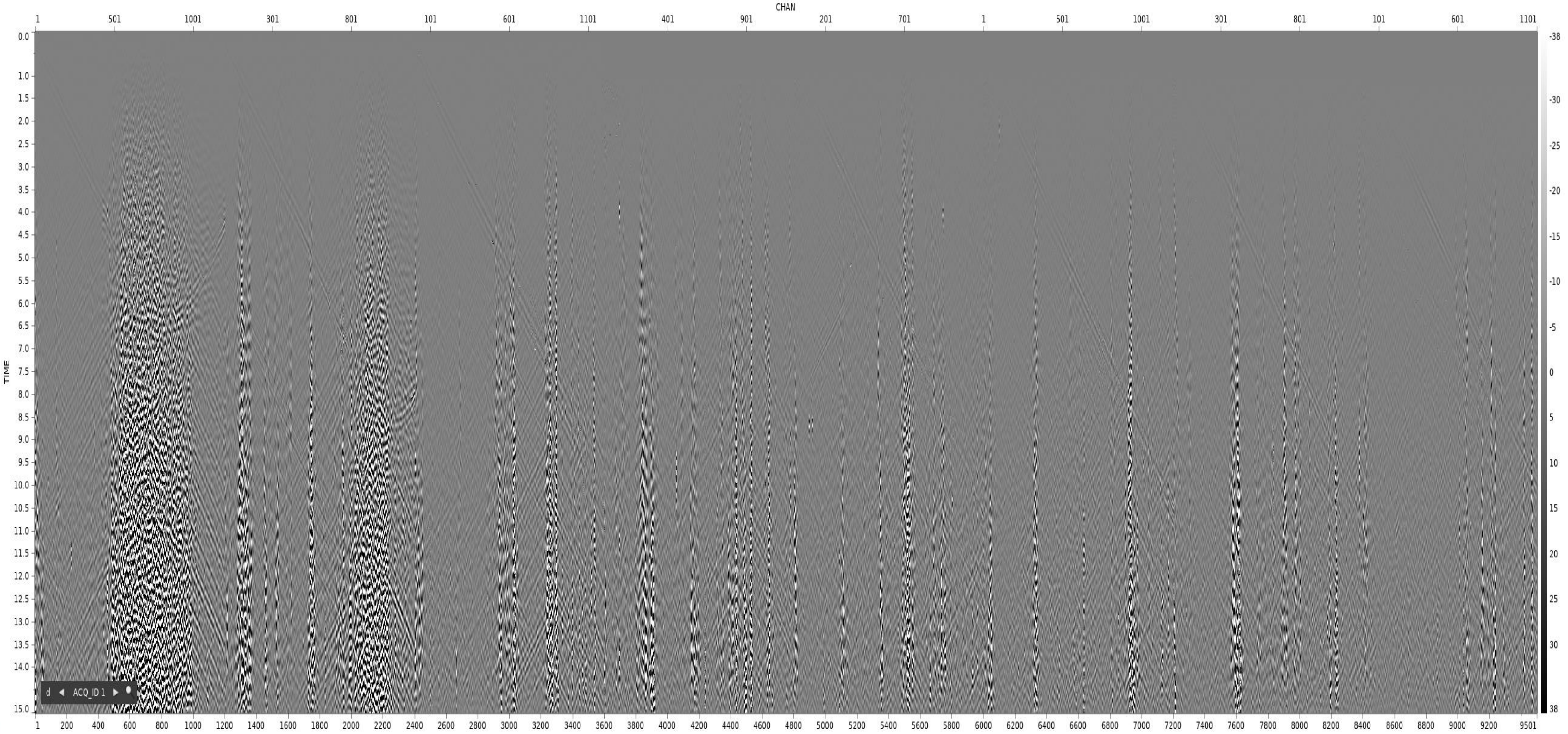
MGL2104PD09 : SHOT GATHERs before De-noise



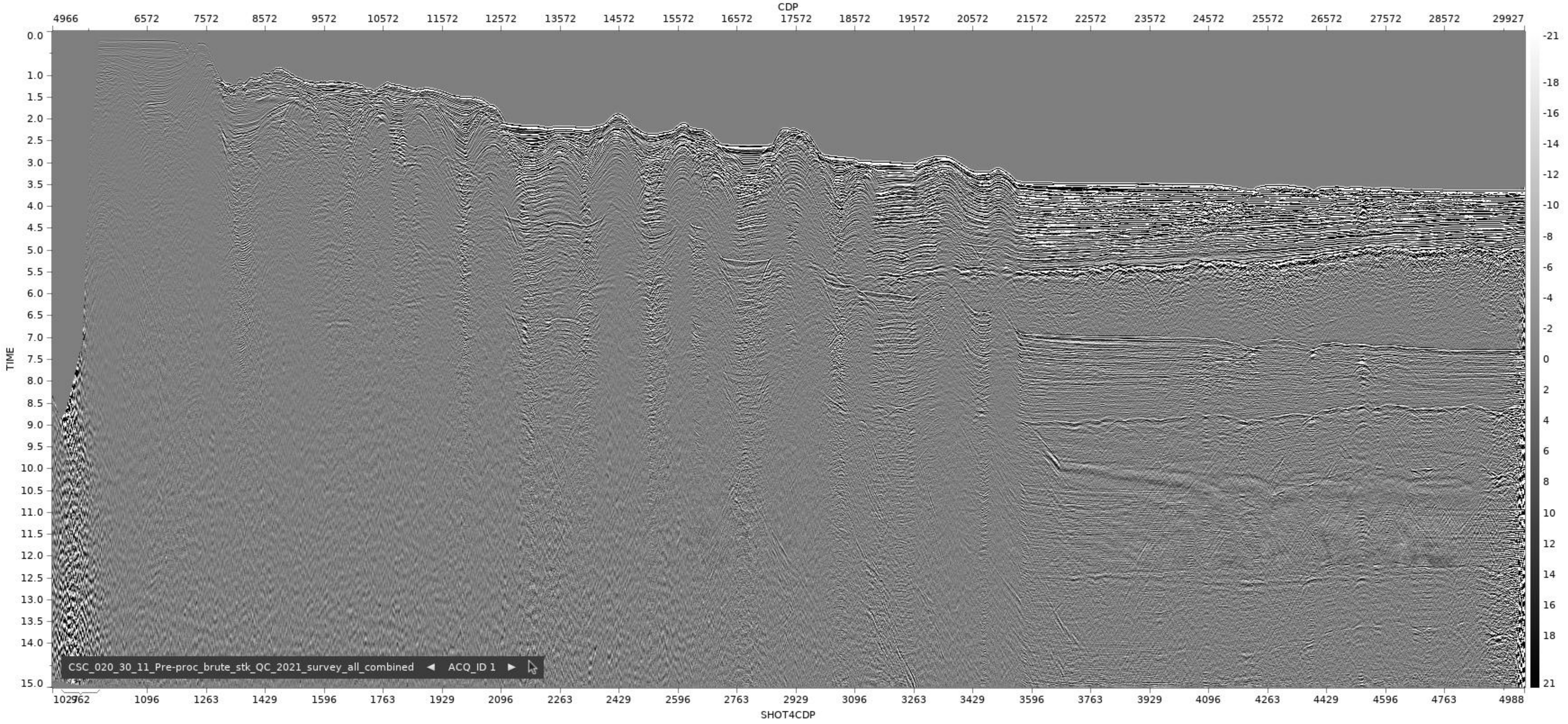
MGL2104PD09 : SHOT GATHERs after De-noise



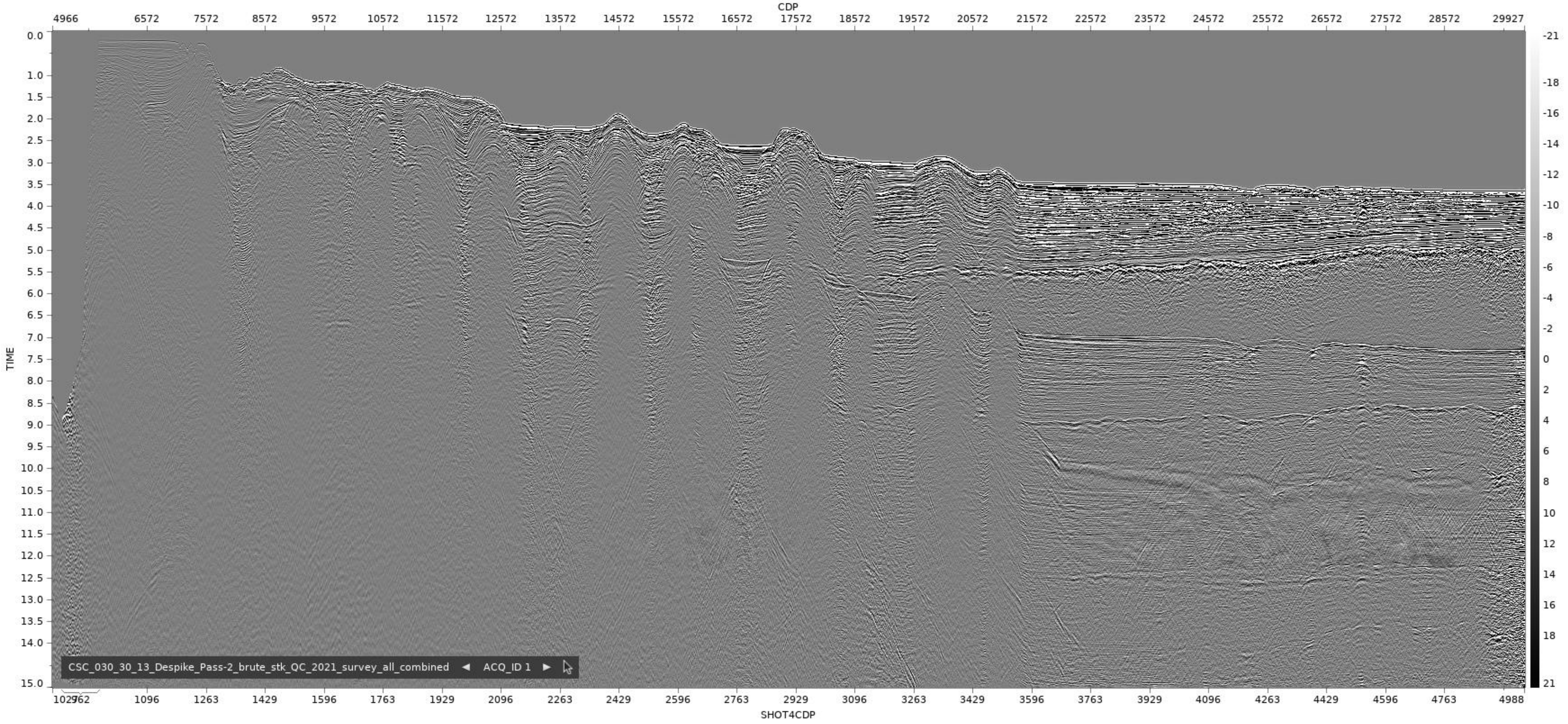
MGL2104PD09 : SHOT GATHERs difference De-noise



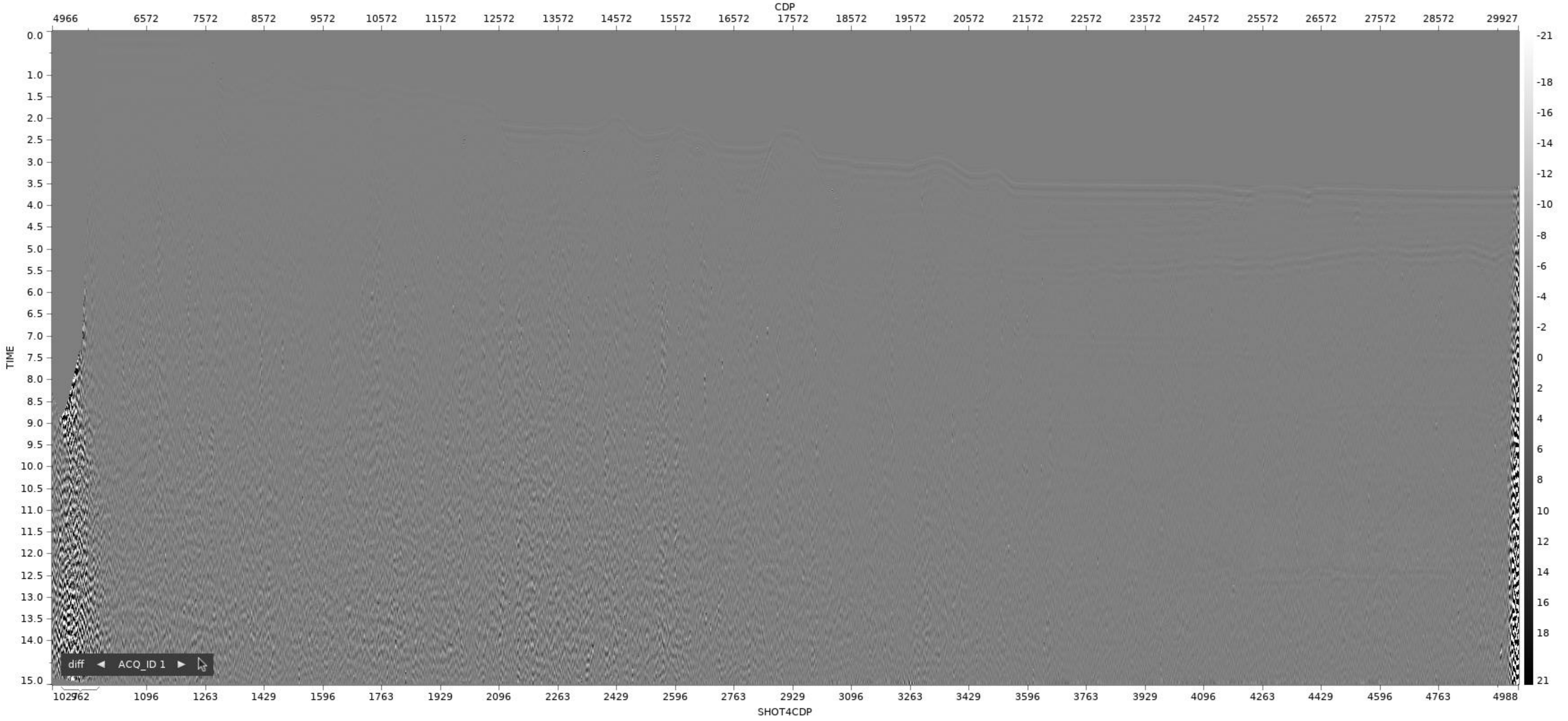
MGL2104PD09 : BRUTE STACK before De-noise



MGL2104PD09 : BRUTE STACK after De-noise

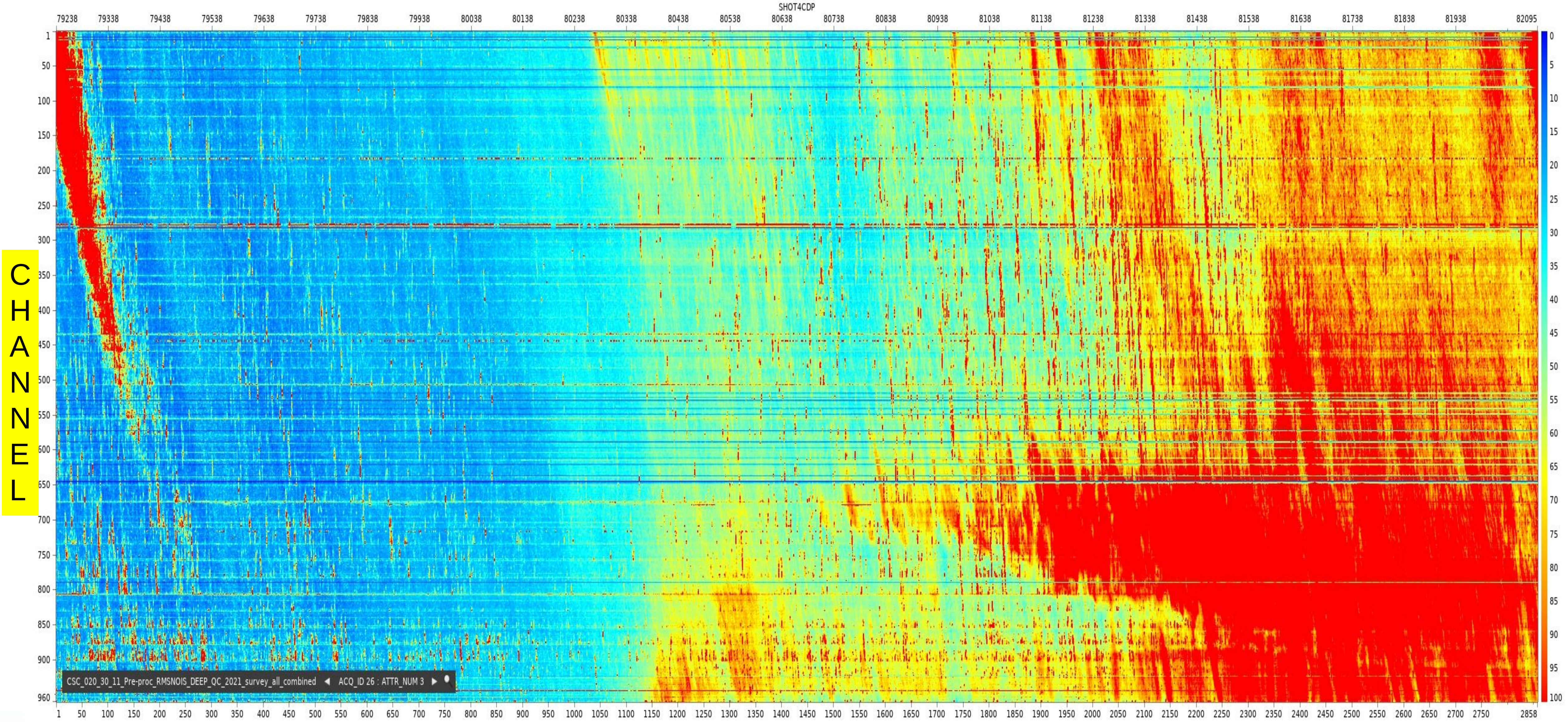


MGL2104PD09 : BRUTE STACK difference De-noise

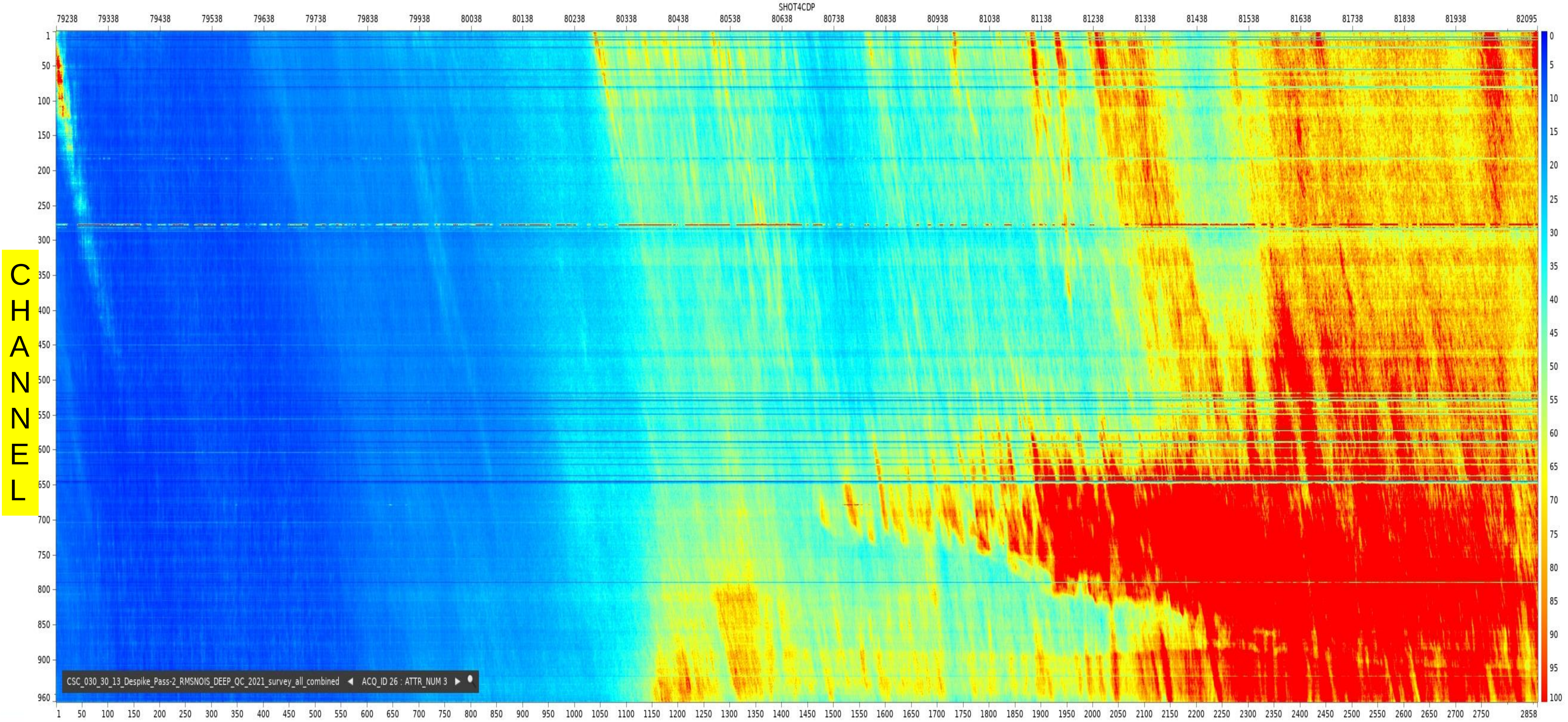


MGL2104PD14 : RMS Amplitude Deep Window (14300-14800ms)

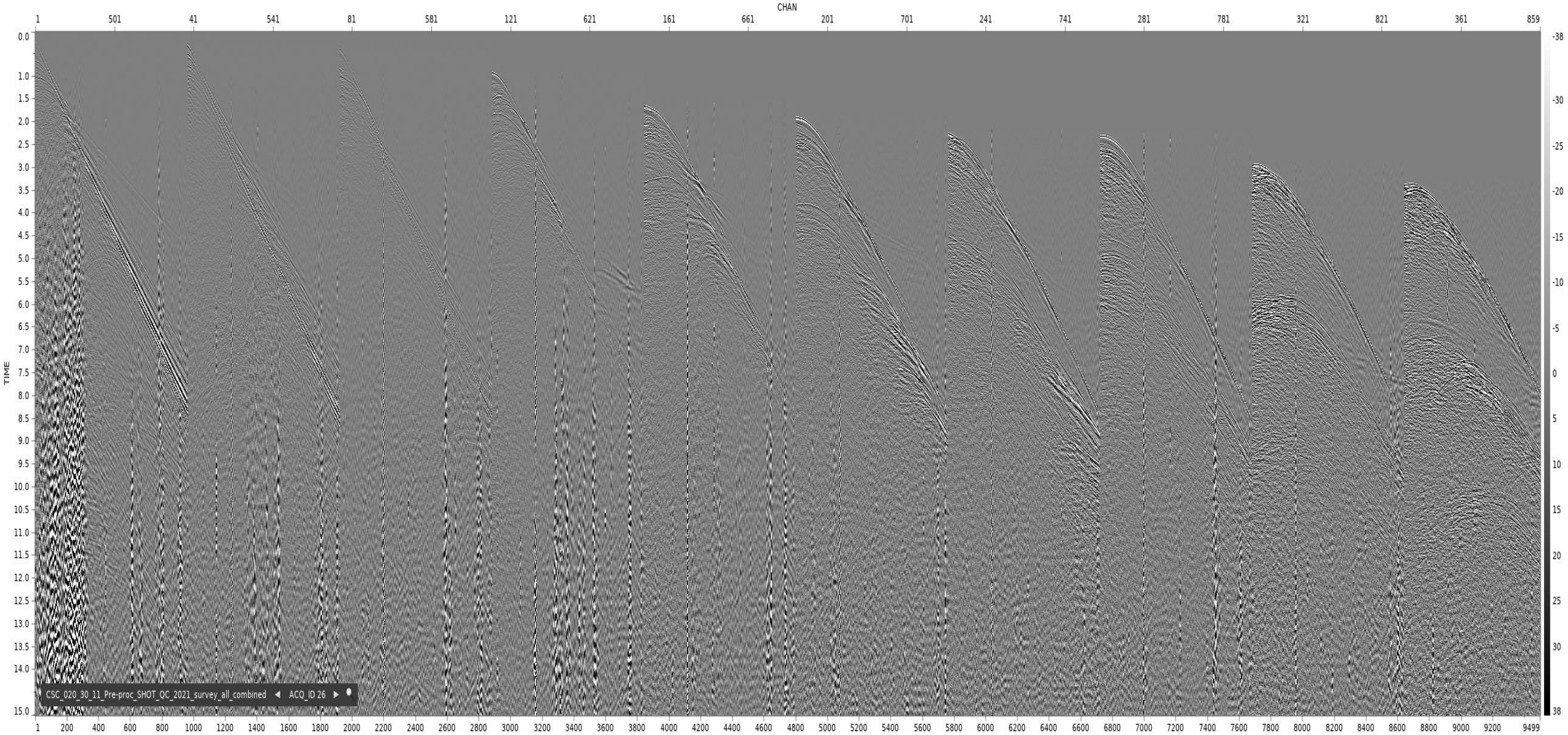
Before De-noise



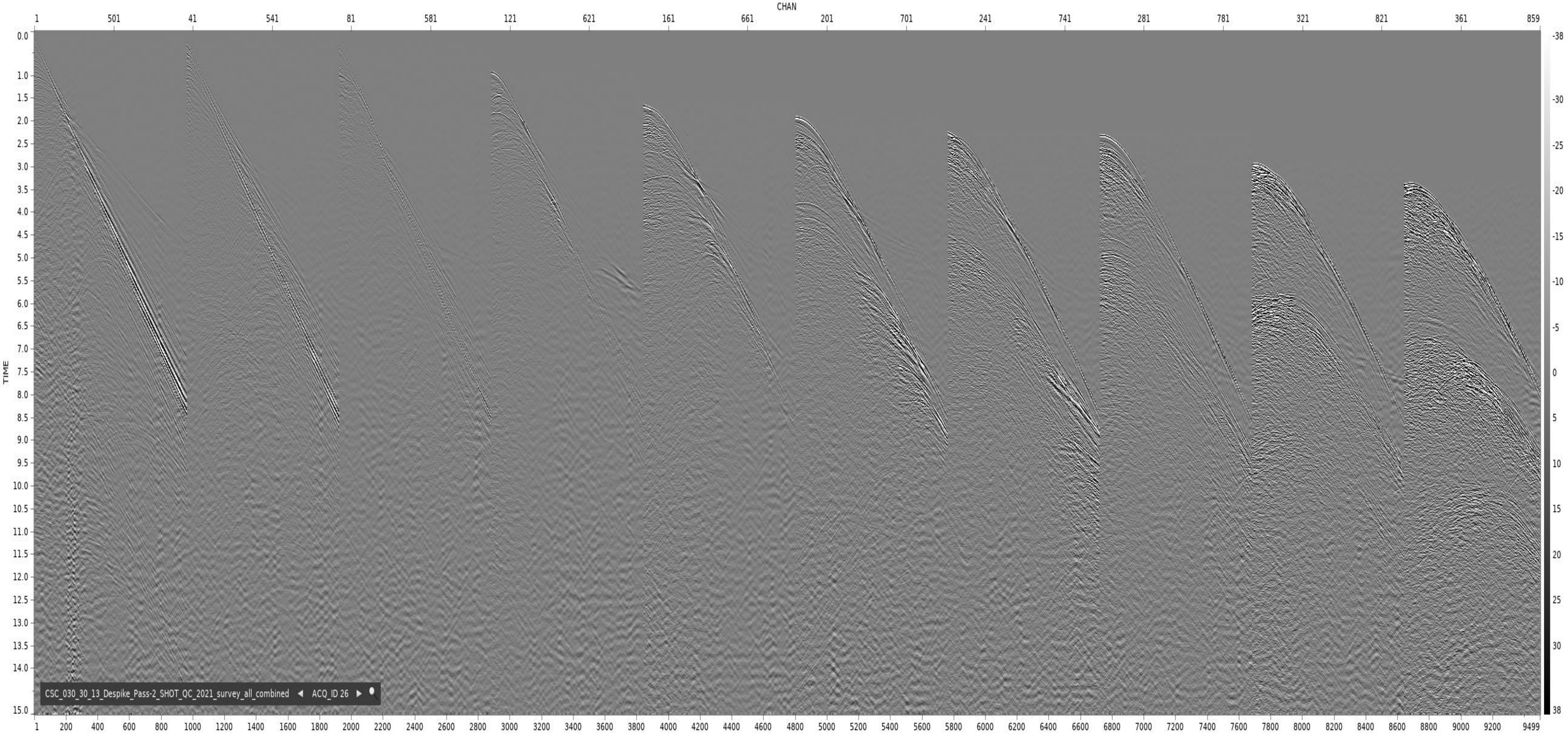
MGL2104PD14 : RMS Amplitude Deep Window (14300-14800ms)
After De-noise



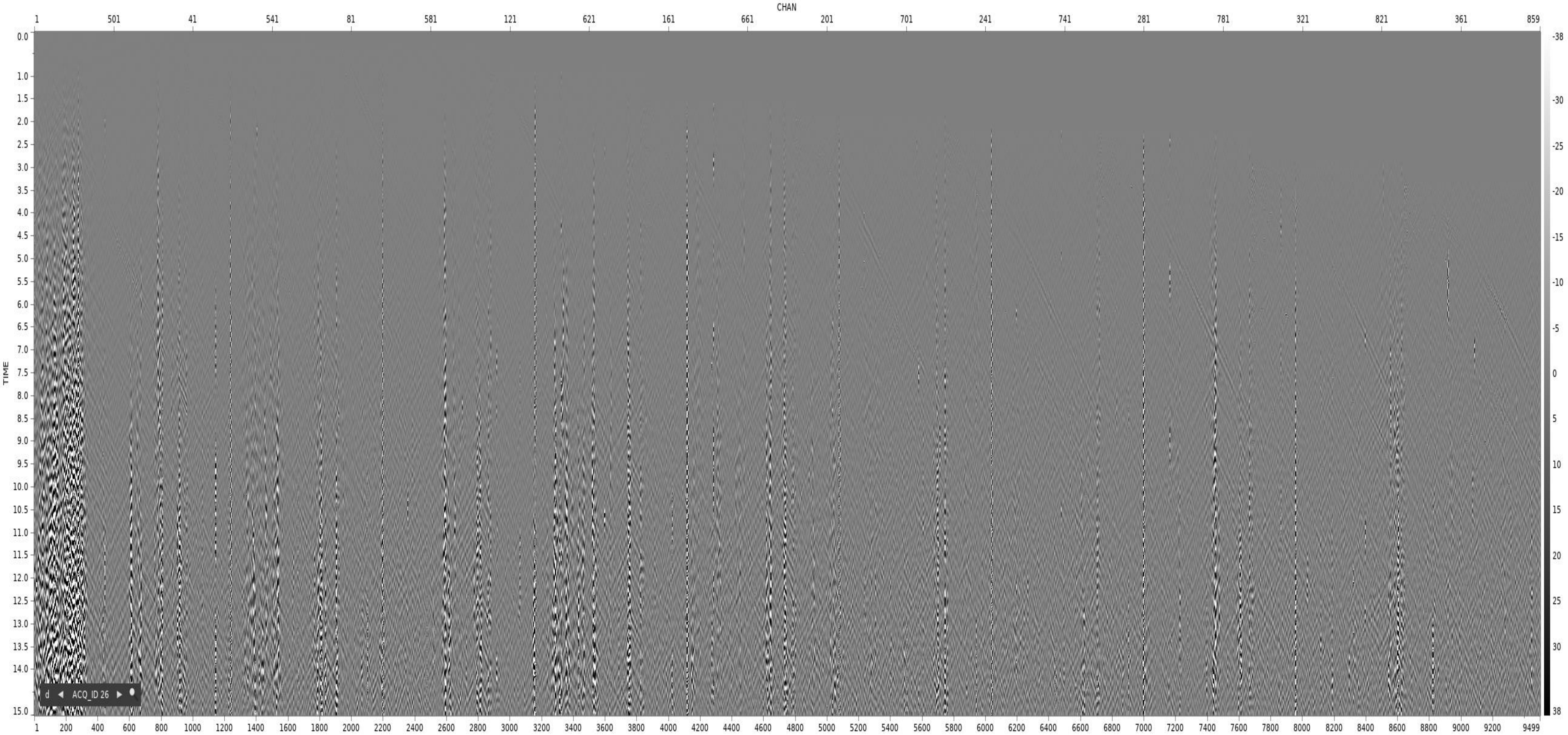
MGL2104PD14 : SHOT GATHERs before De-noise



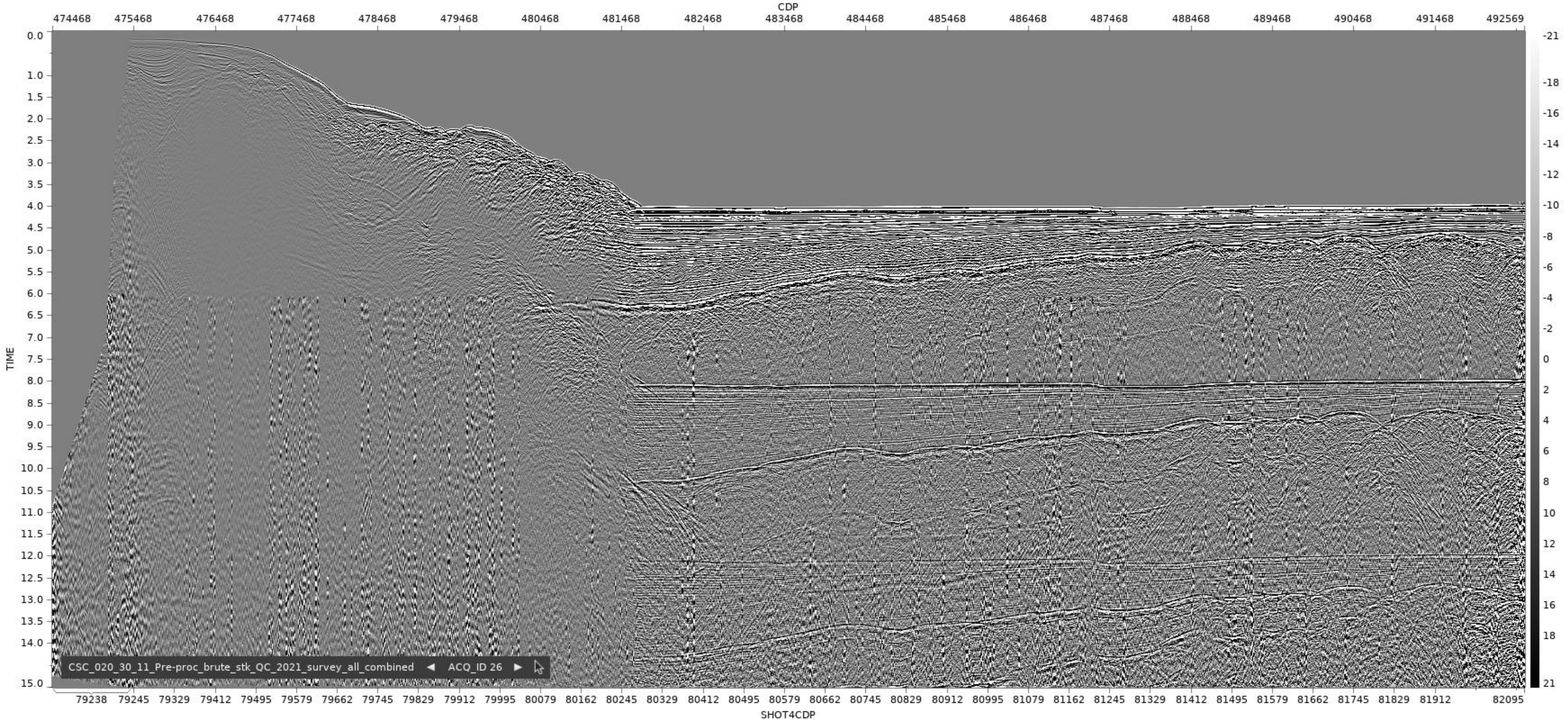
MGL2104PD14 : SHOT GATHERs after De-noise



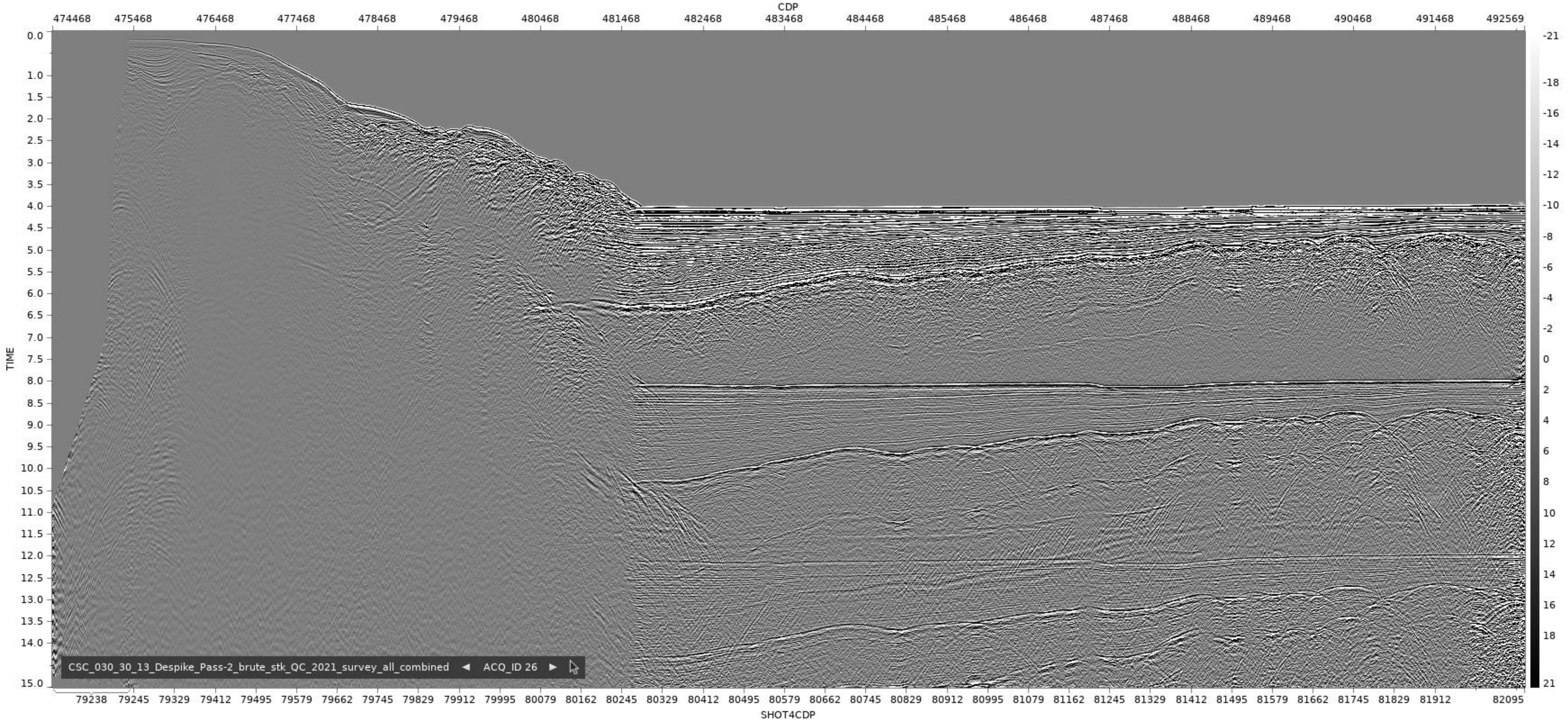
MGL2104PD14 : SHOT GATHERs difference De-noise



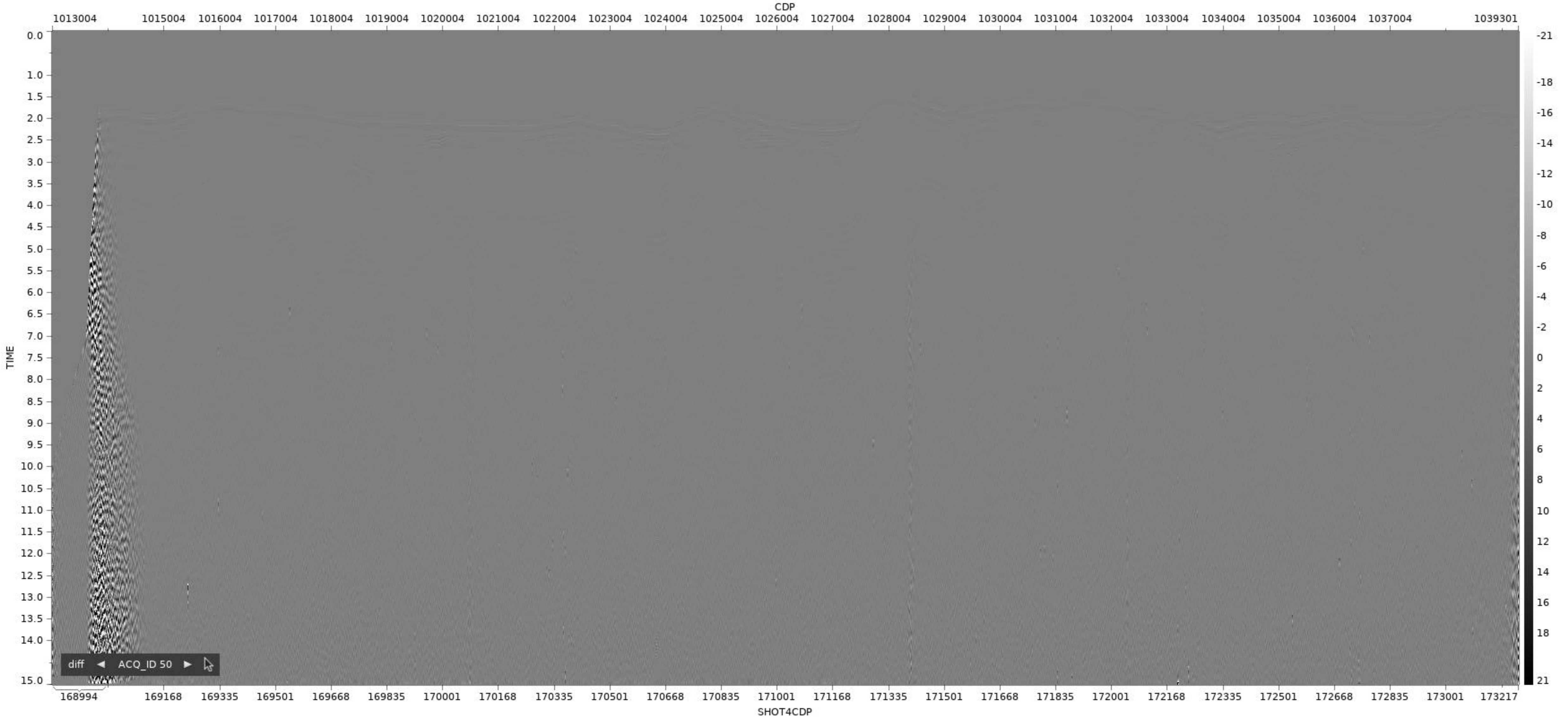
MGL2104PD14 : BRUTE STACK before De-noise



MGL2104PD14 : BRUTE STACK after De-noise



MGL2104PS06 : BRUTE STACK difference De-noise

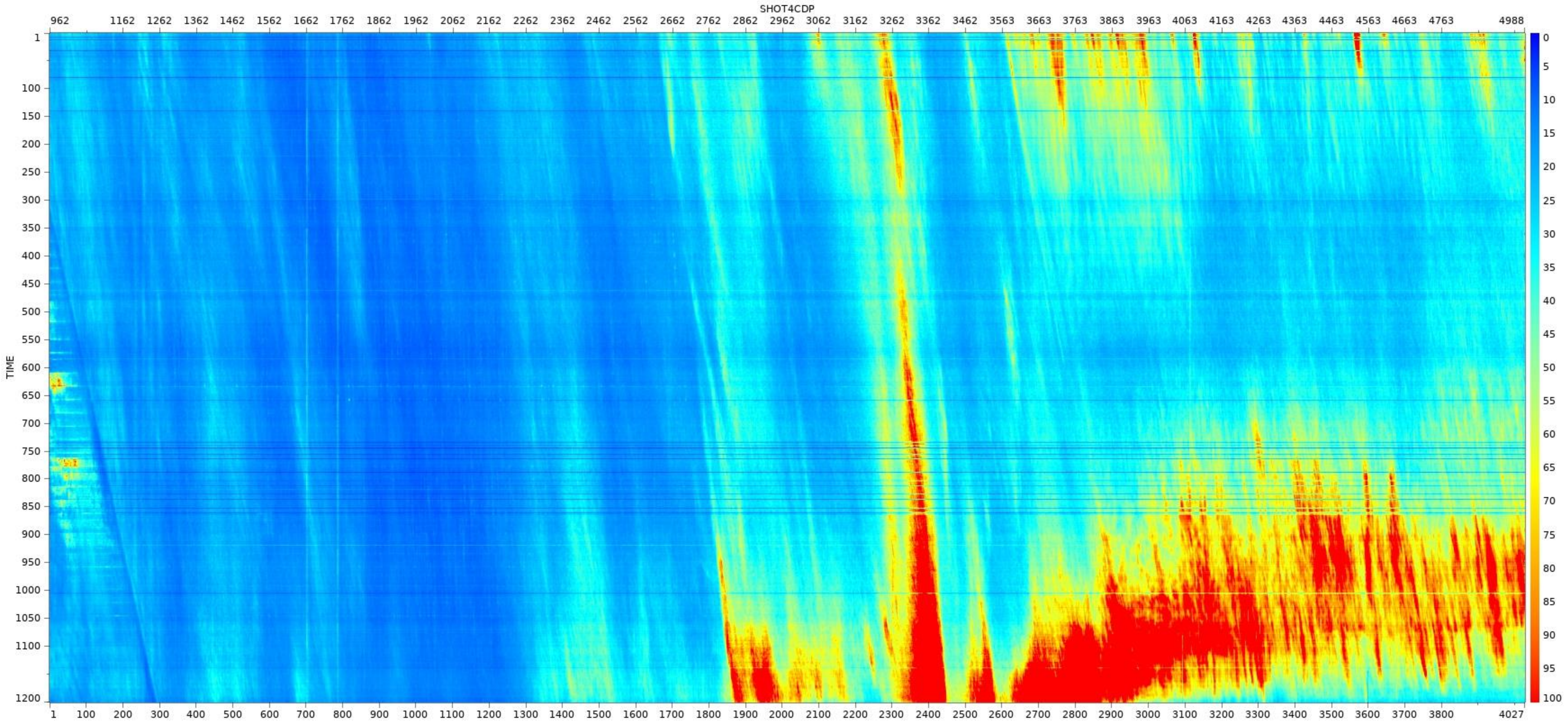


Acquisition Footprint Removal – Channel Corrections

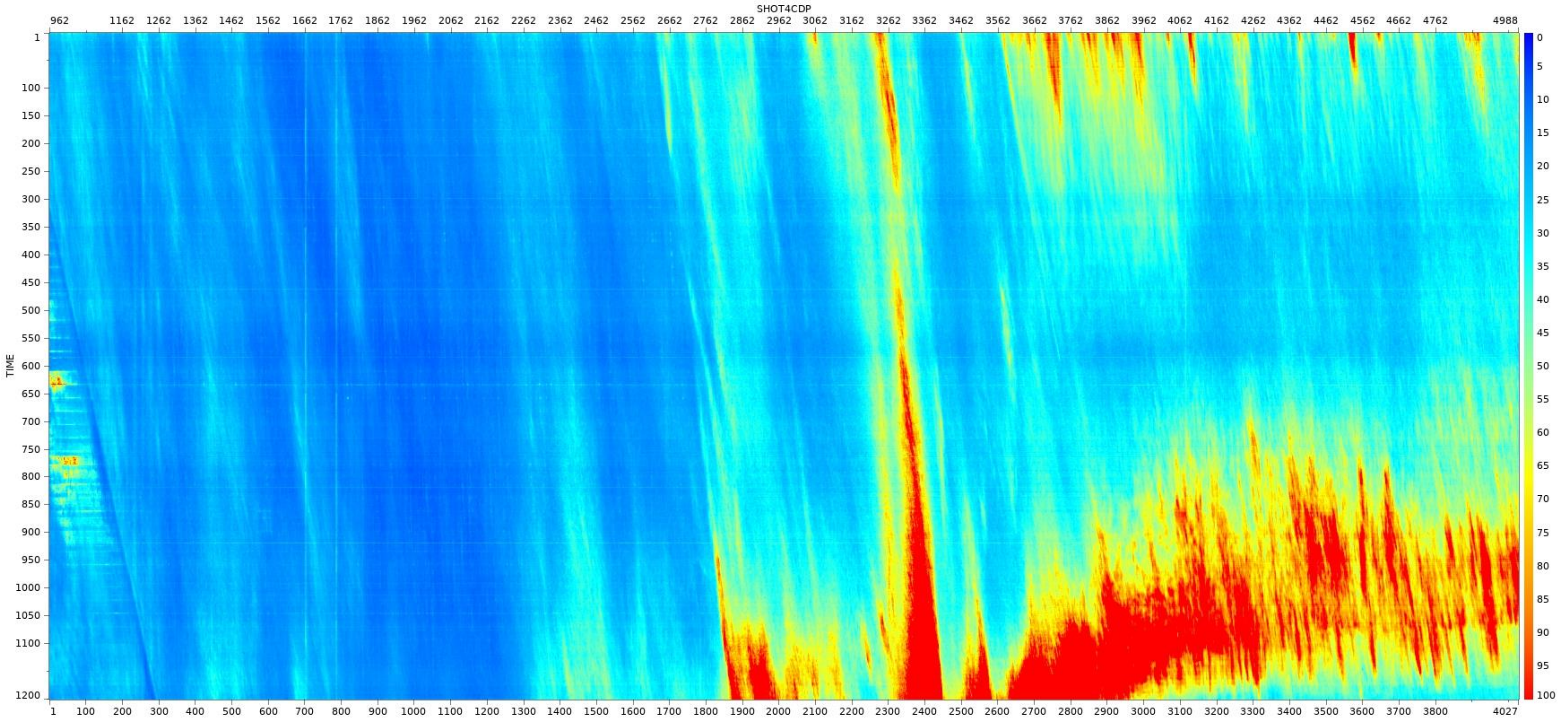
- Absolute mean amplitude measured in a signal window after application of section based scalars.
- Measured amplitudes are locally smoothed across channels within a cable using a running mean with outlier rejection in order to calculate reference amplitudes. Smoothing window of 15 channels was used.
- Scalars are then calculated for each section based on comparison of reference to measured:

$$scalar = \frac{smoothed}{measured}$$

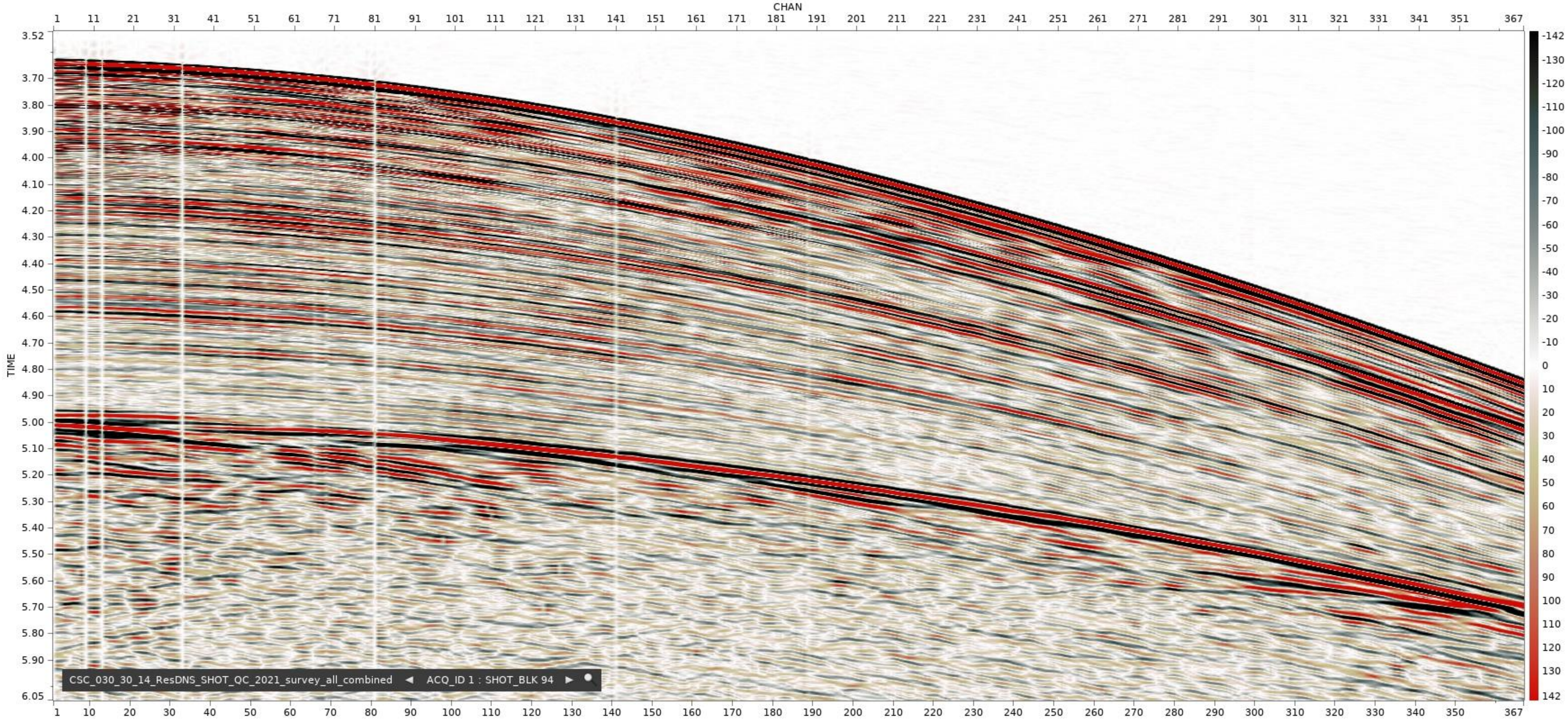
MGL2104PD09 : Deep Window (14300-14800ms) RMS
Before Footprint Attenuation



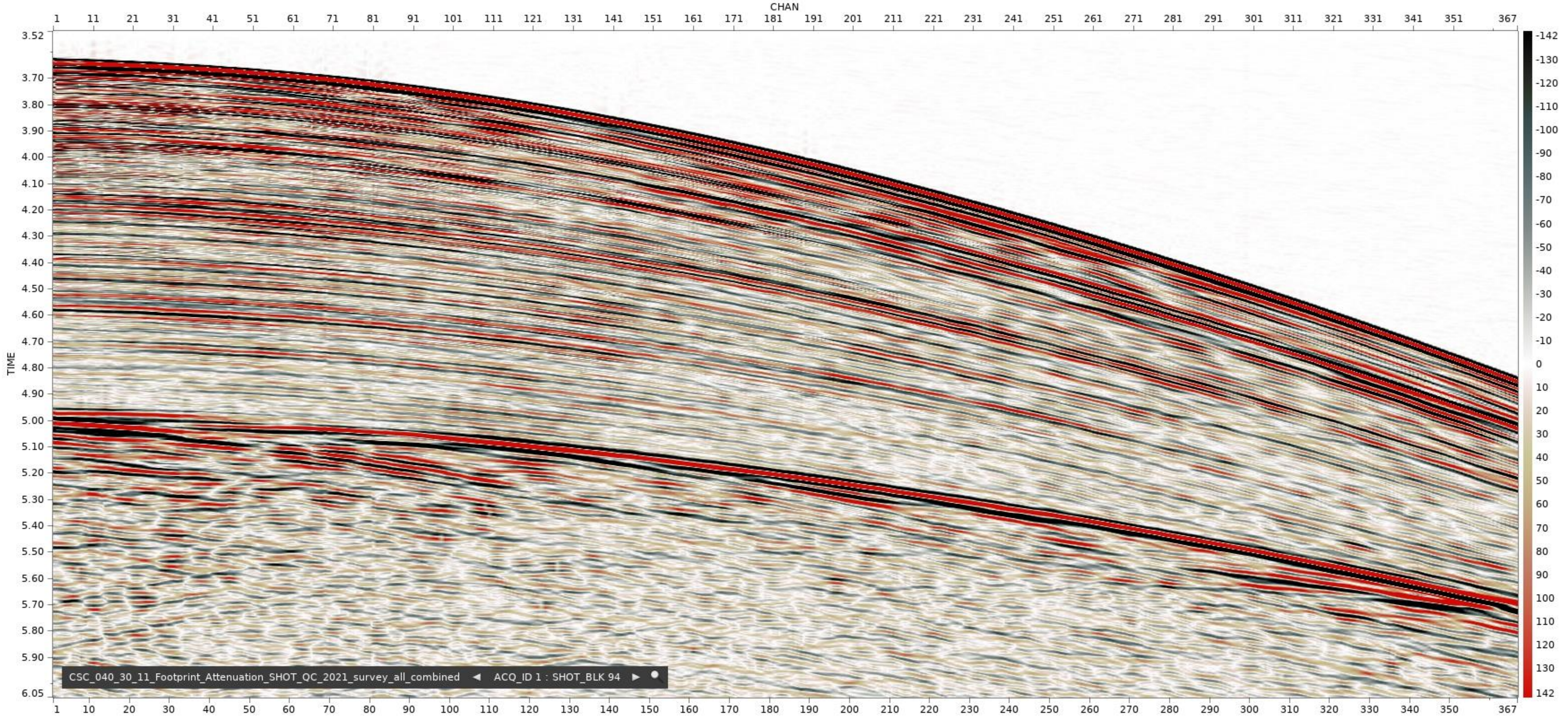
MGL2104PD09 : Deep Window (14300-14800ms) RMS
After Footprint Attenuation



MGL2104PD09 : SHOT Gather before Footprint Attenuation



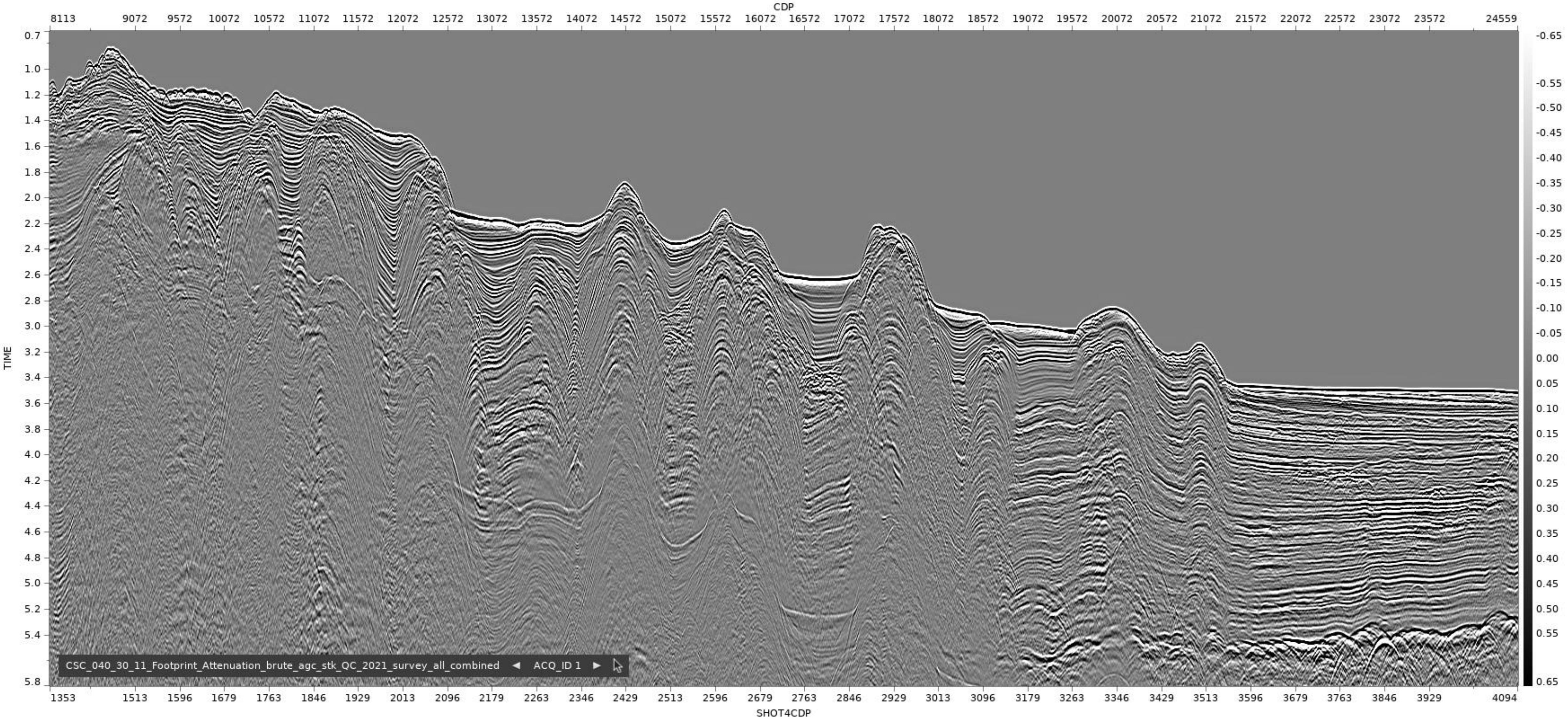
MGL2104PD09 : SHOT Gather after Footprint Attenuation



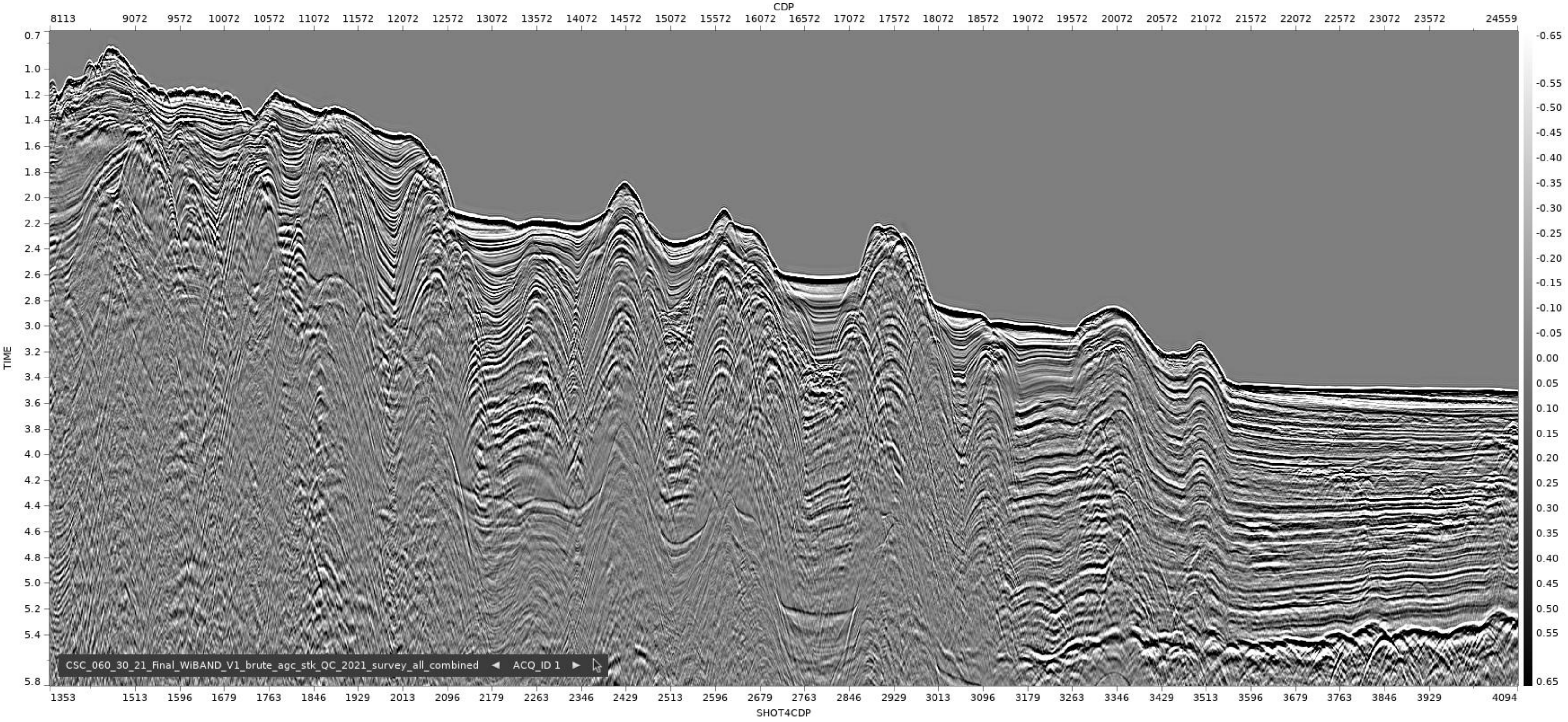
Source & Receiver De-ghosting (WiBand™)

- A signal reaching a receiver is followed shortly by its reflection from the water surface with the opposite polarity. The same effect occurs at the source. These ghosts interfere with the primary signal, creating notches in the amplitude spectrum.
- ION's proprietary WiBand™ algorithm accounts for this process recovering those frequencies within the source and receiver ghost notches.
- WiBand™ data-adaptively derives a stable operator to remove the effects of the source and receiver ghosts from the data prior to migration. As such, it strives to recover the signal weakened by the ghosts, rather than 'creating' new signal, and relies on the presence of usable signal at and near the ghost frequencies in the raw data.
- Key parameters in Deghosting
  - **Source Depth** – 11 - 13m
  - **Receiver Depth** – Based on depth header
  - **Reflection Coefficient** search

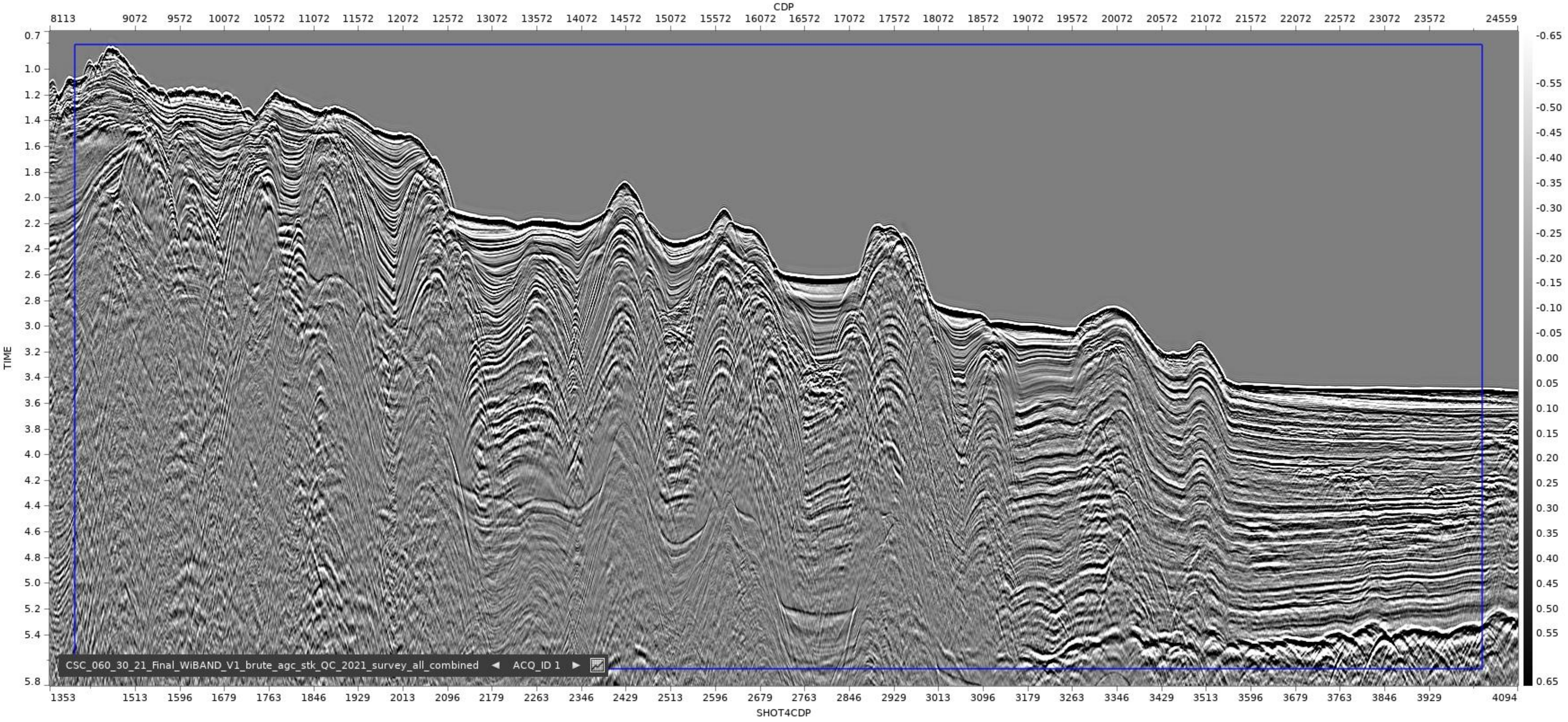
MGL2104PD09 : Stack before WiBAND



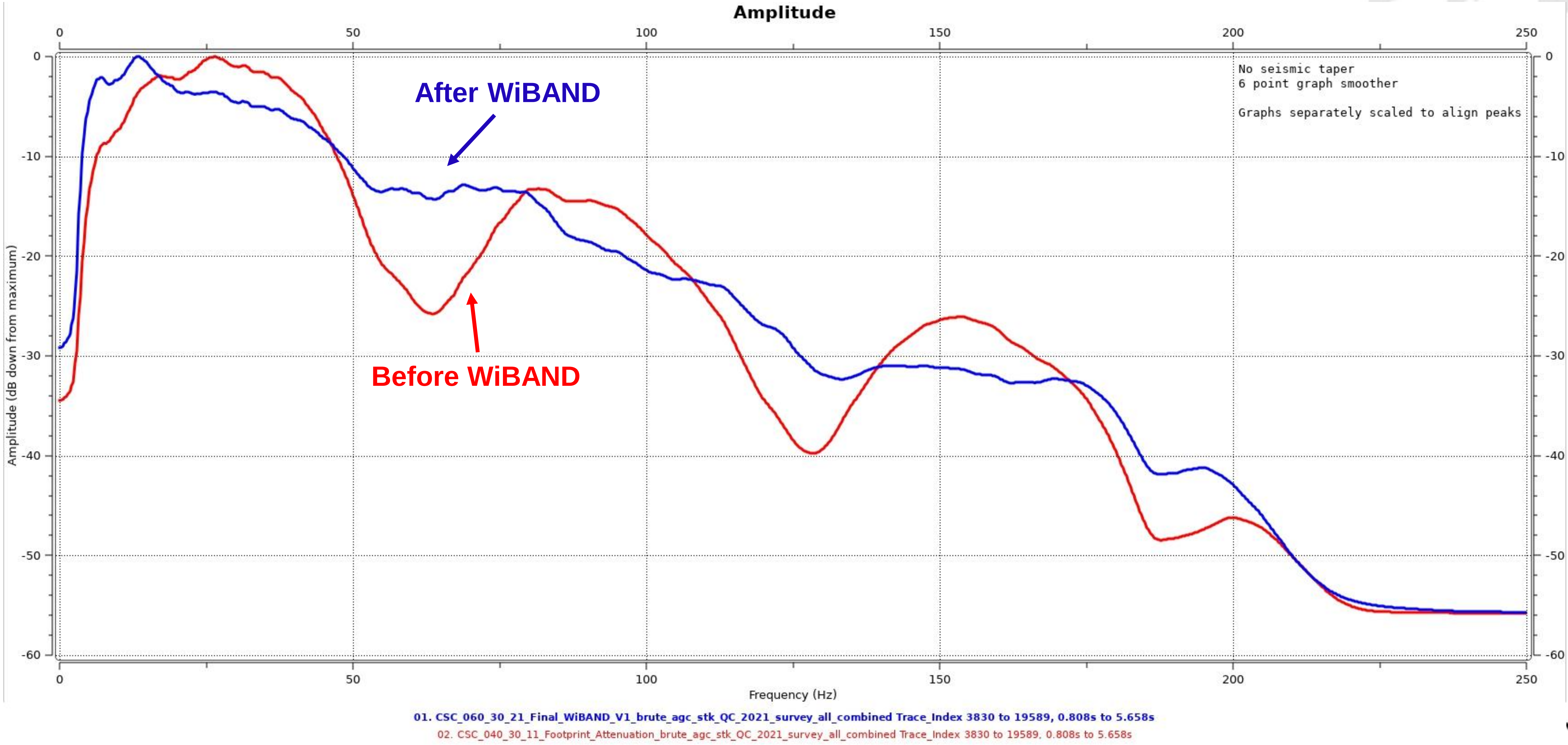
MGL2104PD09 : Stack after WiBAND



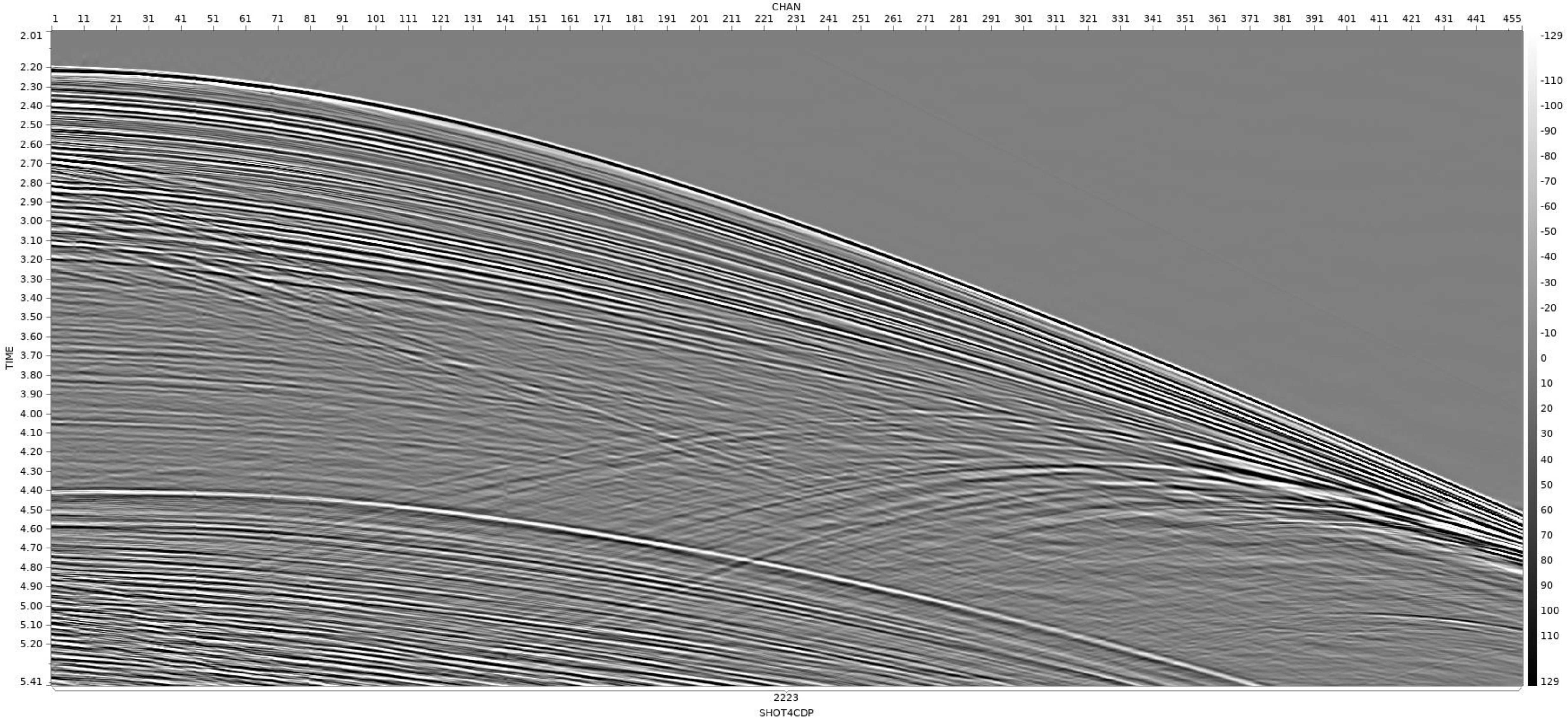
MGL2104PD09 : Blue box is window selected for Amplitude Spectra



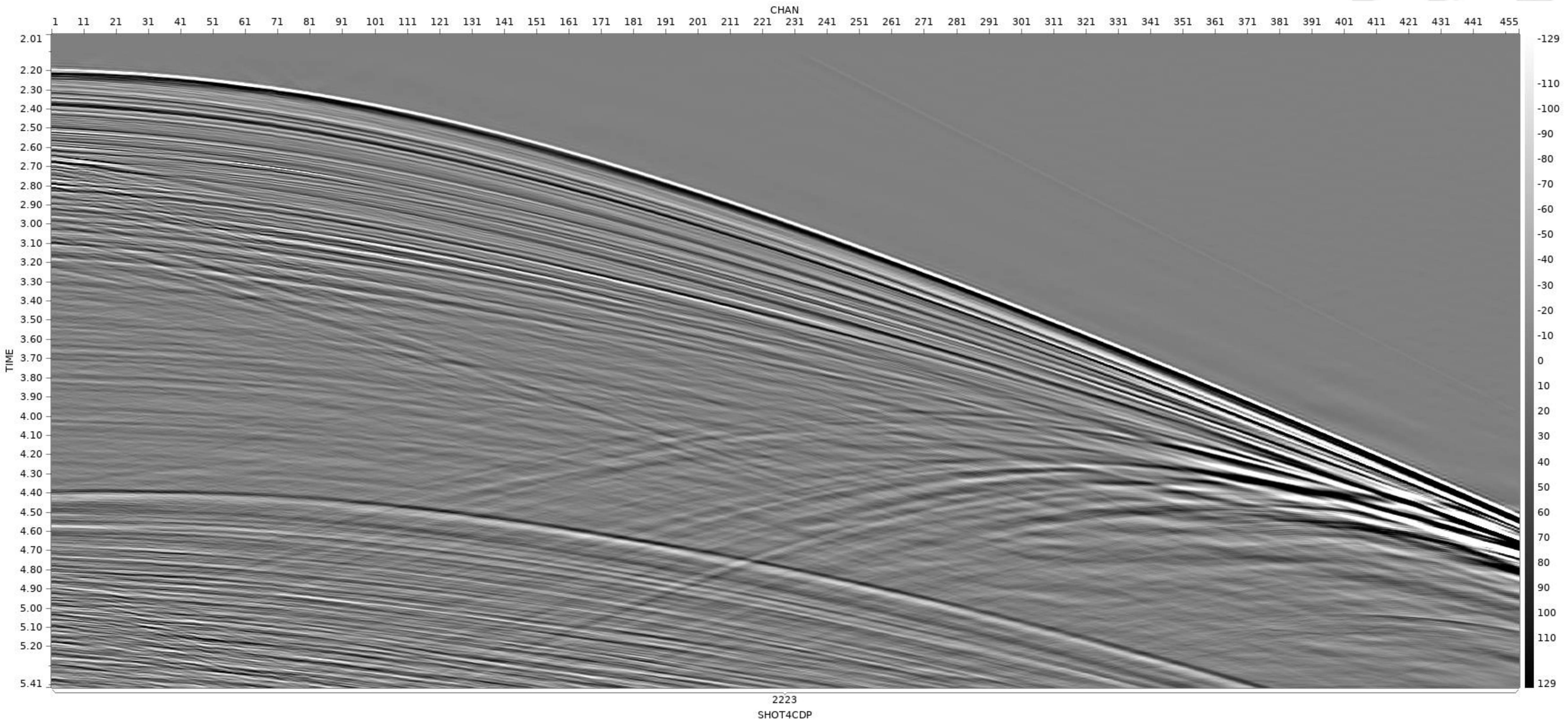
MGL2104PD09 : Amplitude Spectra



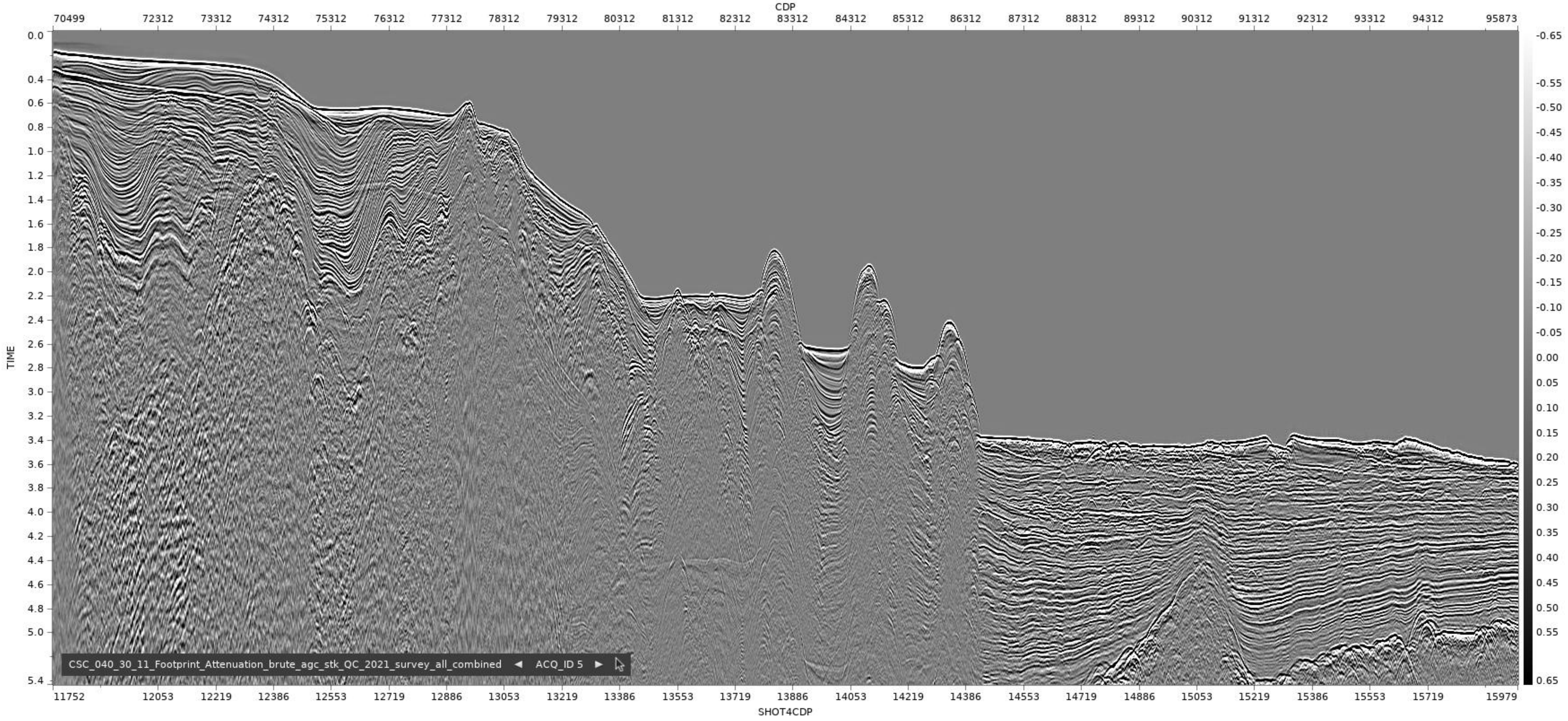
MGL2104PD09 : SHOT Gather before WiBAND



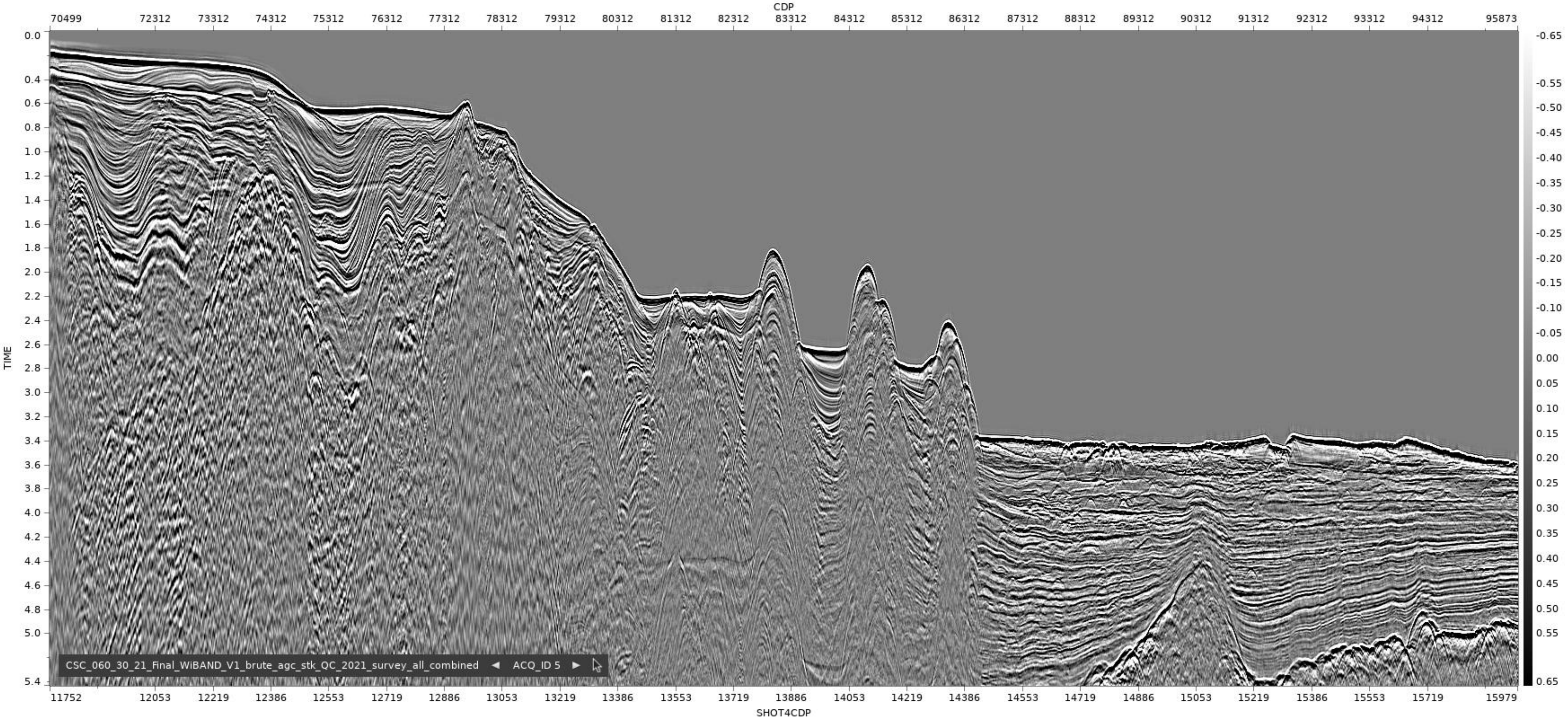
MGL2104PD09 : SHOT Gather after WiBAND



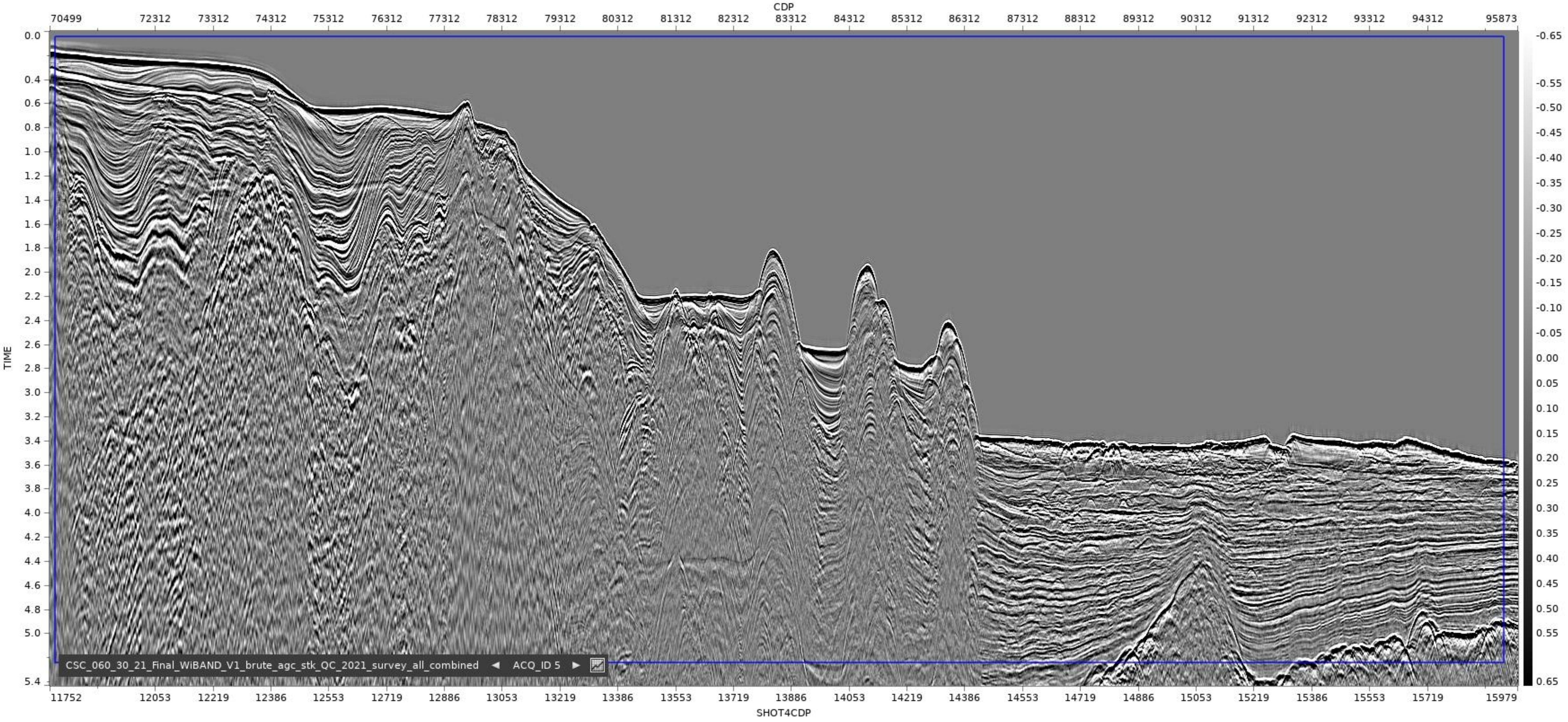
MGL2104PD11 : Stack before WiBAND



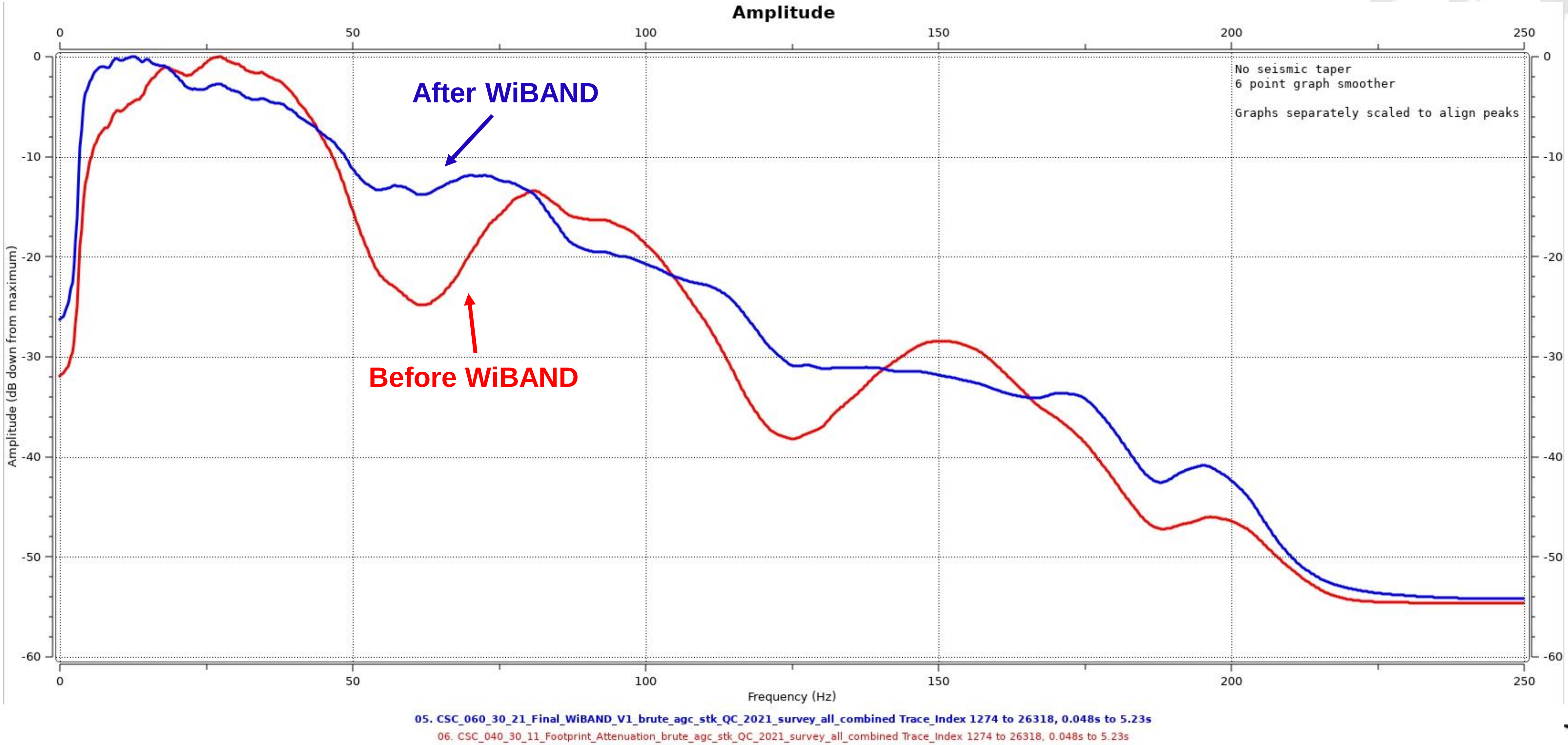
MGL2104PD11 : Stack after WiBAND



MGL2104PD11 : Blue box is window selected for Amplitude Spectra



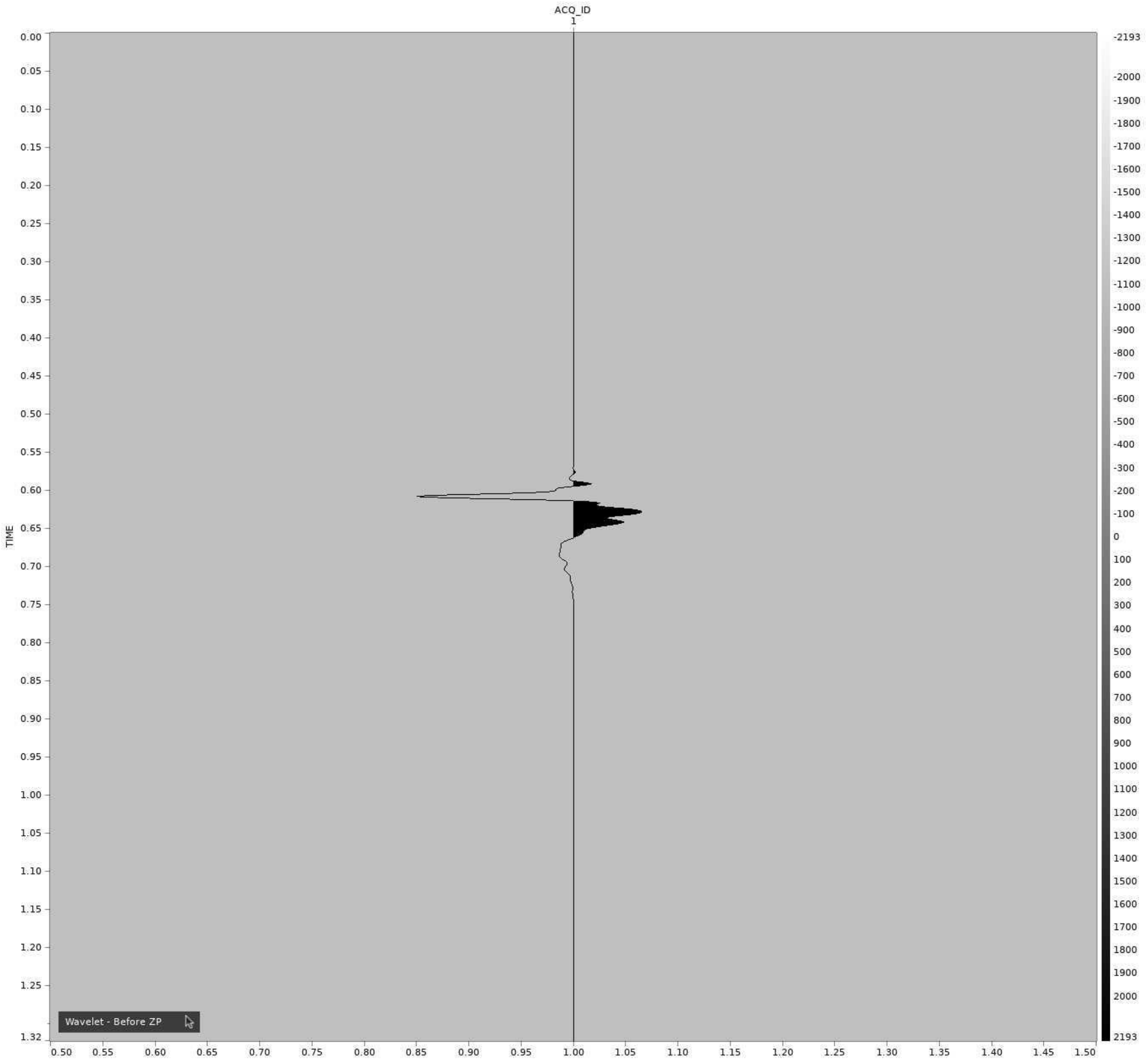
MGL2104PD11 : Amplitude Spectra



Zero-Phase Conversion

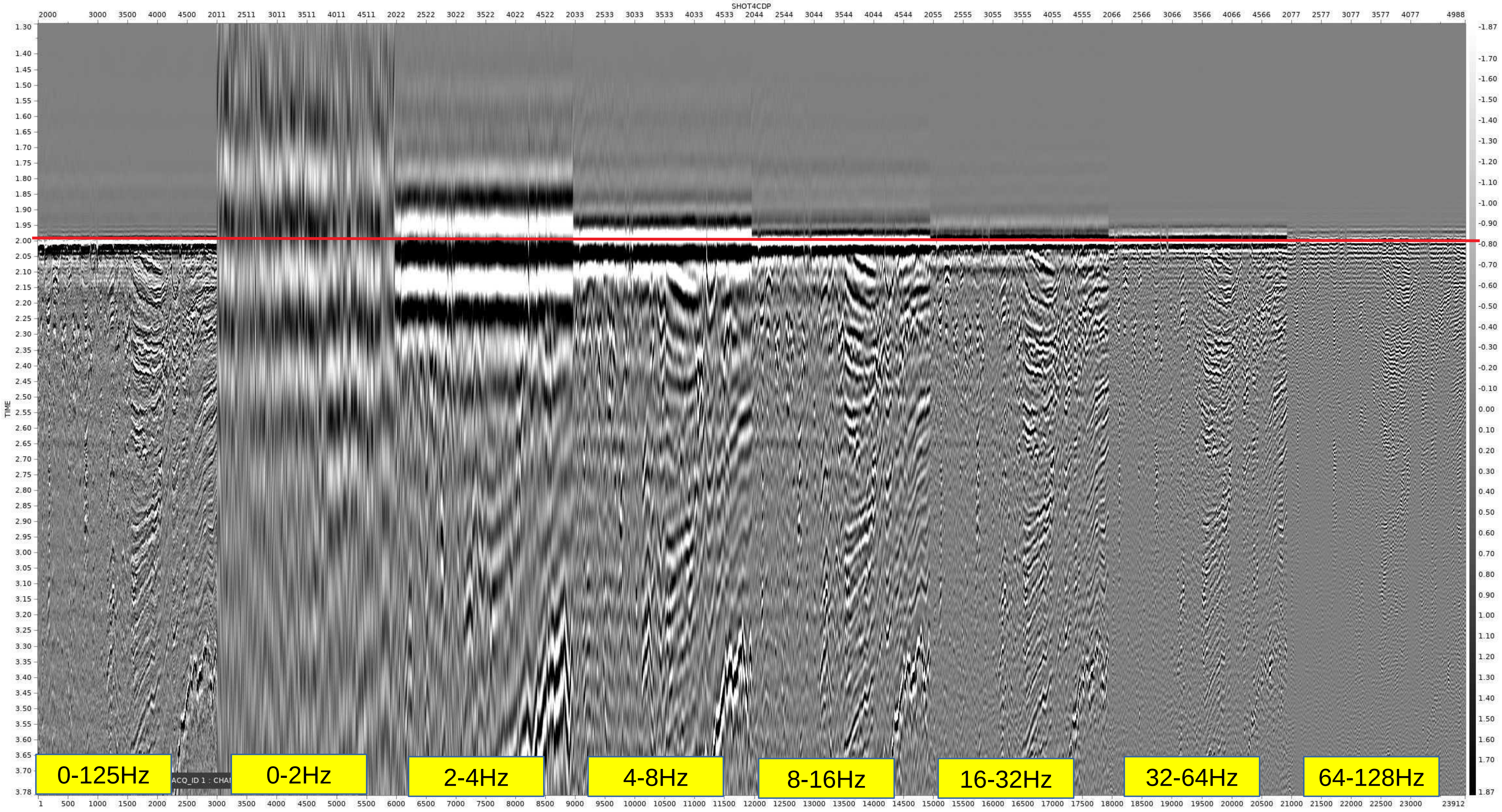
- This process was implemented to rotate the data to zero-phase, a polarity flip so that the water bottom is a peak.
- An input signature was derived from the data by flattening and stacking near-offset small-angle traces at the water bottom post WiBand. The geological variation stacked out well, and a good representation of the de-ghosted far-field signature resulted.
- The previously debubbled wavelet was zero-phased and a matching filter designed to convolve the seismic to its zero phased form. A zero-phasing operator was thereby obtained and was applied to the seismic dataset.
- A zero-phased and symmetric wavelet at water bottom was obtained after application of the zero-phasing operator. The polarity achieved was a peak (positive number) for increase in acoustic impendence for the zero-phase wavelet (i.e., the water-bottom shows as a central peak). The peak was centered to coincide with the AI change associated with the water bottom event.

