Wister 2013 3D Seismic Processing Report

Prepared for Ormat Technologies
by CGG Subsurface Imaging

September 2014

Passion for Geoscience
cgg.com

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Proprietary Notice

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1. Introduction

This report describes the analysis, testing and processing applied to the Wister 2013 3D data set. The work was performed by CGG subsurface imaging for Ormat Technologies, in CGG processing centre in Calgary, Canada 2013.

The final processing sequence was developed based on a complete set of CGG standard tests, auxiliary tests as deemed relevant to this data set, and client requested displays and analysis.

Where appropriate, a small-scale figure is included directly within the text. Please note all images included in the report and additional images are also assembled as PowerPoint® slides on the accompanying CD. The reader may wish to toggle the PowerPoint slides on the screen as a convenient method to visually compare the images.

1.1 Ormat 2013 3D Acquisition Parameters

AREA:	Wister 3D		
LOCATION:	Imperial, California		
BIN SIZE:	110 x 110 FT	ACQUIRED:	2010

SOURCE INFORMATION

SHOT BY:	Dawson Geophysical Company
LINE ORIENTATION:	N-S
NUMBER OF SHOTS:	1275
SOURCE TYPE:	Vibroseis
SWEEP SPECTRUM:	4 TO 96 HZ
SOURCE ARRAY:	SINGLE VIBES
SWEEP LENGTH:	24SEC
SOURCE INTERVA:	220 M
SOURCE LINE INTERVAL:	229 M

RECEIVER INFORMATION

LINE ORIENTATION:	NE-SW
RECEIVER TYPE:	3C Geophone
NUMBER OF STATIONS:	1826
RECEIVER ARRAY:	SINGLE
RECEIVER INTERVAL:	311 M
RECEIVER LINE INTERVAL:	95 M

RECORDING PARAMETERS

INSTRUMENT:	GSR
FILTER:	LOWCUT 3 HZ HIGHCUT 207 HZ
NOTCH FILTERS:	OUT
SAMPLE RATE:	1MS
RECORD LENGTH:	6000MS

2. Processing Flow and Parameters

1. Demultiplex / Re-format

2. 3D Geometry
   Bin size: 110 x 110 FT

3. Rephrase: zero phase to minimum phase
   Spherical Divergence
   Type: T^1.4

4. Surface Consistent Scaling
   Line, shot, receiver components
   Design window: as per Decon design window
   Design window:

Offset [ft]	Time[ms]
139	250-1600
4300	1000-1800

5. Structure Statics

Analysis method:	FirstBreak Tomography
Datum elevation:	0 ft
Weathering velocity:	3000 ft/s
Replacement Velocity:	5000 ft/s
Application:	Surface consistent short wavelength component only

6. Low Frequency Coherent Noise Attenuation C.N.A. on shots

7. BLAST and FLASH De-burst

8. Preliminary Velocity Analysis: Double square root NMO

Type:	Constant Velocity Stacks – 20 row interval
Reference:	Datum

9. Stack for QC – Noise attenuation and structure

10. Residual long wavelength static correction. Calculated from shot and station stacks.

11. Surface Consistent Scaling
    Line, shot, receiver components
    Design window: as per Decon design window
    Design window:

Offset [ft]	Time[ms]
139	250-1600
4300	1000-1800

12. Surface Consistent Deconvolution
    Line, shot, and receiver components were applied.
    Operator Length: 120 ms
    Pre-whitening: .01%
    Operator design gate:

Offset [ft]	time [ms]
139	250-1600
4300	1000-1800

13. Automatic Surface Consistent Statics 1

Design window:	300 - 1500 ms
Design filter:	10/15 – 40/50 Hz
Max. Static:	+/- 10 ms

14. Velocity Analysis: Double square root NMO

Type:	Interactive Semblance – 800 ft interval
Zone:	3x3
Reference:	Datum

15. BLAST and FLASH De-burst

16. Final Velocity Analysis
    Referenced from floating datum
    Analysis interval: 250 x 250 m grid

17. Second pass residual long wavelength static correction.

18. Automatic Surface Consistent Statics 2

Design window:	300 - 1500 ms
Design filter:	10/15 – 70/80 Hz
Max. Static:	+/- 30ms

19. Surface Consistent Scaling
    Design window:

Offset [ft]	time [ms]
139	250-1600
4300	1000-1800

20. 5D Interpolation – Regularization of data.

Pre-Stack Migration Sub-Flow

**** Input Gathers from STEP #19 ****

21. Accordion binning migration prep

22. PSTM Velocity Analysis – Migrated Constant Velocity Stacks

23. 3D Kirchhoff Pre-Stack Time Migration

Half aperture:	8800 ft
Anti-aliasing:	75%
Max angle:	80 degrees

24. Residual velocity Analysis

25. Stacking mute, Stack

26. Structure Statics

Analysis method:	Refraction Tomography
Application:	Long wavelength component

3. Geometry

3.1 Overview

The accuracy of the geometry information is crucial not only for proper positioning of structural features, but also to obtain the best overall signal to noise ratio. Incorrect positioning of shots and/or receivers will result in improper distribution of traces into CDP bins and degraded signal-to-noise ratio.

The geometry was generated using various pieces of information. These included:

- Source and receiver locations and elevations from SEGP1
- Source/field file number relationships
- Receiver pattern information for individual shots
- Driller's reports for specific hole depth information
- Observer logs

3.2 Geometry Information from Trace Headers

The primary source of the relationship between Field Record Number (FFID) and Source Location was the tape headers of the seismic. These headers also contain detailed shot pattern information (cable), relating source and receiver number to physical location for each recorded trace on all individual shots.

3.3 Survey Information QC

Survey information was received in the form of SEGP1 files. This information is first checked for any gross errors before being incorporated into the geometry. Small-scale errors are later determined by combining the geometry with the recorded seismic data.

The methodology used to determine gross errors is to graphically display the source and receiver coordinate information to ensure overall compliance with the acquisition map. Relative distances between consecutive source/receiver locations were displayed to confirm that the interval fell within an anticipated range.

Survey information is used to ensure overall compliance with the acquisition map. Relative distances between consecutive source/receiver locations were displayed to confirm that the interval fell within an anticipated range.

Elevation Maps

In addition to checking the elevations of the individual source and receiver lines during the reading of the SEGP1 files, the elevations of the total survey were also verified by creating and inspecting a color map of the surface elevations.

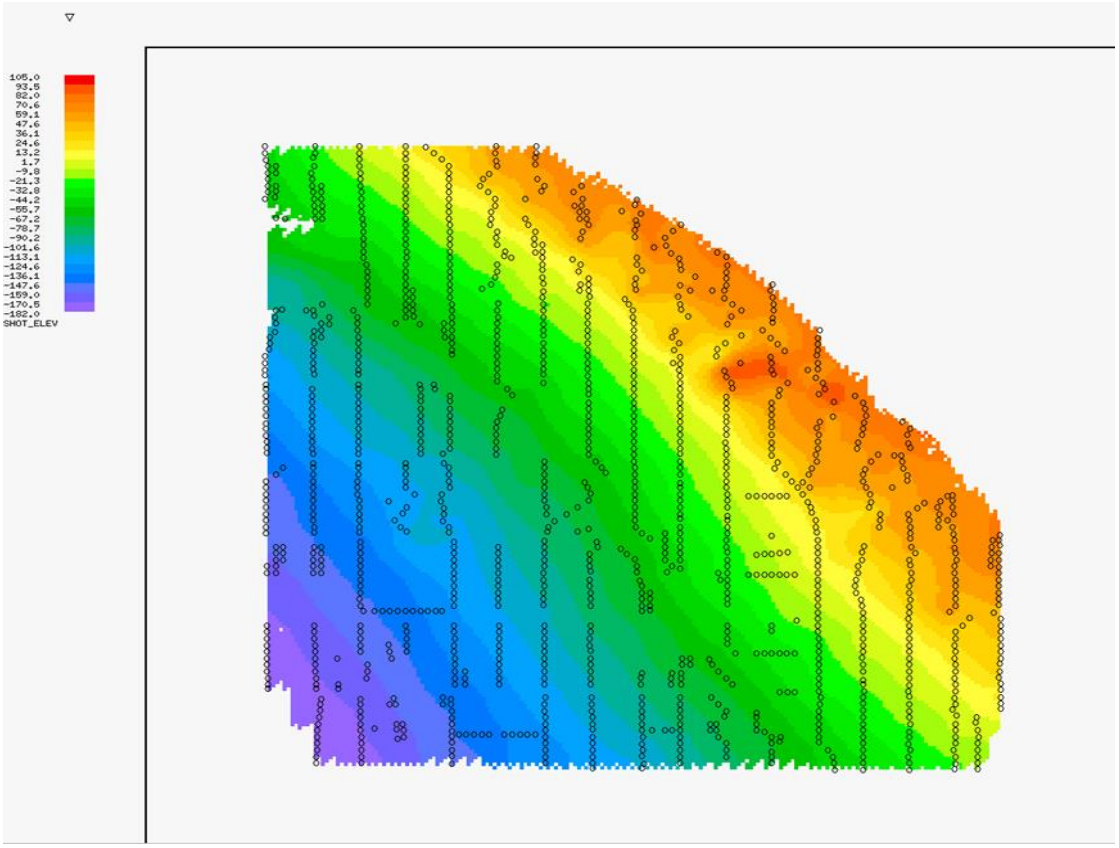


Figure 3-1: Surface elevation map of geometry with shots shown.

3.4 Geometry QC

A number of different approaches to ensure proper shot and receiver positioning may be used. Shot and receiver positions identified as having potential coordinate errors were interactively reviewed and adjusted if necessary. A description of the various geometry QC methods is given below.

Linear Velocity Overlay

In the first pass through the linear velocity QC procedure, the first break pick times are used independent of the refraction solution. This locates any large skid or positioning errors in the relational data, provided that the first break picks are reasonable.

A utility called GLIMDL_STK was run on the data set to estimate shot / station skid errors and store them in the geometry database. This estimate is based upon the actual first break time of the data compared to the offset as stored in the geometry. The value assigned represents the difference, in ms, between the geometry profile and the actual pick time. The validity of this method is dependent on the quality of the first break picks, so visual analysis of the shot with respect to the geometry profile is a necessity.

This error information can be displayed in two ways. The first method is a simple SHOT vs. ERROR graph done over the entire shot range. A second method is to display the error value attributes in the geometry database in plain view.

Either QC method will indicate any shot records that require further checking. At this point, any problematic shot is reviewed interactively with first break pick times and time/distance profile displayed.

A line that represents a simple linear velocity (time/distance profile) is overlain above the first arrival on data display. A shot that has incorrect geometry assigned to it will show a discrepancy between the first arrival data and the linear velocity overlay. A misalignment represents either a shot that is mispositioned or incorrect cable configuration. The cable can be easily checked with other surrounding shots. As long as the surrounding shots' first breaks match their profiles, it may be assumed that they are correctly positioned. To verify the cable, distinctive receiver stations (such as dead or noisy stations) can be compared to the surrounding shots. In this way, it can be determined whether an error is due to incorrect source x-y position or is cable related.

Once we have determined that the error is a positioning issue, the shot is skidded into its correct position. This can either be done manually or with the interactive auto-skid utility. Note that at this stage the auto-skid utility is entirely based upon the first break picks. For finer detail, the difference between the refraction model and first break pick times may be displayed after running refraction analysis.

If a shot requires a positioning correction, the new x-y co-ordinate is saved and updated into the geometry database (geometry database). As mentioned previously, this method is dependent on the quality of the first break picks. The resolution of this method with exceptional first breaks is approximately ½ station interval. Generally speaking, errors of greater than 1 station intervals are found through the first pass QC checking.

REFRACTION Based Geometry QC

After correcting any large-scale errors via the SKID utility and updating the geometry database, the data are subjected to a second pass of geometry verification. This method combines the refraction solution and common source and receiver stacks.

In this geometry verification pass, the statics calculated through the refraction analysis are used instead of the first break pick times to further detect any possible shot/station errors. Rather than using the error graph display or the color map display to show problematic shots, common shot and receiver stacks are generated. Common shot stacks that have been flattened to the TOMO_MODEL are output. The TOMO_MODEL is the theoretical pick time derived from the model generated through the refraction analysis package as described in the next section. If the model is reasonable, and the theoretical picks flatten the data well, the resulting stacked trace compares well with surrounding traces. If the shot or station is positioned incorrectly, the resultant stacked trace is quite different from its neighbors and that shot needs to be examined further.

Quadrant QC (azimuth-restricted) stacks

In this QC, prior to stacking, each shot is split into four azimuthally-restricted quadrants based on shot-receiver azimuth. Five shot stacks are then generated: data from all azimuths, data from the first quadrant, second quadrant, third quadrant, and fourth quadrant. Windowed data (the first 500ms, typically) of the quadrant stacks are arranged in a tiered display. Even slight positional errors will stand out, as the opposite effects can be seen in opposite quadrants. As well, quadrant stacks were used to identify reverse polarity receivers.

Predicted first breaks applied as a static shift

This method applies the predicted first break pick times (calculated from the refraction model) as static shifts to the data. Shot and receiver stacks are then generated from the shifted data. The resulting stacks are analyzed for changes in the stack response that can indicate:

- Geometry errors (incorrect shot or receiver coordinates, incorrect cable definition)
- Poor quality first break picks
- Reversed/noisy/dead receivers
- Changes in the S/N for specific shots or receivers

All shots and receivers are reviewed and any apparent problems are investigated and corrected.

CMP Stack QC

Stack QCs are done throughout the processing flow as an efficient way to identify various problems.

