# Wingman-Jasmine 3D Merge

# Processing Report

**April 2018**

**Data Processed by:**

## CONTENTS

## TABLE OF FIGURES

# 1 INTRODUCTION

Earth Signal Processing Ltd. was chosen to do the re-processing of the Wingman-Jasmine 3D Merge in the Cooper Basin, SA, Australia. The Wingman 3D survey was recorded in June-July 2013, while the Jasmine 3D survey was recorded in March 2015. Portions of each 3D were used to provide full fold within a client specified target area.

The processing took place in the processing centre of Earth Signal, located in Calgary, Canada. The field seismic data, observer reports, survey information and list of wells (LAS files) were all delivered in February 2018. Earth Signal was also provided with SEG-Y stacks of the previous processing in order to do a comparison to the volume. All processing took place from February 2018 to April 2018.

## 1.1. About Earth Signal Processing Ltd.:

Earth Signal is a Canadian seismic processing company dedicated exclusively to land data since 1993. We have worked with data from 40 different countries spanning the globe and have processed thousands of 2D lines and hundreds of 3D surveys. Our experience working internationally allows us to effectively work closely with our clients regardless of location.

Our processing software is written 100% by Earth Signal's programmers and R&D personnel. The software efficiently uses parallel processing architecture in CPU cluster machines. Our software has been written with the product needs of the client in mind and is always evolving to better suit the clients' needs and our ever expanding areas of focus.

## 2 SURVEY DATUM

| | |
|---|---|
| Projection: | GDA94 |
| MGA Zone: | 54 |
| Central Meridian: | 141 |

## 3 SURVEY LOCATION

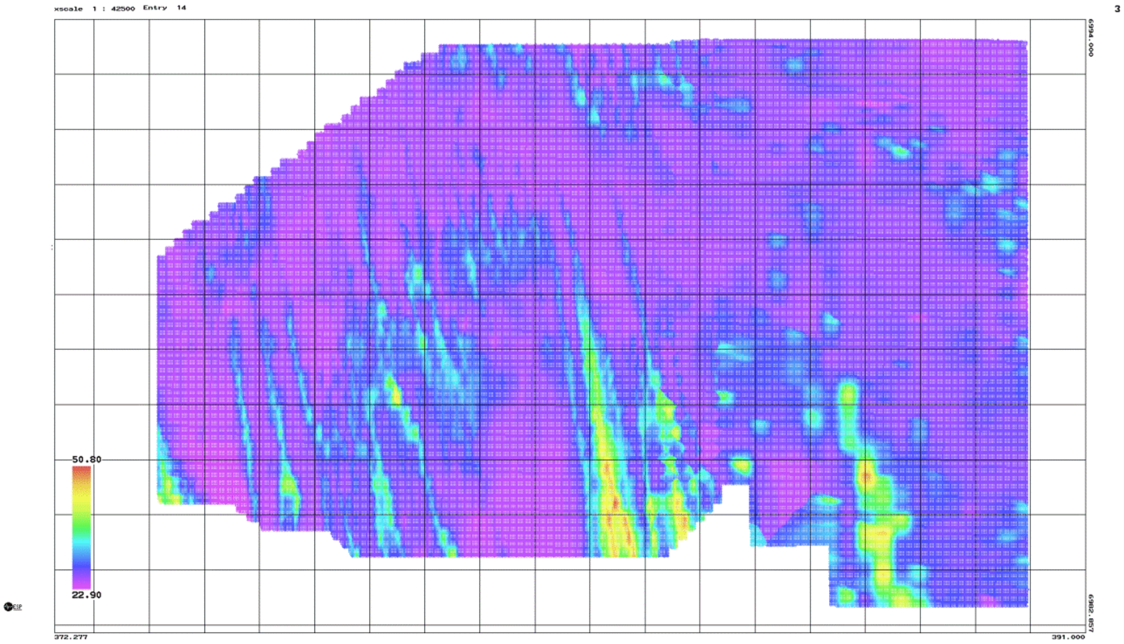



**Figure 1: Wingman-Jasmine 3D Merge Elevation Profile**

## 4 KEY PERSONNEL

The main personnel involved with the project were:

TerraNova Energy Ltd.:

Istvan Gyorfi, Exploration Manager

Holloman Energy Corp.:

Rod Lovibond, Consultant Geophysicist

Earth Signal Processing:

Greg Staples, Senior Processing Advisor

Ernest Balagtas, Senior Processing Geophysicist, P. Geo.

# 5 DATA ACQUISITION PARAMETERS

| | Wingman-Jasmine 3D Merge | |
|---|---|---|
| Location of Survey | Australia | |
| Area of Survey | Cooper/Eromanga Basin | |
| Survey Operator | Terrex Seismic | |
| Data Type | Land 3D | |
| Area Processed | 123 $km^2$ | |
| Survey | Wingman | Jasmine |
| Date Recorded | June – July 2013 | March 2015 |
| Record Length | 3 s | 4 s |
| Sample Interval | 2 ms | 2 ms |
| Source Type | Vibroseis<br>Linear Sweep: 4-100 Hz Sweep Length: 4s | Vibroseis<br>Linear Sweep: 4-90 Hz Sweep Length: 8s |
| Spread | Orthogonal 14 x 160 | Orthogonal 20 x 192 |
| Receiver Line Interval | 320 m | 320 m |
| Shot Line Interval | 320 m | 320 m |
| Shot Spacing | 20 m | 40 m |
| Receiver Spacing | 40 m | 40 m |
| Recorder | Sercel 428 | Sercel 428 |
| Filters | Out – 200 Hz | Out – 200 Hz |
| Average Natural Fold | 51 | 53 |

## 6 PROCESSING GRID INFORMATION

The data was processed on a 20 m x 20 m bin grid covering an area of approximately 123km$^2$. There were 17,541 shots processed with a maximum fold of 153.

| Inline | Crossline | UTM-X | UTM-Y |
|---|---|---|---|
| 1 | 1 | 389958 | 6993622 |
| 1 | 791 | 374159 | 6993627 |
| 515 | 1 | 389955 | 6983342 |
| 515 | 791 | 374155 | 6983347 |

# 7 AVO-COMPLIANT PROCESSING SEQUENCE

The AVO compliant pre- and post-stack migration processing flow for the 3D is shown below. Parameters were tested along the way to ensure an optimal product.