Wavelet - Before Zero Phase

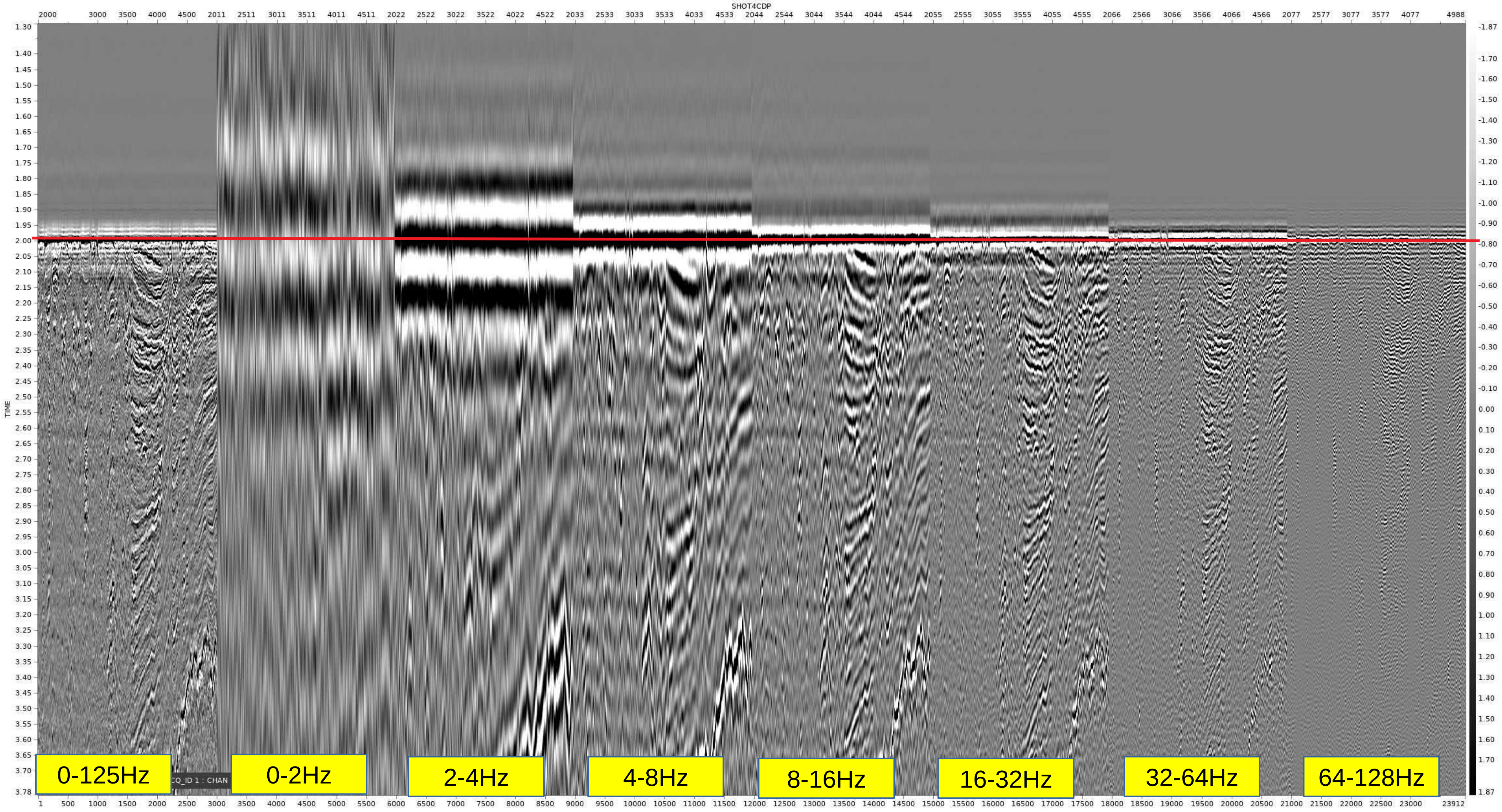


Wavelet - After Zero Phase

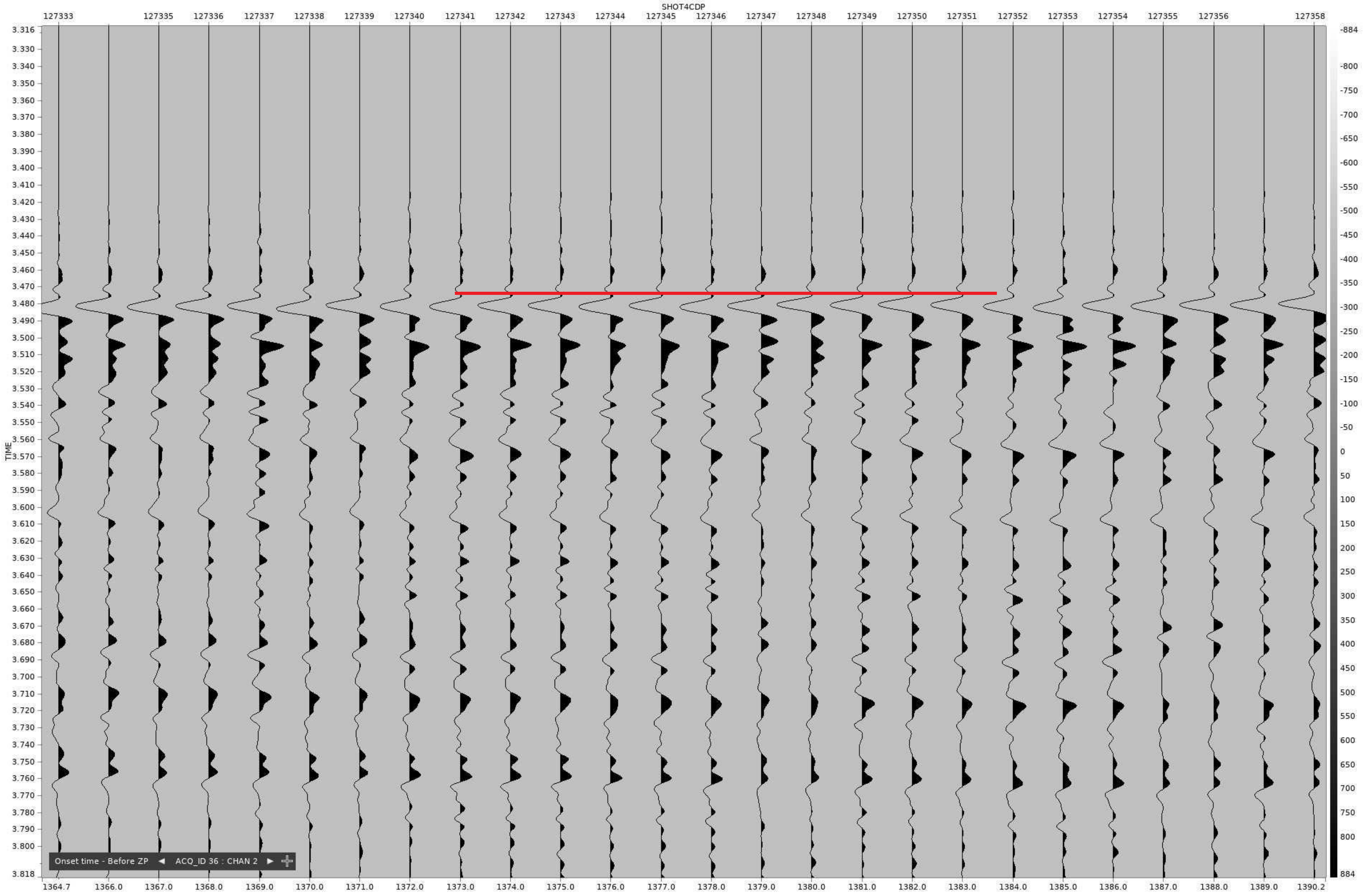
Octave Panels - Before Zero Phase



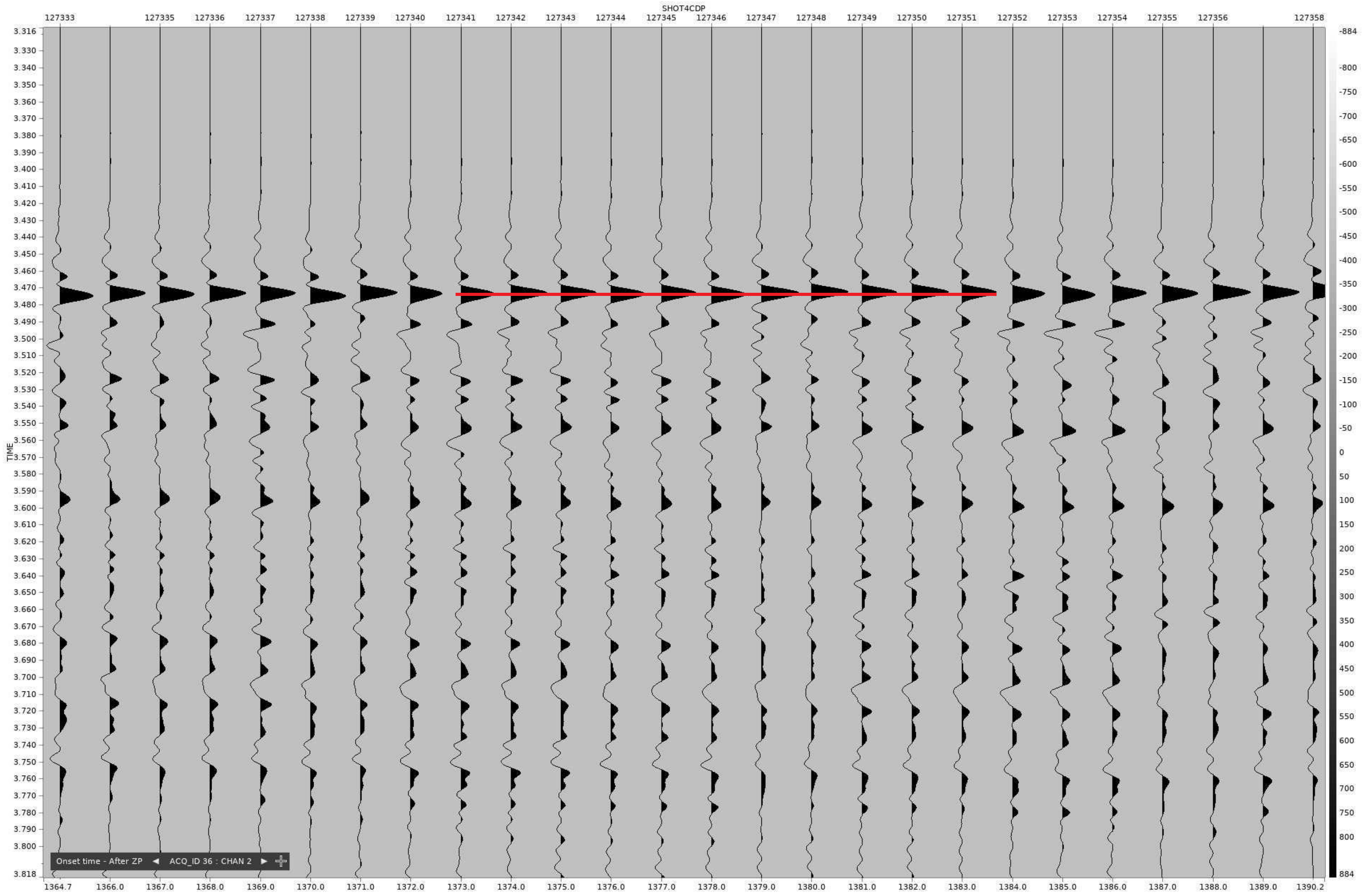
Octave Panels - After Zero Phase



Onset time - Before Zero Phase



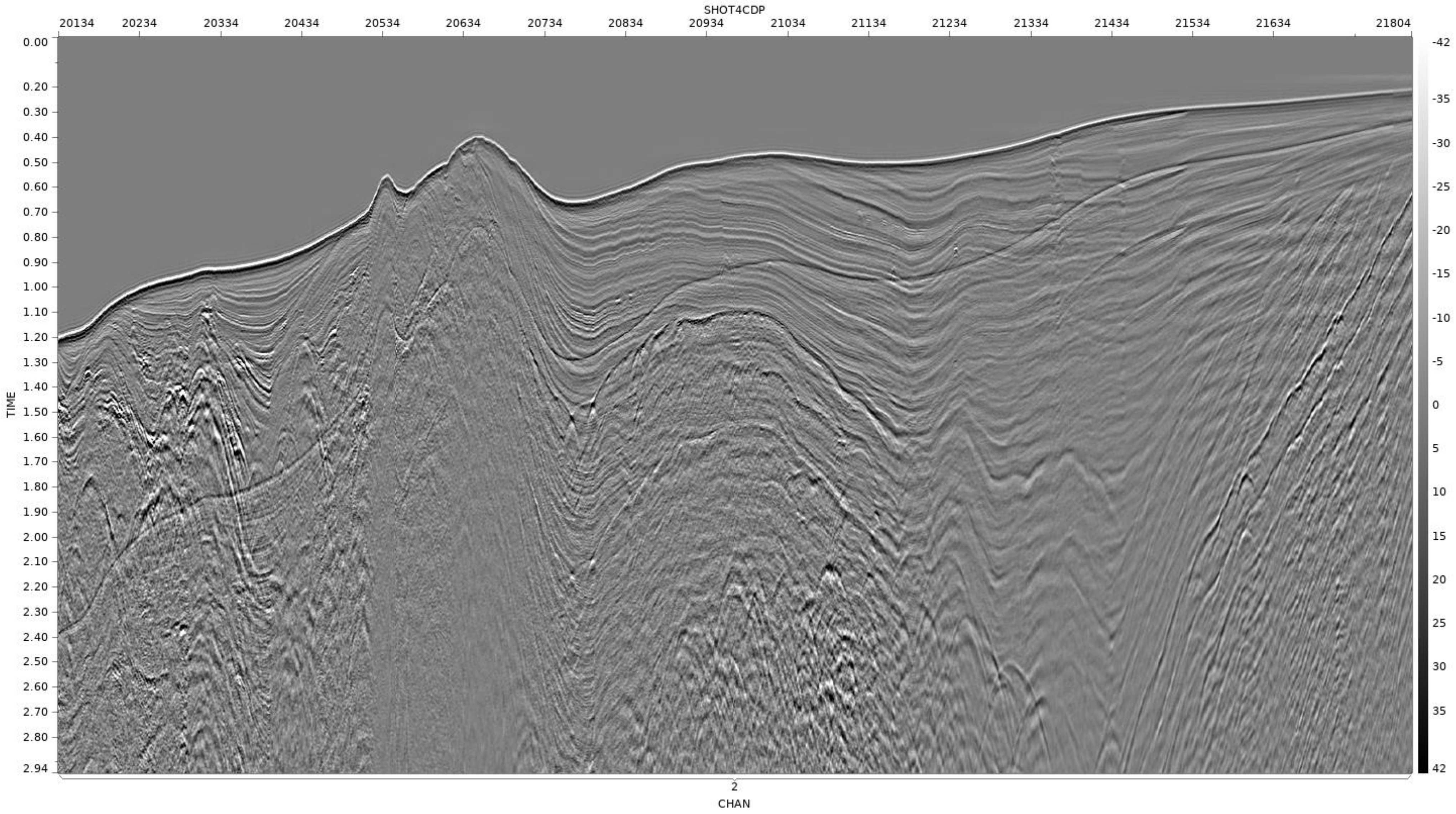
Onset time - After Zero Phase



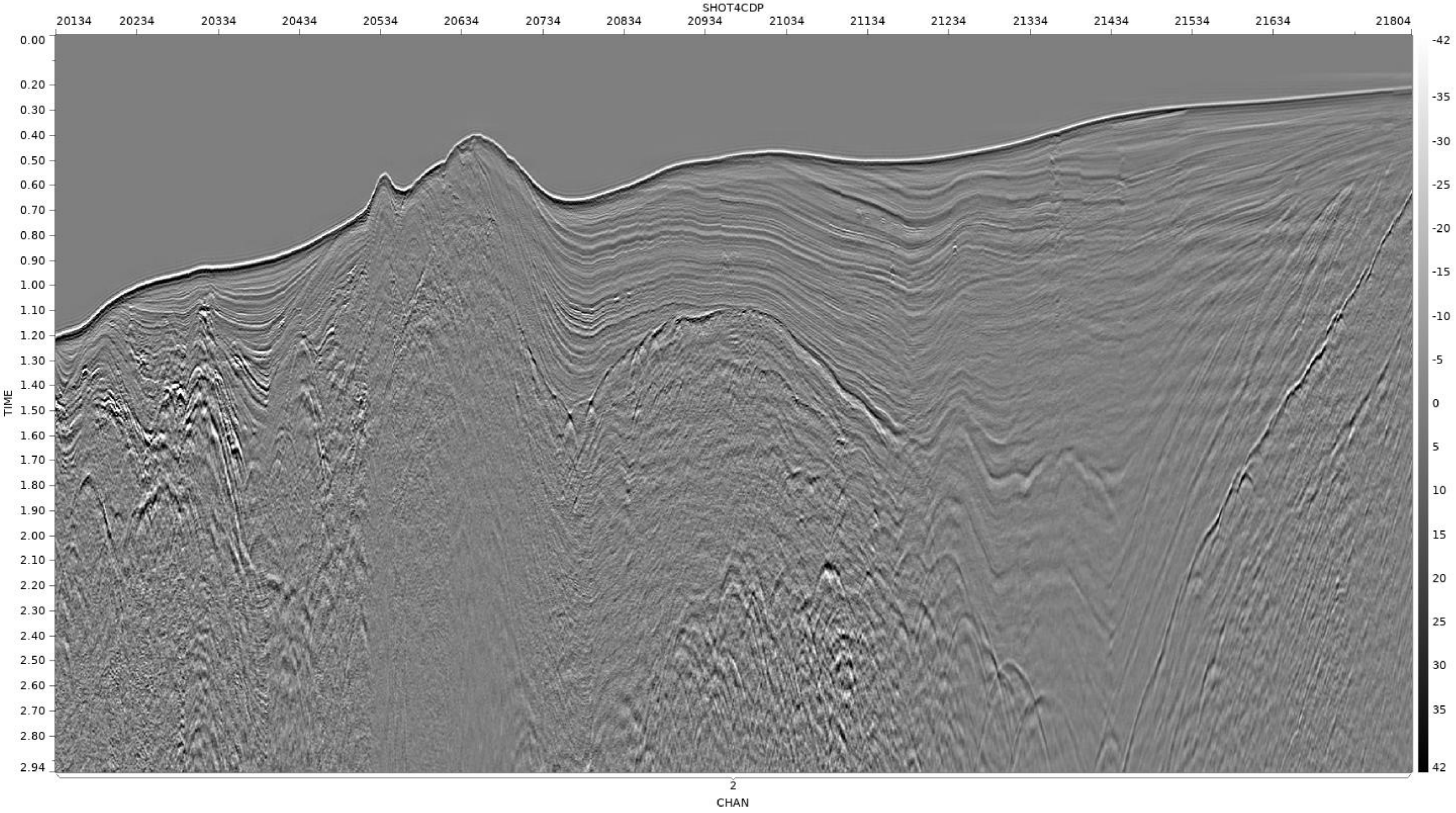
SPMA (Short Period Multiple attenuation)

- Data acquisition in shallow water introduces noise in the form of short period multiples that may not be effectively removed using traditional 2D SRME technologies.
- ION employs a proprietary short period multiple attenuation (SPMA) technique, in combination with 2D SRME to remove this noise and to improve image resolution throughout the seismic section. This method uses pre stack migration to overcome the problem of predicting multiples when near offset data are missing, then uses standard adaptive subtraction and matching techniques to attenuate the short period reverberations.
- SPMA is only effective in shallow water so its application was restricted to areas with a two-way water bottom time of less than 1100ms.
- Key parameter in predicting multiples - **Water bottom time**

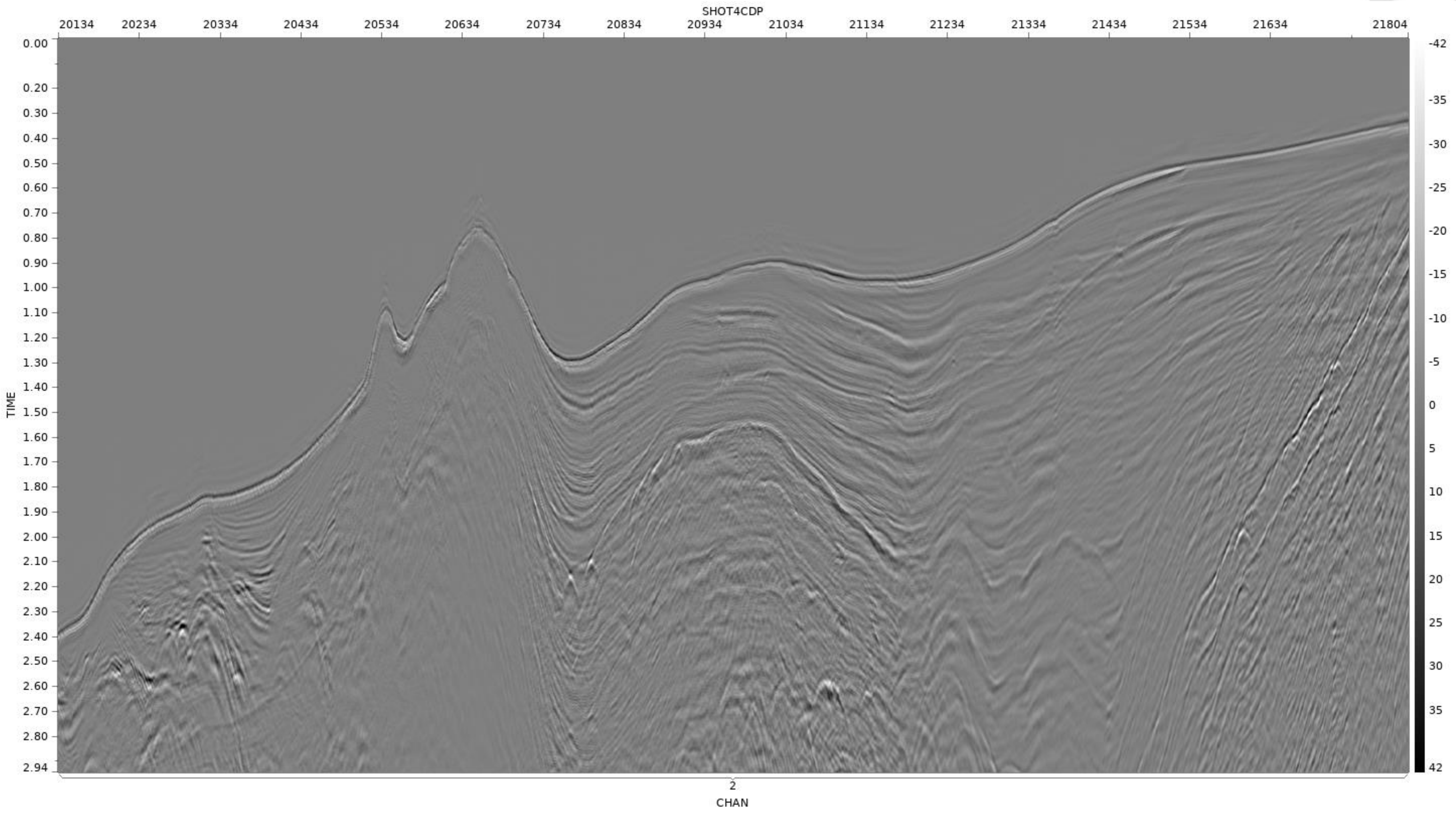
MGL2104PD12 CHAN – 1 before SPMA



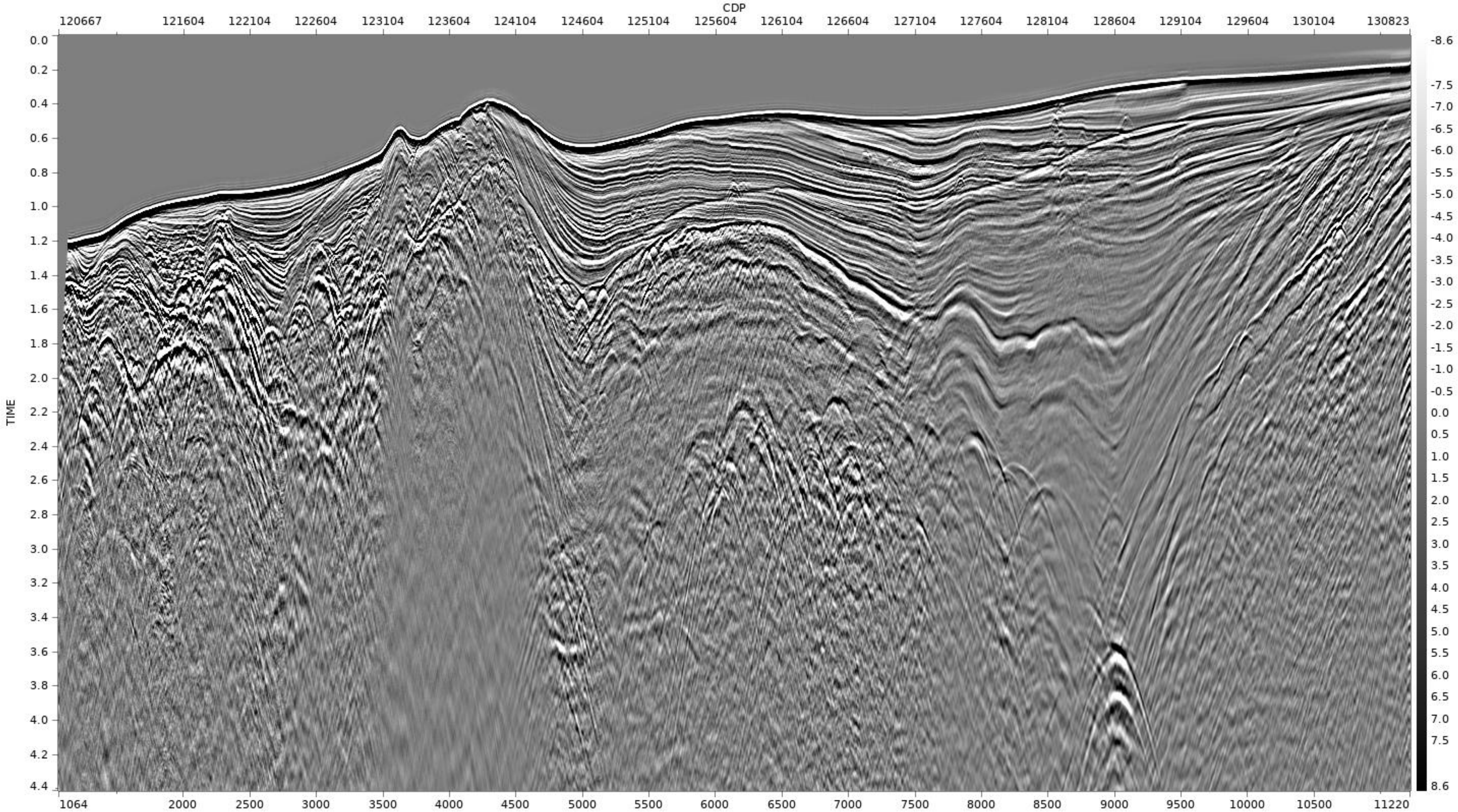
MGL2104PD12 CHAN – 1 after SPMA



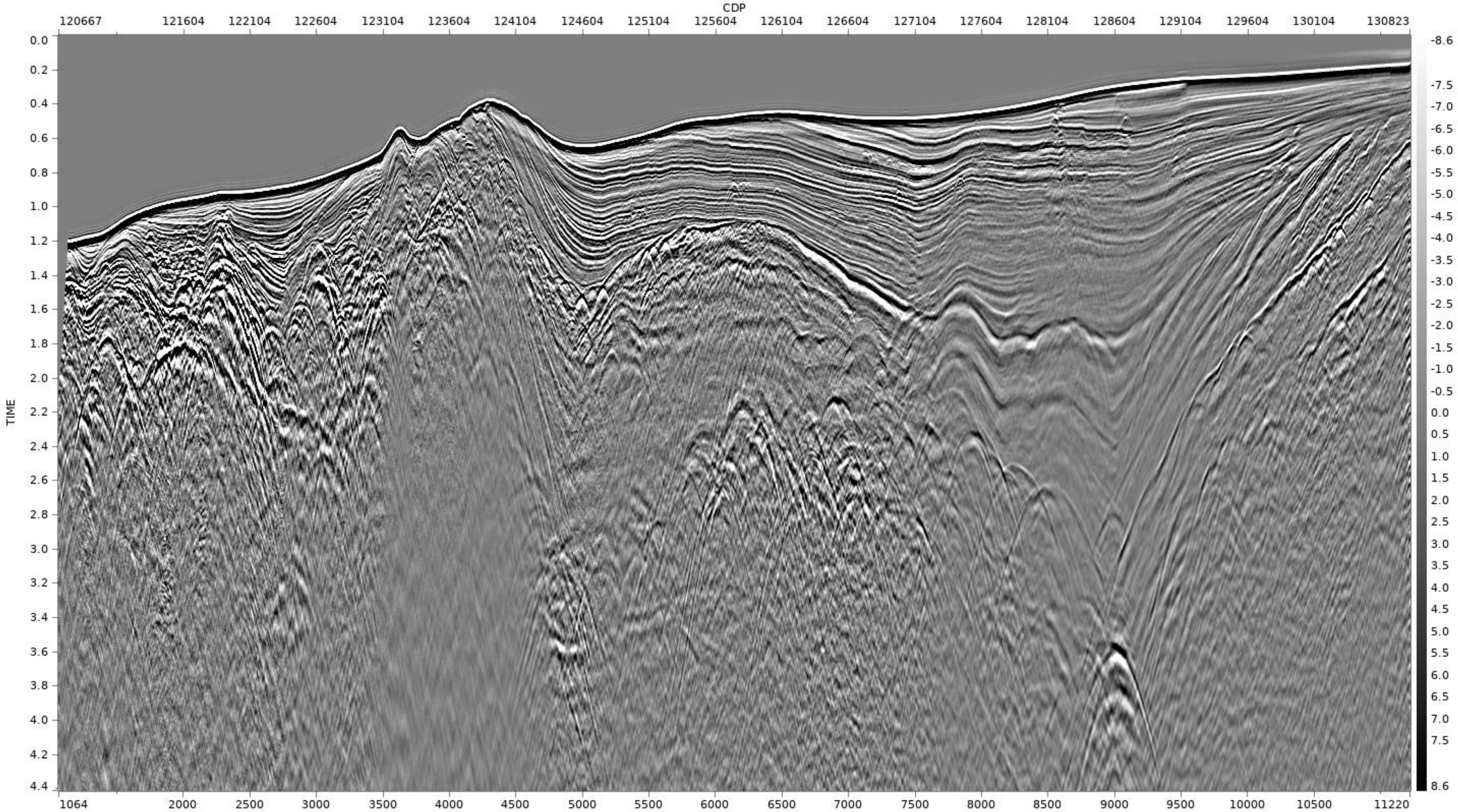
MGL2104PD12 CHAN – 1 difference SPMA



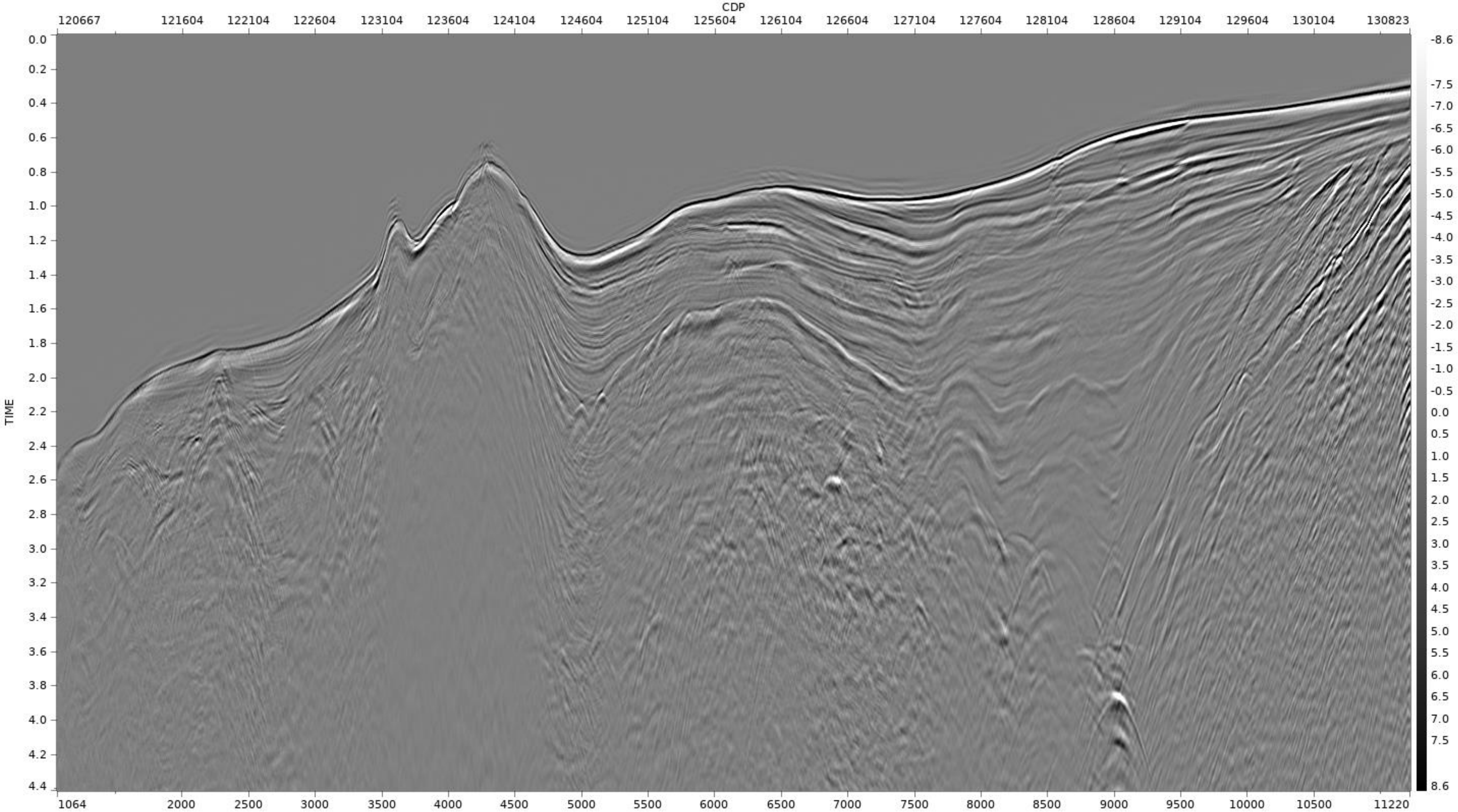
MGL2104PD12 STACK before SPMA



MGL2104PD12 STACK after SPMA

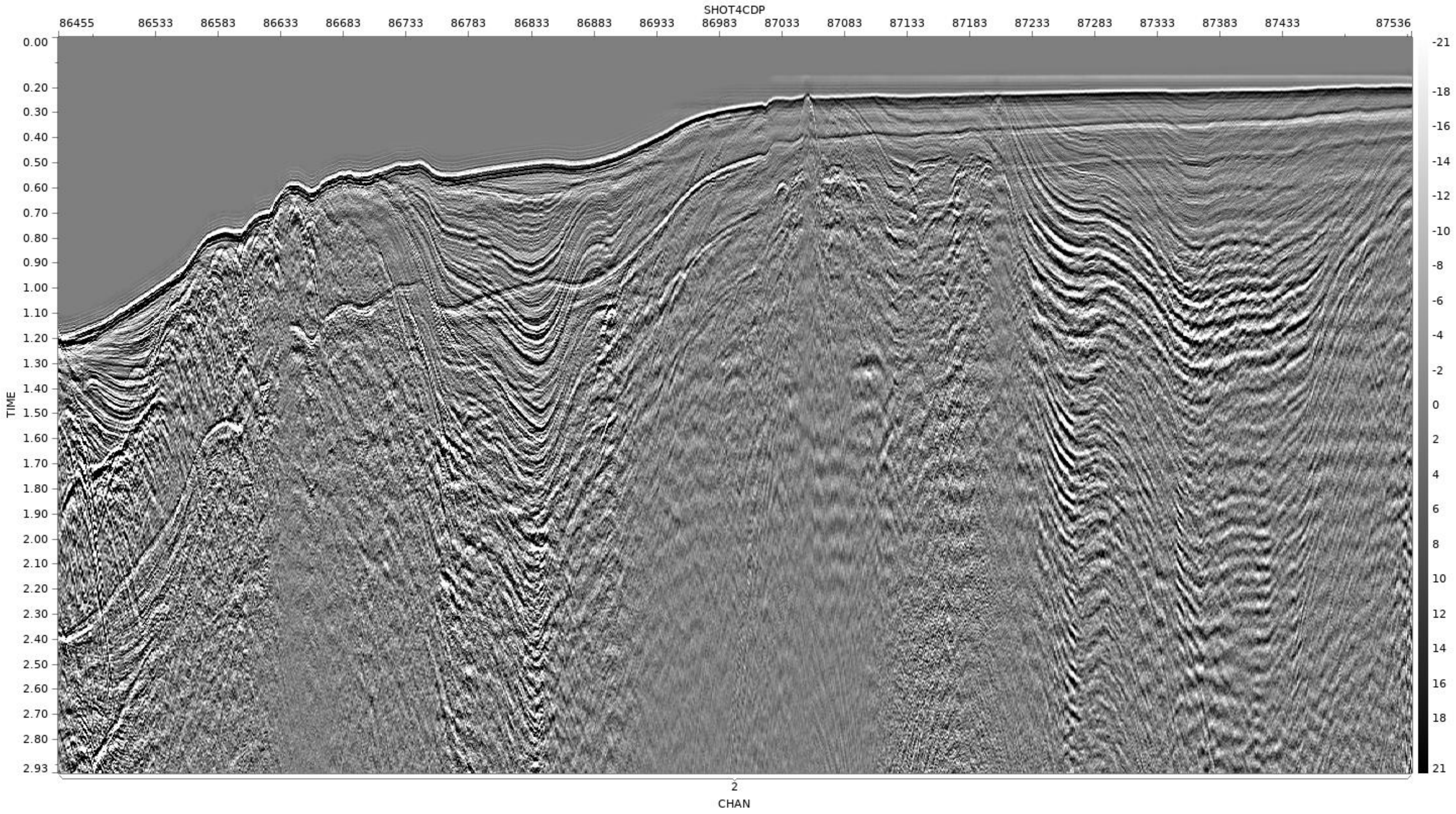


MGL2104PD12 STACK difference SPMA

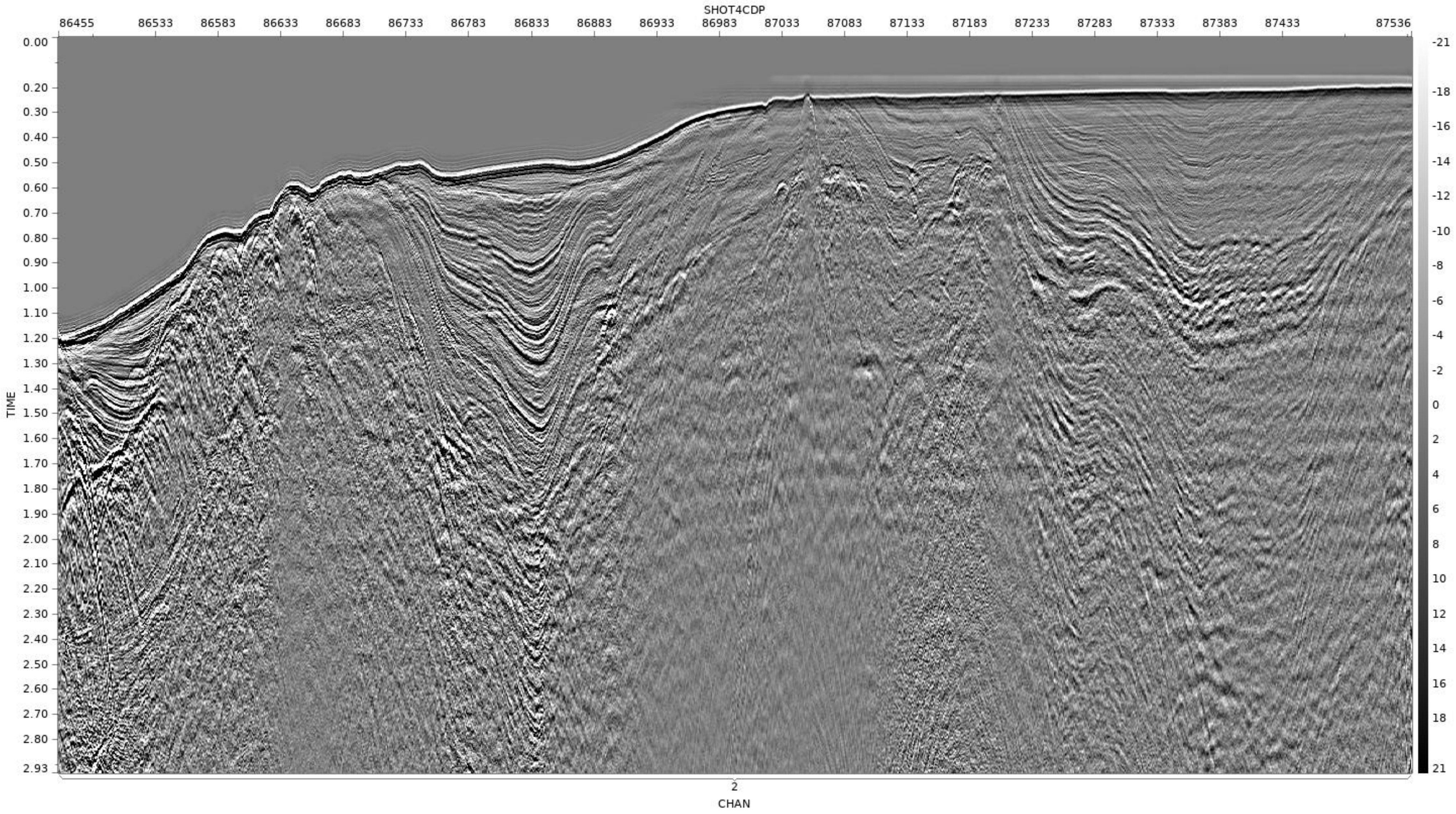


ion

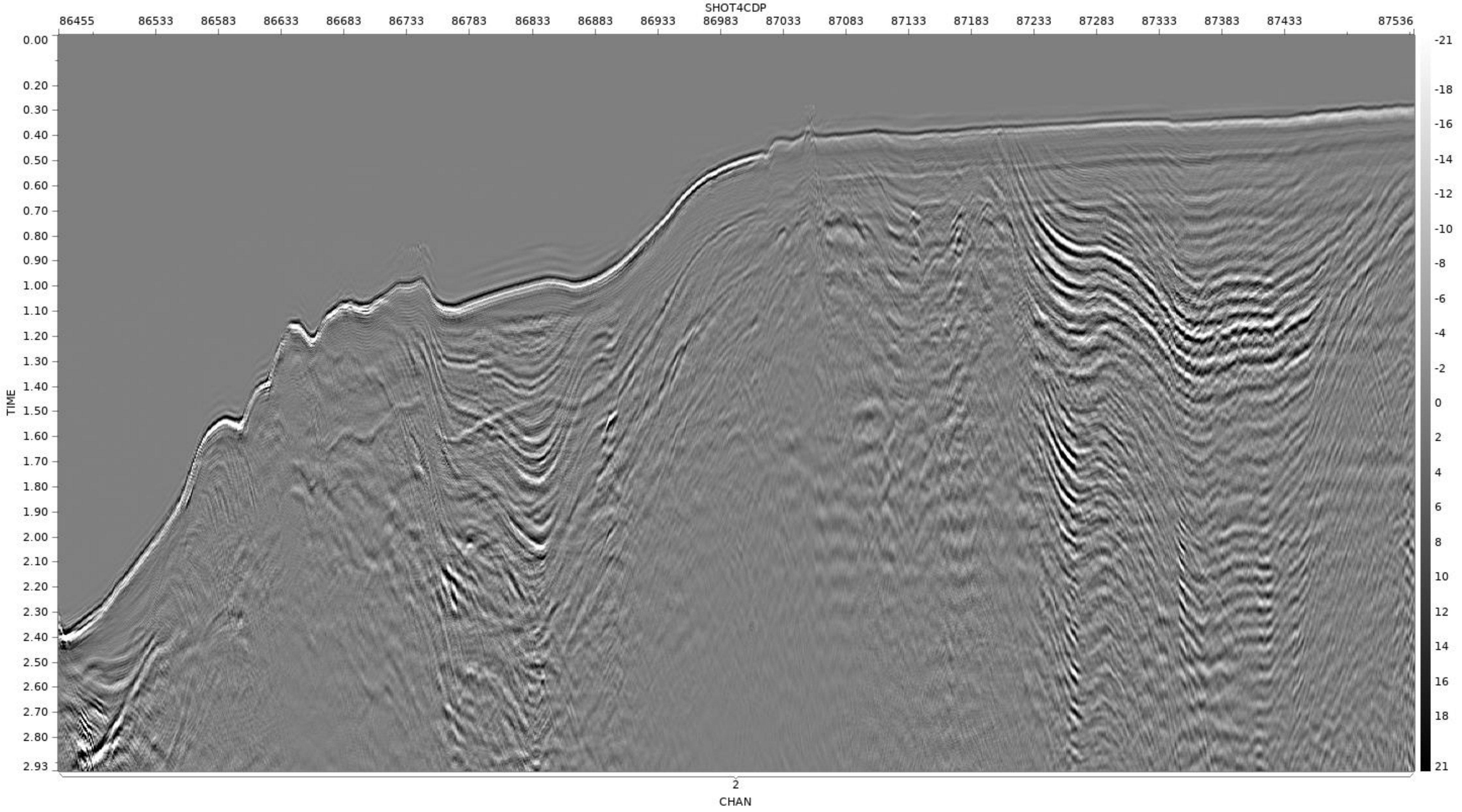
MGL2104PD13 CHAN – 1 before SPMA



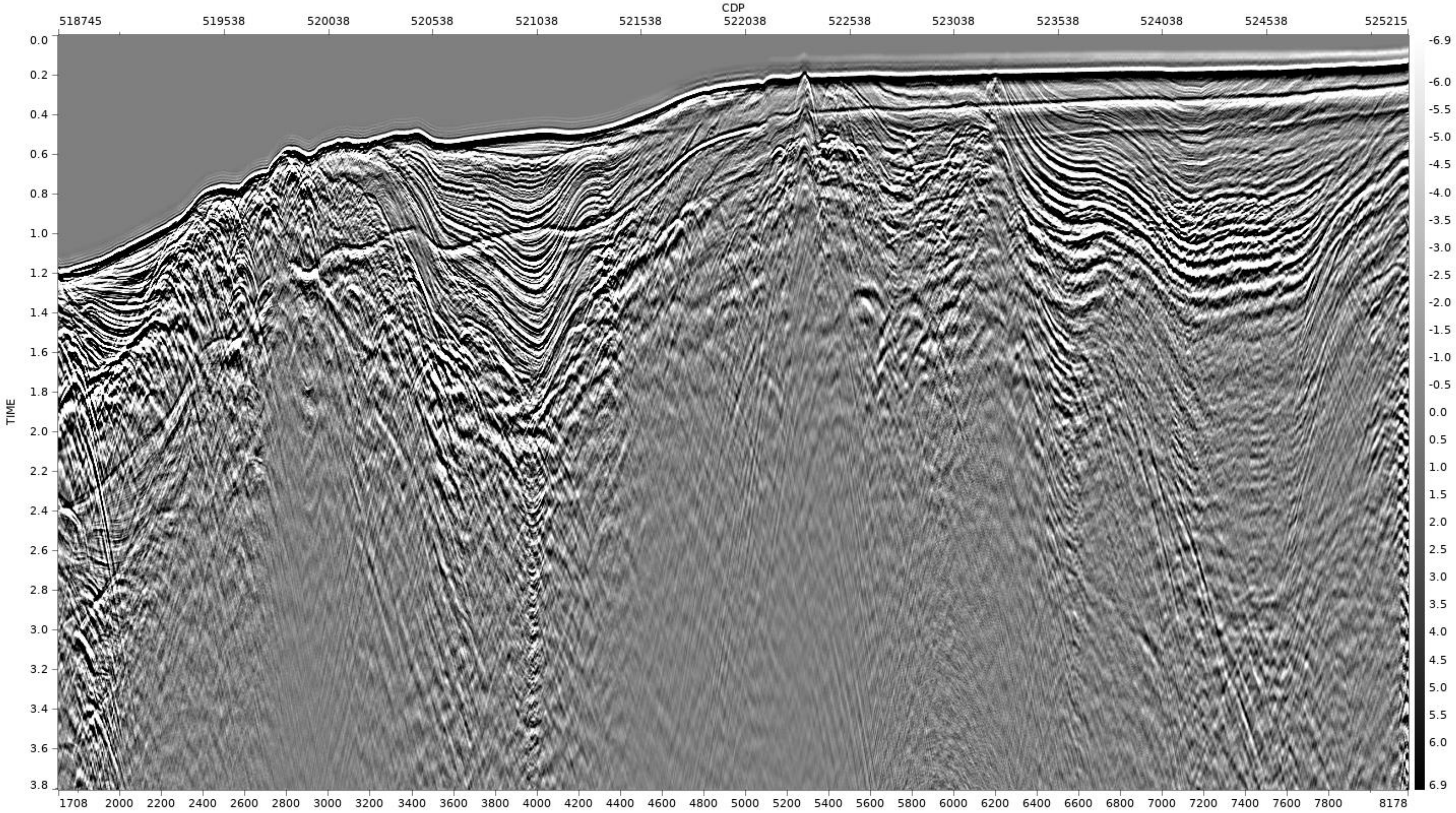
MGL2104PD13 CHAN – 1 after SPMA



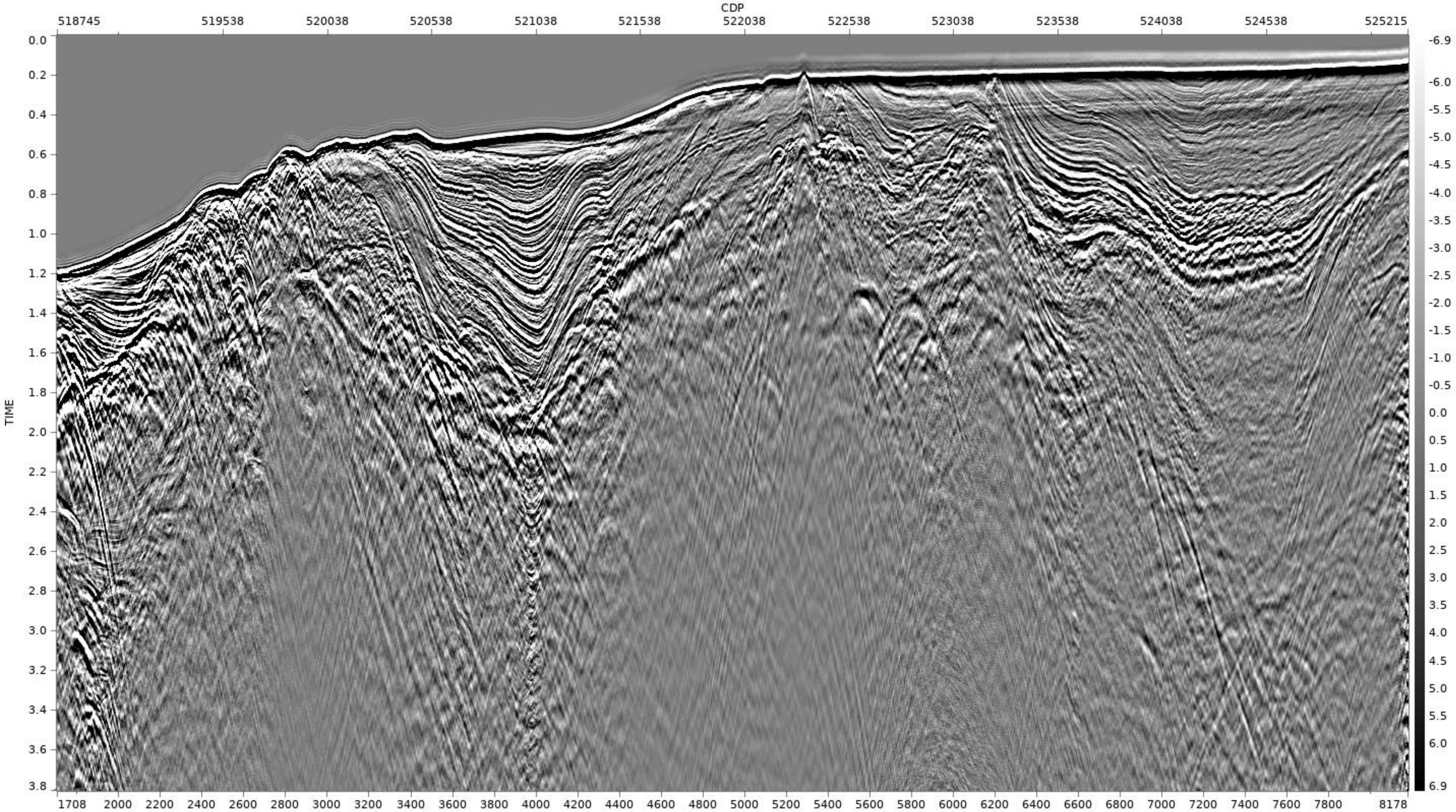
MGL2104PD13 CHAN – 1 difference SPMA



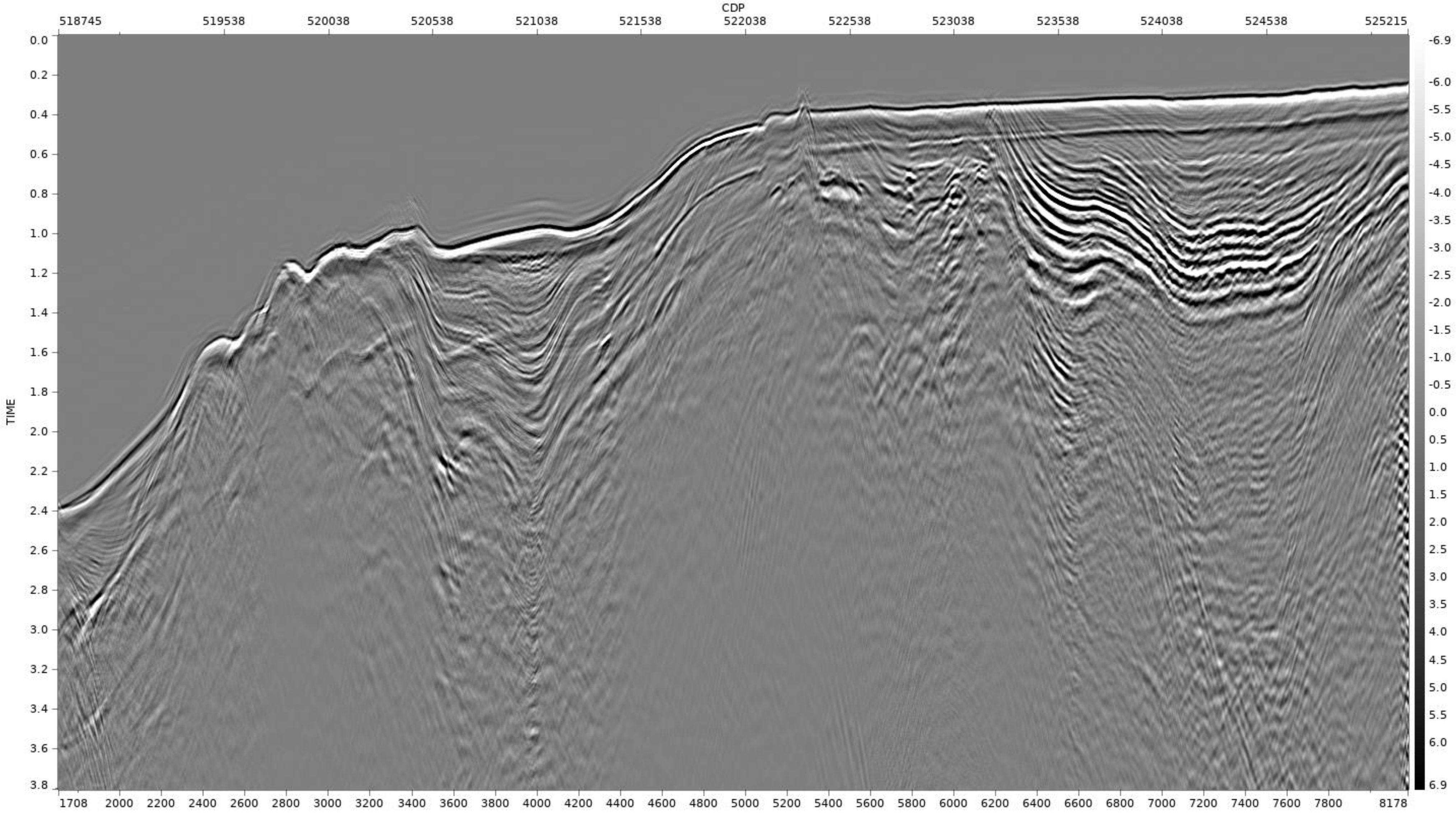
MGL2104PD13 STACK before SPMA



MGL2104PD13 STACK after SPMA

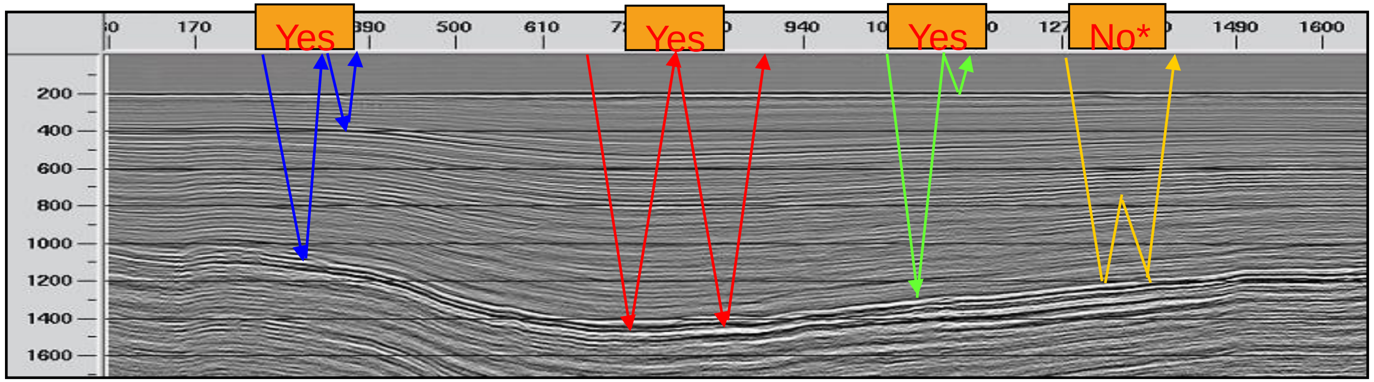


MGL2104PD13 STACK difference SPMA



Surface Related Multiple Elimination (SRME)

- 2D SRME is a data driven process where primary reflections arriving on different source-receiver pairs are convolved to emulate the ray path taken by an associated multiple bounce which involves the sea surface. Thus predicting a multiple model, (Multiples without a bounce at free surface will not be predicted).



- 2D SRME Processing had the following main steps:
  - Data Preparation
  - Multiple Prediction
  - Adaptive Subtraction

SRME – Subtraction parameters

- Global matching parameters

Temporal Window Size:	4000	ms
Spatial Window Size:	2001	traces
Temporal Overlap:	50	%
Spatial Overlap:	50	%
Number of temporal filter coefficients:	101	samps

- Local matching parameters

LOW FREQ PARAMETERS:

Temporal Window Size:	500	ms
Spatial Window Size:	31	traces
Temporal Overlap:	50	%
Spatial Overlap:	50	%
Number of temporal filter coefficients:	17	samps
Number of spatial filter coefficients:	11	trcs
Transition Freq 1:	20	Hz
Transition Freq 2:	30	Hz

MID FREQ PARAMETERS:

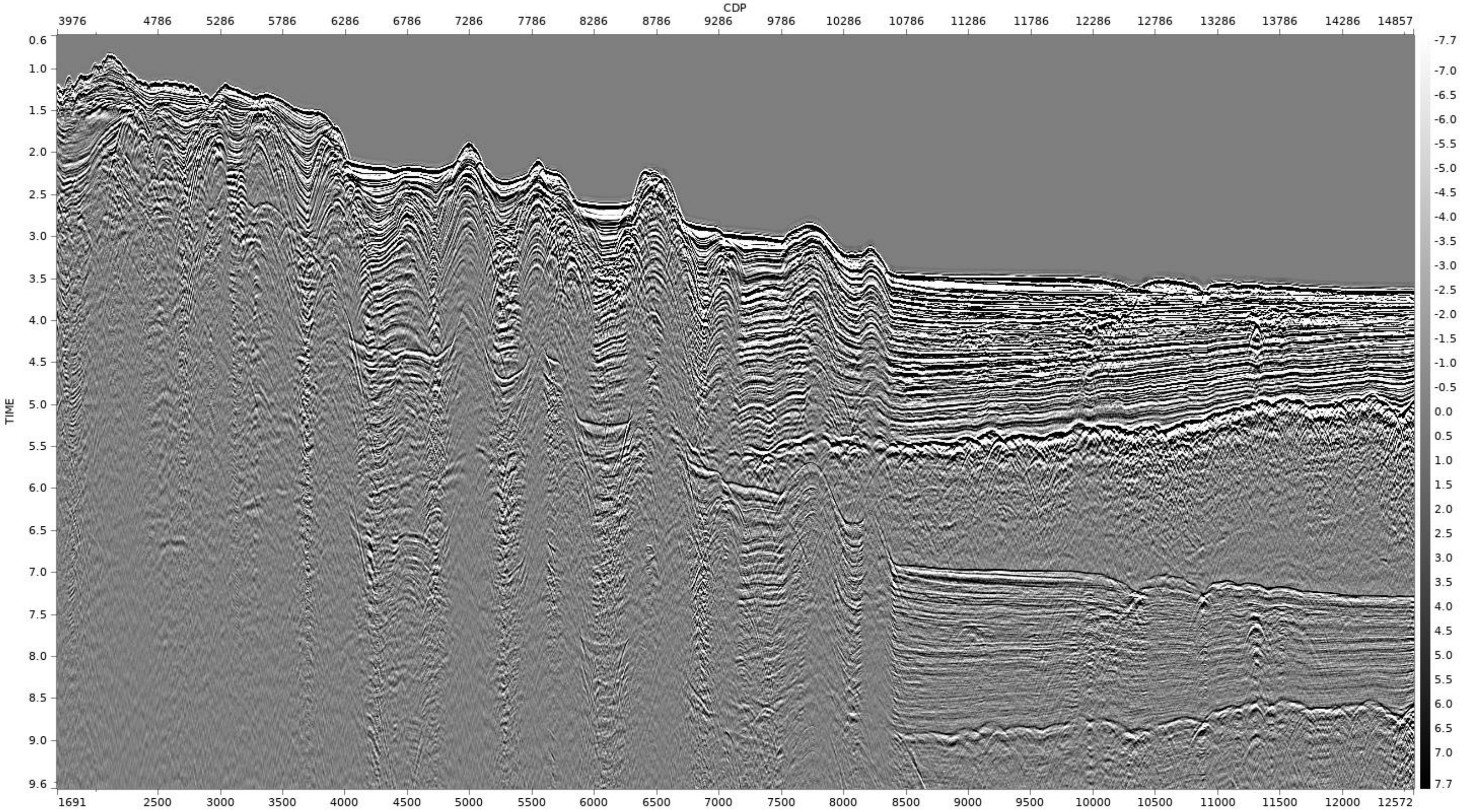
Temporal Window Size:	100	ms
Spatial Window Size:	11	traces
Temporal Overlap:	50	%
Spatial Overlap:	50	%
Number of temporal filter coefficients:	9	samps
Number of spatial filter coefficients:	5	trcs
Transition Freq 1:	80	Hz
Transition Freq 2:	90	Hz

HIGH FREQ PARAMETERS:

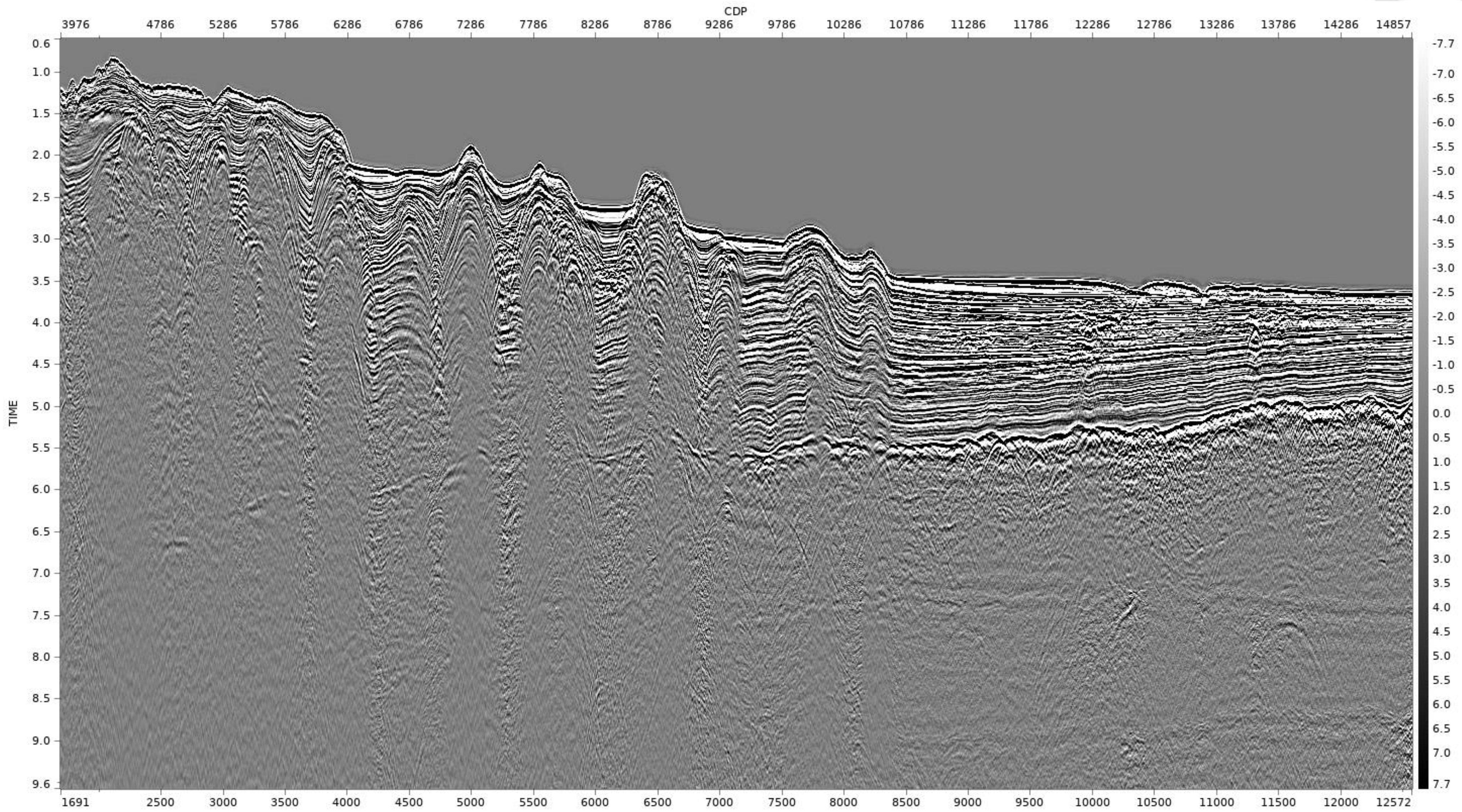
Temporal Window Size:	100	ms
Spatial Window Size:	11	traces
Temporal Overlap:	50	%
Spatial Overlap:	50	%
Number of temporal filter coefficients:	9	samps
Number of spatial filter coefficients:	5	trcs
Max Frequency:	125	Hz

Subtraction parameters in 3 different frequency ranges

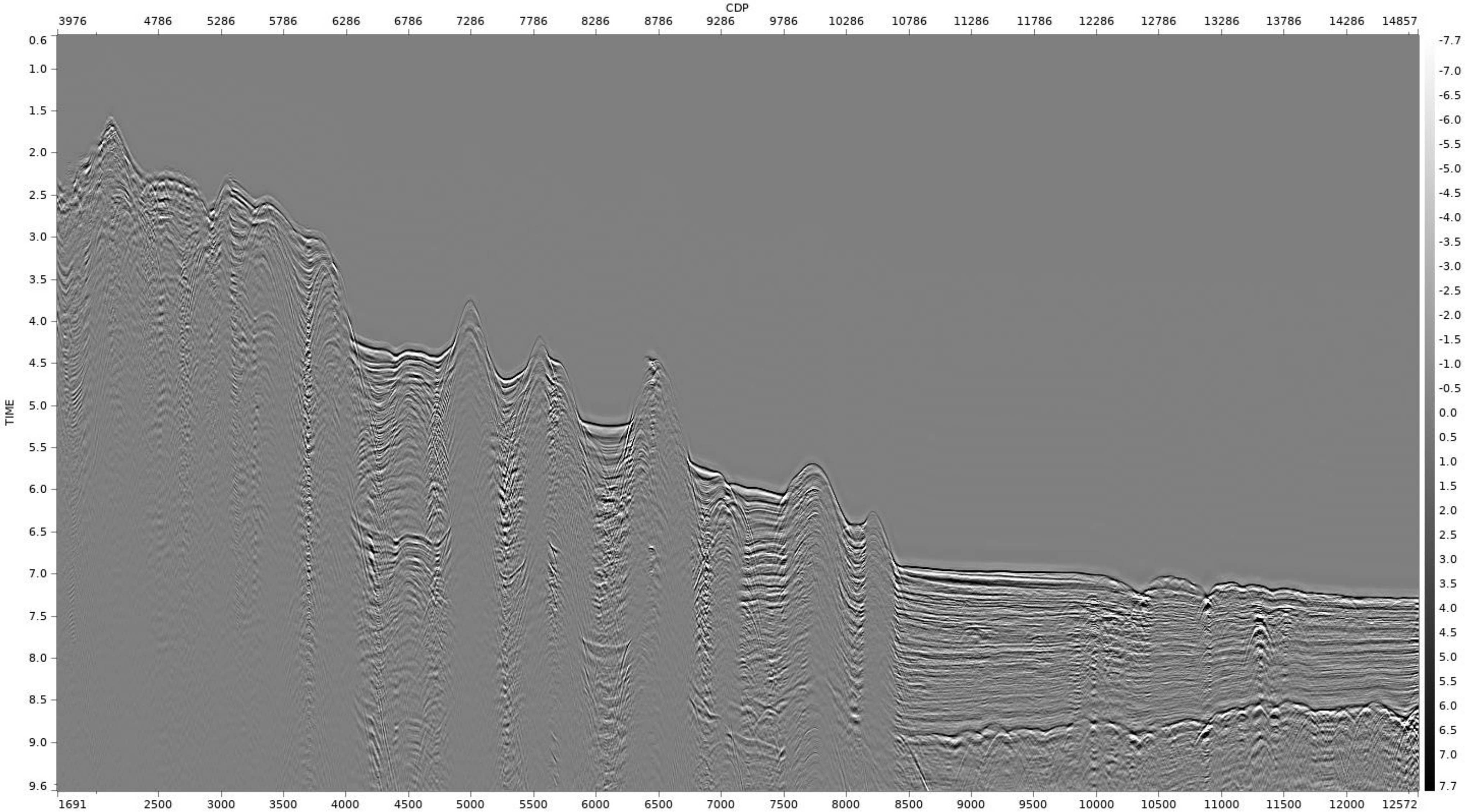
MGL2104PD09 STACK before SRME



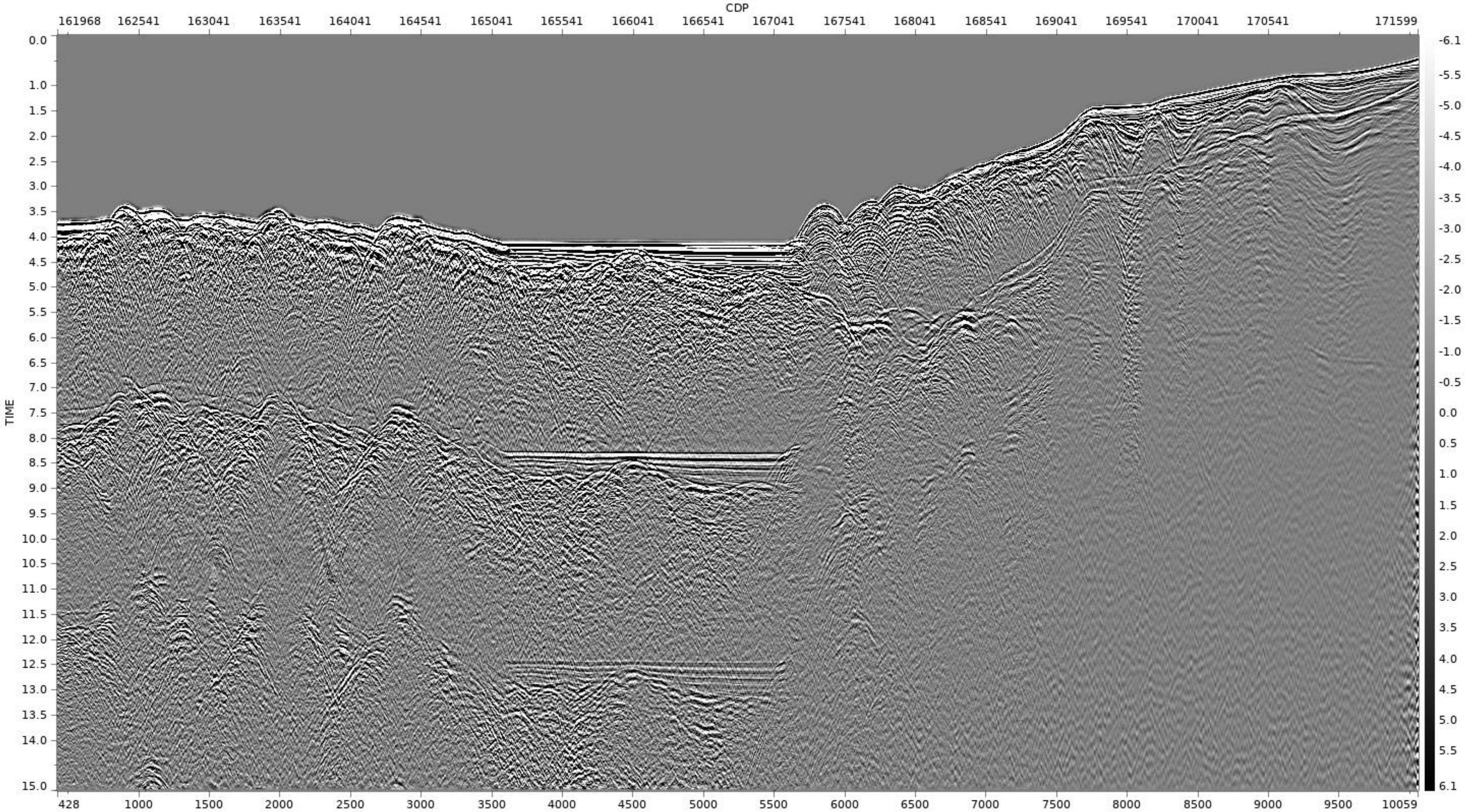
MGL2104PD09 STACK after SRME



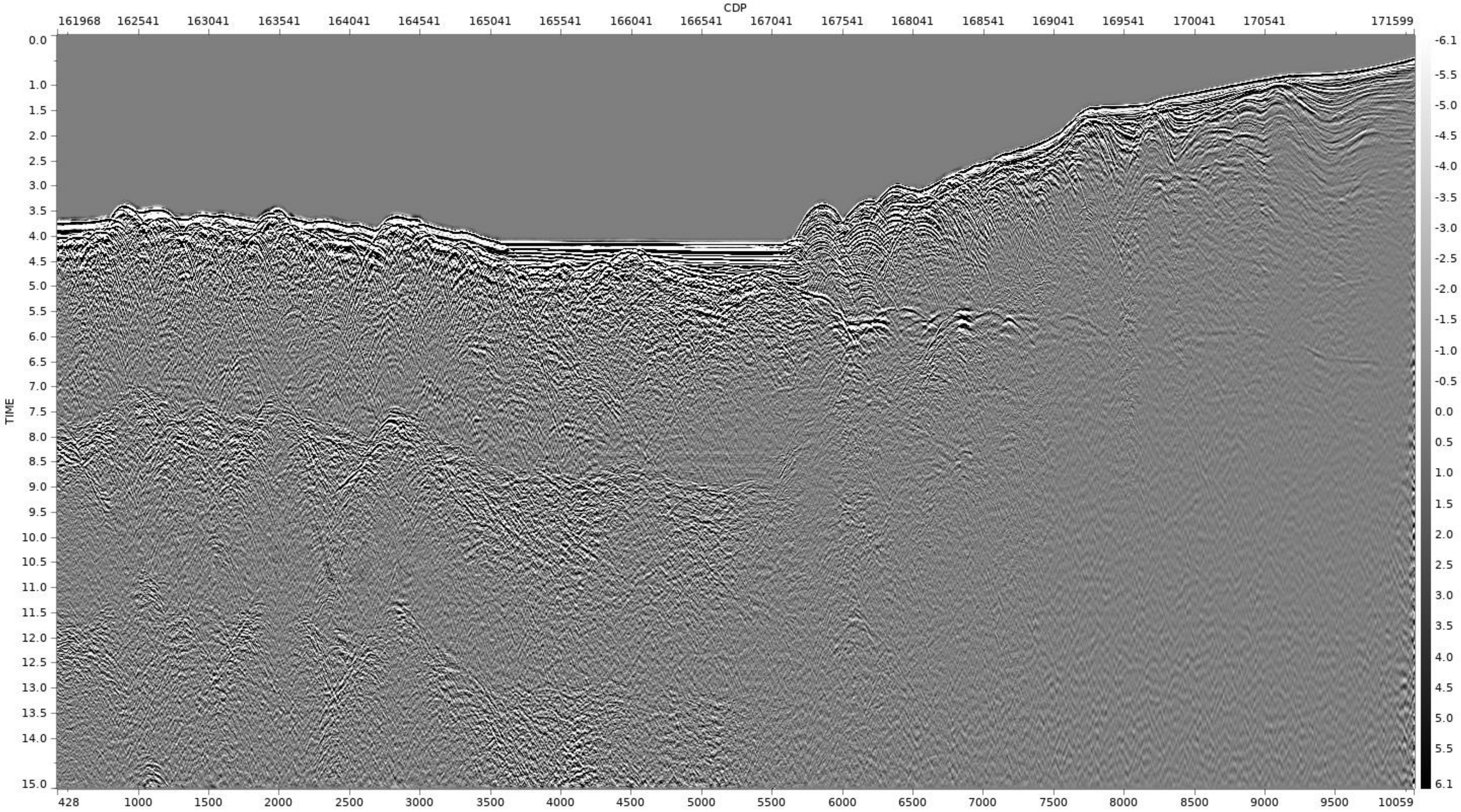
MGL2104PD09 STACK difference SRME



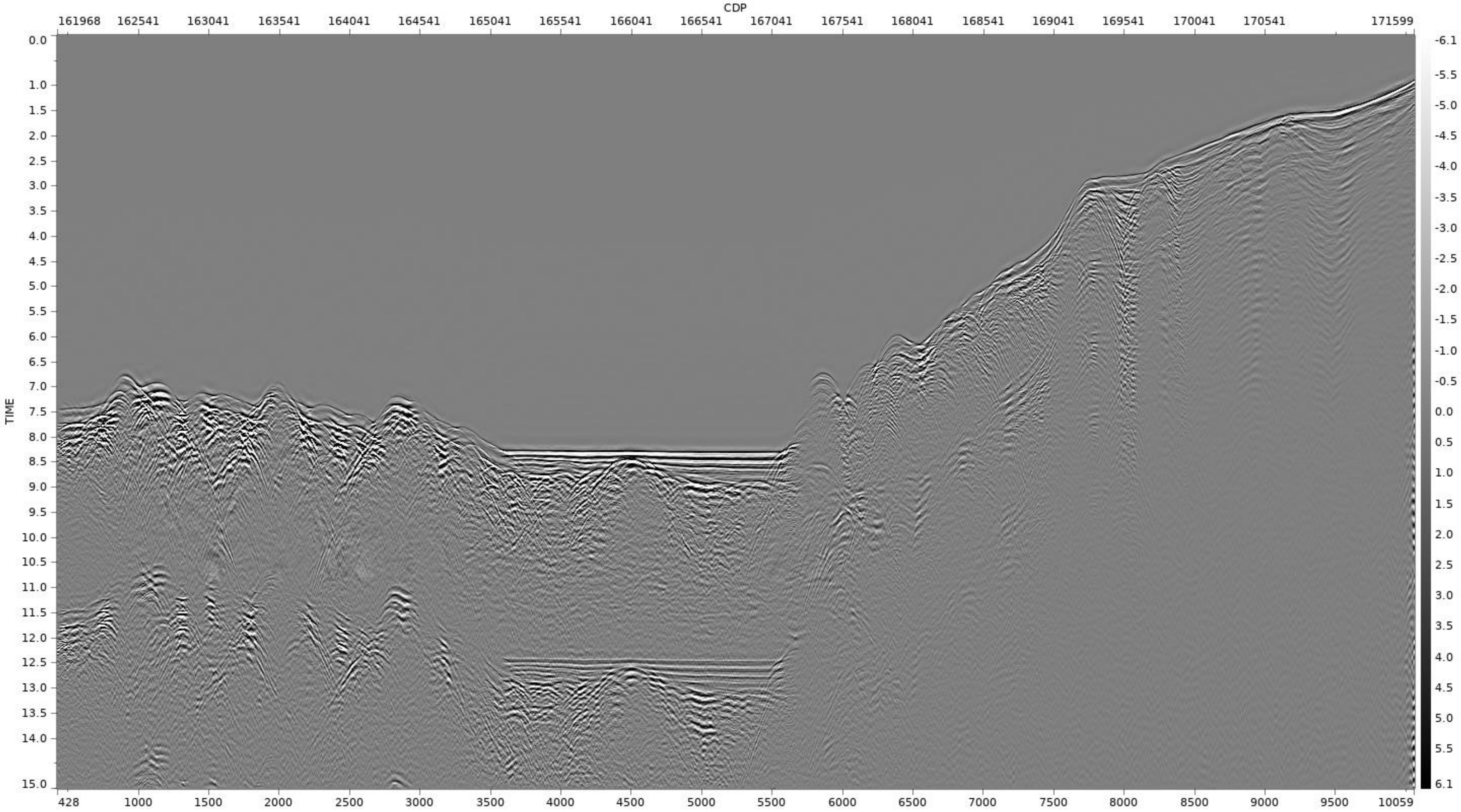
MGL2104PD19 STACK before SRME



MGL2104PD19 STACK after SRME



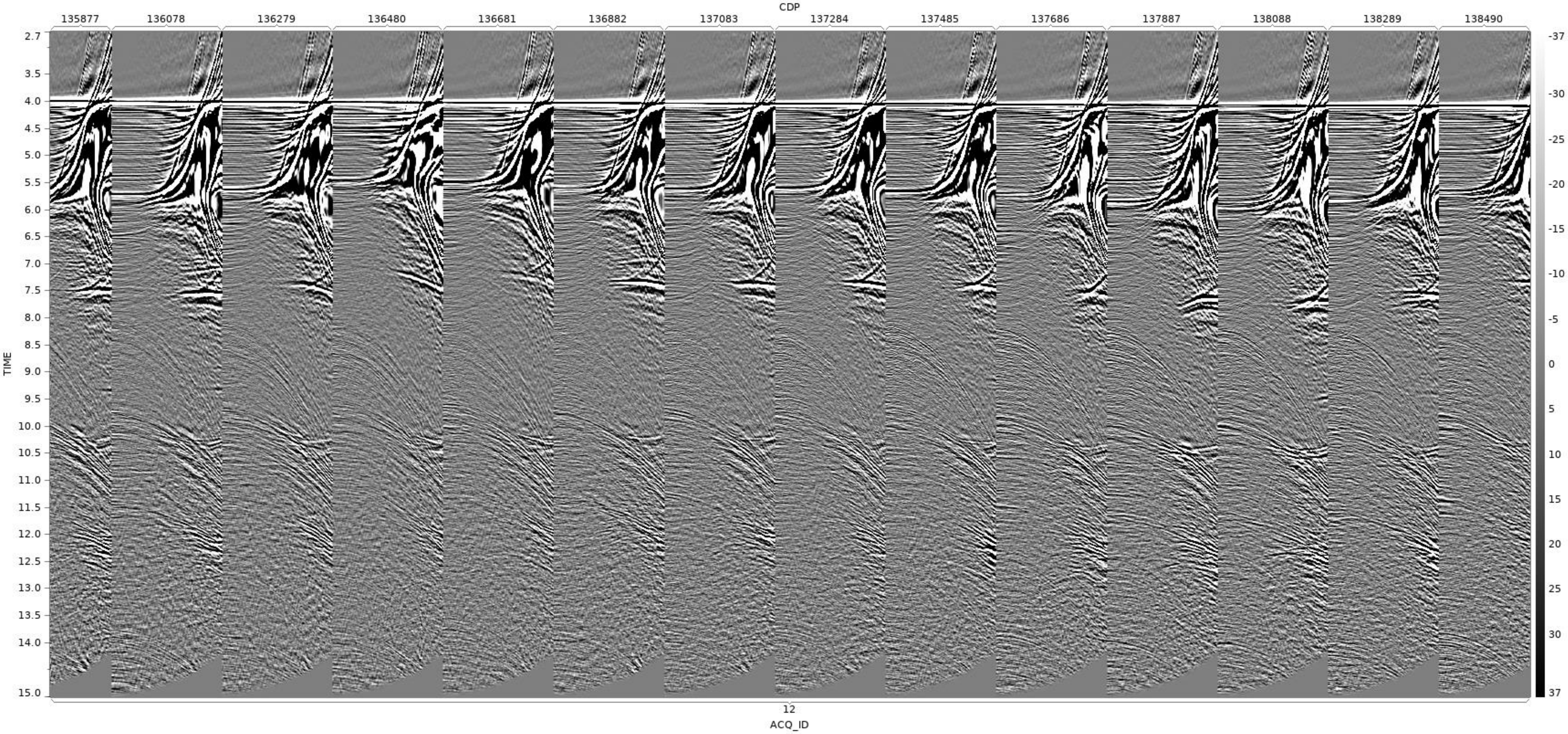
MGL2104PD19 STACK difference SRME



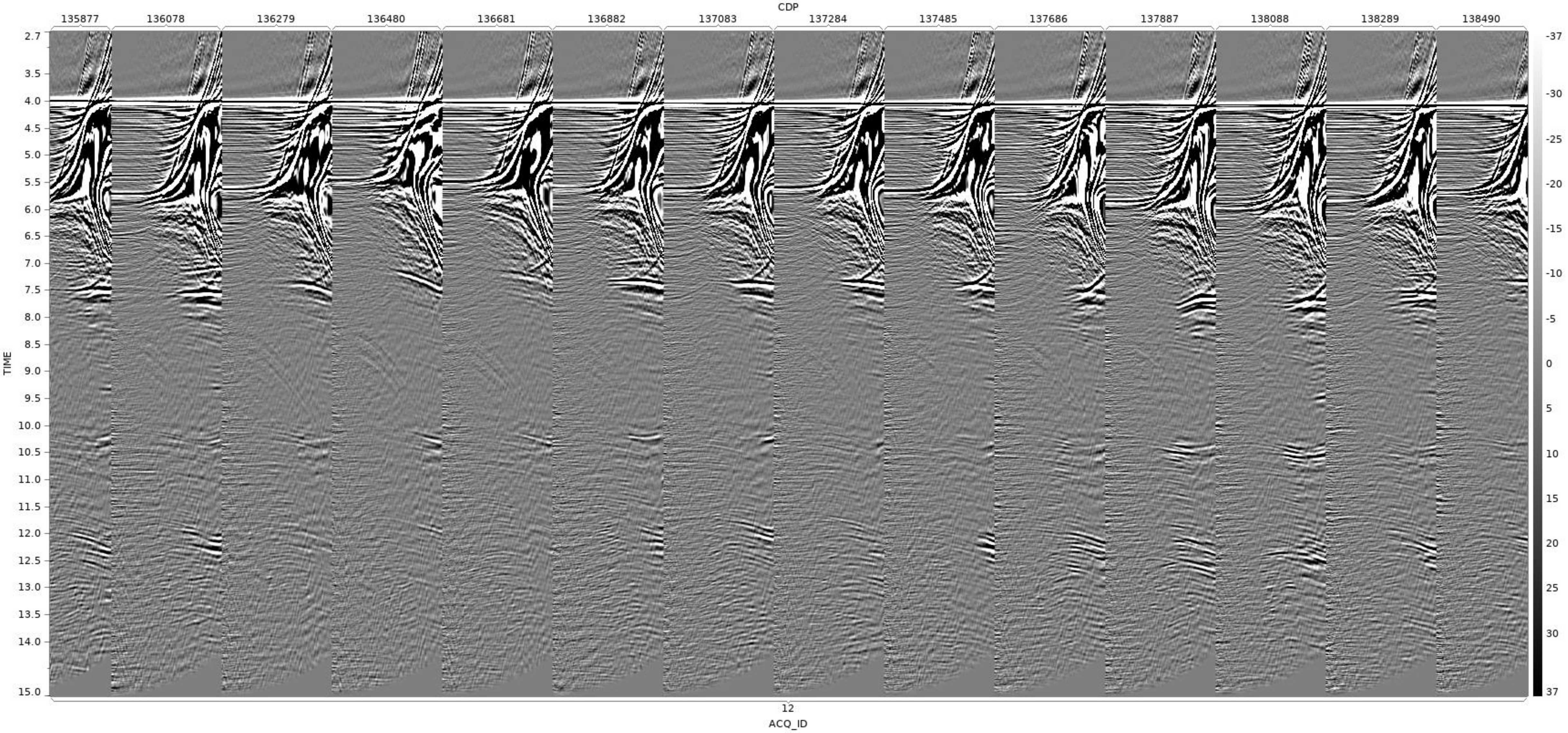
High Resolution Parabolic Radon Multiple Attenuation