3.5 Binning Strategy

The data were gathered into 110 x 110 ft bins. After the initial binning had been assigned, midpoint scatter maps were generated interactively to examine the distribution of midpoints within the binning space. At this point the grid could be shifted or rotated interactively to achieve the best possible fit between midpoint scatter and bin centers.

Corner Coordinates of Grid:

XY coordinates (Inline 1, Xline 1)	(2040355.1, 6771661.0)
XY coordinates (Inline 192, Xline 1)	(2061365.1, 6771661.0)
XY coordinates (Inline 1 Xline 196)	(2040355.1, 6793111.0)
XY coordinates (Inline 192, Xline 196)	(2061365.1, 6793111.0)

GEODETIC DATUM: NAD 83

3D Azimuth angle from north: 0 Degrees

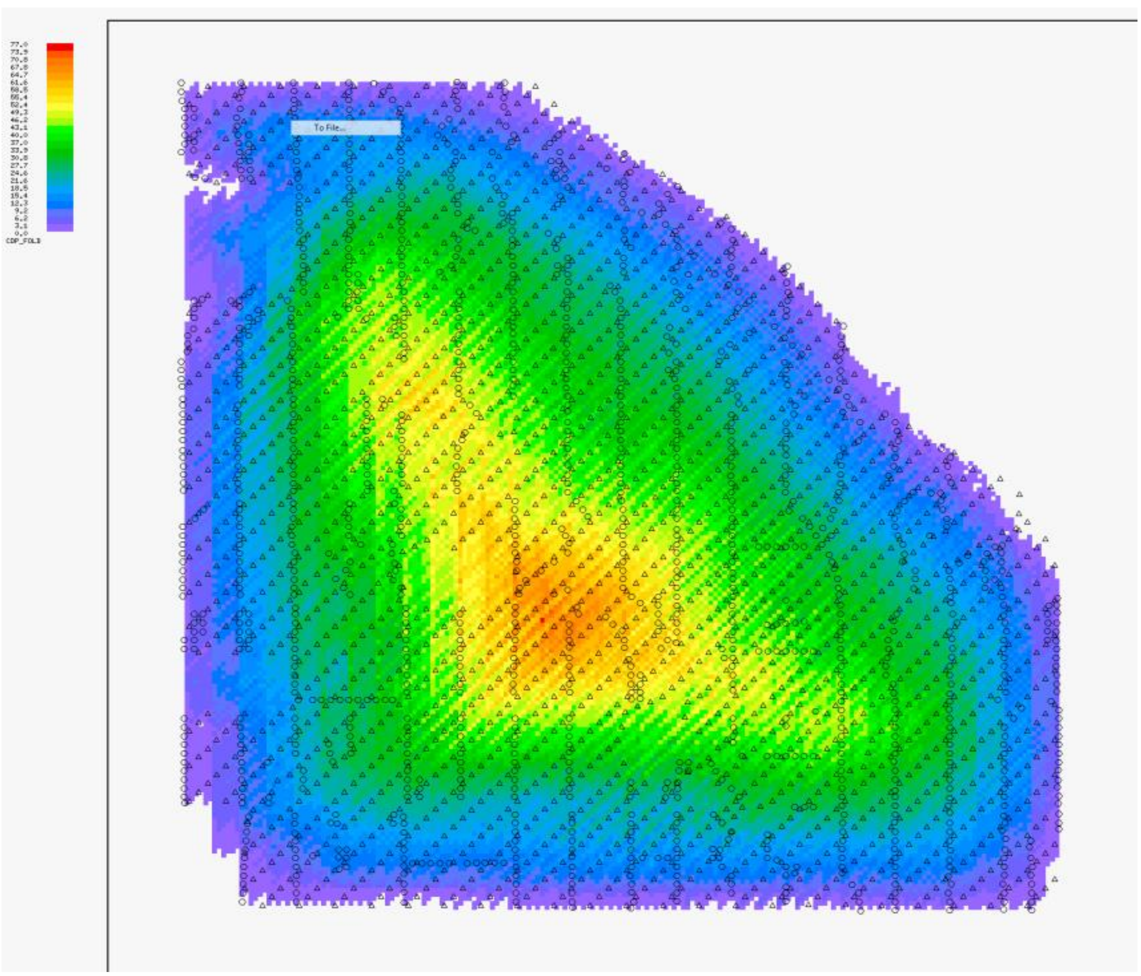


Figure 3-2: Full offset CMP fold associated with the final binning

4. Near-Surface Statics

4.1 Overview

Near-surface statics are always a significant concern, primarily due to the fact that the existing surface conditions during acquisition influence the accuracy of the resulting time structure. In this case, the first arrivals produced from the vibroseis source were of reasonable quality and provided reliable first arrival pick times. Errors associated with the refraction analysis are thus significantly reduced.

First breaks were picked and then used to generate both GLI and TOMO refraction static solutions, upon review, the TOMO solution was selected for production.

4.2 First Break Picking

Field data proved to have reasonable signal to noise ratio to allow for a guided automatic picking of the first breaks in batch mode. Upon subsequent interactive checks of first break pick quality, some areas required the additional manual re-picking process.

4.3 GLI Generalized Linear Inversion Method

GLI (Generalized Linear Inversion) mathematically ray-traces an initial earth model (defined by the processor) and compares the differences between the modeled and the actual first break pick times. The program then uses a linear inversion method to determine a corrected near surface earth model. The corrected model is iterated back through the program generating another set of solutions, continuing for a specified number of iterations to achieve a final model. The initial near surface earth model for the GLI refraction statics may be built using the velocity and time intercept information extracted from the first break picks of the seismic data.

GLI is appropriate for a layered near surface with mild lateral variations, and computes a natural base of drift. **Turning-Ray Tomography** represents the near surface as a grid model and is better equipped to handle vertical gradients, inversions and more complex velocity variations than traditional layer-based methods.

4.4 Turning-Ray Tomography Method

Tomography is a method of determining the internal structure of a solid body by observation and analysis of waves that have travelled through the body along different paths. For seismic tomography, this usually translates into analyzing the difference between observed travel-times and travel-times calculated by ray tracing through a gridded velocity model. The model is globally updated to minimize these travel-time differences.

The near surface velocity structure is represented by a grid model. Each node of the grid is assigned a node velocity and velocity within a grid cell is linearly interpolated from its node velocities. As the grid spacing is small and the node velocities can vary in an arbitrary fashion, the method can model strong velocity variations in both vertical and horizontal directions. First arrivals are treated as direct body waves propagating along turning rays, enabling the method to determine the first layer velocity as well.

The node velocities are determined by solving a nonlinear least-squares problem which minimizes the differences between the observed travel times of first arrivals and those predicted from the grid model. As the inversion requires intensive ray tracing, an accurate and efficient algorithm for travel time and ray path calculation is essential for practical applications. The algorithm must also be robust and devoid of the shadow-zone problem, which can severely reduce the number of observations usable in a tomography calculation and has hindered the tomography methods based on the traditional ray tracing techniques.

Grid Ray-tracing

CGG has developed a grid ray tracing (GRT) technique that combines the advantages of both wave front construction and fast marching methods (Zhu and Cheadle, 1999). This method calculates travel times and wave propagation vectors by tracing rays locally within a grid cell and has been shown to be highly accurate and efficient in modeling turning rays in near-surface environments.

Inversion Scheme

The nonlinear least-squares problem for determining the node velocities of a grid model is solved by successive linearization. The linear least-squares problem resulting from this linearization is, in general, ill-posed due to the limitations of data constraints and the nonlinearity of the inverse problem. Additional constraints on the inverse problem are necessary in order to stabilize the iteration. We regularize our inversion by including in its matrix equation both smoothing and step size constraints; the former reduces the roughness of the velocity model and the latter limits the linear approximation within a trust region. The nonlinear inverse problem is thus reduced to solving iteratively a regularized, linear least-squares problem.

We solve the linear least-squares problem with the LSQR algorithm introduced by Paige and Saunders (1982). The algorithm exploits the scarcity of the matrix equation for time and memory efficiency has been found to have a superior convergence property to other commonly used algorithms for solving sparse matrix equations (Paige and Saunders, 1982). The efficiency of the algorithm is further enhanced in our implementation by a number of modifications made to the original implementation. This, coupled with the grid ray tracing technique, makes our tomography method a highly efficient process for near-surface velocity estimation.

4.5 Near Surface Statics

As mentioned above, the TOMO solution was selected for production for this data set. The replacement velocity used was 2100 m/s and the final datum 750 m above sea level. TOMO was run on the merged data set.

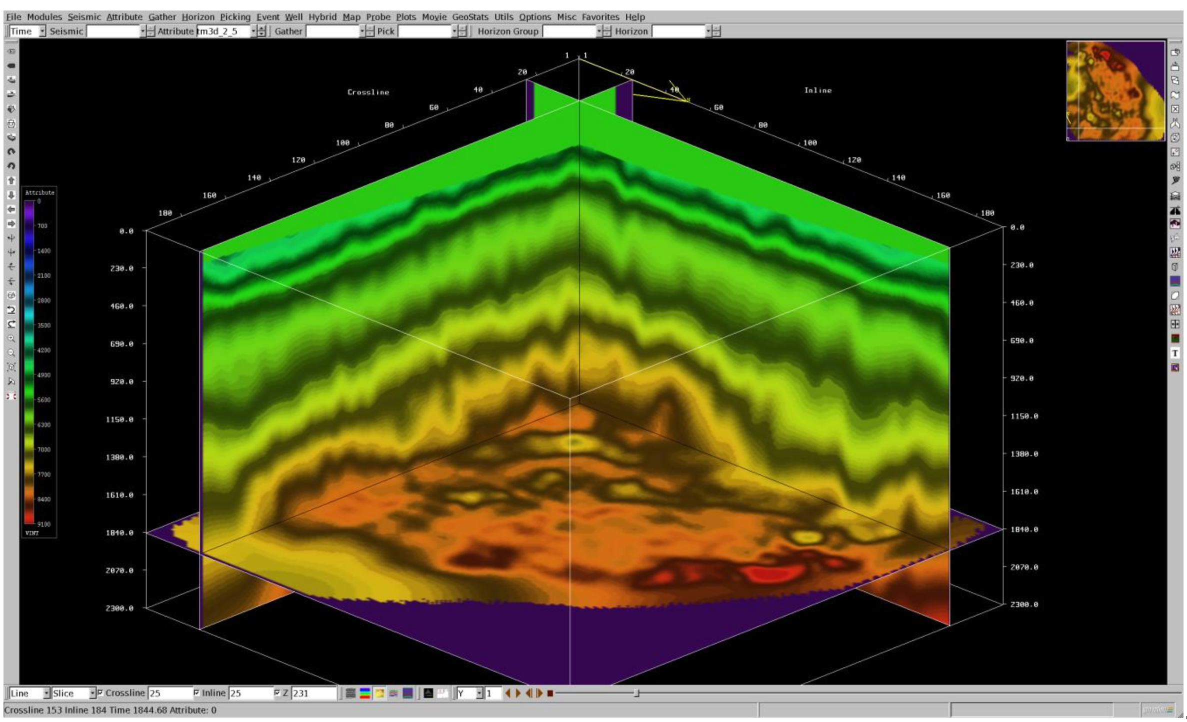


Figure 4-1: TOMO model. Pseudo-datum=400 ft.

5. Amplitude Recovery

Divergence is the spreading out of energy into a greater area as the wave front travels and spreads. Divergence correction was applied via At^N. Various values of N were tested, and simple t^1.4 divergence correction was applied.

6. Re Phase – Zero Phase to Minimum Phase

Vibroseis data is zero phase, our surface consistence decon requires minimum phase data. So we need to adjust the zero phase data to minimum phase by following method: Specify a geophone setting, a recording instrument, a Klauder wavelet (Vibroseis sweep), feeds these responses into a spiking deconvolution algorithm to determine by how much the responses fail to be converted to zero phase, then removes this phase difference from the data.

7. Surface Consistent Scaling

Surface-consistent source and receiver scalars are calculated to account for shot-to-shot and receiver-to-receiver amplitude variations which may arise from physical differences (for example, charge size or receiver-sensitivity differences from station to station) and coupling differences. Further, surface consistent scalars are usually calculated and applied at several stages in the processing sequence to ensure preservation of amplitude integrity after processes which may have affected amplitudes. For this project, it was performed 3 times at these stages: on the raw data after spherical divergence correction, after pre decon noise attenuation and after final post decon noise attenuation.

The surface consistent scalars were calculated over the same window as the deconvolution design window.

8. Pre-Deconvolution Noise Attenuation

8.1 C.N.A. - Pre-stack Adaptive Coherent Noise Attenuation

CNA is an AVO-friendly adaptive process to attenuate coherent noise such as ground-roll, air blasts, or guided waves on wide patch 3D shot or receiver gathers. It is also applicable for 2D shot or receiver gathers.

For each output trace, an offset- and azimuth-limited corridor of traces around the output trace is used to construct 2D “zone” for noise estimation. A modified pie slice filter is applied - in the FX domain - to the corridor of traces to estimate the noise on the output trace. The estimated noise is subtracted from the input to obtain the noise-attenuated output.

While ordinary FK filtering is global in nature and tends to smear large amplitude noise, C.N.A. is adaptive. That is, because a small number of traces are used in the model, and a new corridor model is constructed for each output trace, CNA is localized and therefore can adapt to changing noise conditions at different offsets and azimuths in 3D records. For example, the corridor for the output trace may contain seven traces. These seven traces are used to estimate the coherent noise train over a specified frequency range. The traces are offset ordered to construct a pseudo 2D gather, and a pie-slice velocity model based on the noise characteristics of this corridor of data is found that best fits the data in the FX domain.