- Reformat
- Geometry and QC
- Refraction Analysis
- Replacement Statics
- Surface Consistent Amplitude Scaling
- Frequency Dependent Noise Attenuation
- Anti-Aliasing Anti-Leakage Fourier Filter
- Surface Consistent Amplitude Scaling
- Trace Editing
- Exponential Scaling
- Vibroseis Designature
- Surface Consistent 5-Component Deconvolution
- Residual Scaling
- Frequency Dependent Noise Attenuation
- Anti-Aliasing Anti-Leakage Fourier Filter
- Surface Consistent Amplitude Scaling
- TPXY Noise Attenuation in Cross-Spread Domain
- Surface Consistent Amplitude Scaling
- CDP Binning on Common Grid and Geometry Application
- Trace Gather
- Frequency Dependent Noise Attenuation on Gathers
- Processing Datum
- Preliminary Velocity Analysis
- Surface Consistent Statics
- Final Velocity Analysis
- Trim Statics
- Final Mute
- Post-Stack Migration
- Gaussian Normalized Offset Gathers
- 5D Minimum Weighted Norm Interpolation
- Pre-Stack Kirchhoff Time Migration
- Singular Spectrum Analysis and Rank Reduction on PSTM Gathers
- PSTM Residual Velocity Analysis
- TX Decon Noise Reduction on Stack
- Final Filter and Scaling
- Event Guided Scalar Factors

# 8 PROCESSING

## 8.1 Reformat

Both datasets were received in SEG-D, and then reformatted to Earth Signal's internal format before processing.  All data was processed at a 2 ms sample rate.

## 8.2 Geometry and QC

Geometry assignment entails matching each received data file to the correct shotpoint identification and position. Headers were updated using survey geometry from supplied coordinates and elevations in GDA94 projection.

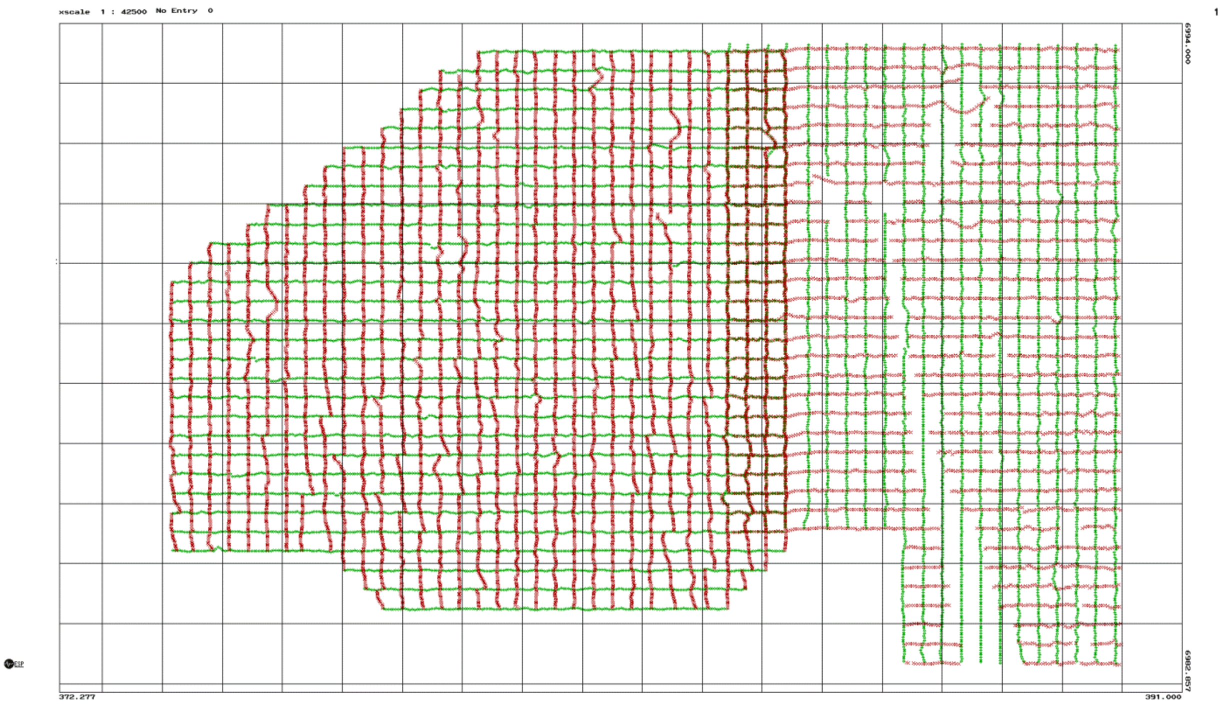



**Figure 2: Map of SEG-P1 Surveys**

## 8.3 Refraction Analysis

An automated picking algorithm was used, with manual modification to areas where the algorithm failed due to low quality breaks. The initial refraction model used is the slope-intercept method, which is then input into first break tomography to arrive at the final near surface model. First Break Tomography (FBT) ray traces a given model and calculates the theoretical first break. The difference between the observed and calculated travel time was obtained and used to get a new model by the least squares inverse method. In this project, a one-layer refraction solution calculated from 0 to 400m of offset was used due to the variability of the second layer picks.

## 8.4 Replacement Statics

A datum elevation of 100 m was used during processing, as well as a replacement velocity of 2000 m/s, and weathering velocity of 700 m/s.