- High-resolution parabolic radon technique is applied for long period multiple attenuation.
- Multiples are modeled in parabolic radon domain.
- Modeled multiples are subtracted from original input in T-X domain.
- Parameters:
  - Number of P-values = 600
  - Min. P-value = -3000ms
  - Max. P-value = 7000ms
  - Reference offset = 9200m
  - Multiple Model Mute = 600-1000 (sine square taper in P-values)

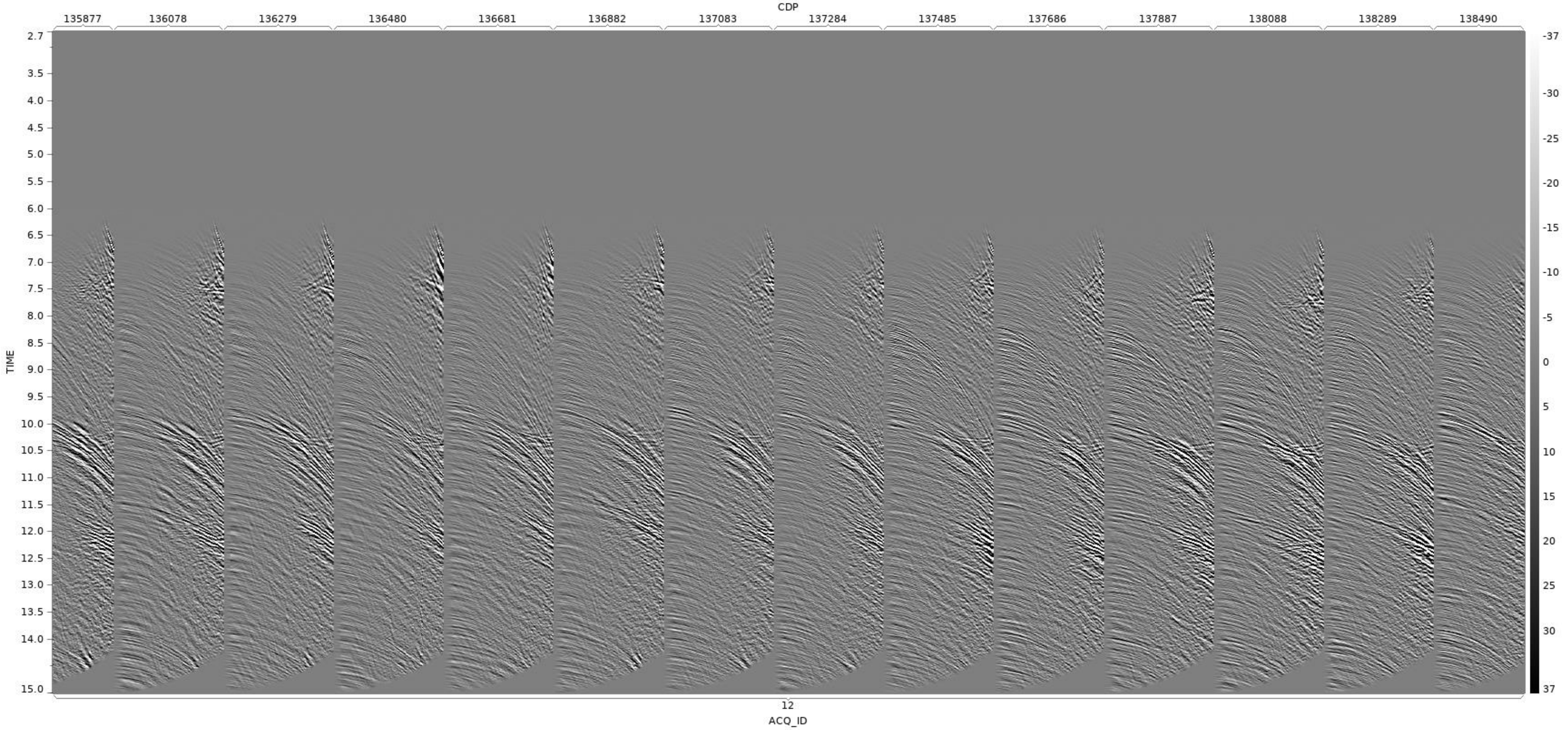
MGL2104PS03 : CDPs before Radon



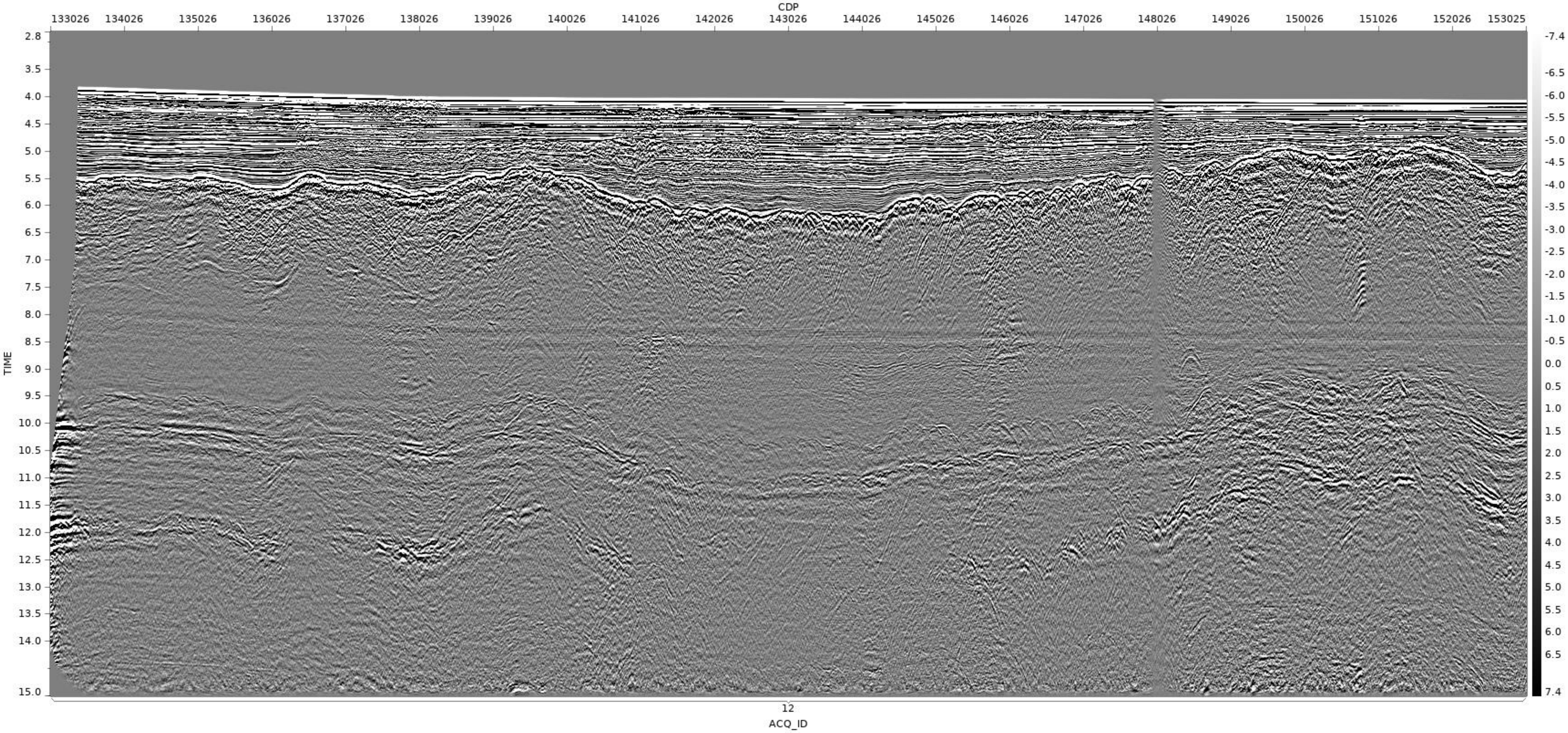
MGL2104PS03 : CDPs after Radon



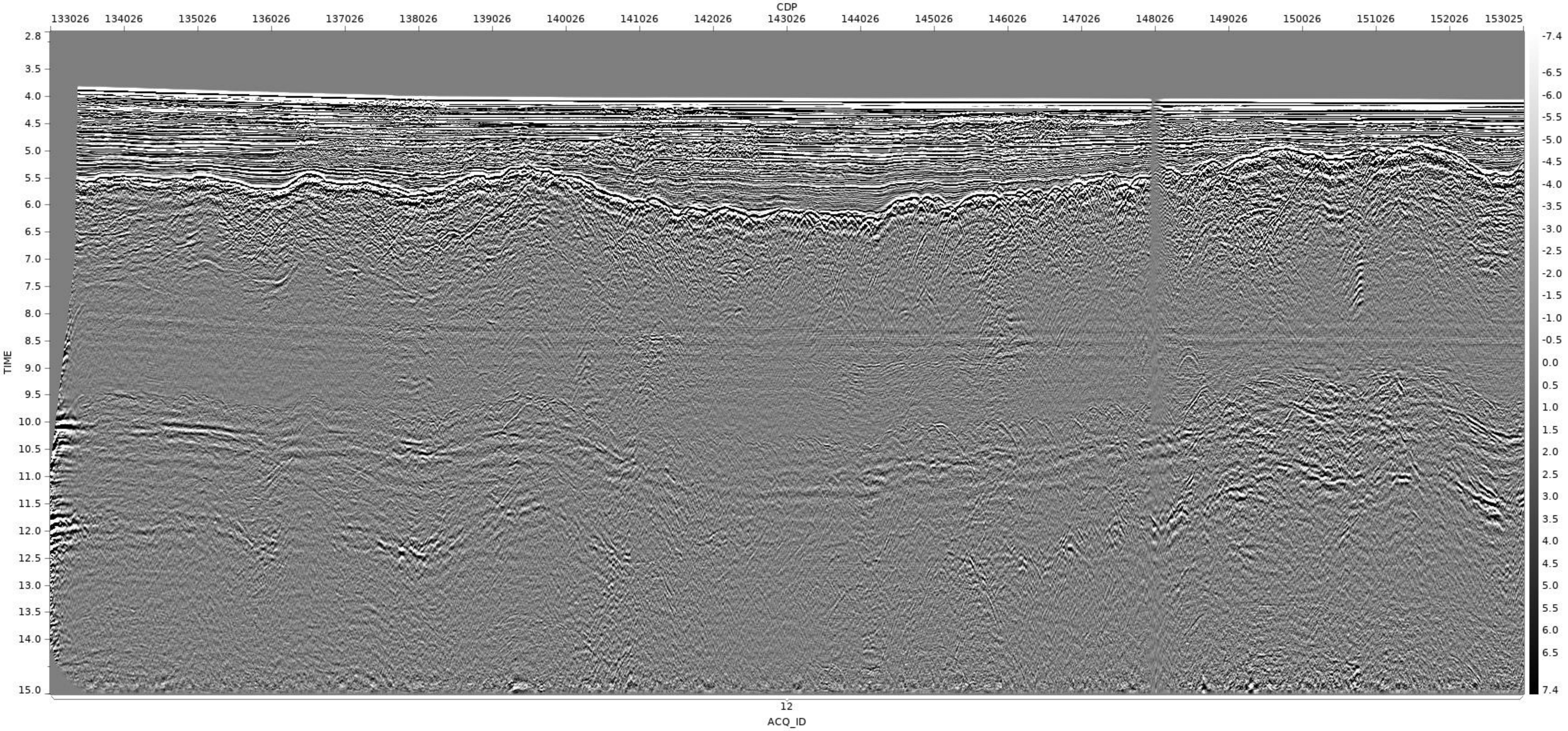
MGL2104PS03 : CDPs diff Radon



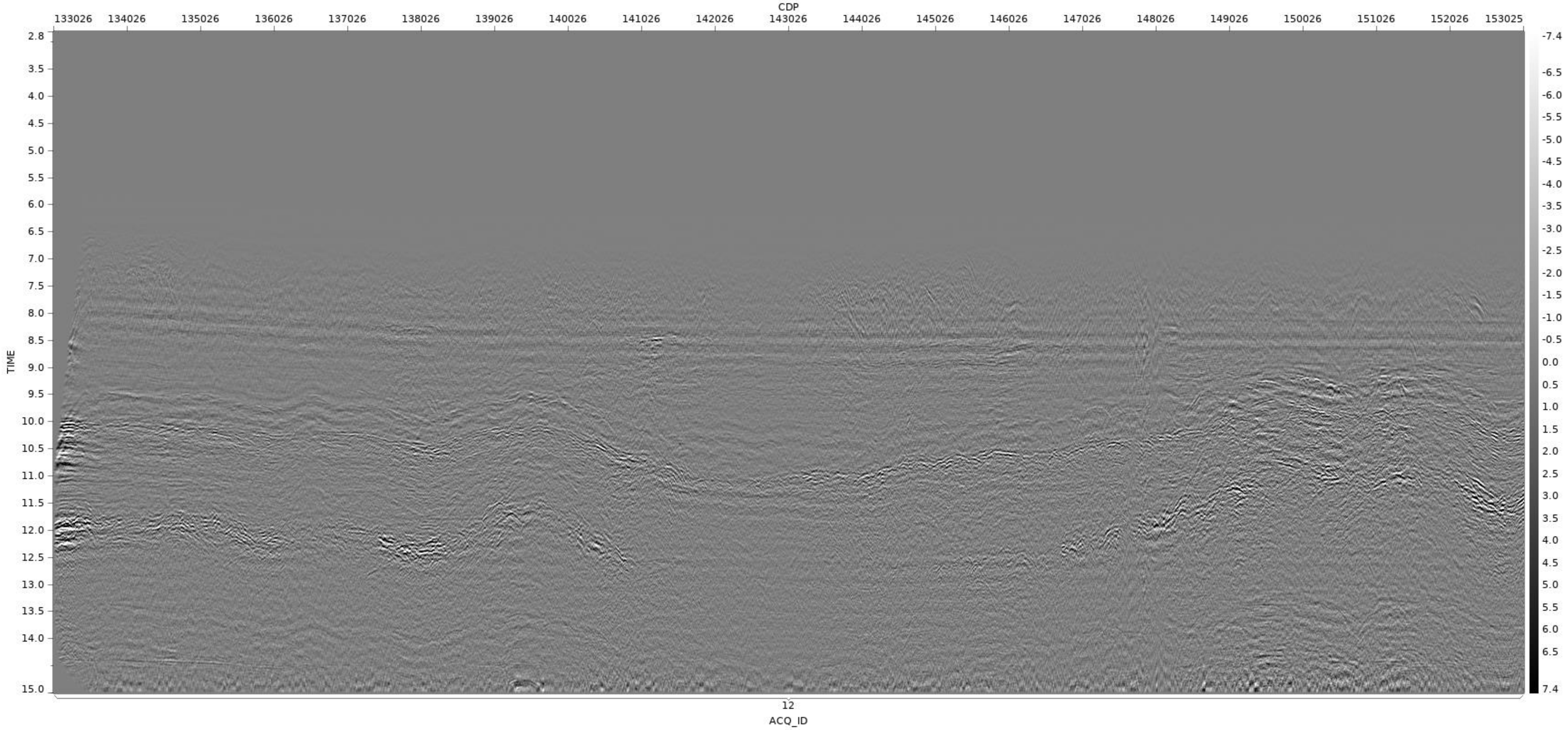
MGL2104PS03 : Stack before Radon



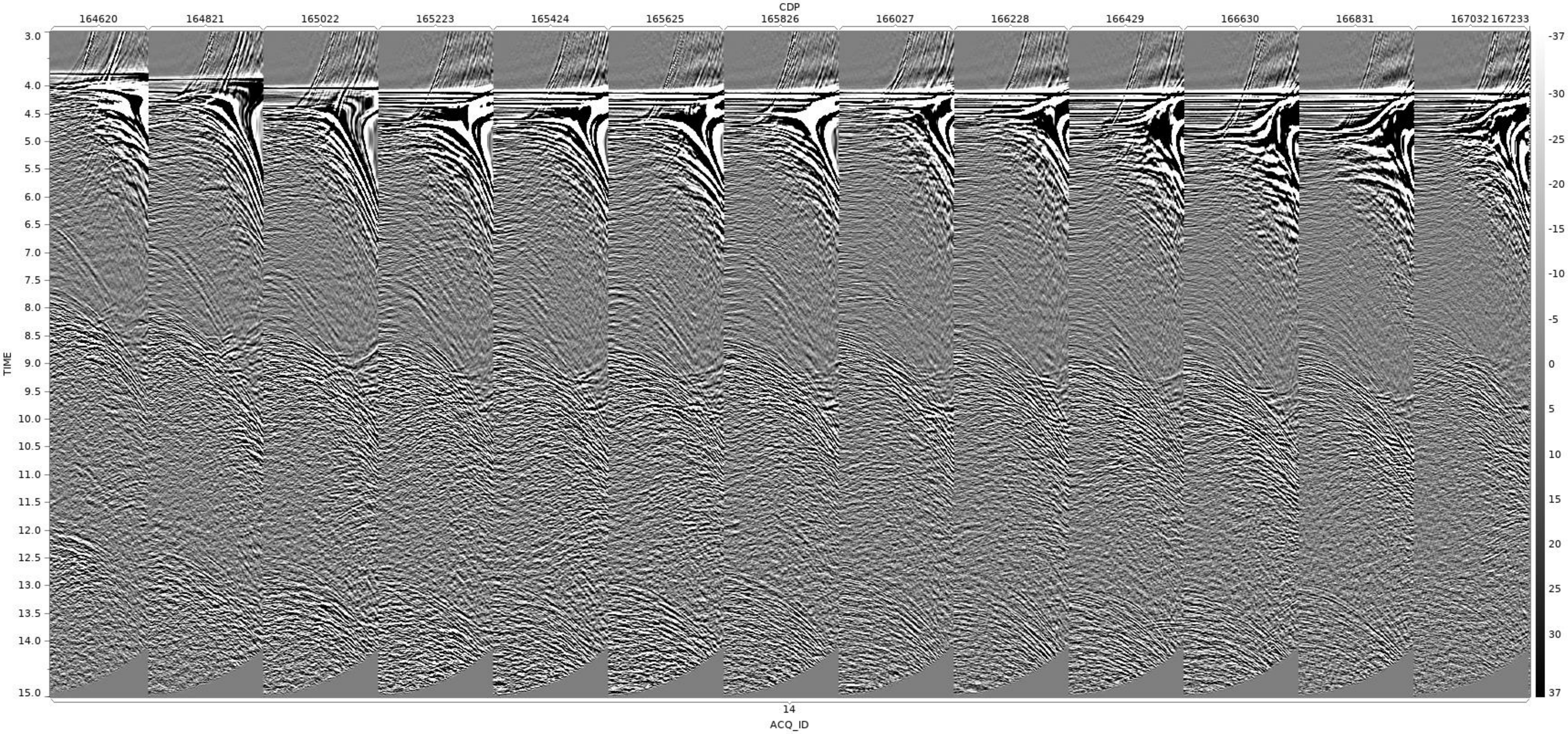
MGL2104PS03 : Stack after Radon



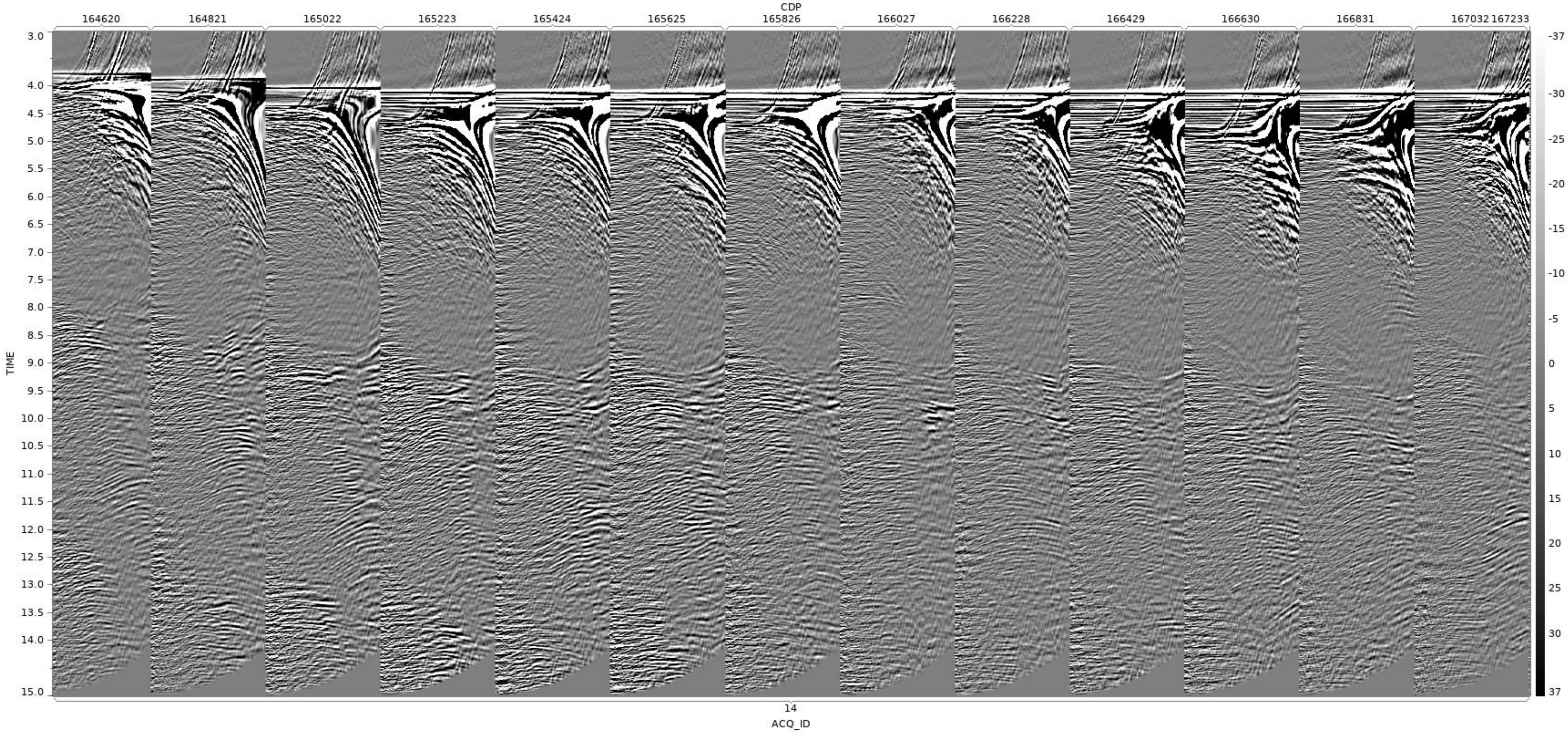
MGL2104PS03 : Stack diff Radon



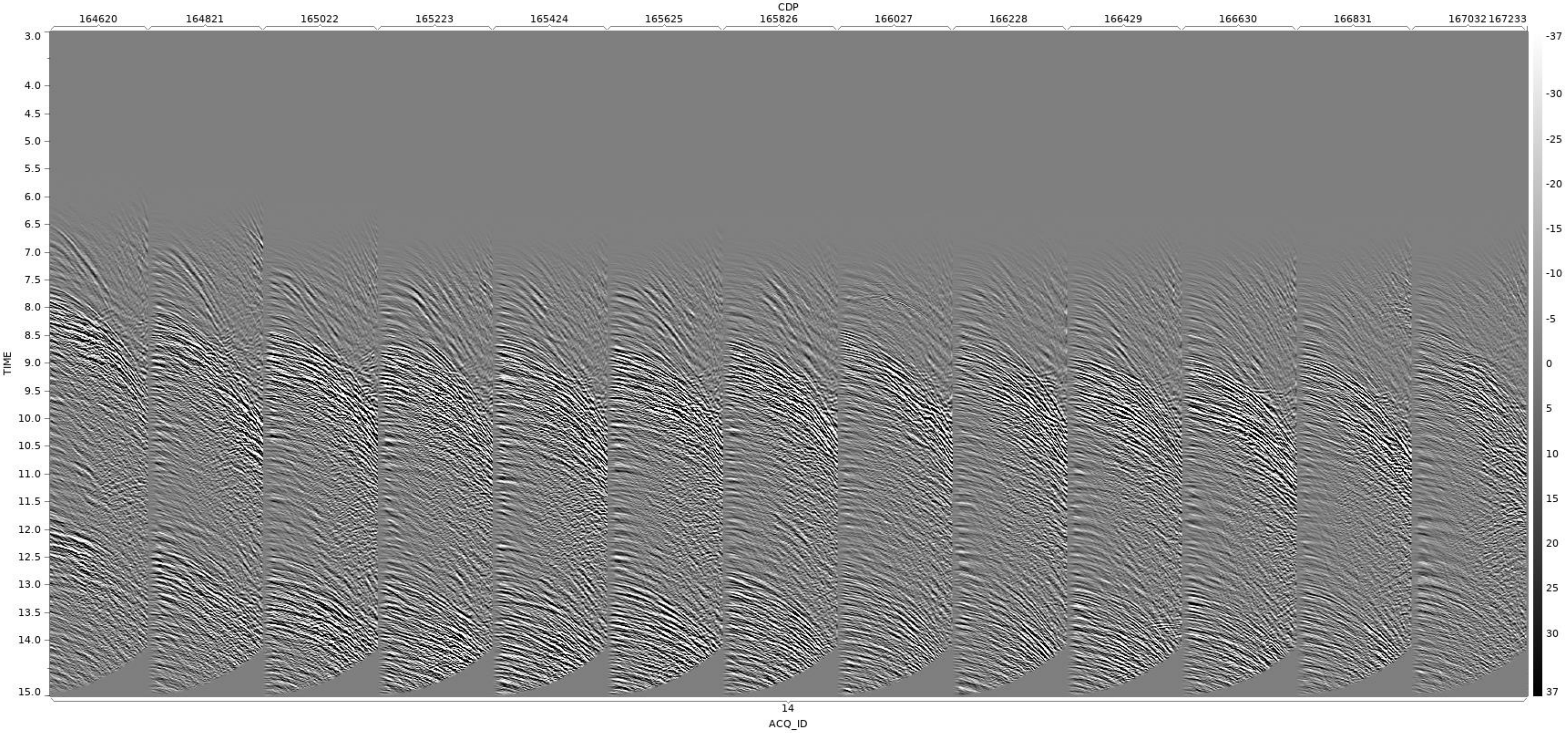
MGL2104PD19 : CDPs before Radon



MGL2104PD19 : CDPs after Radon

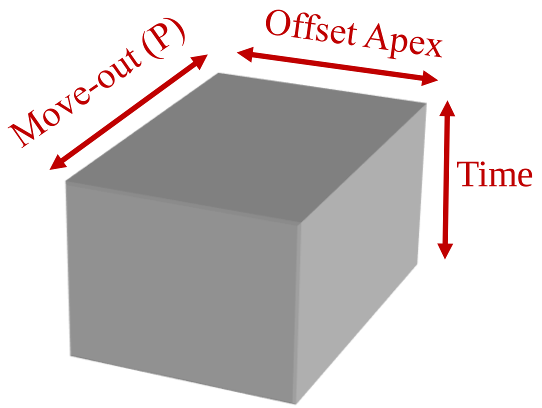


MGL2104PD19 : CDPs diff Radon

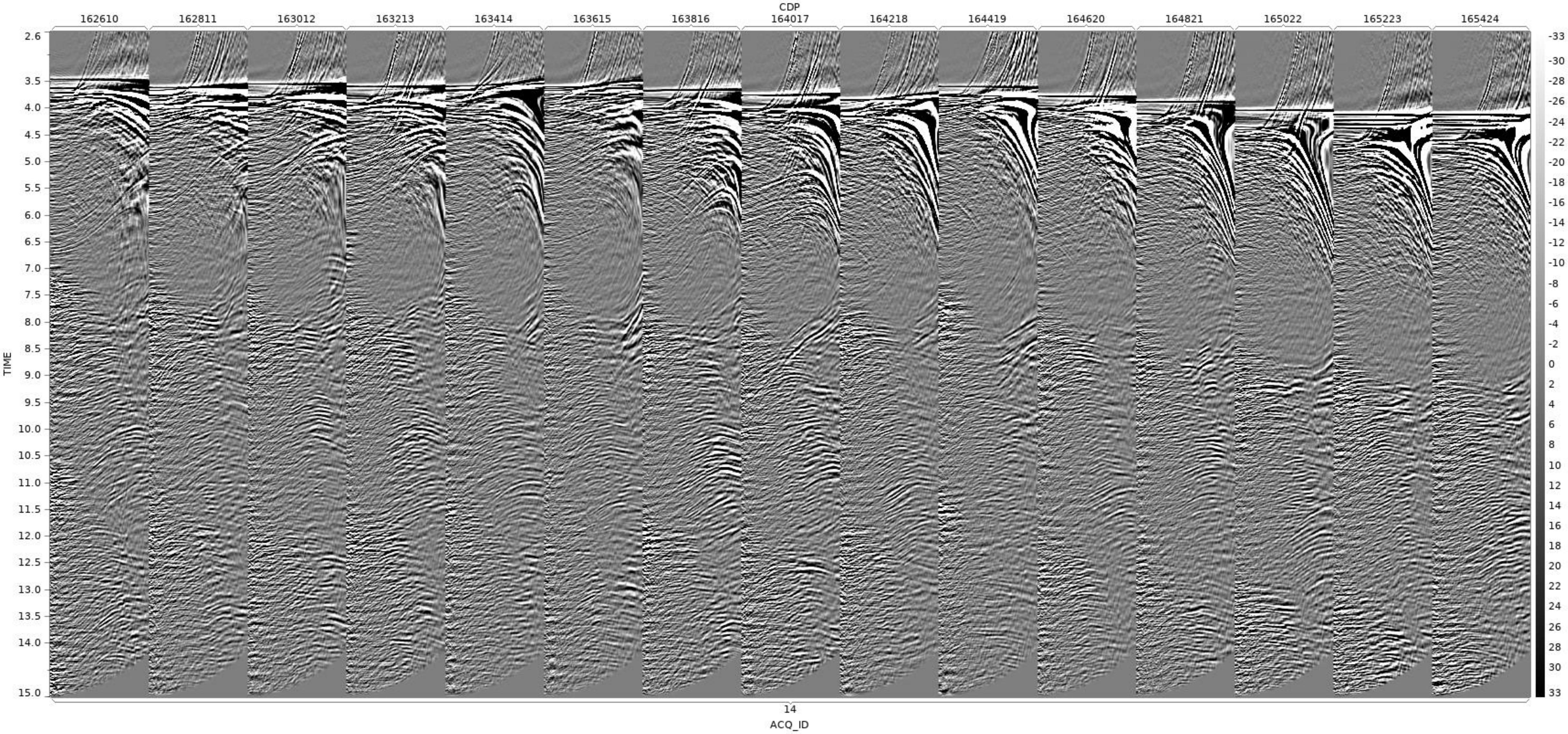


Apex-Shifted Multiple Attenuation (ASMA)

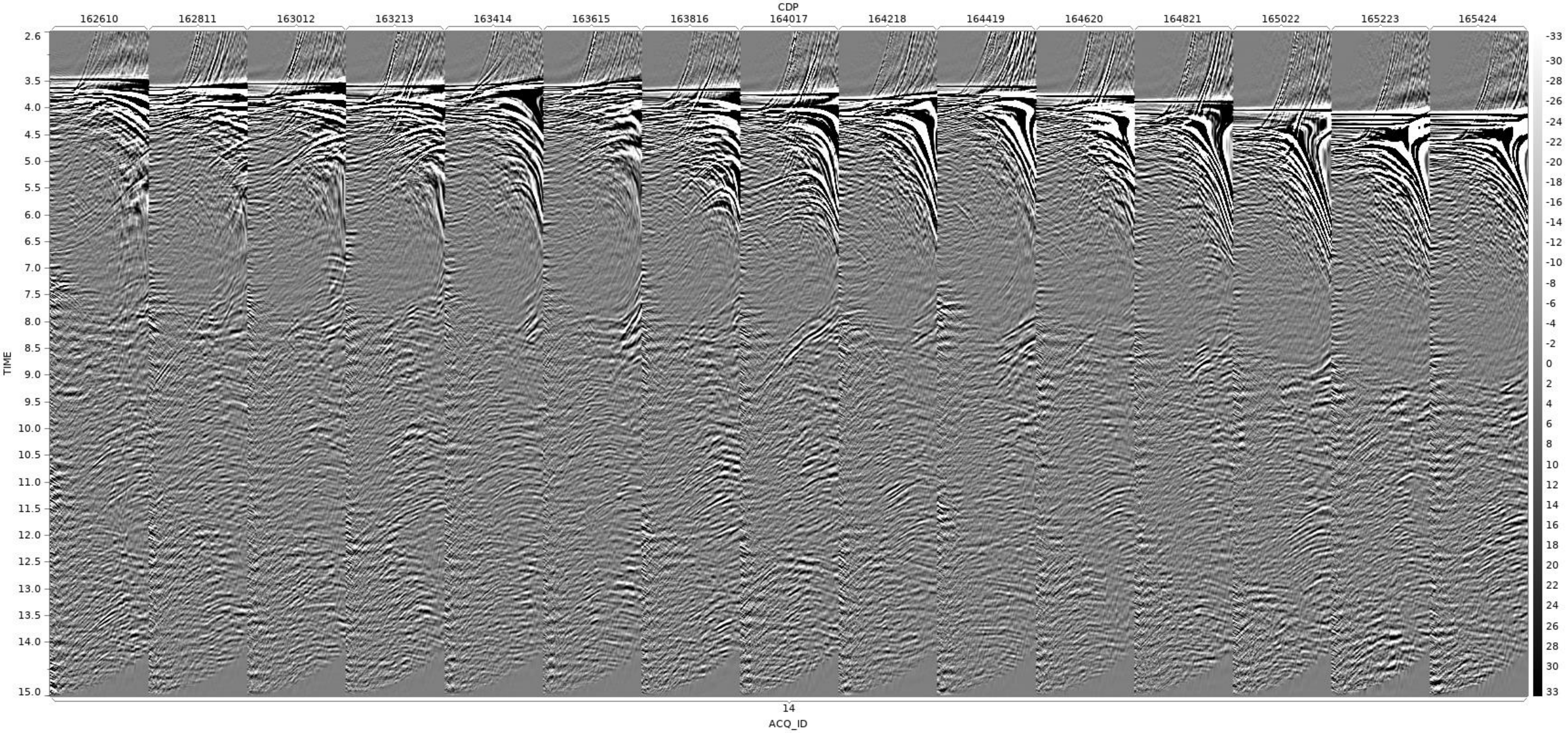
- A conventional hyperbolic radon transform consists of axis of move-out (P) and time with an apex for the move-out at zero offset.
- Because the apex of the multiple may be at any offset, an extra dimension to the transform is needed to sample all possibilities.
- Multiples with apex at non-zero offset are modeled using a hyperbolic focusing operation.
- Modeled multiples are further conditioned by removing half cycles where the peak amplitude is below a given threshold.
- Modeled multiples are adaptively subtracted from original input.



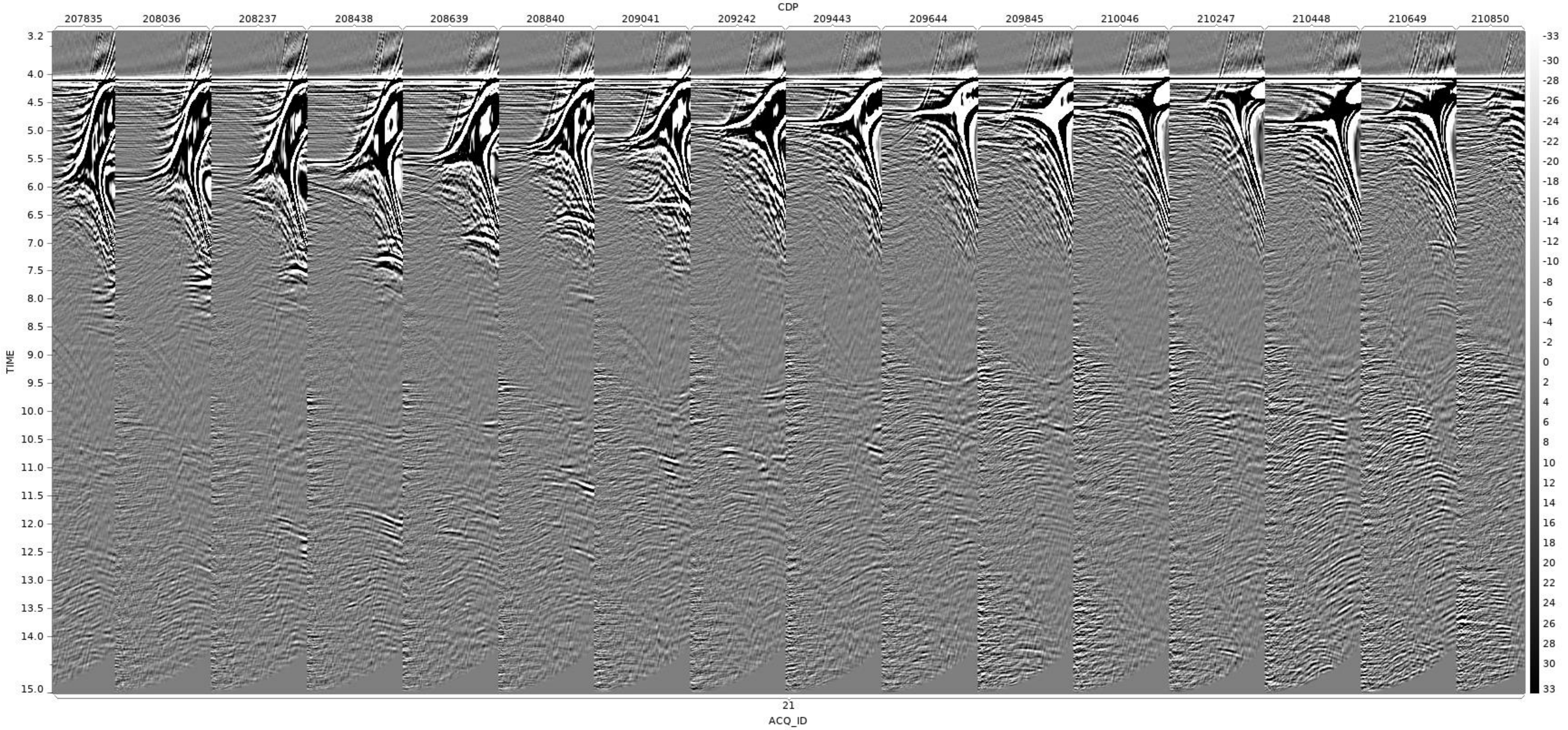
MGL2104PD19 : CDPs before ASMA



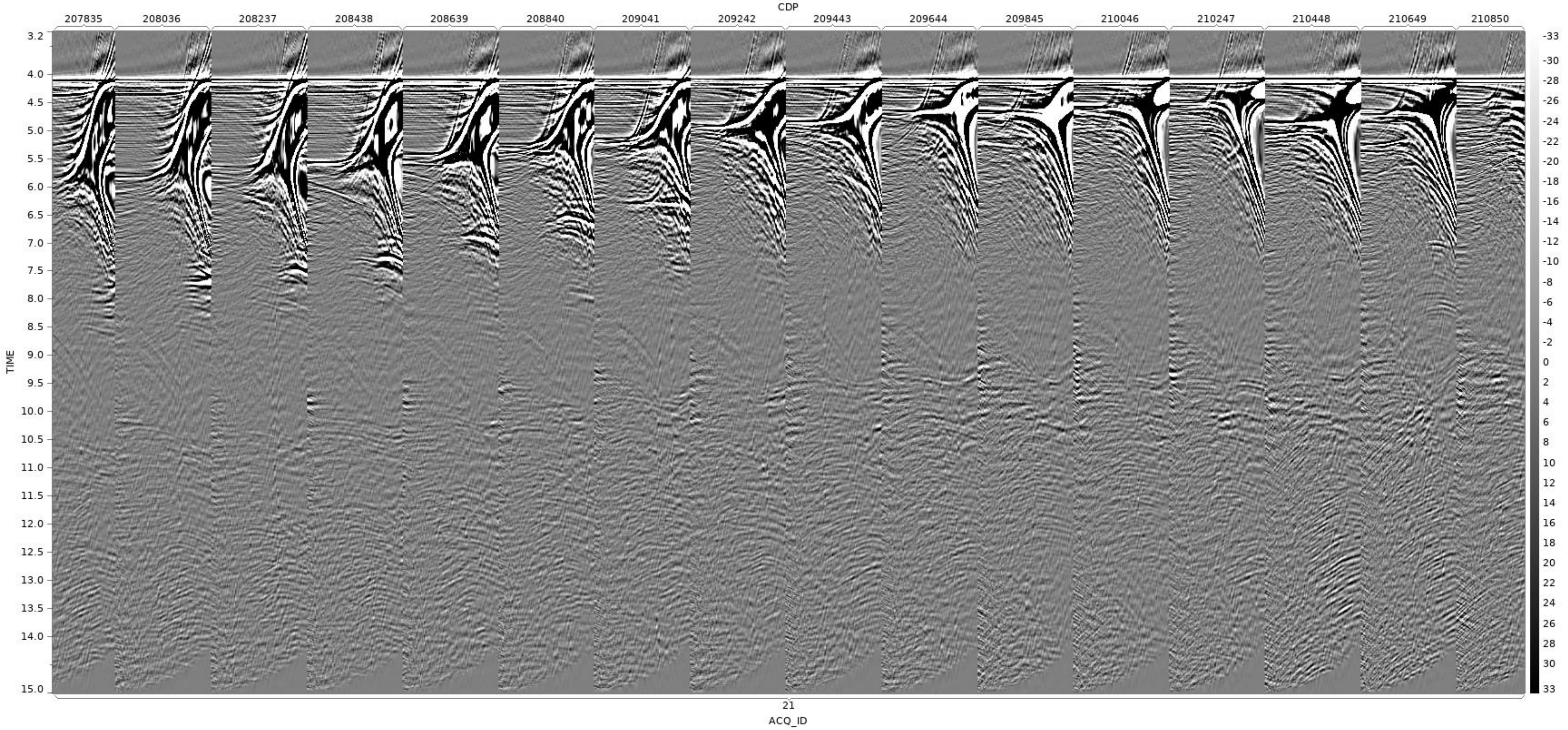
MGL2104PD19 : CDPs after ASMA



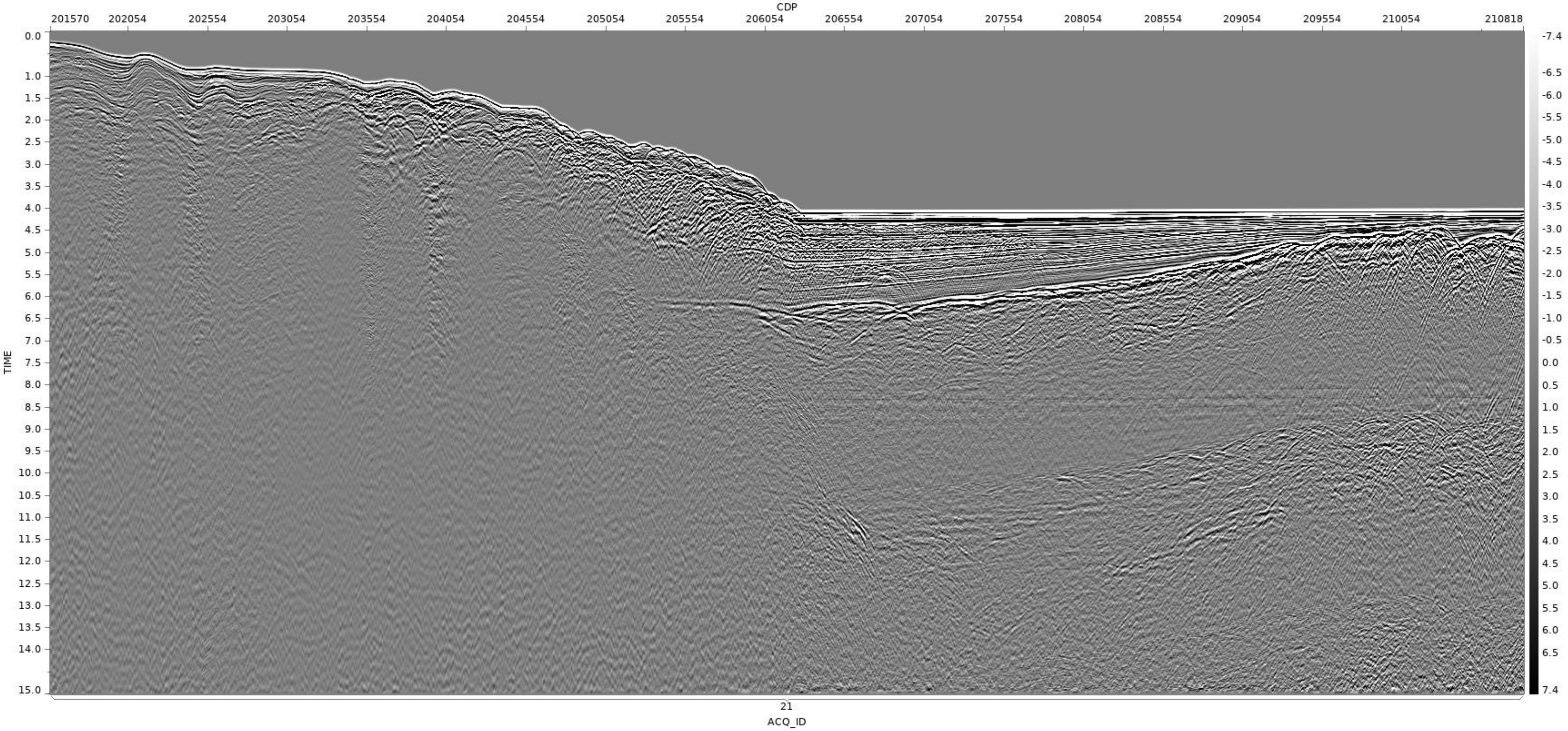
MGL2104PD16 : CDPs before ASMA



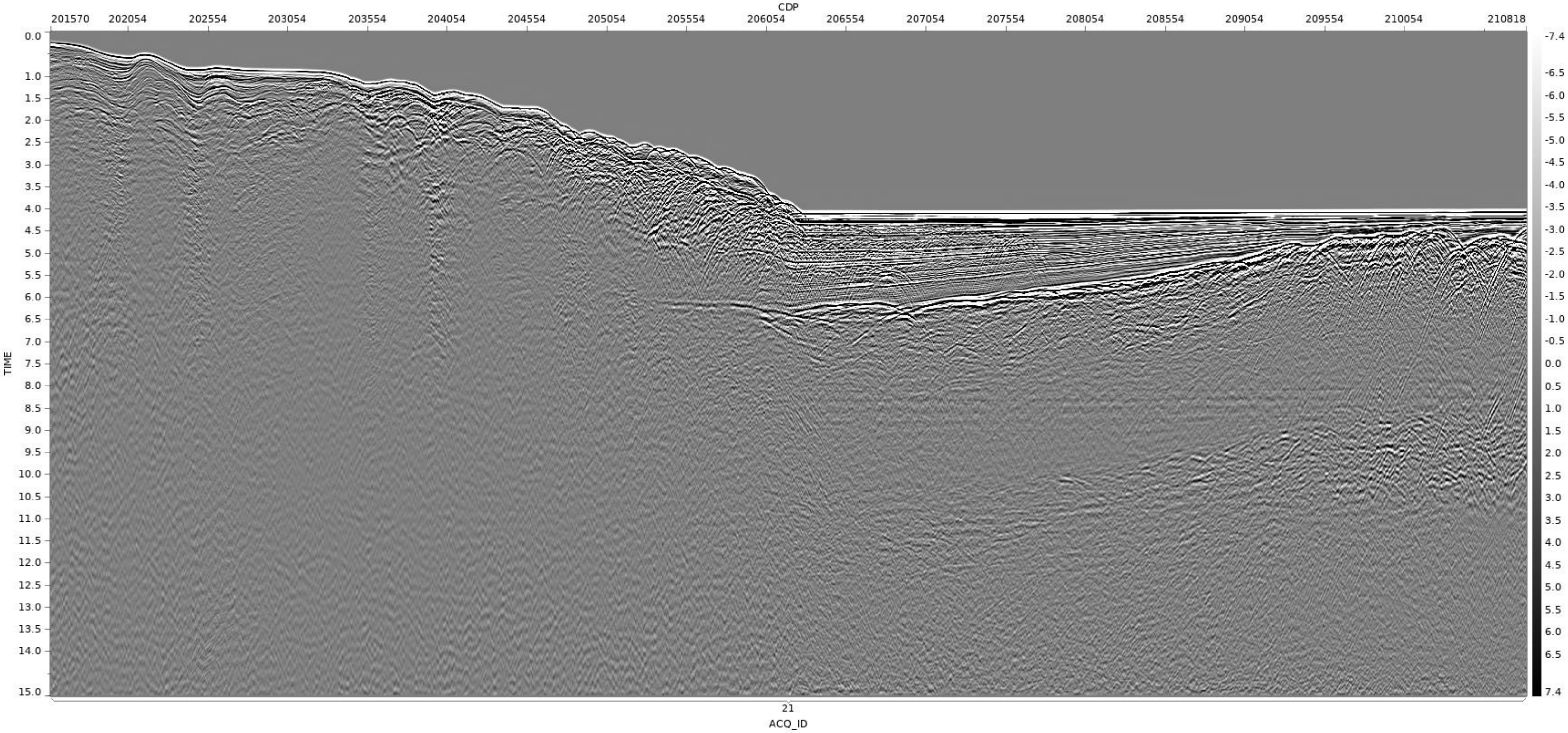
MGL2104PD16 : CDPs after ASMA



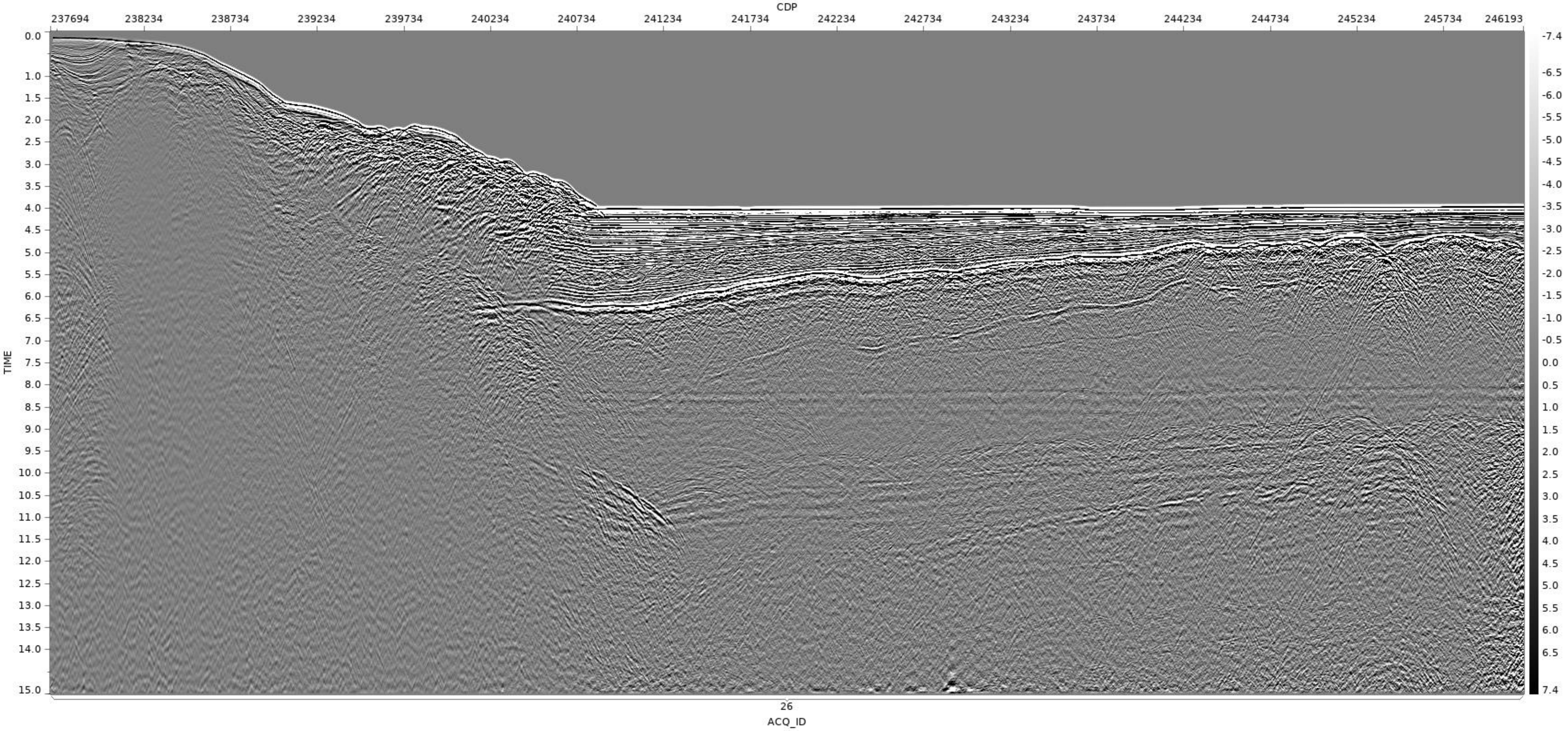
MGL2104PD16 : Stack before ASMA



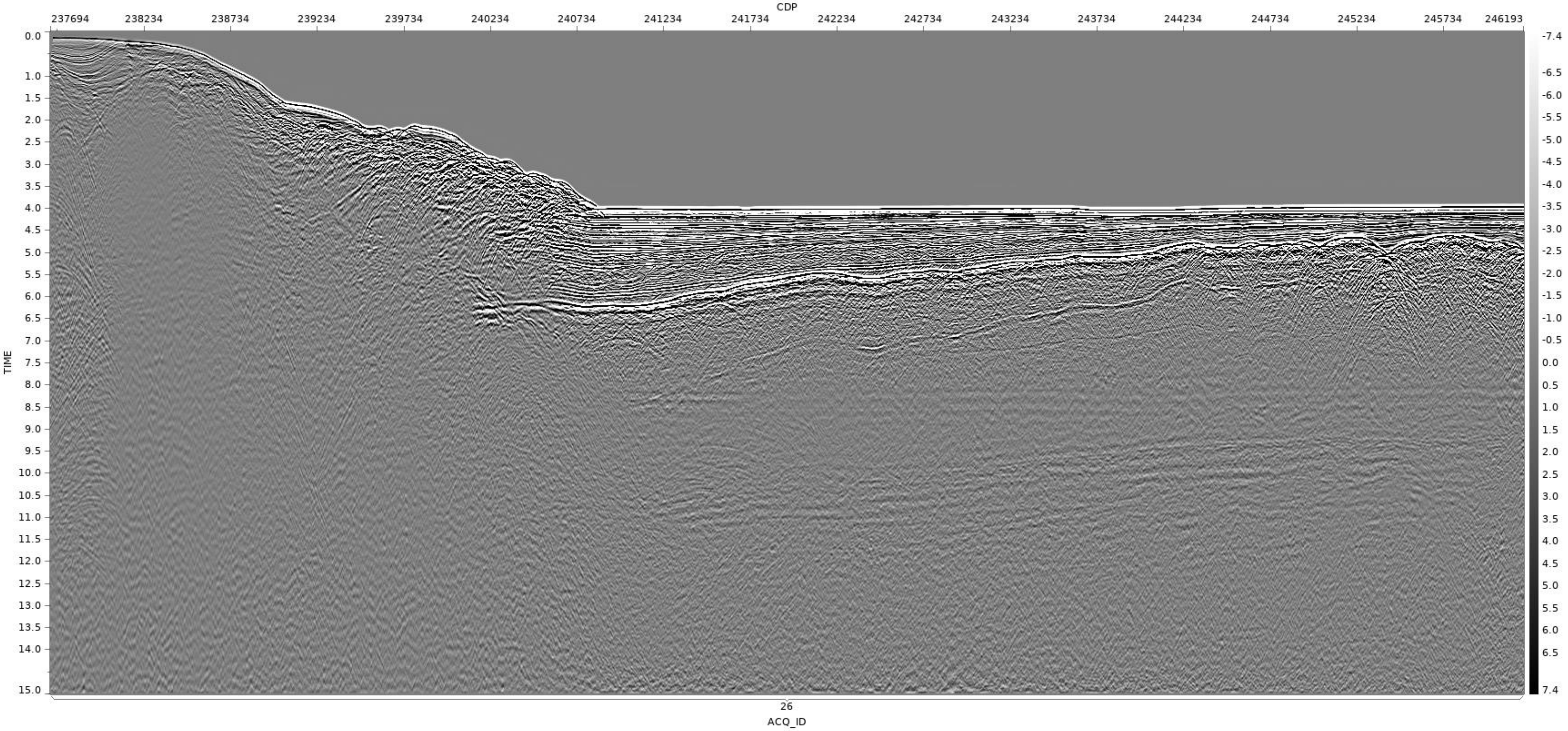
MGL2104PD16 : Stack after ASMA



MGL2104PD14 : Stack before ASMA



MGL2104PD14 : Stack after ASMA



Phase Only Q

- When seismic waves propagate through the Earth’s subsurface, anelasticity and inhomogeneity will result in:
  - Dissipation as the wave energy is absorbed by the media
  - Velocity dispersion where different frequency components travel with different speeds
- Consequently, the phase of the wavelet generally rotates with increased travel time. Phase-only Q compensation (Phase only inverse-Q filtering) attempts to correct for this phase rotation, aiming to give a wavelet which is approximately zero-phase throughout the section.
- The filter is derived from a direct frequency domain implementation. Prior to migration the data had a phase only inverse-Q filter applied. Amplitude-Q is typically applied during or after migration.
- Application of phase only inverse-Q gave improved phase stability with increasing time, confirmed against a well synthetic.

- Parameters:
  - Quality Factor: 100
  - Reference frequency: 40 hz
  - Application start time: referenced from water bottom

- Data Acquisition
  - Line layout and acquisition specification
- Pre-processing
  - Flow and data examples
- Pre-stack Depth Migration (PSDM)
  - Flow and data examples
  - Potential fields modeling
- Post Processing
  - PSDM

PSDM Velocity Model Building Summary

- PSDM Workflow
- Velocity Model Building - velocity updates examples
- FWI results
- Anisotropy results
- Residual Move-out Correction
- Gravity Modeling

Velocity Model Building and Kirchhoff PSDM Workflow

- Initial velocity & initial Kirchhoff migration
  - Initial velocity model built from converted PSTM velocities to depth
- Isotropic sediment velocity updates (tomographic update)
  - Run Auto-picker followed by tomographic inversion to update the sediment velocity
  - Smooth the updated velocity
  - Run Kirchhoff pre-stack depth migration
    - Max depth 40 km
    - Max frequency 45 Hz
    - Migration aperture 6 km
- Reflection and Diving wave FWI (deeper water section)
- Residual tomographic velocity update
- Data-derived Anisotropy parameters
  - Epsilon derived from scans on isotropic depth gathers
  - Delta created from scaling epsilon grid (x0.5)
  - Anisotropy grids were merged/tapered at water bottom horizon and masked below Basement / wedge horizon
- Velocity tie analysis
  - 3D velocity gridding was run to ensure velocities tie at every 2D line intersection

Velocity Model Building and Kirchhoff PSDM Workflow

- Incorporate potential field data to get crustal velocities
  - Gravity model defined using a combination of the USGS model and interpretation of the shallow prism
  - For shelf section, available streamer refraction or OBS velocity model used for some lines (details in next slide)
  - To finalize the velocity model, sediment velocity grids were merged with crustal velocities
- Final Kirchhoff PSDM + RMOC
  - 8 km migration aperture for 12 km cable length lines
  - 9 km migration aperture for 15 km cable length lines
  - Max Migration dip angle: 90 degrees
  - Max frequency: 100 Hz
  - Depth sample rate: 5 meters

Shelf section: Velocity Model Building and Kirchhoff PSDM Workflow

- Details on available streamer refraction or OBS velocity model for some lines

  - PD09, PD12, PD16 and PD19
    - Reflection tomography merged with provided streamer tomography velocities
    - Velocity then merged with USGS 3D velocity model merged to oceanic crust

  - PD13, PD14, MCS01, PS01ACD and PS01B
    - Reflection tomography merged with OBS 3D velocity model
    - Velocity then merged with USGS 3D velocity model merged to oceanic crust

  - For other lines without streamer tomography or OBS velocity model
    - Reflection tomography merged with USGS 3D velocity model merged to oceanic crust

  - All 2D lines: Hang provided “Oregon 1D profile” below top of crust horizon

Examples of PSDM Velocity Updates

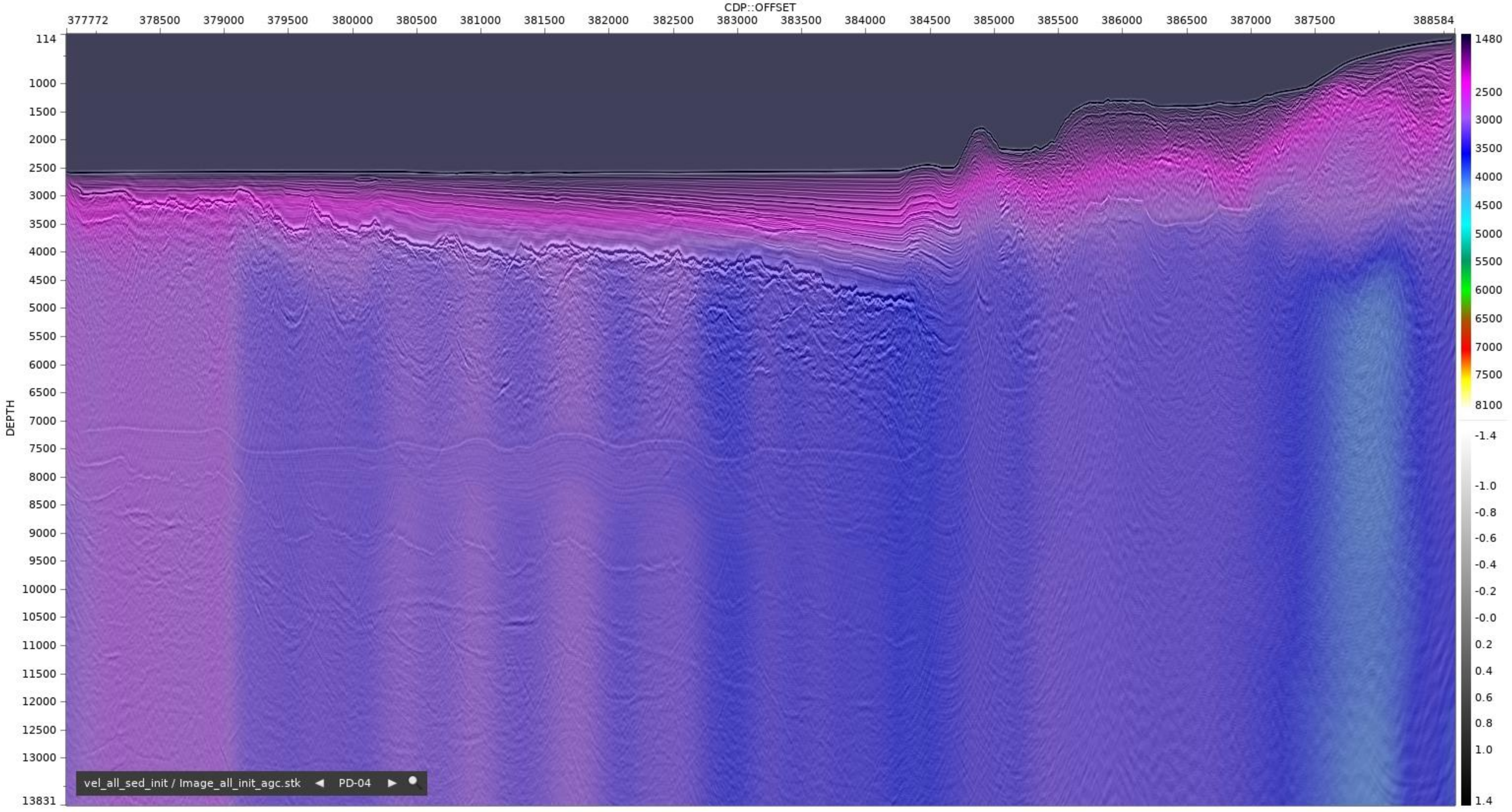
(Tomography & FWI included in model building)

- Results of lines PD-04, PD-14, PS-05 & TD-15D14A
- Comparison of initial, intermediate and final PSDM results
- Set of images corresponding to PSDM velocity/stack overlay, PSDM stack only & gather