The FX domain is used since it honors the true shot-receiver spacing, even if spacing is irregular. Because C.N.A. works in the FX domain, it is able to account for irregular shot-receiver spacing (ordinary FK filtering assumes regular spatial sampling, an assumption which is often not met by 3D shot geometry).

8.2 BLAST De-Burst

BLAST identifies high amplitude noise blasts and scales or mutes the zones. The method locates zones in traces where the amplitude envelope is excessively high (exceeding a user defined threshold). BLAST uses a global estimate of the median amplitude level for thresh holding purposes. The process usually targets a restricted frequency band to specifically target the noise while leaving the bulk of the signal band unaffected. The identified noisy zones are then muted or down scaled and a difference taken to isolate the noise. This is then subtracted from the original broadband input.

BLAST is particularly good for attenuating incoherent shot blast noise and eliminating clipped or spiked signals. BLAST is robust and safe noise removal method and does not alter data anywhere except in zones where amplitudes exceed the threshold and only within the restricted frequency range of the targeted noise problem. If there are no high amplitude zones in the data, BLAST leaves the data unaltered.

8.3 FLASH

Process FLASH was performed to identify and scale down any high amplitude outliers in a zone of traces by comparing the amplitude of each trace with the localized median estimate in the zone. The identified noisy traces are scaled to zero and a difference is taken to isolate the noise in that frequency range. To execute noise attenuation, the noise is then subtracted from the original broadband input.

FLASH is particularly effective for eliminating clipped signals or spikes. FLASH is a robust and safe noise removal method and does not alter data anywhere except in zones where amplitudes exceed the threshold of the targeted noise problem. If there are no high amplitude zones in the data, FLASH leaves the data unaltered.

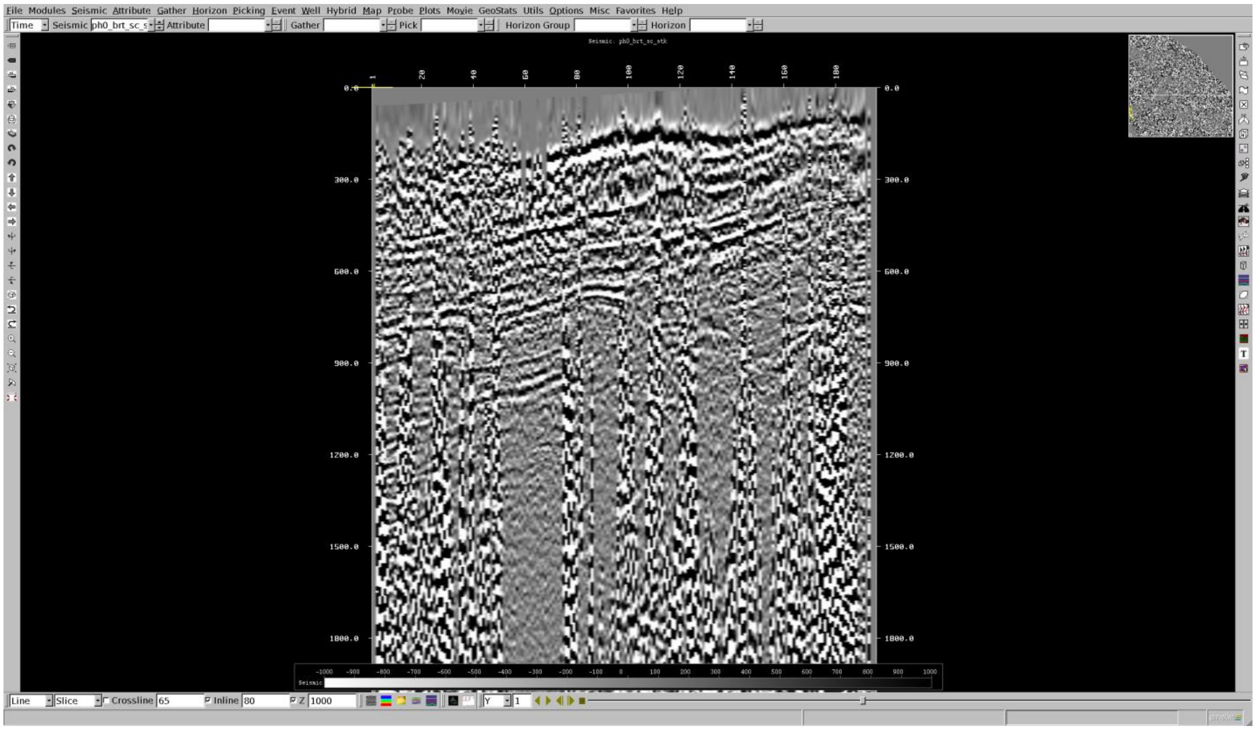


Figure 8-1: Stack before noise attenuation IL 80.

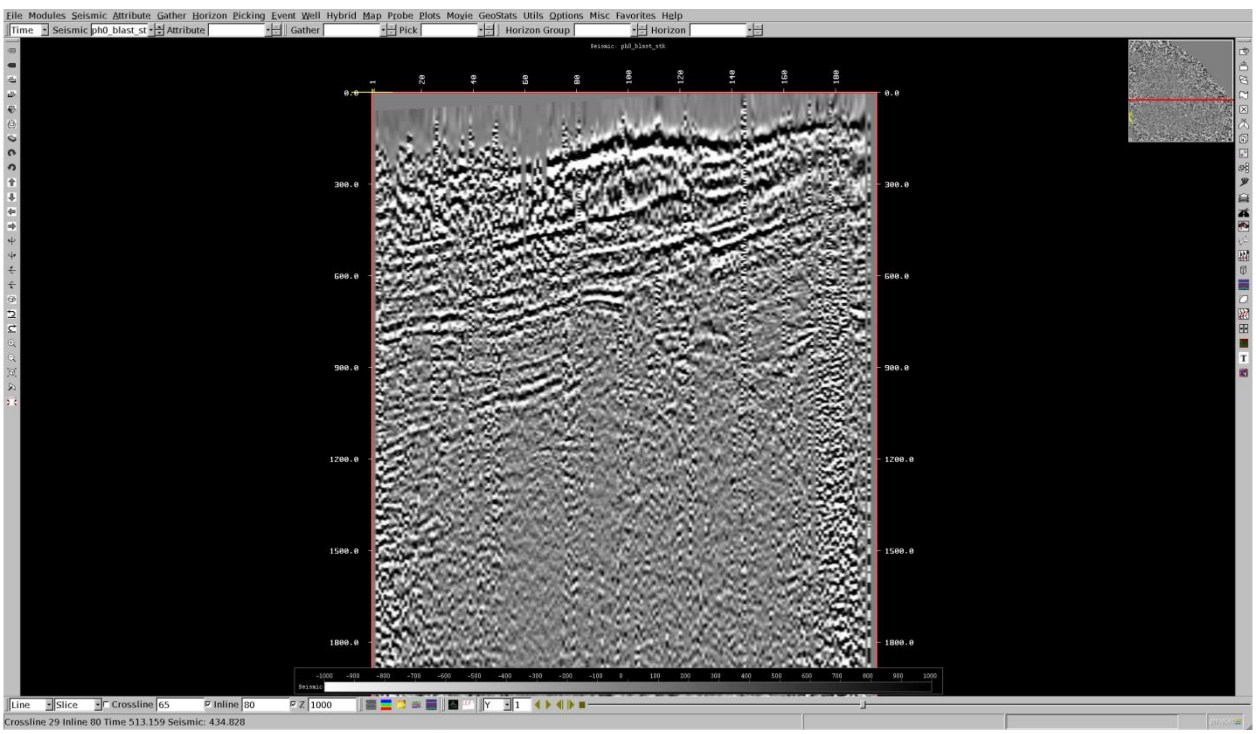


Figure 8-2: Stack after noise attenuation IL 80.

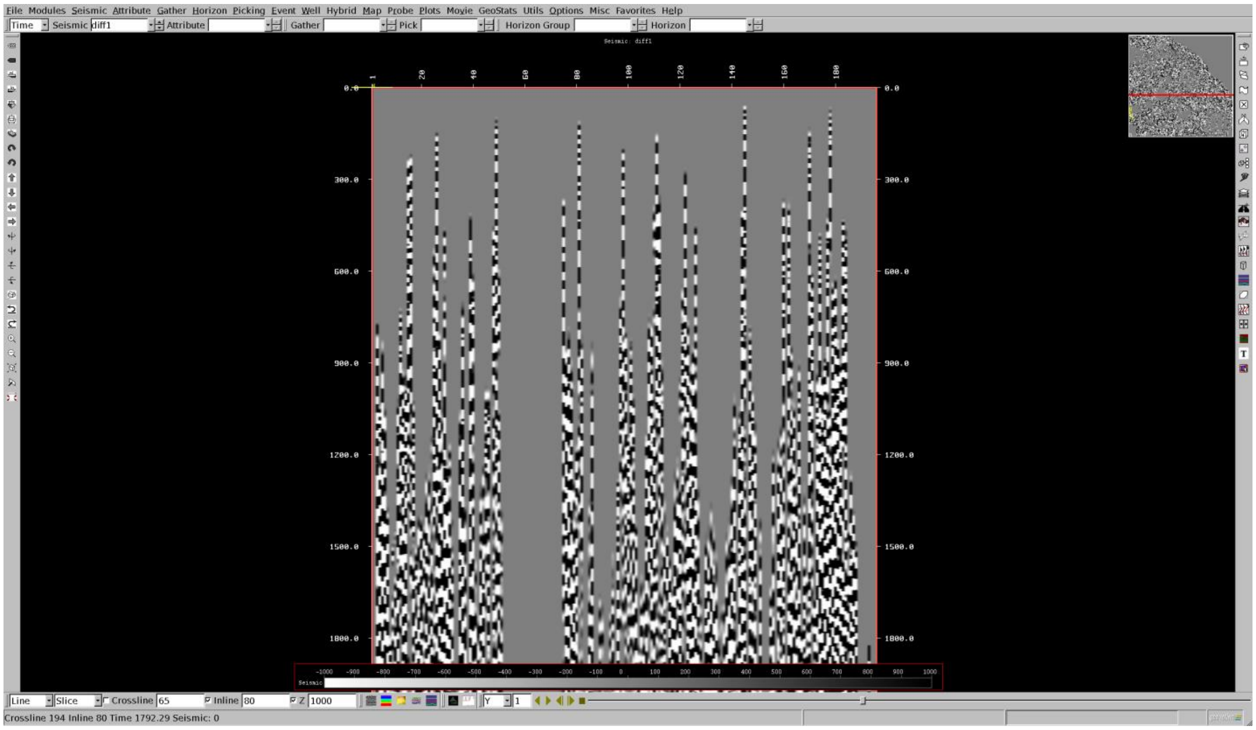


Figure 8-3: Total noise removed by Pre-Decon Noise Attenuation IL 80.

9. Deconvolution

Surface-consistent deconvolution is a multi-channel process. By using the redundancy of multichannel seismic data in deconvolution, we see increased reliability of operator estimates. Since the deconvolution operates surface-consistently, it improves the picking process for residual statics corrections. A key assumption behind statics determination is that the cross-correlation of two reflection events is maximized when the events are aligned. Unless the events are similar wavelets, this will not be the case. Surface-consistent deconvolution acts to balance the spectra of seismic traces, improving the similarity of the wavelets. This is a helpful benefit for surface-consistent statics decomposition, which assumes the trace-to-trace shifts fit a surface-consistent model.

The surface-consistent model compensates for the variations in source and receiver coupling. These are amplitude variations that are due to the seismic method and not indicative of legitimate variations in reflection coefficients. If we are to extract true AVO responses, we must de-convolve the data with care; the surface consistent deconvolution model makes it possible to accurately prepare the data for subsequent AVO and/or AVAZ analysis.

Data are often contaminated by noise which is not consistent to the surface. In such cases, pre-conditioning the data before deconvolution design can be a useful strategy to get better deconvolution operators. For this project, high amplitude noise and some coherent noise was attenuated prior to deconvolution, so that the deconvolution operators are calculated on clean signal rather than on data contaminated by noise.

The window over which the deconvolution operators were designed was based on the zone of interest as well as excluding consistently noisy zones – such as the first arrivals – from the deconvolution design. The deconvolution operators were computed from data within the design window, and applied to the whole trace length and to every offset. Line, shot, and receiver components were applied.