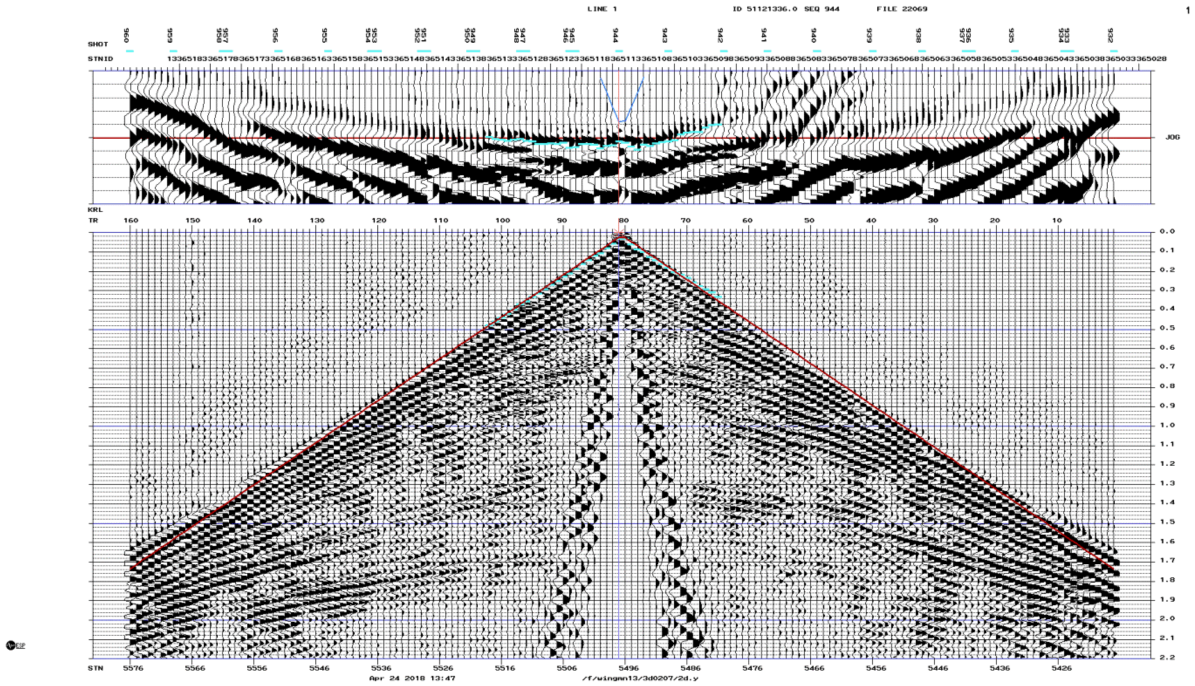


**Figure 3: First break arrivals from Wingman 3D**

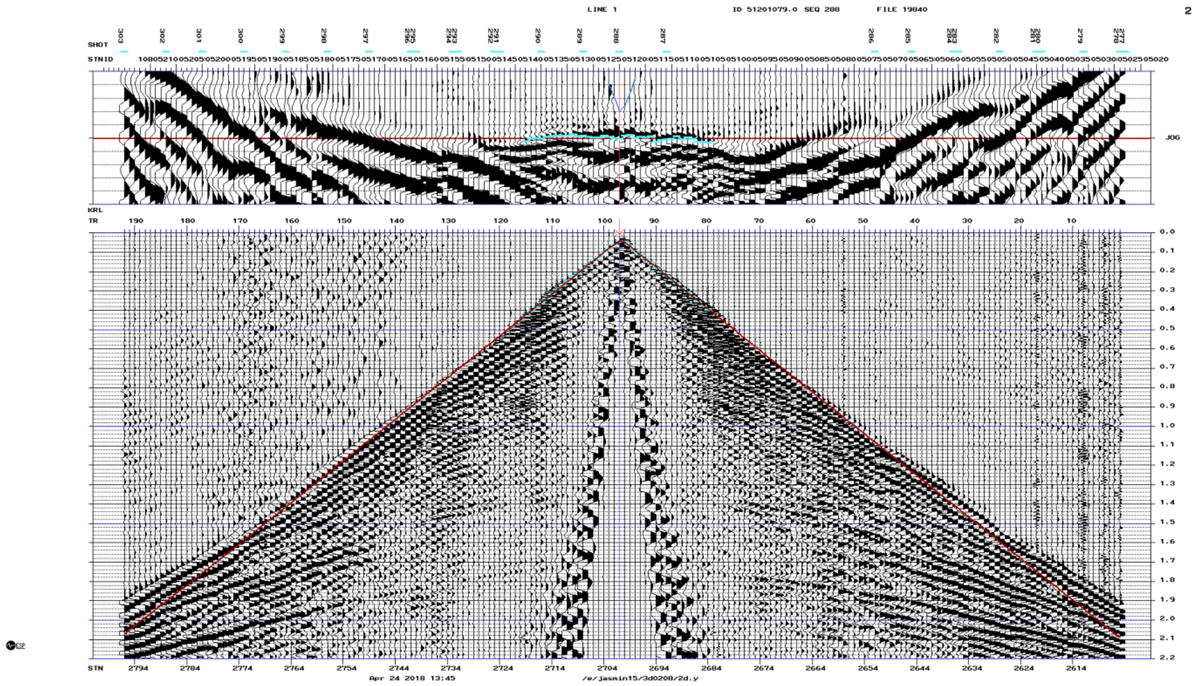


**Figure 4: First break arrivals from Jasmine 3D**

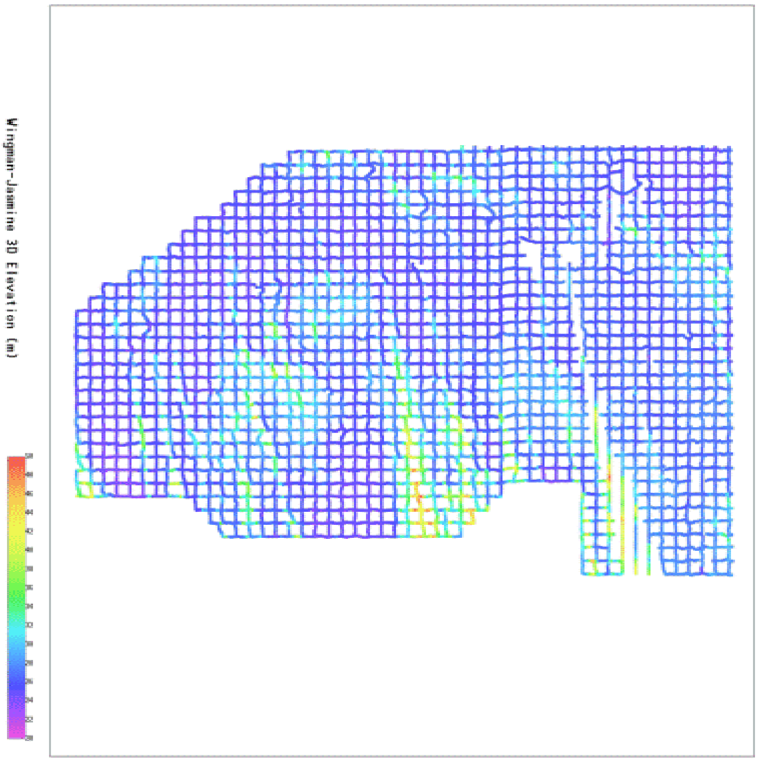



**Figure 5: Surface Elevation**

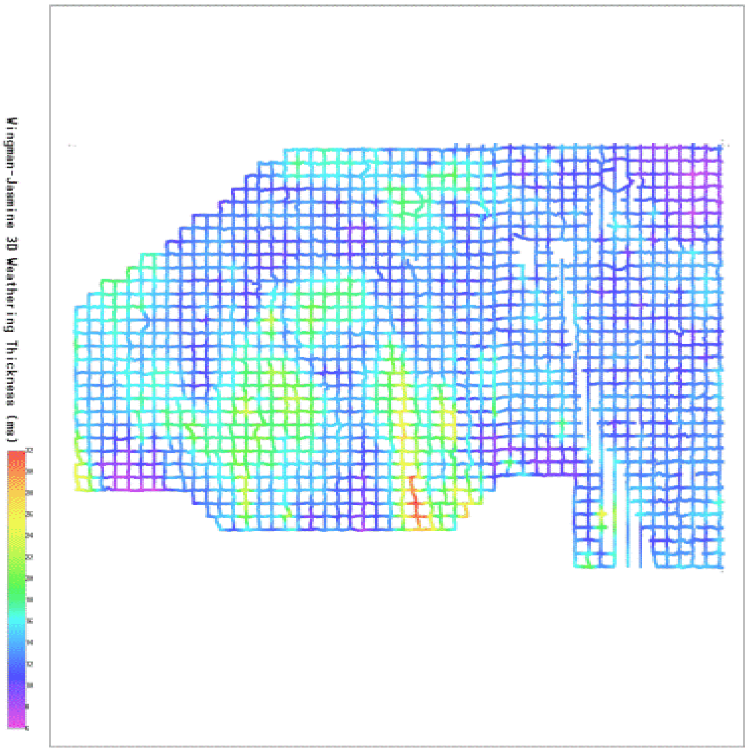



**Figure 6: Weathering Thickness**

### 8.5 Surface Consistent Amplitude Scaling

Surface Consistent Scaling was used to compensate for variable source/receiver coupling among other variations. It was calculated using the Line, Shot, Receiver, CDP and Offset Components with just the Line, Shot and Receiver components applied. This was done using offline band limited data so that the influence of noise was minimized. At the same time, the amplitude spectrum of each trace was compared to the corresponding shot and receiver spectrums. Any trace that does not compare within the cutoff boundaries was flagged and killed later in the processing flow, and not utilized in any of the calculations. The sloping design window was large, extending from just beneath the first breaks, down to just beneath basement time at 2500 ms.

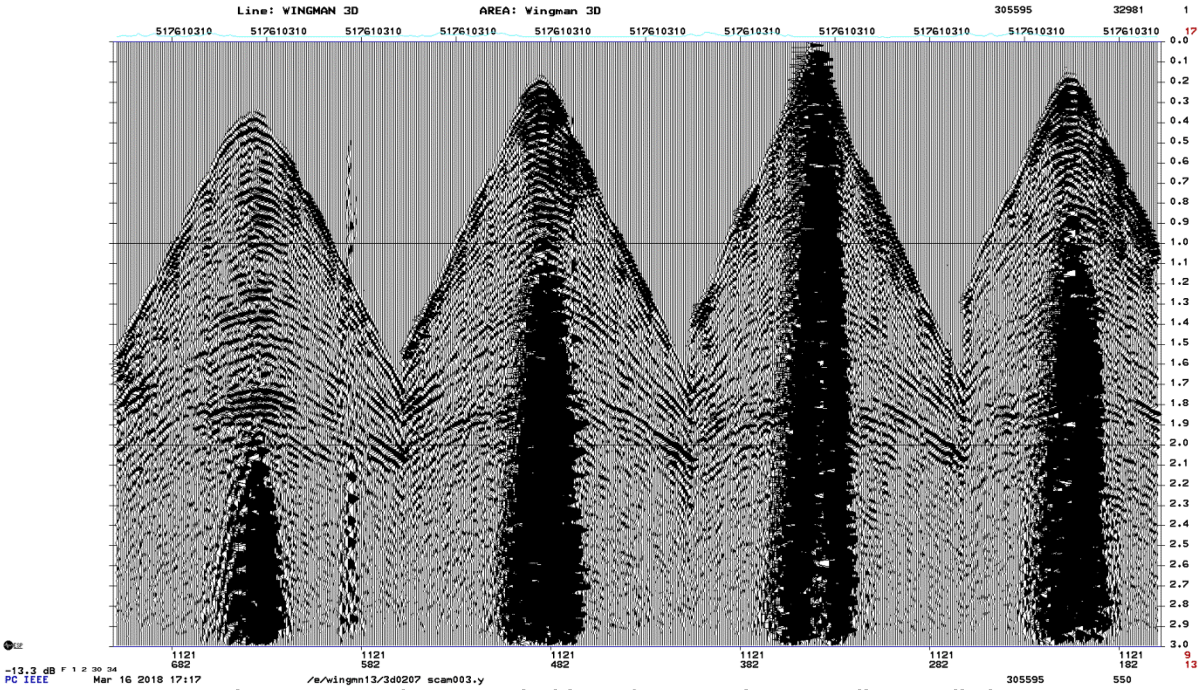



**Figure 7: Raw Shot Record with Surface Consistent Scaling Applied**

### 8.6 Frequency Dependent Noise Attenuation

The frequency spectrum of each trace was split into bands, which were compared in amplitude to surrounding traces in a given window. If a threshold was reached within a frequency band, the amplitude was brought back to the average of the amplitude for that band. Frequencies above 16Hz. were examined in this process, with lower frequencies unchanged and left to the ground roll attenuation.

### 8.7 Anti-Aliasing Anti-Leakage Fourier Filter

ALFF is a localized Fourier domain dip filter that handles irregular spatial sampling

- Localized: it computes spectra over small and sliding spatial windows.
- Irregular spatial sampling: It uses the Anti-Leakage Fourier transform as opposed to a Fast Fourier transform. The filter also attempts to perform anti-aliasing of noise dips for higher frequencies.
- Dip filter: given a set of velocities to define (1) the signal cone and (2) the noise cone in FK space; the filter separates the input data into (1) estimated signal, (2) estimated noise (3) residual energy within the frequency band affected by the noise. The Processor can mute these volumes independently and subtract noise and/or residual estimates from the original data.

- 5 point operator
- Constrained to below 16 Hz
- Noise and residual estimates removed