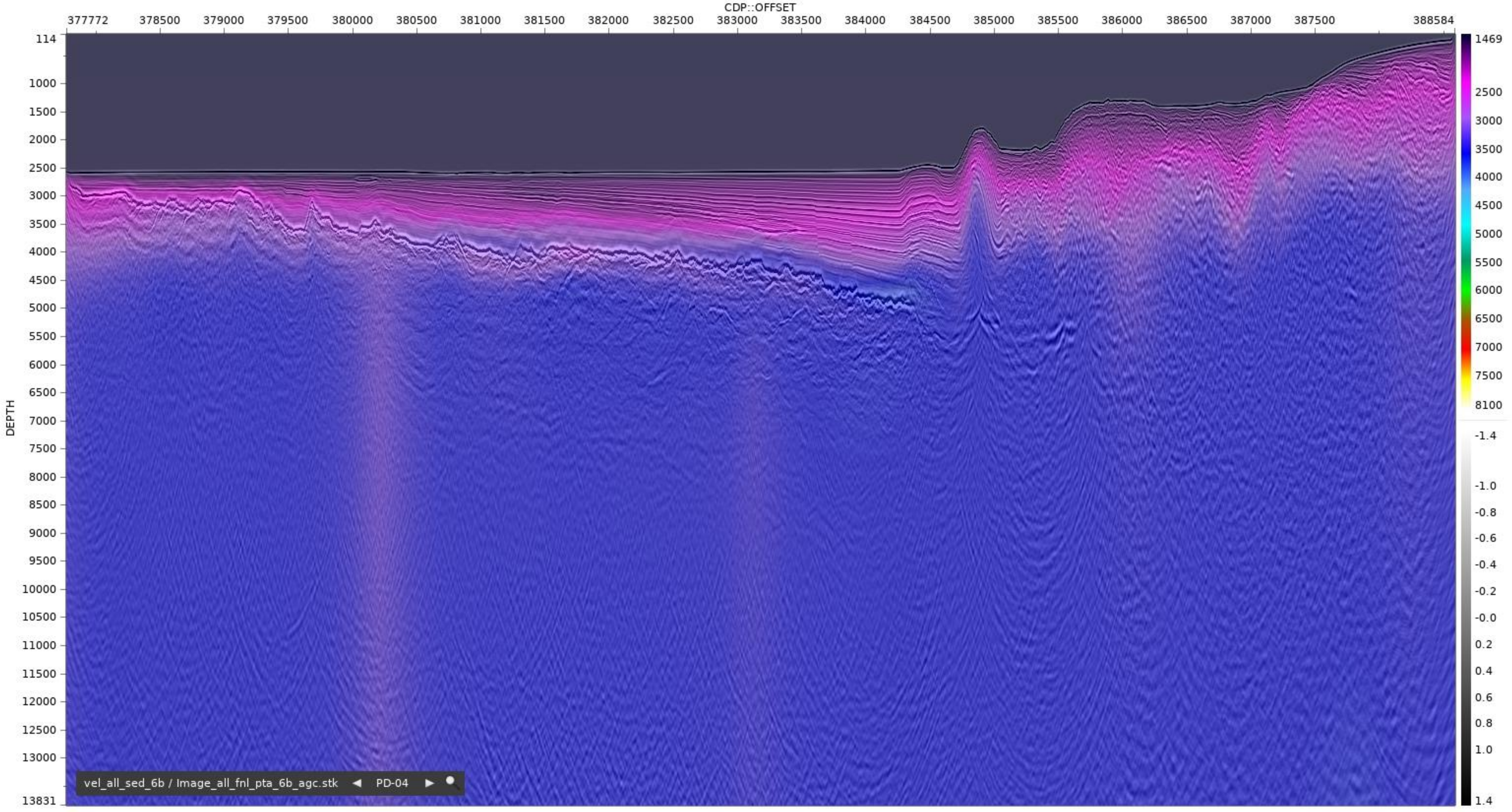
Line PD-04

CANADA
PD-03
PD-04
PS-0
MCS-03
MCS-02AB
PD-06
PD-07
TD08D06
PD-09
PD-10
PD-11
PS-03
PD-13
MCS-01
PD-15
PD-16
PD-17

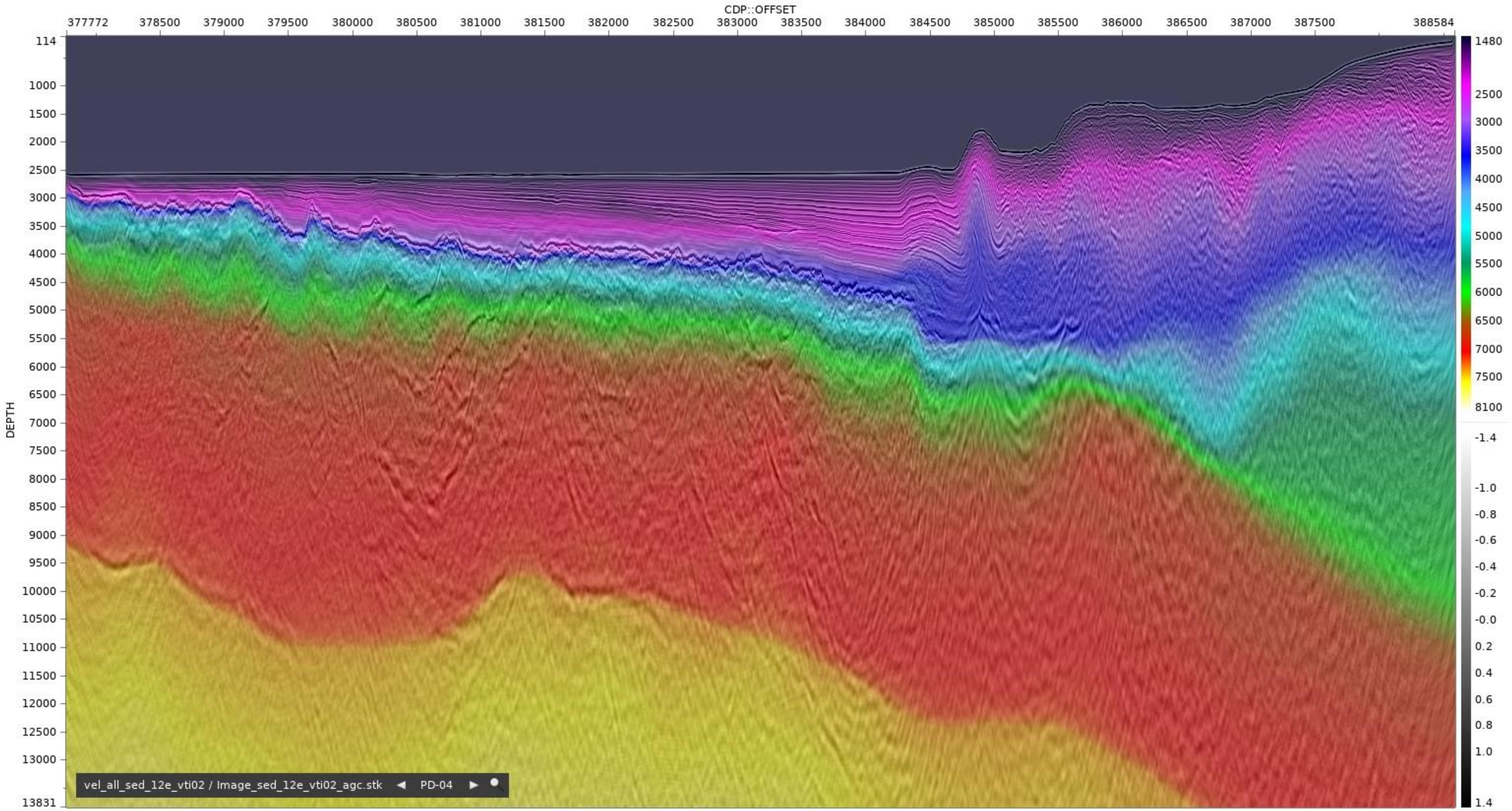
PD-04 - Initial PSDM Stack and Velocity



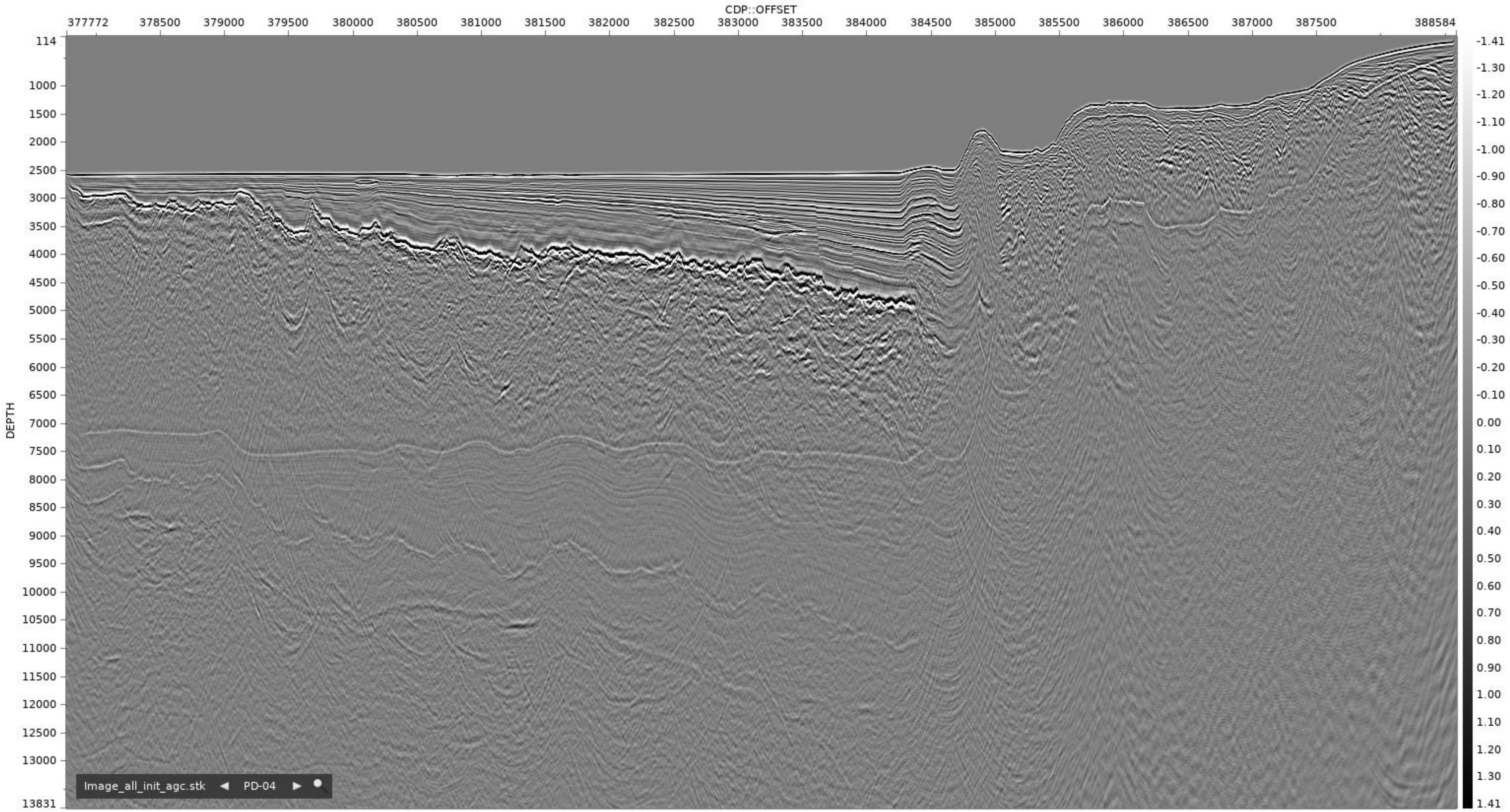
PD-04 – Updated PSDM Stack and Velocity



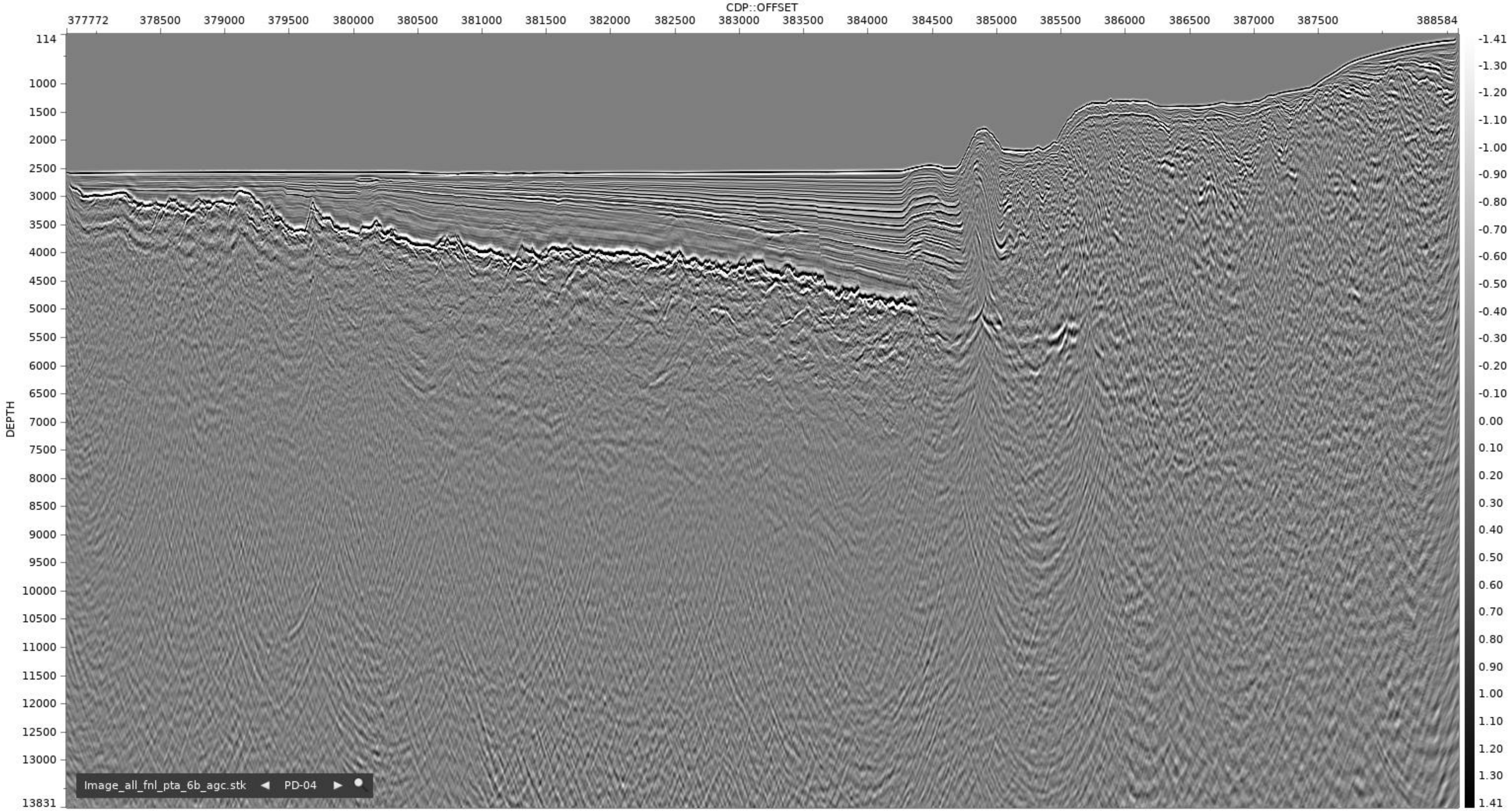
PD-04 – Final PSDM Stack and Velocity



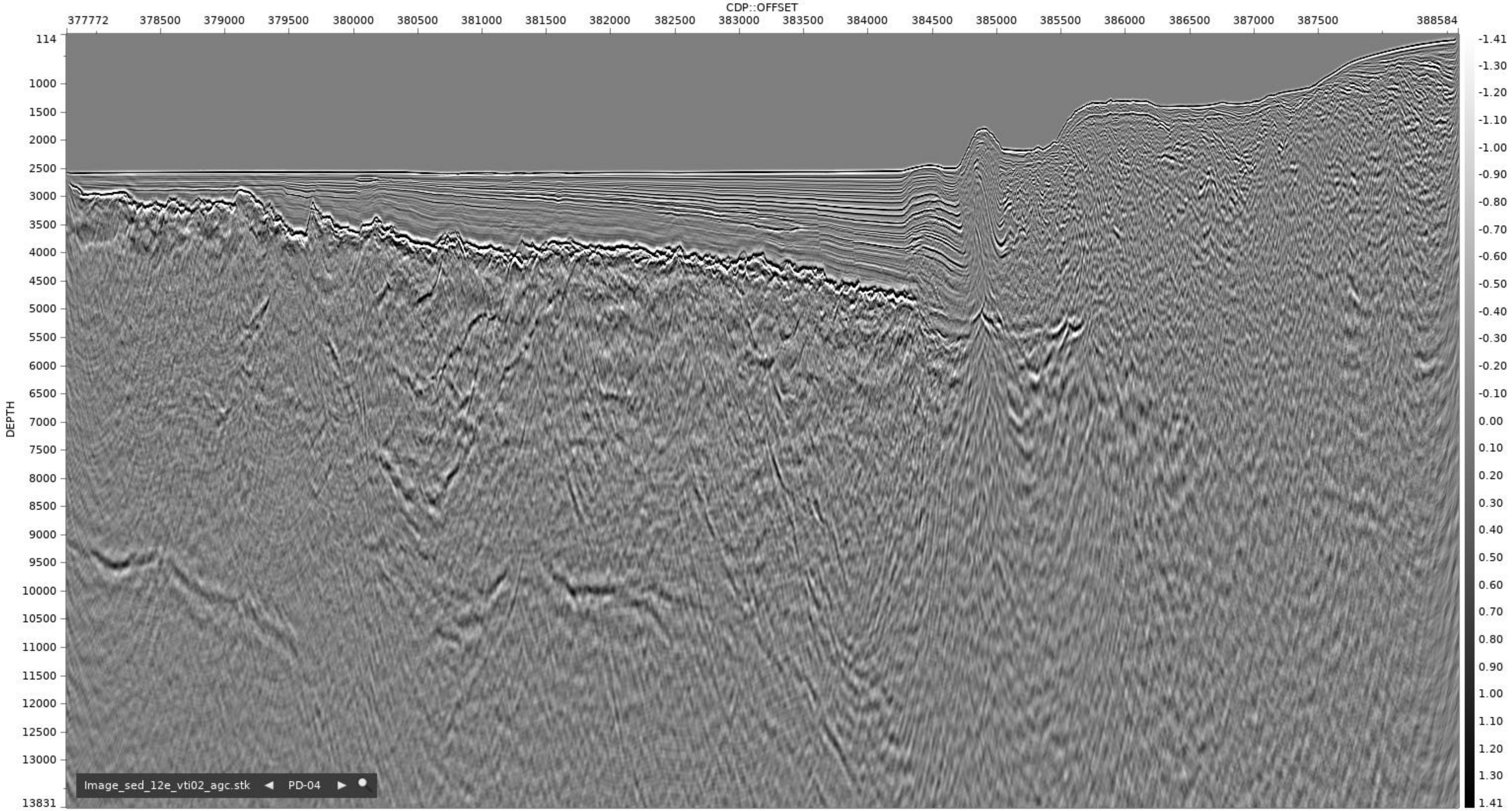
PD-04 - Initial PSDM Stack



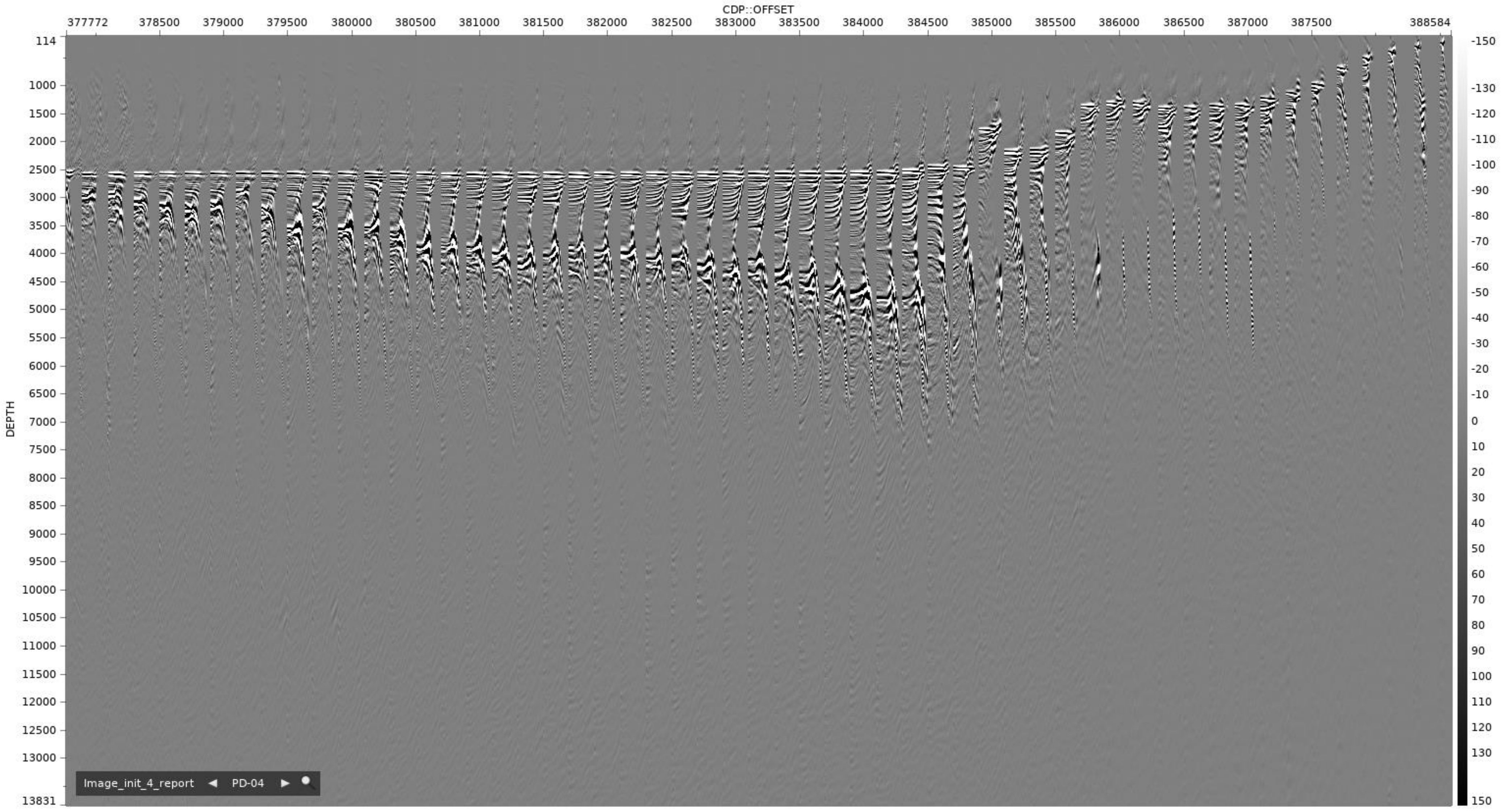
PD-04 – Updated PSDM Stack



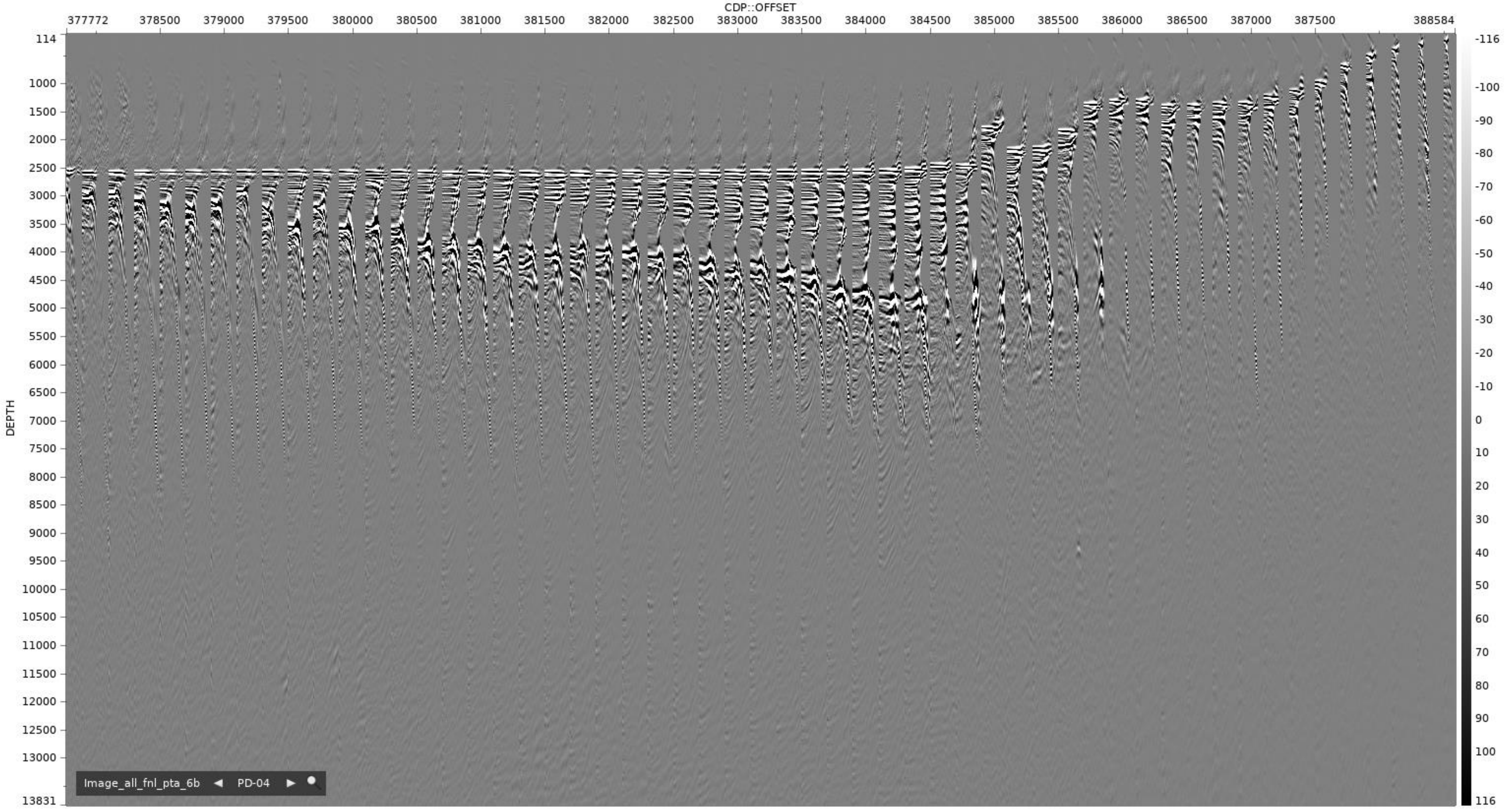
PD-04 - Final PSDM Stack



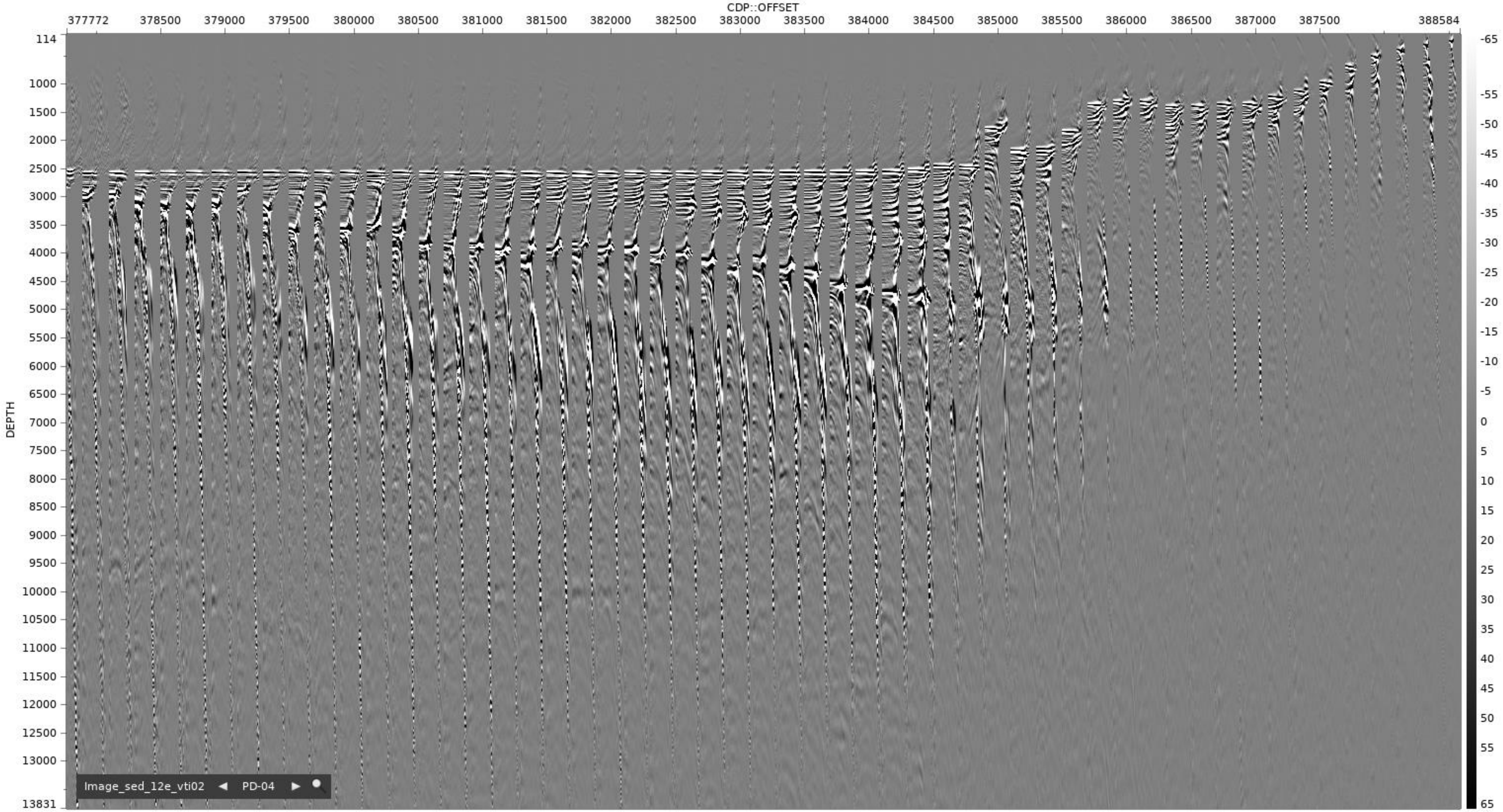
PD-04 - Initial PSDM Gathers



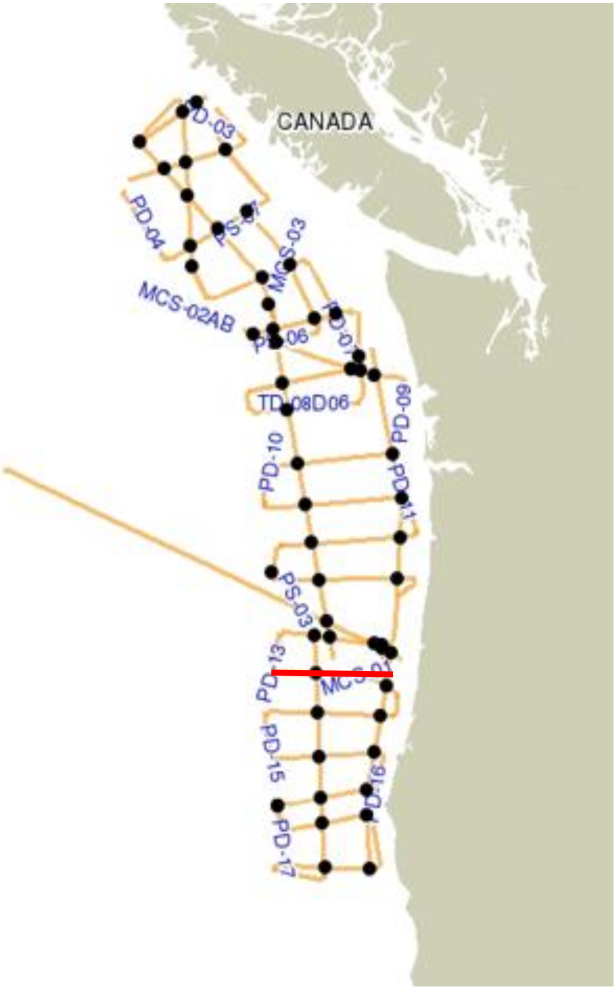
PD-04 - Updated PSDM Gathers



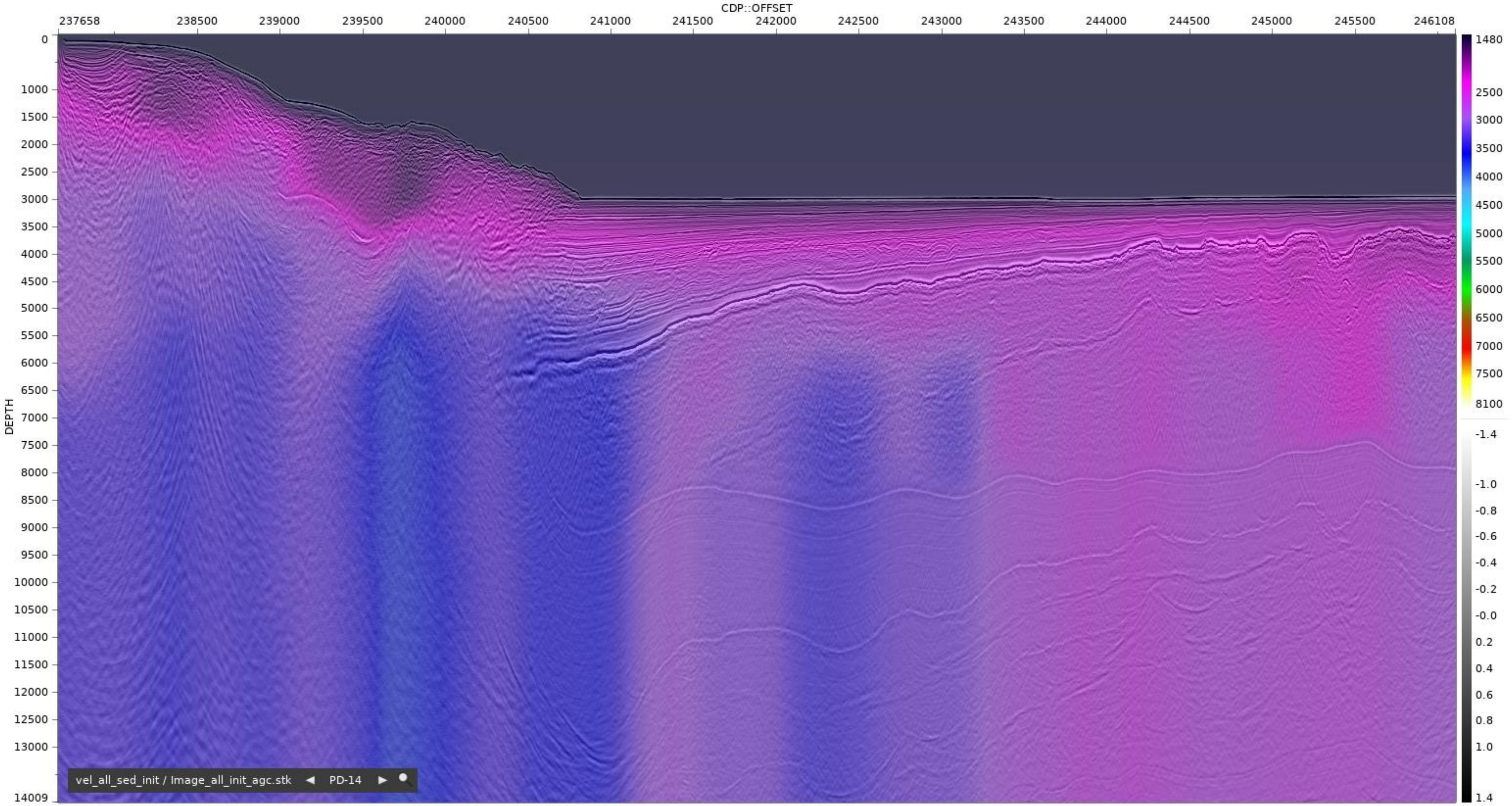
PD-04 - Final PSDM Gathers



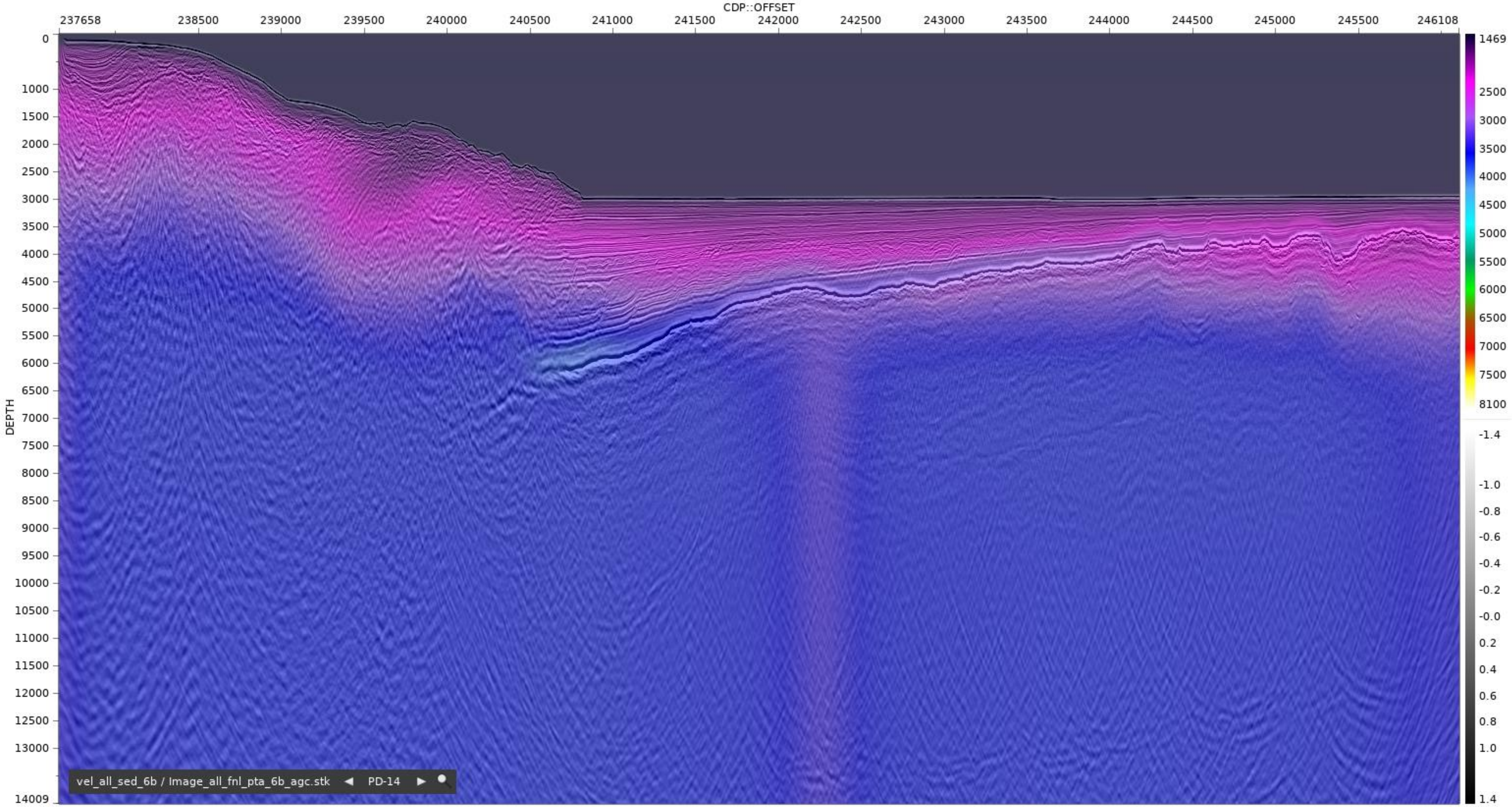
Line PD-14



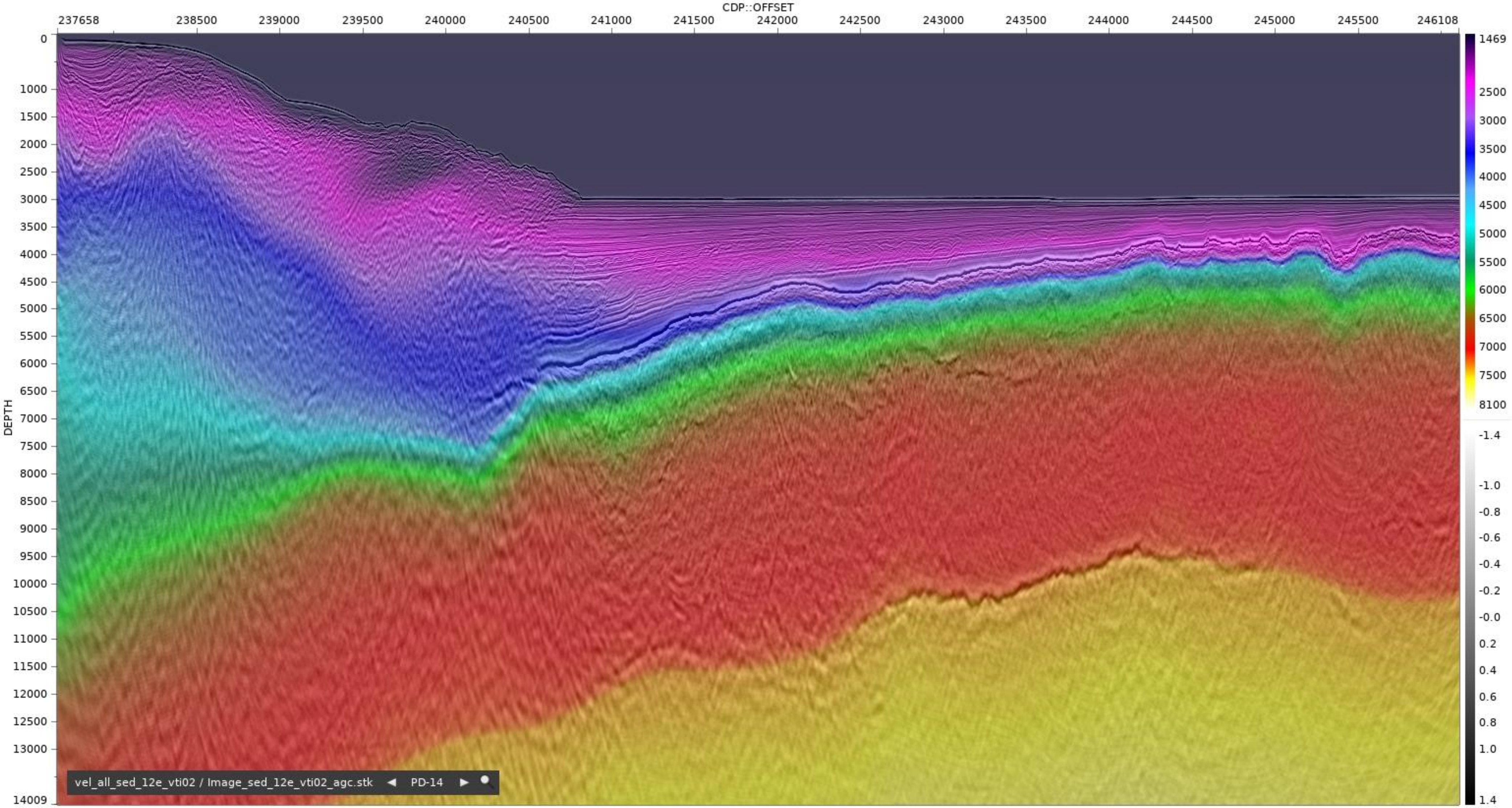
PD-14 - Initial PSDM Stack and Velocity



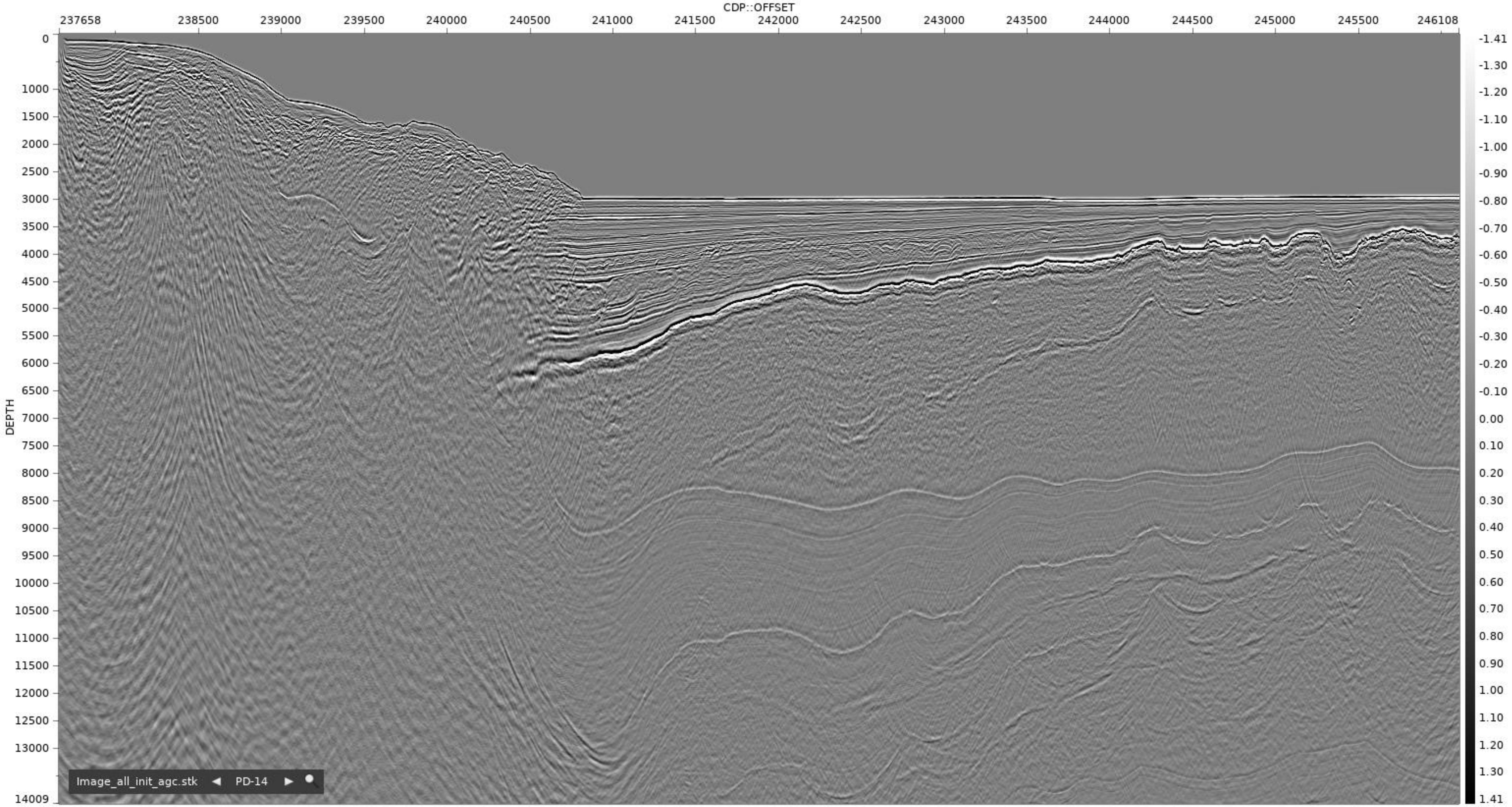
PD-14 – Updated PSDM Stack and Velocity



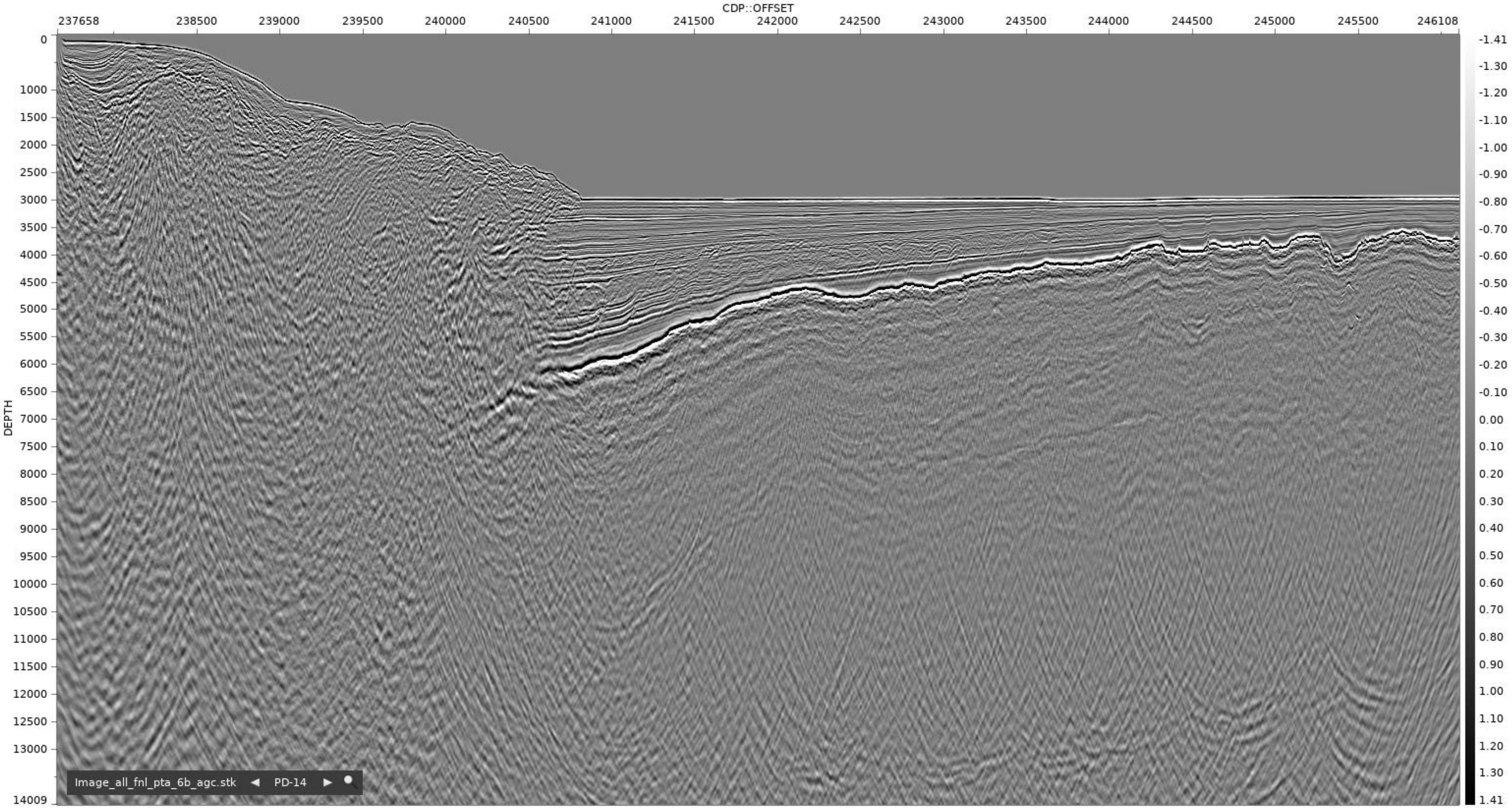
PD-14 - Final PSDM Stack and Velocity



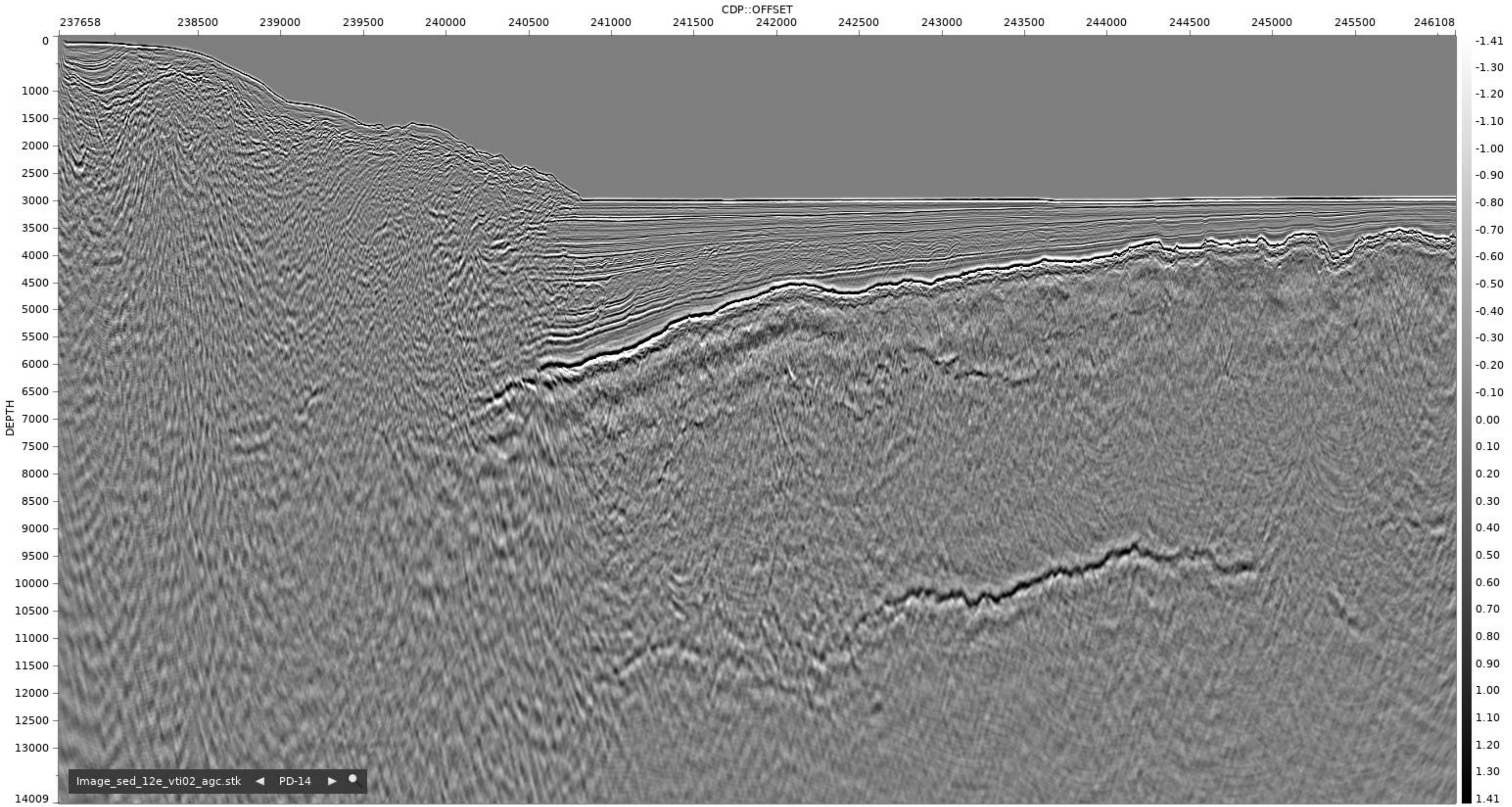
PD-14 - Initial PSDM Stack



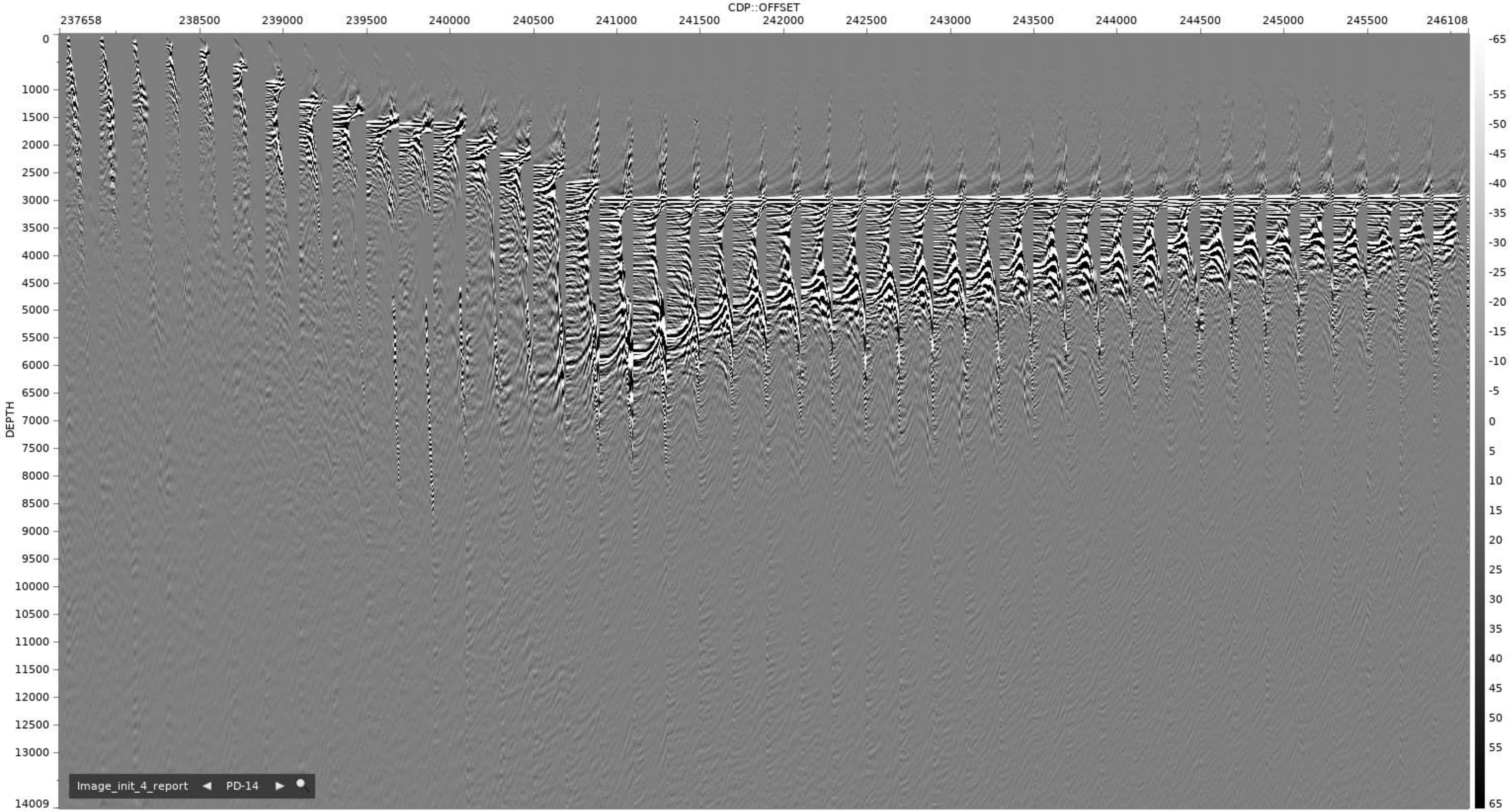
PD-14 - Updated PSDM Stack and Velocity



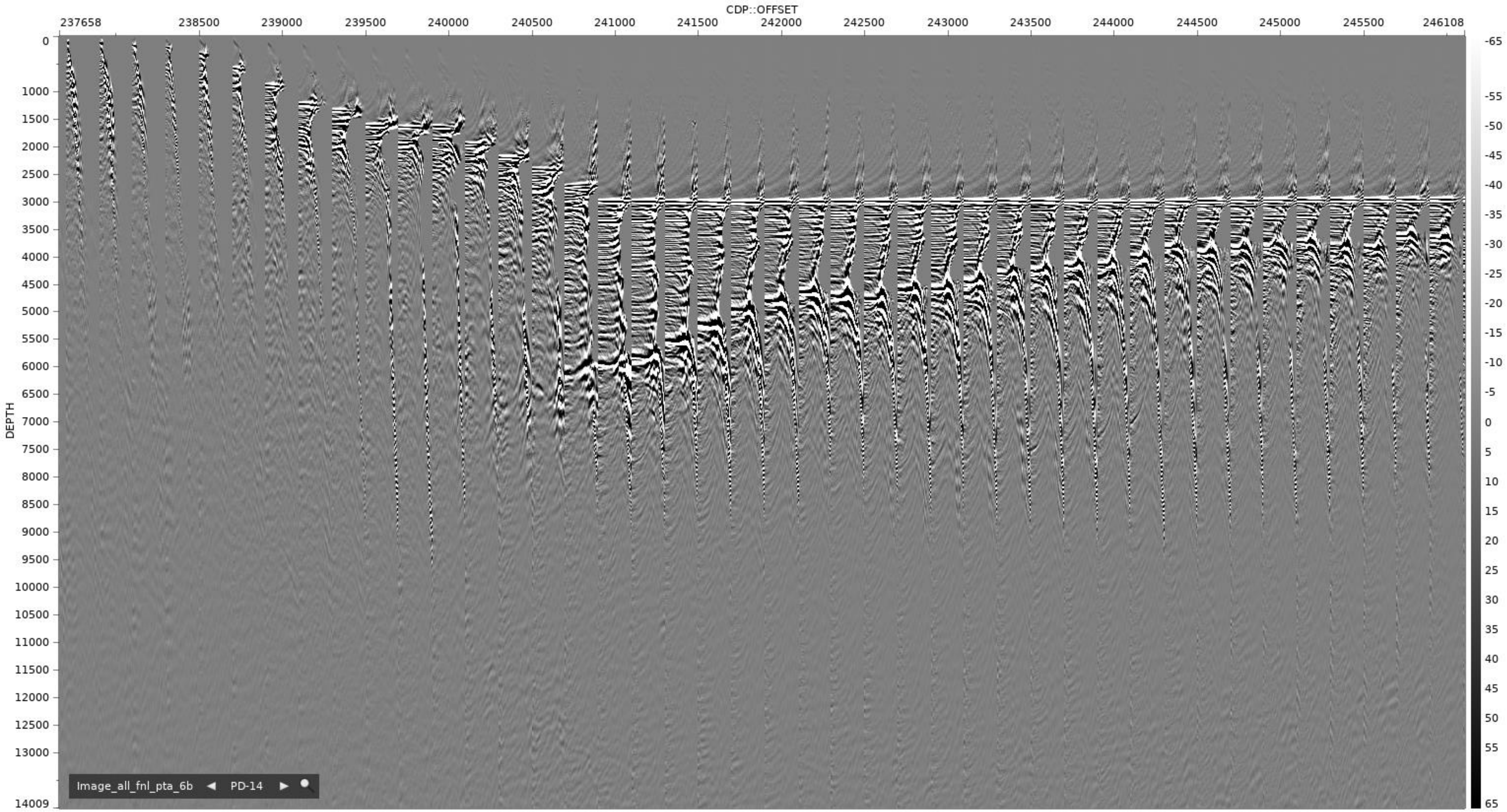
PD-14 - Final PSDM Stack and Velocity



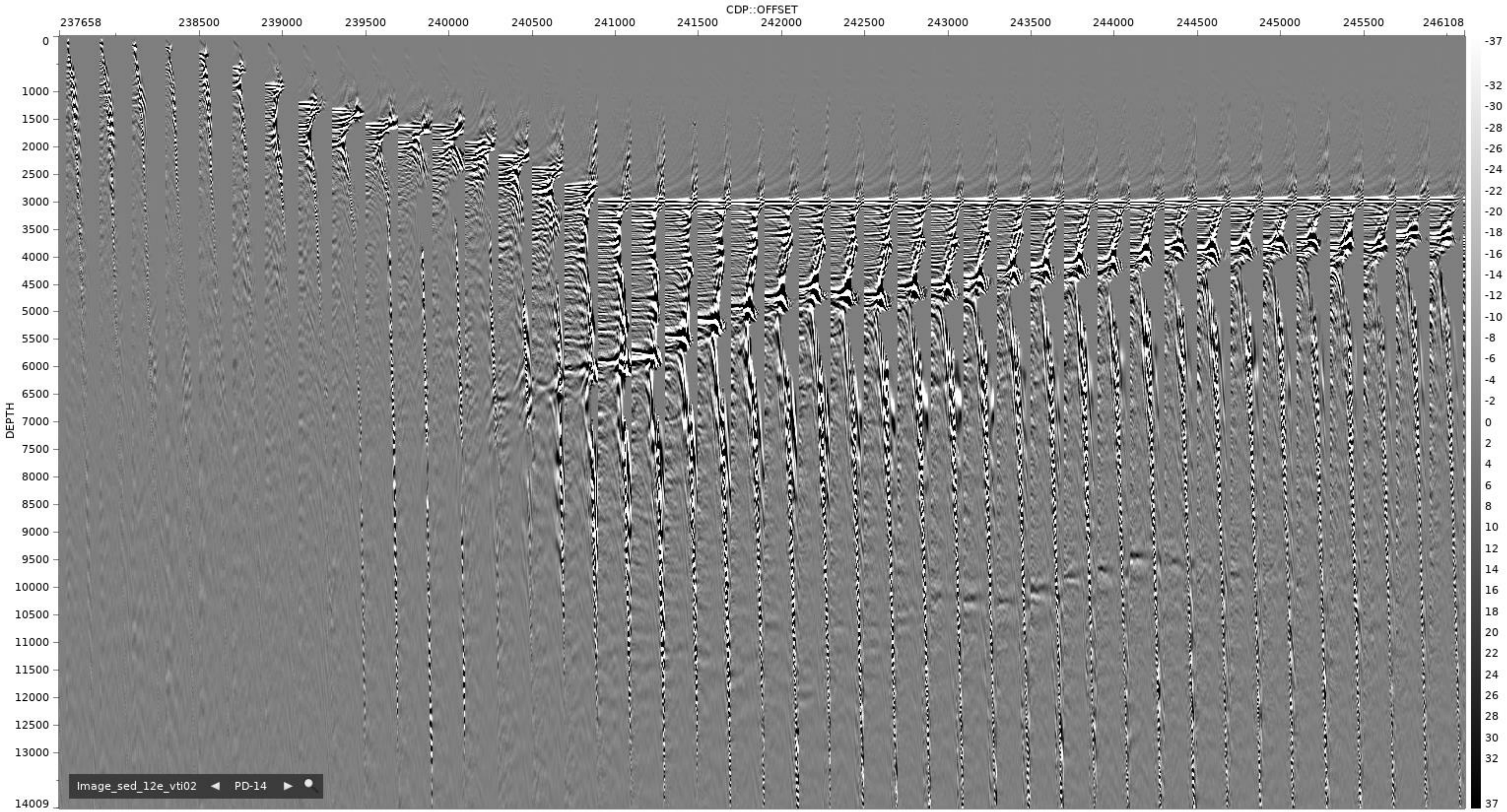
PD-14 - Initial PSDM Gathers



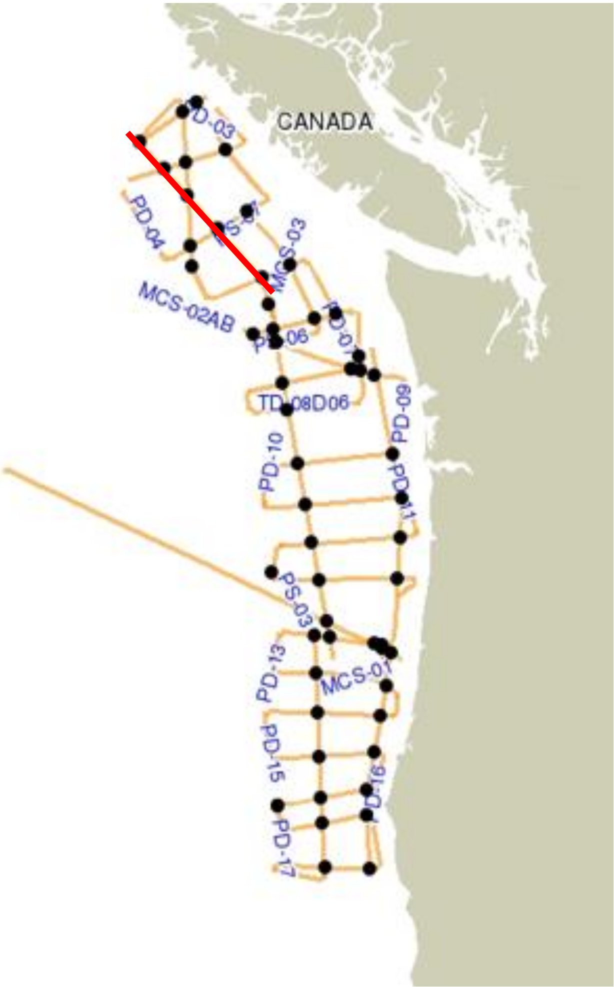
PD-14 - Updated PSDM Gathers



PD-14 - Final PSDM Gathers



Line PS-05



CANADA
PD-04
MCS-02AB
MCS-03
PD-09
PD-10
PS-03
PD-13
MCS-01
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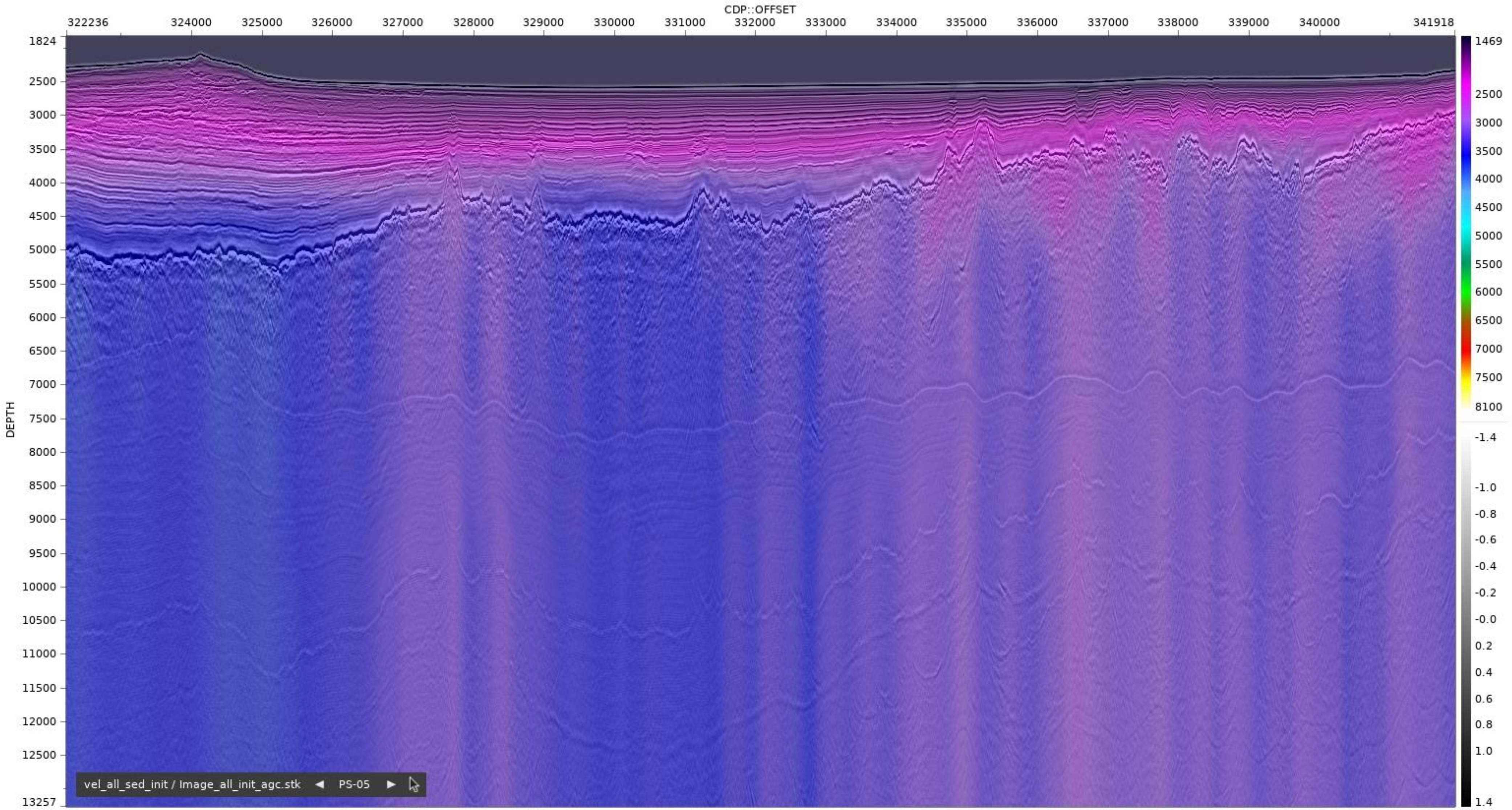
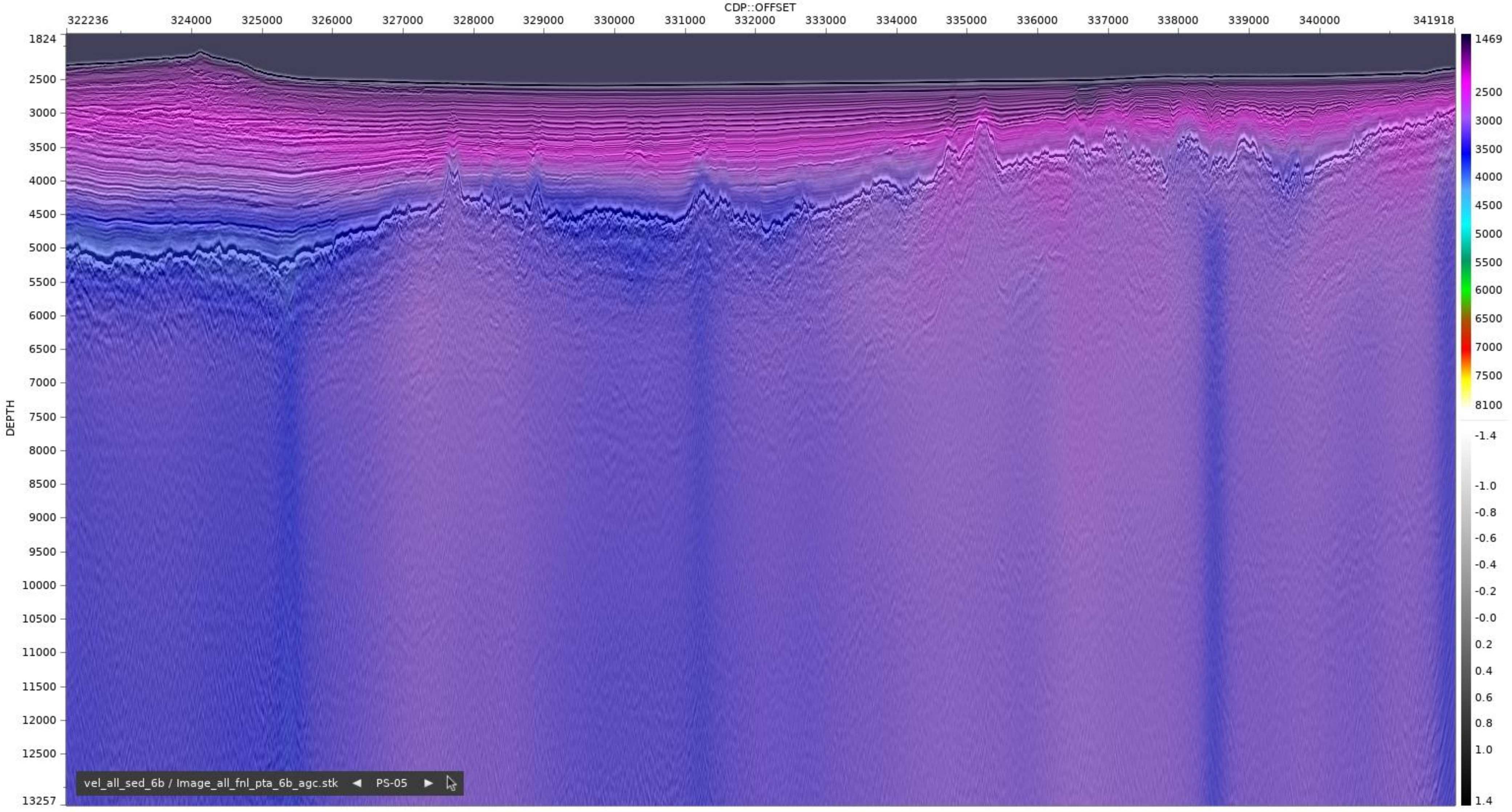
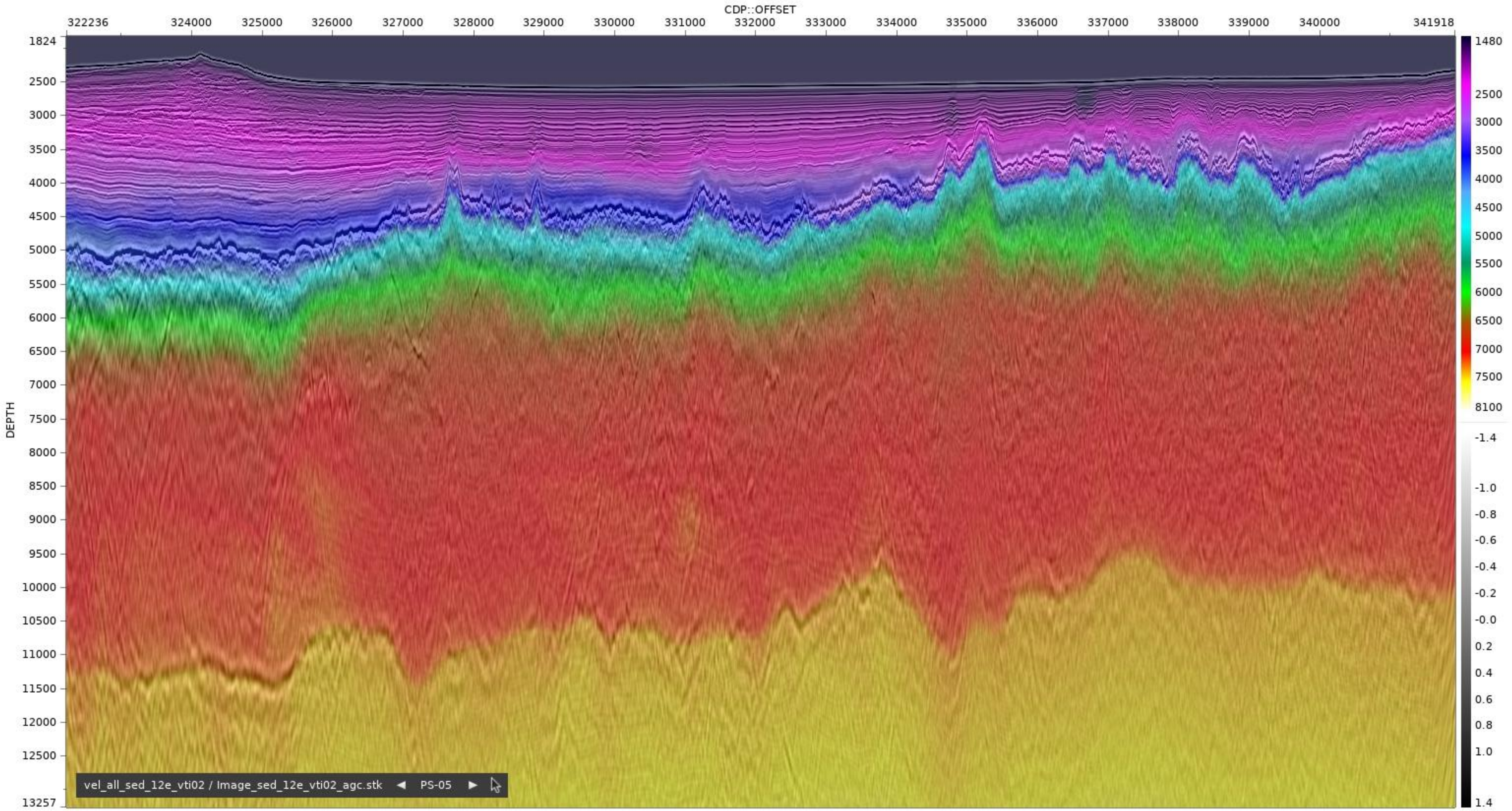
PS-05 - Initial PSDM Stack and Velocity



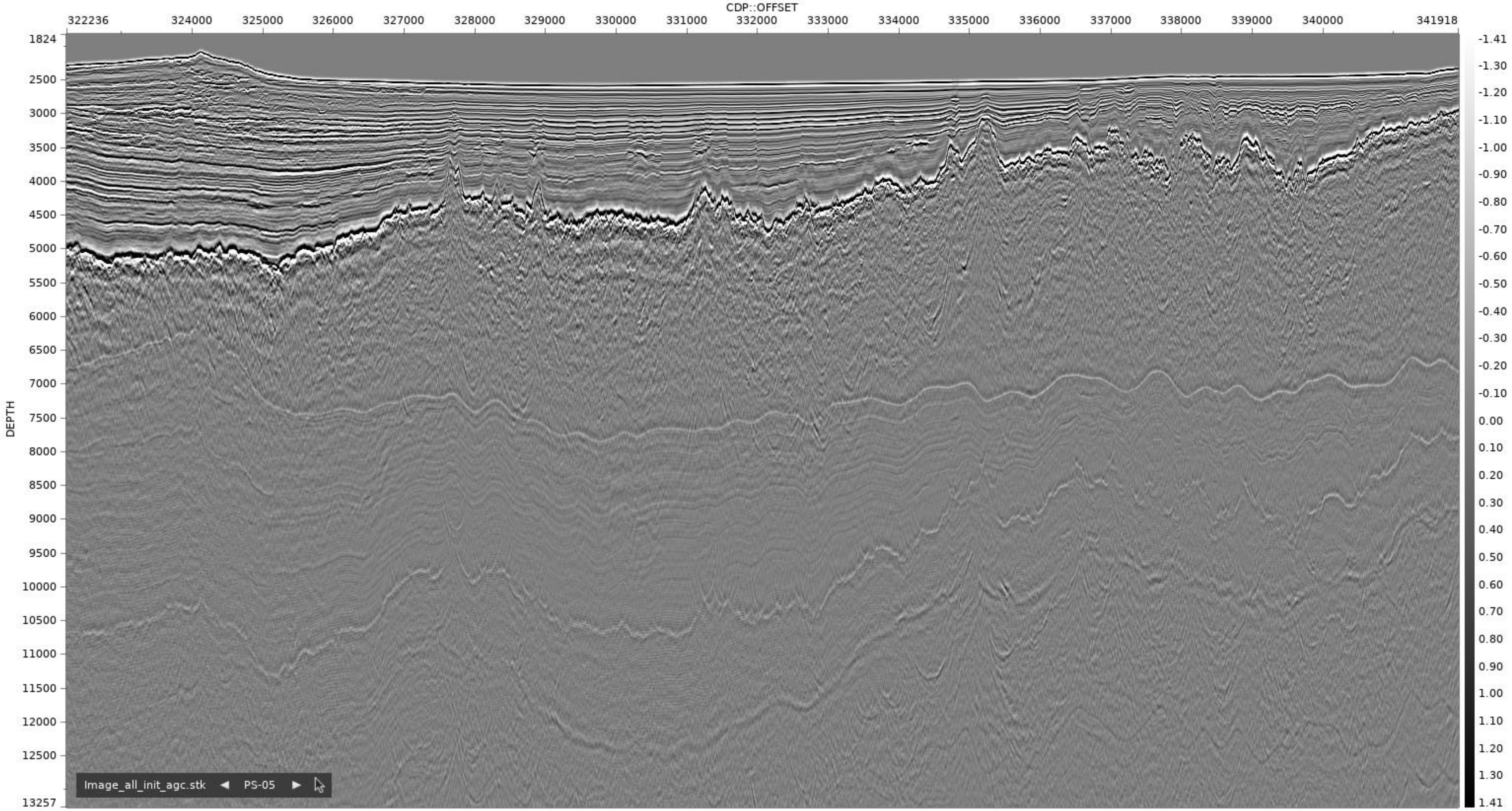
PS-05 - Updated PSDM Stack and Velocity



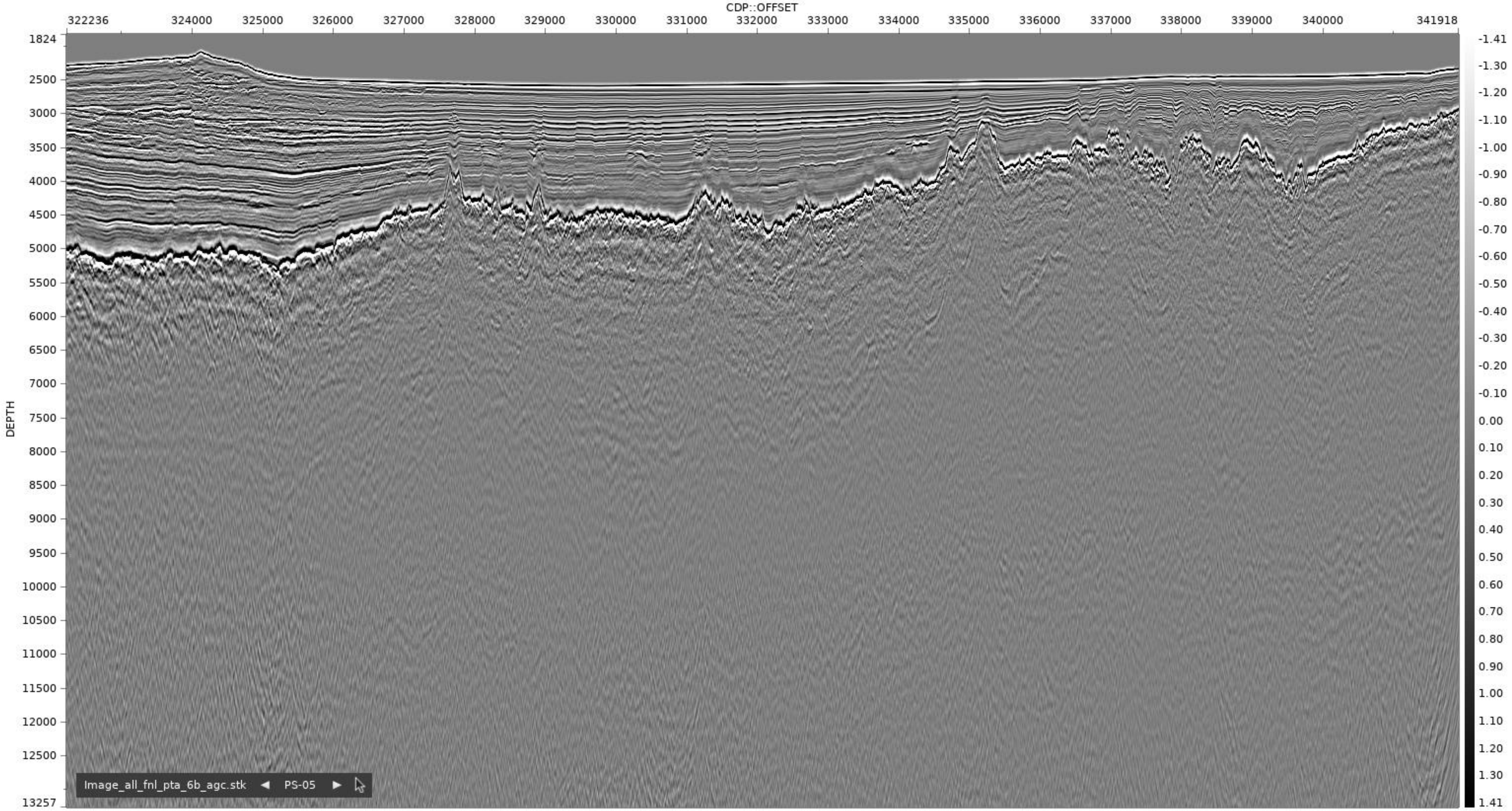
PS-05 - Final PSDM Stack and Velocity



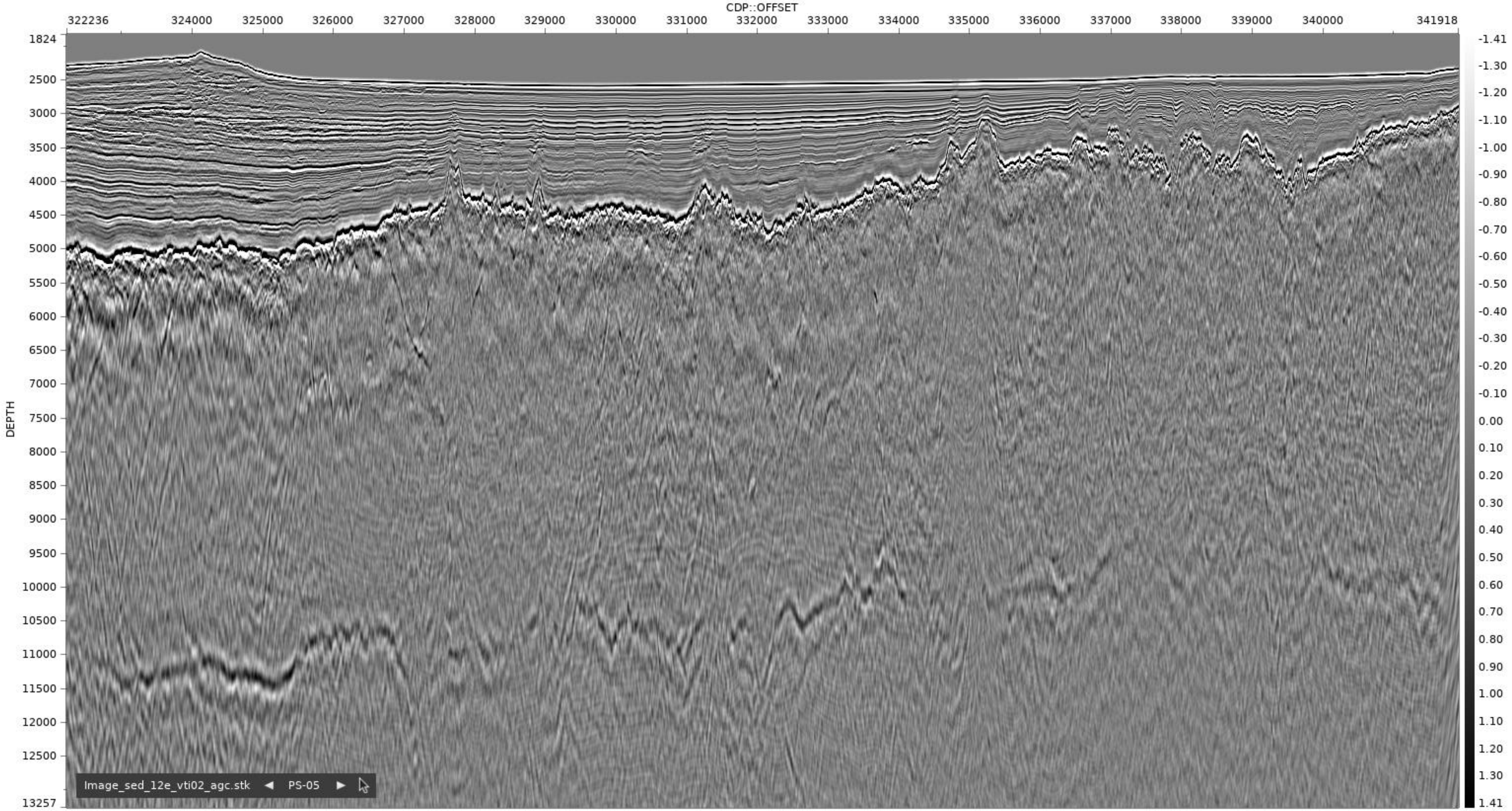
PS-05 - Initial PSDM Stack



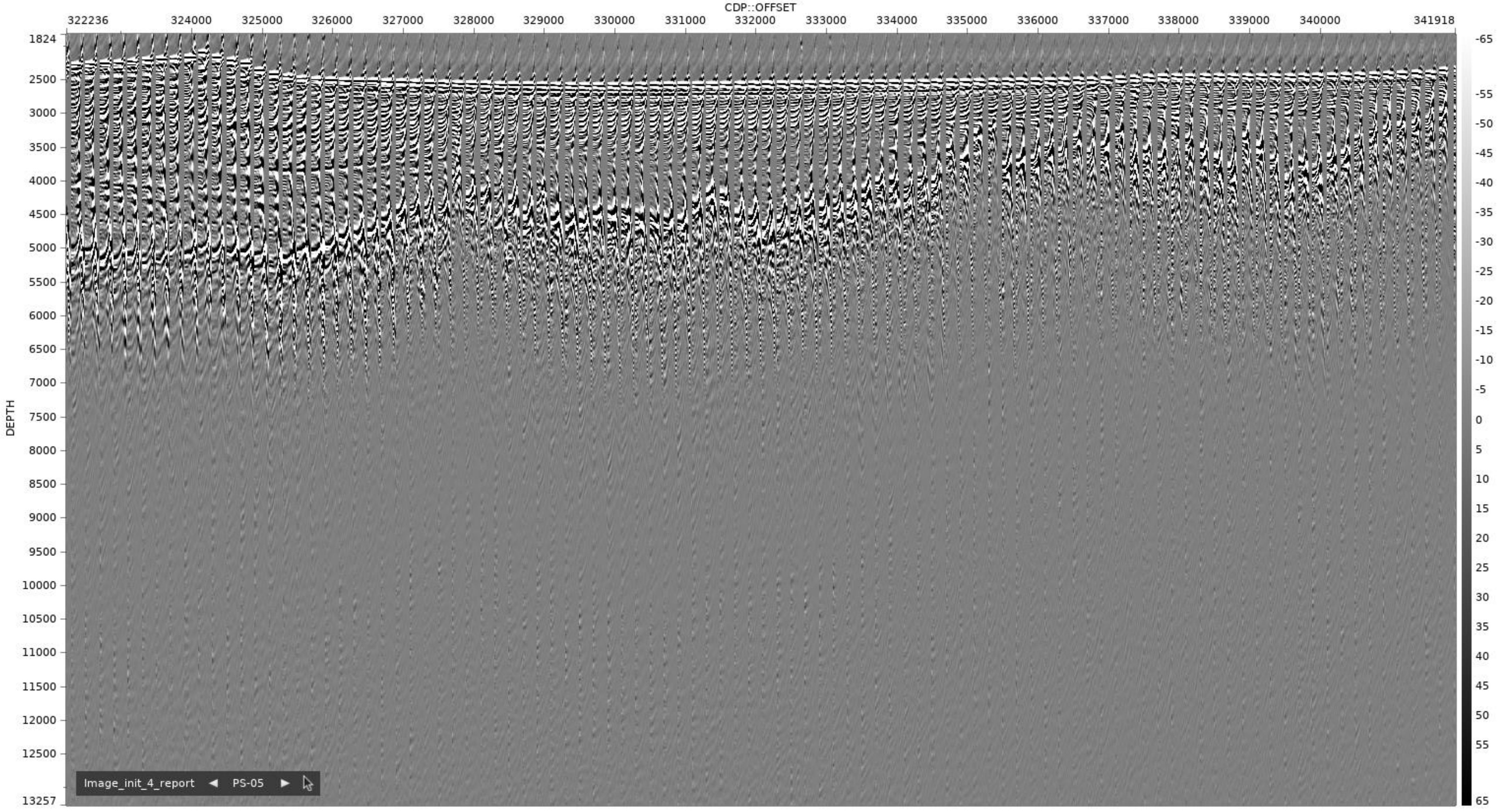
PS-05 - Updated PSDM Stack



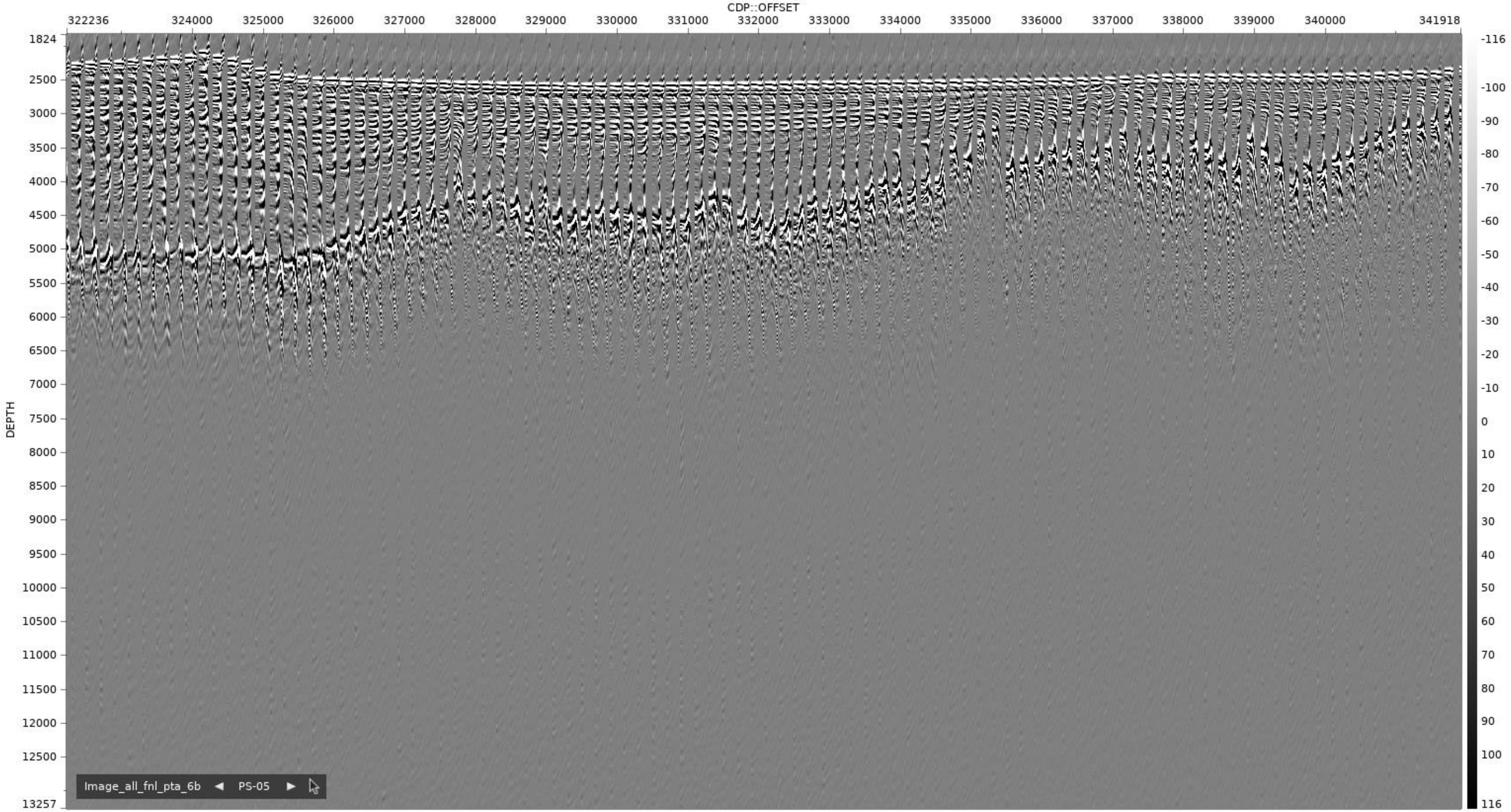
PS-05 - Final PSDM Stack



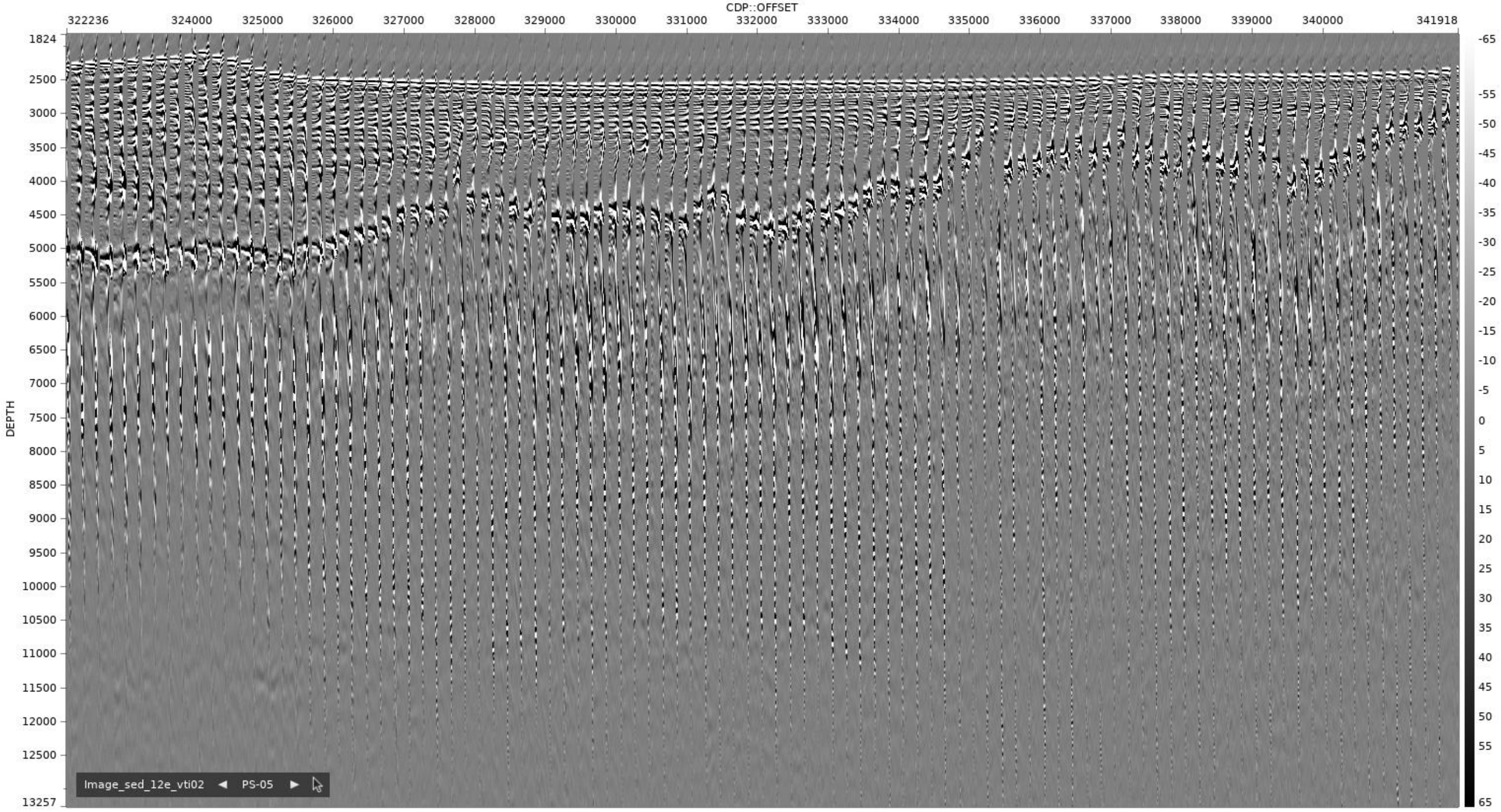
PS-05 - Initial PSDM Gathers



PS-05 - Updated PSDM Gathers

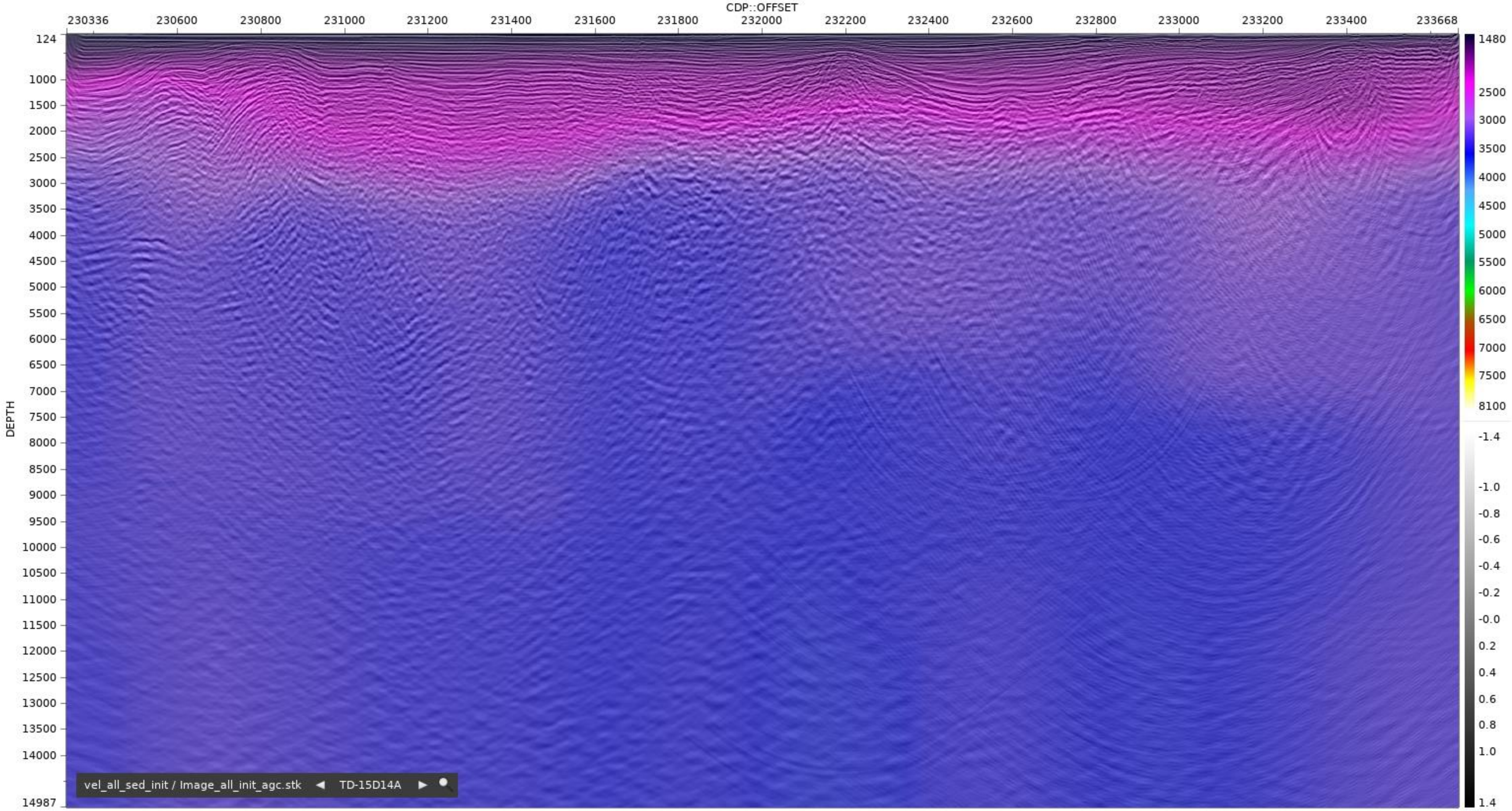


PS-05 - Final PSDM Gathers

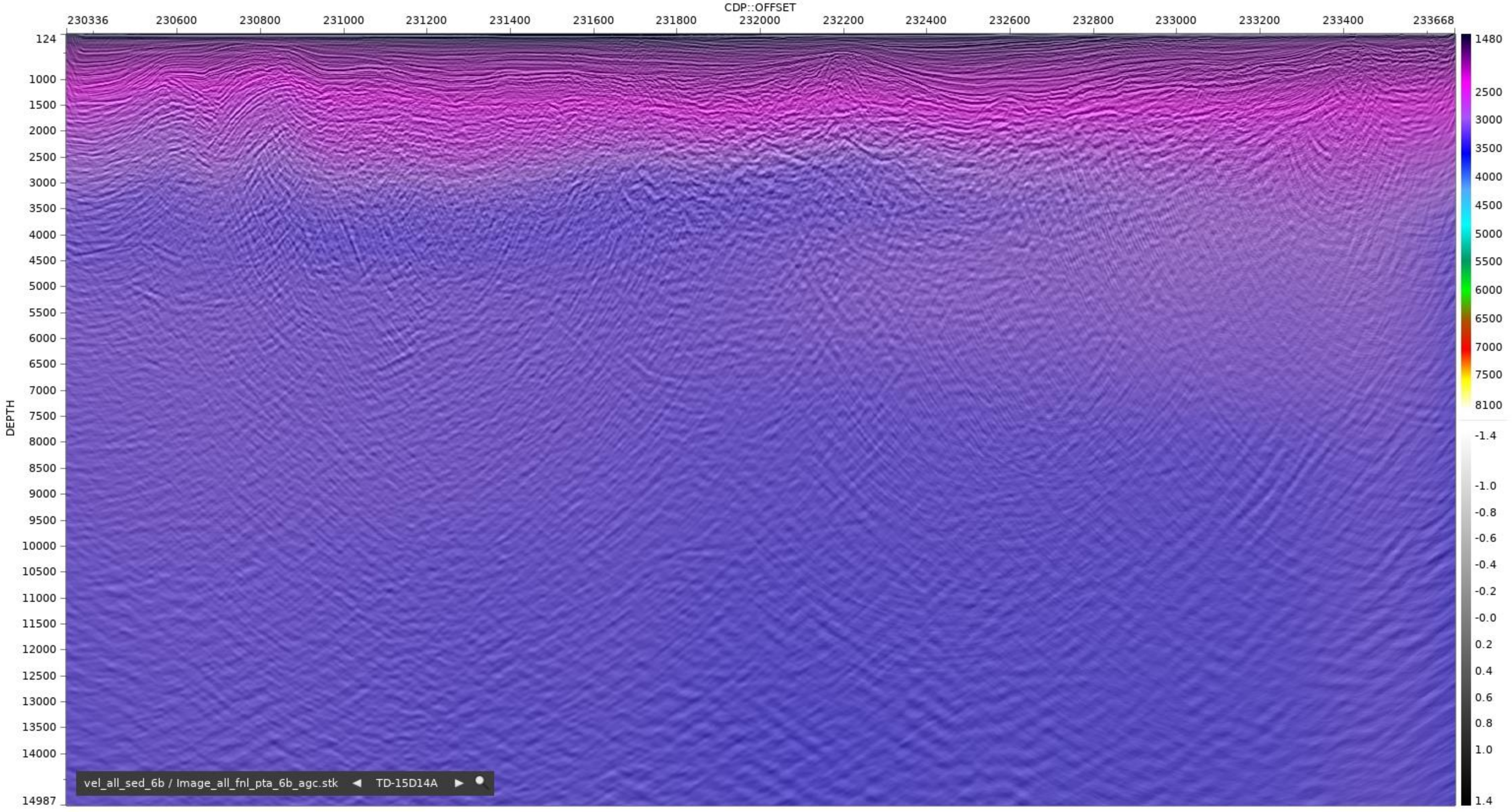


Line TD-15D14A

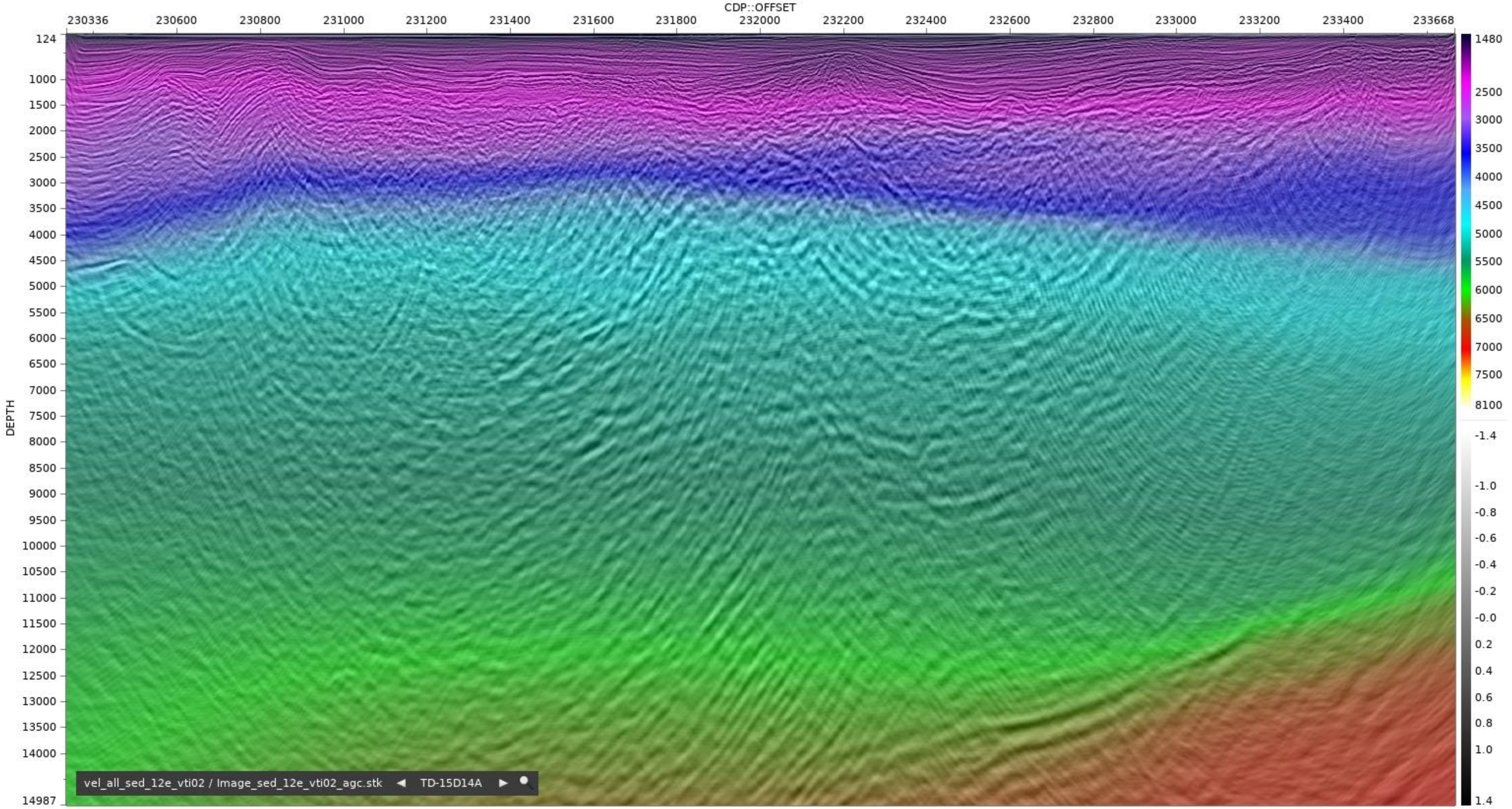
TD-15D14A - Initial PSDM Stack and Velocity



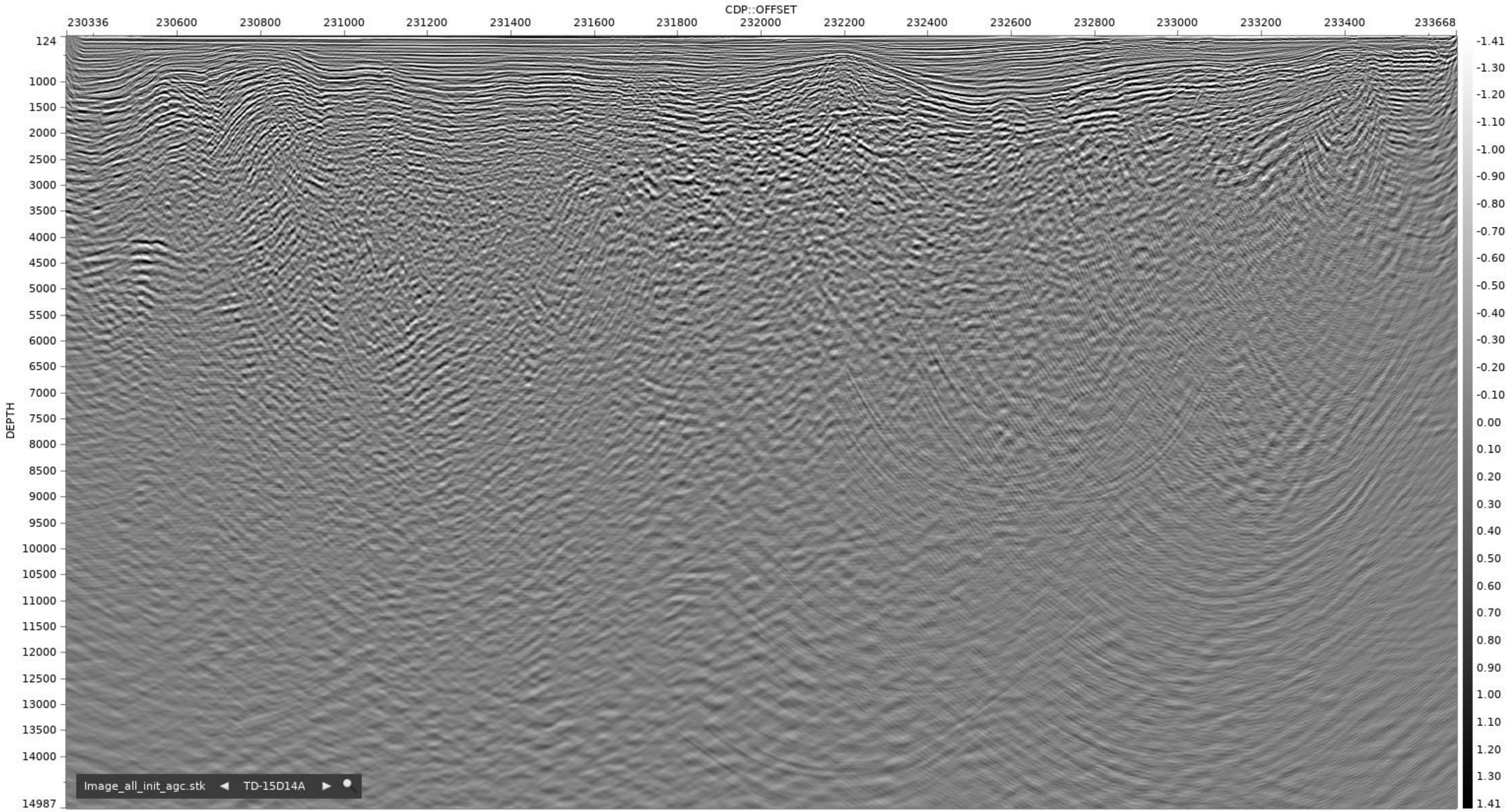
TD-15D14A - Updated PSDM Stack and Velocity



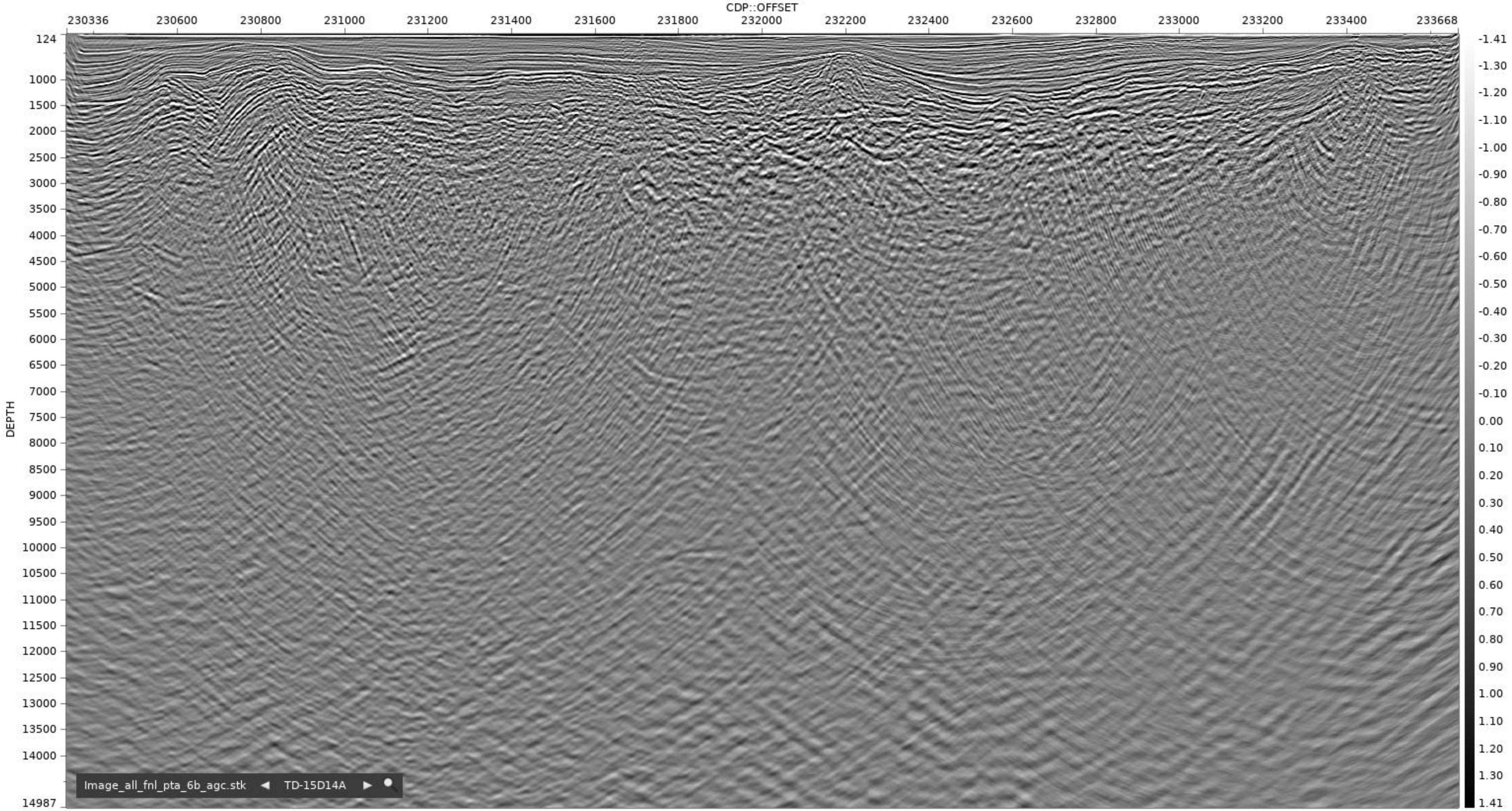
TD-15D14A - Final PSDM Stack and Velocity