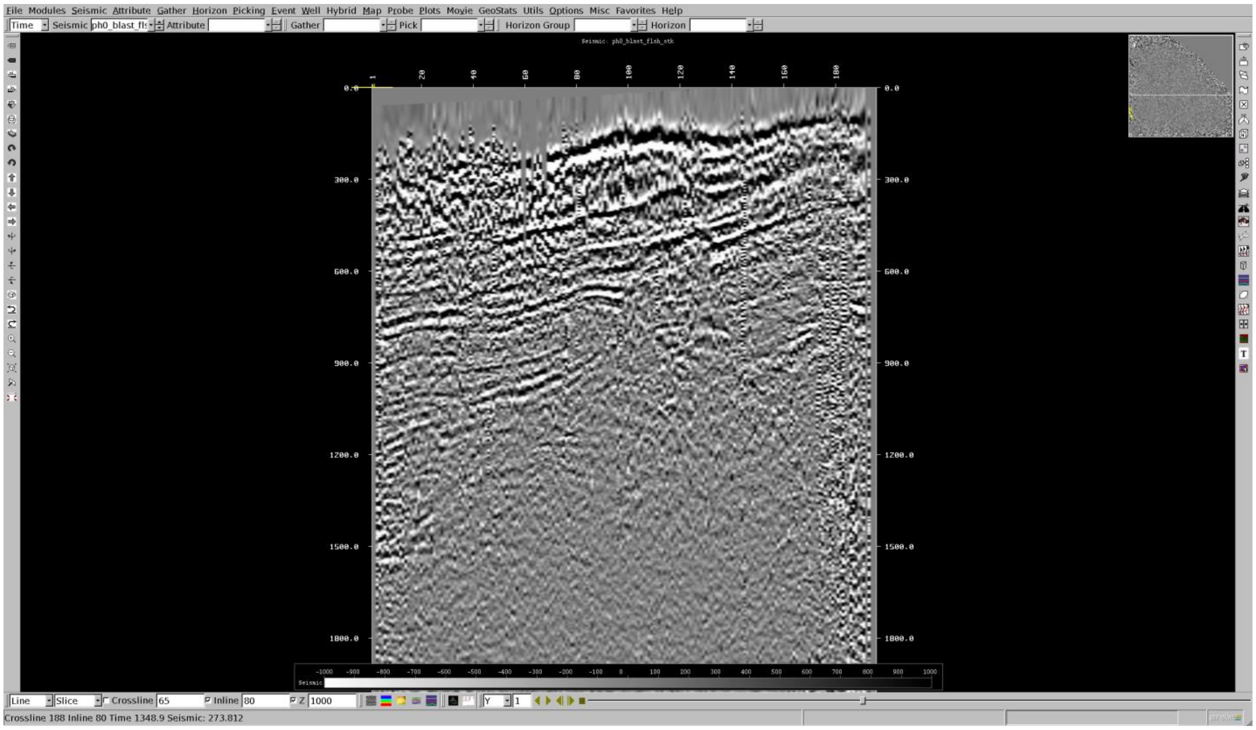


Figure 9-1: Stack after Surface consistent deconvolution IL 80.

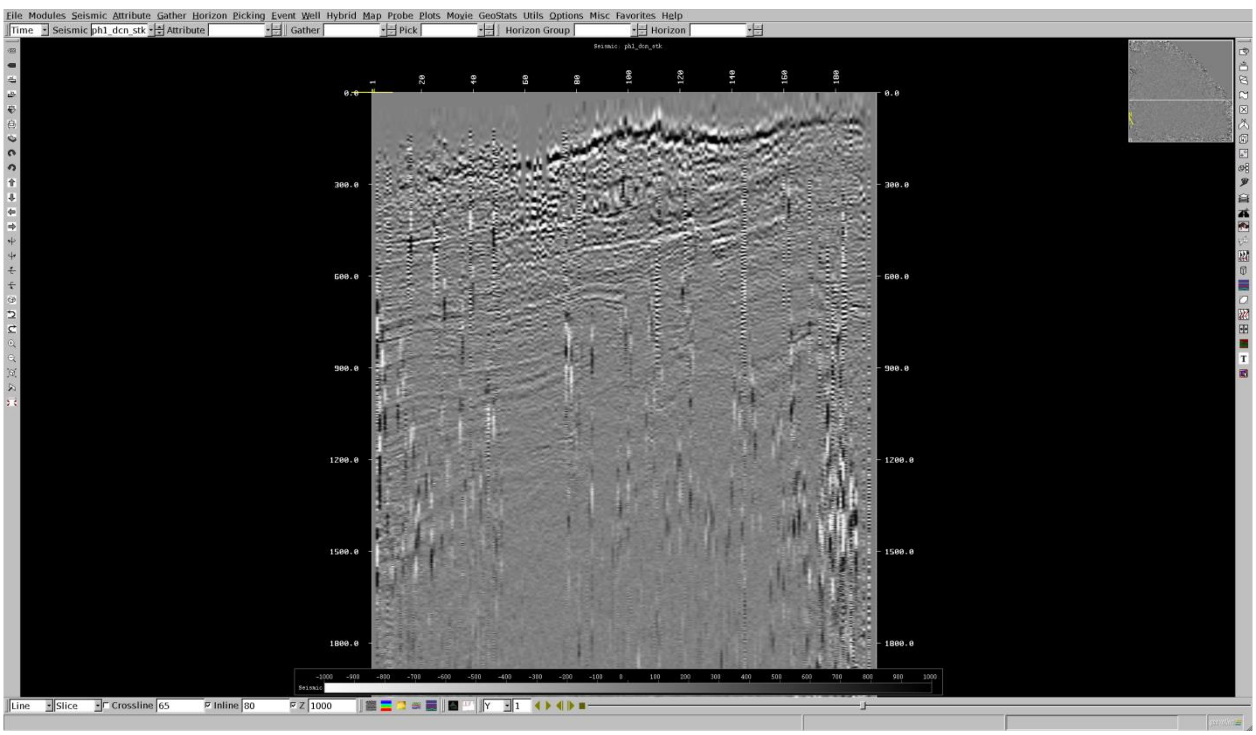


Figure 9-2: Stack after Surface consistent deconvolution IL 80.

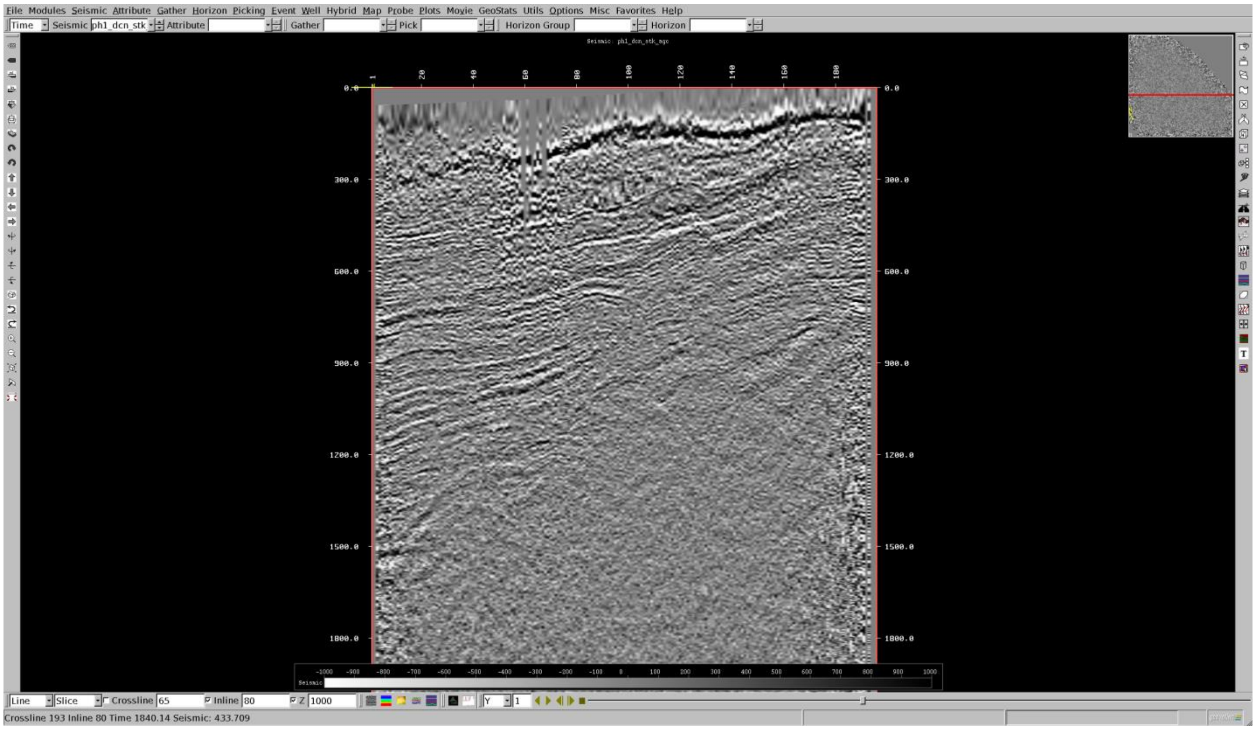


Figure 9-3: Stack after Surface consistent deconvolution IL 80 with 500 ms AGC.

10. Velocity Analysis

10.1 Overview

An initial pass of velocity analysis was performed with TOMO statics applied on constant velocity stacks. The velocities were then used to apply NMO correction prior to calculating the first pass of surface consistent residual statics (MASTT). The final pass of velocities was picked on common offset data.

10.2 Velocity Analysis

Velocities were picked interactively using common offset data and semblance panels. As part of the interactive velocity picking, NMO corrections were applied to Common Offset Stacks in real time, every time a velocity pick was adjusted. This was used as an initial QC of the velocity function.

Specifically, common offset stacks were generated using a 5x5 bin zone at 800 ft interval across the survey. Interactive velocity picking was performed to generate a stacking velocity field. A double square root NMO equation which compensates for any elevation difference between the shots and receivers was used.

The final first break mute function was also picked at this stage.