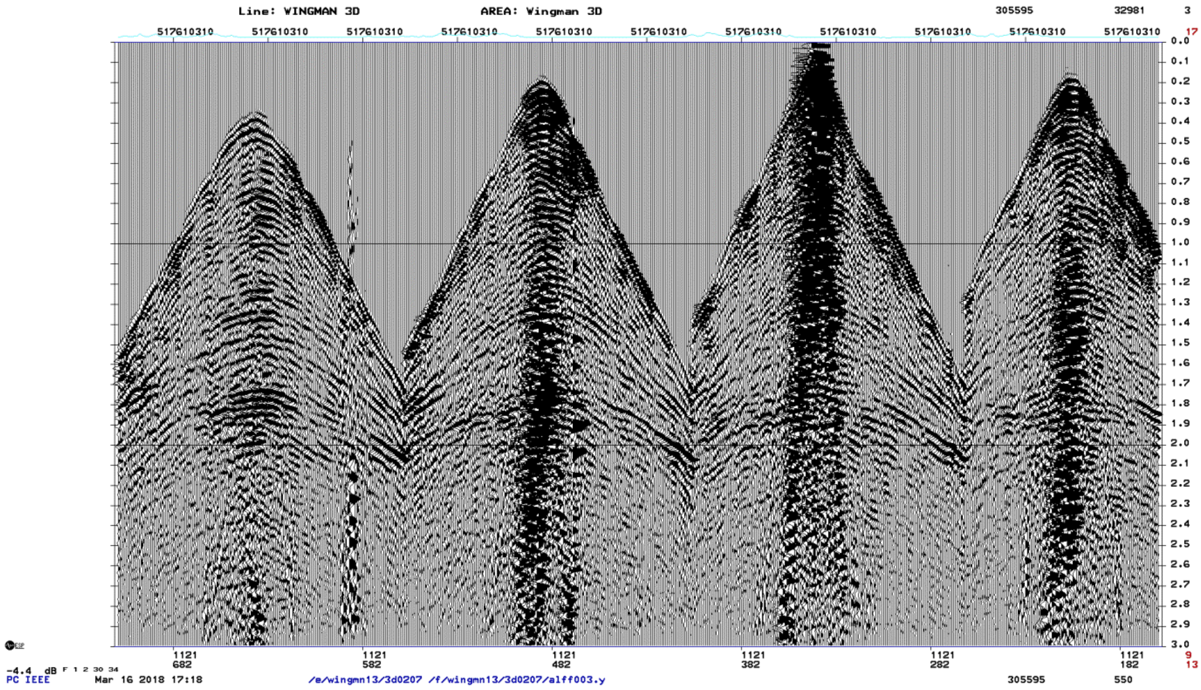



**Figure 8: Anti-Aliasing Anti-Leakage Fourier Filter**

### 8.8 Surface Consistent Amplitude Scaling

### 8.9 Trace Editing

Interactive edits to traces on shot records was done at this point. Each record was analyzed for noisy traces, glitches and reversed traces prior to deconvolution.

### 8.10 Exponential Scaling

Exponential Scaling was applied to correct for spherical divergence, using a simple T function:

$T^p$, p = 1.4 for vibroseis shot records

### 8.11 Vibroseis Designature

The phase effects of the vibrator sweep were calculated, and an inverse operator was applied to convert the recorded signal back to minimum phase.

### 8.12 Surface Consistent 5-Component Deconvolution

5-Component frequency domain deconvolution was used. It was calculated using the Line, Shot, Receiver, CDP and Offset components with just the Line, Shot and Receiver components applied. One of the main benefits of working in the frequency domain is that it requires minimal processor input compared to similar time domain programs, resulting in more consistent results between datasets. The design window was the same as that for the surface consistent scaling, with the large window aiding in stability of the deconvolution operator. A boxcar of frequencies was selected to be the desired response of the deconvolution, based on the sweep of each dataset.

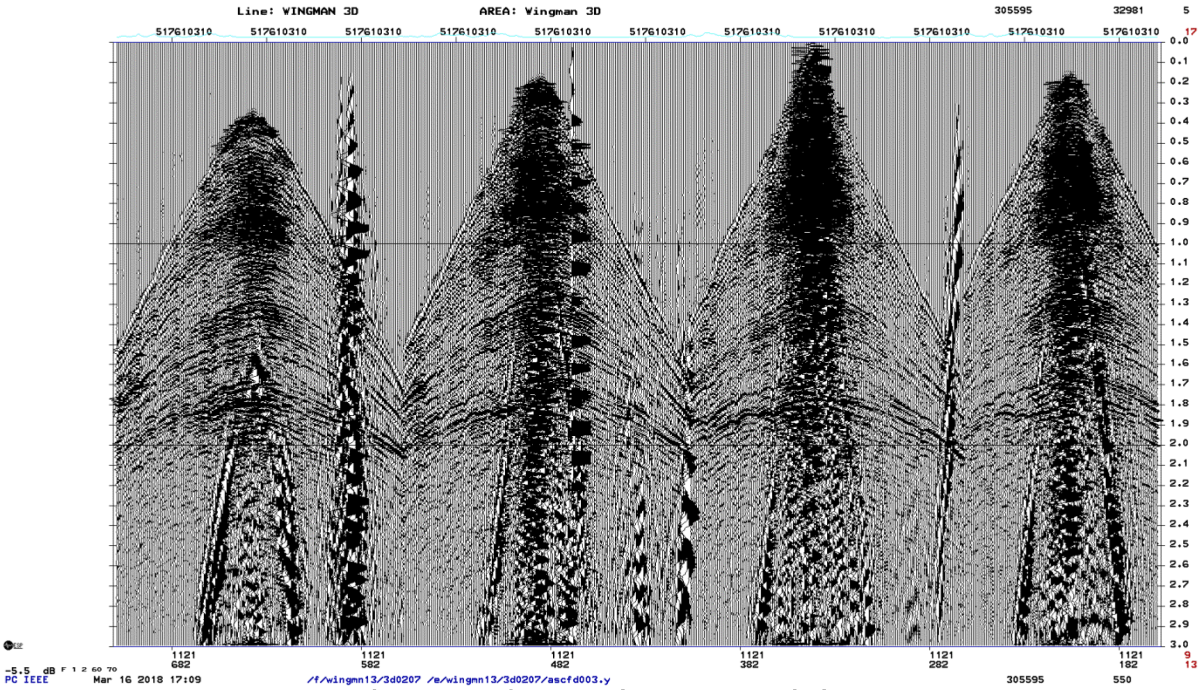



**Figure 9: Surface Consistent Deconvolution**

### 8.13 Residual Scaling

First Break Equalization Scaling - The first breaks are equalized using a short window AGC applied upward from the design window.

### 8.14 Frequency Dependent Noise Attenuation

After some noise and ground roll attenuation, frequencies below 16Hz were examined in this process and low frequency glitches were removed.