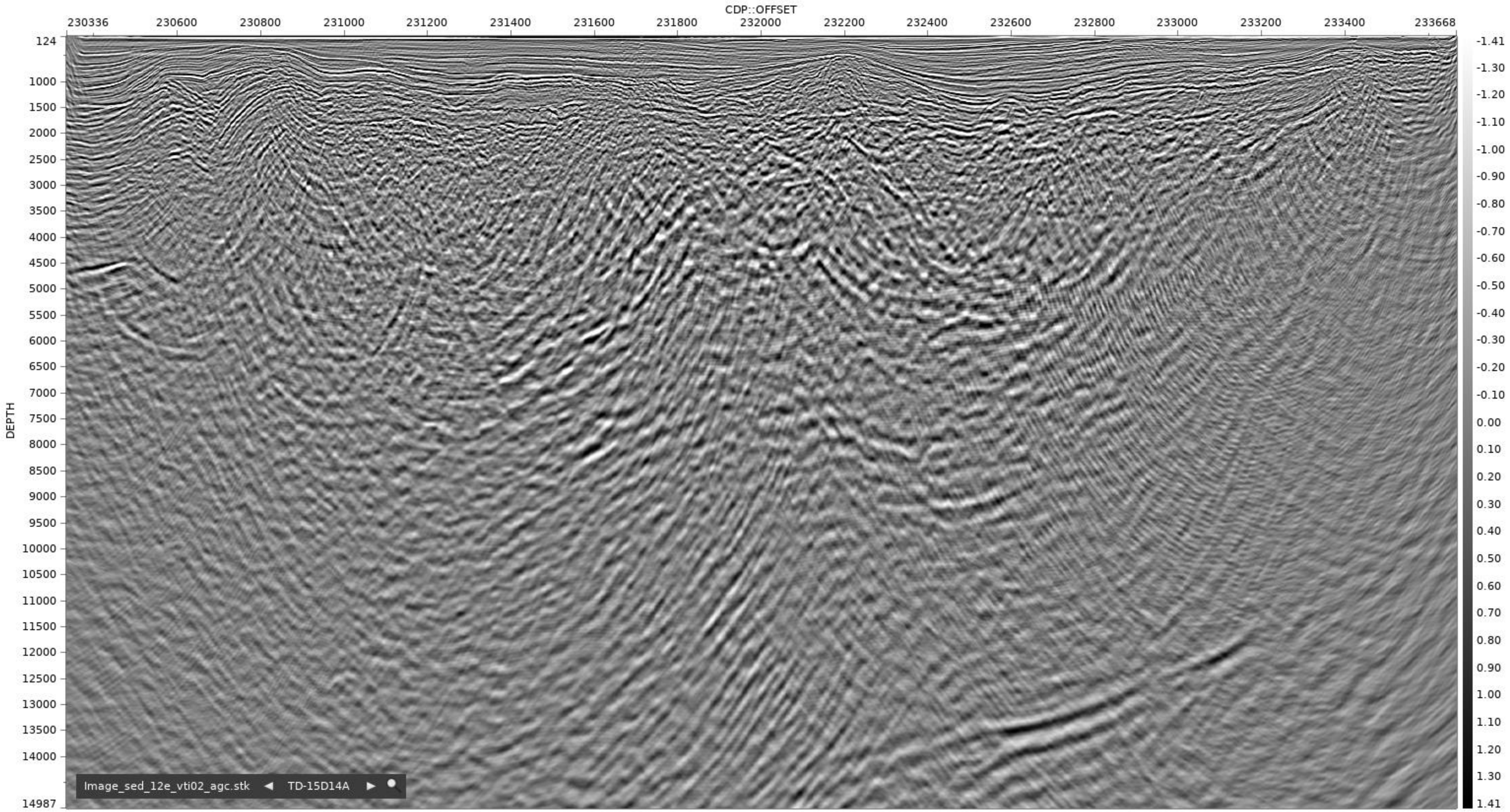
TD-15D14A - Initial PSDM Stack



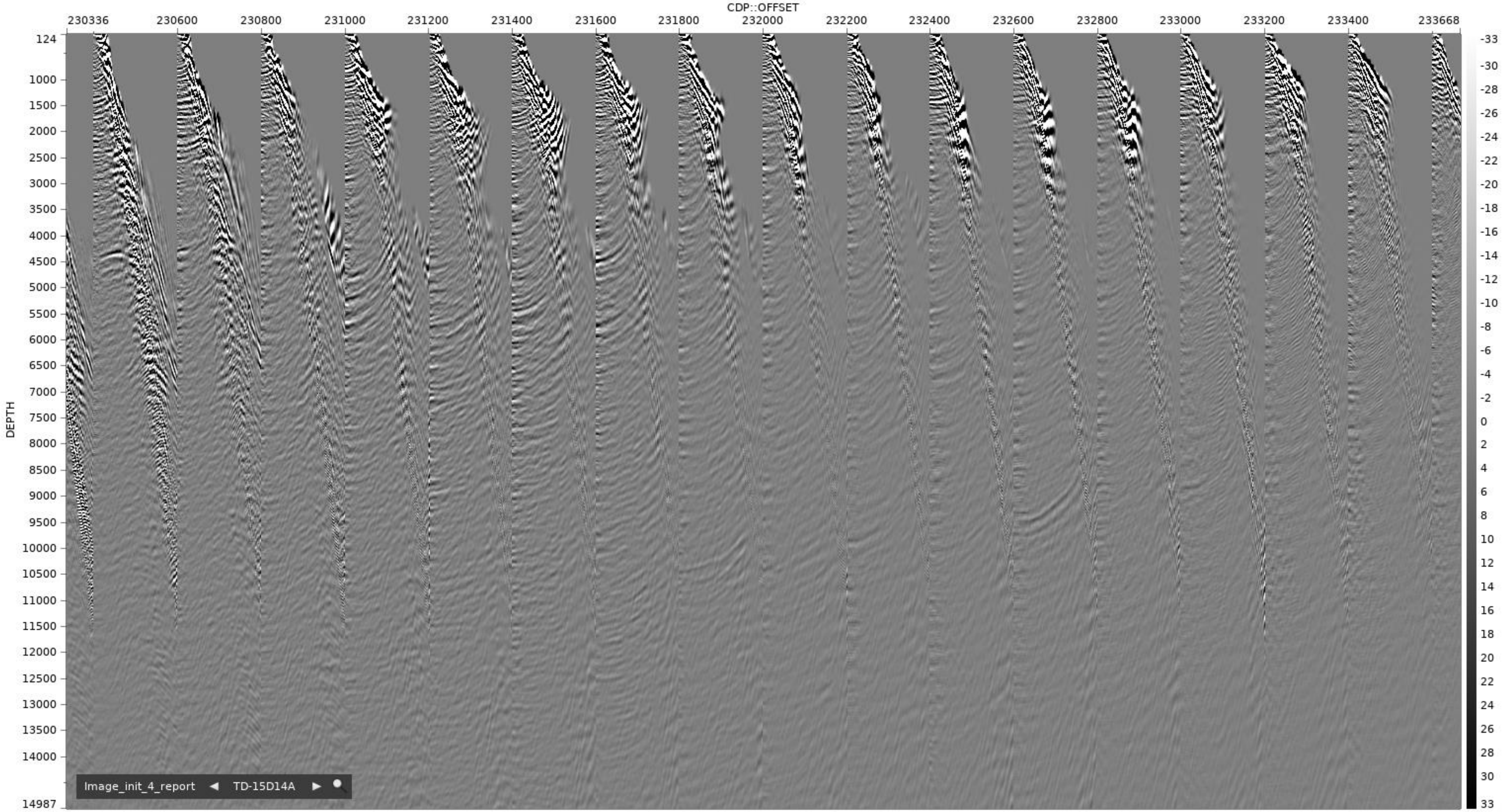
TD-15D14A - Updated PSDM Stack



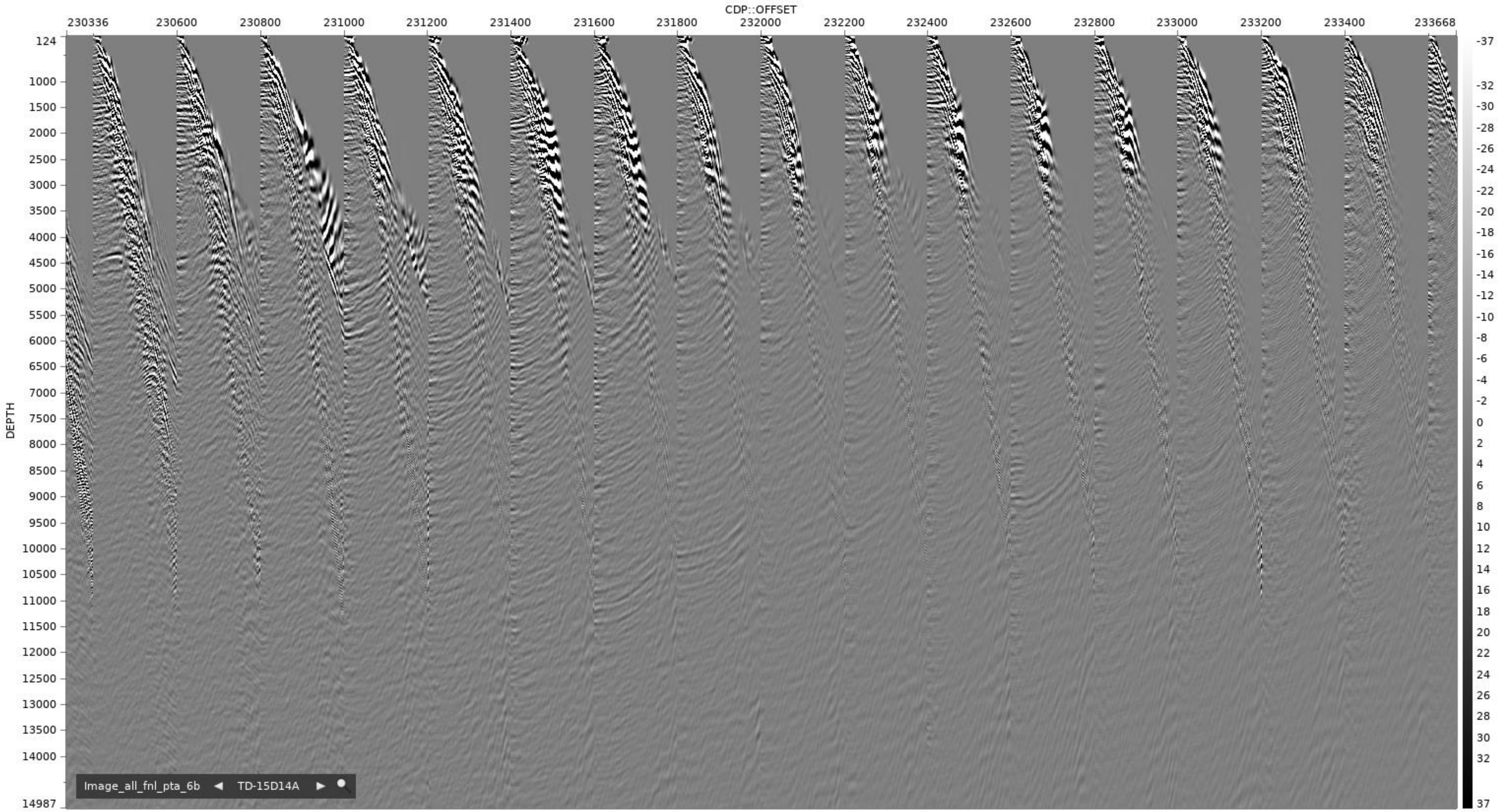
TD-15D14A - Final PSDM Stack



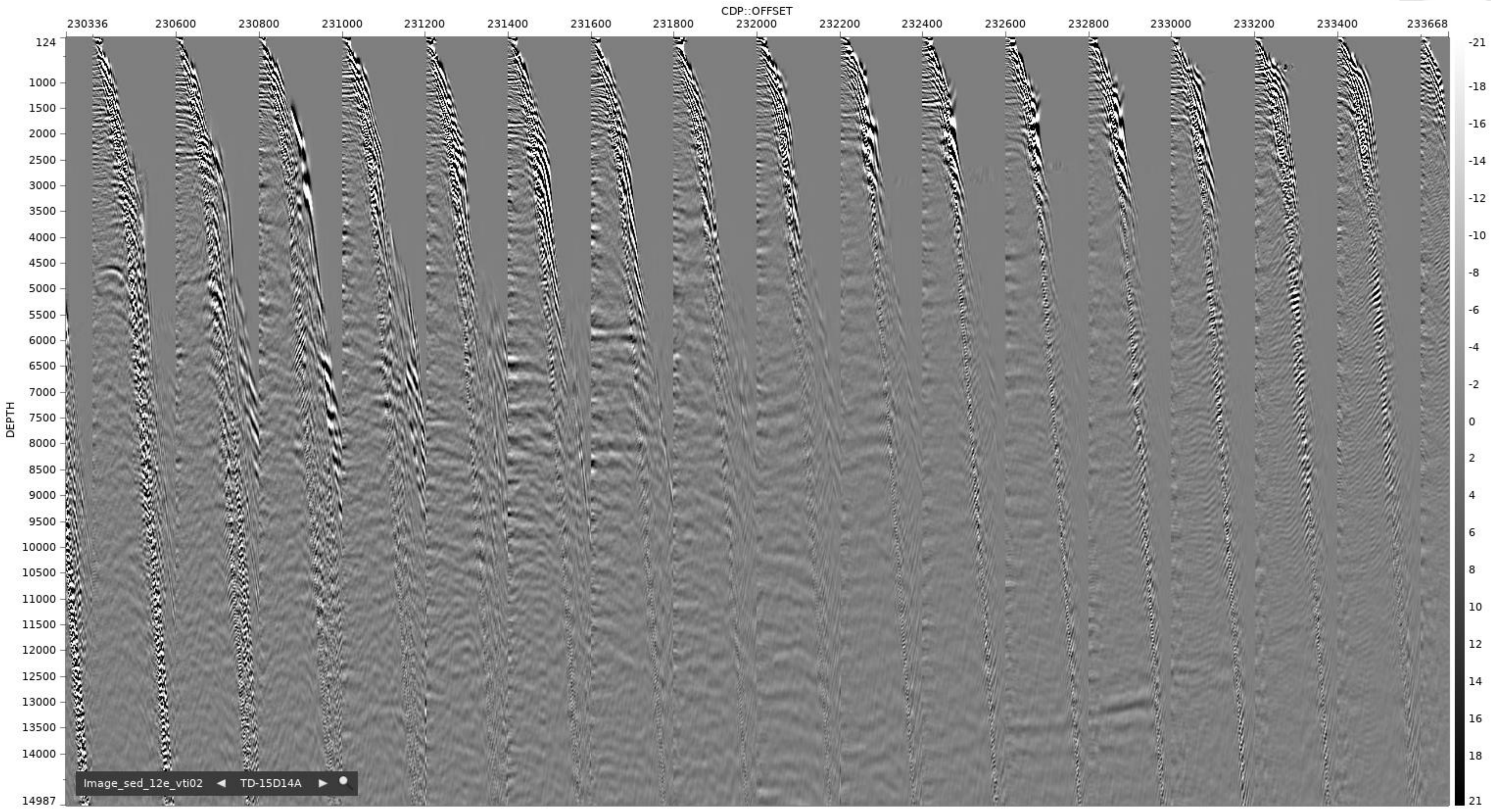
TD-15D14A - Initial PSDM Gathers



TD-15D14A - Updated PSDM Gathers



TD-15D14A - Final PSDM Gathers



FWI Summary

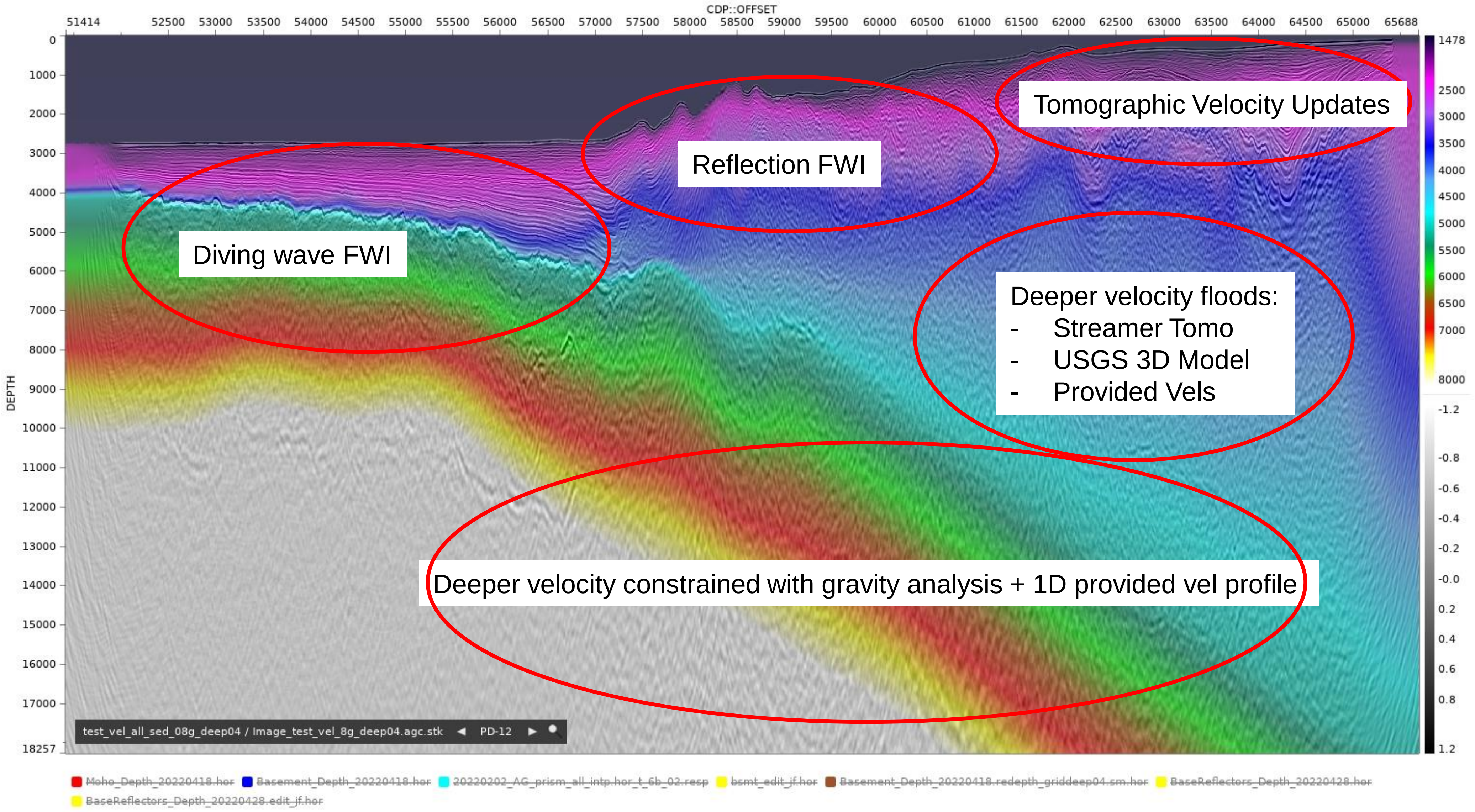
- Due to the variability of geology and water depth varying approaches to FWI were tested

- Different FWI cost-functions, frequency ranges, offset ranges, types of events (reflection, refraction and diving waves) were tested

- Below we present results from some of the items tested:
  a) Reflection data FWI (water bottom approx. 1 to 2.5 km meter depth)
  b) Diving Waves data FWI (water bottom >2.5 km depth)

- Sediment FWI Velocities were then merged with velocities derived with reflection tomography (next slide show)

Velocity Model Building Merge Methodology

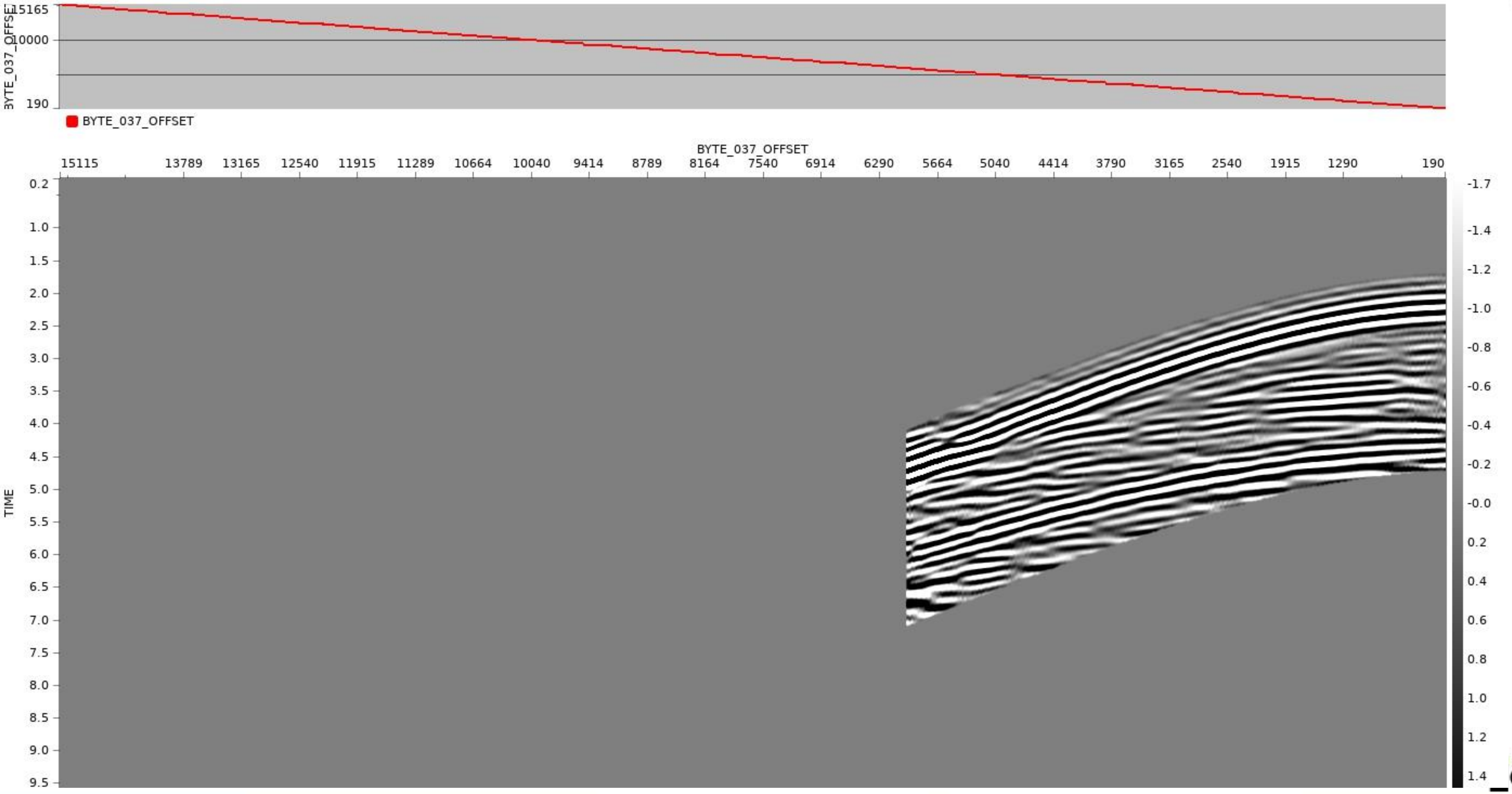


Reflection Data FWI

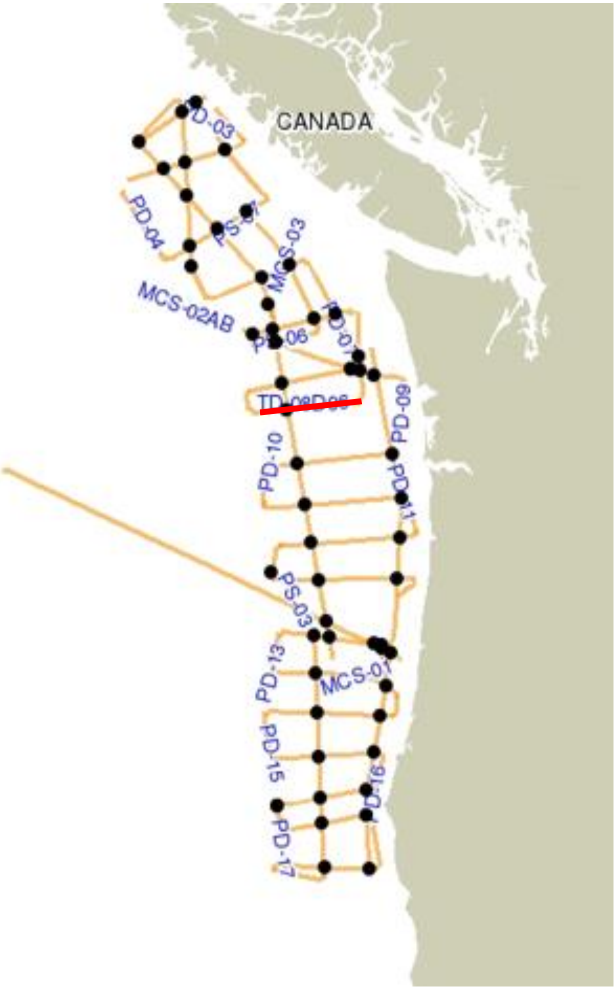
Applied to section of 2D line: water bottom approx. 1 to 2.5 km meter depth

Cost Function – Sphere
Offsets – Up to 6.0km
Data Length – Water bottom to basement plus 1.0 sec
Bandpass Filter – 0-2-13-15Hz

Data selection for Reflection FWI



Line PD-08



CANADA
PD-03
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PD-11
PS-03
PD-13
MCS-01
PD-15
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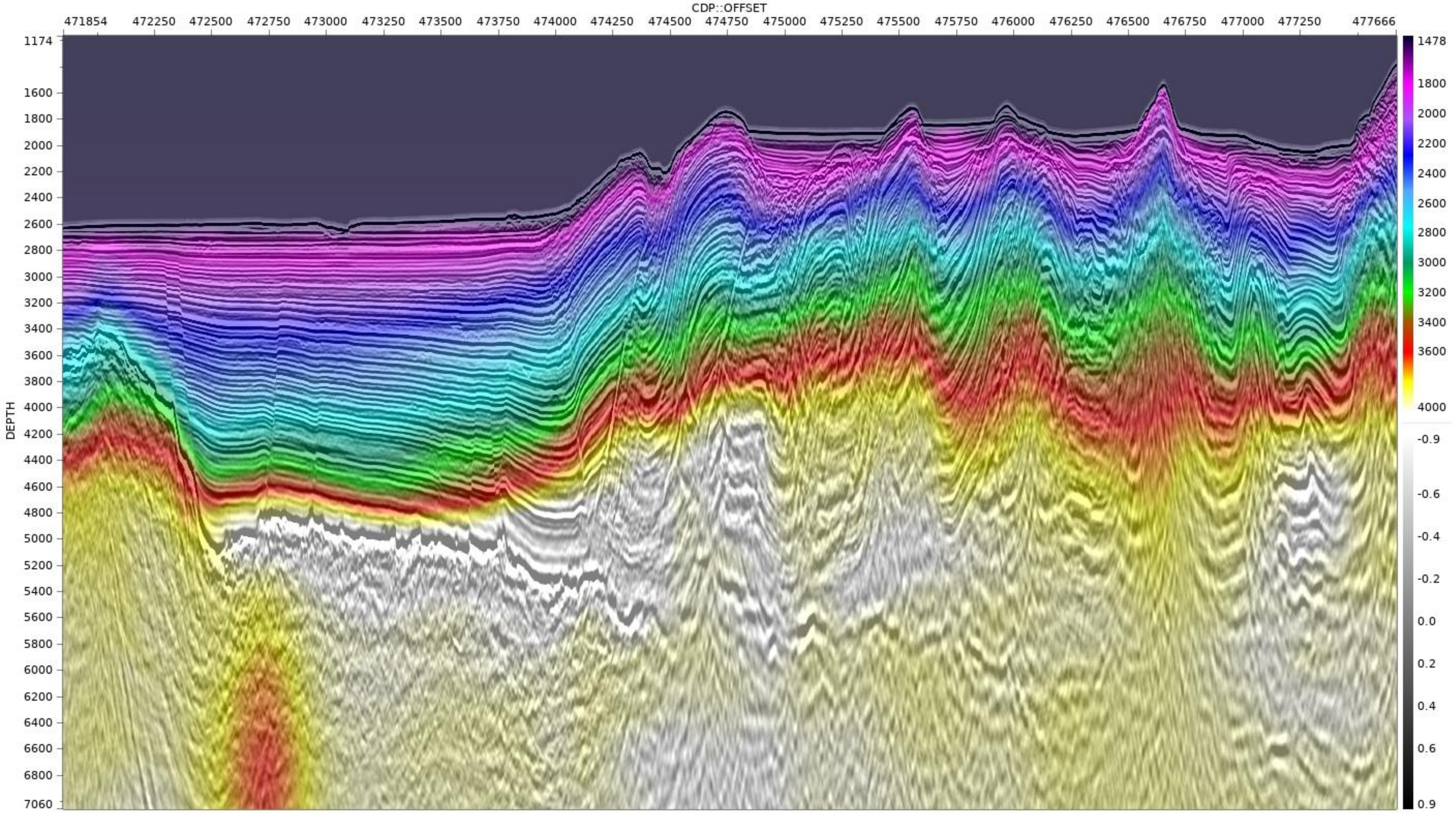
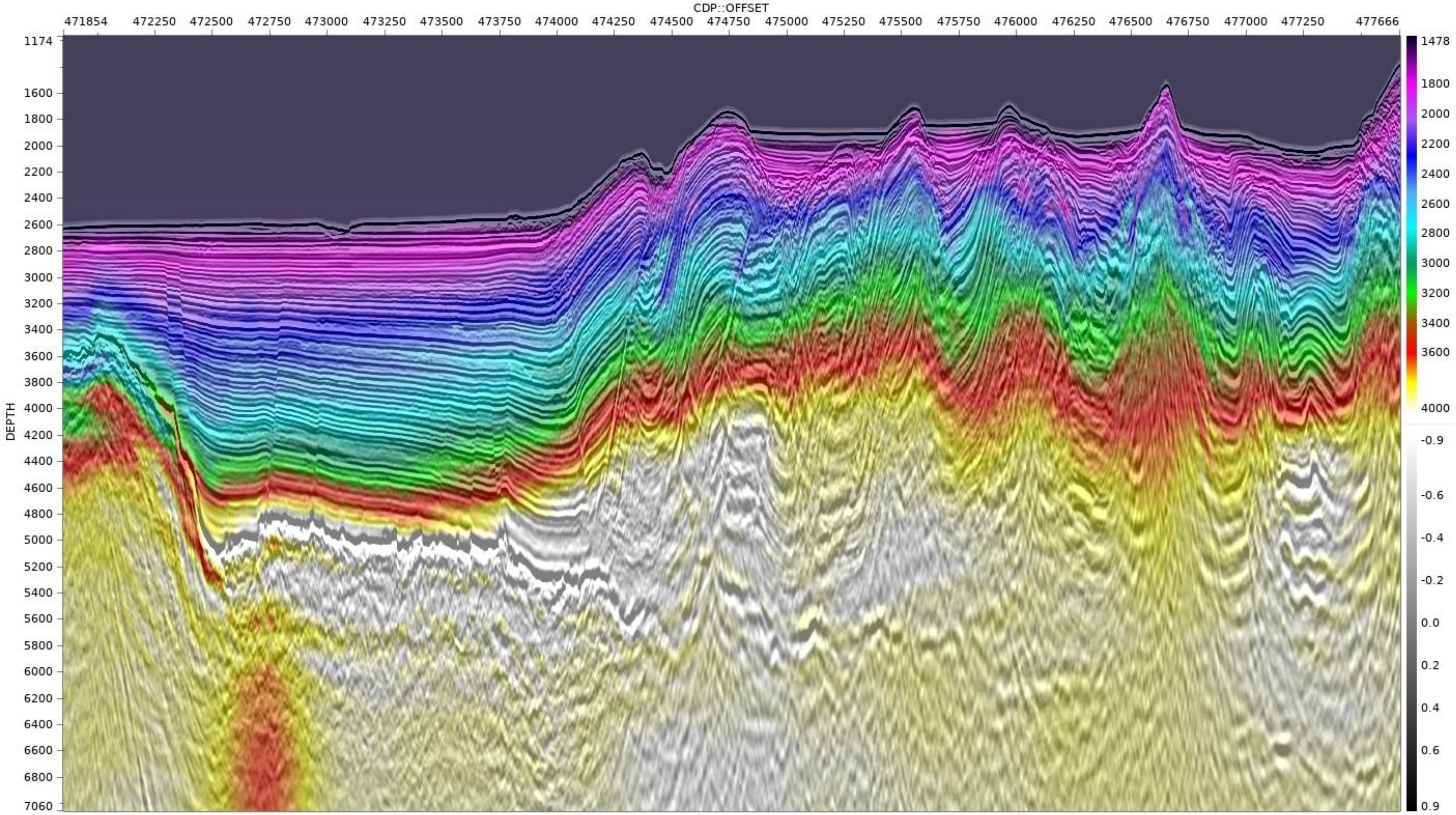
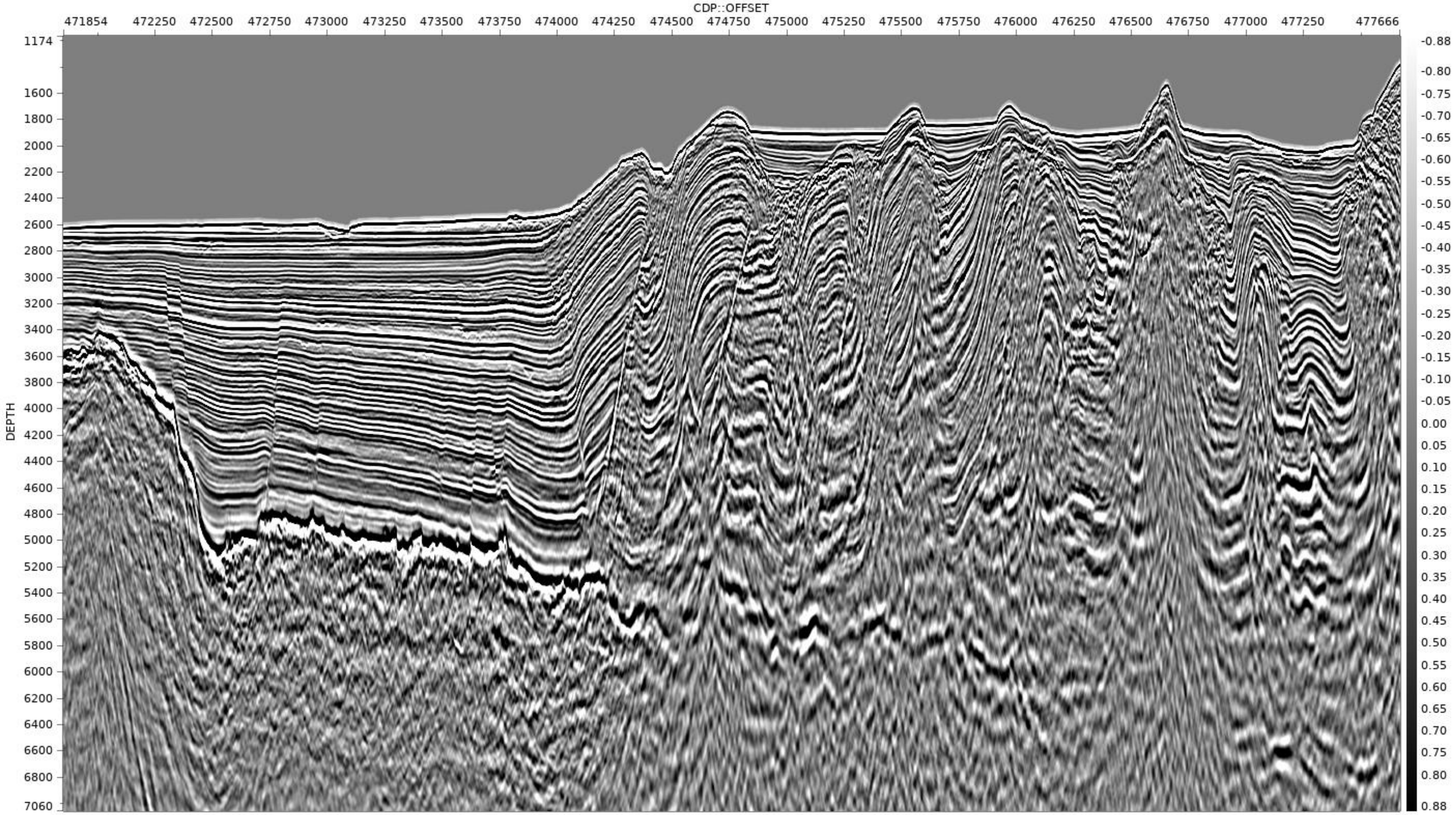
PD-08: Input FWI Velocity



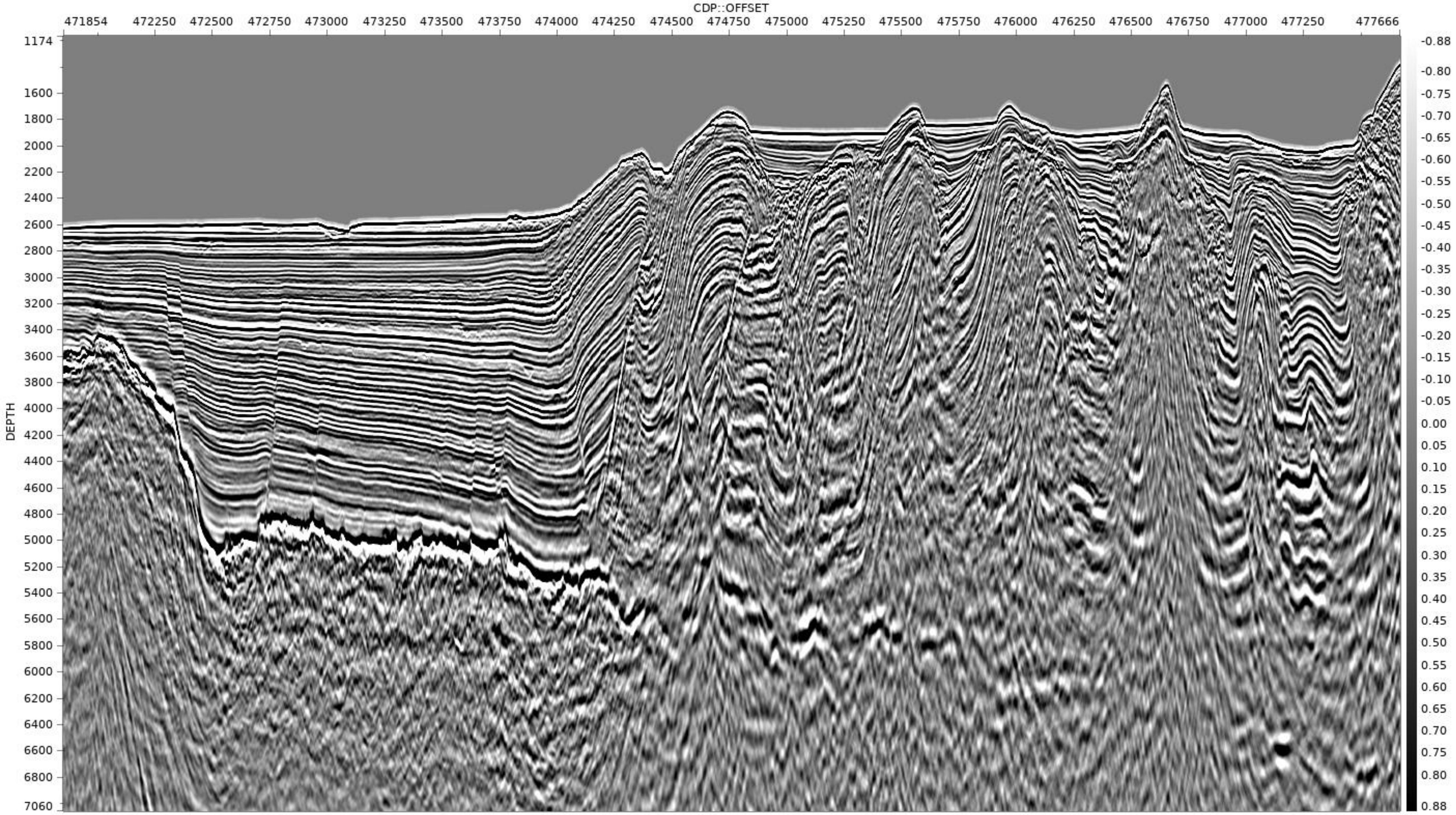
PD-08: Output FWI Velocity



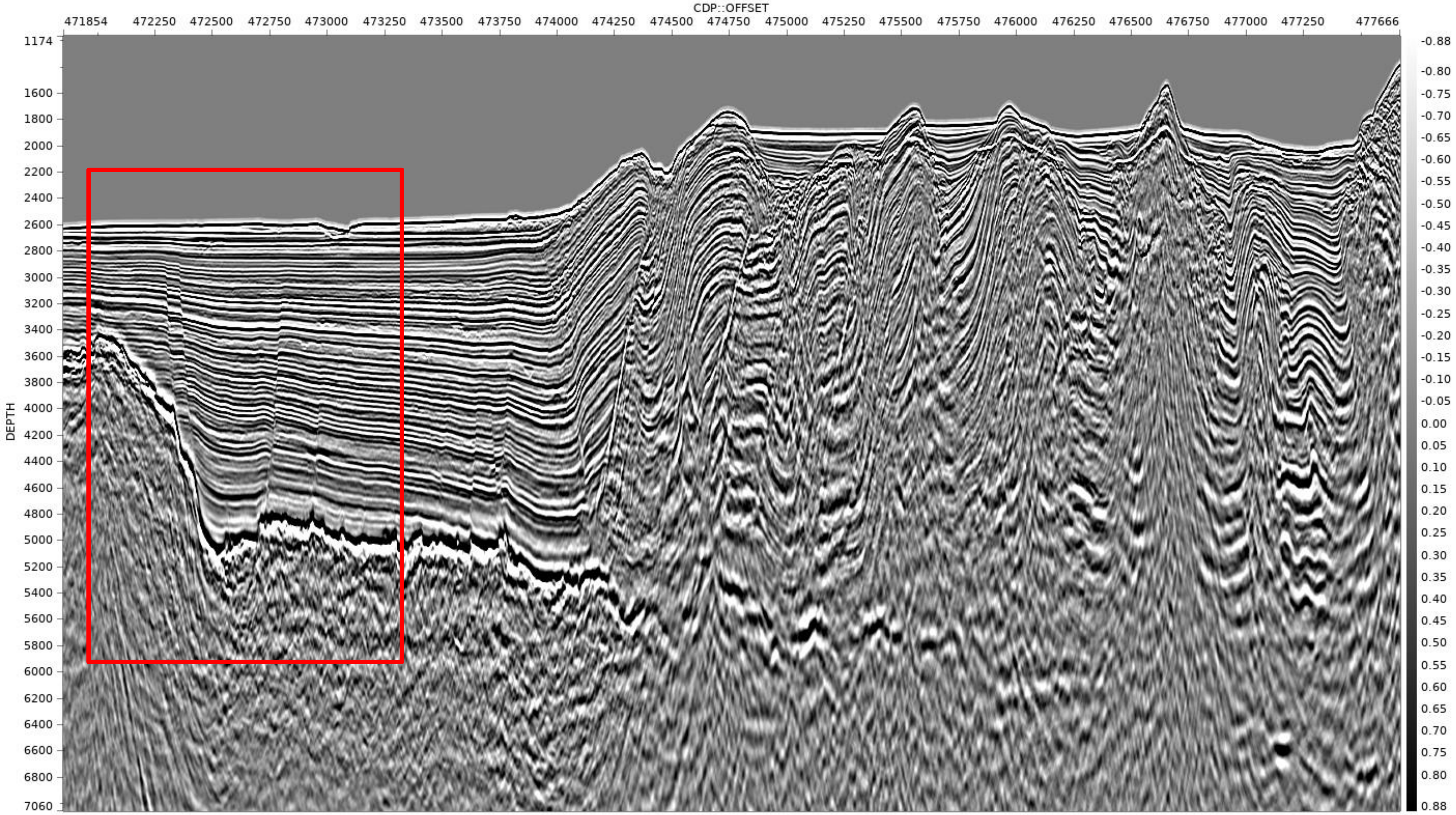
PD-08: Input FWI Stack



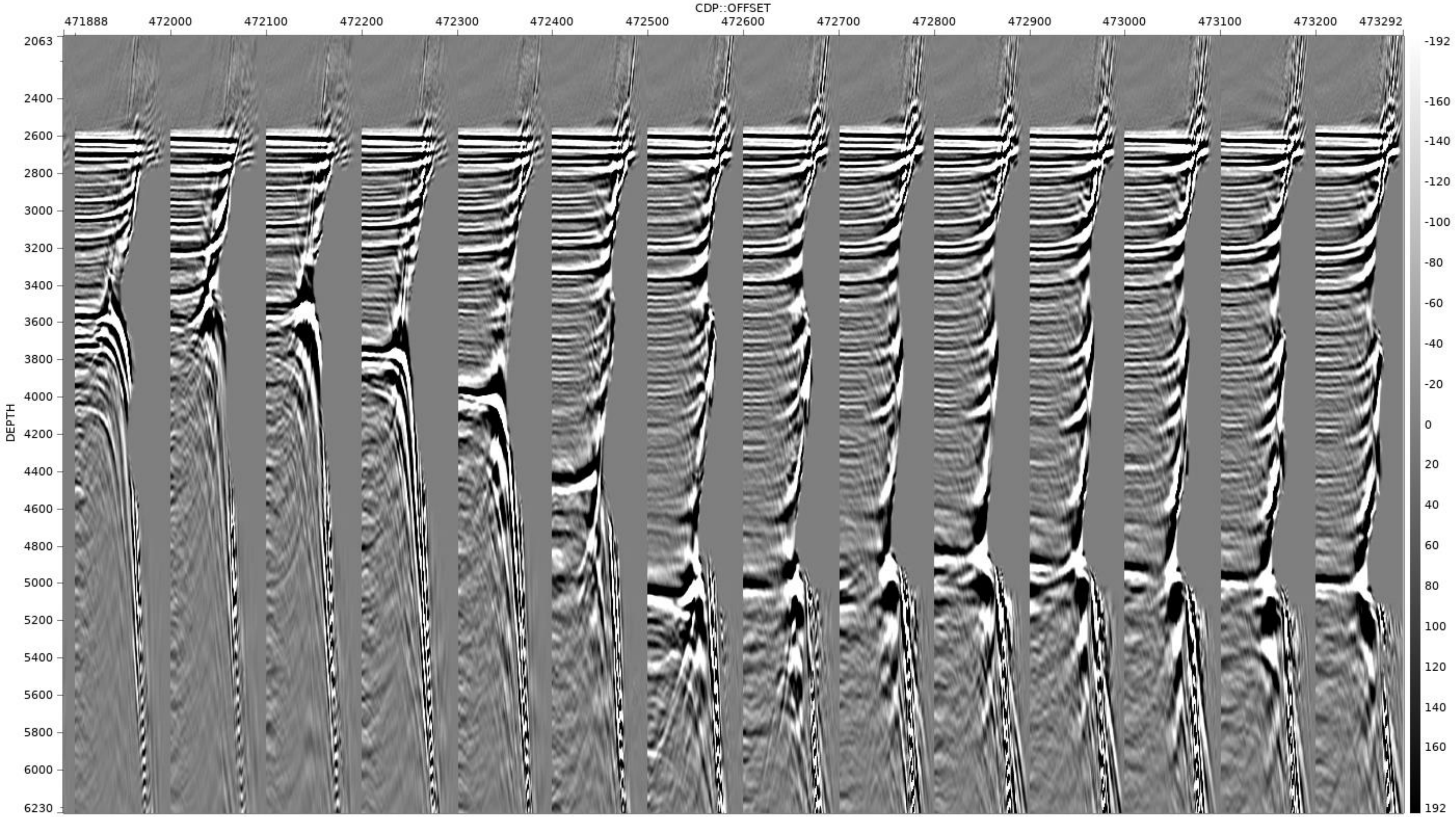
PD-08: Output FWI Stack



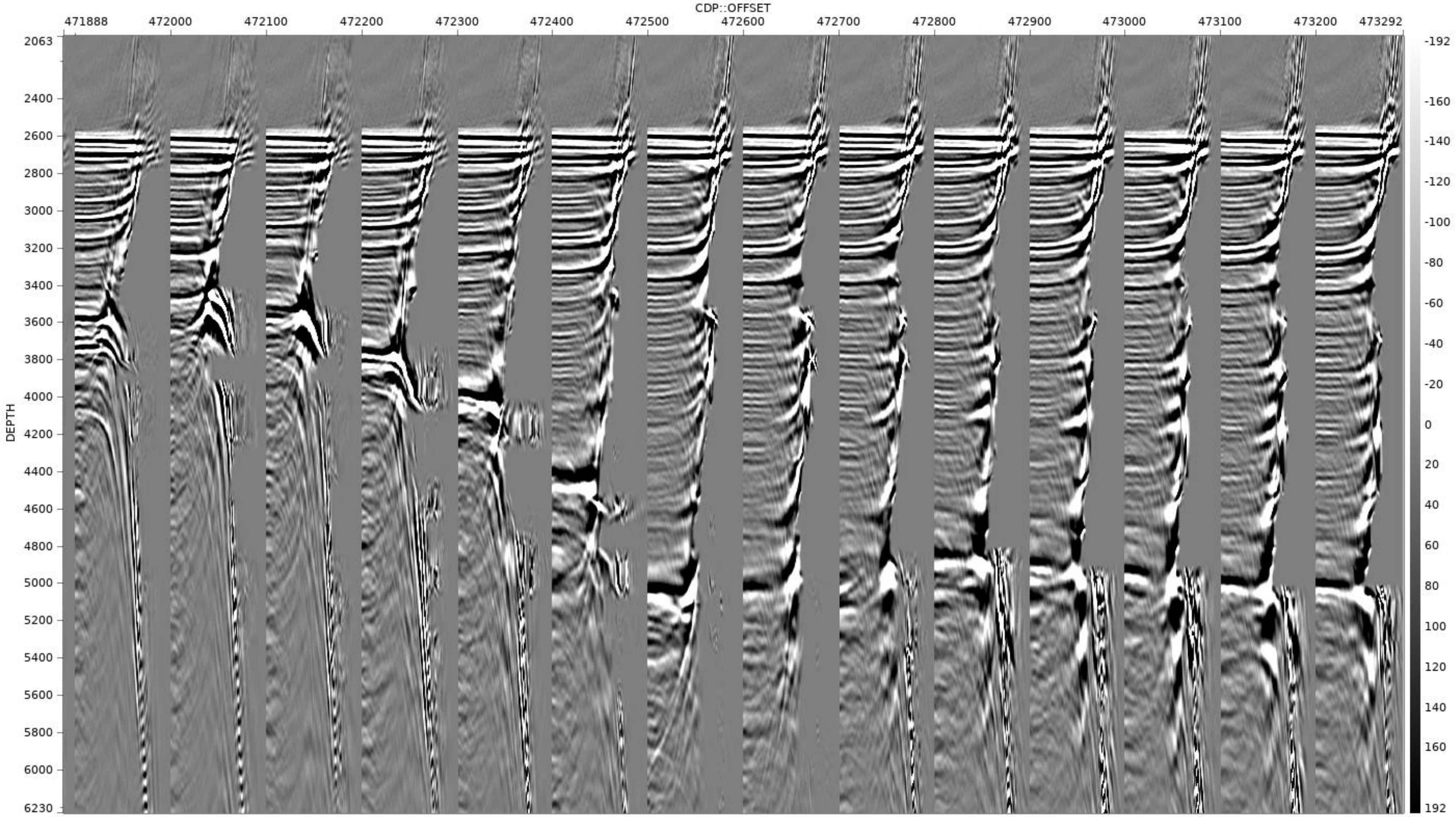
PD-08: Output FWI Stack (Zoom selection)



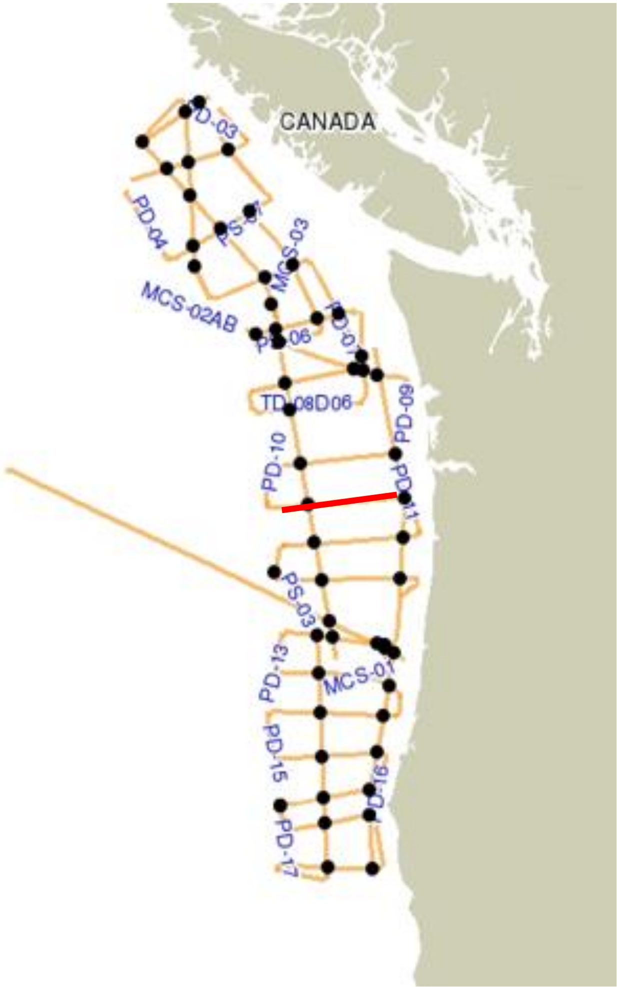
PD-08: Input FWI Gathers (Zoom)



PD-08: Output FWI Gathers (Zoom)



Line PD-10



CANADA
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TD-08D06
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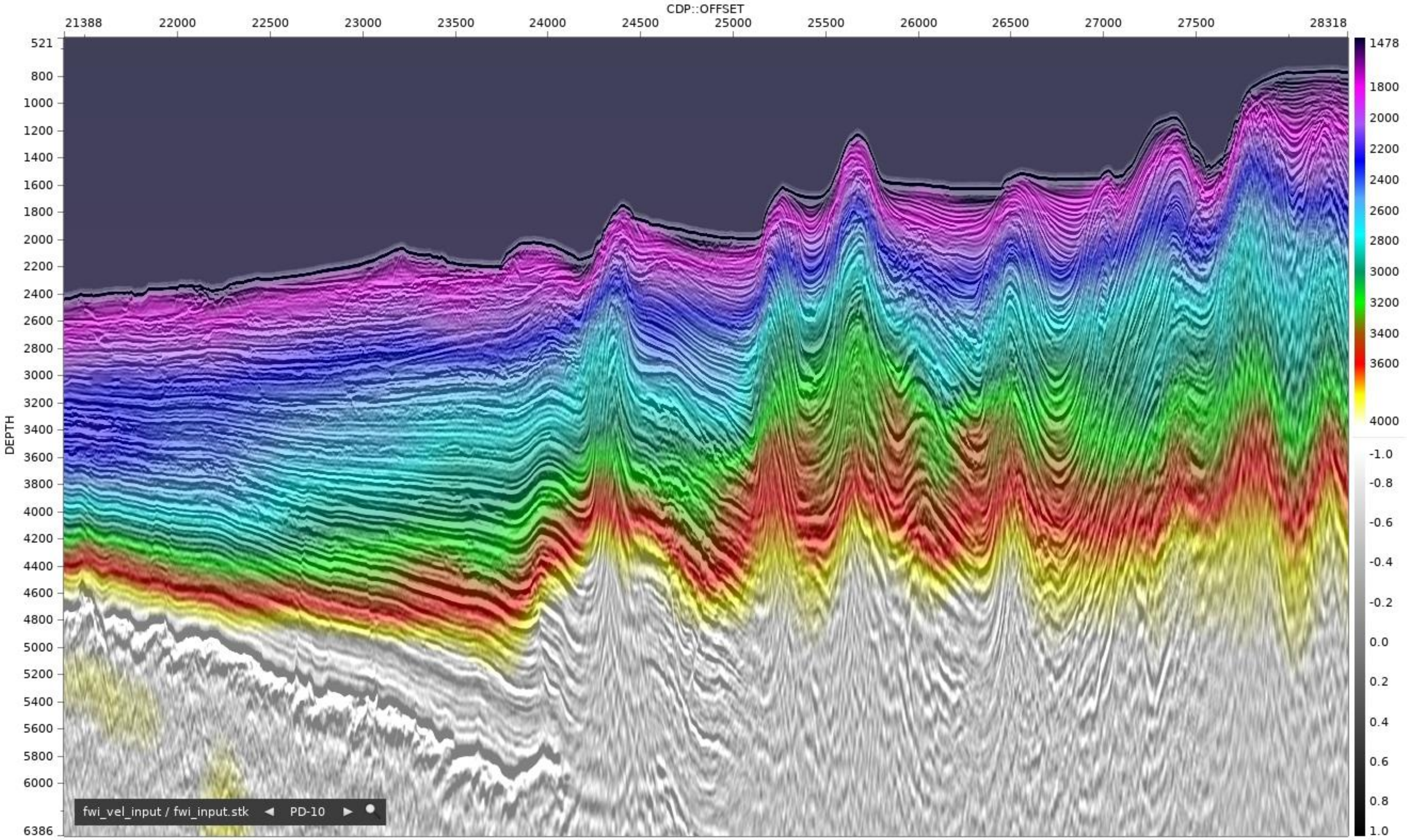
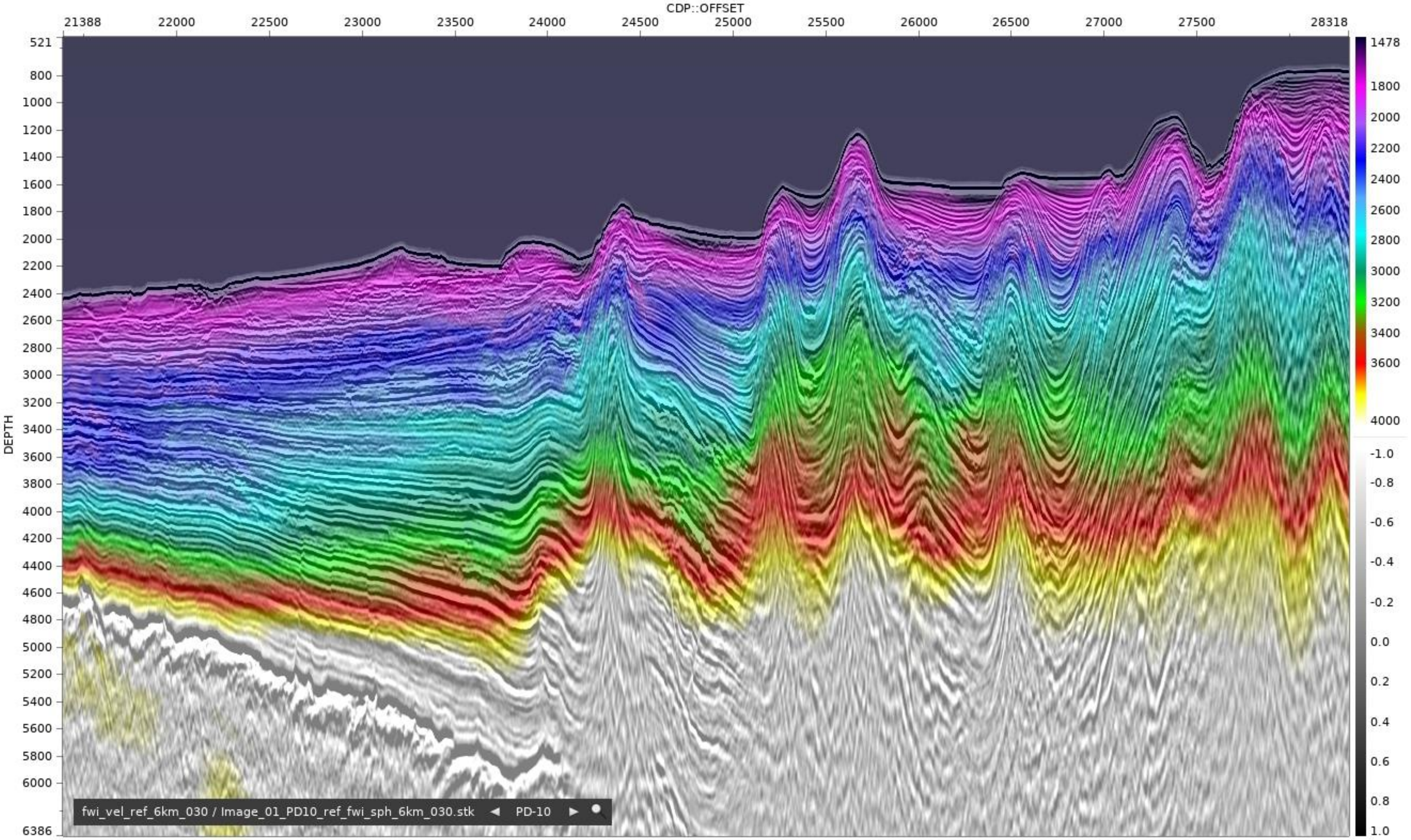
PS-03
PD-13
MCS-01
PD-15
PD-16
PD-17

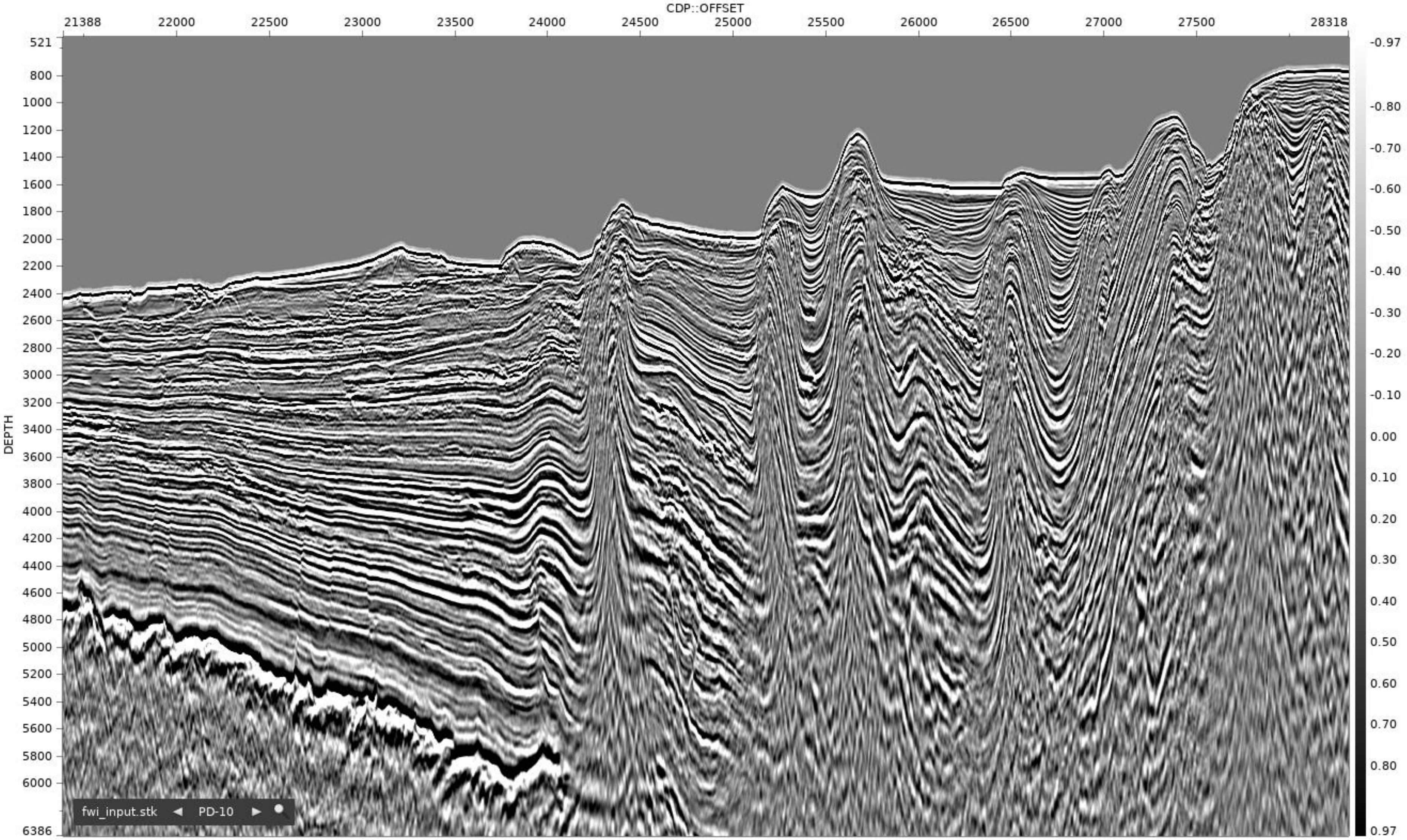
PD-10: Input FWI Velocity



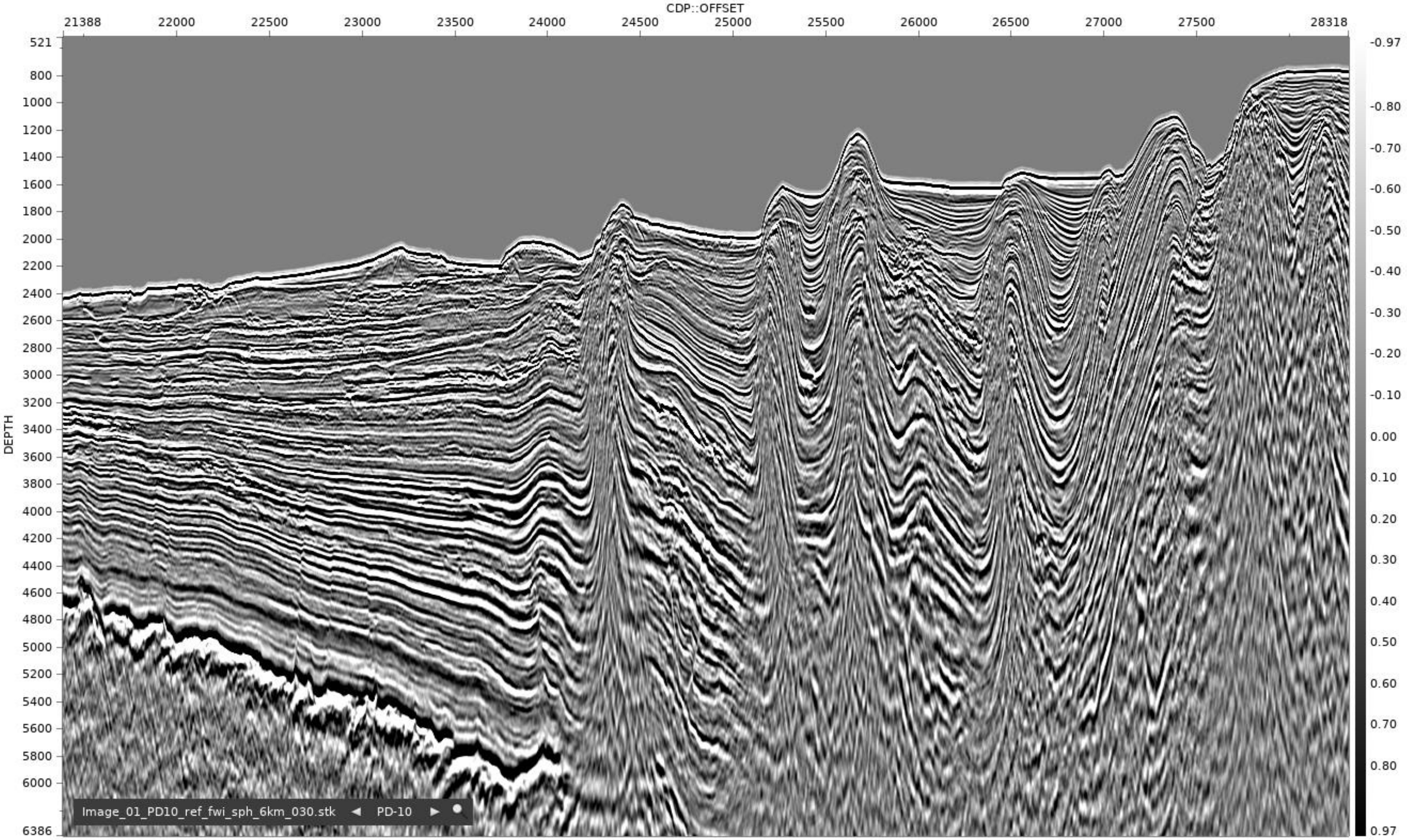
PD-10: Output FWI Velocity



PD-10: Input FWI Stack



PD-10: Output FWI Stack

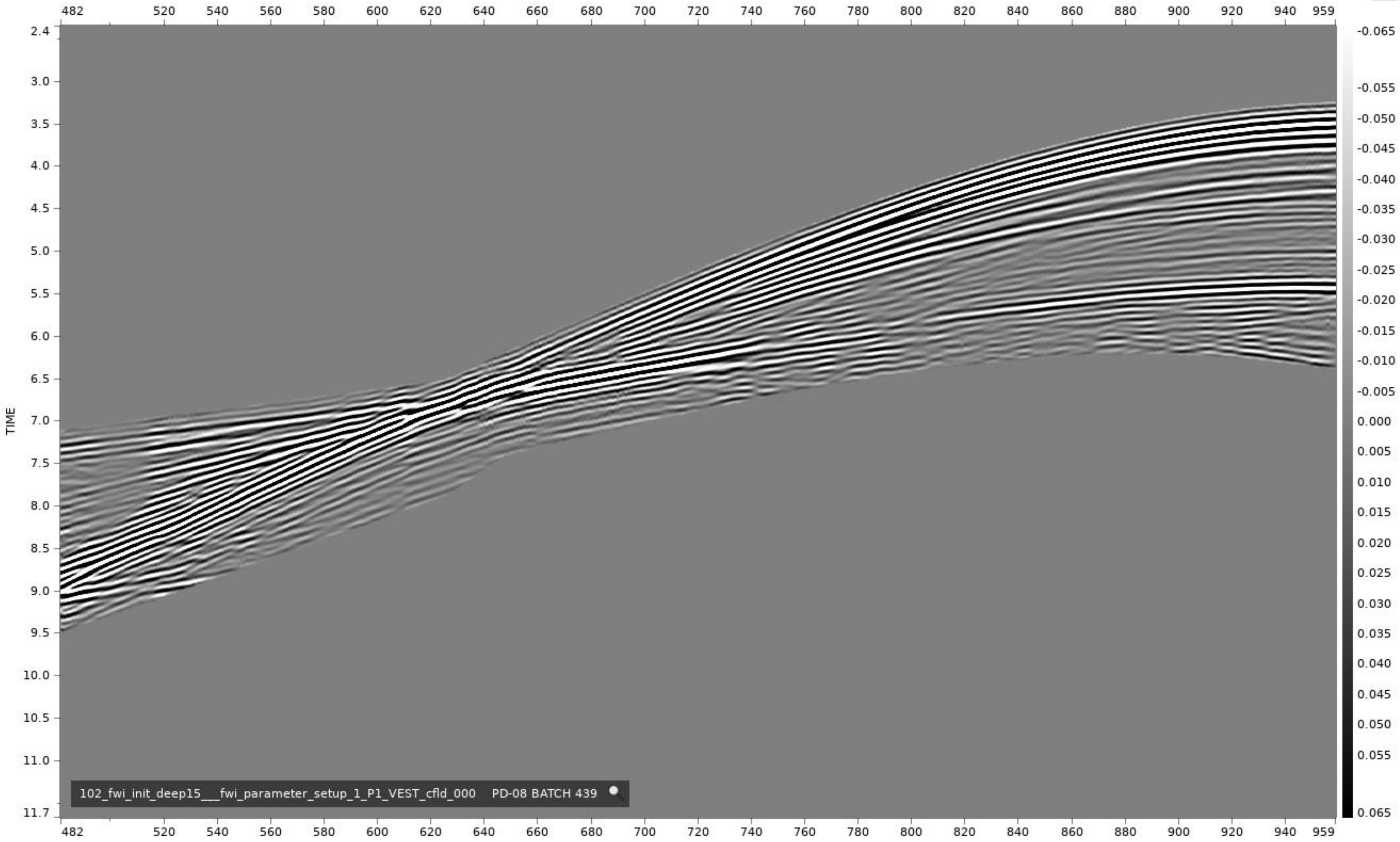


Diving Wave FWI

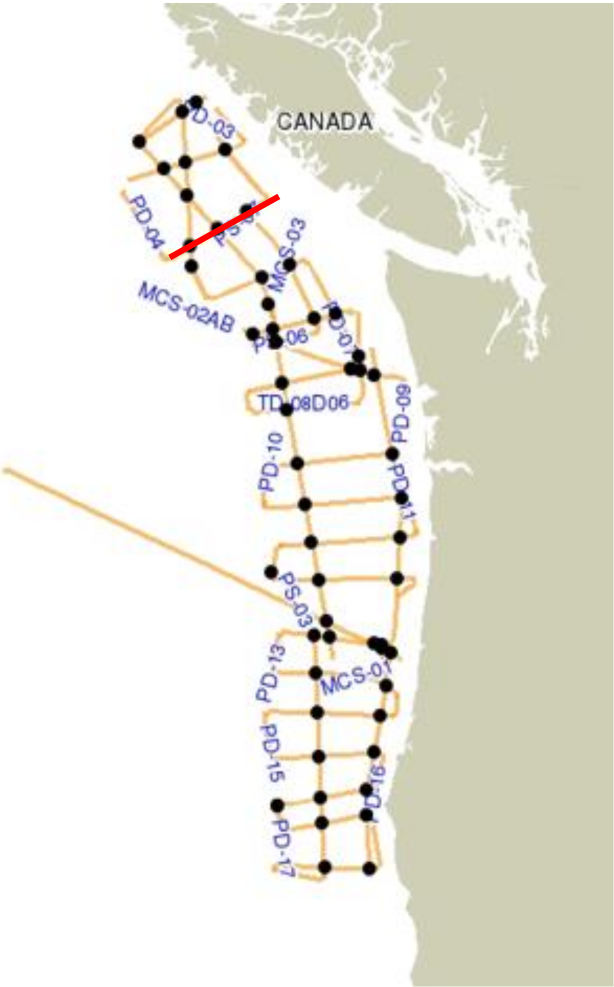
Applied to section of 2D line: approx. greater than 2.5 km meter depth

Cost Function – Travel Time
Cross-correlation Window Length – 400ms
Min/Max Lag – -200ms/+200ms
Offsets – Full cable
Data Length – First Break plus 3.0 sec
Bandpass Filter – 0-10-12-15Hz

Data selection for Diving Waves FWI

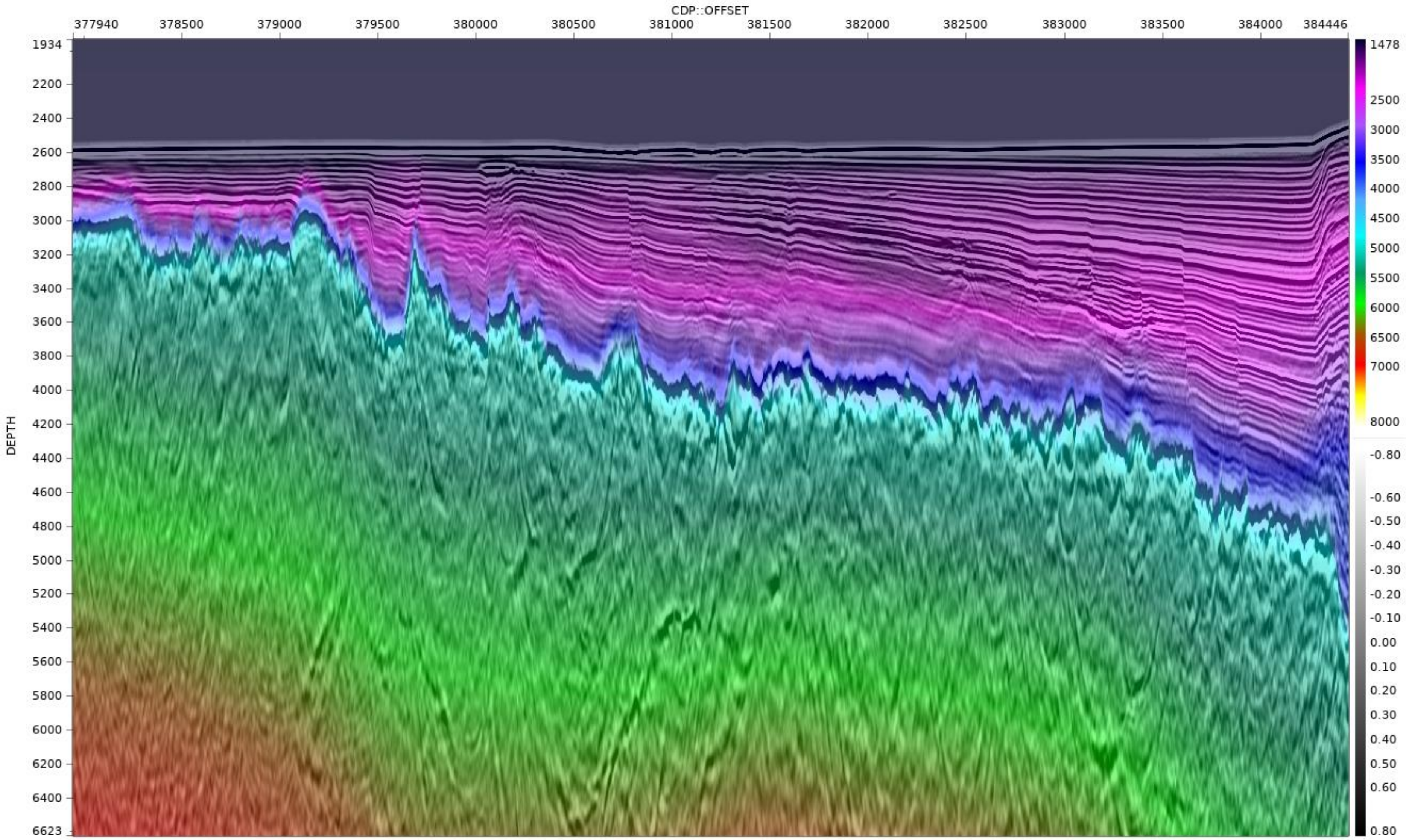


Line PD-04

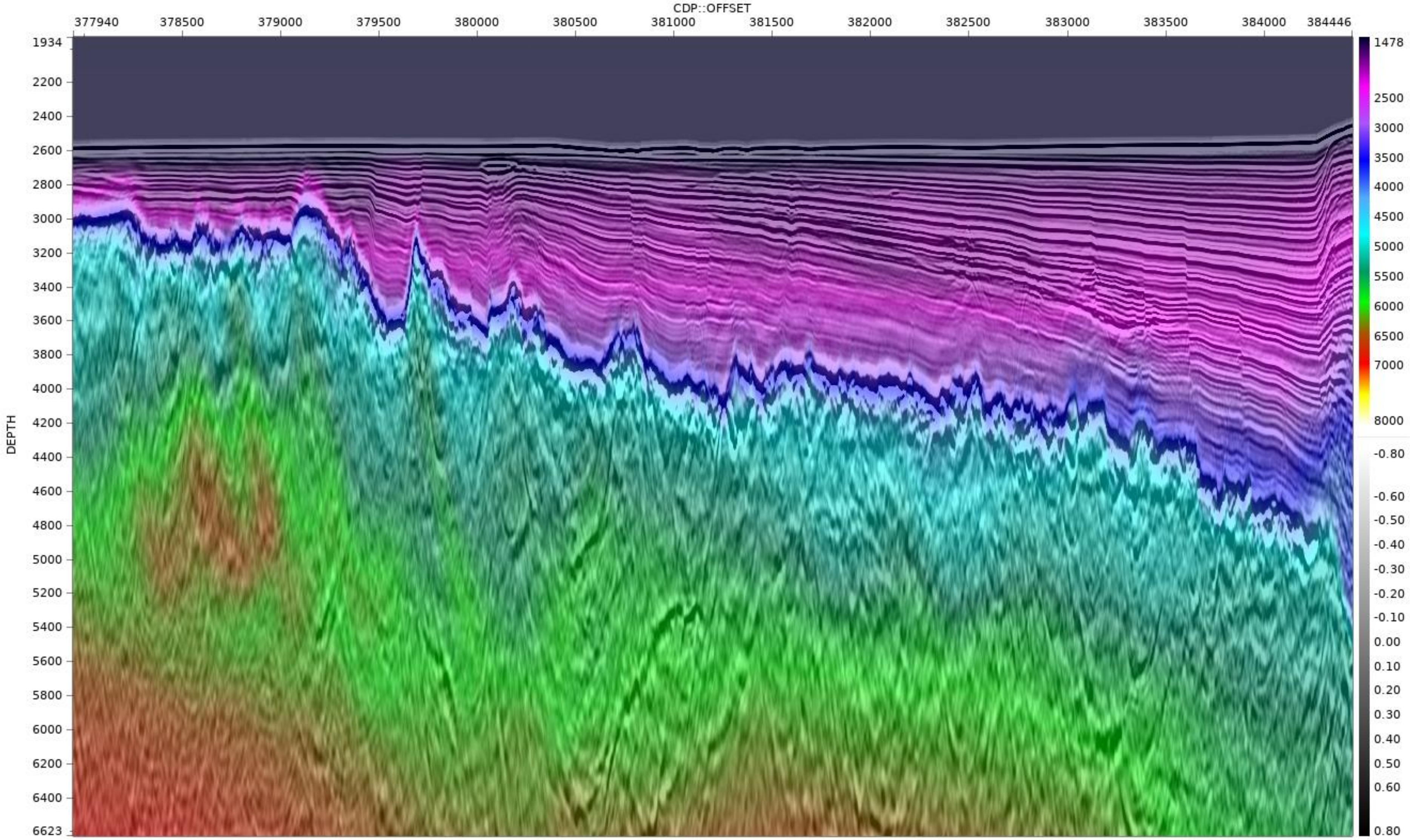


CANADA
PD-03
PD-04
MCS-03
MCS-02AB
PD-06
TD-08D06
PD-09
PD-10
PD-11
PS-03
PD-13
MCS-01
PD-15
PD-16
PD-17

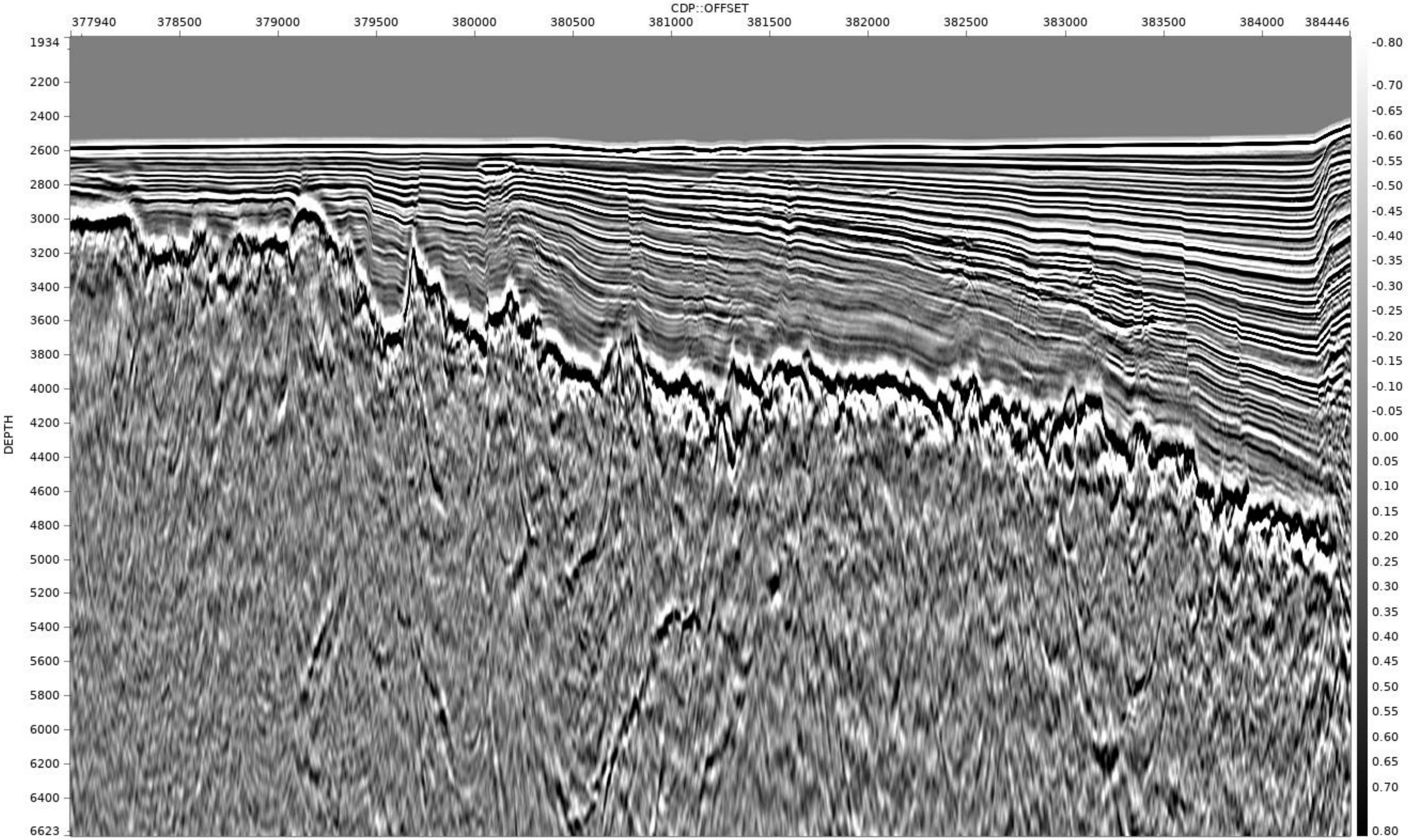
PD-04: Input FWI Velocity



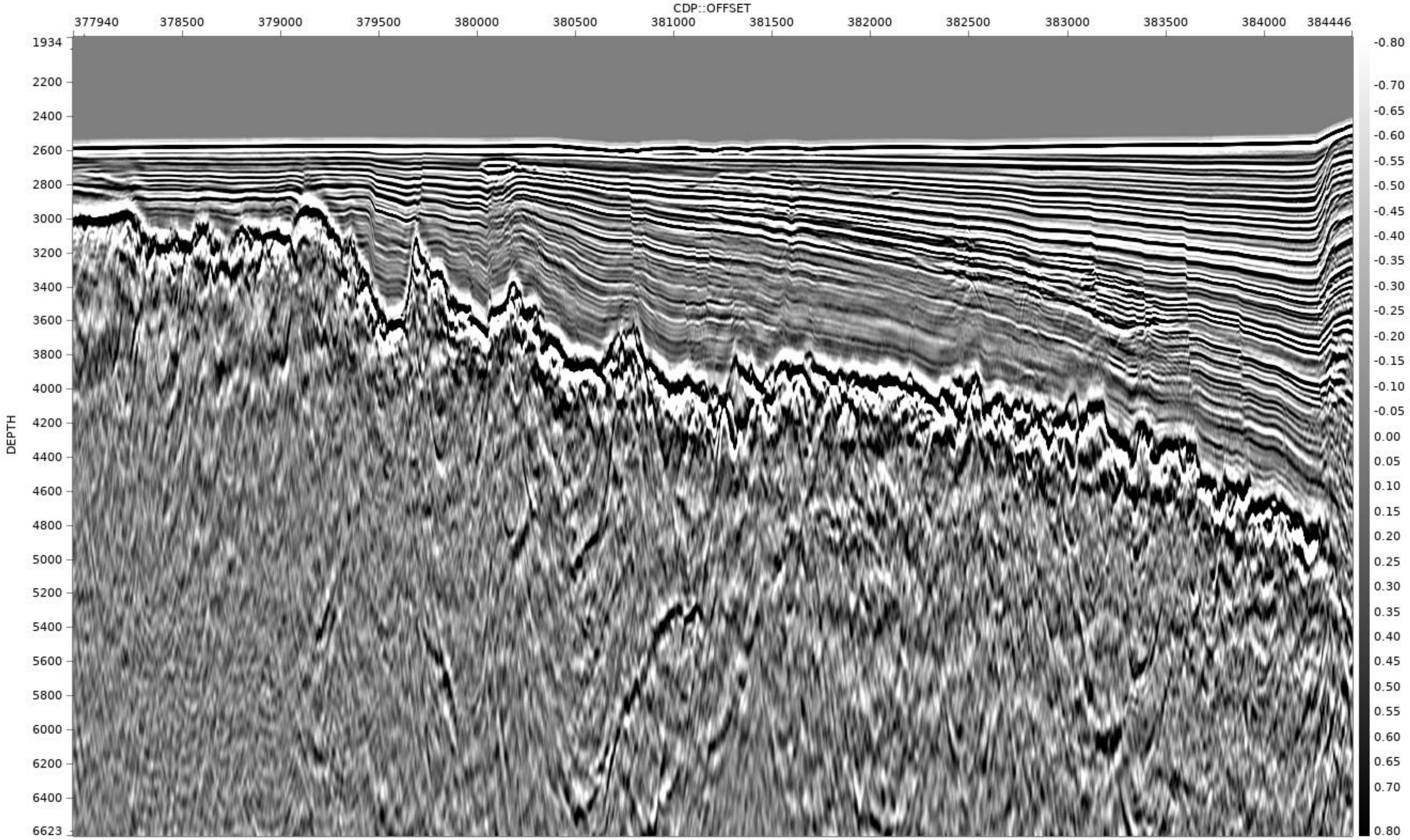
PD-04: Output FWI Velocity



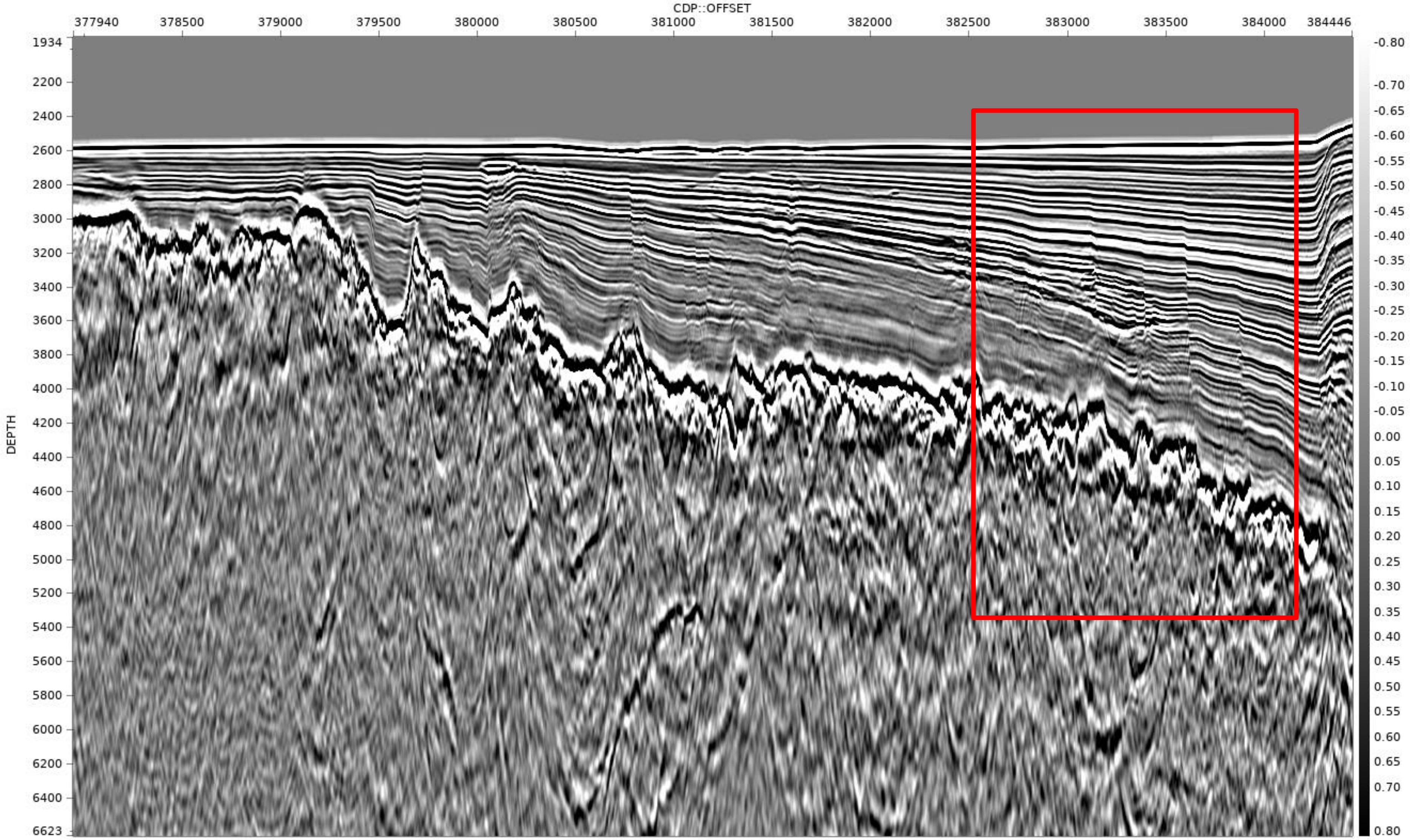
PD-04: Input FWI Stack



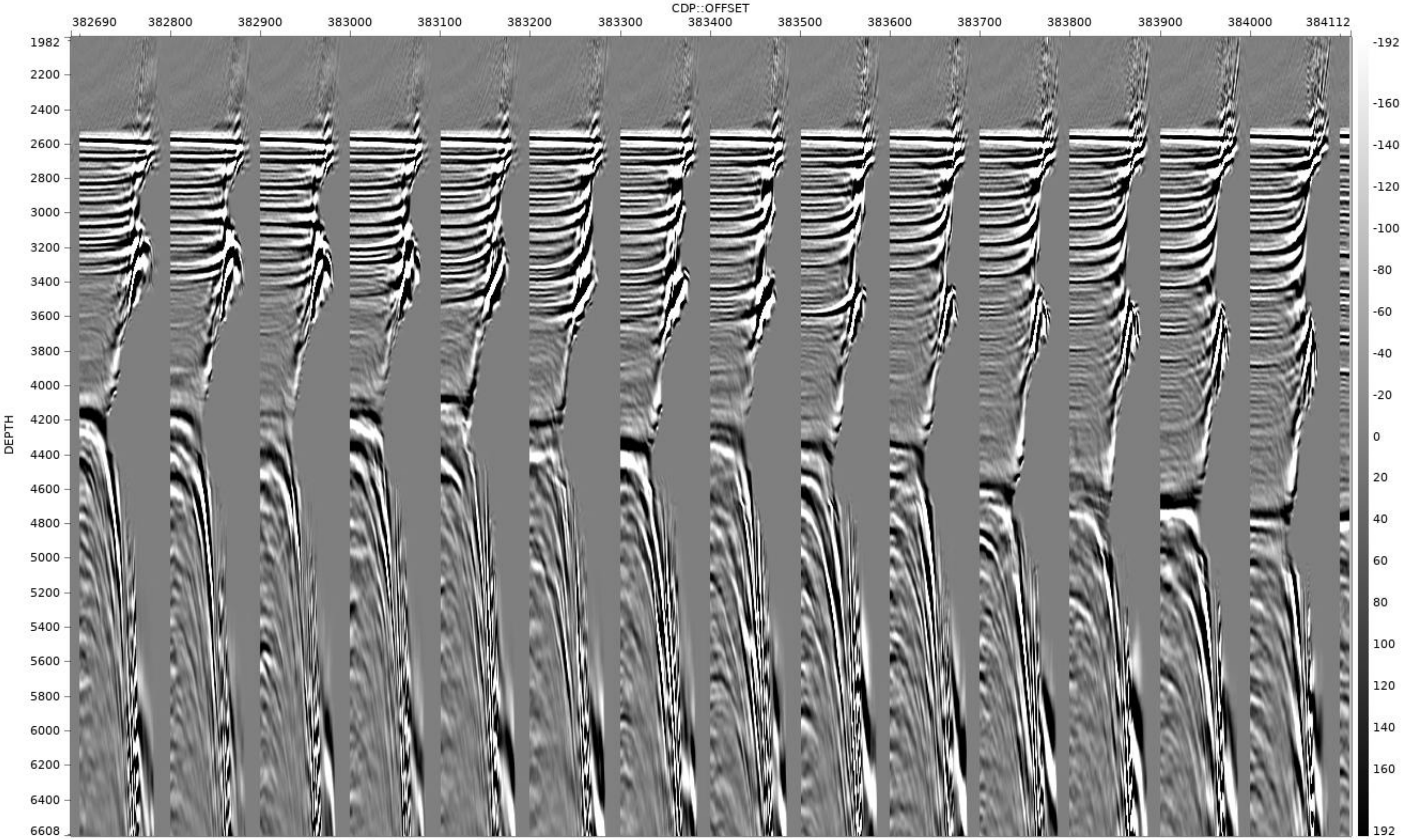
PD-04: Output FWI Stack



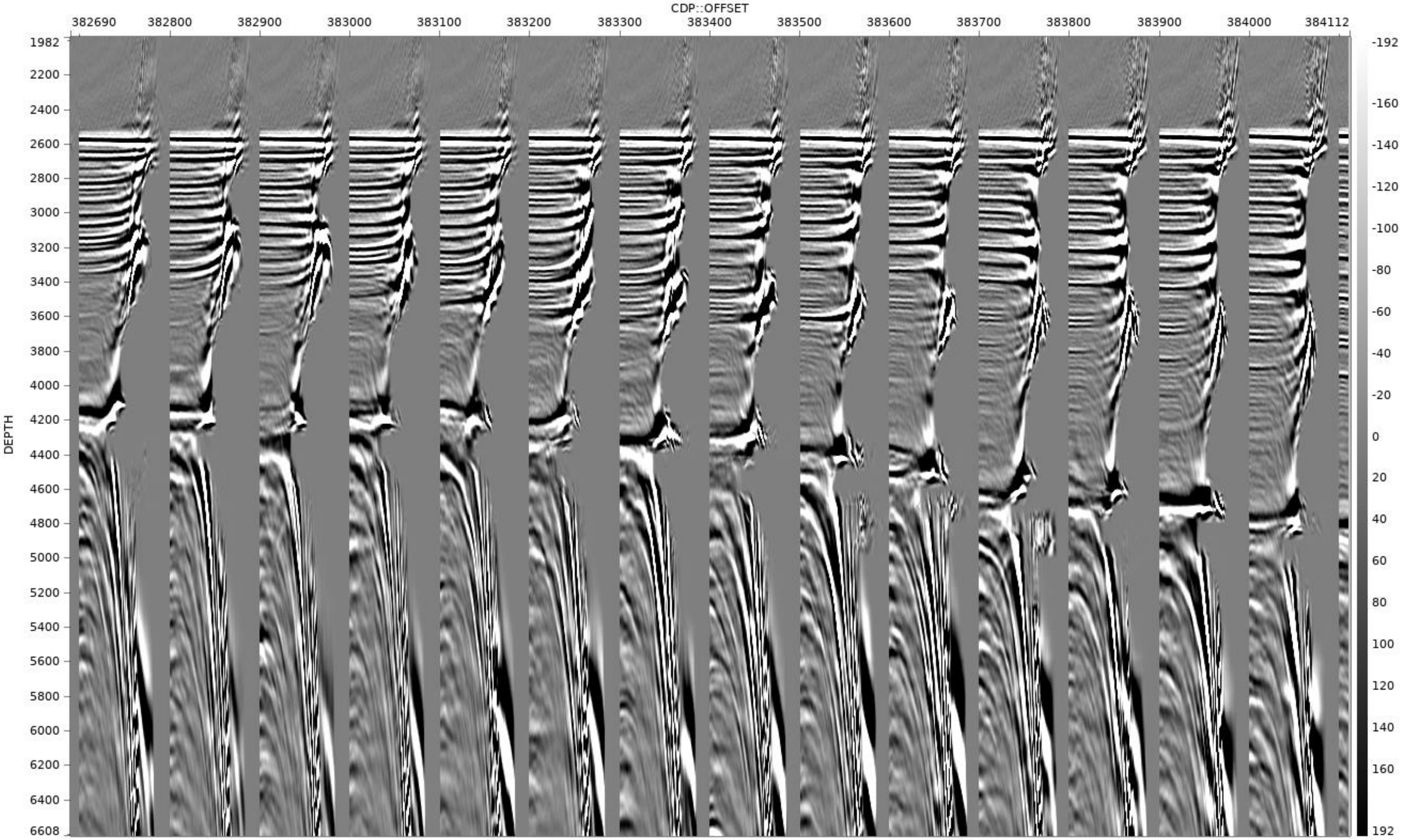
PD-04: Output FWI Stack (Zoom selection)