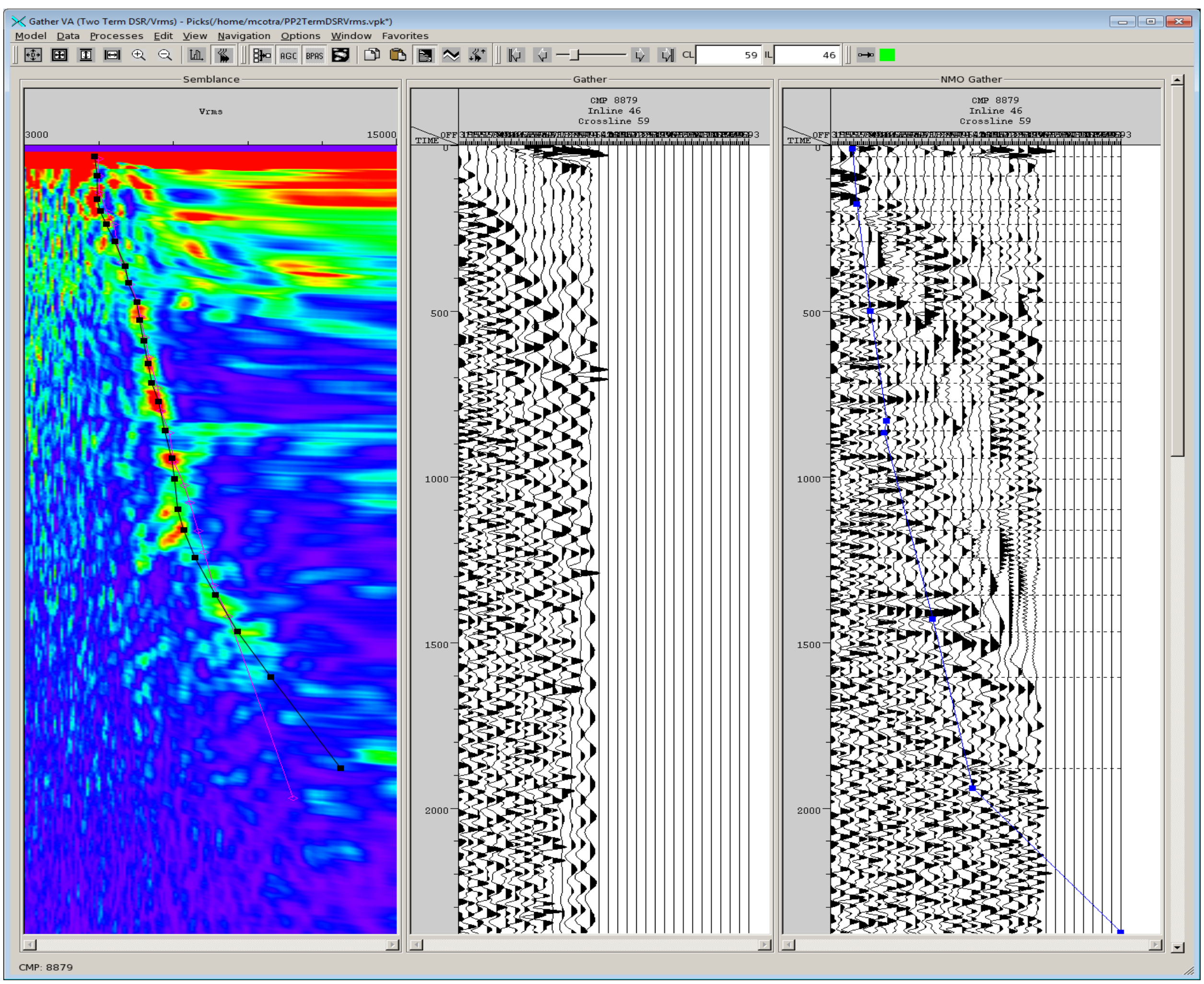


Figure 10-1: Velocity and mute analysis using common offset gathers

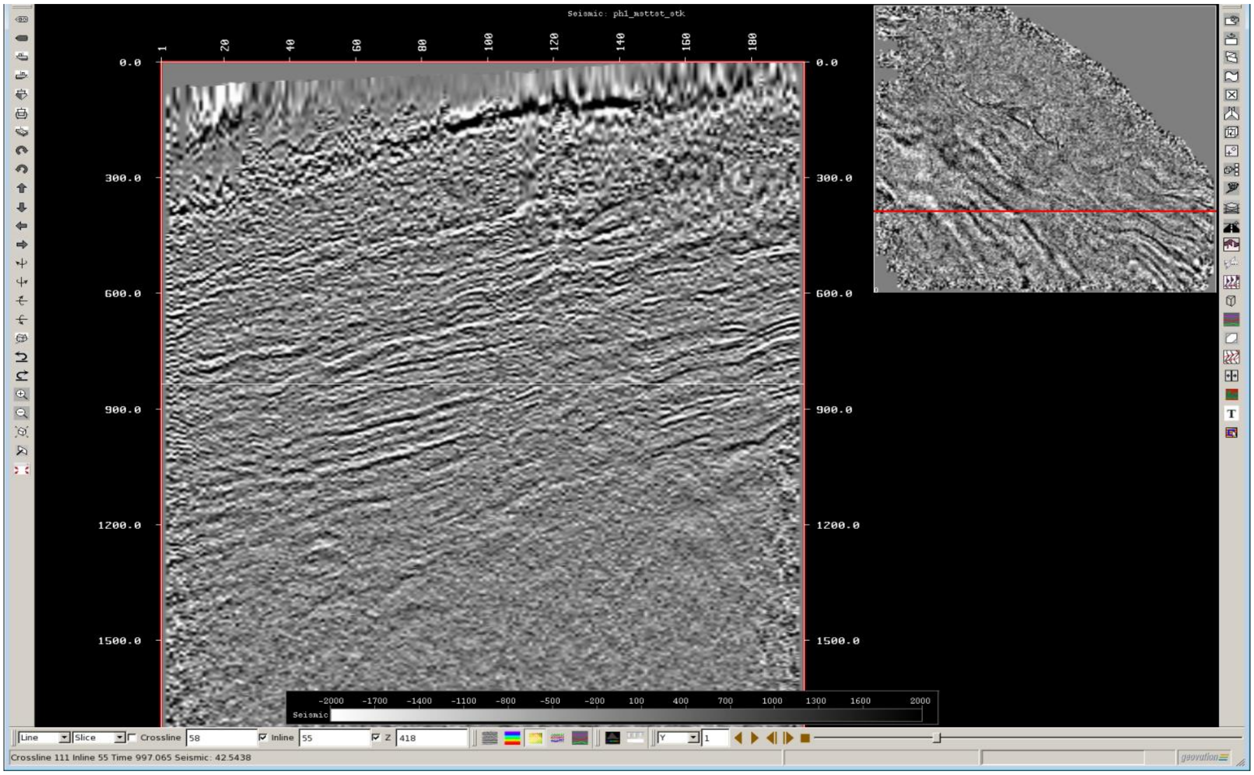


Figure 10-2: Stack after initial pass of velocity and mute analysis – IL 55

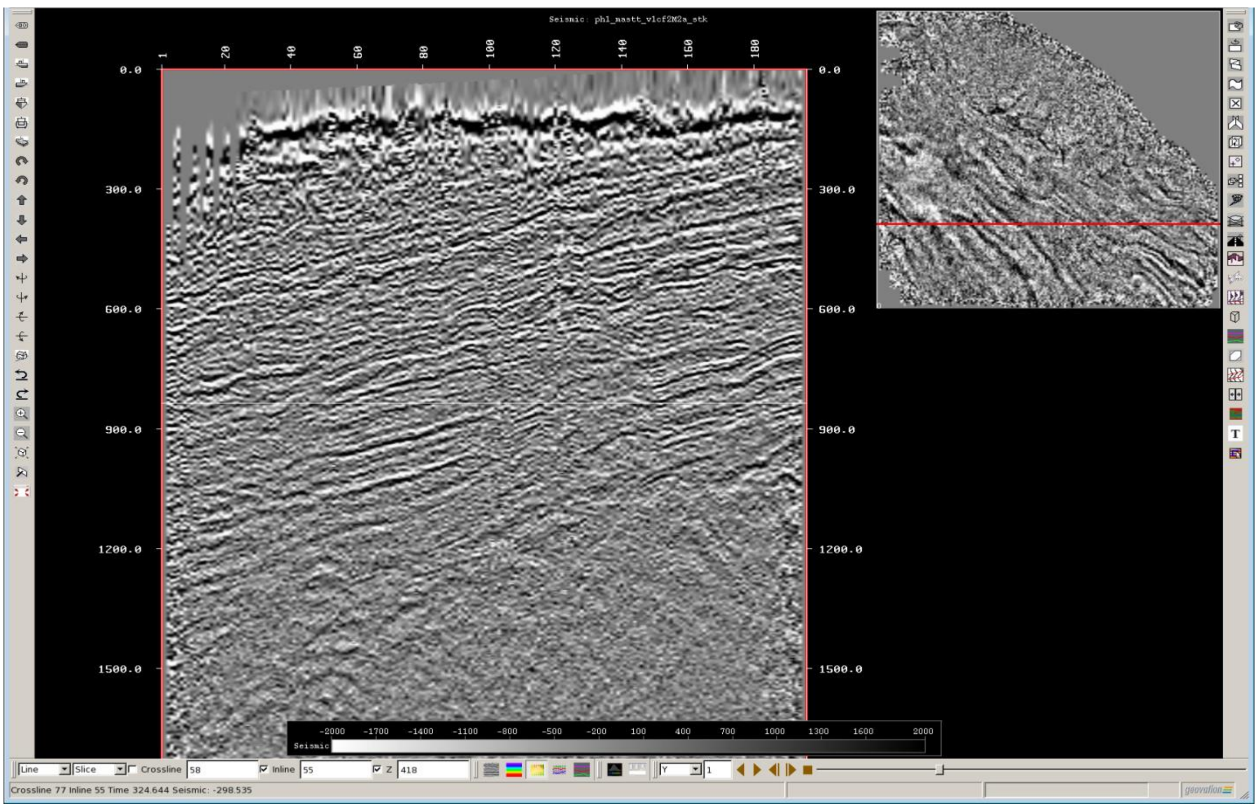


Figure 10-3: Stack after final pass of velocity and mute analysis – IL 55

11. Surface Consistent Residual Statics

Two passes of MASTT surface consistent residual statics were carried out. This method – developed by Techco Geophysical - uses the cross correlation of individual traces against each other, and hence does not rely on a predetermined model. This method is quite robust and generally produces optimum surface consistent statics.

The first pass of surface consistent statics are calculated using the initial pass of velocity, and then applied in a second velocity analysis phase, to be able to better define the velocity field. Then, a second pass of surface consistent statics (typically small residual statics +/-10ms) are then calculated and applied using the newest velocity function on CDP gathers to address any residual high amplitude noise.

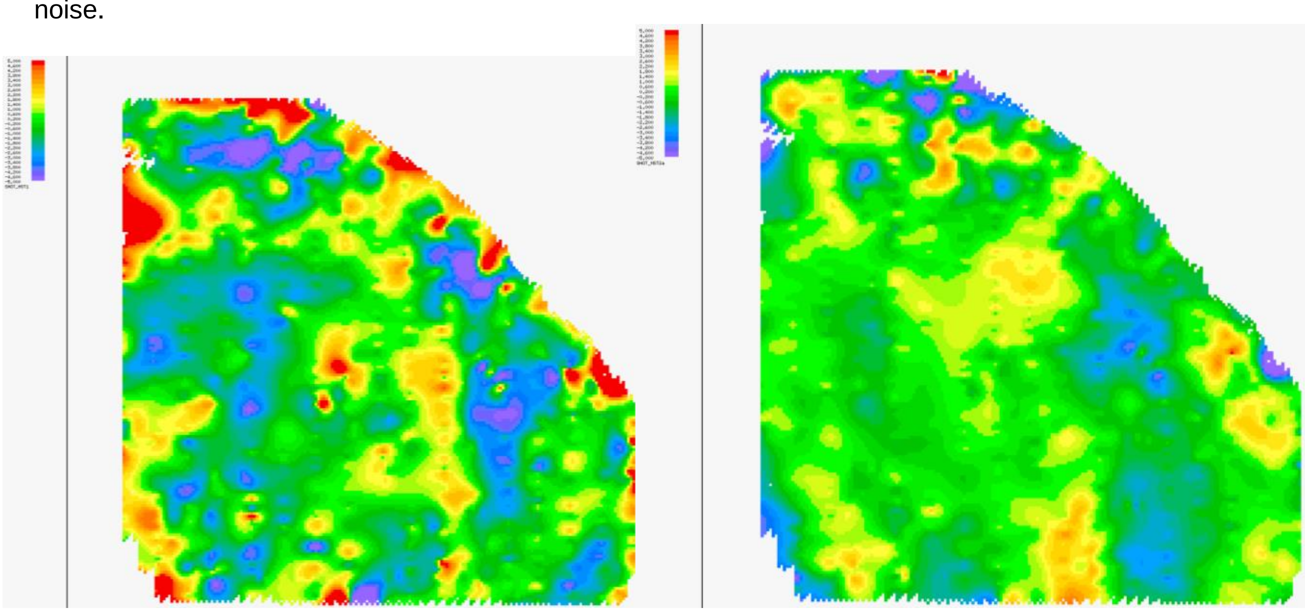


Figure 11-1: Left: shot statics after first pass of reflection statics, ±5ms. Right: shot statics after second pass of reflection statics ±5ms.

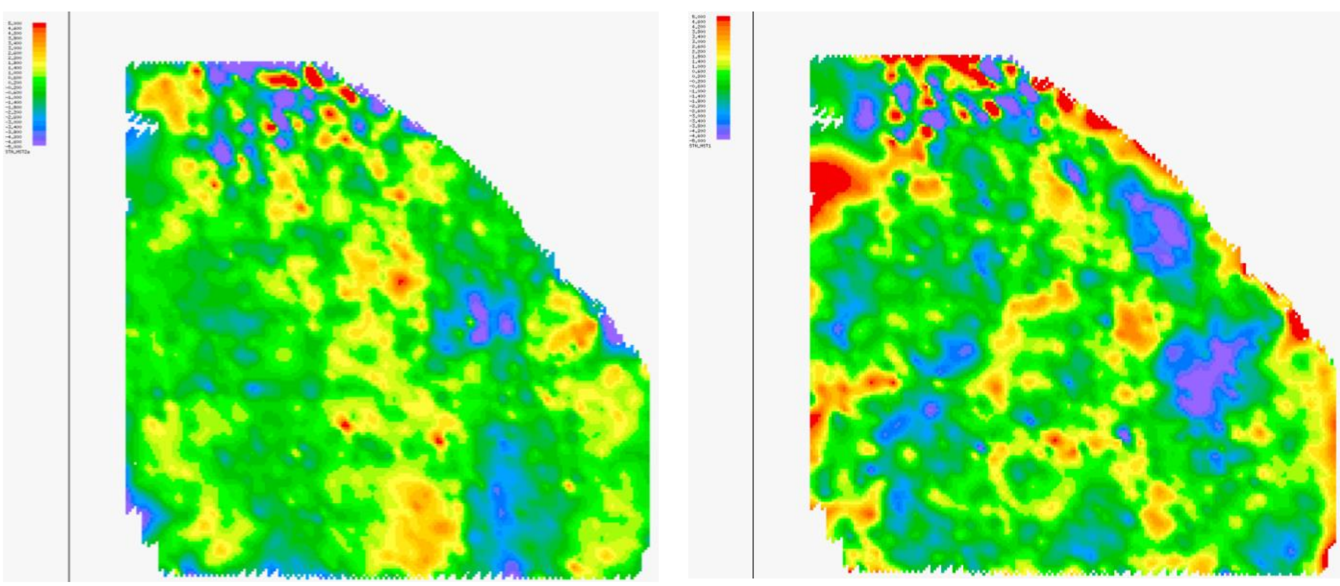


Figure 11-2: Left: receiver statics after first pass of reflection statics, ±5ms. Right: receiver statics after second pass of reflection statics, ±5ms.

12. Post Decon Noise attenuation

12.1 Post Decon Noise Attenuation

Process such as BLAST and FLASH were used for post decon noise attenuation.

BLAST identifies high amplitude noise blasts and scales or mutes the zones. The method locates zones in traces where the amplitude envelope is excessively high (exceeding a user defined threshold). BLAST uses a global estimate of the median amplitude level for thresh holding purposes.

Process FLASH was performed to identify and scale down any high amplitude outliers in a zone of traces by comparing the amplitude of each trace with the localized median estimate in the zone. The identified noisy traces are scaled to zero and a difference is taken to isolate the noise in that frequency range. To execute noise attenuation, the noise is then subtracted from the original broadband input. See above, page 17 and 18 for detailed descriptions on the three processes.