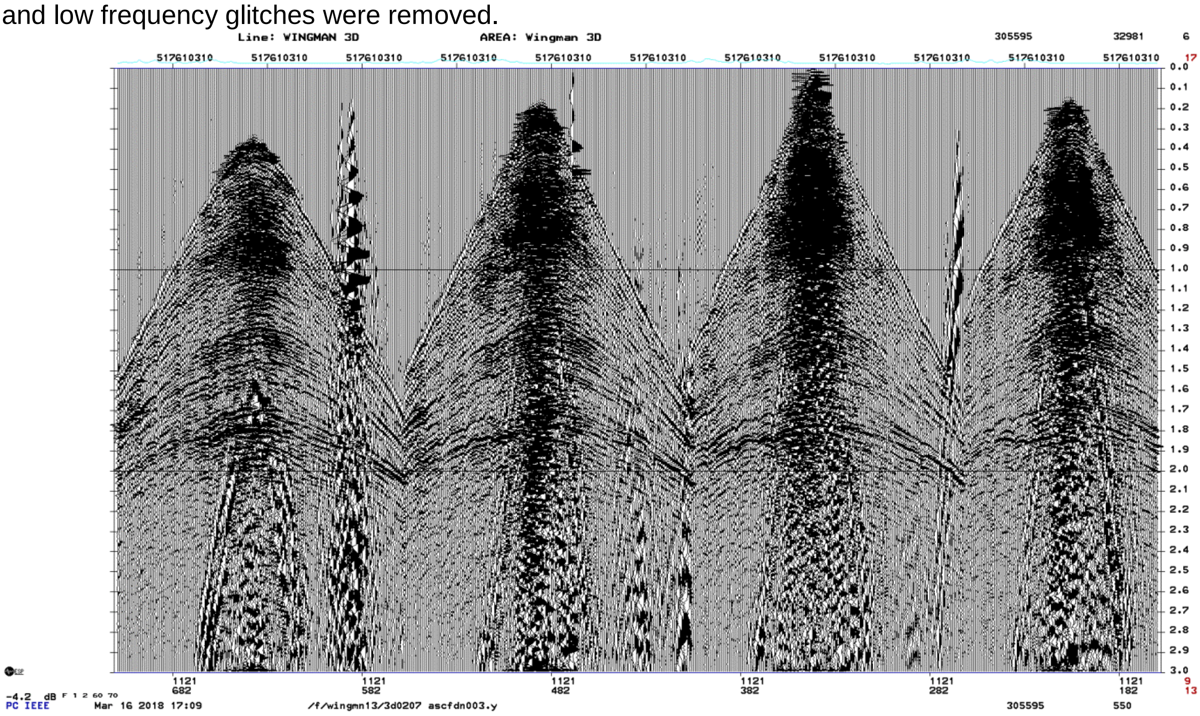
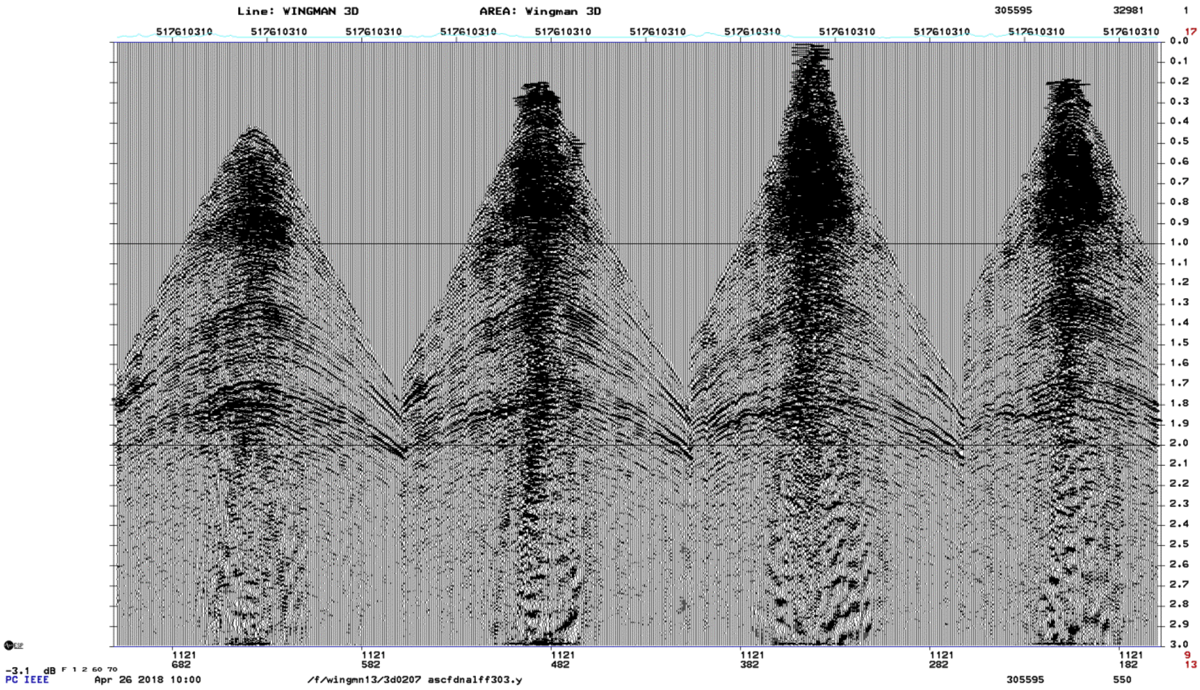



**Figure 10: 2nd Pass of Frequency Dependent Noise Attenuation**

### 8.15 Anti-Aliasing Anti-Leakage Fourier Filter

- 5 point operator
- Constrained to below 24 Hz
- Noise and residual estimates removed




- **Figure 11: 2nd Pass of Anti-Aliasing Anti-Leakage Fourier Filter**

### 8.16 Surface Consistent Amplitude Scaling

### 8.17 TPXY Noise Attenuation on Cross-Spreads

TPXY noise attenuations were applied in the cross-spread domain. The cross-spread was created by selecting all traces common to one source line and one receiver line, creating a single fold subset of the 3D. Random noise was then attenuated from the traces using a 21-trace design. After all cross-spreads were processed, the traces were sorted back to shot gathers for further processing.