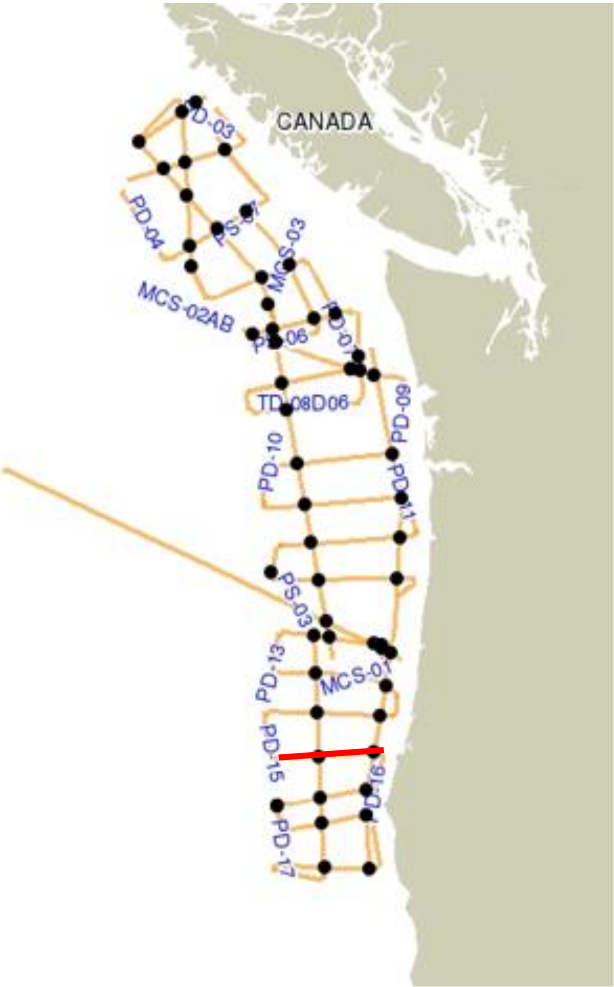
PD-04: Input FWI Gathers (Zoom)



PD-04: Output FWI Gathers (Zoom)



Line PD-16



CANADA
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TD-08D06
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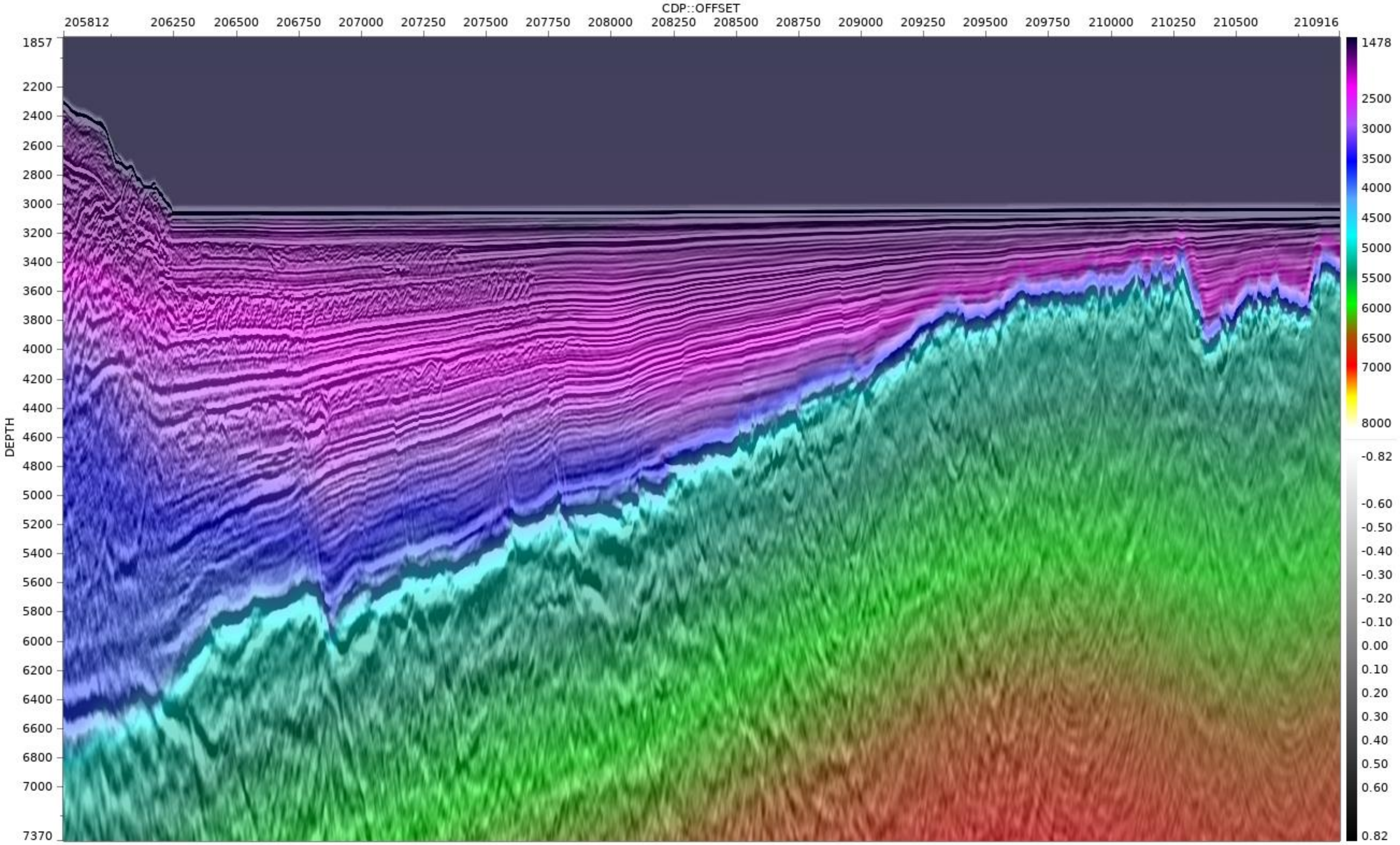
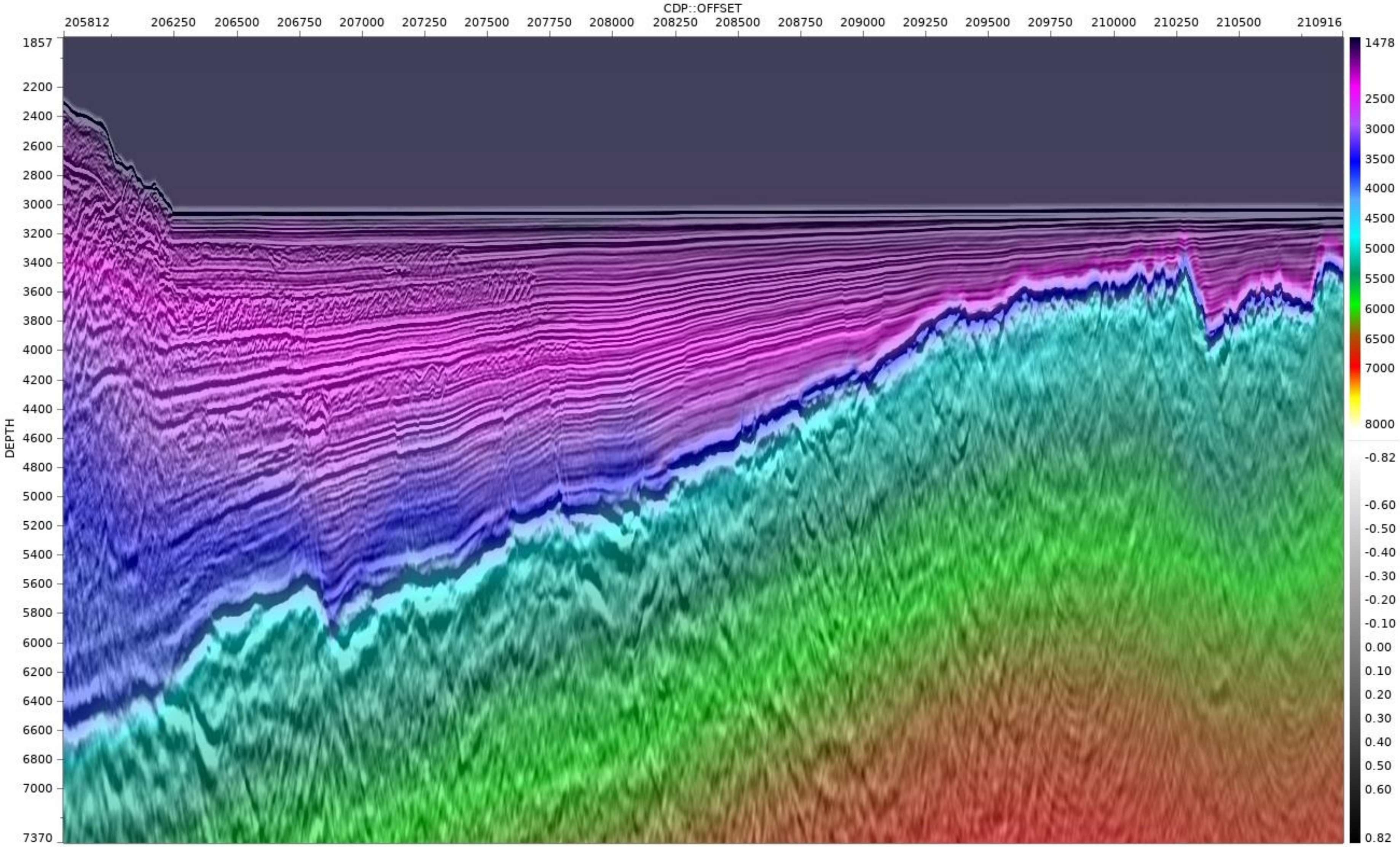
PS-03
PD-13
MCS-01
PD-15
PD-16
PD-17

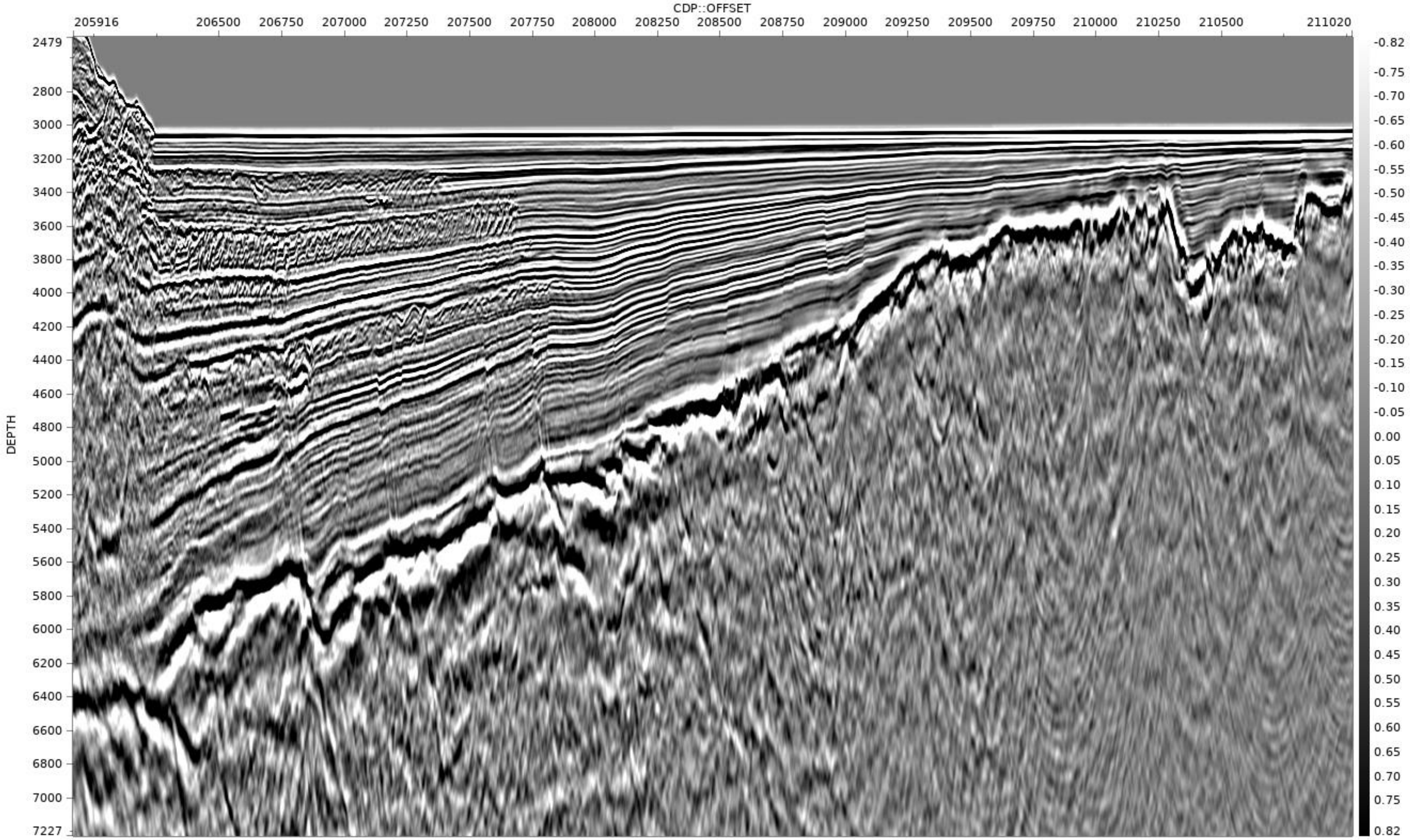
PD-16: Input FWI Velocity



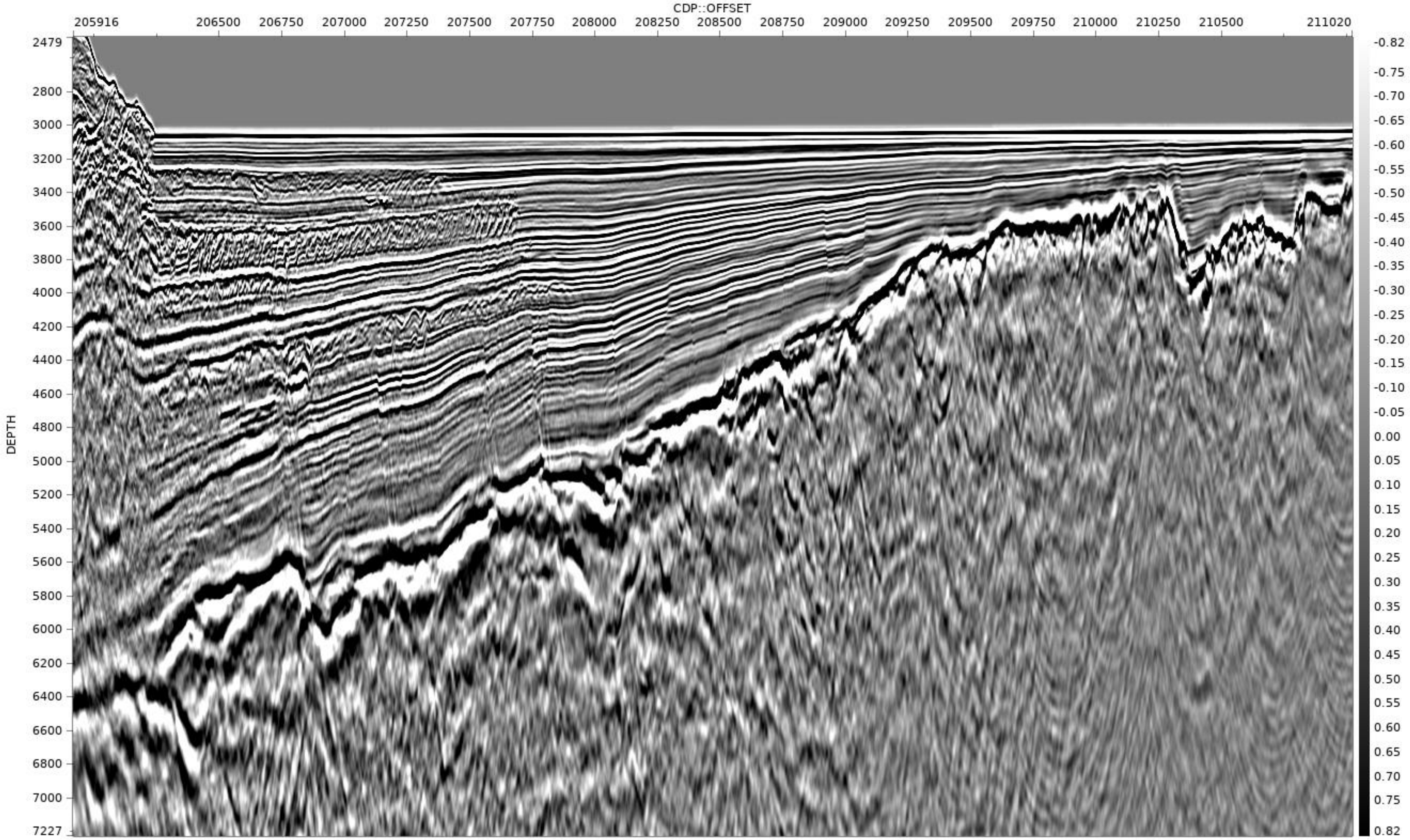
PD-16: Output FWI Velocity



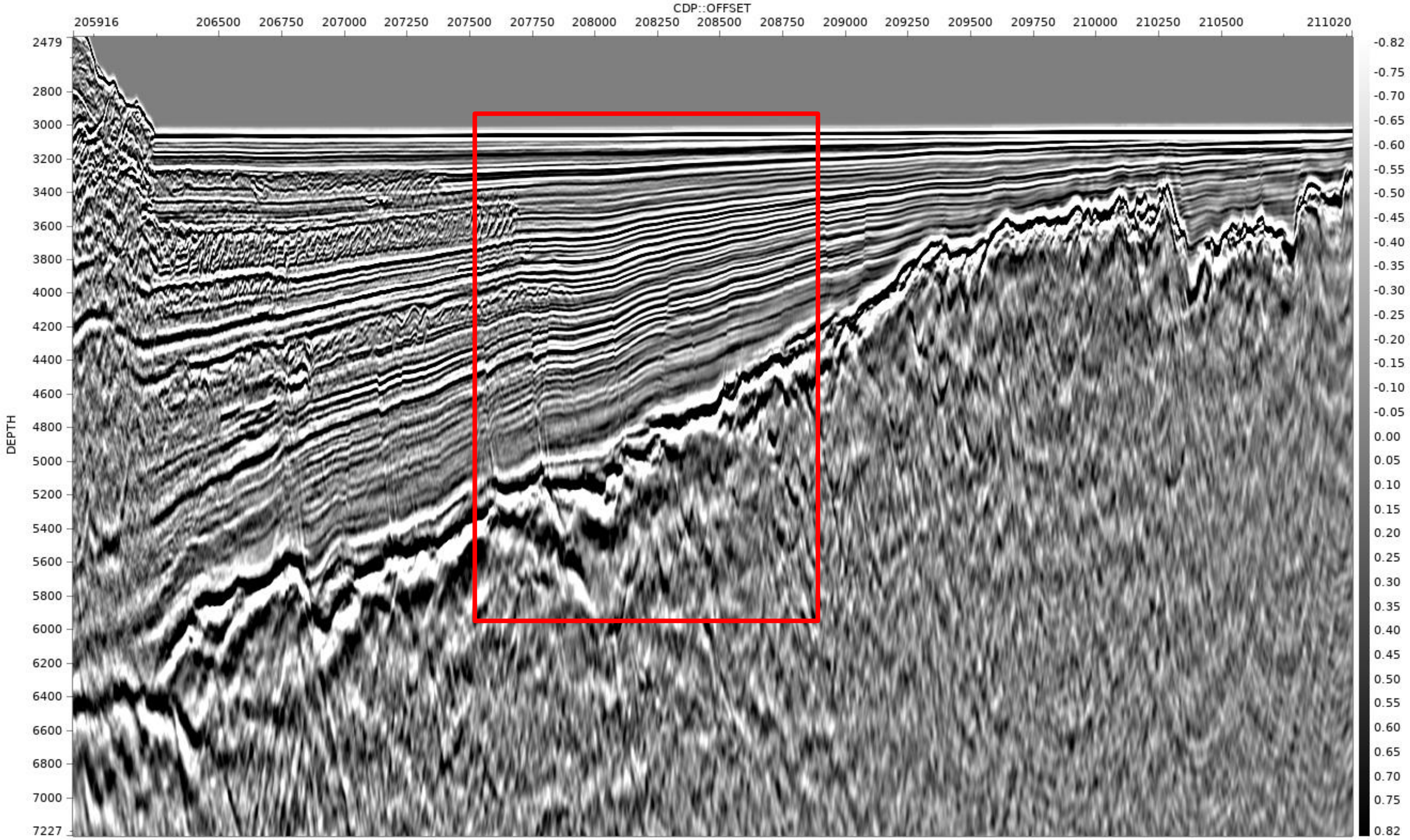
PD-16: Input FWI Stack



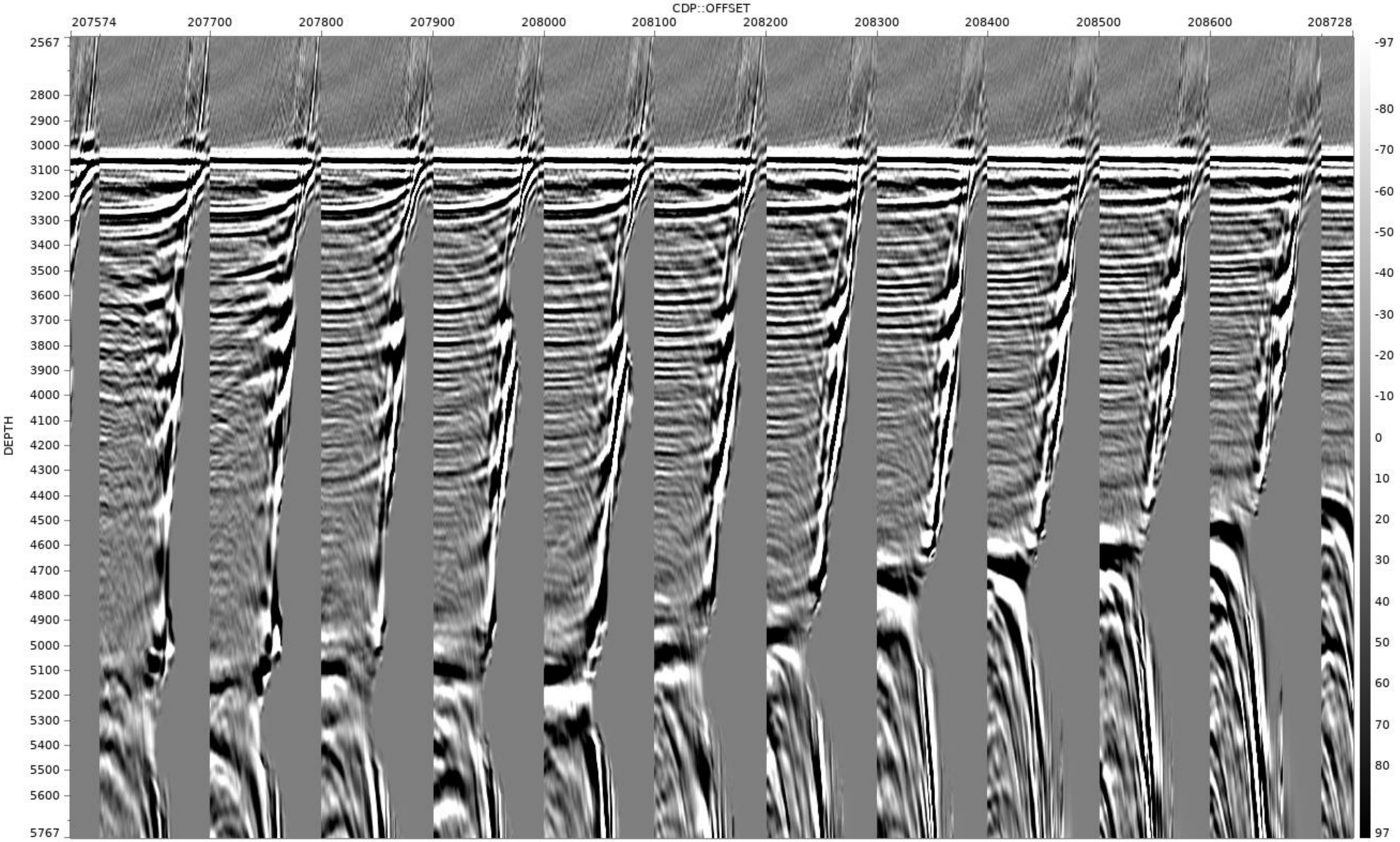
PD-16: Output FWI Stack



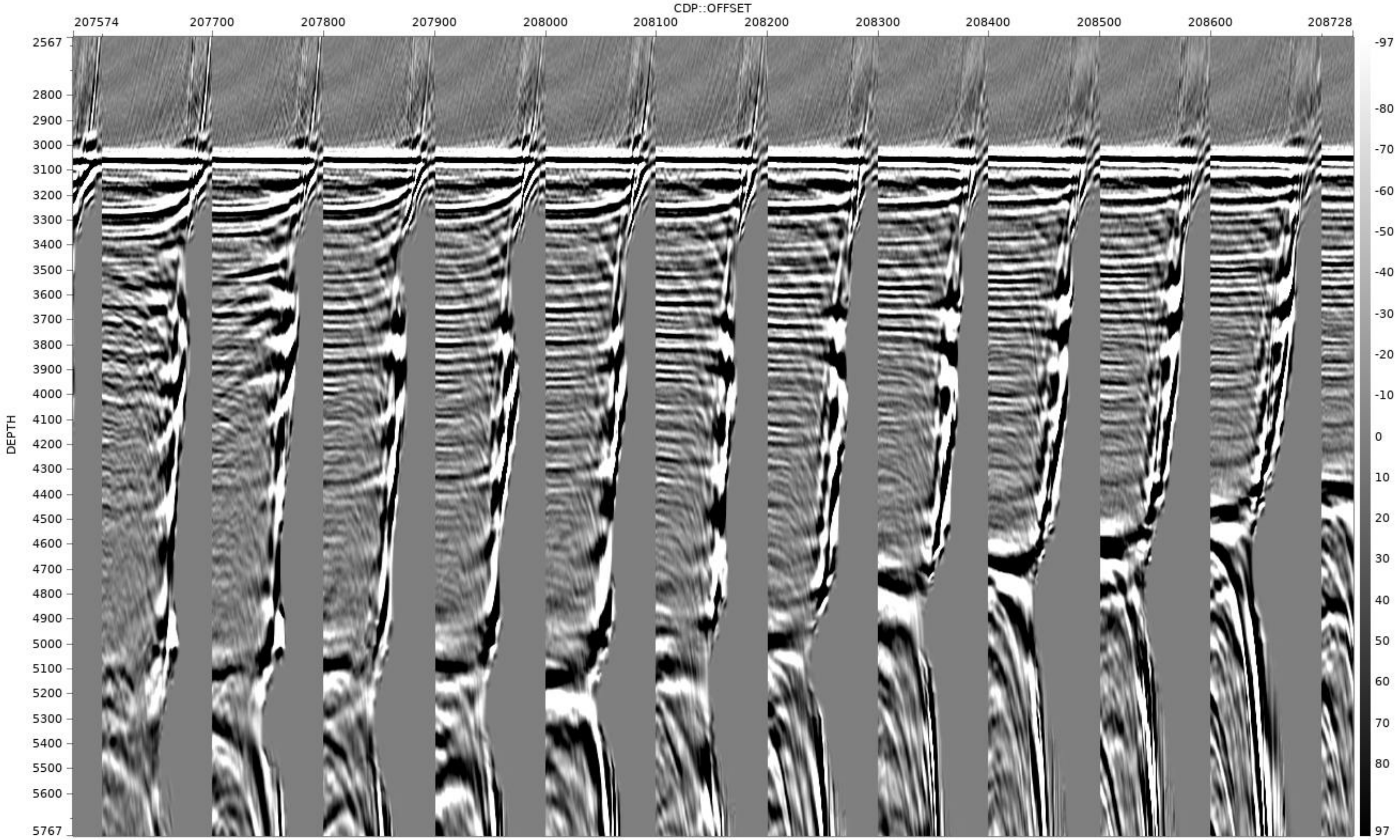
PD-16: Output FWI Stack (Zoom selection)



PD-16: Input FWI Gathers (Zoom)



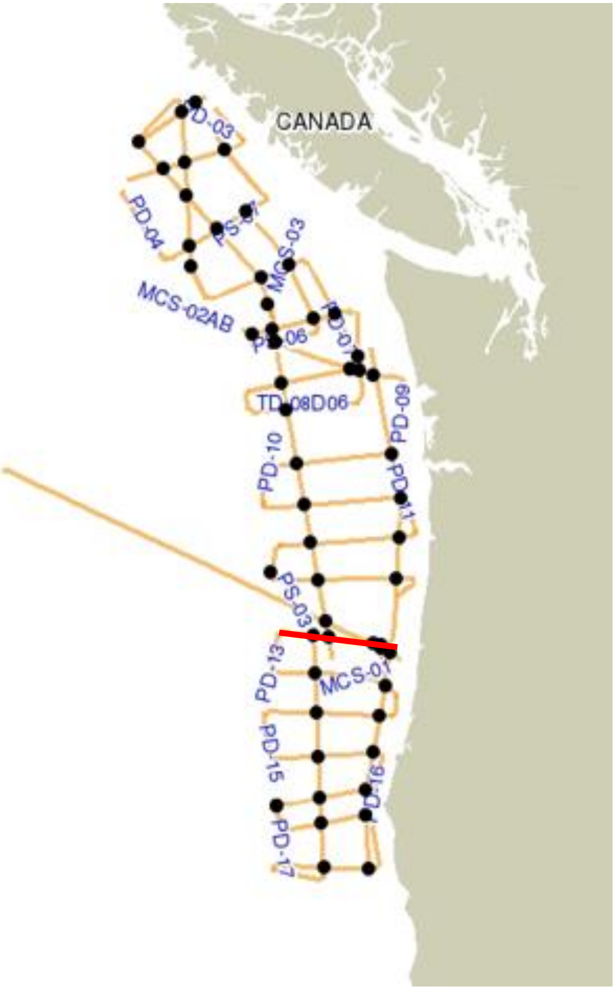
PD-16: Output FWI Gathers (Zoom)



Data Derived Anisotropy Parameters

- Epsilon derived from scans on final isotropic depth gathers
- Delta derived from scaling delta grid by x0.5
- Masked delta and epsilon fields
  - Masked to zero above the water bottom & below Top of crust / wedge horizon

Line PD-13


CANADA
PD-04
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MCS-02AB
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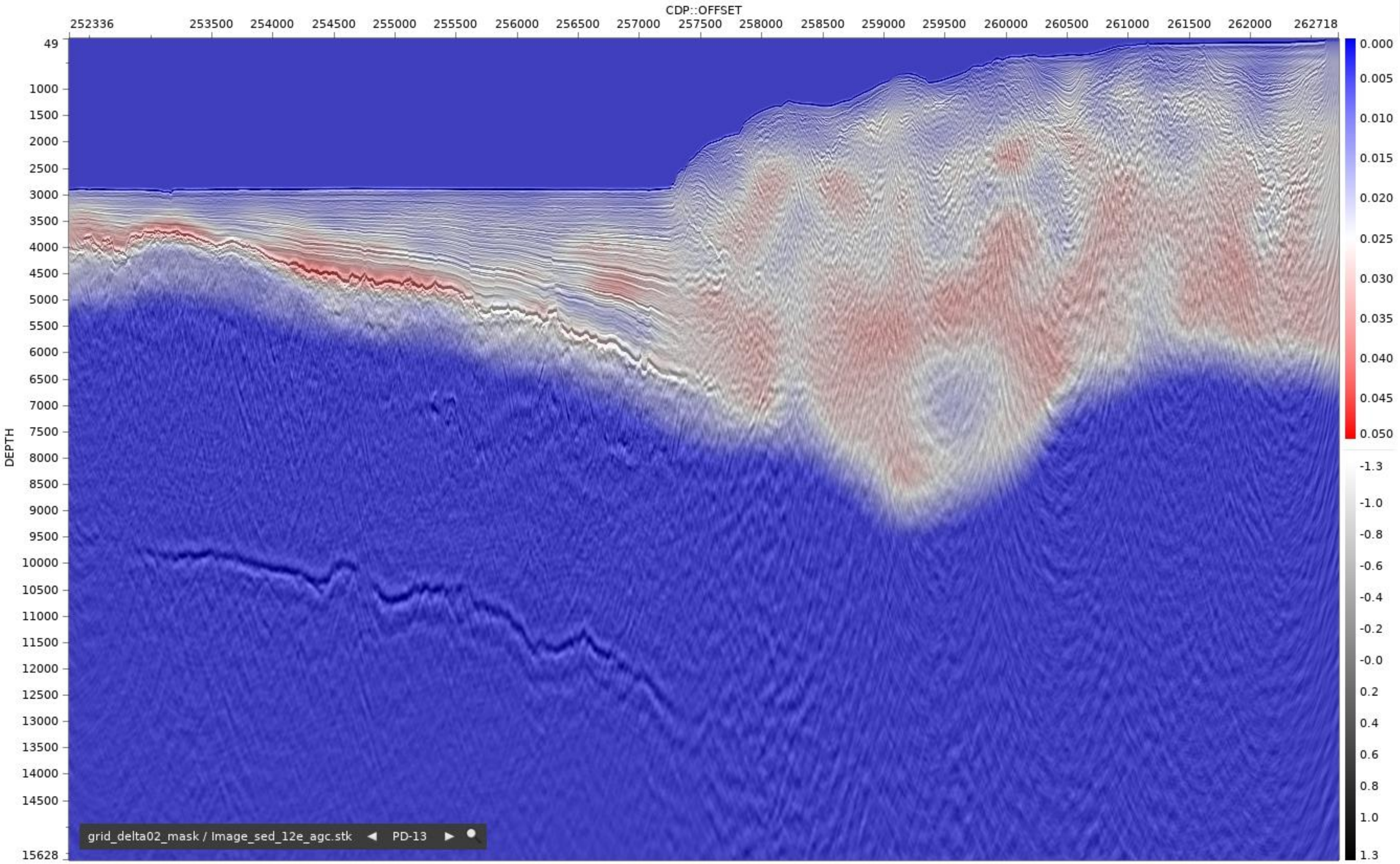
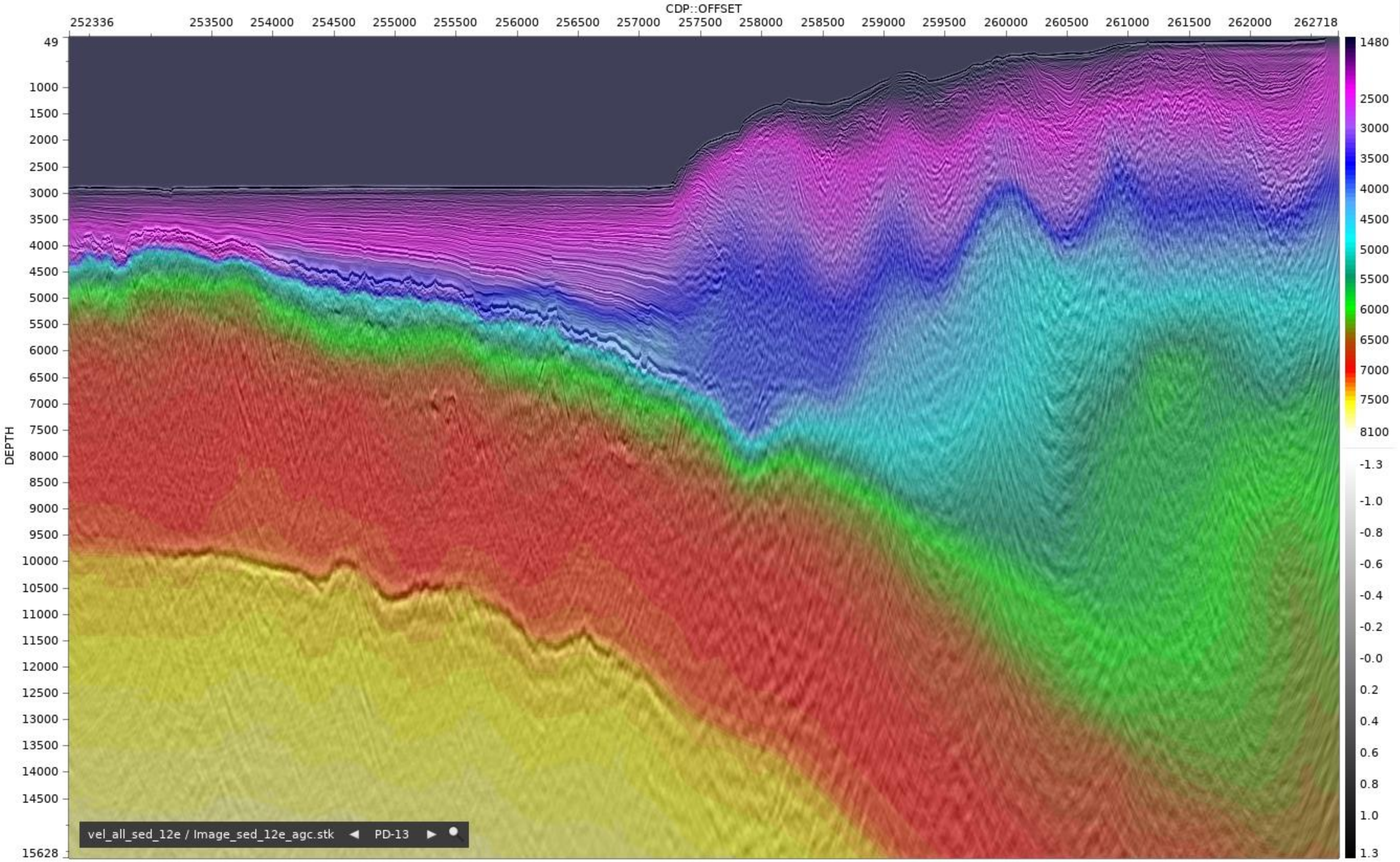
PS-03
PD-13
MCS-01
PD-15
PD-17

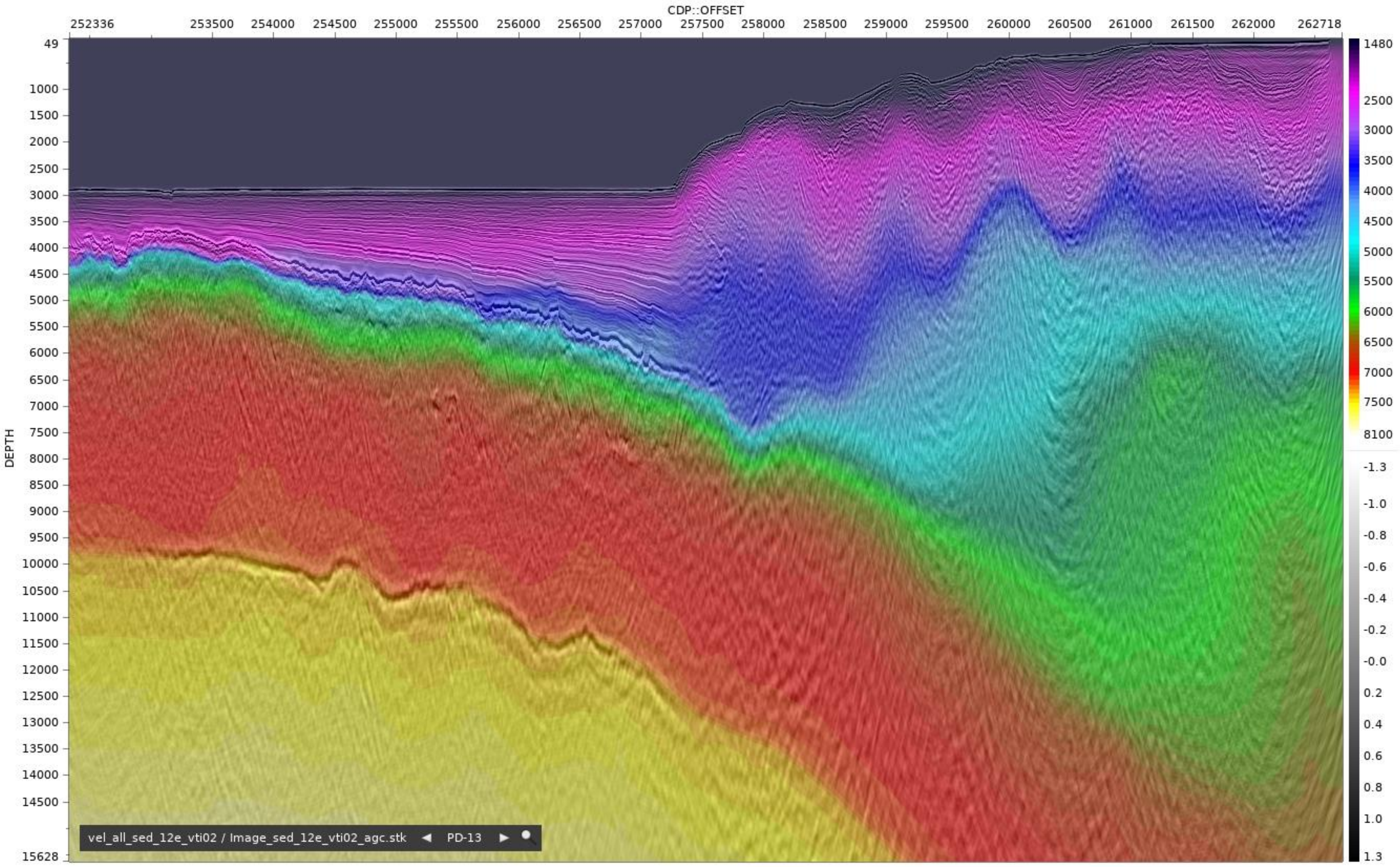
PD-13 Delta / PSDM Stack Overlay



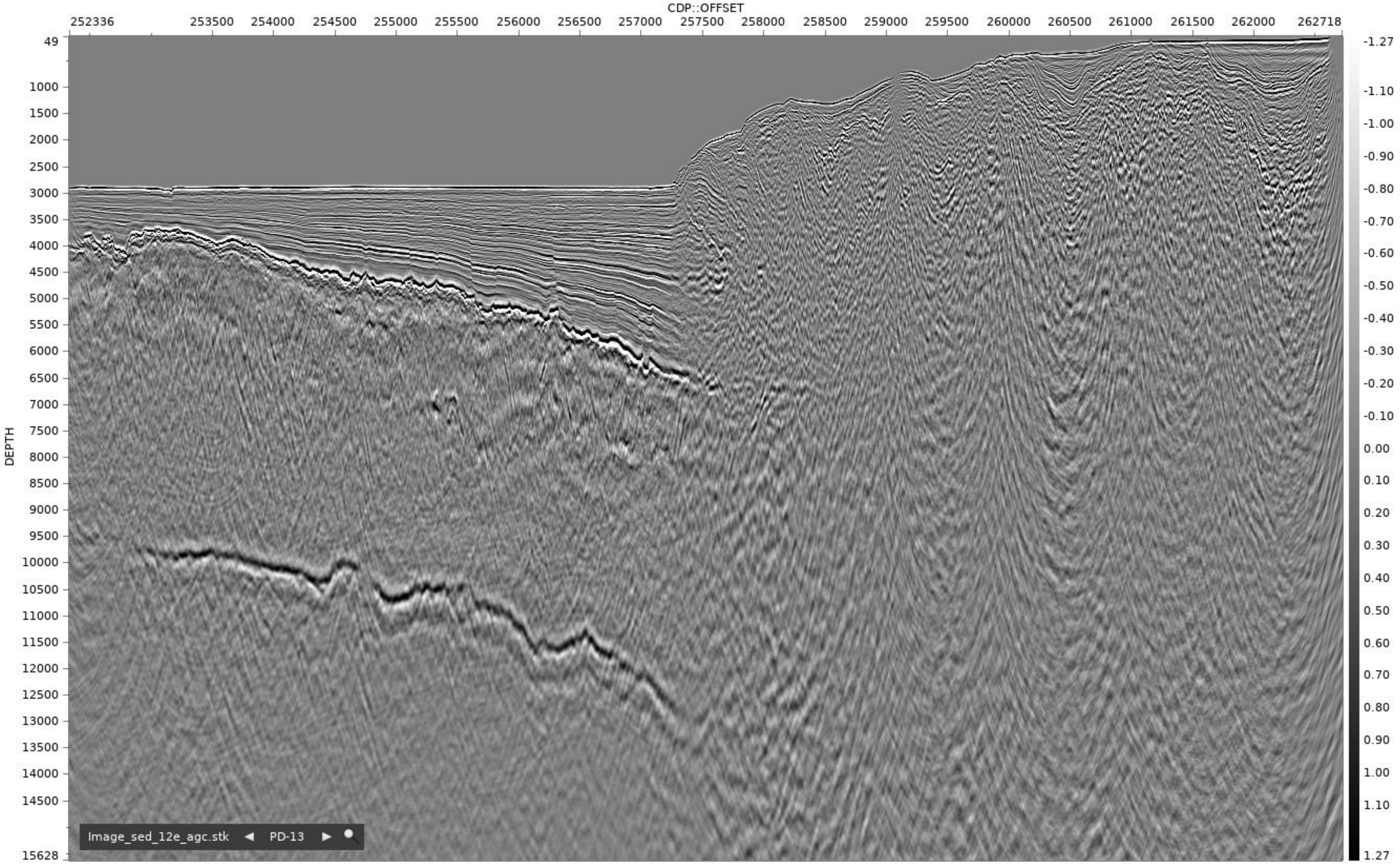
PD-13 Isotropic PSDM Stack overlay



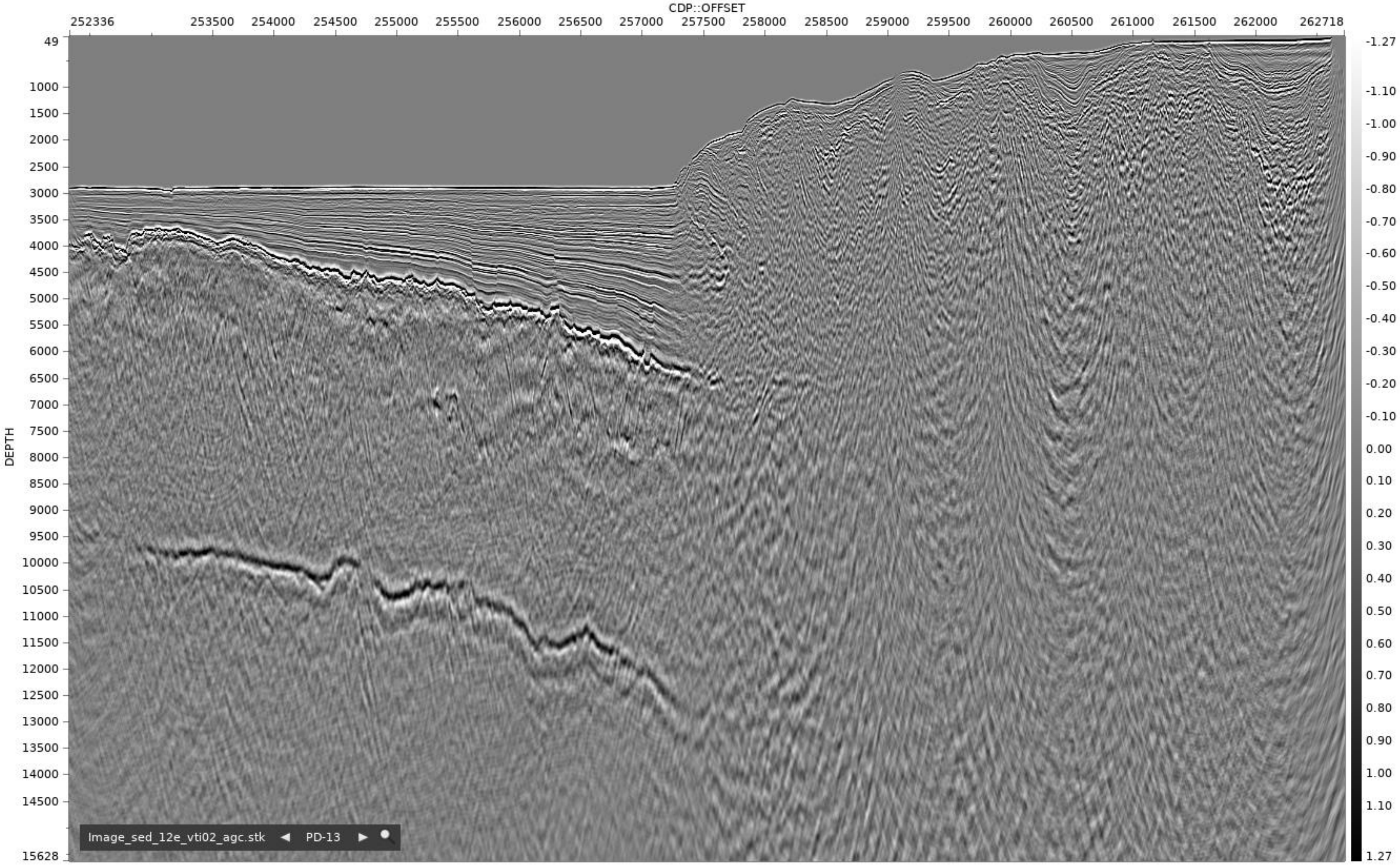
PD-13 Anisotropic PSDM Stack overlay



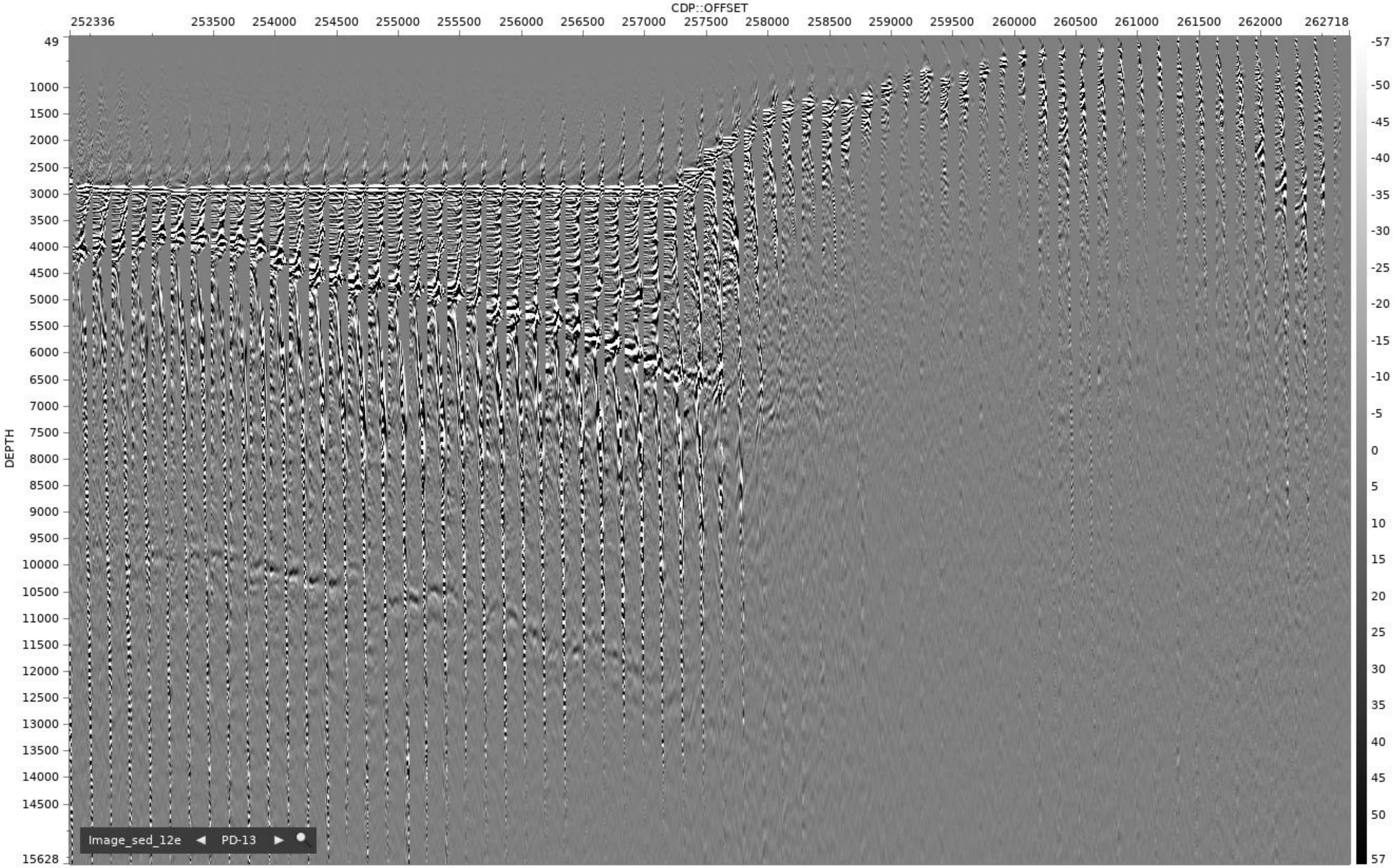
PD-13 Isotropic PSDM Stack



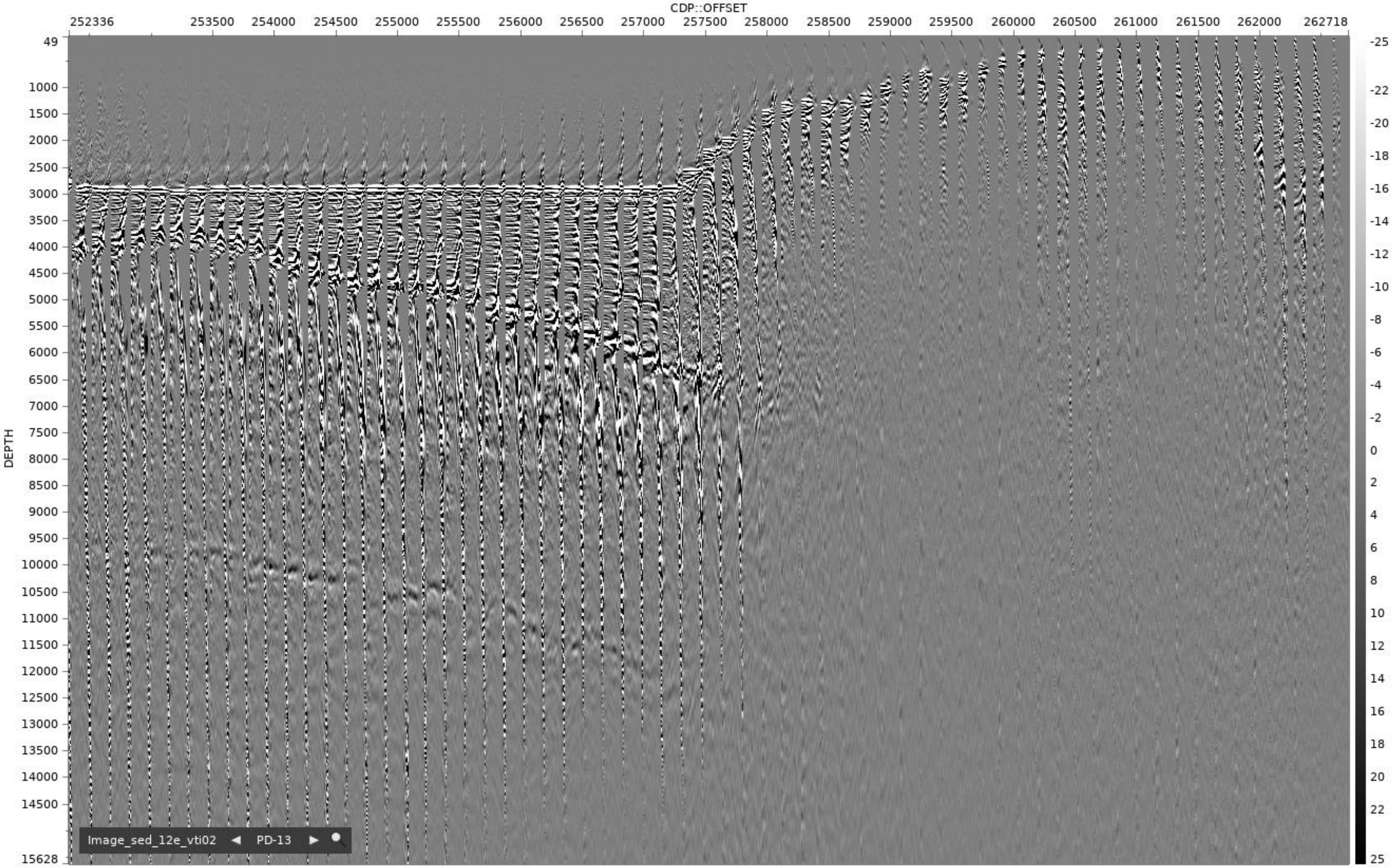
PD-13 Anisotropic PSDM Stack



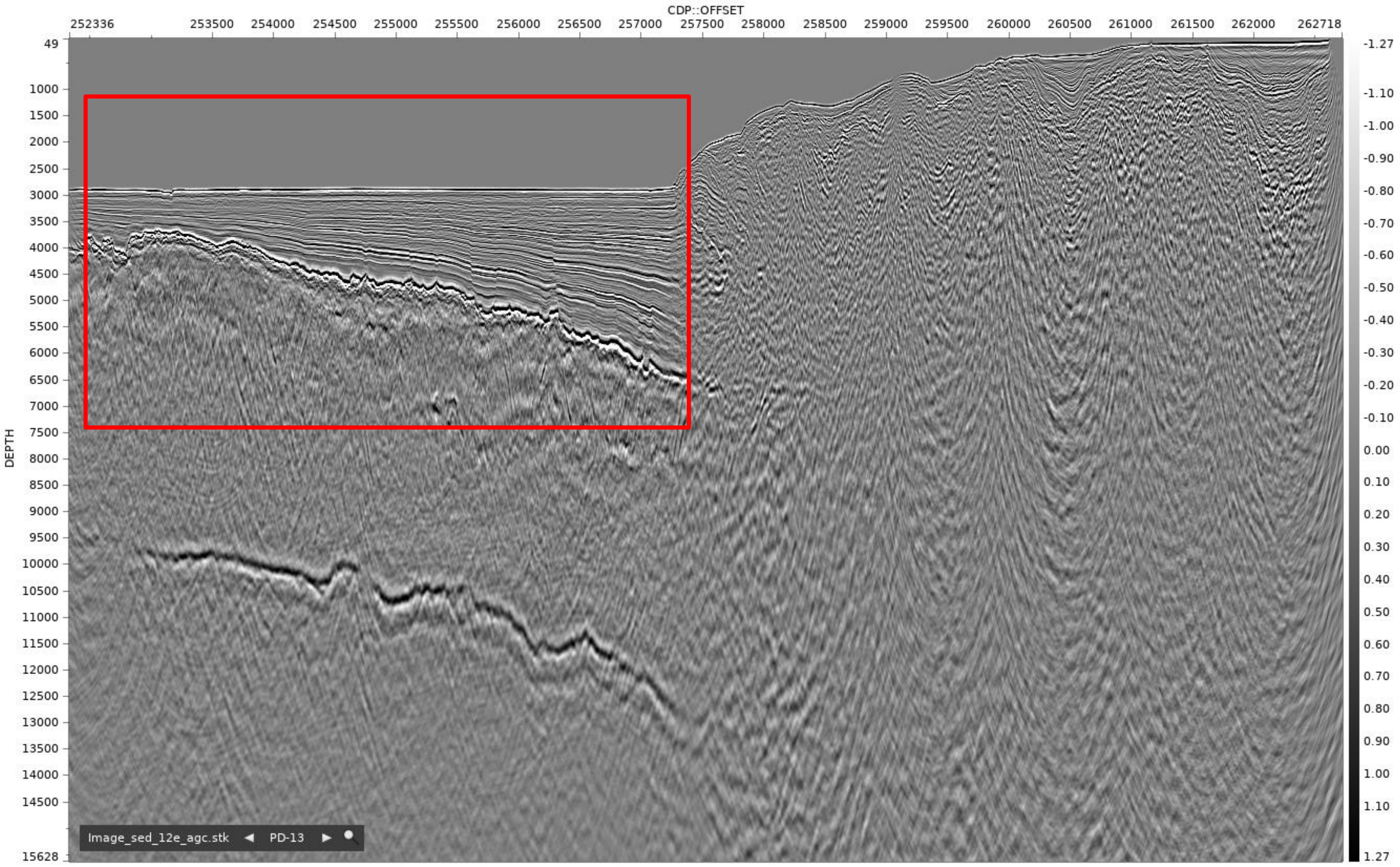
PD-13 Isotropic PSDM Gathers



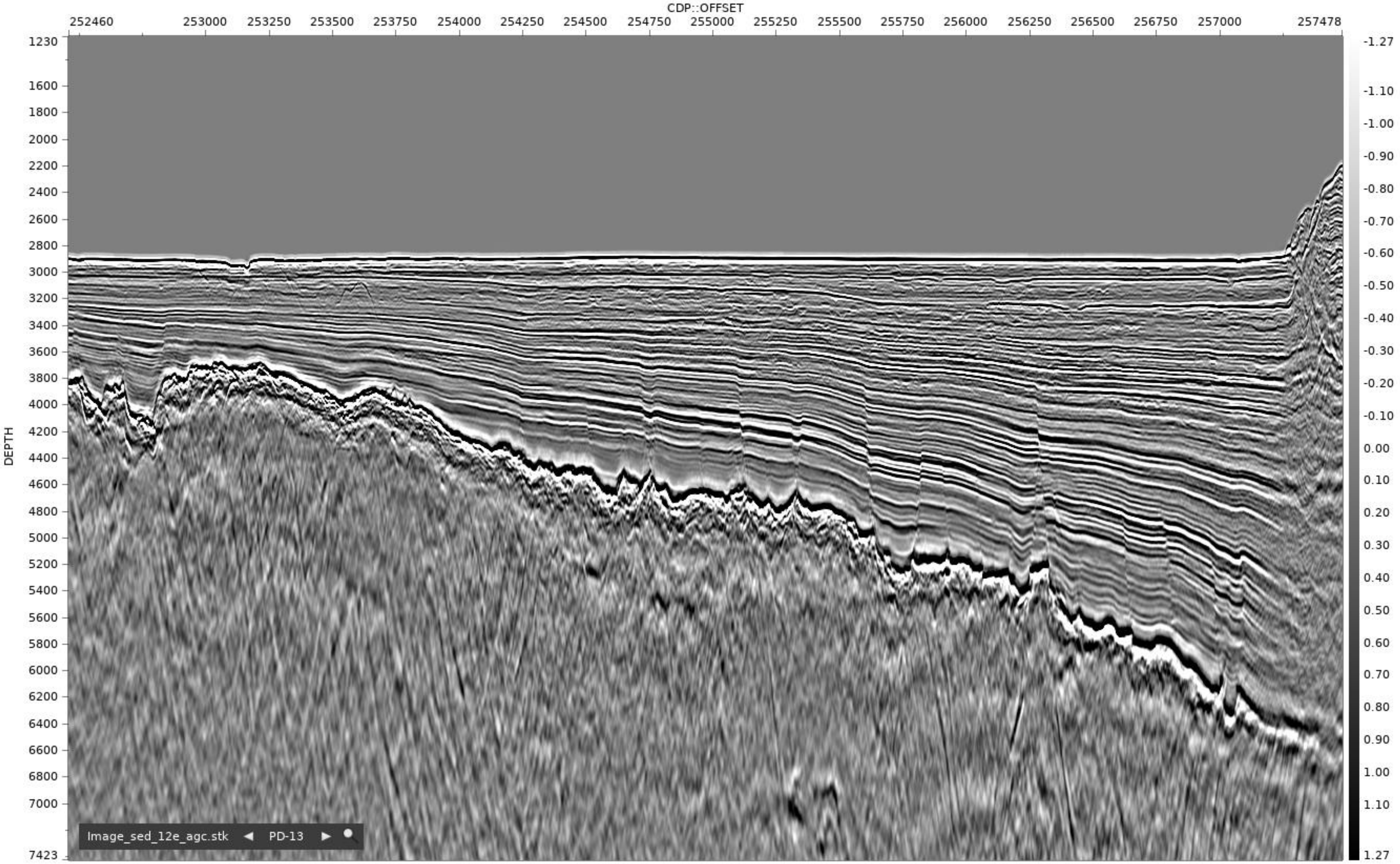
PD-13 Anisotropic PSDM Gathers



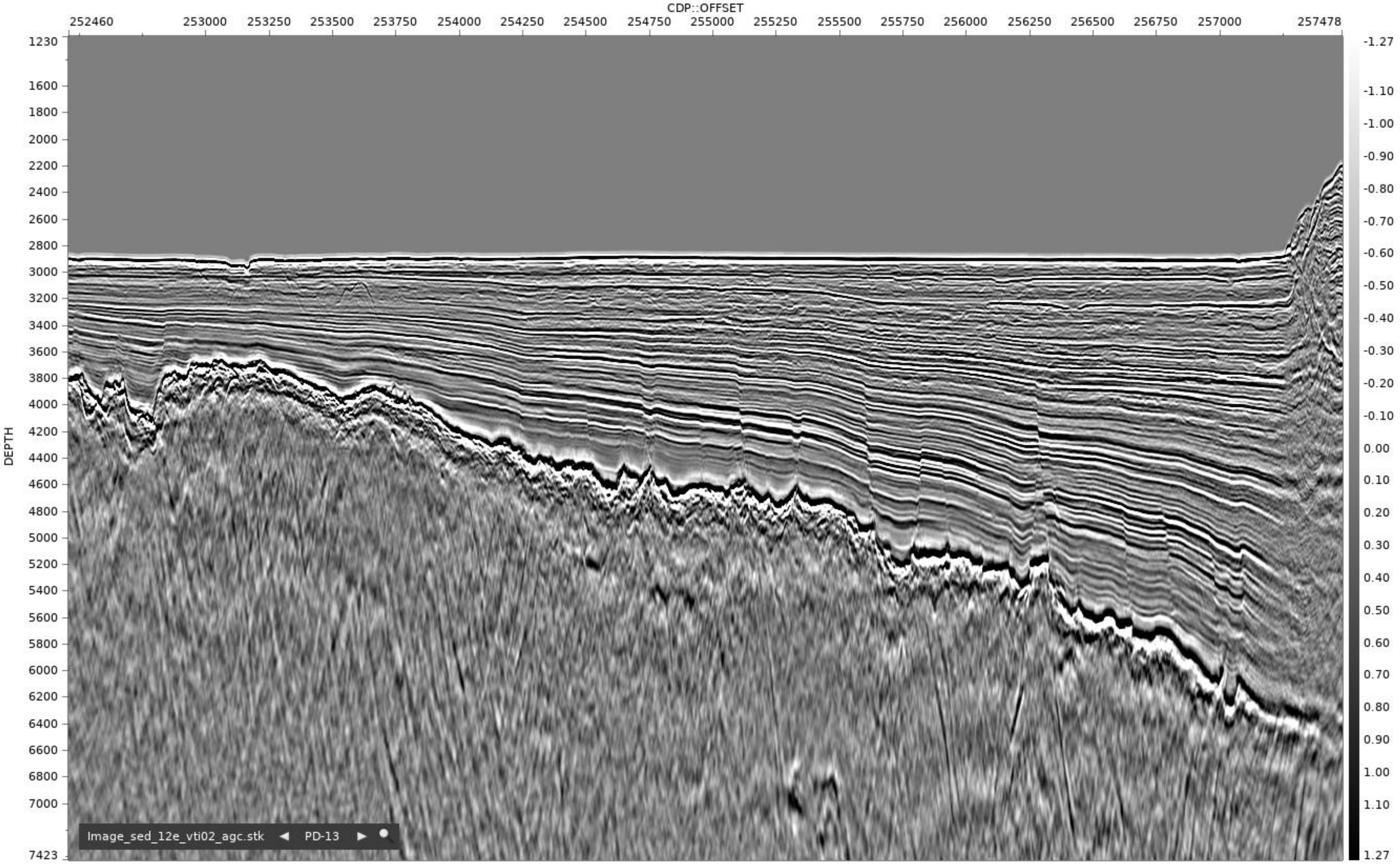
PD-13 Isotropic PSDM Stack – ZOOM SELECTION WINDOW