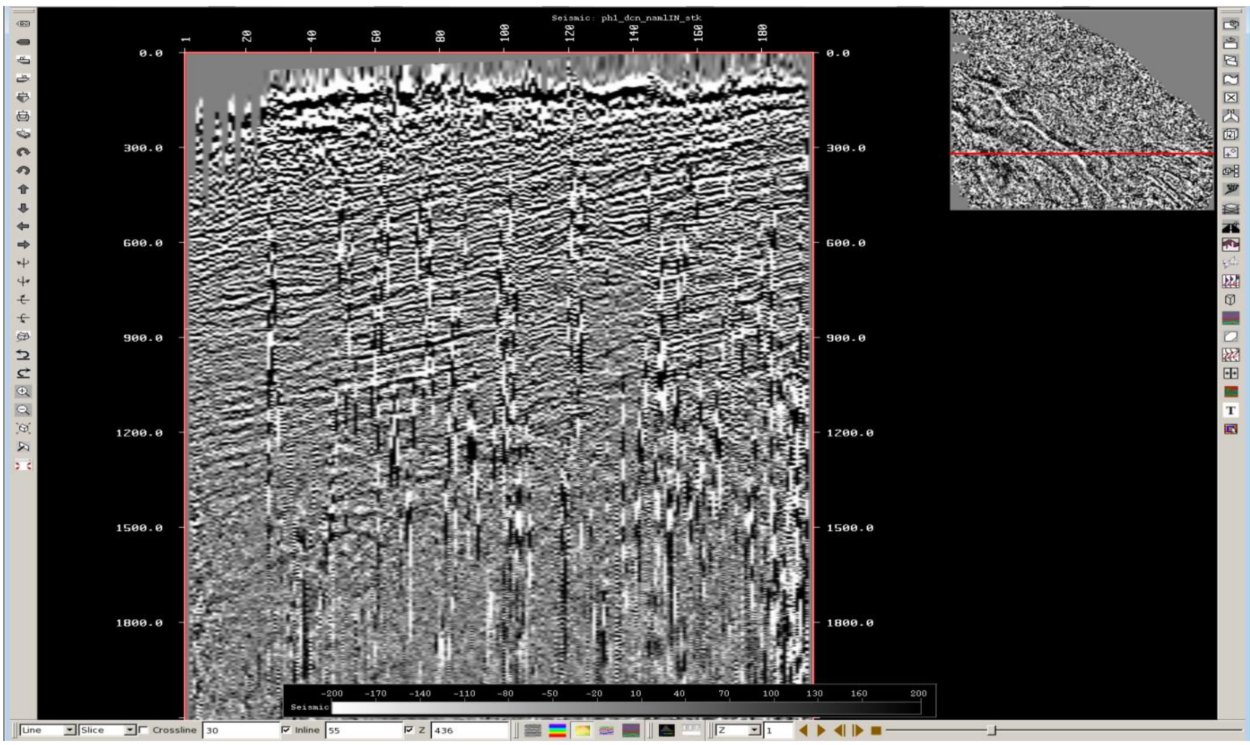


Figure 12-1: Post Decon Stack without post decon noise attenuation – IL 55

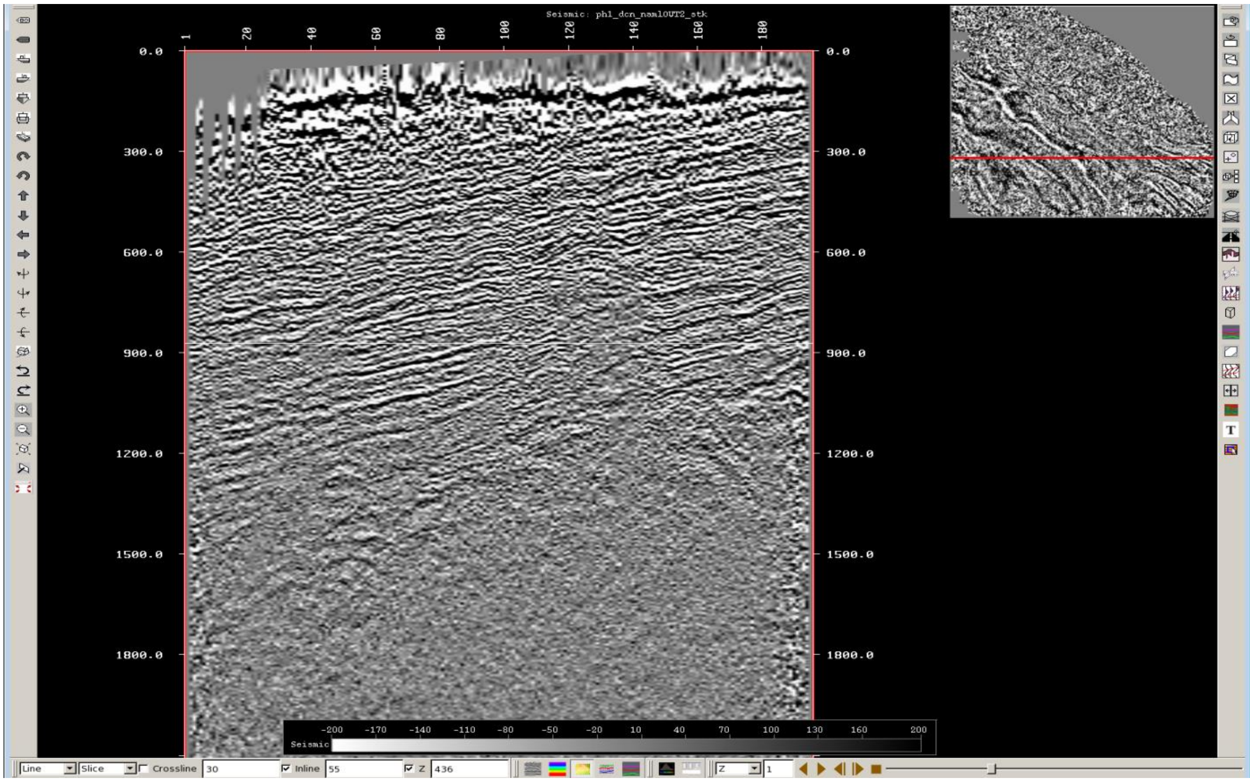


Figure 12-2: Post Decon Stack with post decon noise attenuation – IL 55

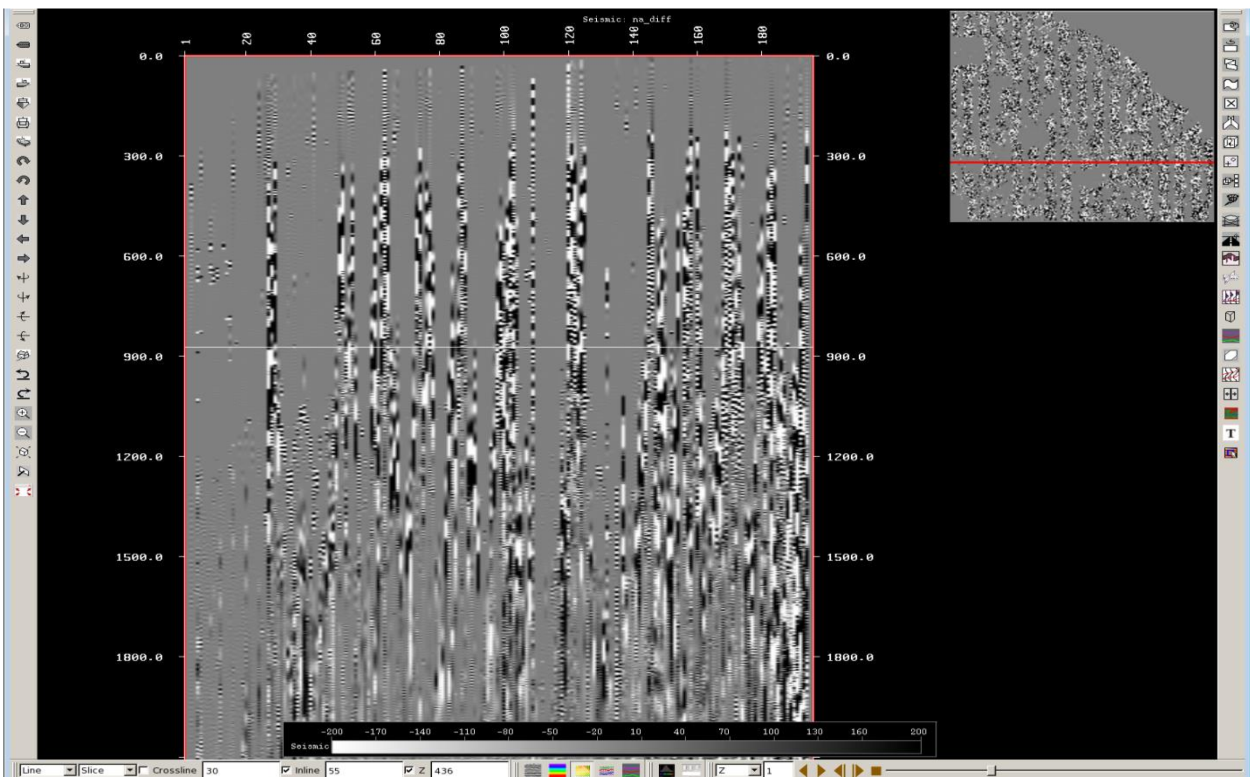


Figure 12-3: Total noise removed by post decon noise attenuation – IL 55

13. 5D Interpolation

13.1 Overview

Sparse or irregularly sampled seismic acquisitions can leave interpreters with uncertain images of the subsurface. To overcome this problem and enable interpreters to have more reliable information from existing surveys, CGG has developed 5D Interpolation, a global multidimensional interpolator to infill sampling gaps and increase spatial sampling while preserving original recorded data.

5D Interpolation performs simultaneous pre-stack interpolation in five dimensions - offset, azimuth, inline, cross-line and frequency – to predict new shots and receivers at desired locations. 5D Interpolation alleviates many of the problems affecting pre-stack processing, and offers a very useful tool to pre-condition the data for pre-stack migration, AVO and AVAZ.

13.2 Data Preparation and Testing

The data were prepared by applying all the statics and the final velocities. Also an open mute was applied to remove some of the NMO stretch. It was decided to only interpolate the shots as these were sparse compared to receivers. The receivers were also already fairly regular.

The data were interpolated using 0 – 15000 ft offsets as this was determined to be the usable range in the dataset.

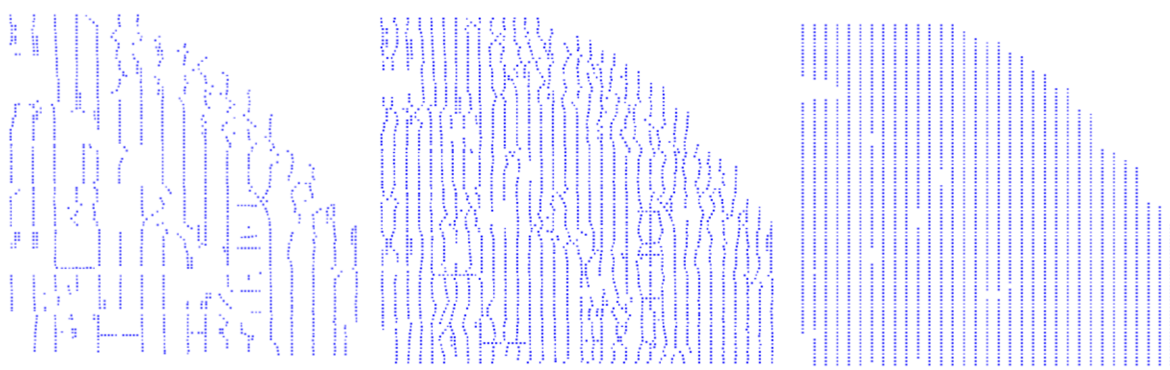


Figure 13-1: Left shows shots before interpolation. Middle shows interpolated shots and original shots. Right shows regularized shots.

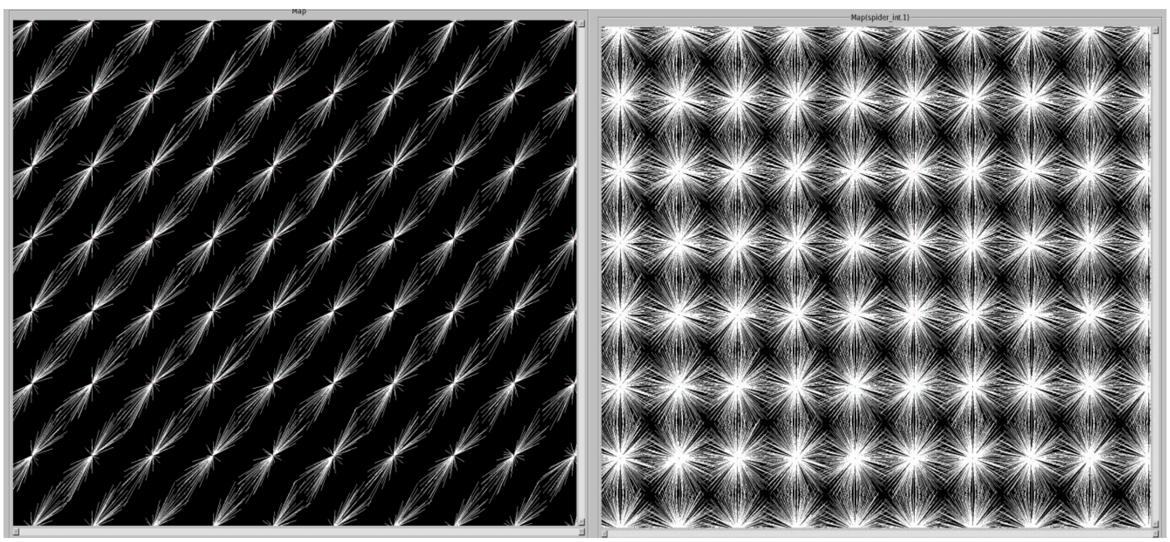


Figure 13-2: Left: spider plot before Interpolation. Right: Spider plot after Interpolation/Regularization.

13.3 5D Interpolation Results

The new total shot count is 2976 (old total shot count 1275). All of the QC's after interpolation were checked thoroughly to see if data integrity was maintained. RMS amplitude maps were checked to see if the amplitude variations were preserved through the Interpolation process. It was decided to proceed with the interpolated data to migration as the original data is still preserved in interpolation but not regularization. The results were also very similar as seen in the stacks below.