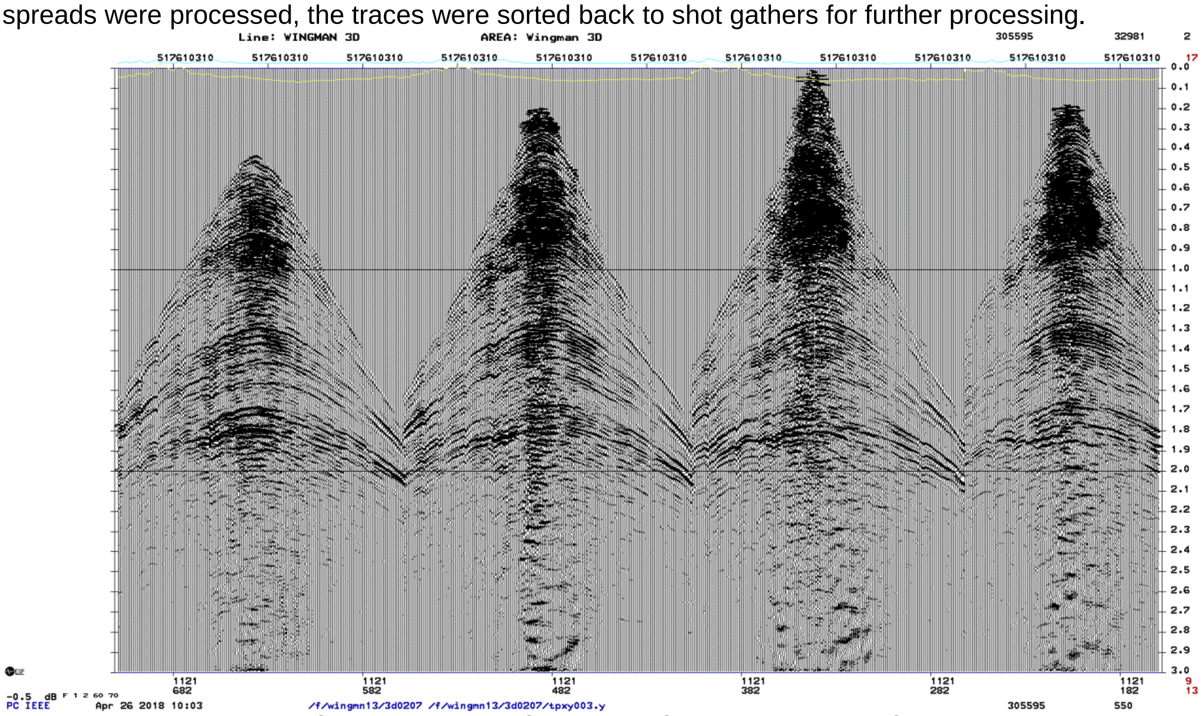



**Figure 12: TPXY Noise Attenuation on Cross-Spreads**

### 8.18 Surface Consistent Amplitude Scaling

### 8.19 CDP Binning on Common Grid and Geometry Application

The 3D was binned based on the orientation of the receiver and shot lines. The angle of rotation for the bin grid was -0.018853 degrees, and a maximum offset of 3600 m was kept with a maximum fold of 153.

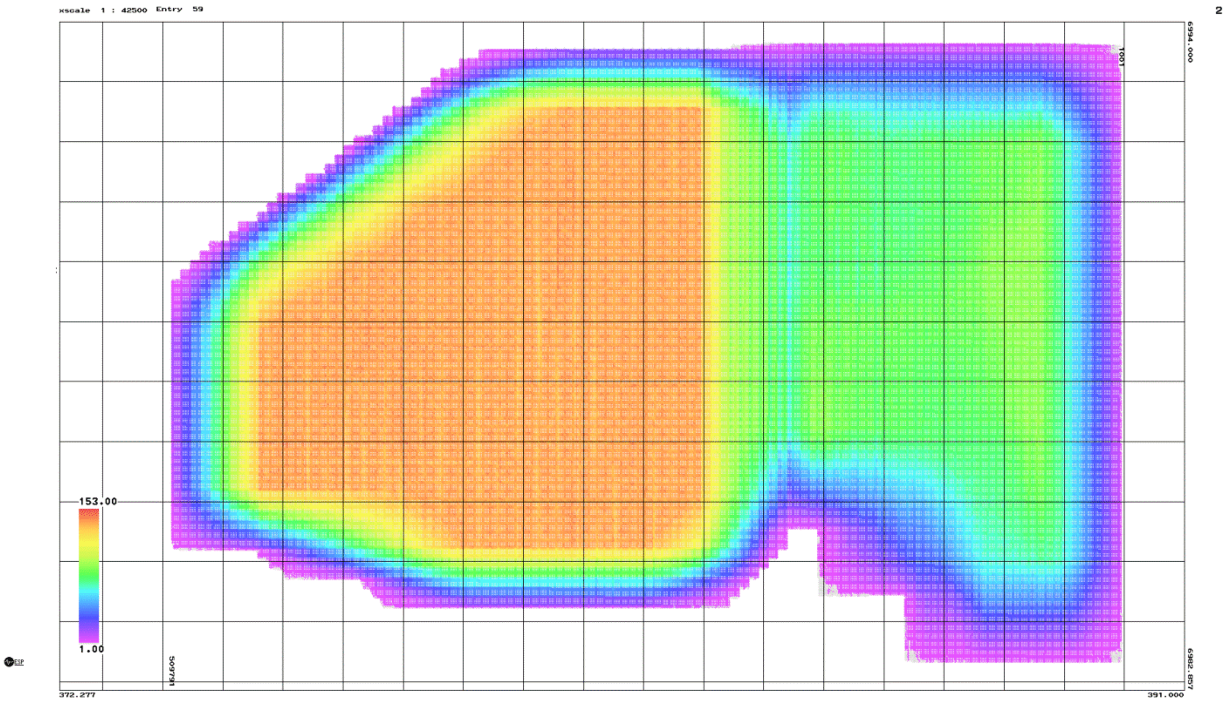



**Figure 13: Fold map at 3600 m offset**

### 8.20 Trace Gather

The shot sorted data was gathered into the CDP domain.

### 8.21 Frequency Dependent Noise Attenuation on Gathers

A final pass of glitch removal is run on the gathers.

### 8.22 Processing Datum

Velocity analysis is referenced to a floating datum, called the surface-in-time. The surface-in-time is equal to two times the total receiver static.

### 8.23 Preliminary Velocity Analysis

Preliminary velocity analysis was done approximately at two control points per square kilometer using an interactive semblance display. The semblance analysis was calculated using a 10 ms time increment and 50 m/s velocity increment with semblance maxima picked down to 3000 ms. The dataset at far offset showed effects of anisotropy (VTI) and a horizontal/vertical velocity ratio of 1.06 was picked to better flatten the far offsets. Offline TP multiple attenuation was applied to the common offsets to aid in velocity picking.