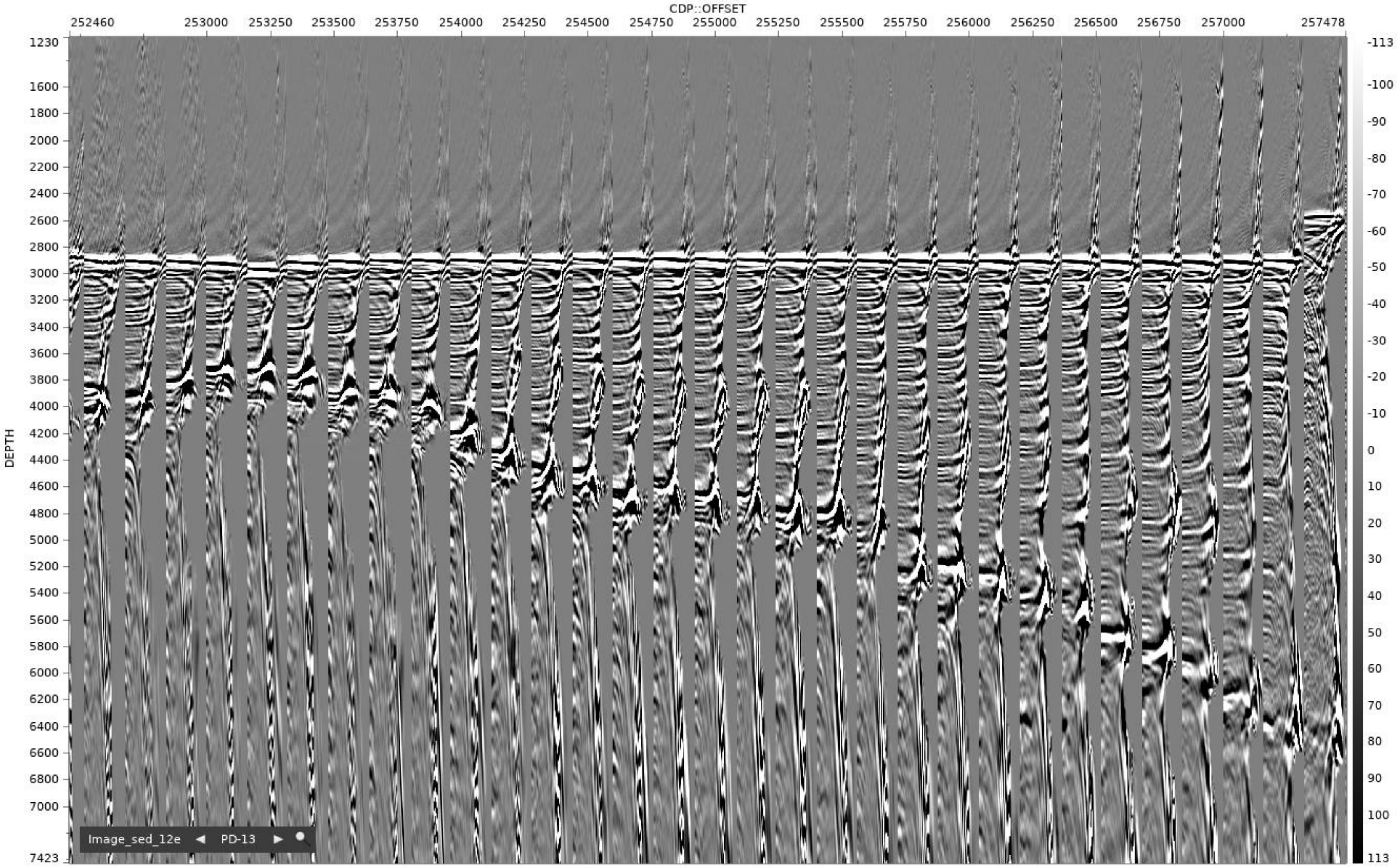
PD-13 Isotropic PSDM Stack - ZOOM



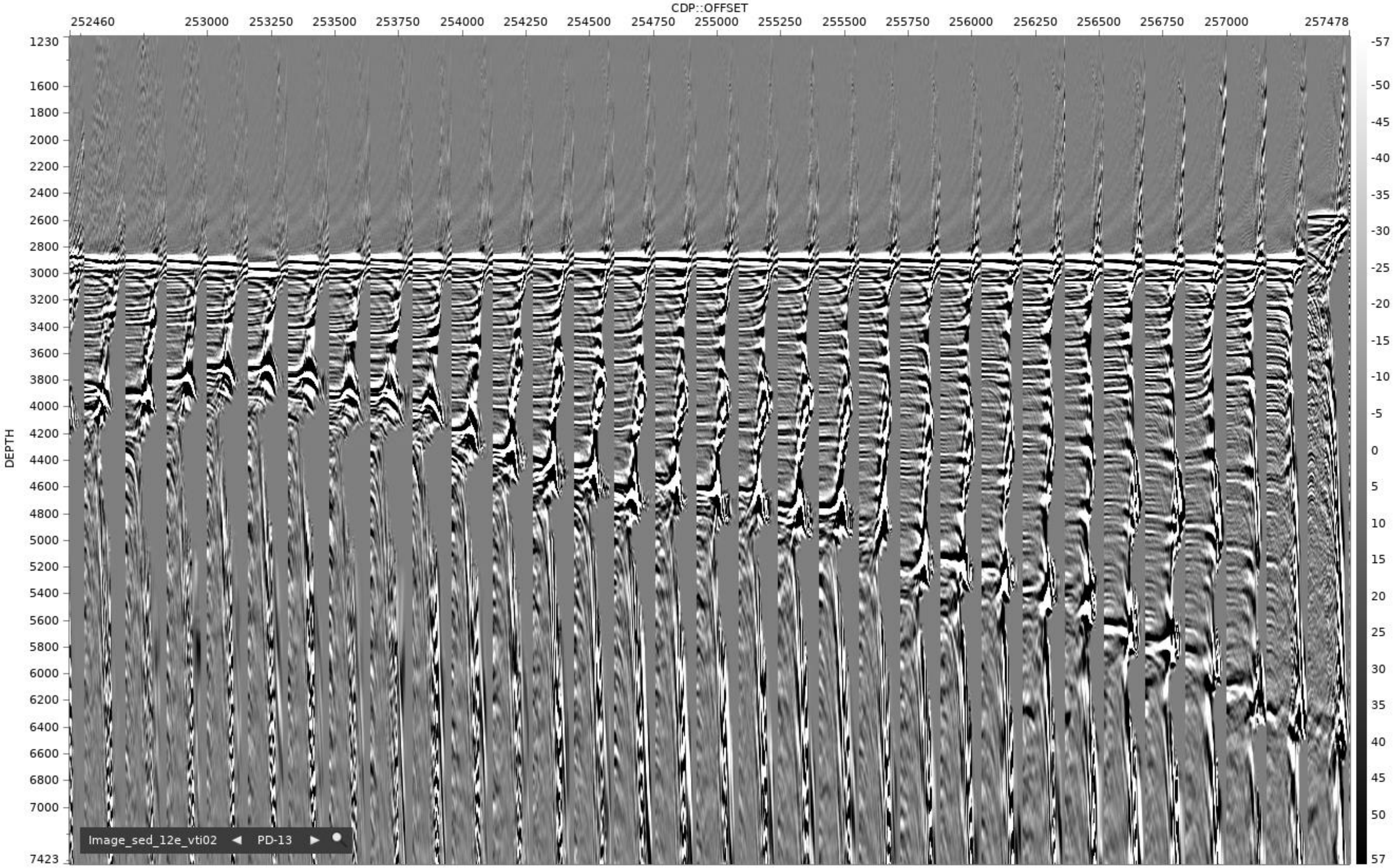
PD-13 Anisotropic PSDM Stack - ZOOM



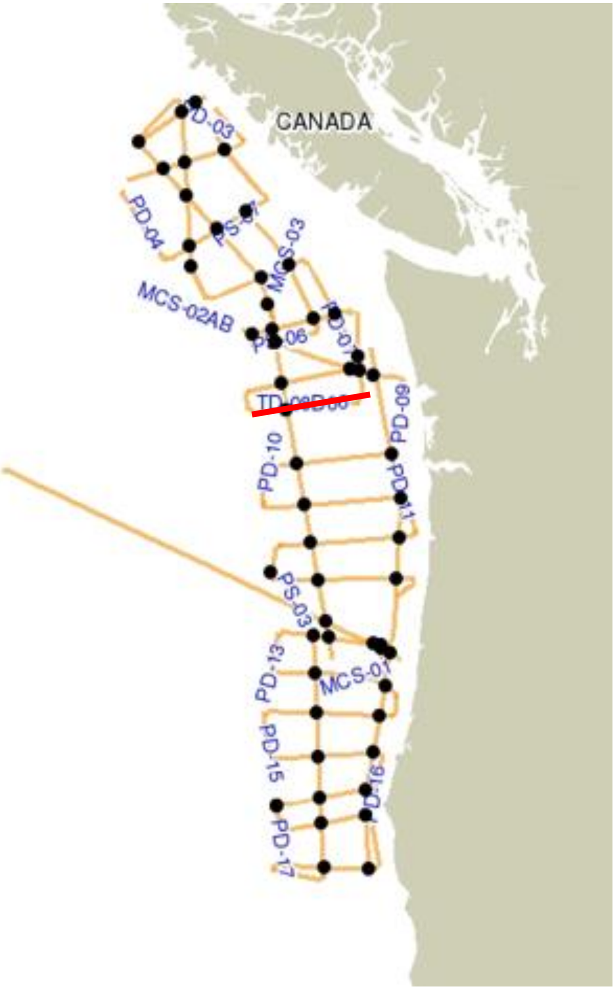
PD-13 Isotropic PSDM Gathers - ZOOM



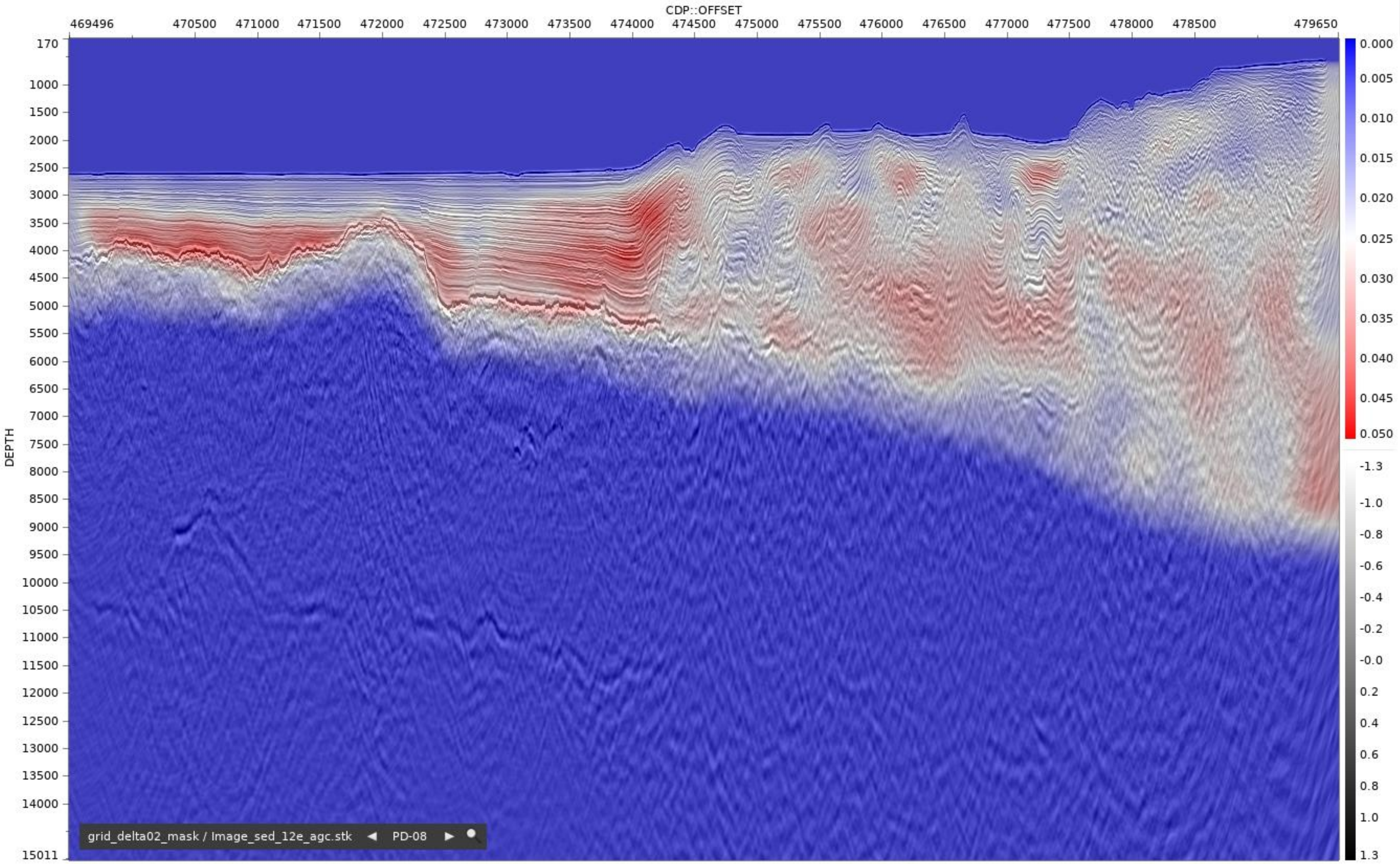
PD-13 Anisotropic PSDM Gathers - ZOOM



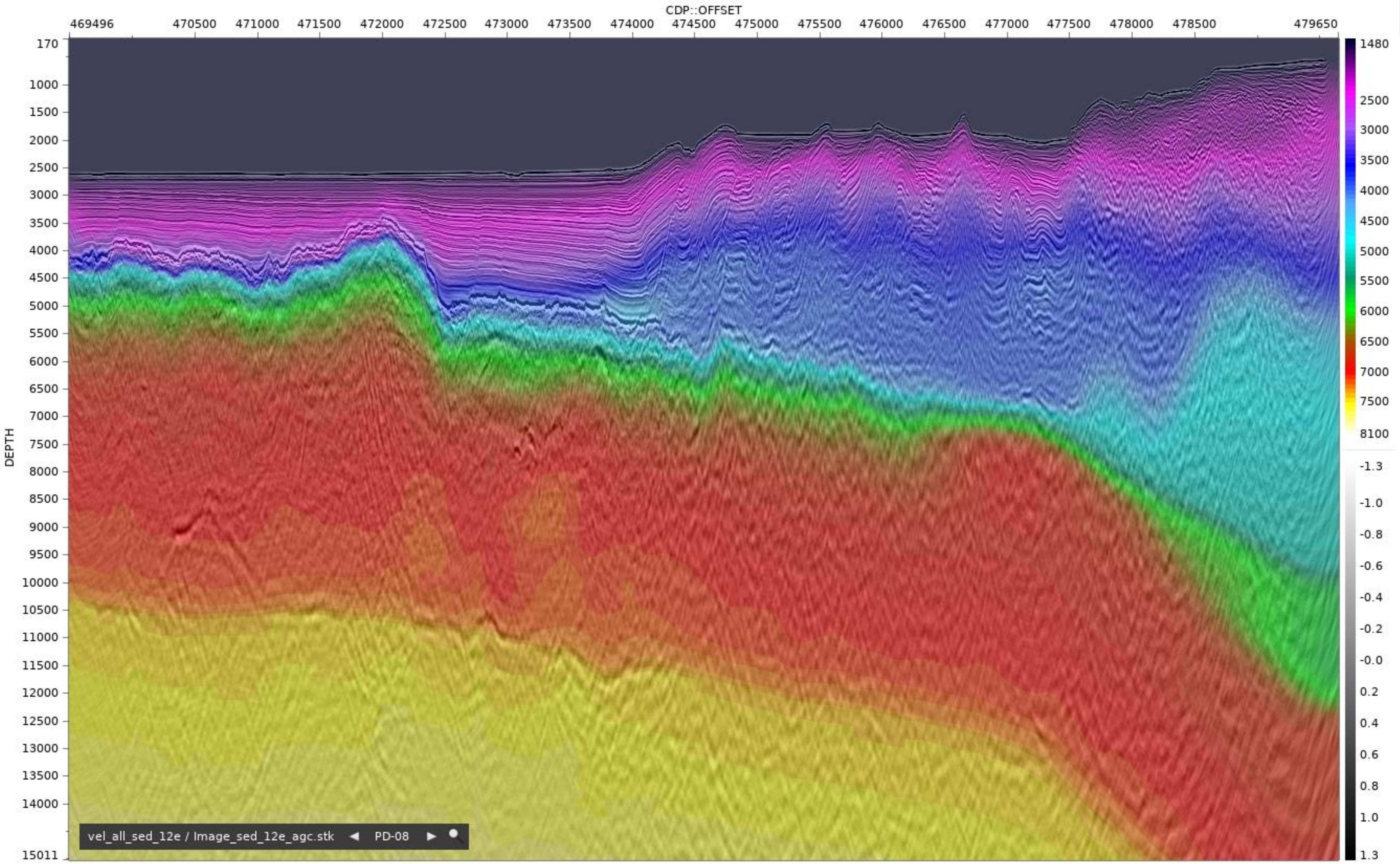
Line PD-08


CANADA
PD-04
MCS-03
MCS-02AB
PD-09
PD-10
PS-03
PD-13
MCS-01
PD-15
PD-17

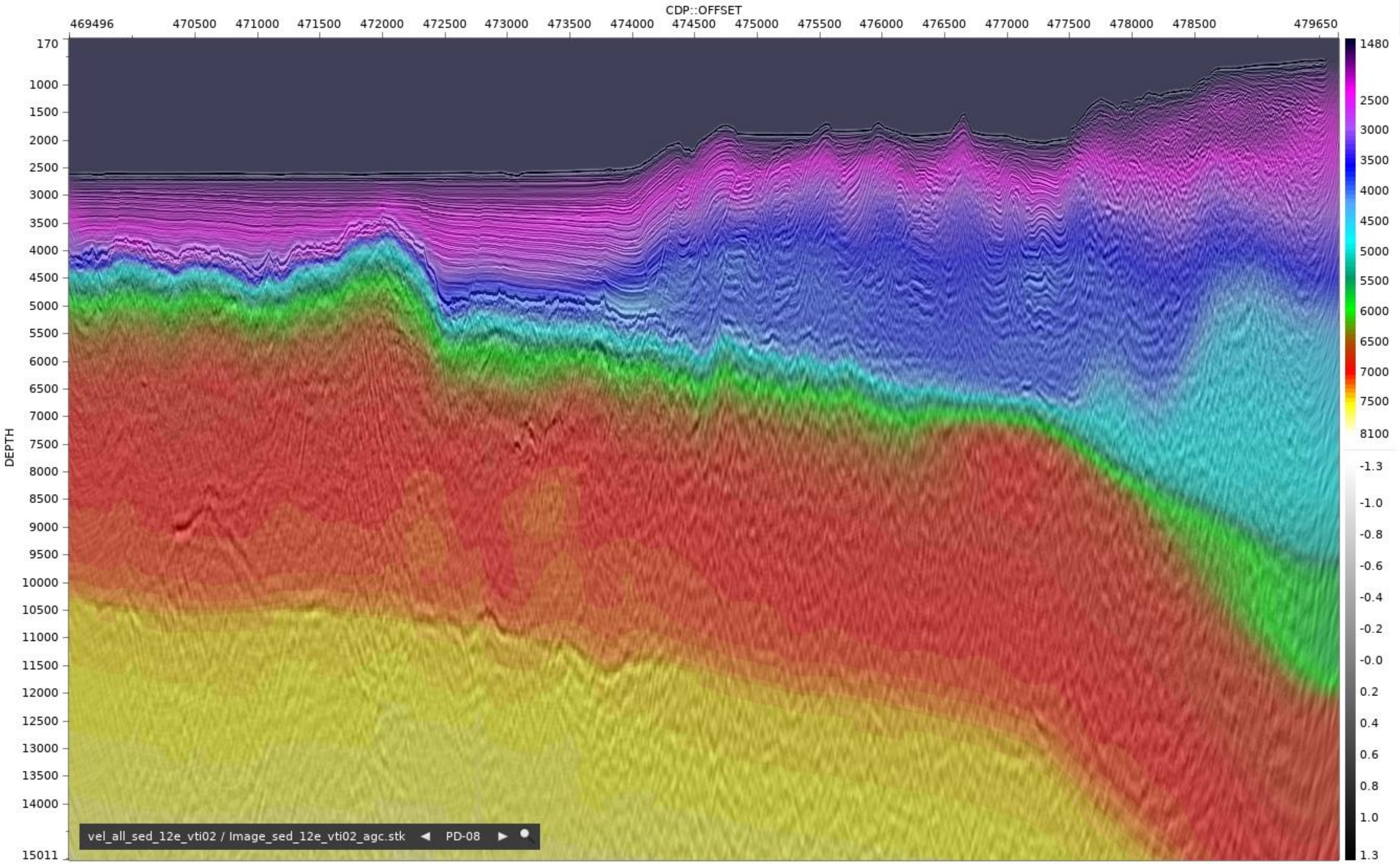
PD-08 Delta/PSDM Stack Overlay



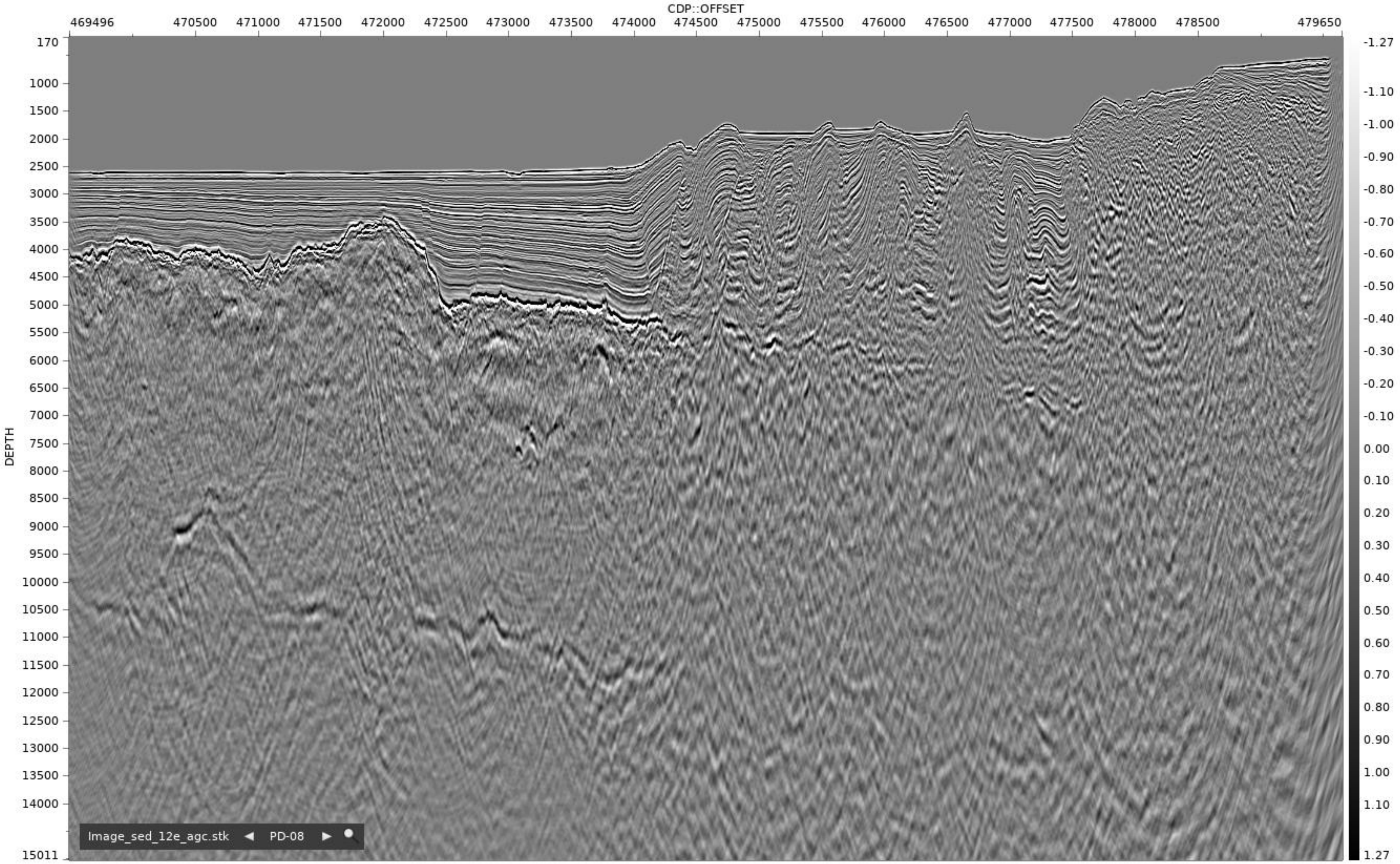
PD-08 Isotropic PSDM Stack overlay



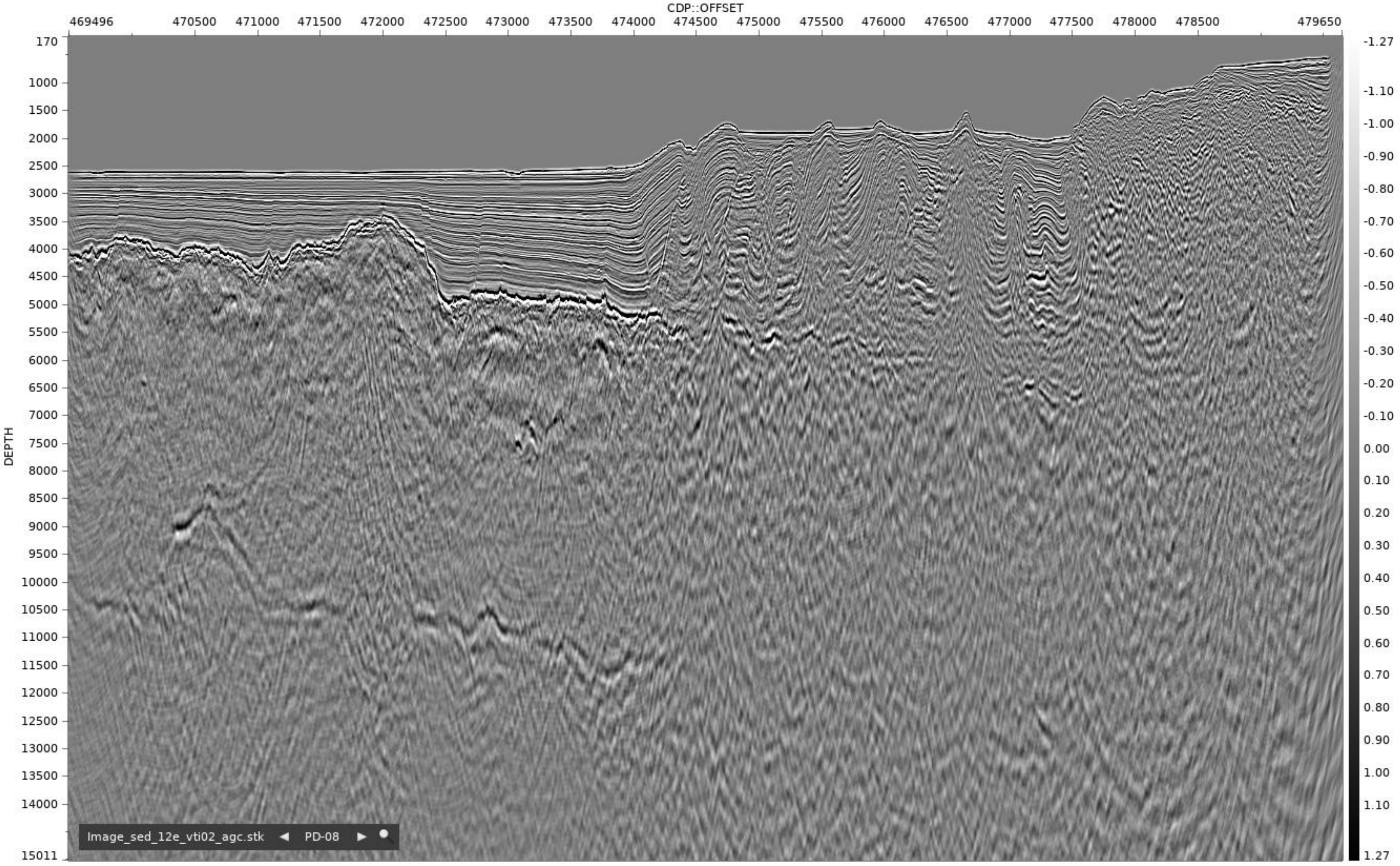
PD-08 Anisotropic PSDM Stack overlay



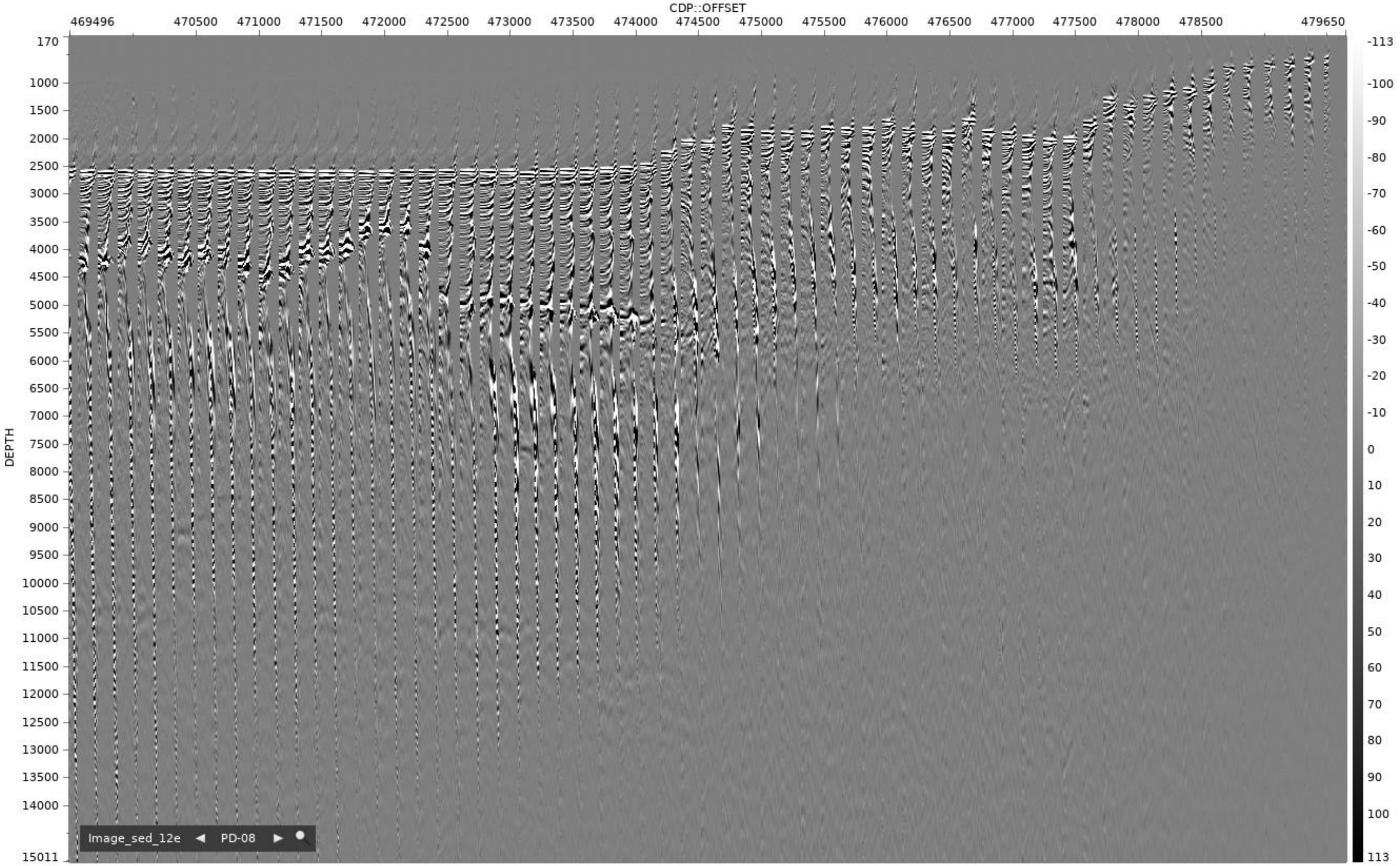
PD-08 Isotropic PSDM Stack



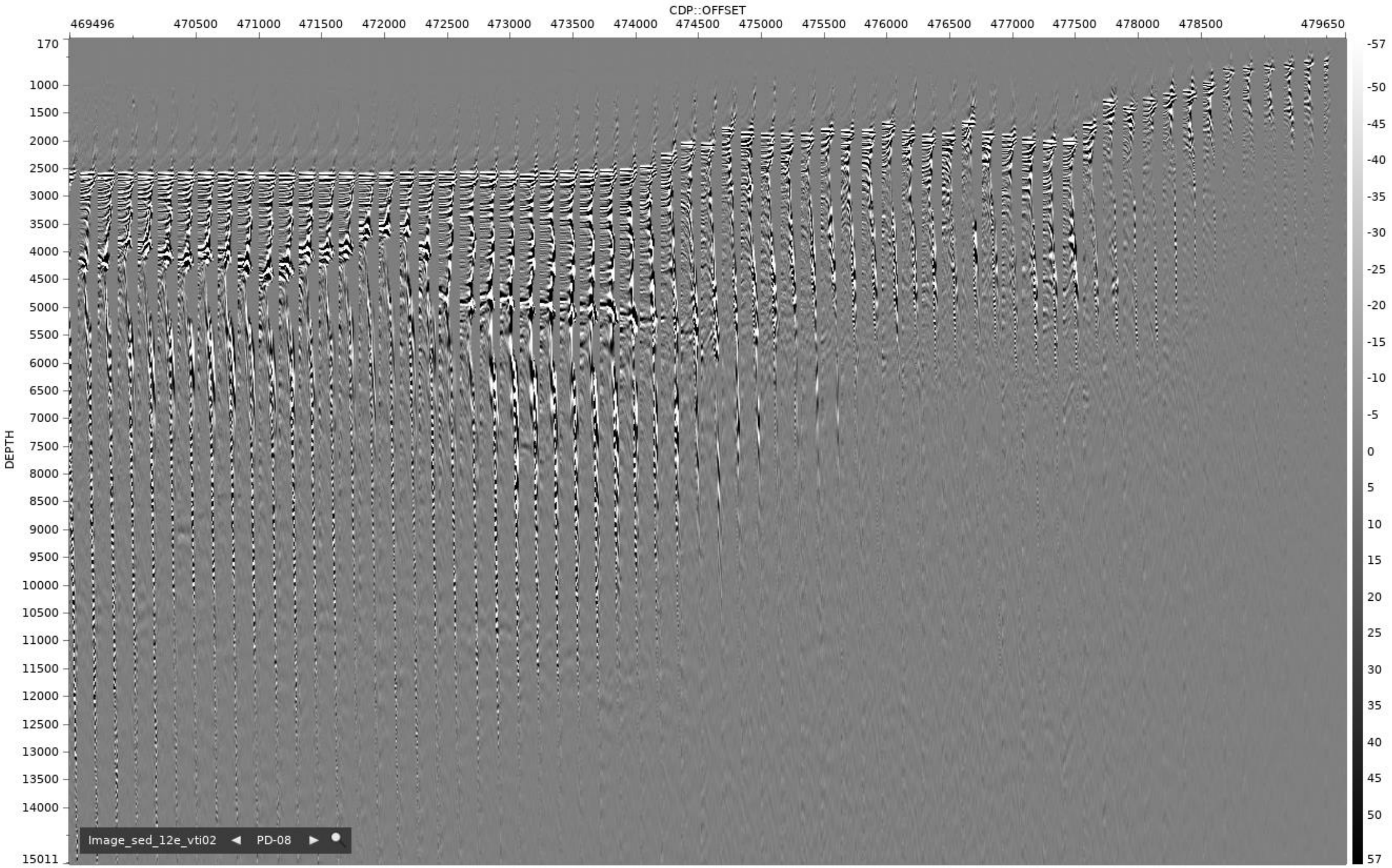
PD-08 Anisotropic PSDM Stack



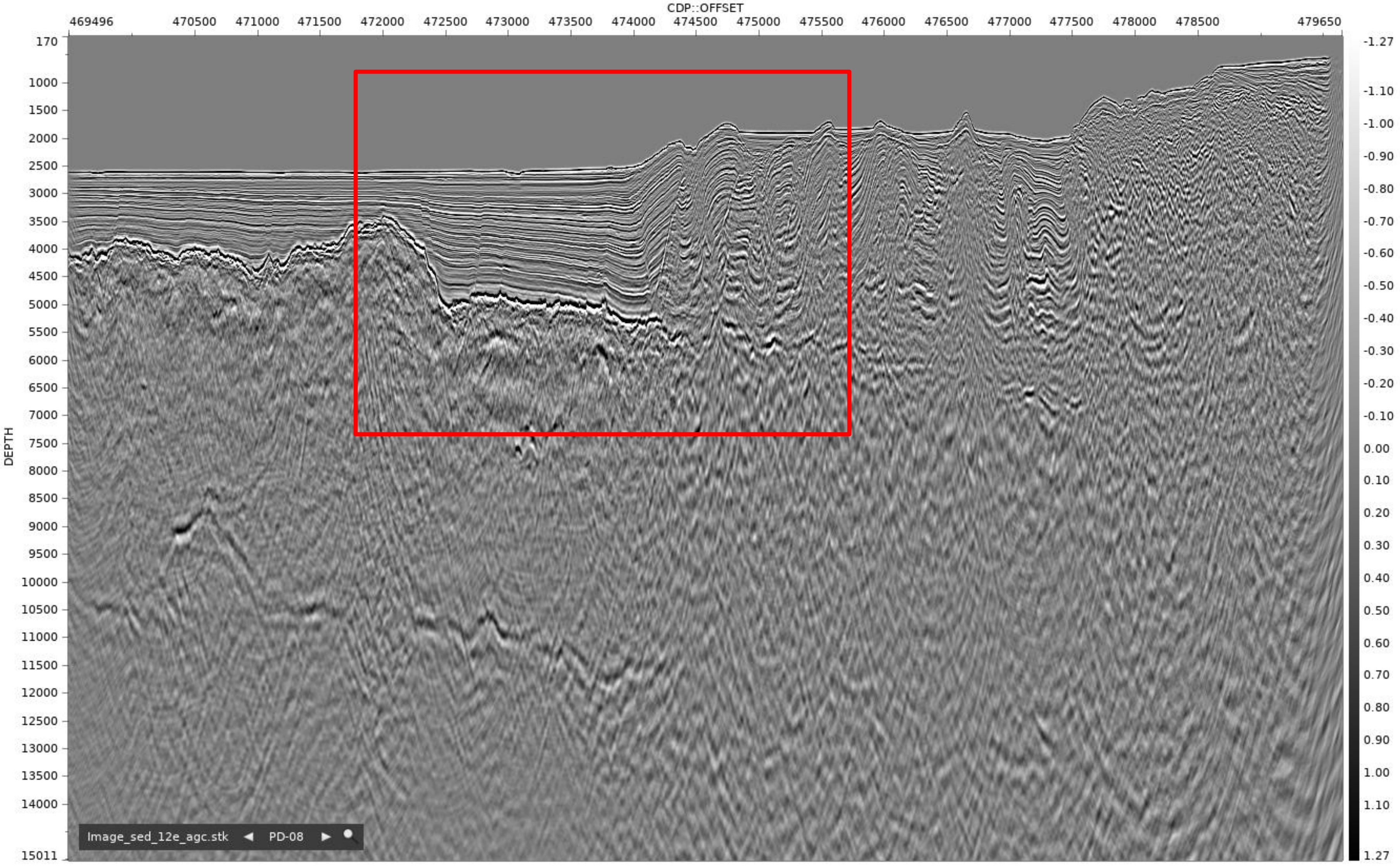
PD-08 Isotropic PSDM Gathers



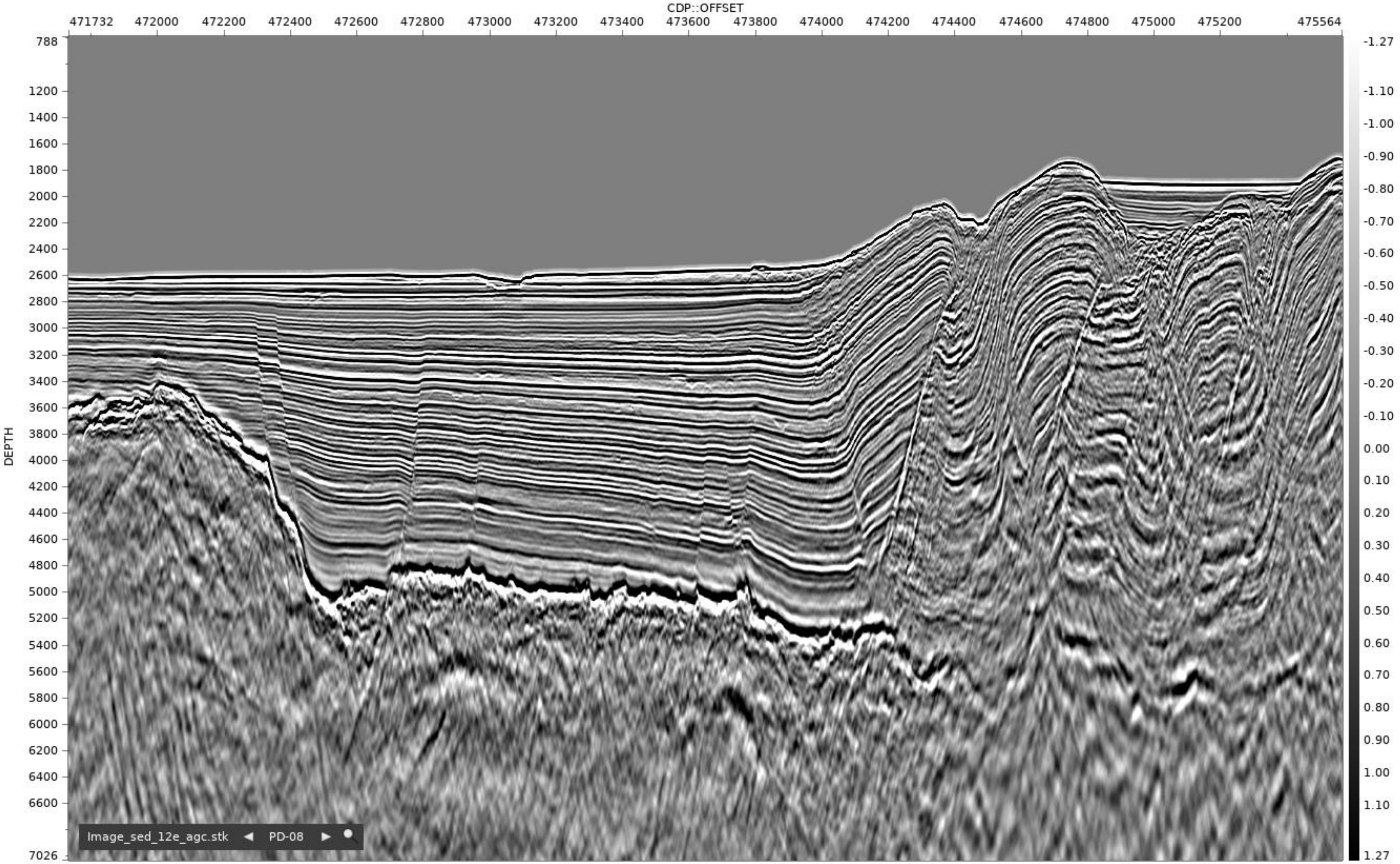
PD-08 Anisotropic PSDM Gathers



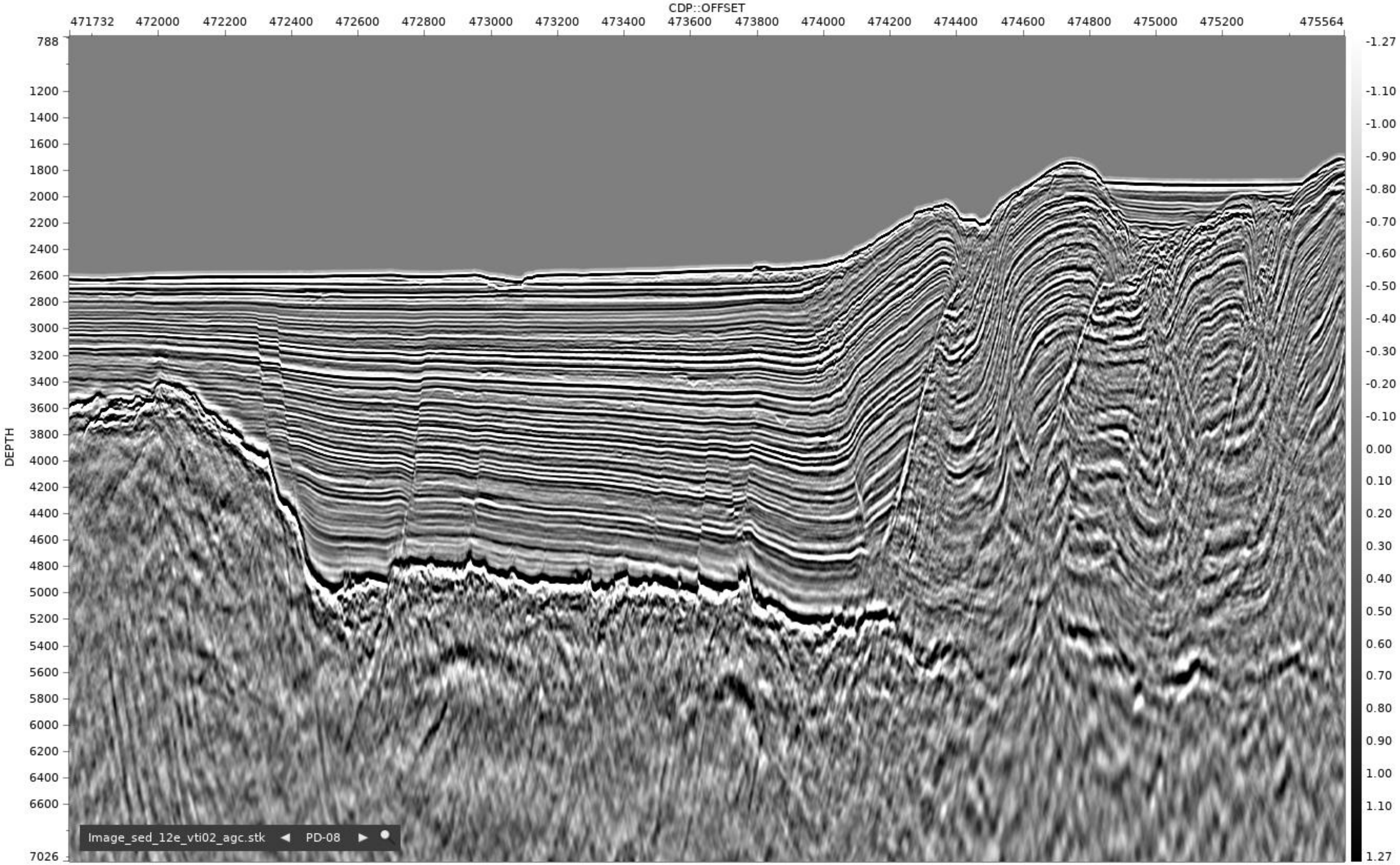
PD-08 Isotropic PSDM Stack – ZOOM SELECTION WINDOW



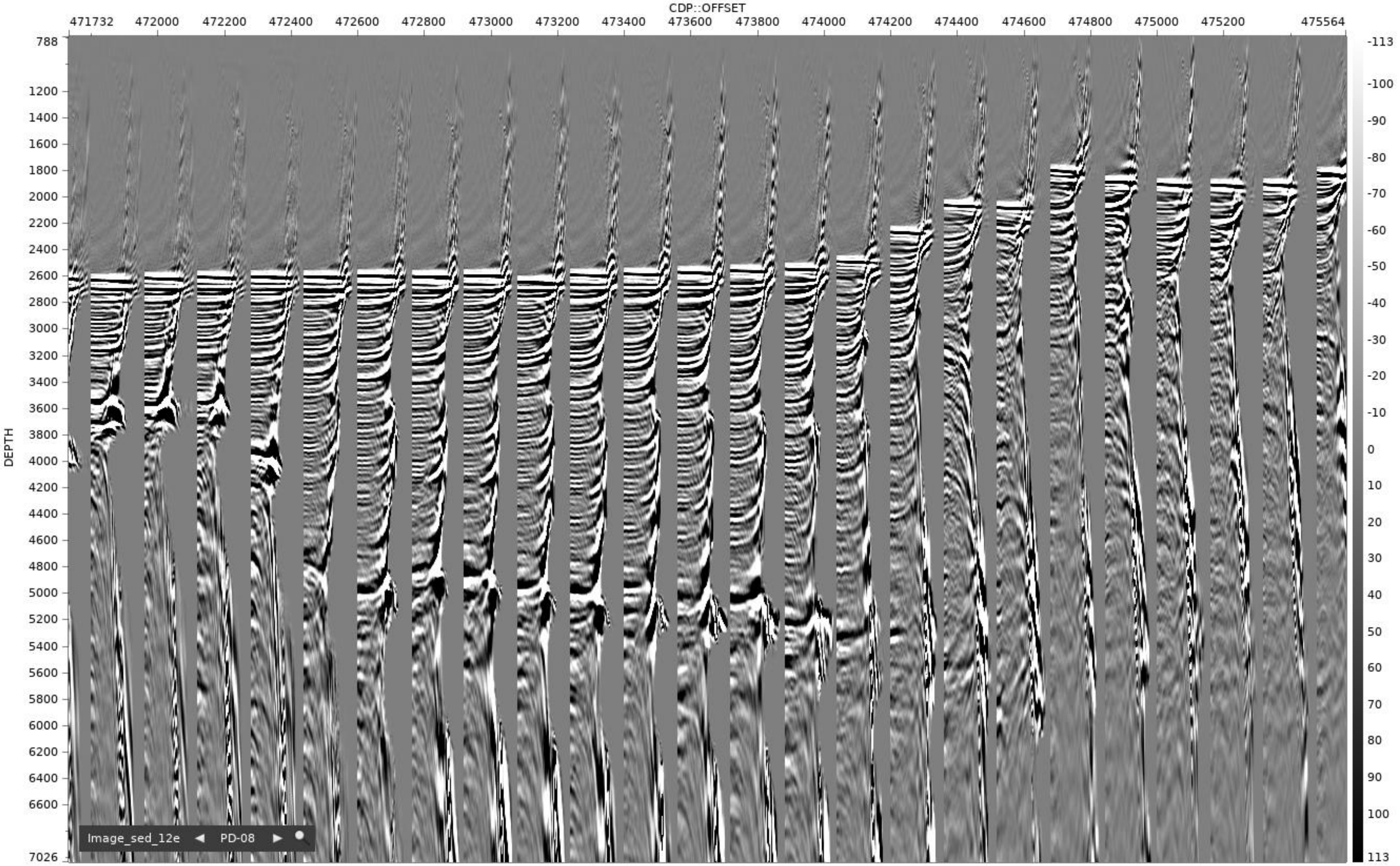
PD-08 Isotropic PSDM Stack - ZOOM



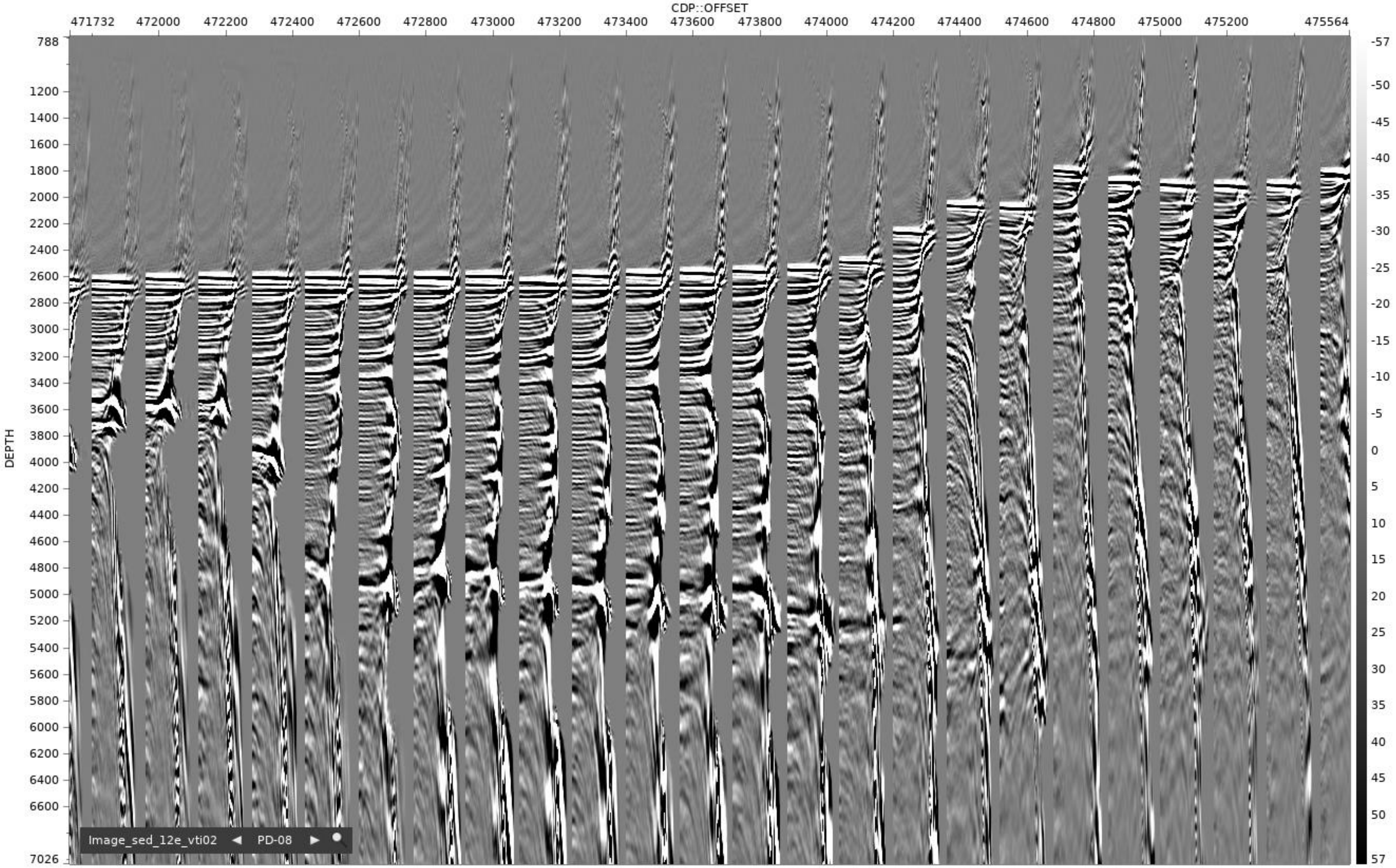
PD-08 Anisotropic PSDM Stack - ZOOM



PD-08 Isotropic PSDM Gathers - ZOOM



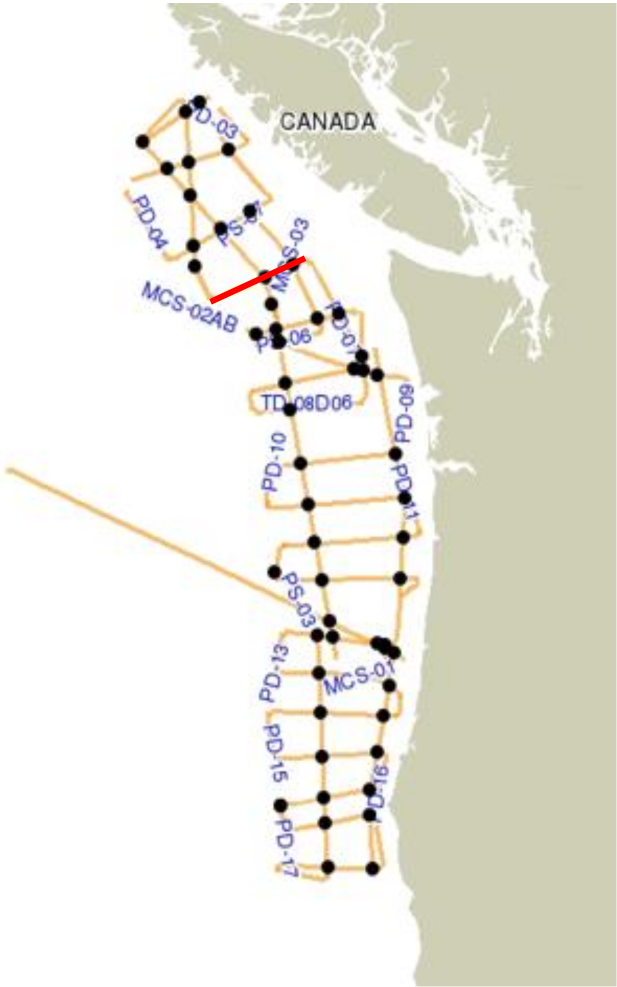
PD-08 Anisotropic PSDM Gathers - ZOOM



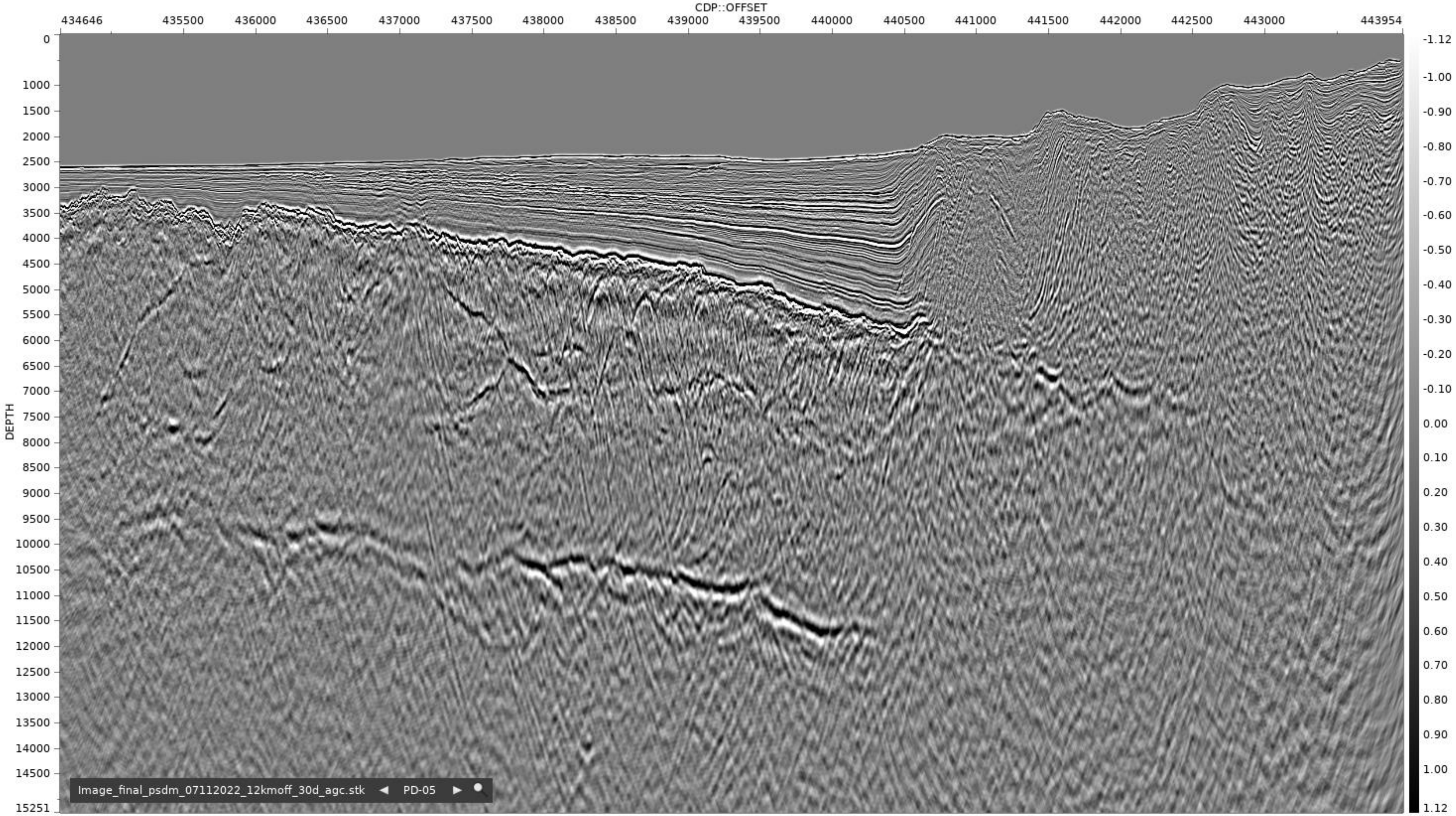
Residual Move-out Correction

- Final PSDM gathers are scanned and have RMOC applied
- Comparison of before and after applying RMOC

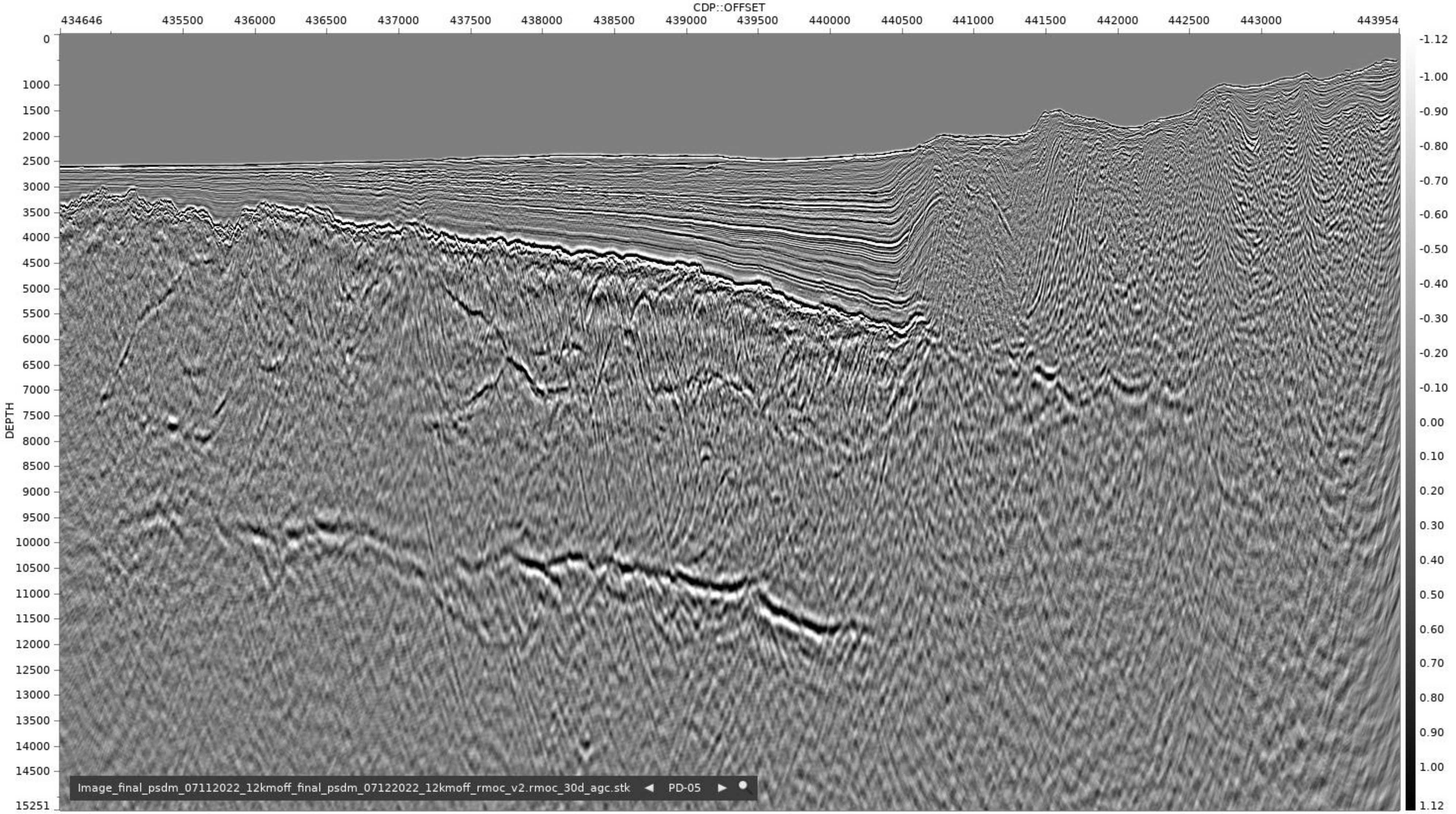
Line PD-05



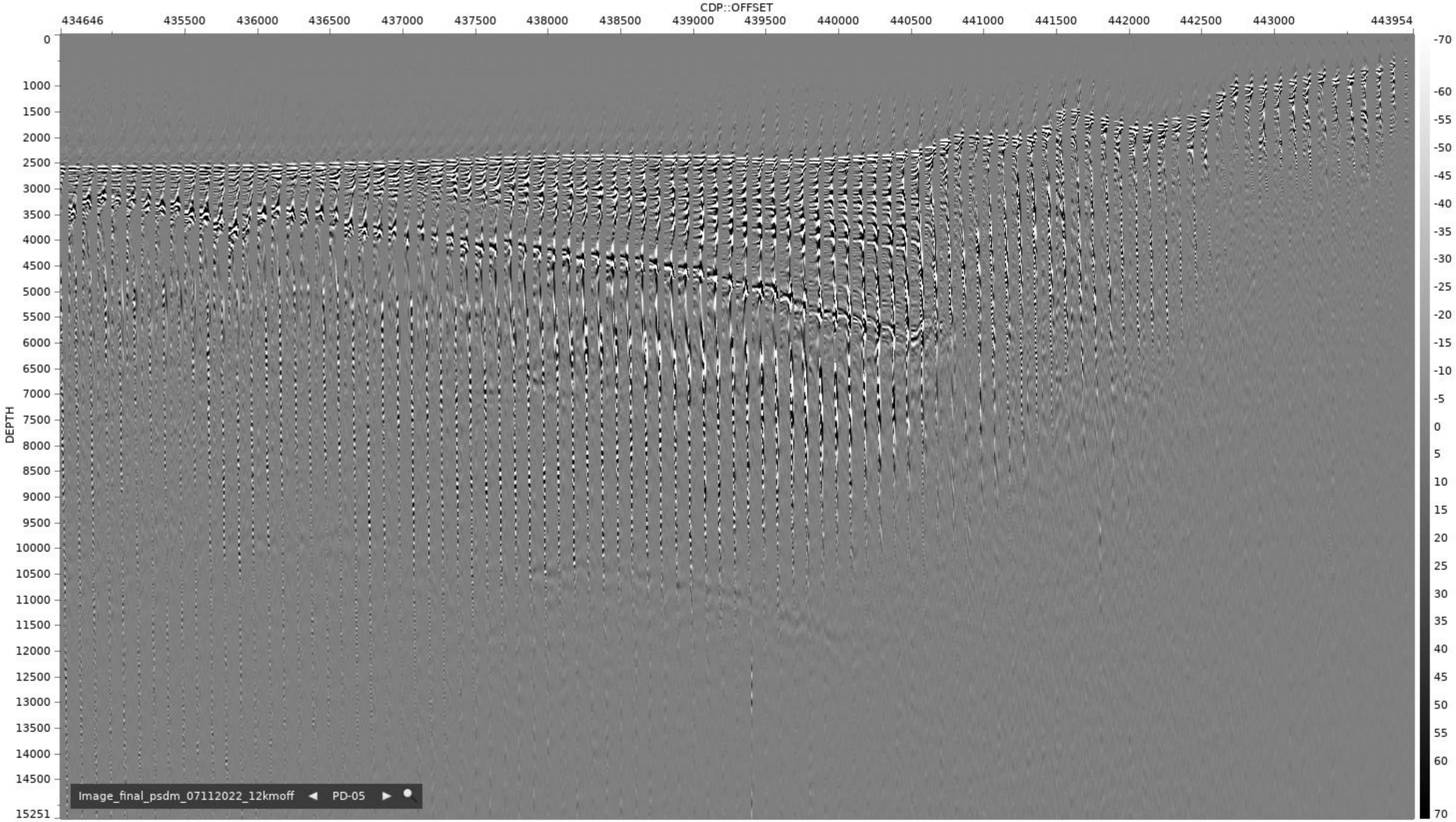
PD-05 Final PSDM Stack



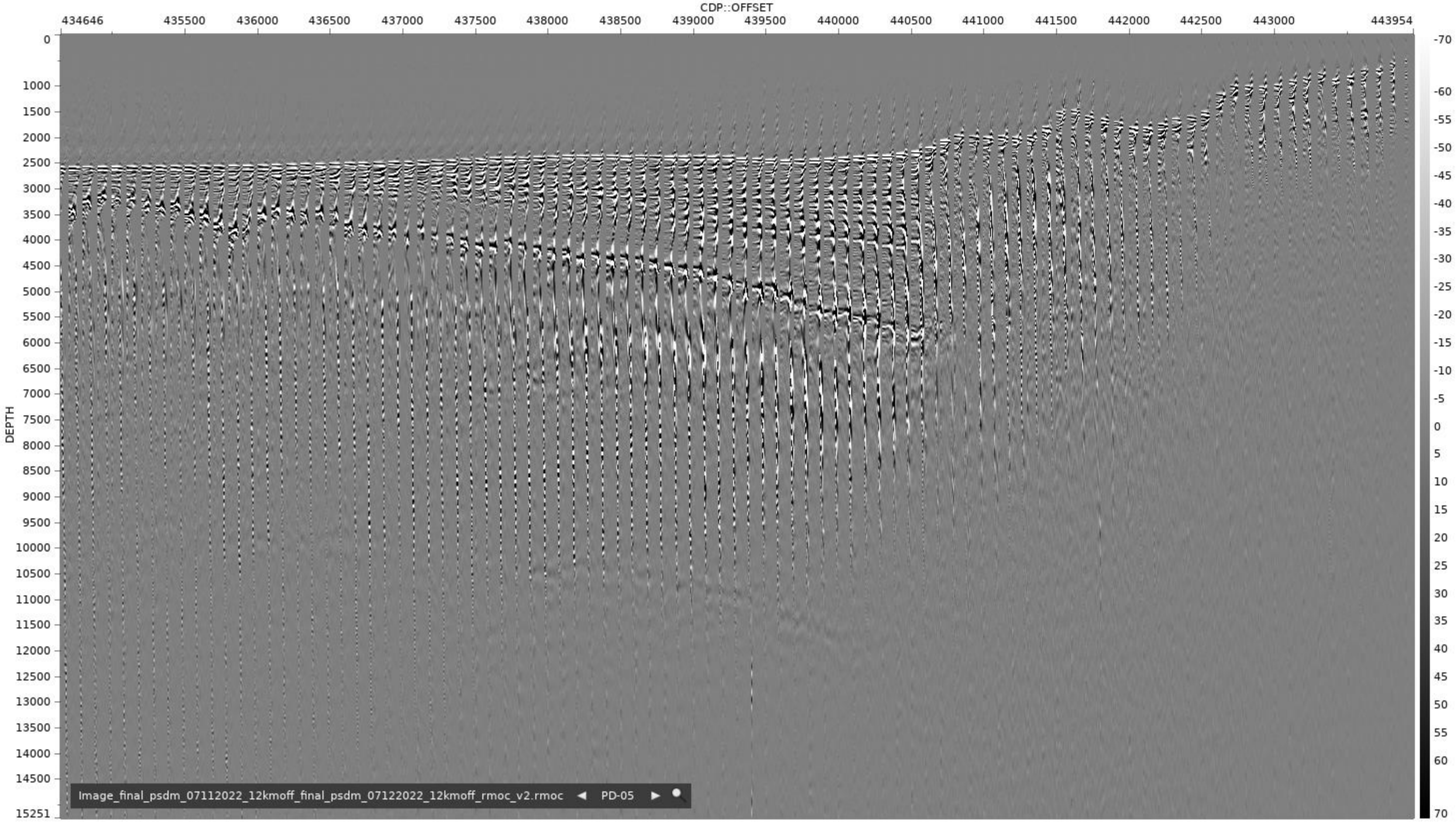
PD-05 Final PSDM Stack with RMOC



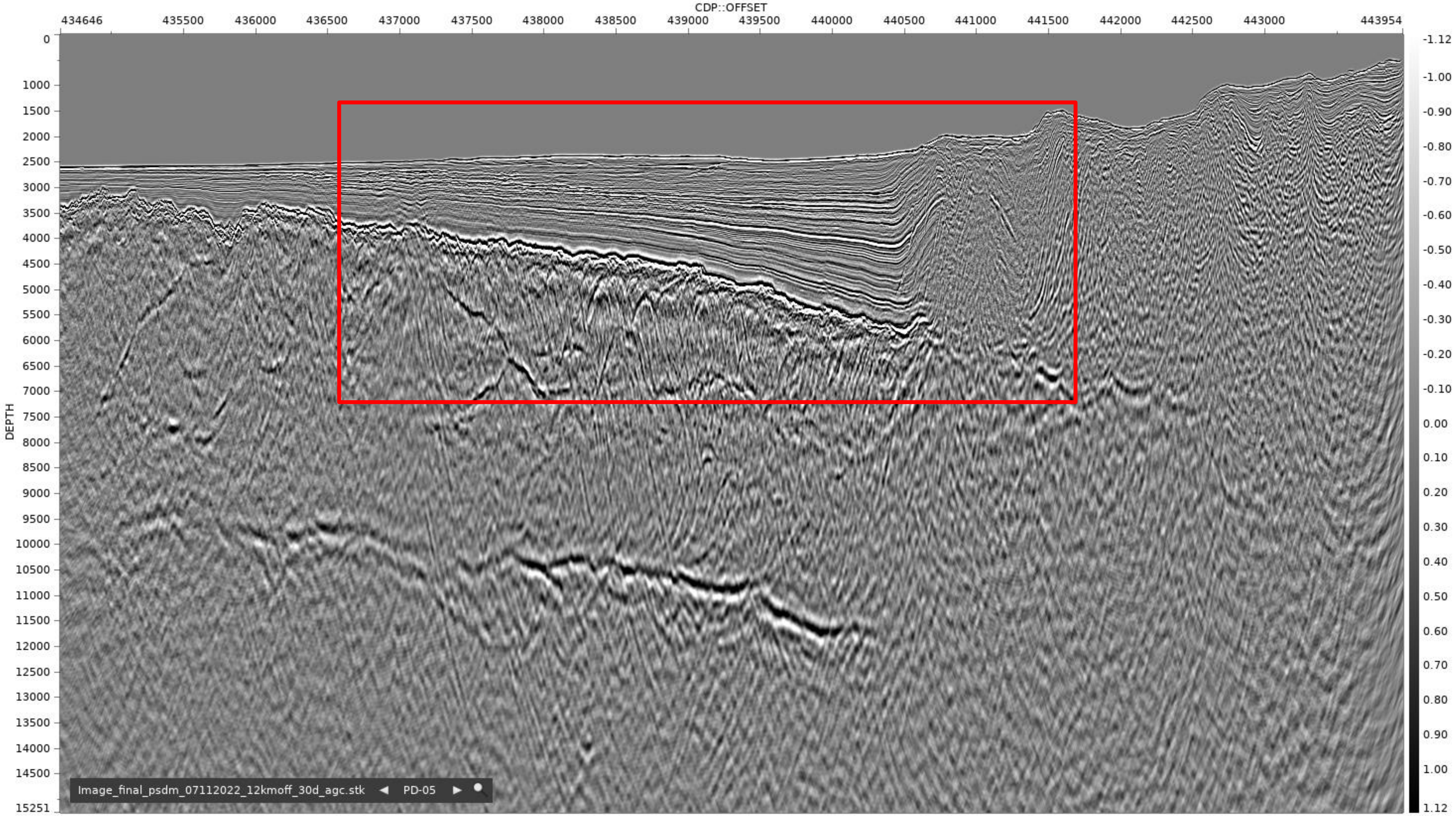
PD-05 Final PSDM Gathers



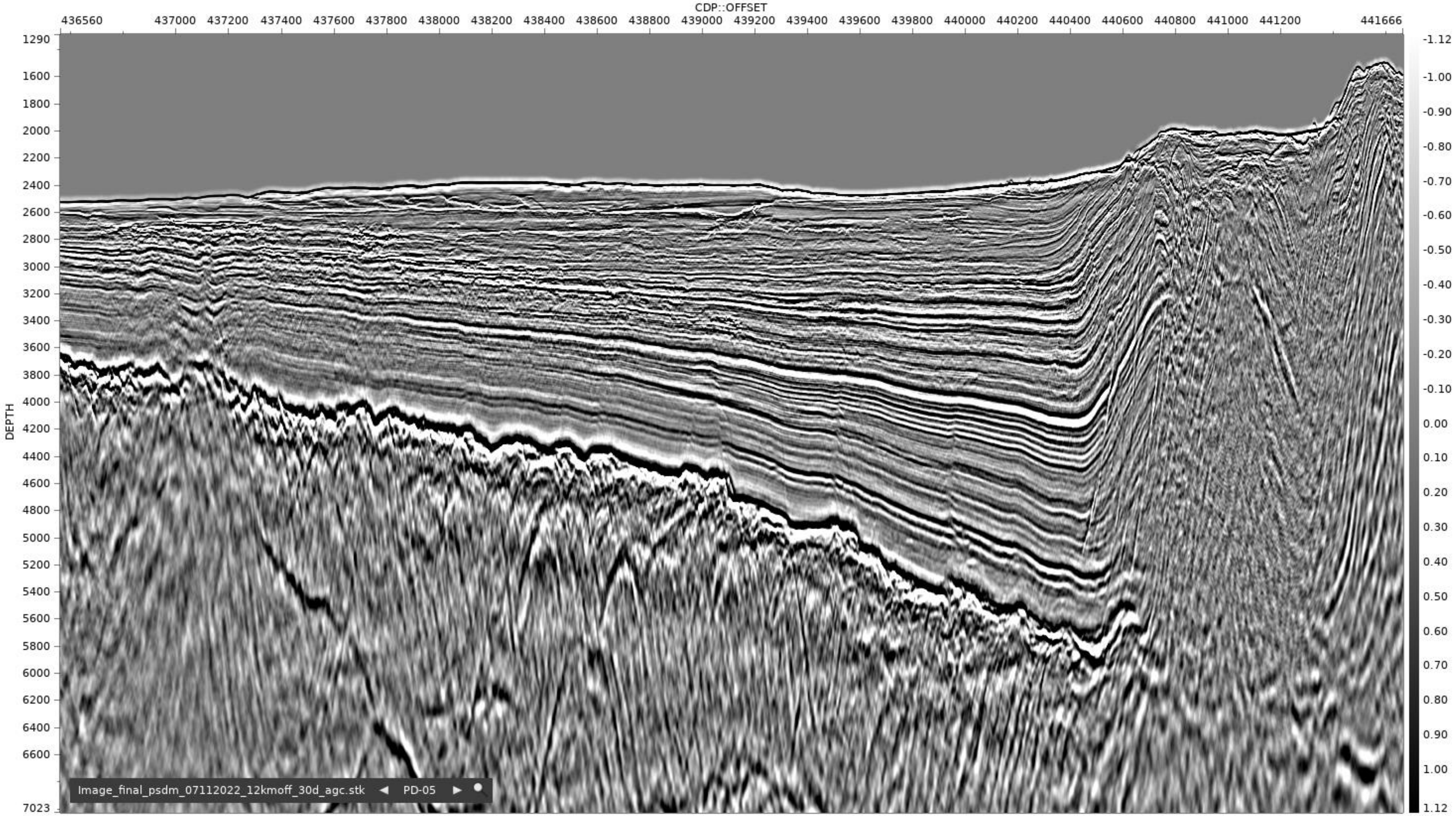
PD-05 Final PSDM Gathers with RMOC



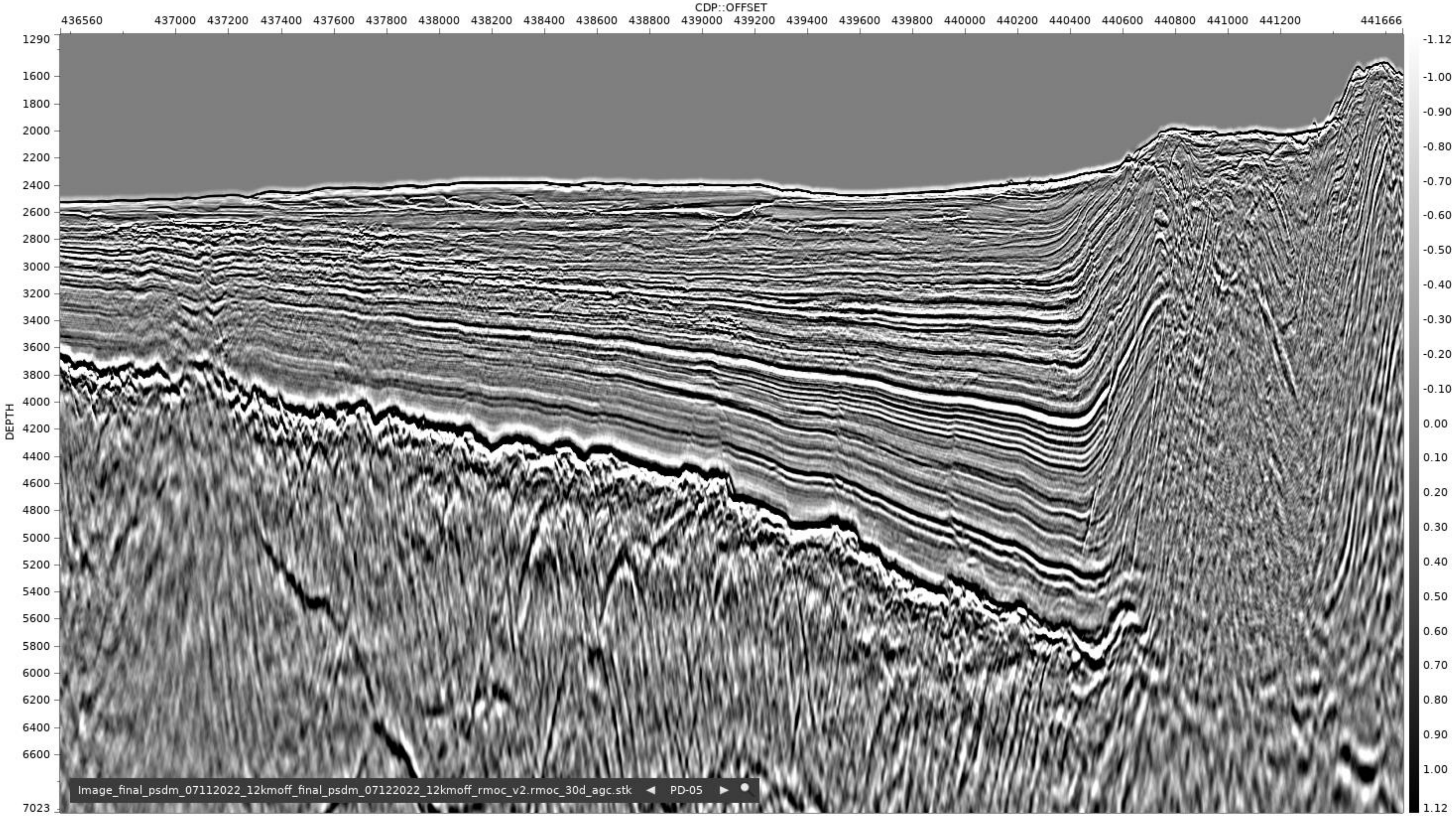
PD-05 Final PSDM Stack – ZOOM SELECTION WINDOW



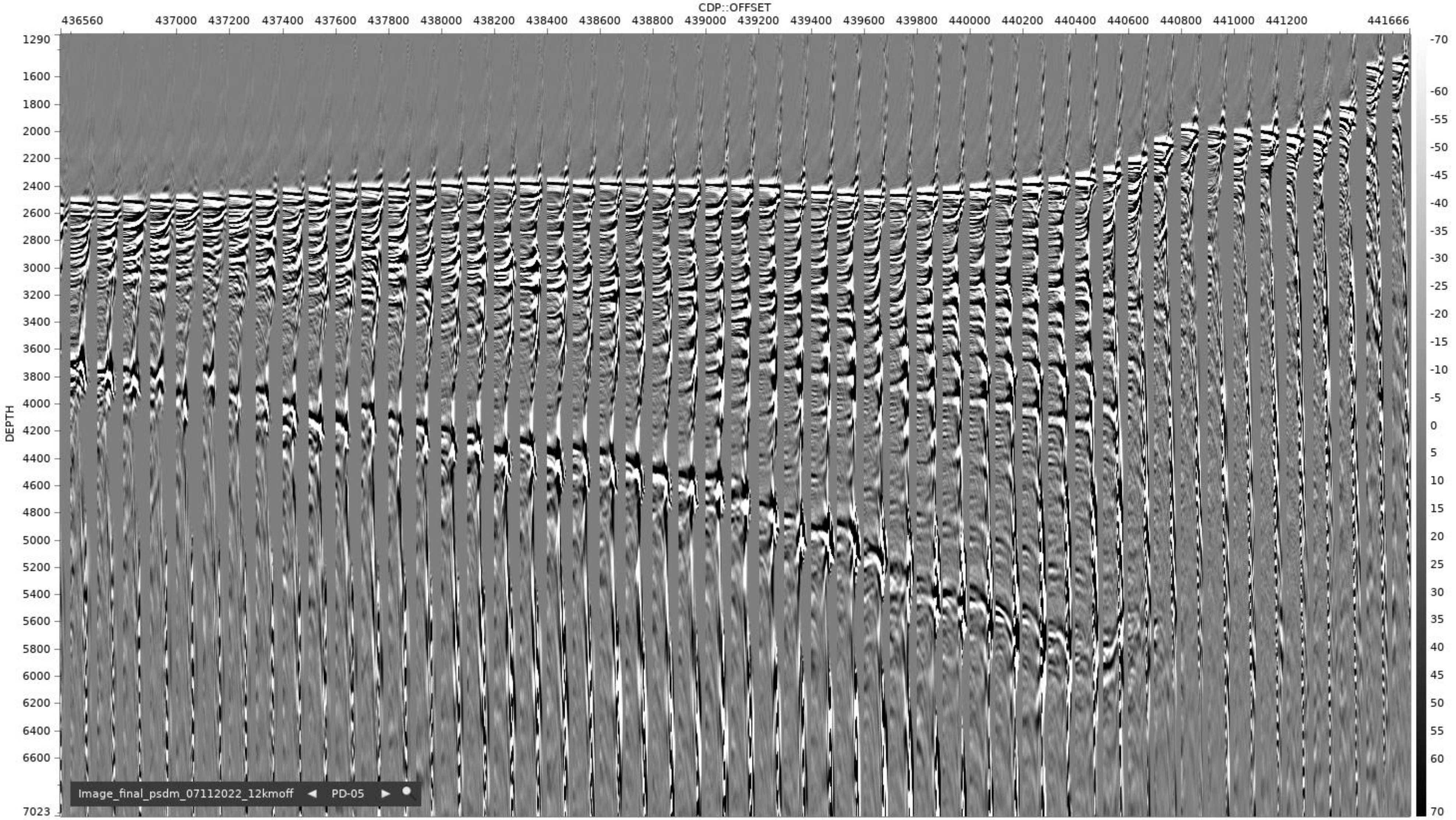
PD-05 Final PSDM Stack - ZOOM



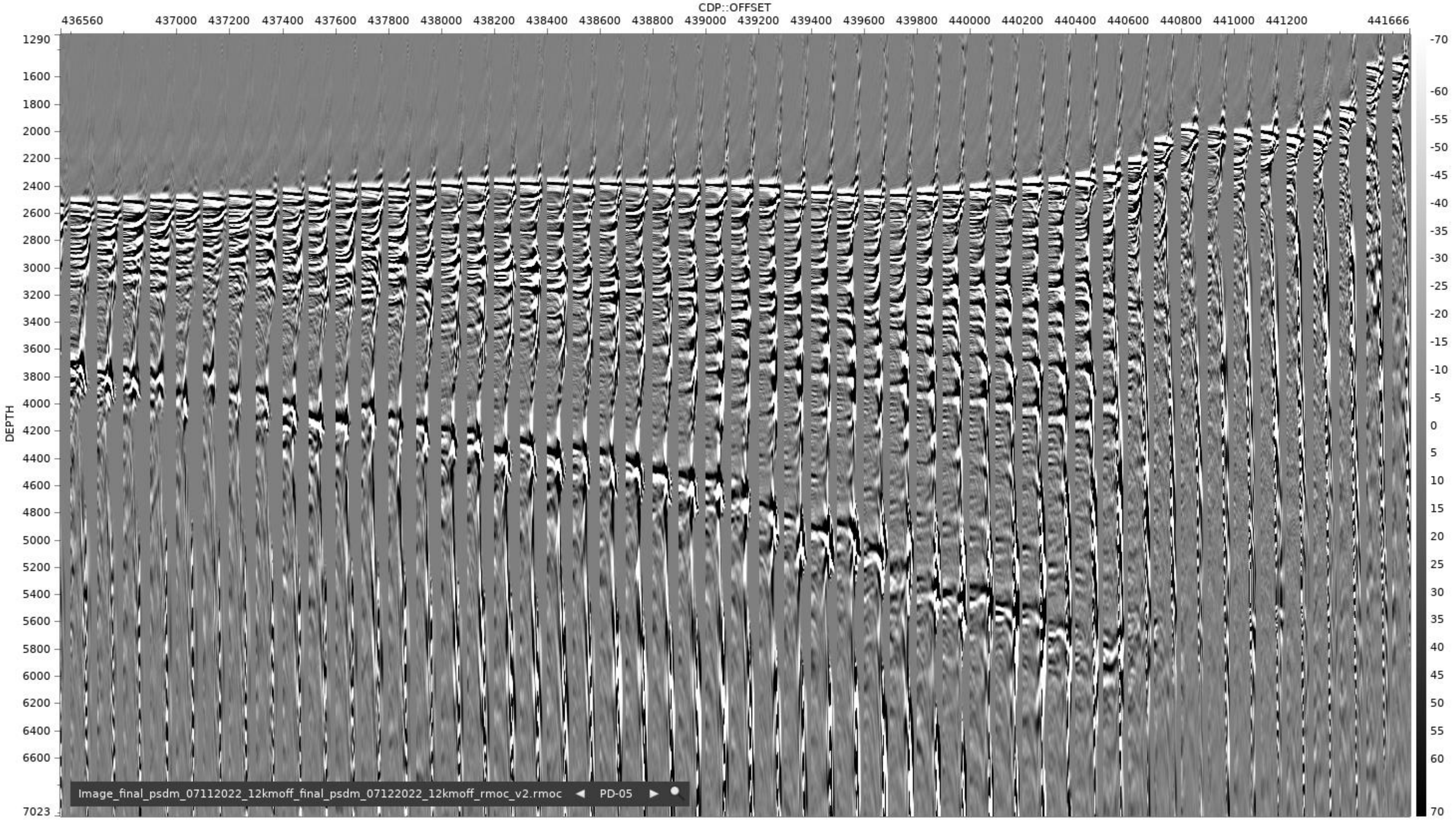
PD-05 Final PSDM Stack with RMOC - ZOOM



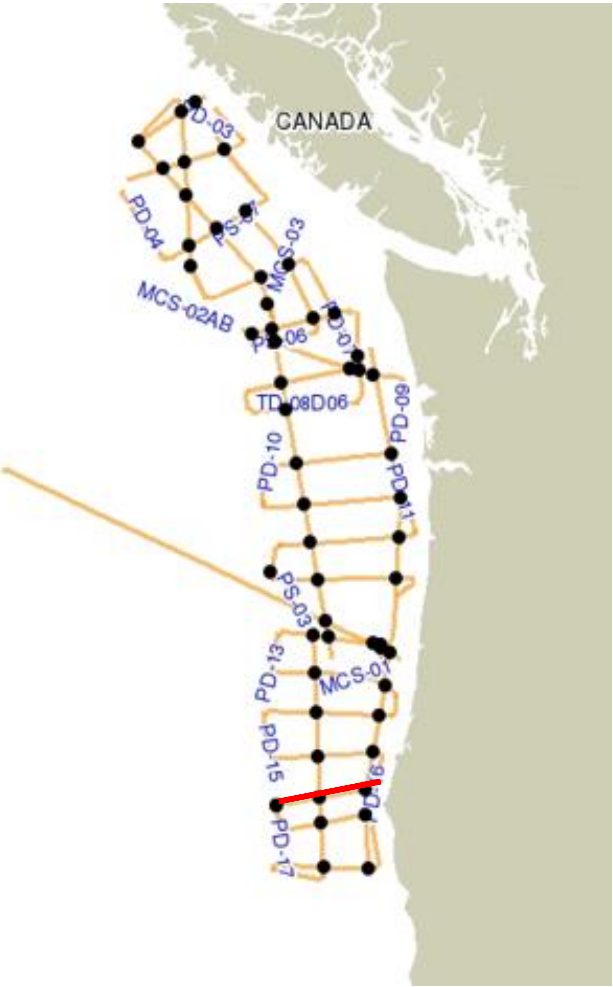
PD-05 Final PSDM Gathers - ZOOM



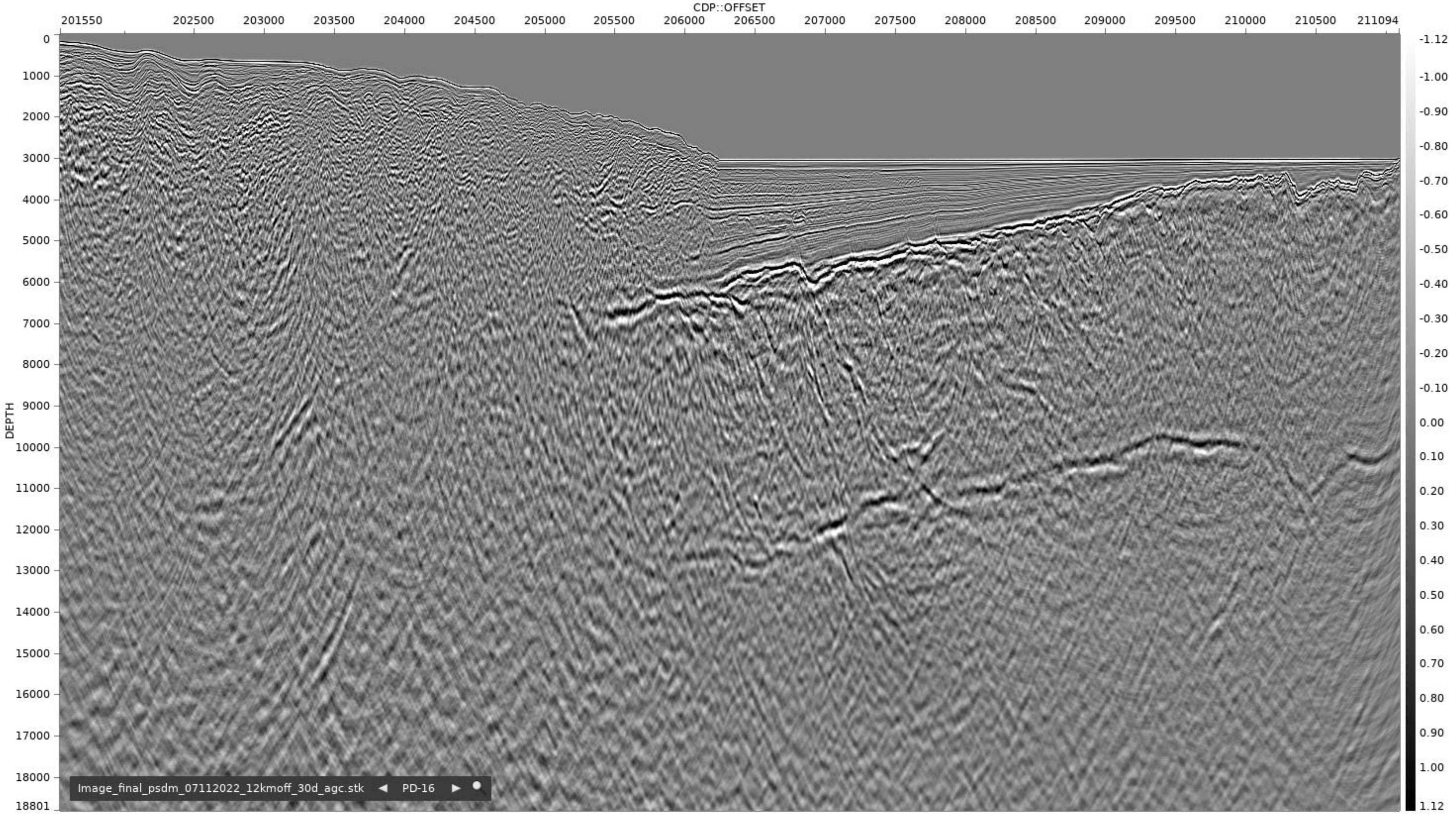
PD-05 Final PSDM Gathers with RMOC - ZOOM



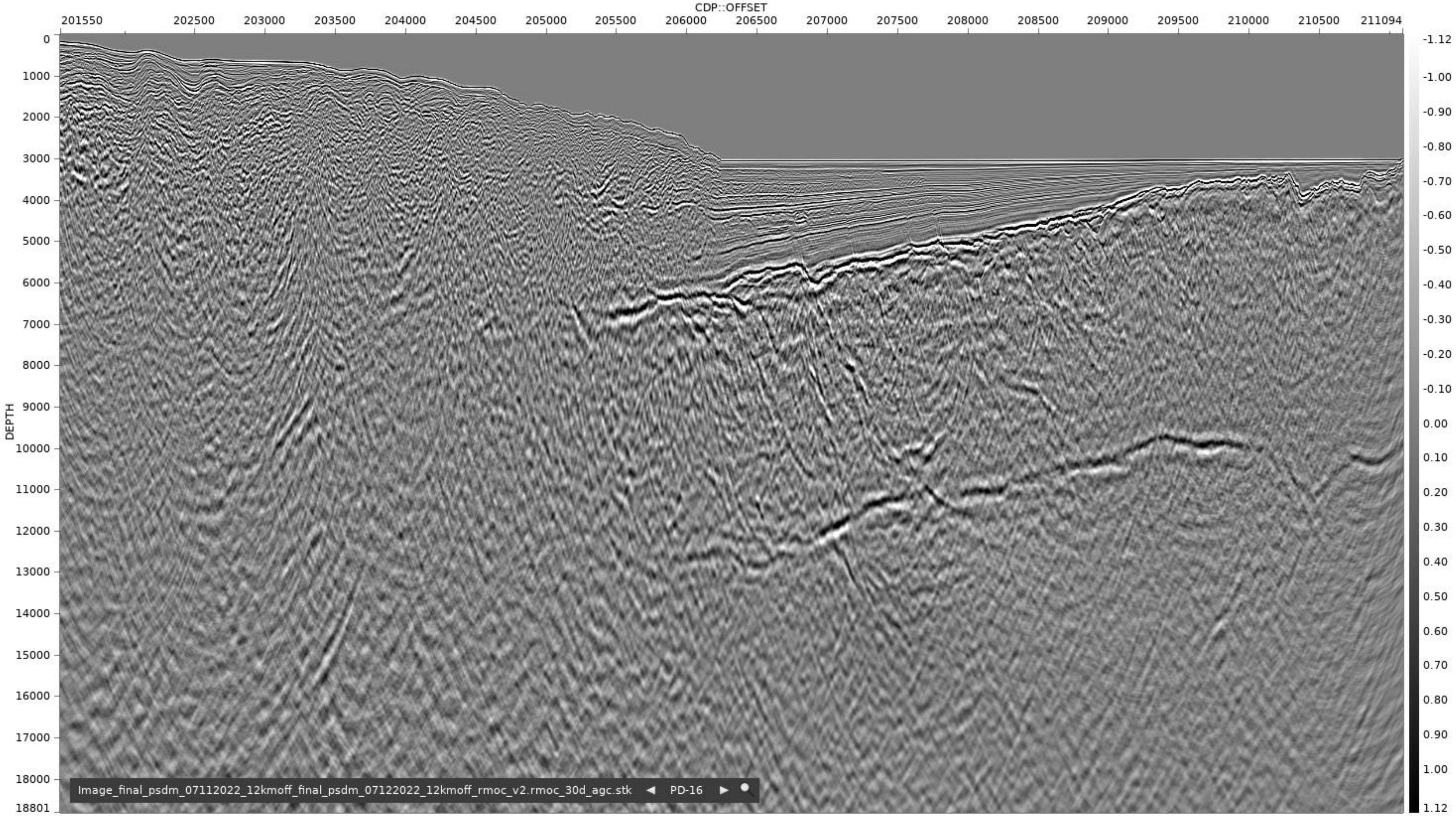
Line PD-16


CANADA
PD-04
MCS-03
MCS-02AB
PD-09
PD-10
PS-03
PD-13
MCS-01
PD-15
PD-17

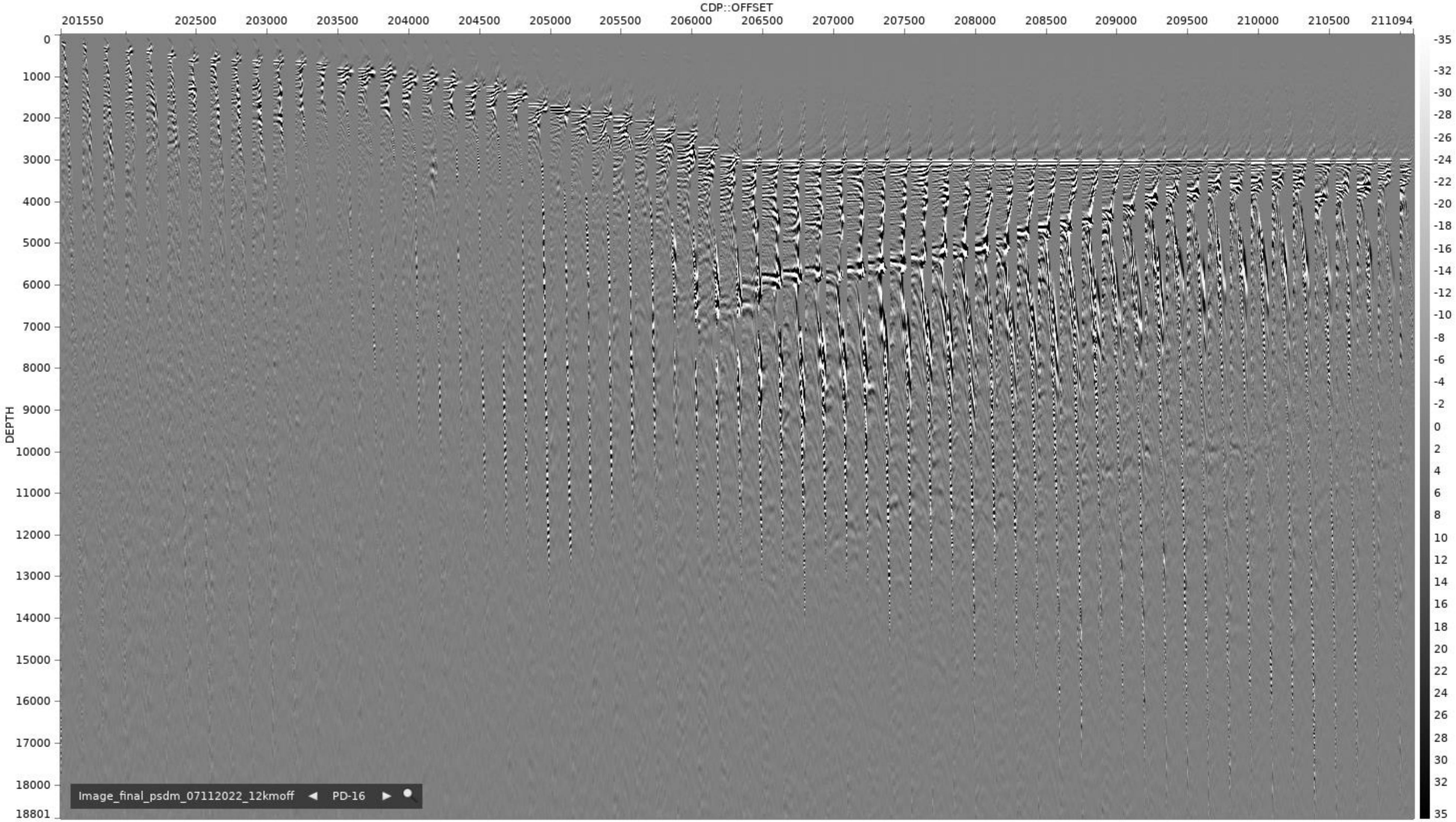
PD-16 Final PSDM Stack



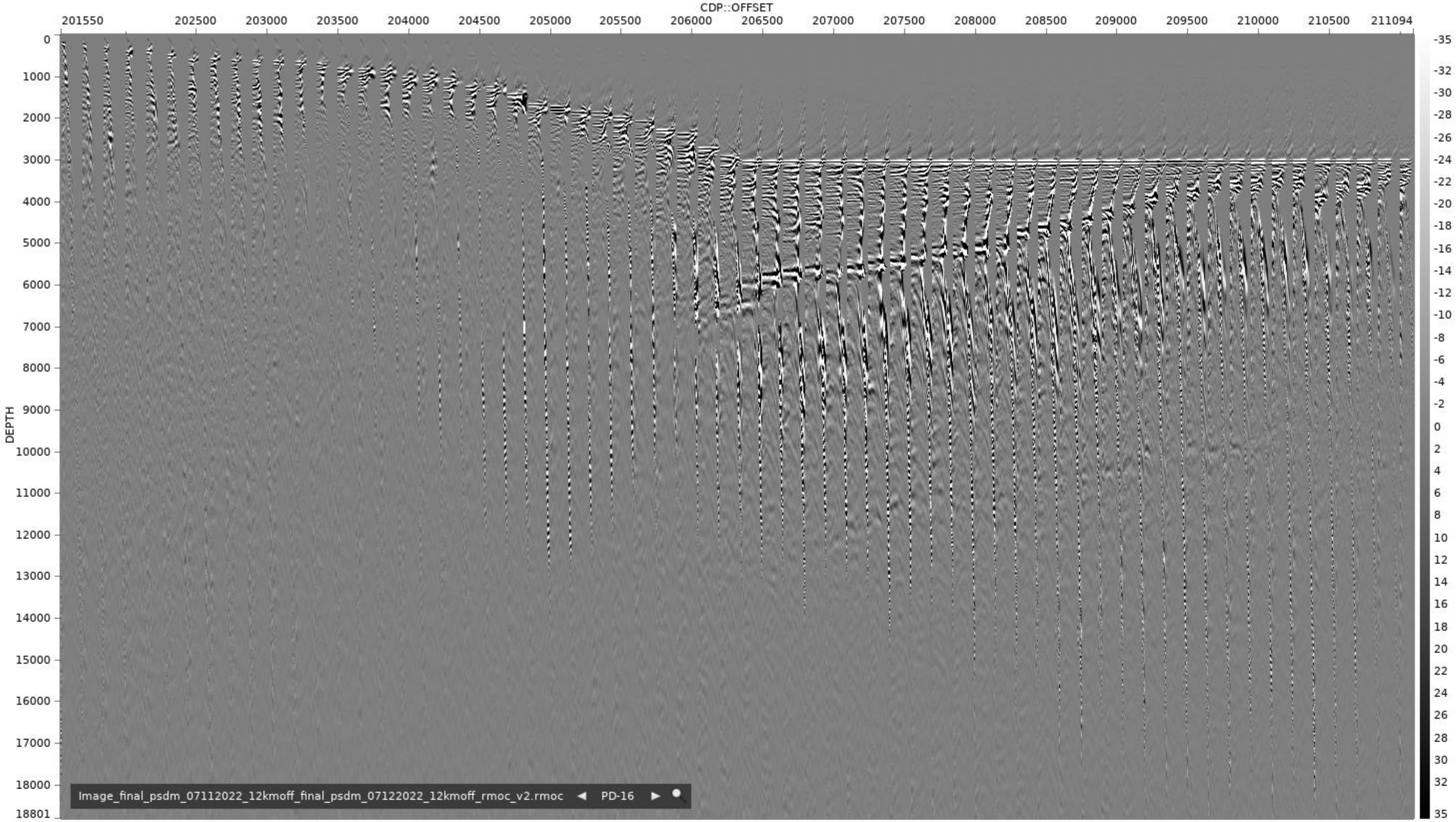
PD-16 Final PSDM Stack with RMOC



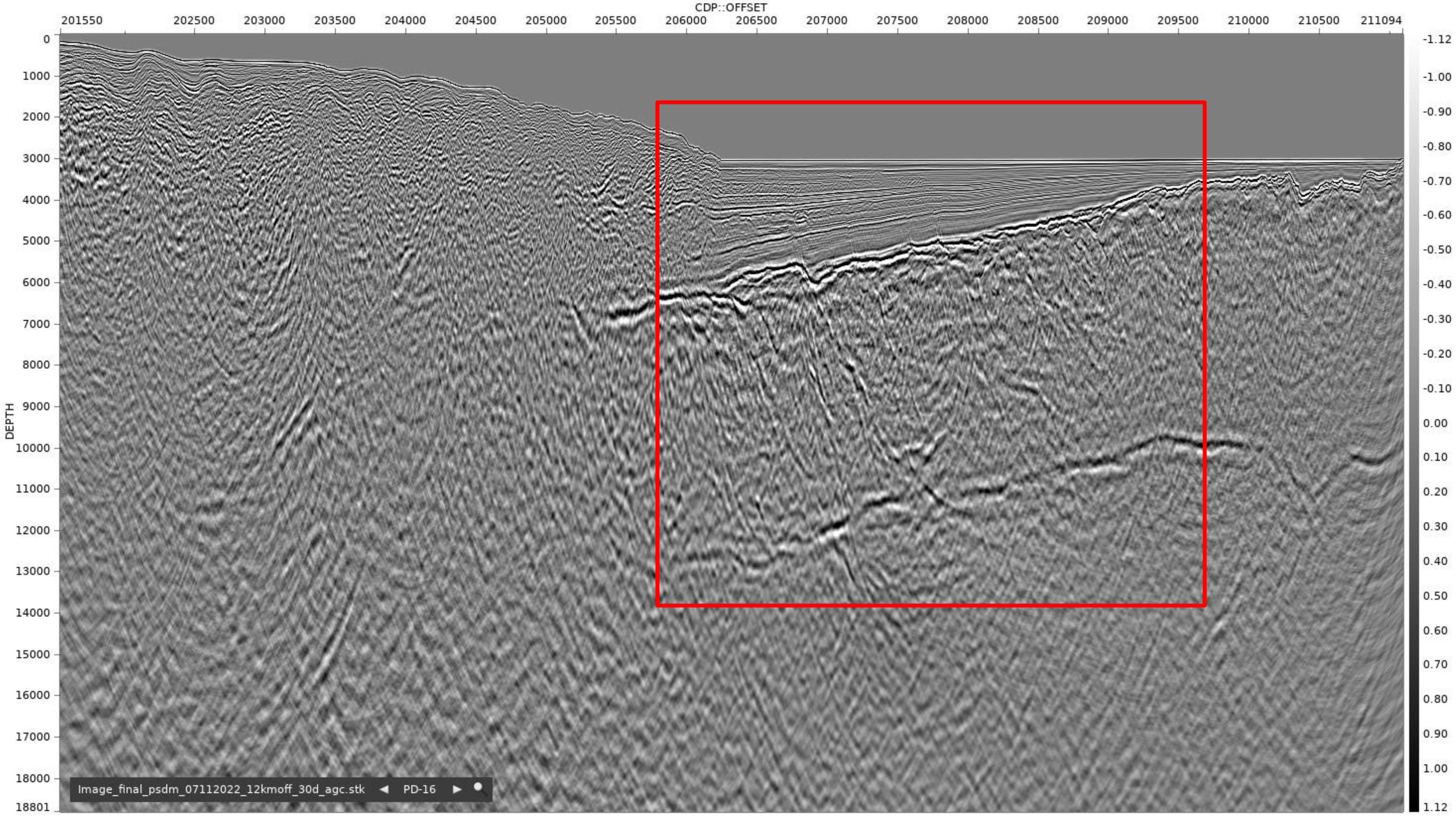
PD-16 Final PSDM Gathers



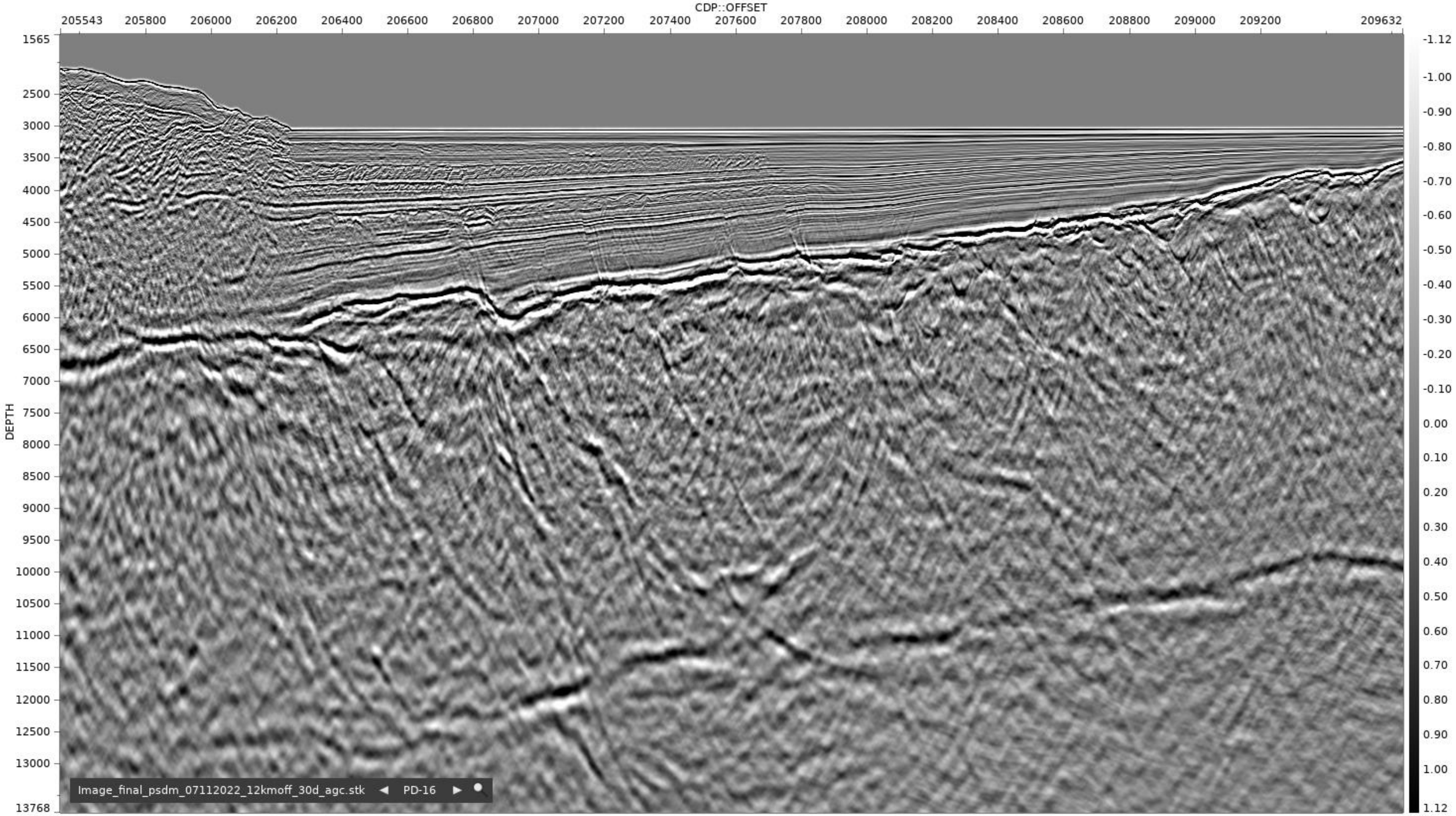
PD-16 Final PSDM Gathers with RMOC



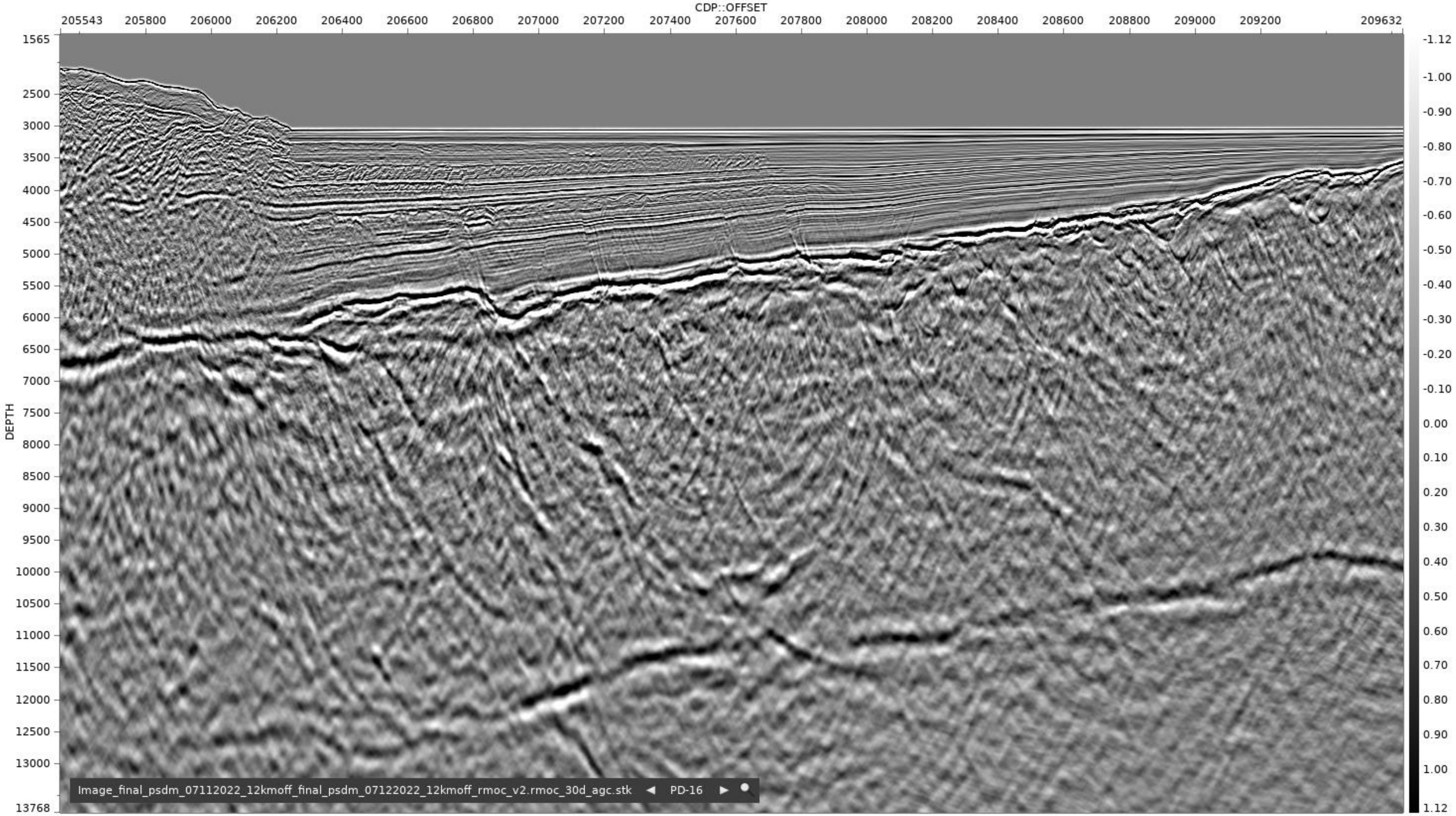
PD-16 Final PSDM Stack – ZOOM SELECTION WINDOW