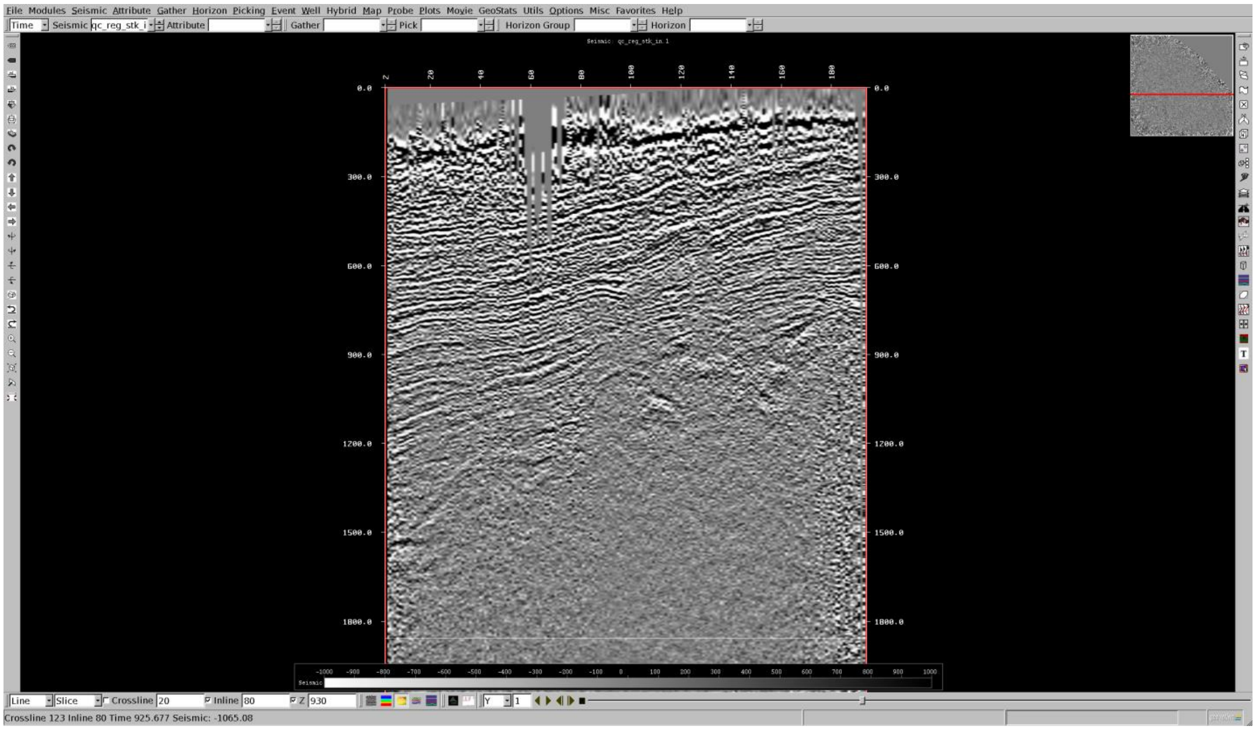


Figure 13-3: Stack before interpolation – IL 80.

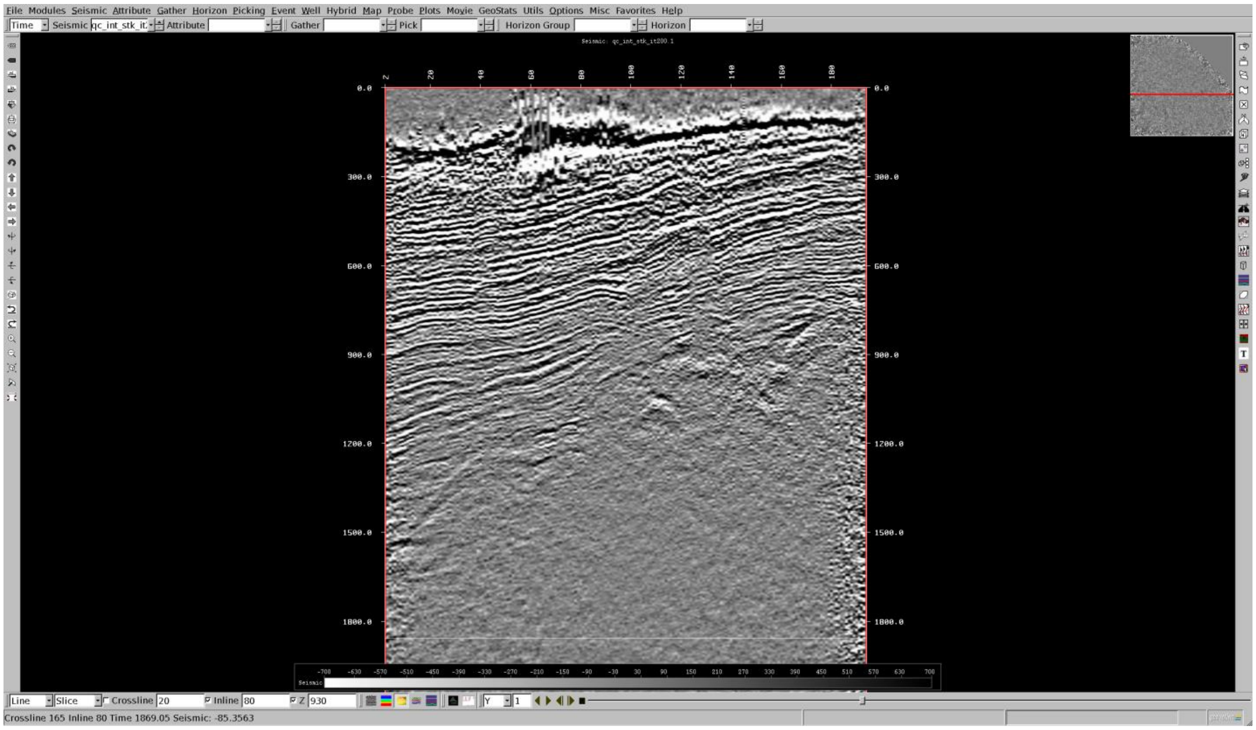


Figure 13-4: Stack after interpolation – IL 80.

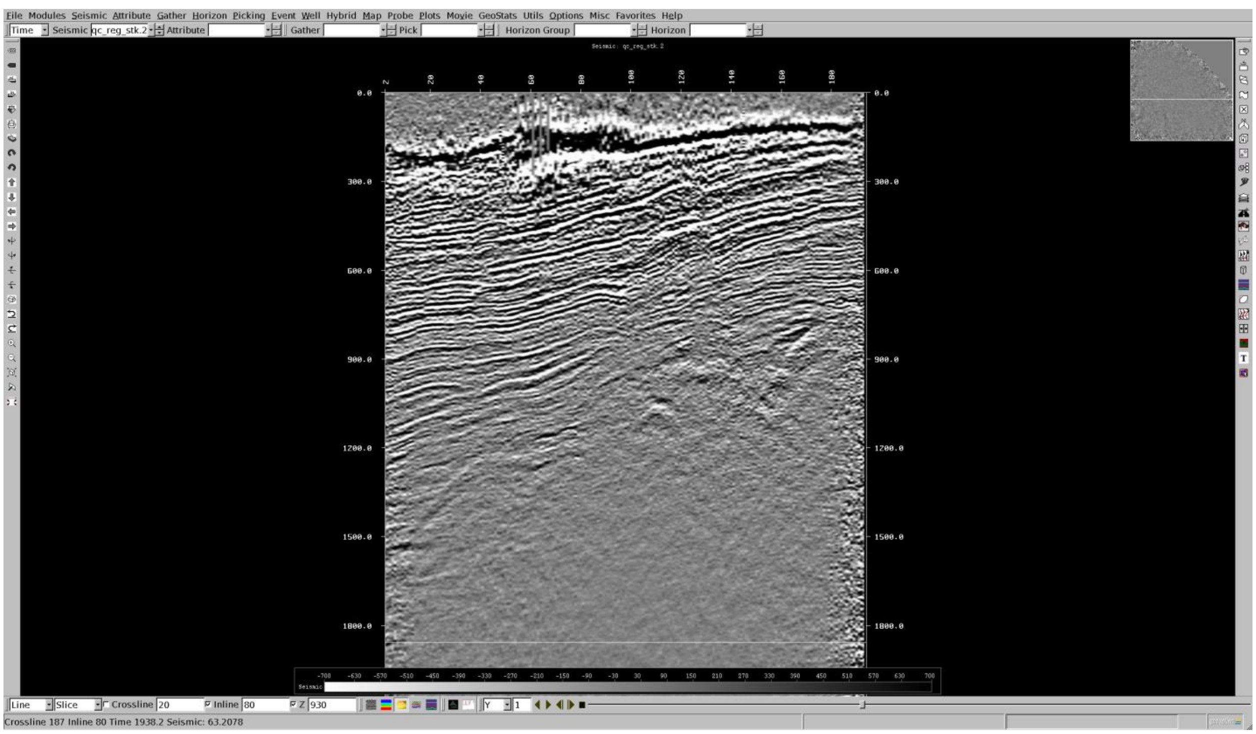


Figure 13-5: Stack after regularization – IL 80.

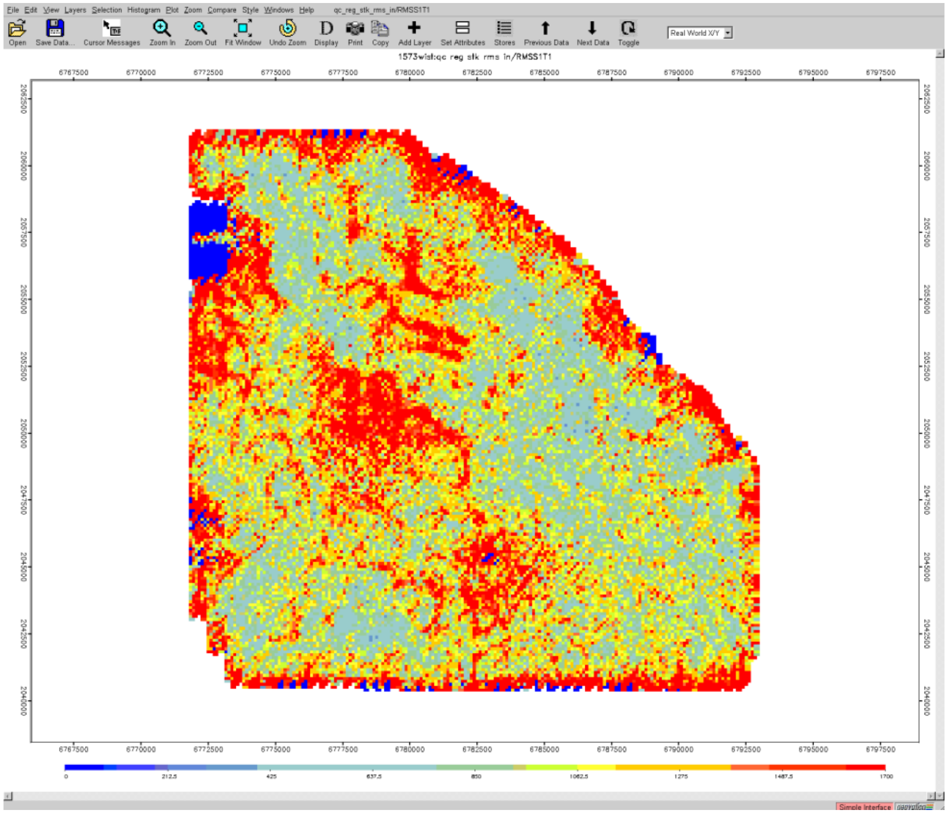


Figure 13-6: Full offset RMS Map before interpolation.

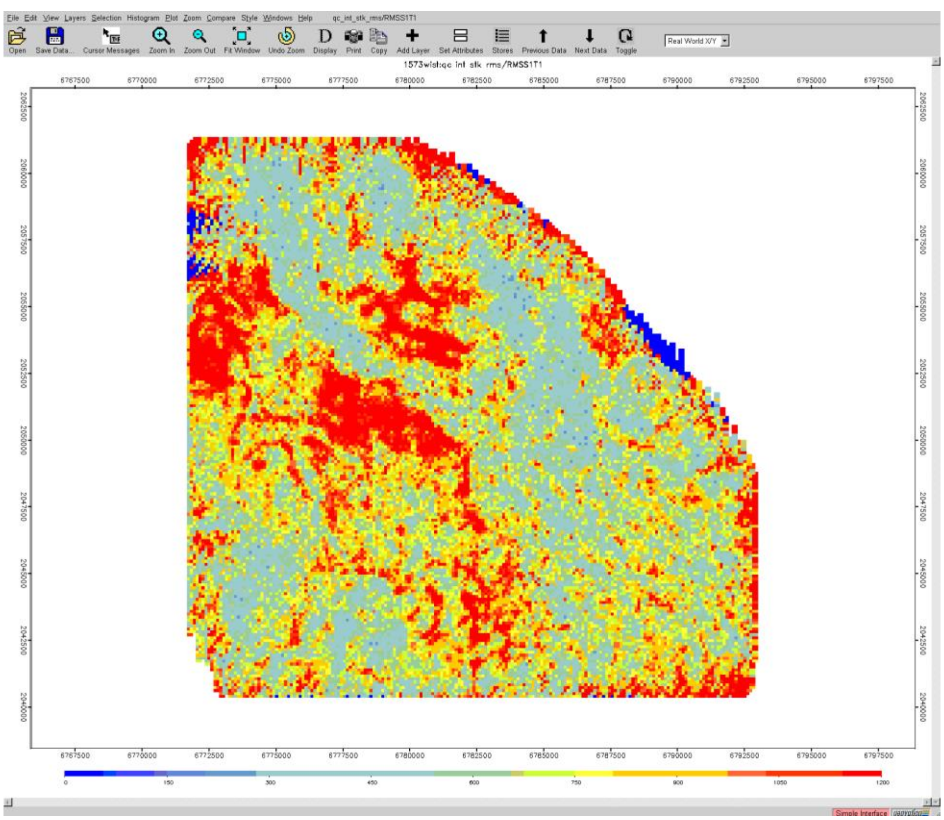


Figure 13-7: Full offset RMS Map after interpolation.