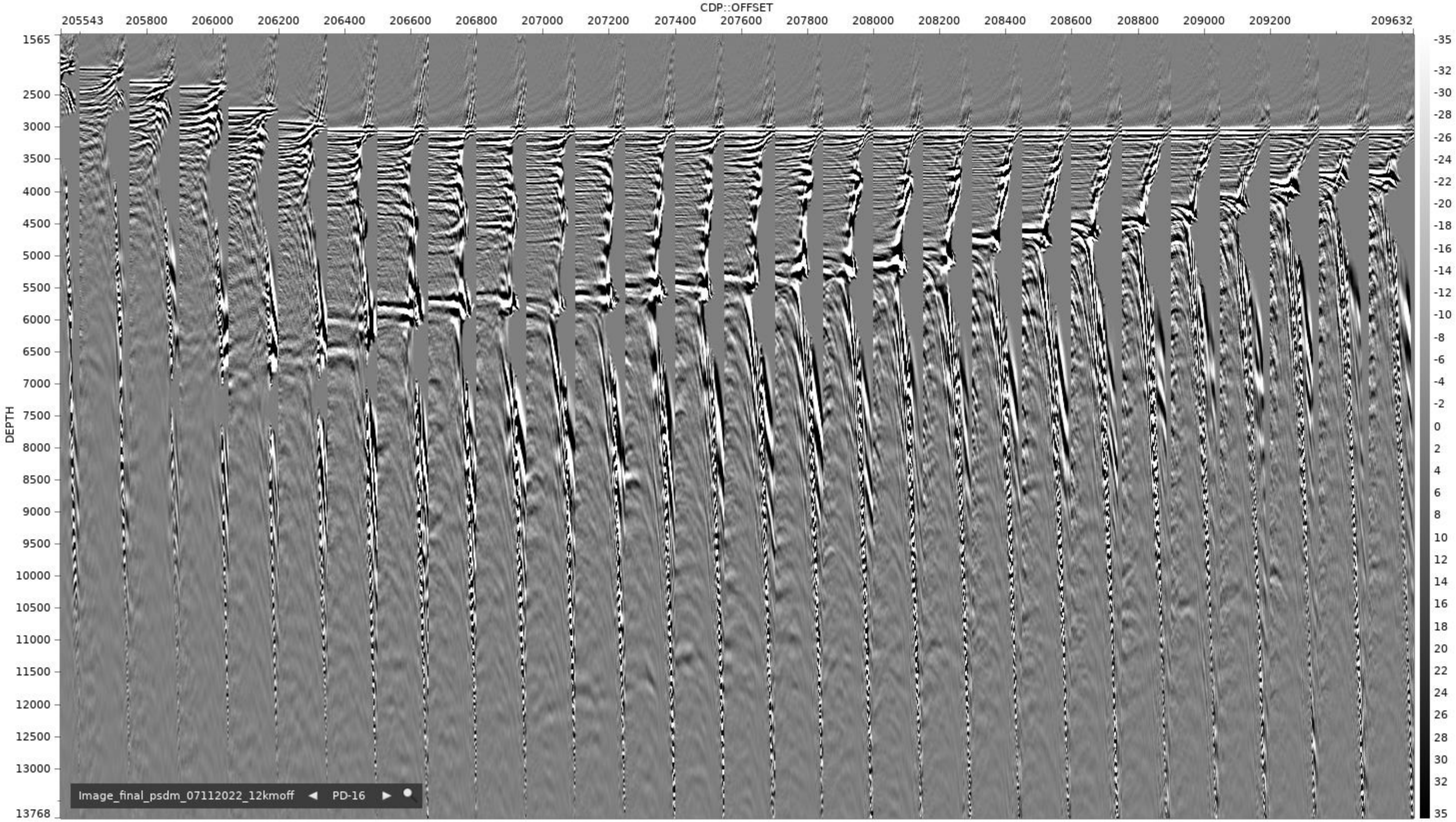
PD-16 Final PSDM Stack - ZOOM



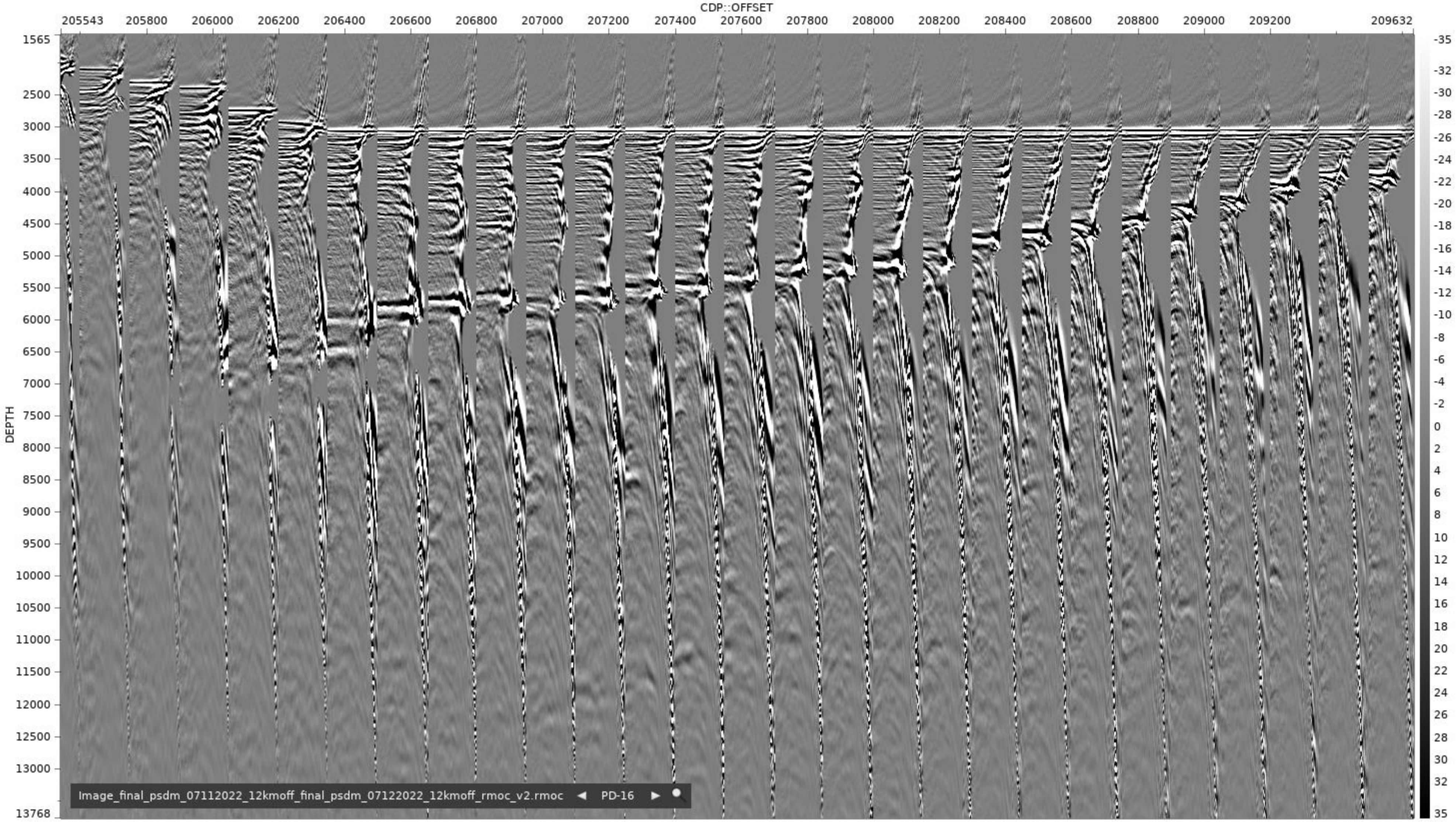
PD-16 Final PSDM Stack with RMOC - ZOOM



PD-16 Final PSDM Gathers - ZOOM



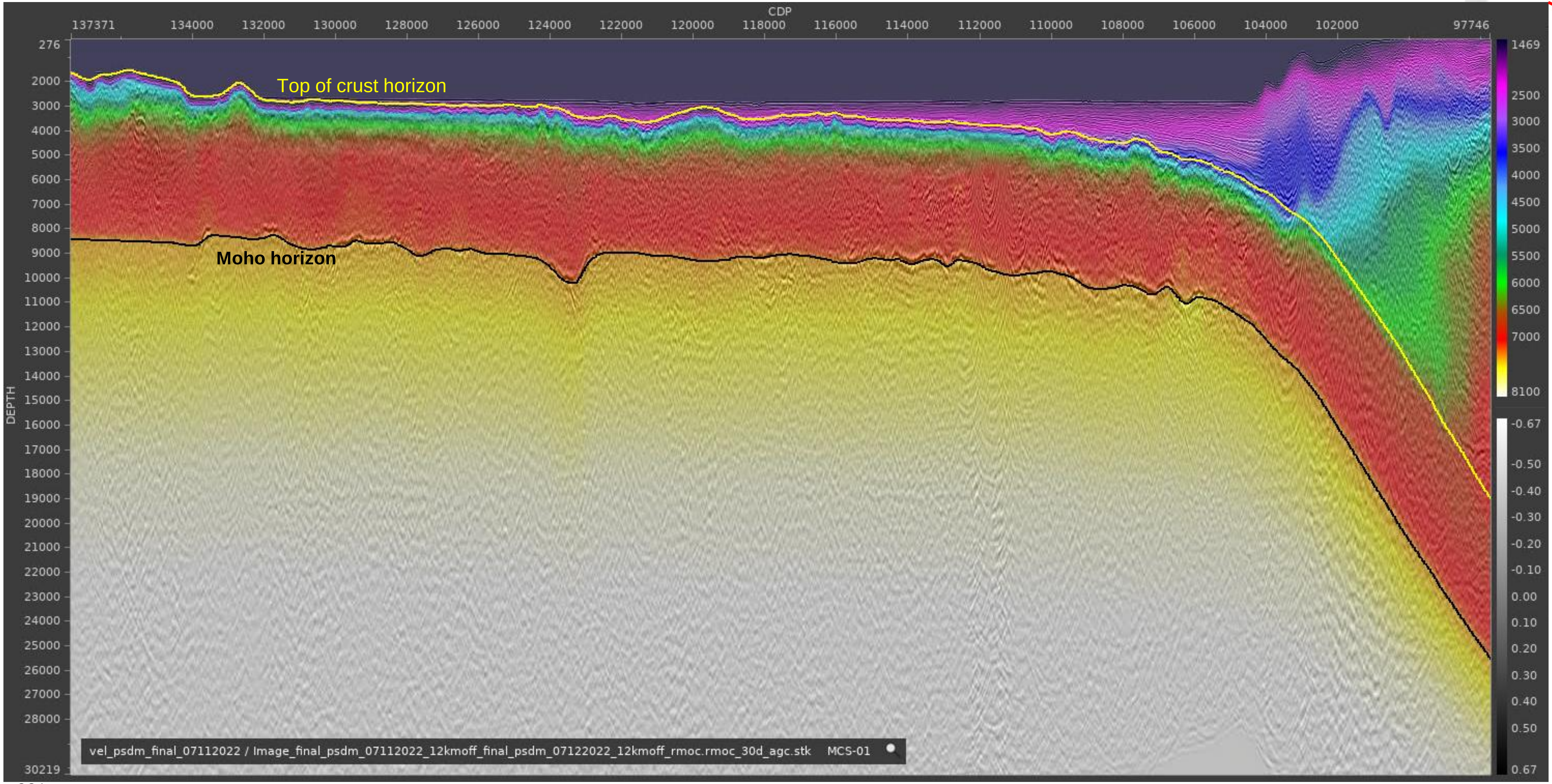
PD-16 Final PSDM Gathers with RMOC - ZOOM



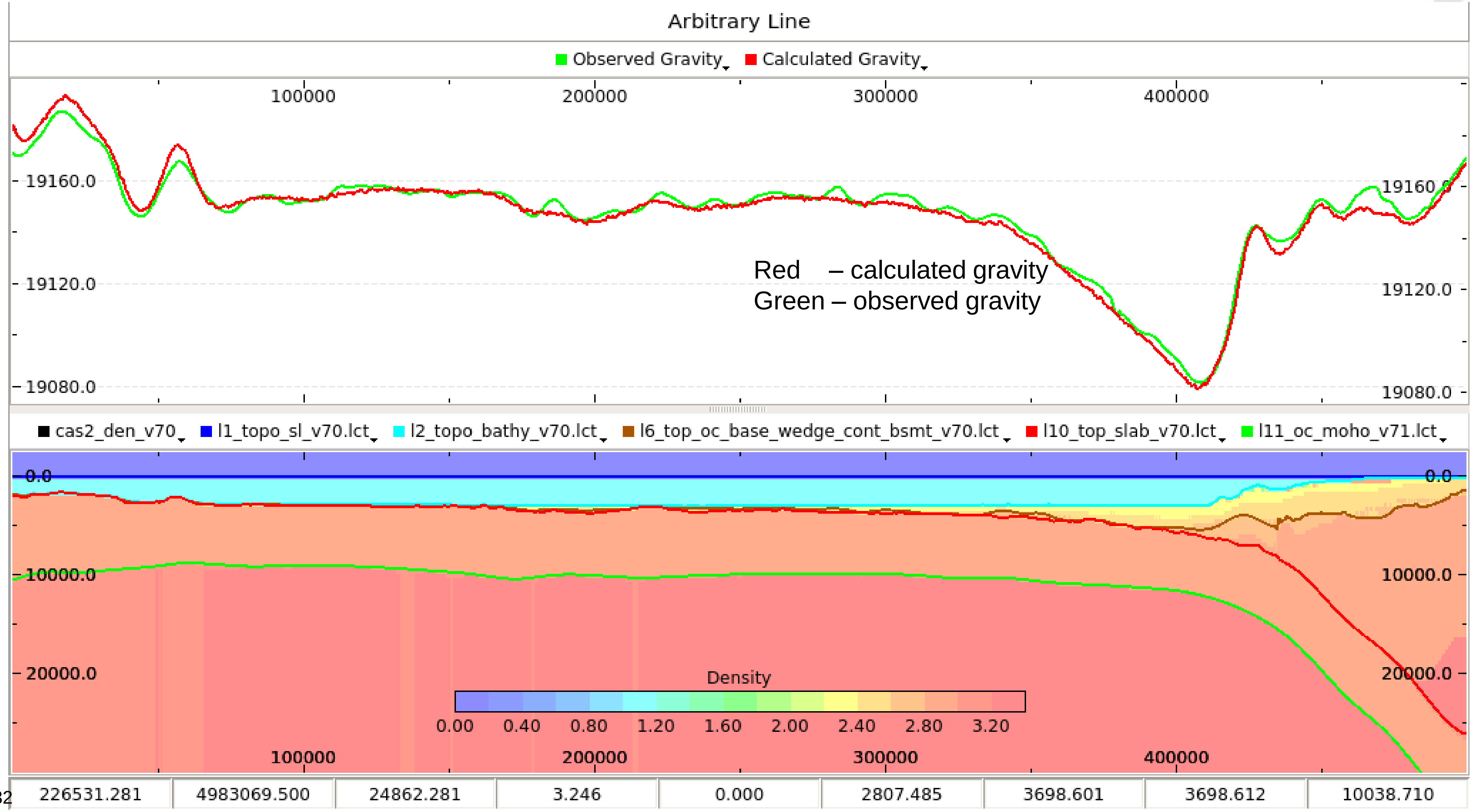
Gravity Modeling

- Incorporate potential field data to obtain crustal velocities
- Gravity model was used to aid the interpretation of Basement and Moho horizons
- Crustal horizons were picked on seismic sections
- Gravity analysis performed to ensure quality of crustal velocity model
- To finalize the velocity model, sediment velocity grids were merged with crustal velocities

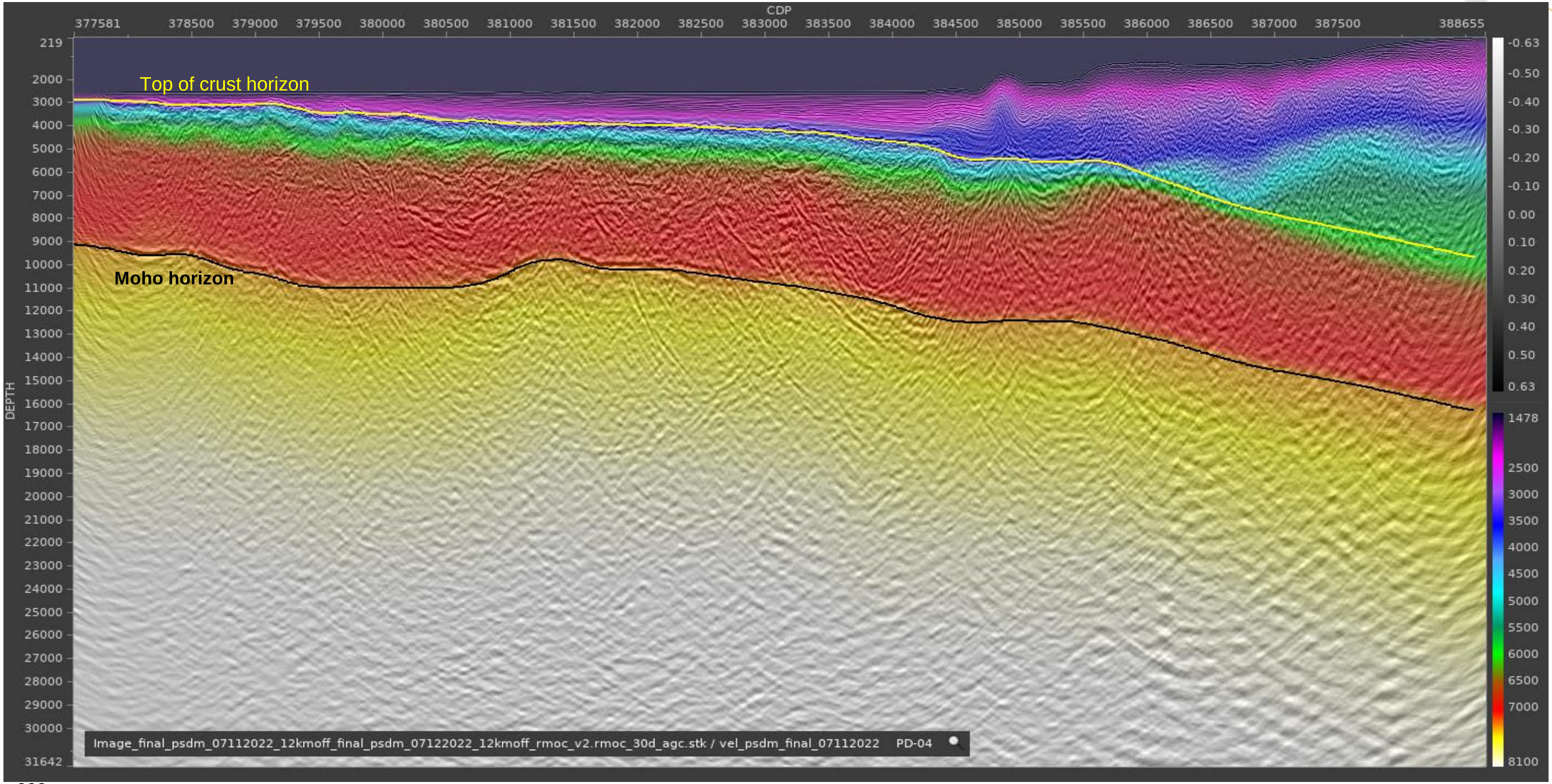
MCS-01: Final PSDM Stack with velocity overlay



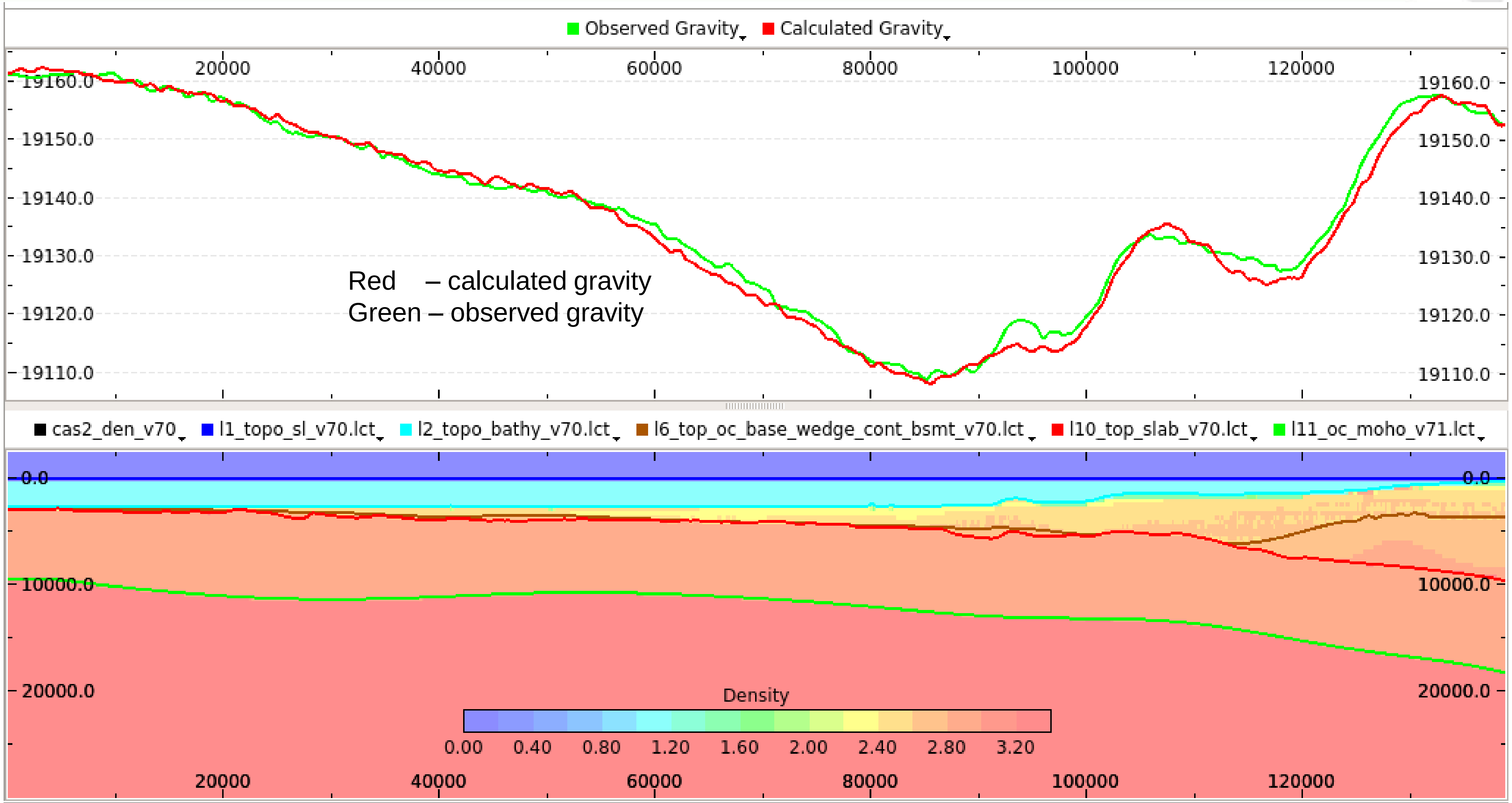
MCS-01: Gravity Analysis



PD-04: Final PSDM Stack with velocity overlay

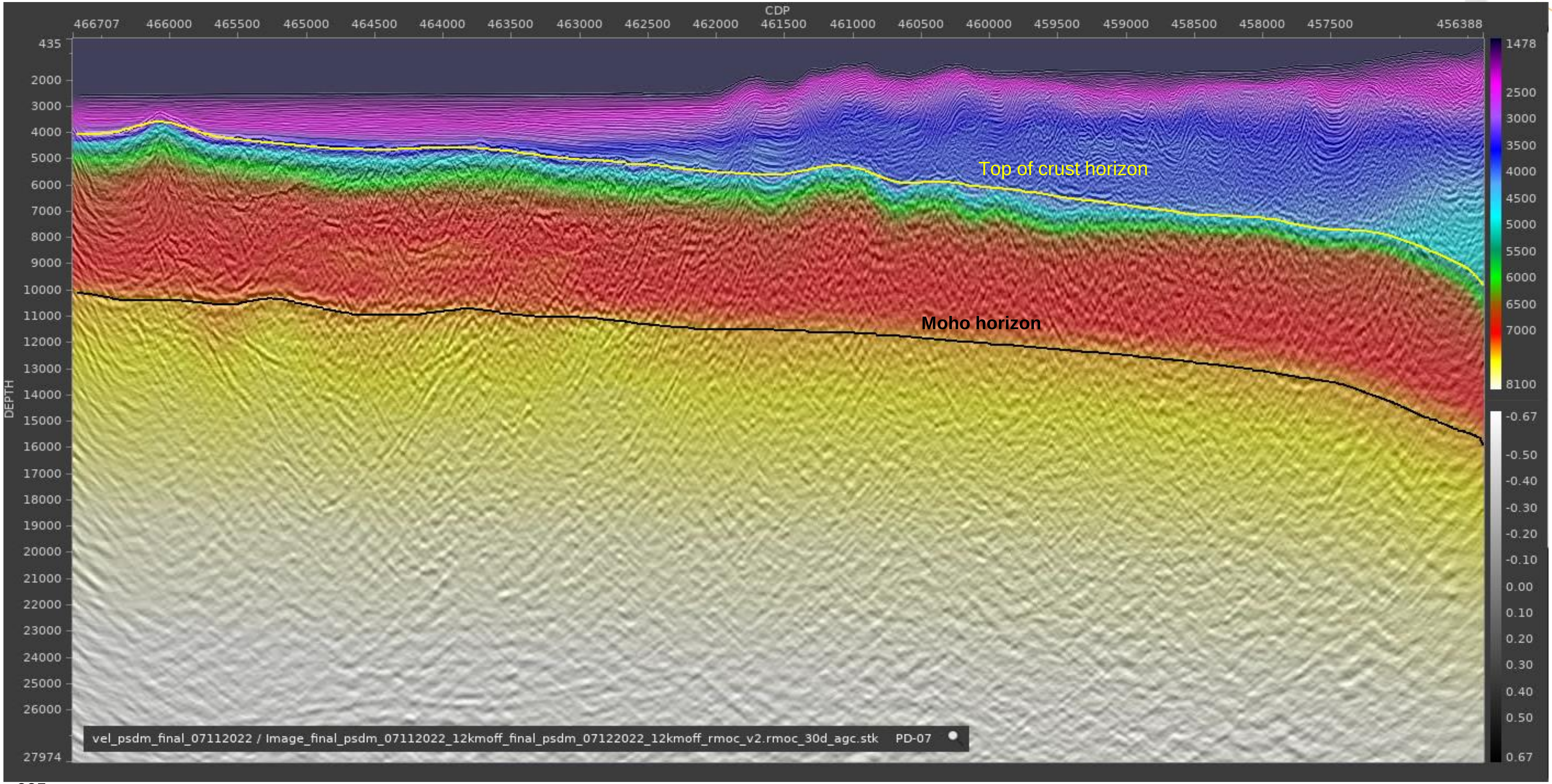


PD-04: Gravity Analysis

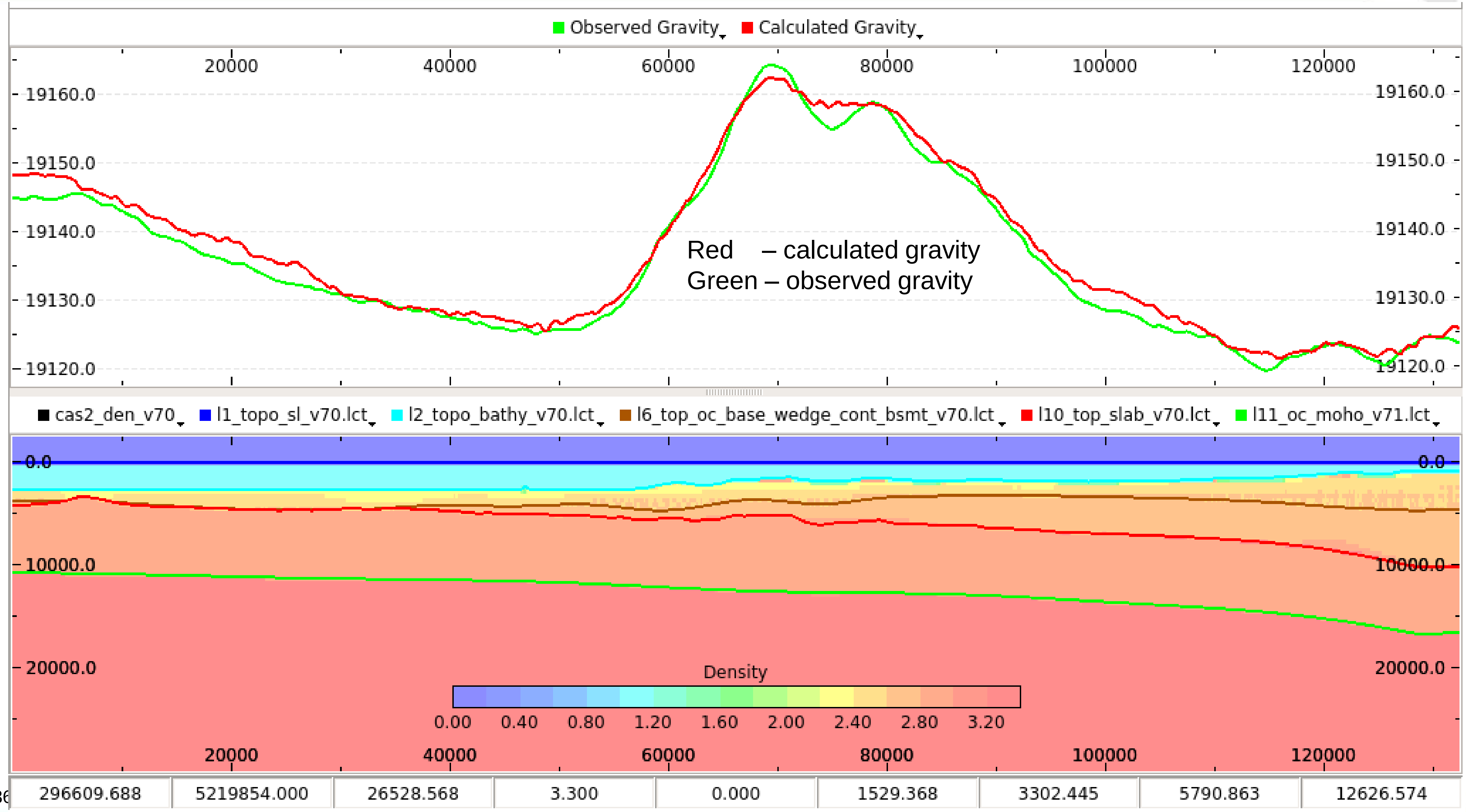


182825.938	5382391.500	24029.137	3.274	0.000	2574.318	3986.694	3986.697	11318.500

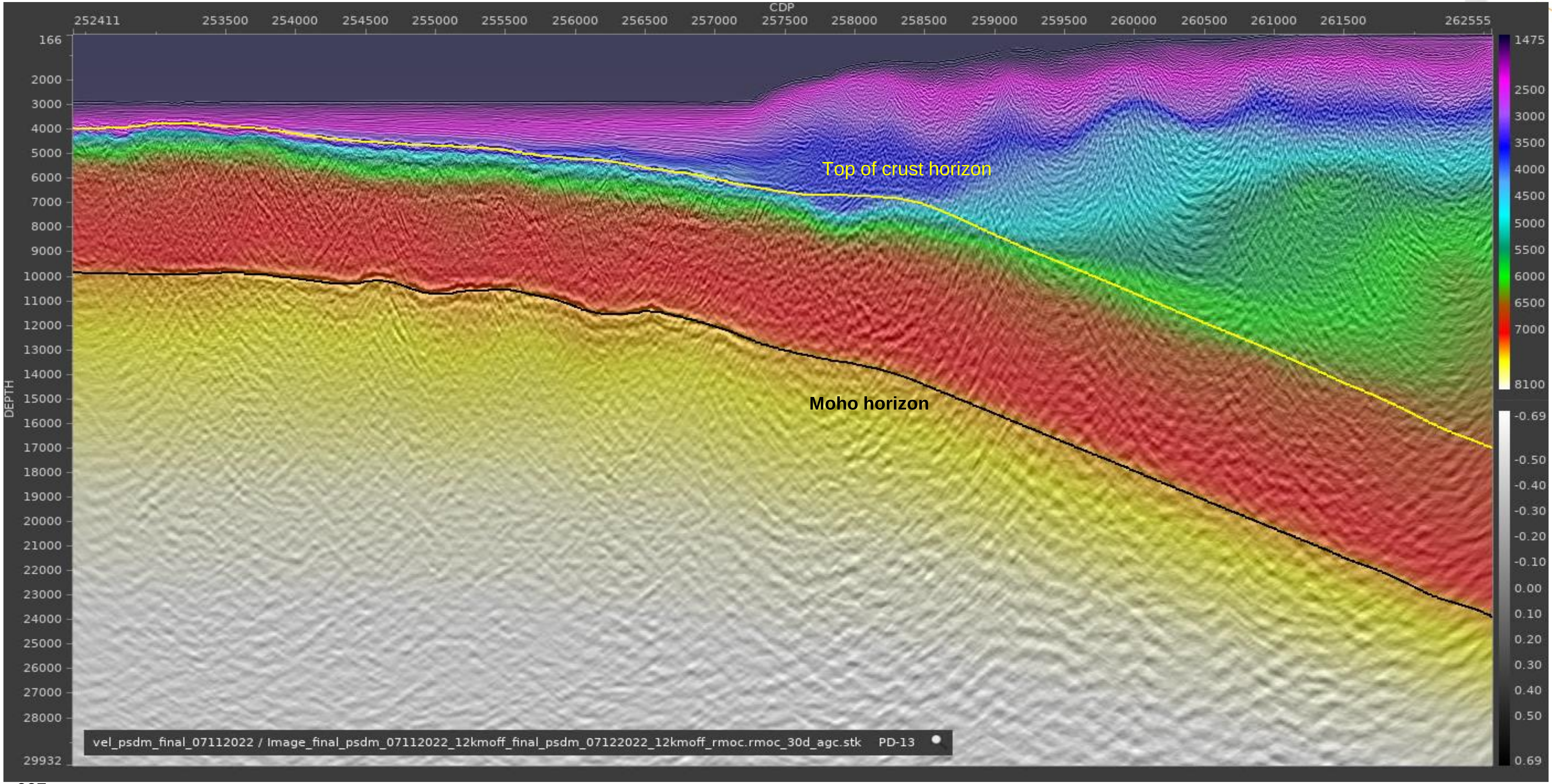
PD-07: Final PSDM Stack with velocity overlay



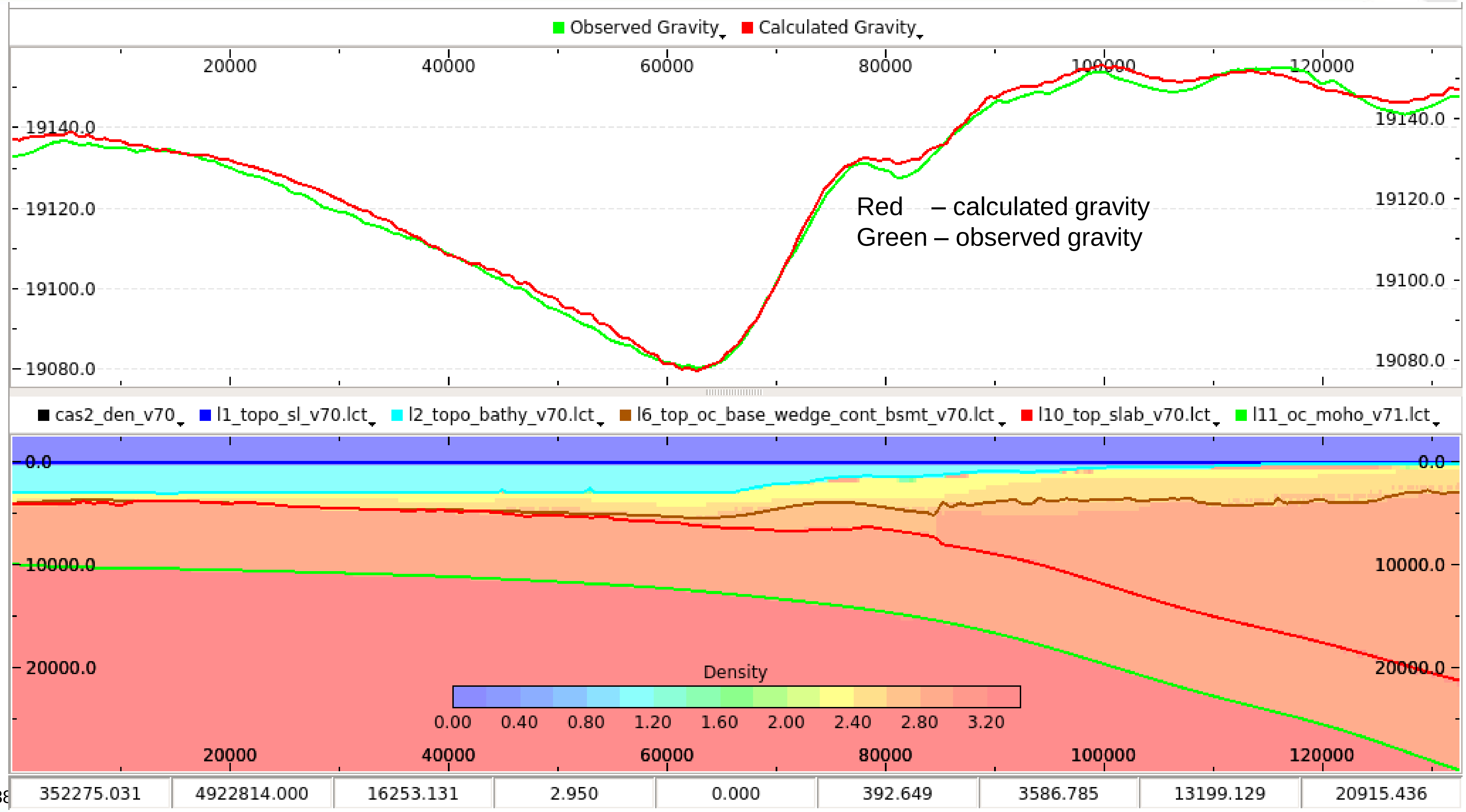
PD-04: Gravity Analysis



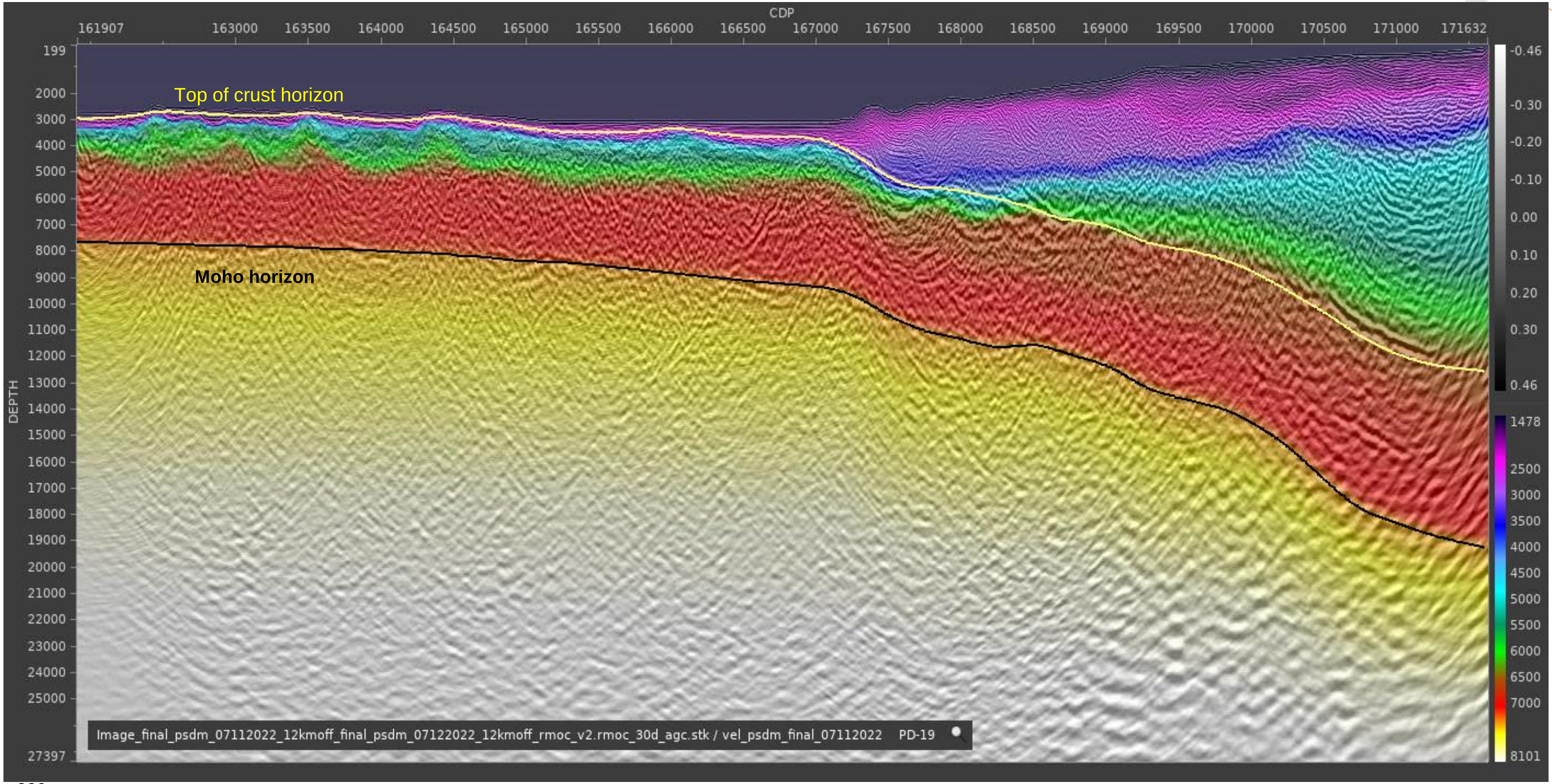
PD-13: Final PSDM Stack with velocity overlay



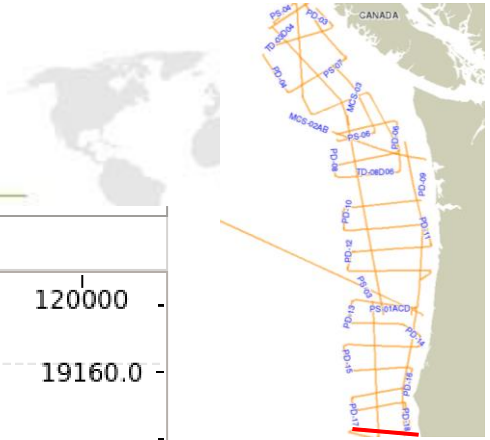
PD-13: Gravity Analysis

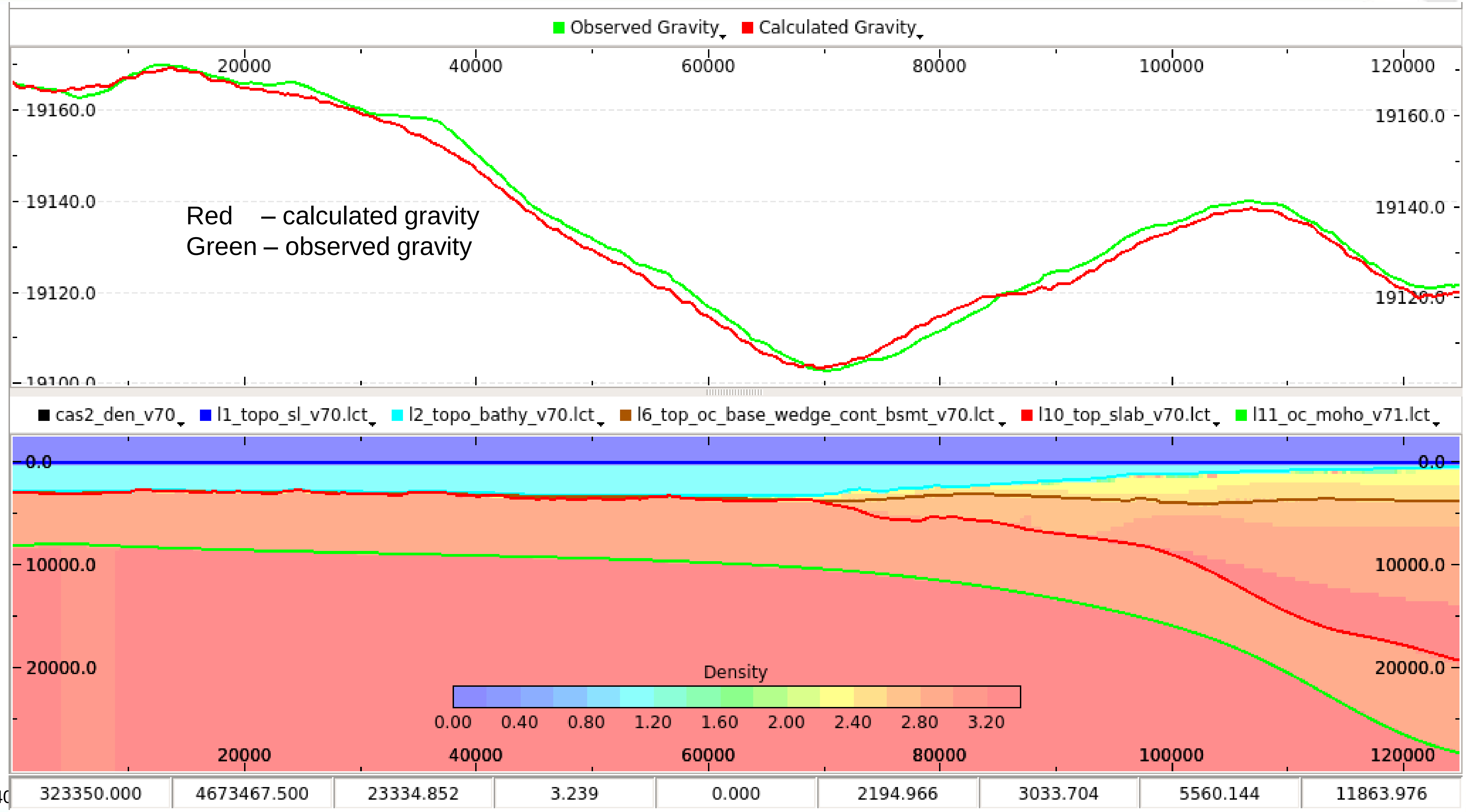


PD-19: Final PSDM Stack with velocity overlay



PD-19: Gravity Analysis





- Data Acquisition
  - Line layout and acquisition specifications
- Pre-processing
  - Flow and data examples
- Pre-stack Depth Migration (PSDM)
  - Flow and data examples
  - Potential fields modeling
- Post Processing
  - PSDM

Post Processing Workflow (PSDM)

- Input migrated RMO-corrected CDP gathers
- Depth-to-time conversion
- High-resolution radon de-multiple
- Linear noise attenuation
- Angle mute – 0-30°
- Stack
- Inverse Q (Amplitude Only)
- Time variant band pass filter (relative to water bottom)
- Signal Coherency Enhancement
- Scaling (RAP scale)
- Time-to-depth conversion
- Output to SEGY

High Resolution Radon Demultiple

- A high-resolution Radon demultiple was applied following the residual move-out correction. This was used to attenuate residual multiples due to the improved velocity control at this point in the imaging flow, which allowed multiples to be better distinguished from underlying primary energy.
- The data were mapped to *τ-q* space using a parabolic Radon transform. Testing focused on two aspects of the process, firstly optimising parameters for the transform to ensure the data was fully mapped in *τ-q* space, and secondly designing a suitable mute to create a model of the multiples. The multiple model was then transformed back to the *x-t* domain and subtracted from the input data.
- Application of the Radon demultiple effectively attenuated residual multiples and unwanted noise from the gathers, enhancing the data and resulting in a cleaner, higher quality final stack.
- **Radon key parameters**

  P –value -1000 to 6000

  Reference offset – 11000m

  No.of P-values – 500

  P-mute 200 to 300

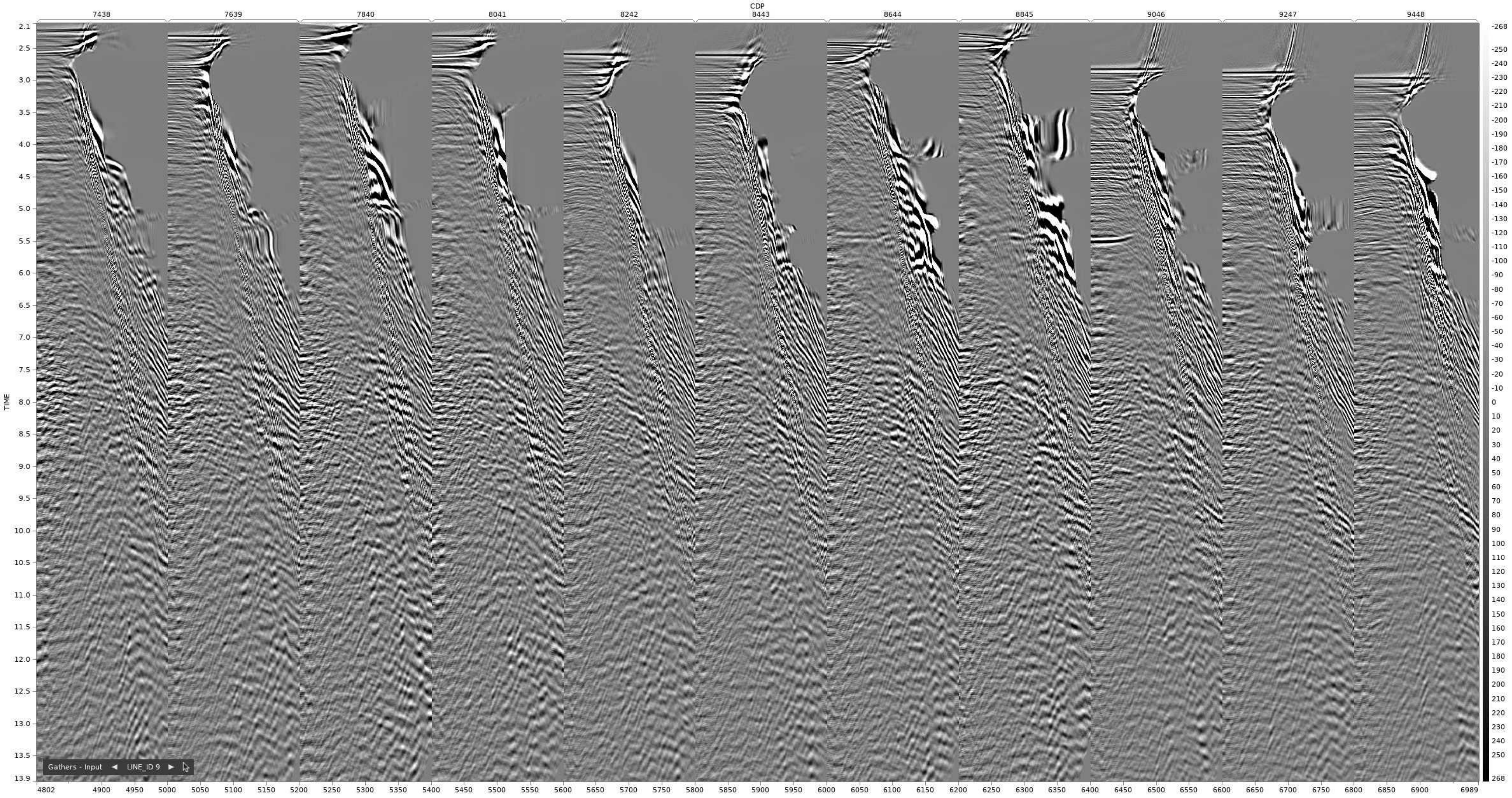
Linear Noise Attenuation

- Following the Radon a Radial Filter was applied to remove linear noise.
- **Radial key parameters**

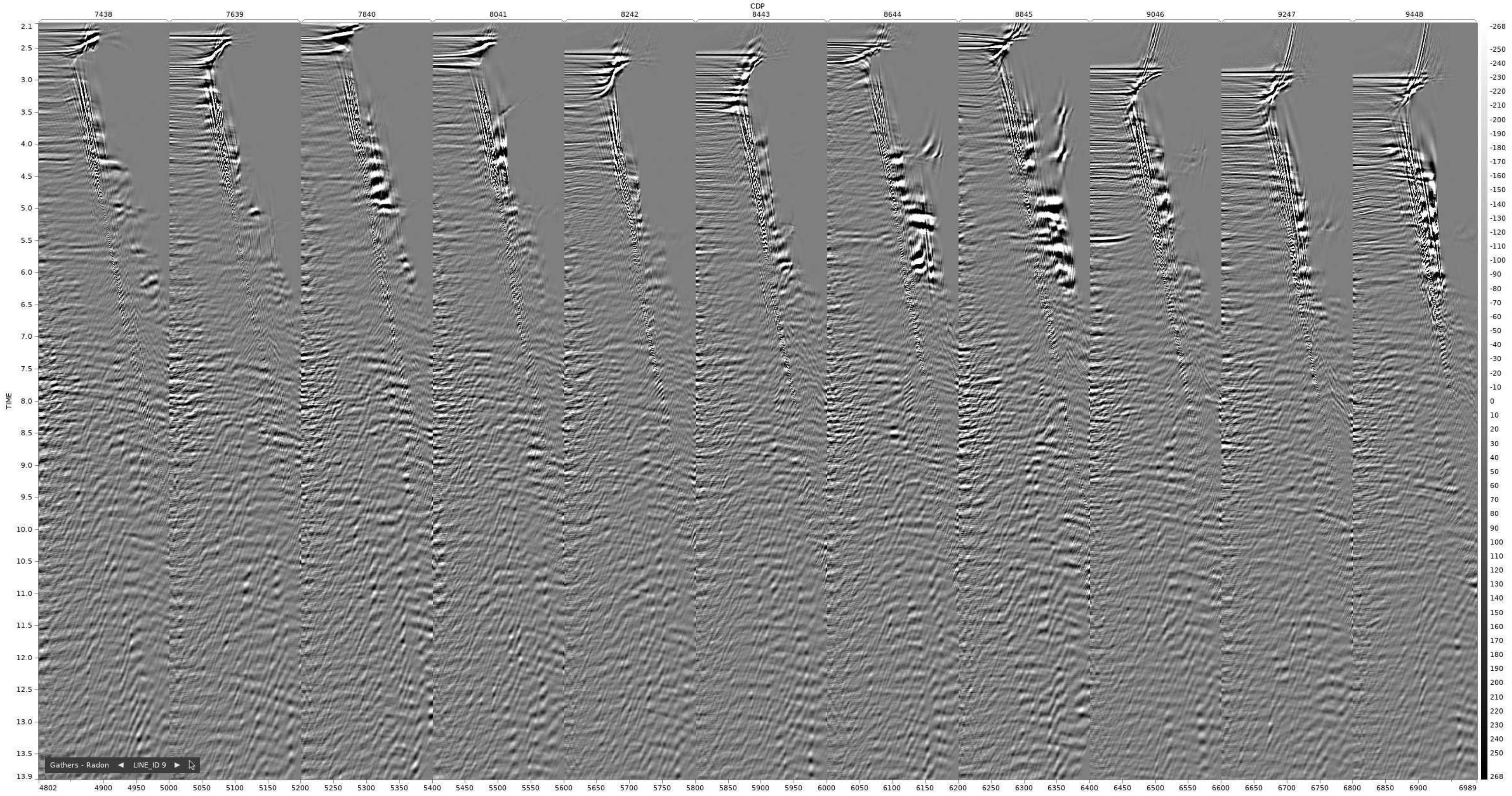
  Dips used in modelling linear noise – 1000, 1200, 1400, 1600, 1800, 2100, 2700, 3000, -1400, -2000, -3000 m/sec

Radon Demultiple Gathers

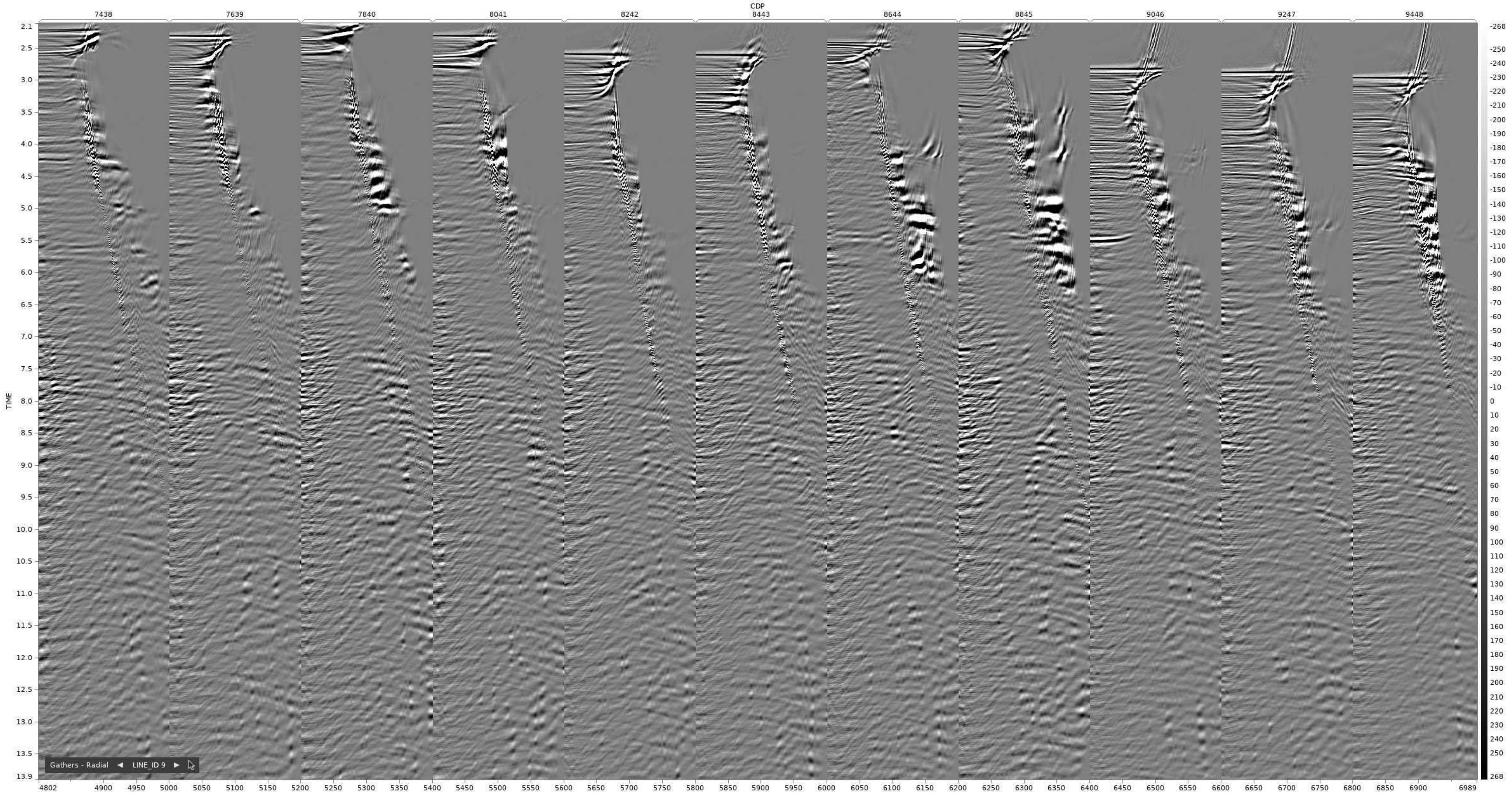
Input LINE - MGL2104PD09



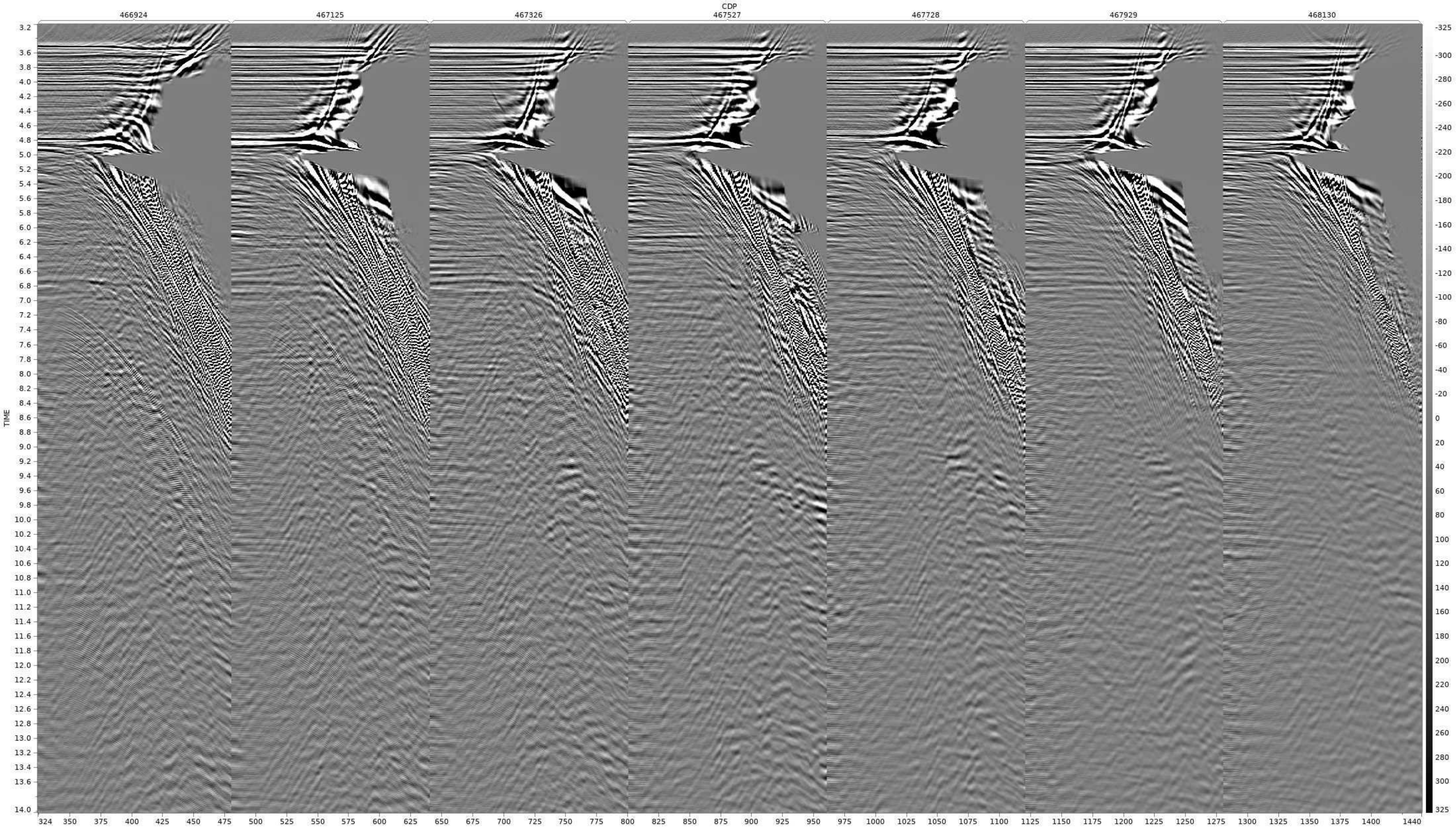
Radon Demultiple Gathers
output LINE - MGL2104PD09



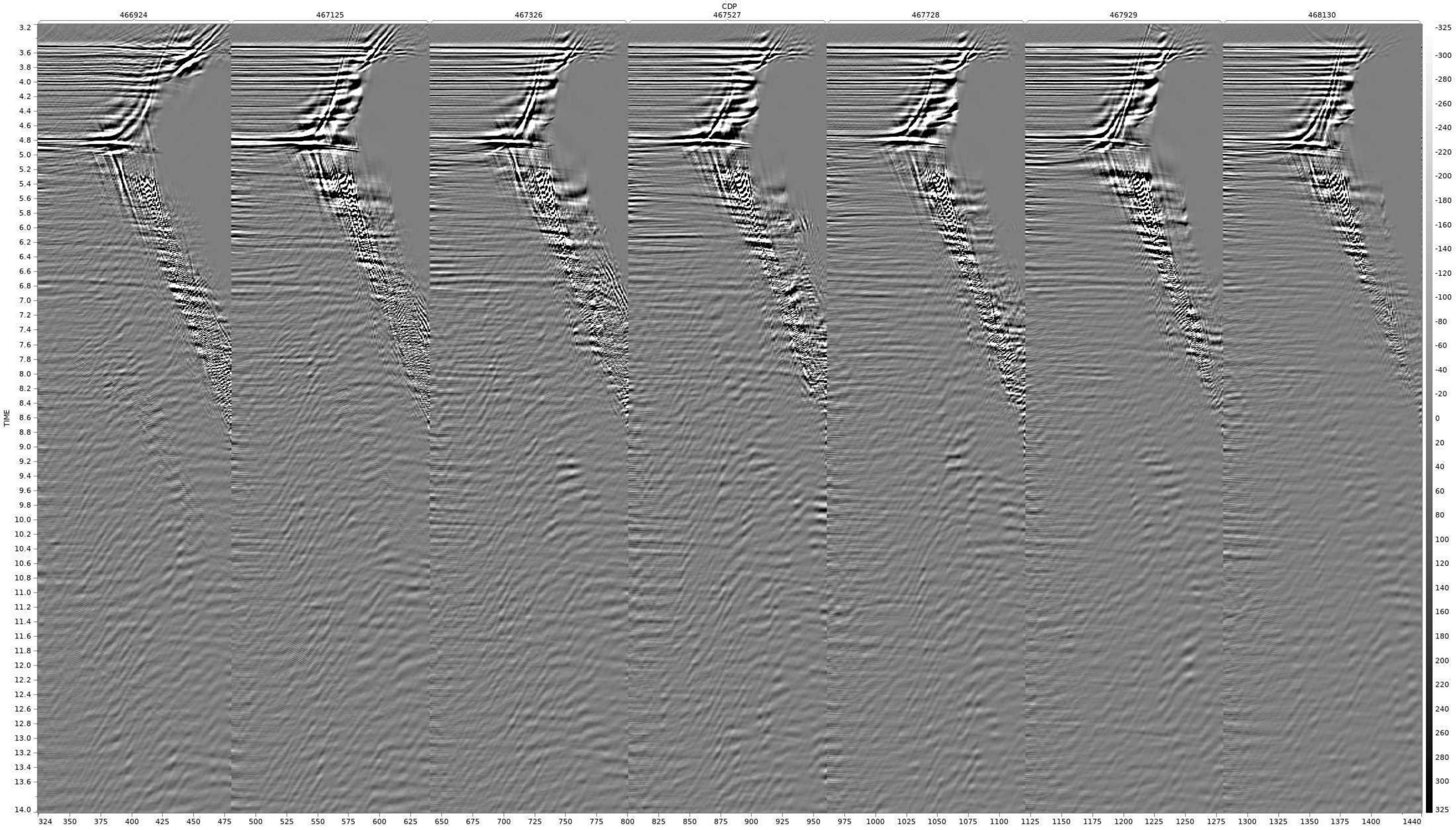
Linear Noise Attenuation Gathers
output LINE - MGL2104PD09



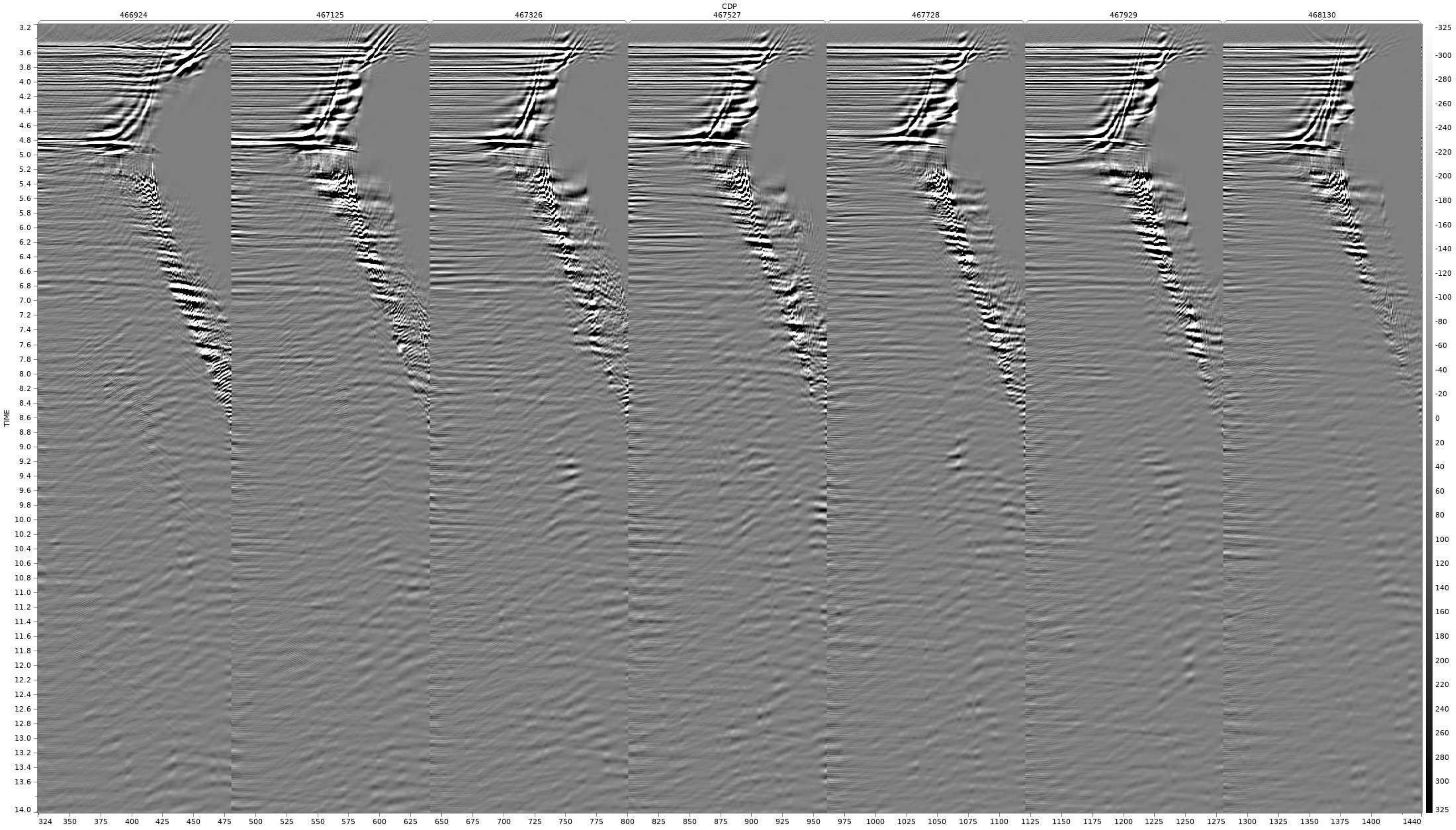
Radon Demultiple Gathers - Input LINE - MGL2104TD07D08



Radon Demultiple Gathers - Output LINE - MGL2104TD07D08



Linear Noise Attenuation - Output LINE - MGL2104TD07D08



Time Variant Filter

- Parameters:
  - Type: Ormsby bandpass (cosine tapers)
  - Phase: zero
  - Filter varied on some lines due to geological differences
  - Application start time: referenced from water bottom

Time (ms)	Freq. 1 (Hz)	Freq. 2 (Hz)	Freq. 3 (Hz)	Freq. 4 (Hz)
0	0	0	90	110
1000	0	0	80	100
2000	0	0	60	70
3000	0	0	50	60
10000	0	0	40	50
14000	0	0	30	40
18000	2	3	20	25

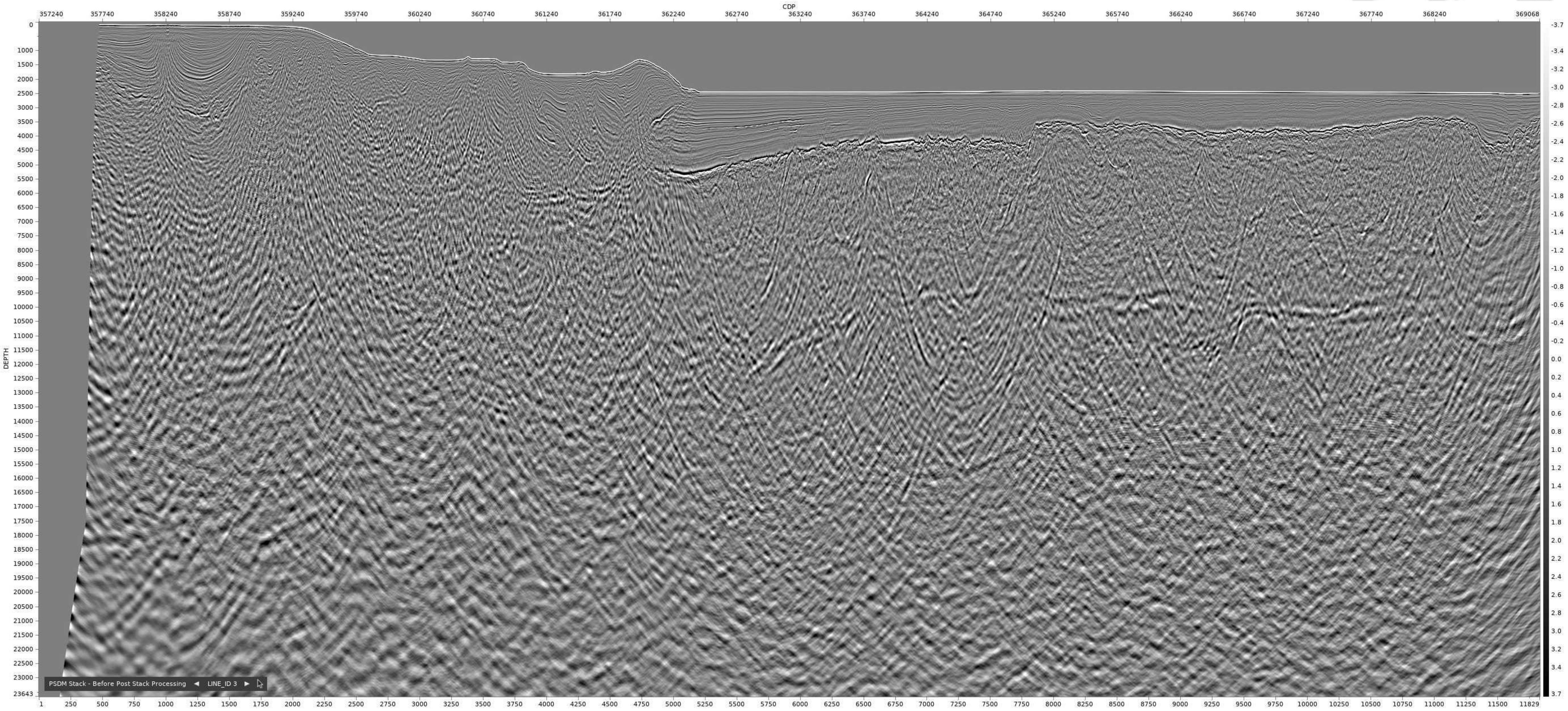
Inverse Q (Amplitude Only)

- Amplitude Q compensation or inverse Amplitude Q filtering corrected for this preferential attenuation of high frequencies. The filter response was applied using the fast short term (windowed) FFT and IFFT. This allowed Q amplitude compensation to be applied without becoming unstable in lower signal to noise scenarios associated with increasing depth (time). Prior to migration the data already had a phase only inverse-Q filter applied. Amplitude Q was applied after migration and post-stack.

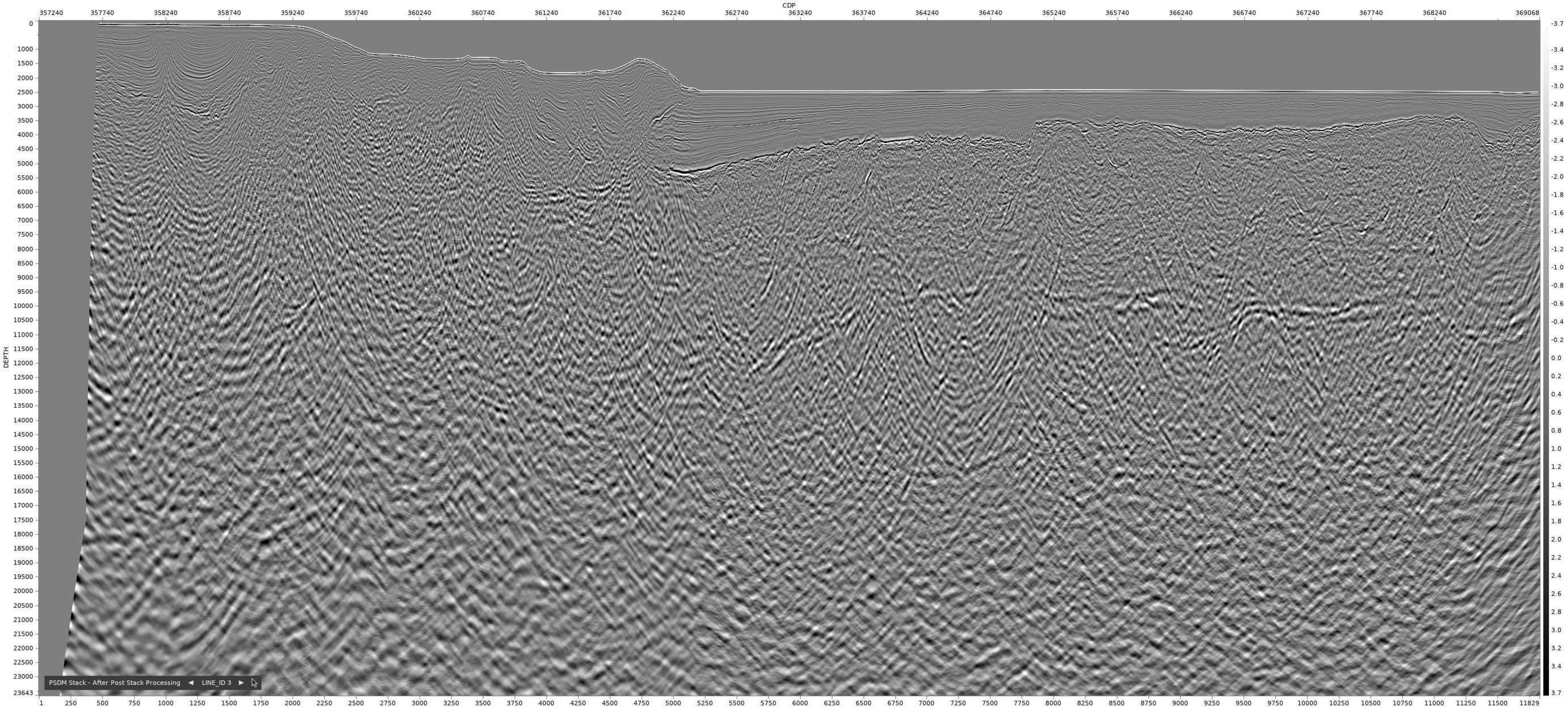
- Q is referenced from the Water Bottom.

- Parameters:
  - Q Value: 100 (entire survey)
  - Reference Frequency: 40Hz
  - Maximum Amplitude Gain: 3

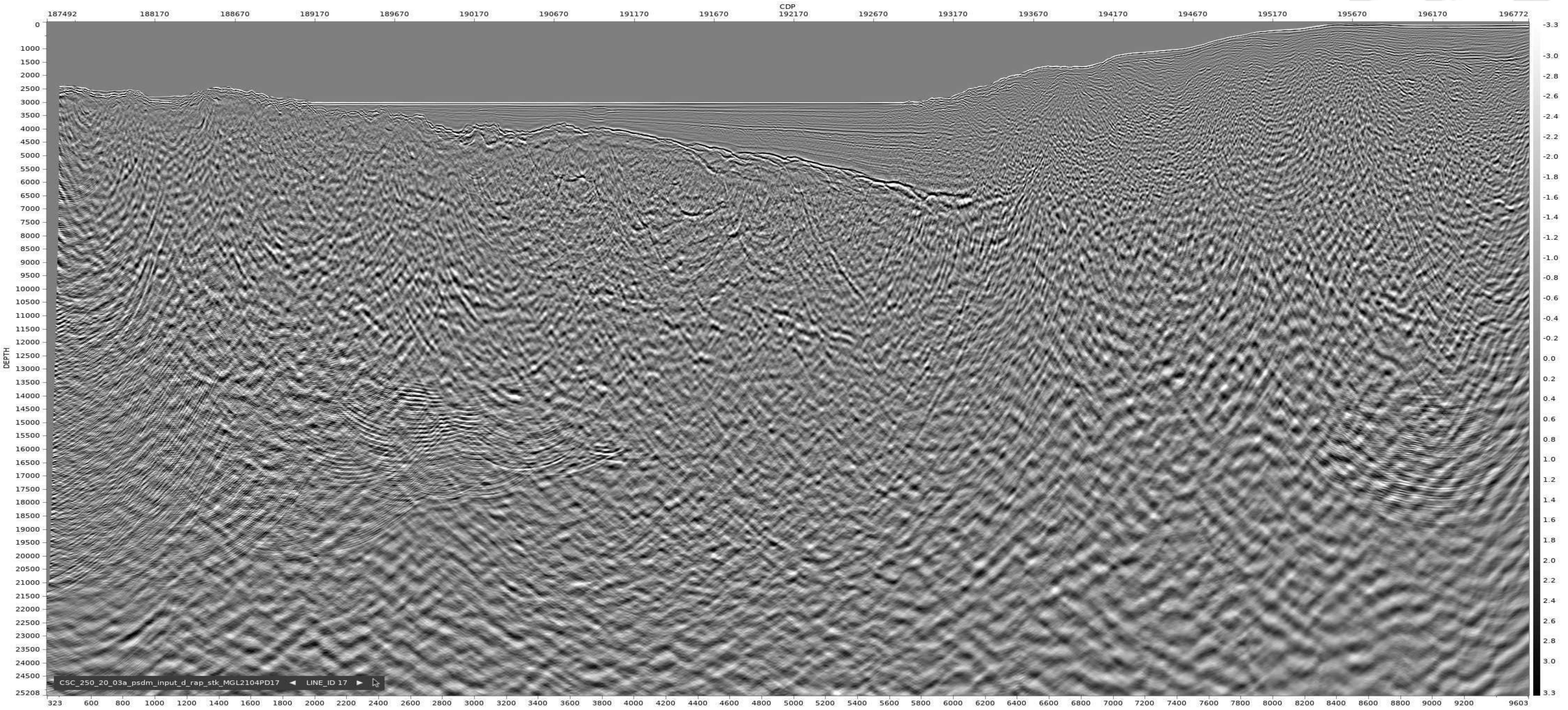
PSDM Stack - Before Post Stack Processing LINE - MGL2104PD03



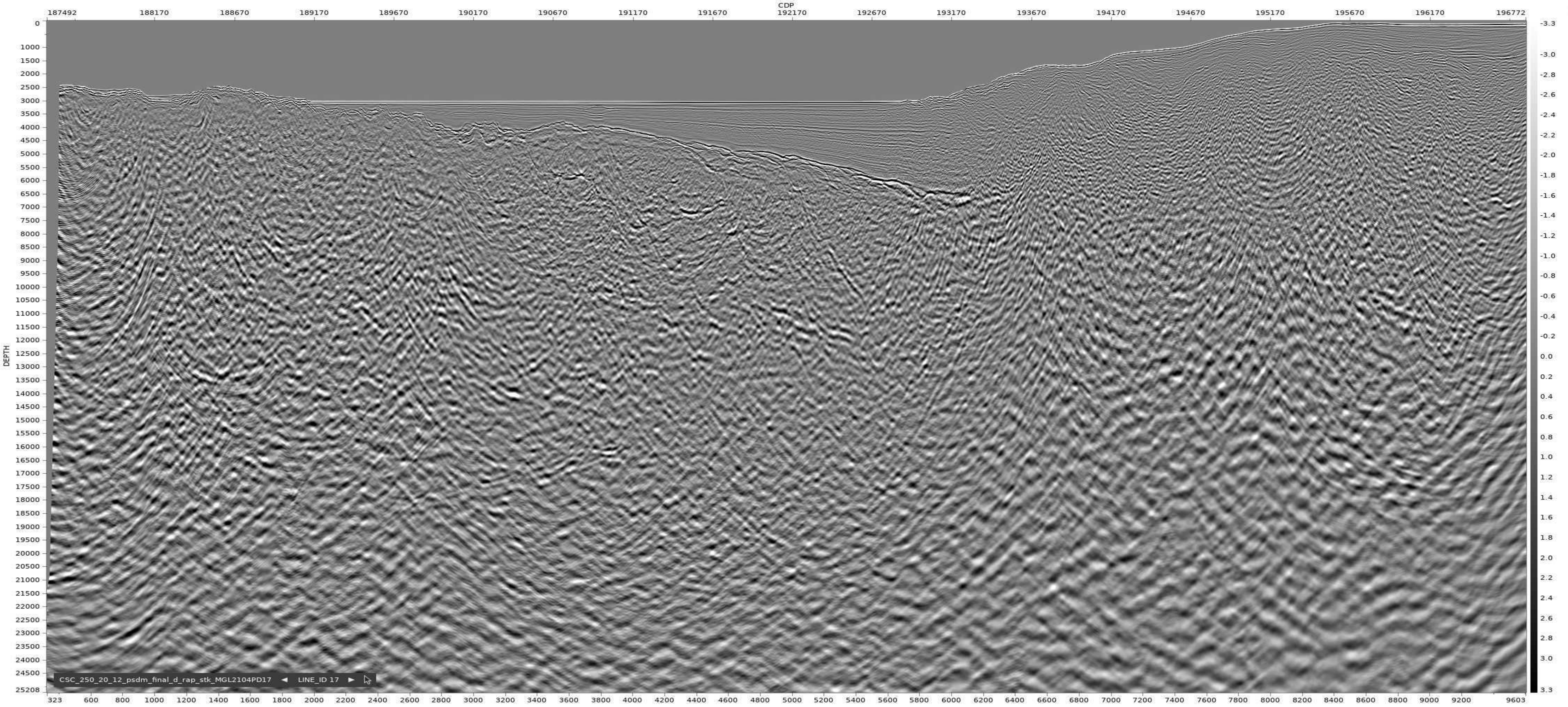
PSDM Stack - After Post Stack Processing LINE - MGL2104PD03



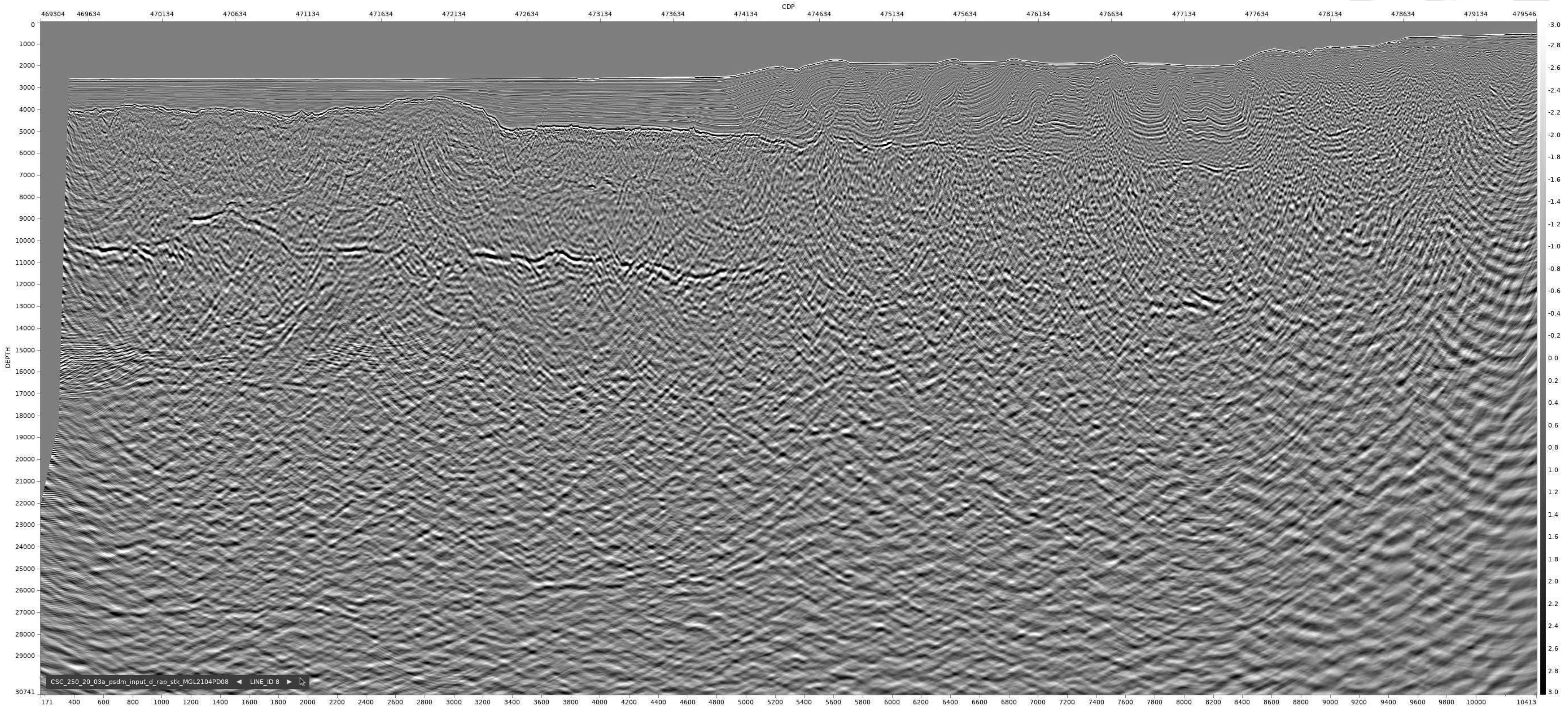
PSDM Stack - Before Post Stack Processing LINE - MGL2104PD17



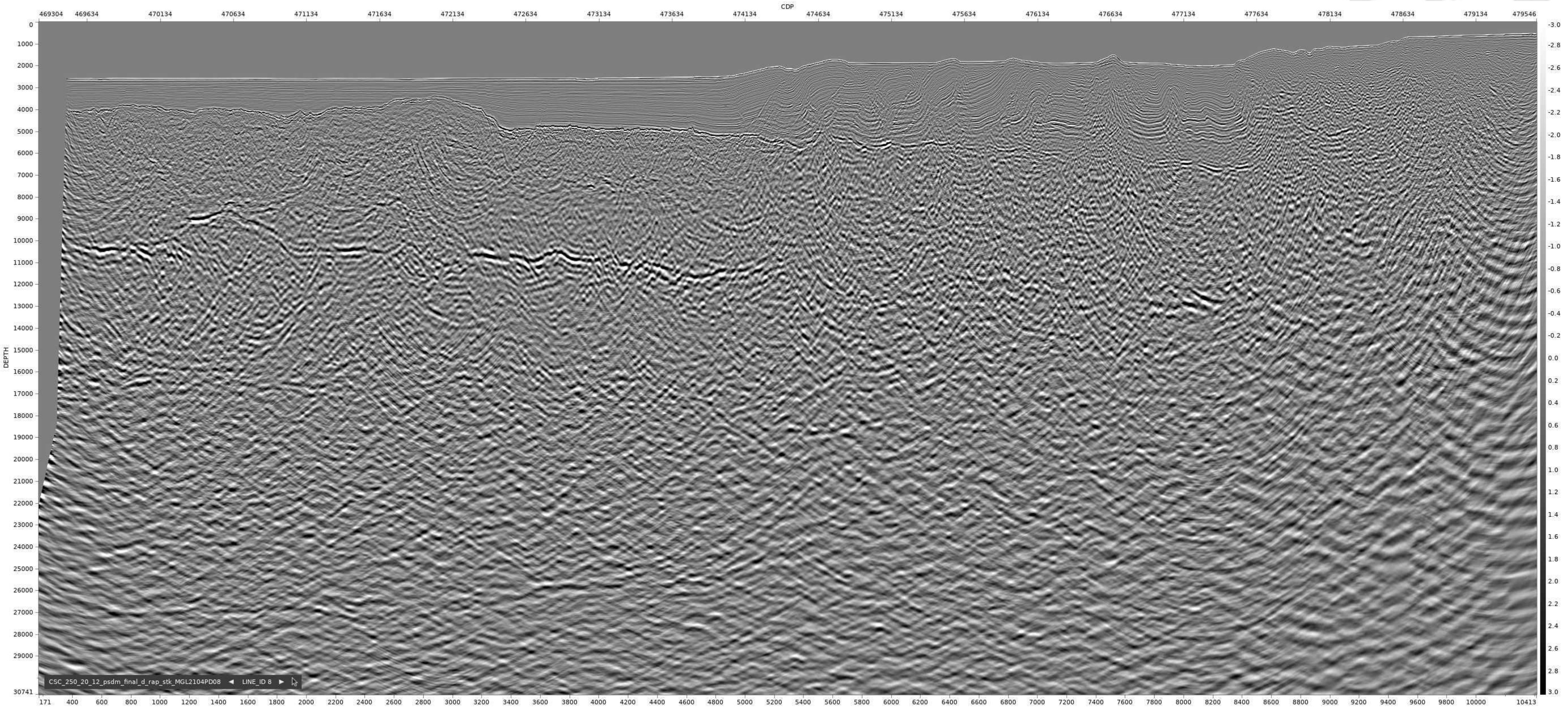
PSDM Stack - After Post Stack Processing LINE - MGL2104PD17



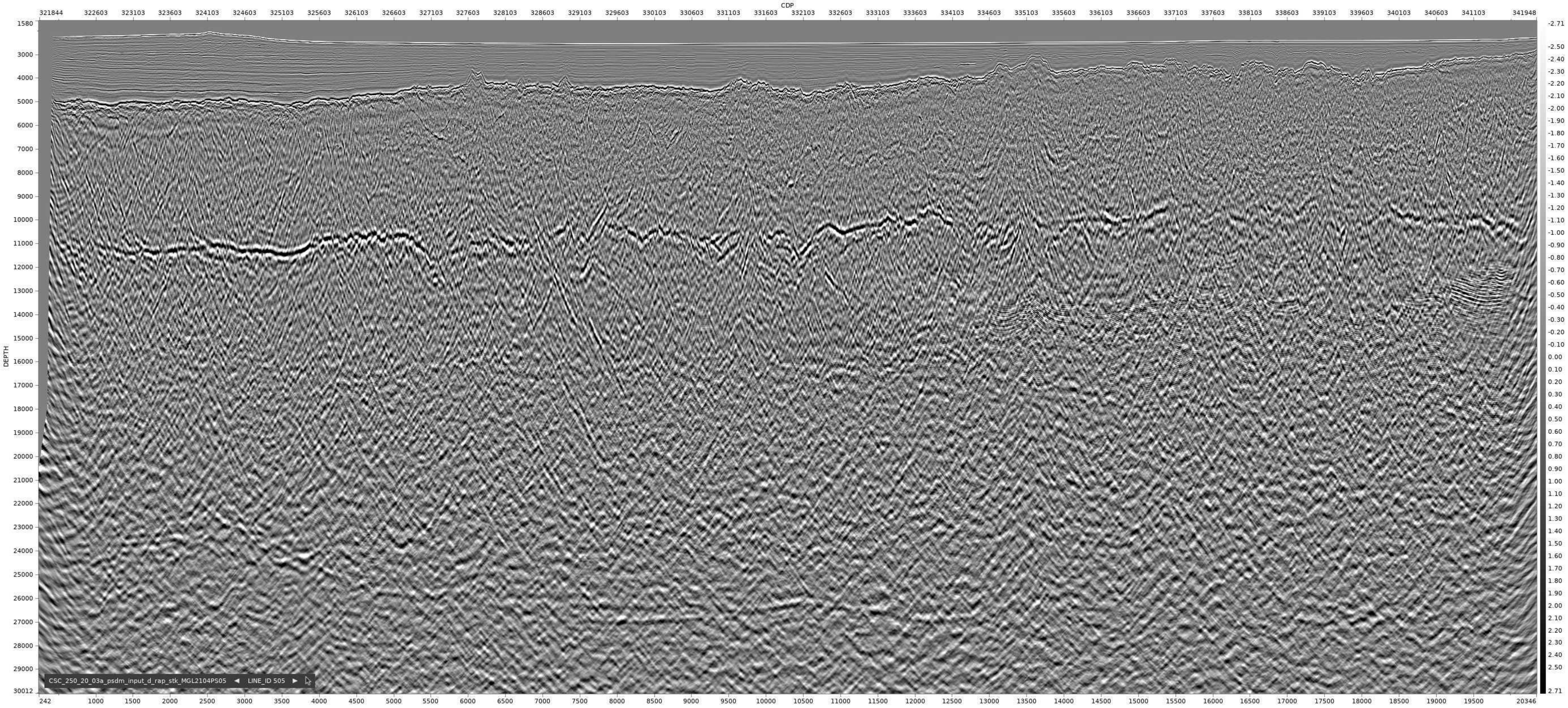
PSDM Stack - Before Post Stack Processing LINE - MGL2104PD08



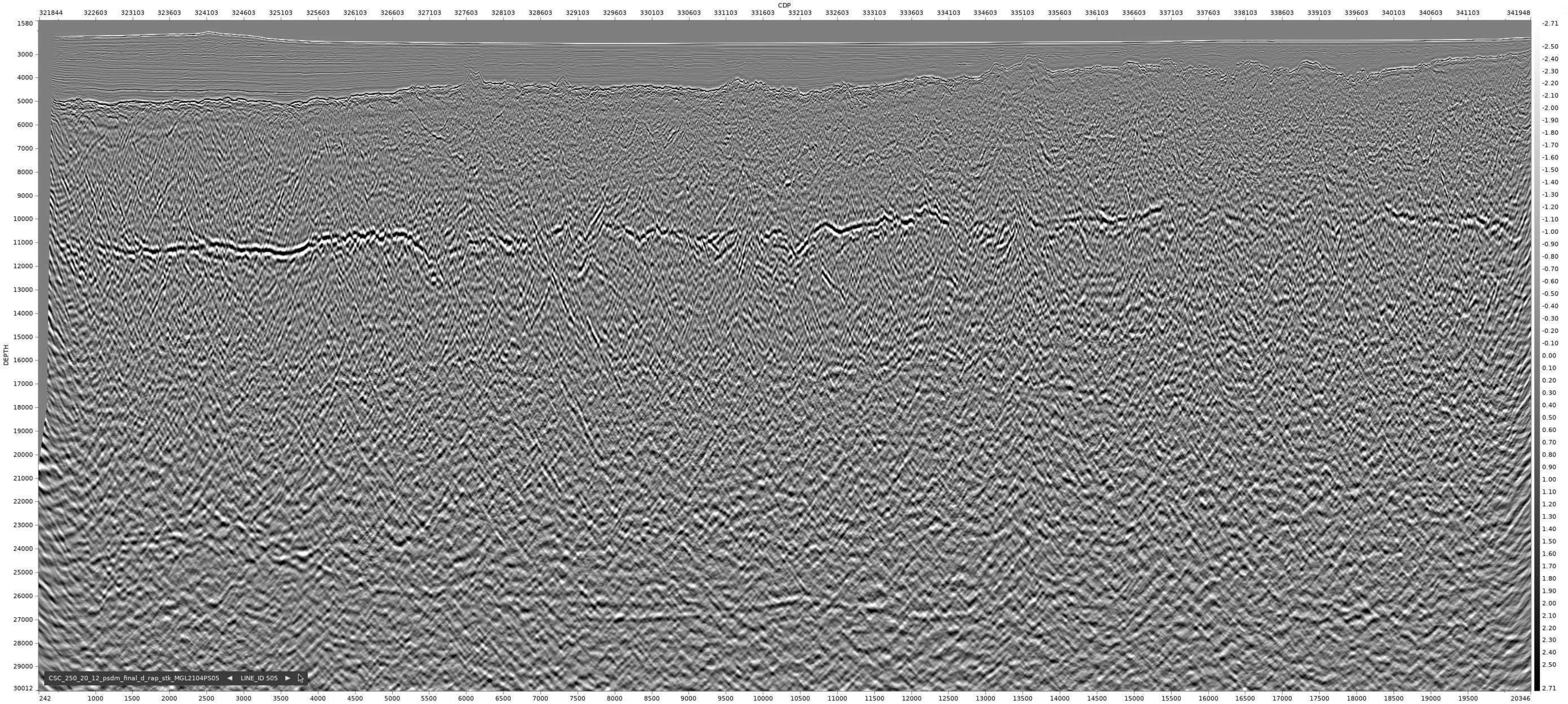
PSDM Stack - After Post Stack Processing LINE - MGL2104PD08



PSDM Stack - Before Post Stack Processing LINE - MGL2104PS05



PSDM Stack - After Post Stack Processing LINE - MGL2104PS05



Powering data-driven decisions