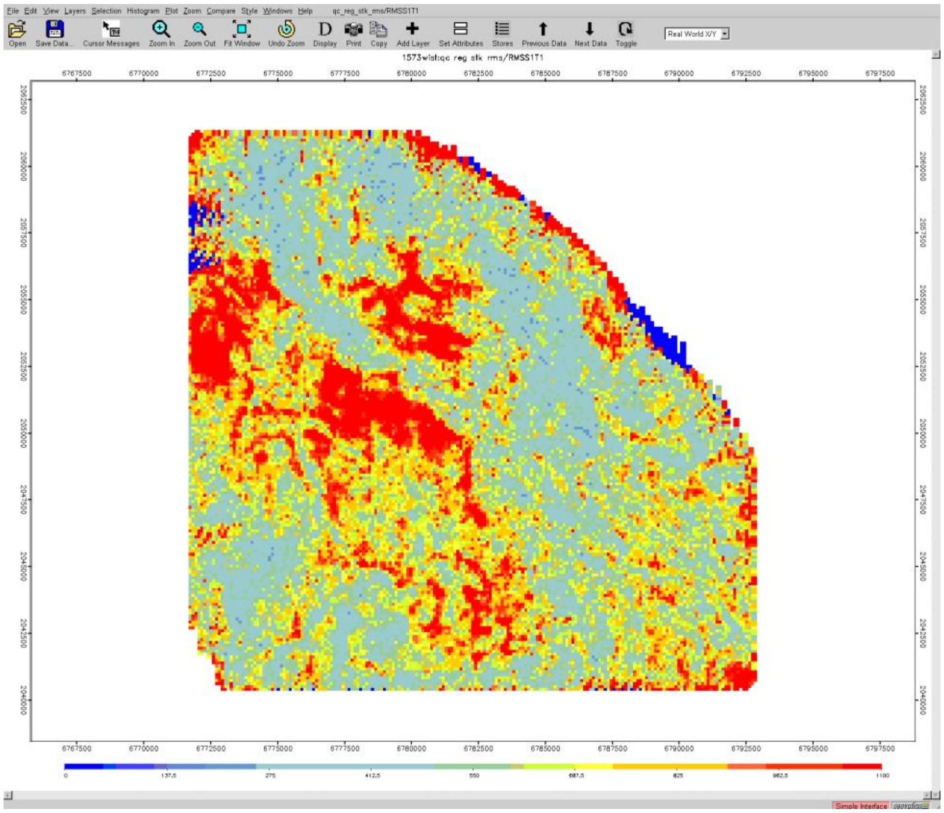


Figure 13-8: Full offset RMS Map after regularization.

14. Pre-stack Time Migration

14.1 Pre-stack Time Migration

The pre-stack time migration was performed using the Kirchhoff algorithm. The practical difference between the pre-stack and post-stack migration is that the former both permits and demands higher velocity resolution than the latter. The result of post stack migration is strictly limited by the quality of the stack that can be realized with conventional NMO and DMO techniques. The results usually show more accurate positioning, better definition of faults and other subsurface features.

Two different binning techniques were tested; accordion binning and common offset vector (COV) binning. After review the tests with the clients, it was decided to proceed with accordion binning.

Area Weighting

This process is used to mitigate any residual sampling gaps within each offset class prior to prestack migration. This computes an equalization weight based on the ratio of populated bins within a Fresnel radius of every CDP bin within each offset class. Traces are thus upweighted in the vicinity of holes or gaps to compensate for the energy missing samples would have contributed to the summation process.

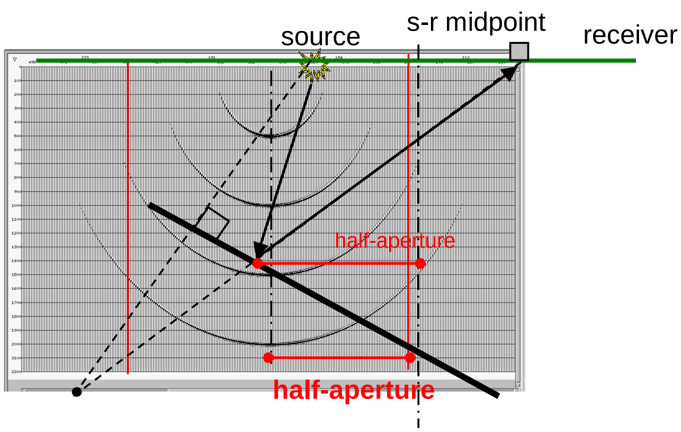
PSTM Velocity Analysis

Pre-stack migration velocity analysis is performed using principle tools similar to conventional stacking velocity analysis. Target lines are migrated with all the data required to form the common offset gathers. An interpolated velocity field is then used to drive the full volume migration. For this data Migrated Constant Velocity Stacks (MCVS's) were used.

Aperture

Aperture refers to the ideal of having samples from an infinite spatial range (the Kirchhoff integral extends from minus infinity to plus infinity), or physically a full angular recording range at all reflection points. In practice, of course, our acquisition perimeters - the coverage of each shot record and the overall survey edges - limit the aperture. The spatial extent of Kirchhoff summation along the diffraction hyperbolae is usually further limited by the user to be carried out over a defined spatial area; this parameter is known as the migration aperture. The advantages of limiting the aperture include decreasing the computational expense and suppressing noise. One consequence of limited apertures, however, is that the migration operators are dip-restricted, meaning that steeper dips are progressively attenuated.

Too narrow a migration aperture will truncate the operators and reduce the 'swing' especially of the deeper events - which may mean steeply dipping events are suppressed. Too wide an aperture may introduce a significant cost in run time with no improvement in quality; in fact a large aperture may degrade the migration of low signal-to-noise ratio data. As well, too wide an aperture leaves velocity artifacts at the edges of the deeper events. The aperture can be viewed as a tradeoff between dip reconstruction and control of operator swing noise.



Aperture parameter shown on migrated spike series.

Aperture controls the lateral distance an operator will swing from the midpoint. This corresponds to the lateral displacement between the midpoint and the reflection point from a dipping reflector.

Pre-stack Time Migration Parameters

The parameters that were tested include migration aperture, dip limit, and offset class discrimination

- Accordion binning was used.
- The selected optimal migration parameters were
  - aperture: 8800 ft (80 traces)
  - maximum angle: 80 degrees
  - alias: 75%

Residual Migration Velocity Analysis

Post-PSTM velocity review for Residual NMO was conducted.

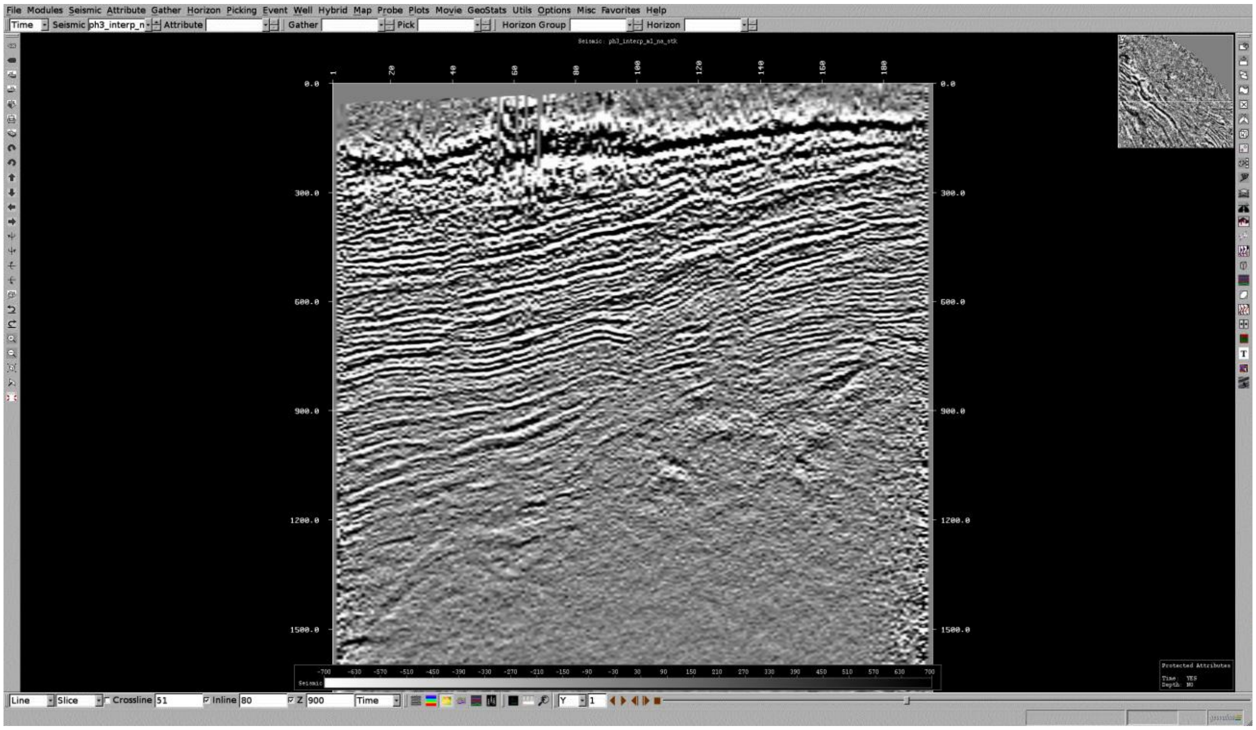


Figure 14-1: Input to migration stack – IL 80.

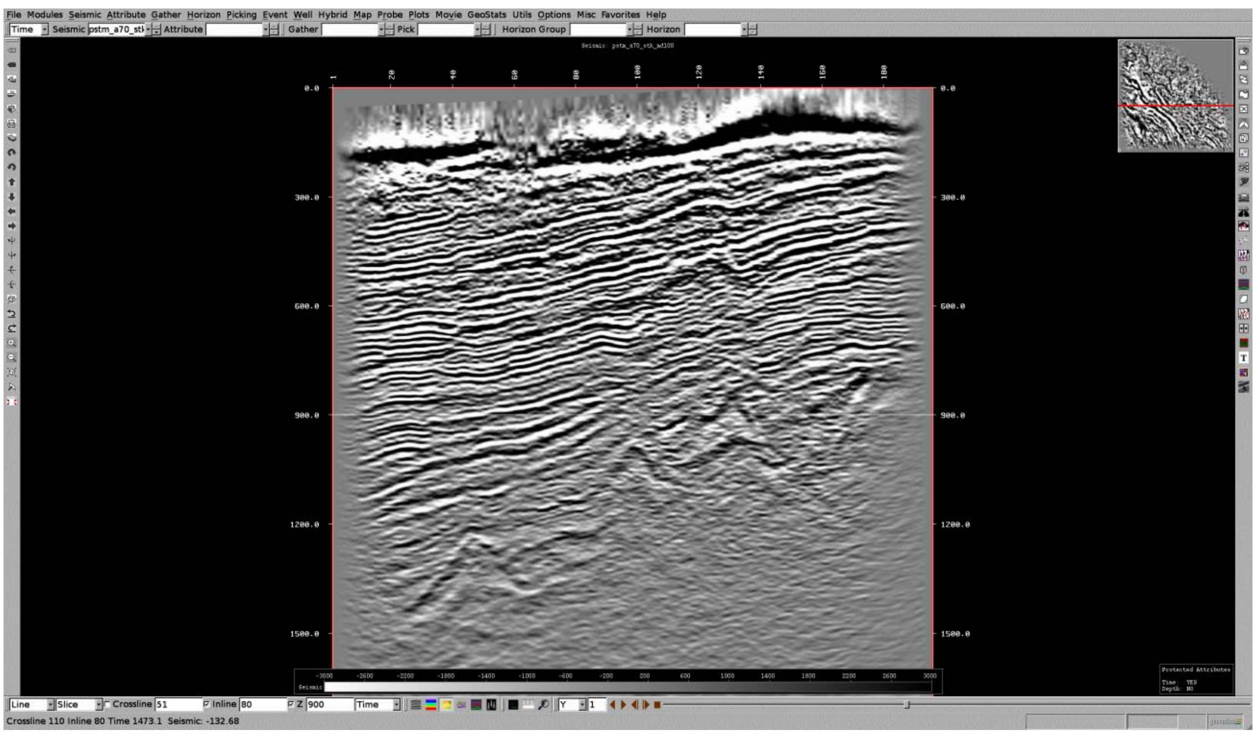


Figure 14-2: PSTM stack migration – IL 80.

15. Final Deliverables – SEG-Y Format

1) Unfiltered PoSTM Stack Migration
2) Fold Cube
3) Interpolated Gathers
4) Interpolated Stack
5) Unfiltered PSTM Stack Migration
6) PSTM Gathers
7) TOMO Velocity Model
8) Final Migration Velocities – Interval
9) Final Migration Velocities – RMS
10) Final Stacking Velocities – Interval
11) Final Stacking Velocities - RMS

16. Contact Information

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