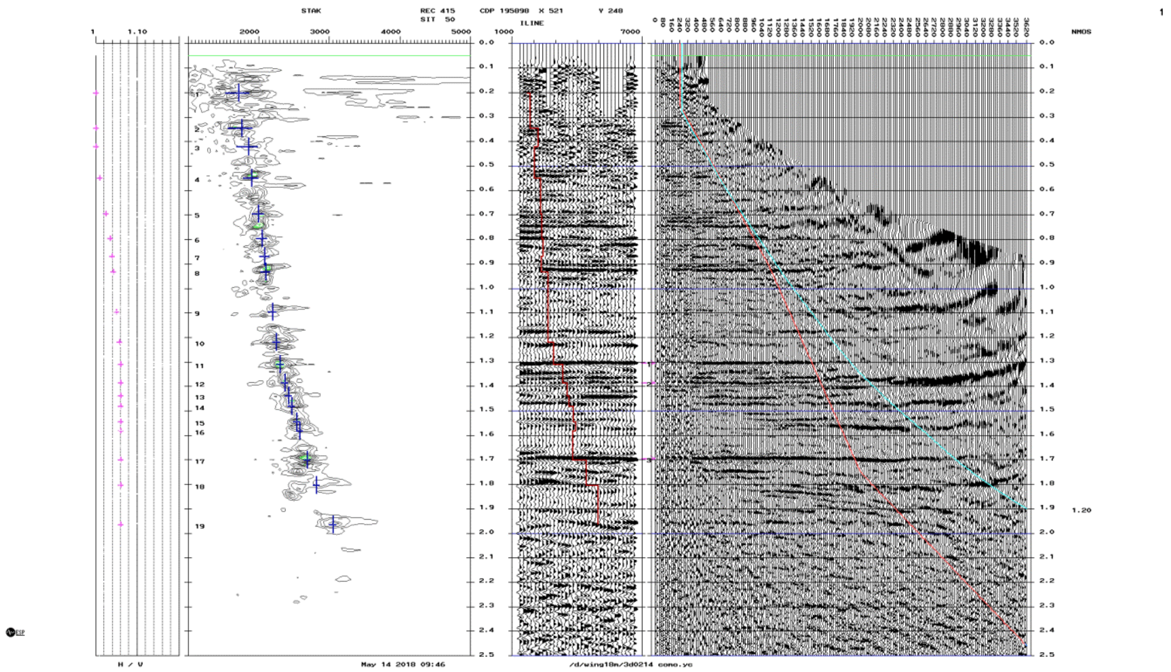


**Figure 14: Velocity Analysis Display from Wingman 3D**

The above figure shows ESP's Velocity Analysis program. The display is broken up into 4 panels, from the left:

- 1st Panel shows the horizontal to vertical ratio to account for anisotropy.
- 2nd Panel shows a semblance contour with the picked RMS velocity function overlay. The semblance calculation uses both amplitude and phase calculations for better focusing of the clouds.
- 3rd Panel shows the interval velocity function calculated from the RMS function in red with the stack underlain.
- 4th Panel shows the common offset stack used in the velocity analysis, as well as the mute function in red. The blue line is representative of 20% NMO stretch.

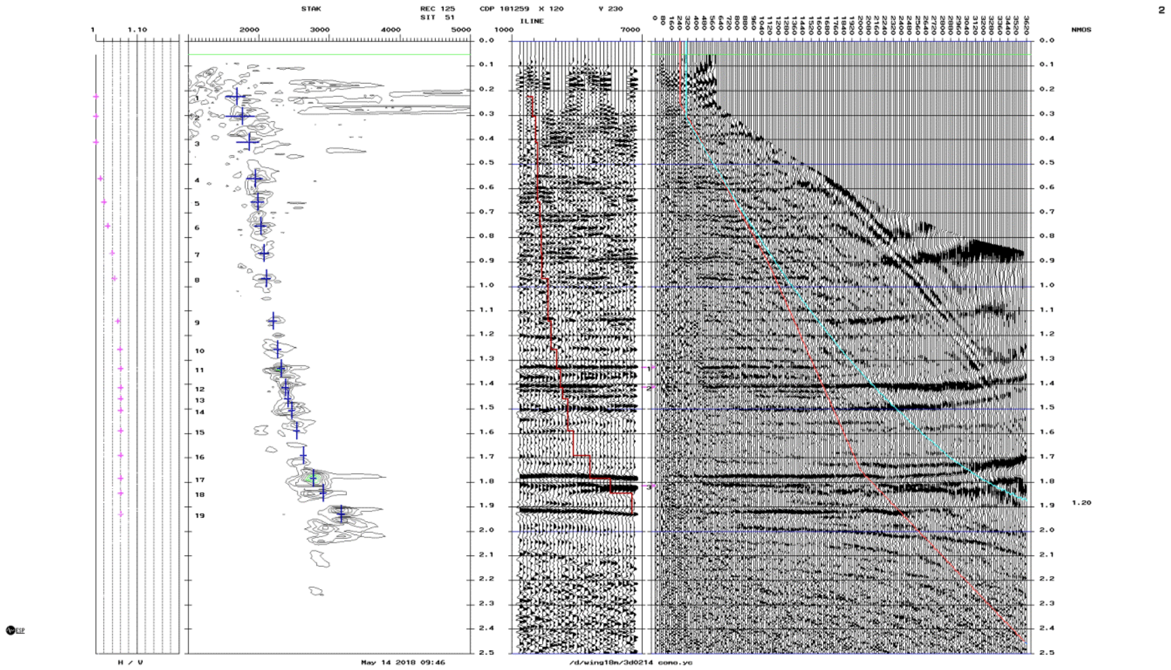



**Figure 15: Velocity Analysis Display from Jasmine 3D**

### 8.24 Surface Consistent Statics

Residual Statics were looked at in a couple of different ways. Initially, Shot and Receiver Stacks were examined and any obvious shifts were applied. The data was then input into a 3-component surface consistent cross-correlation algorithm. A design window of 400-2500 ms. out to far offset was used in the calculations with allowable shifts of +/- 28 ms. This algorithm compares each trace in each CDP to a model trace and decomposes the static value into shot, receiver, and offset components. The offset component ensures that residual velocity move out does not affect the surface consistent statics. Shot and Receiver statics were output and applied. Final shot and receiver stacks were created as a quality check.

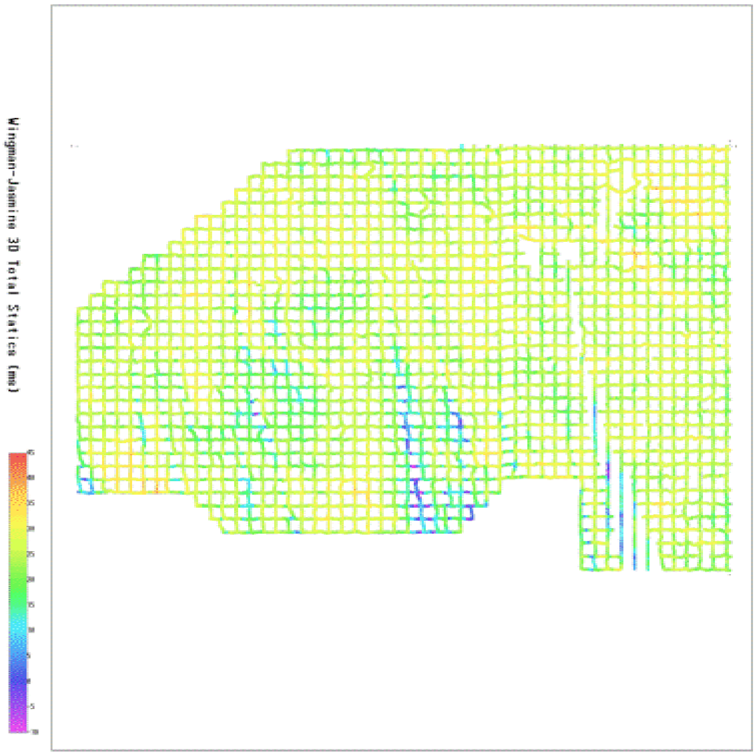



**Figure 16: Total Static Applied**

**The processing steps of velocity analysis and residual statics analysis were iterated until both were optimized.**

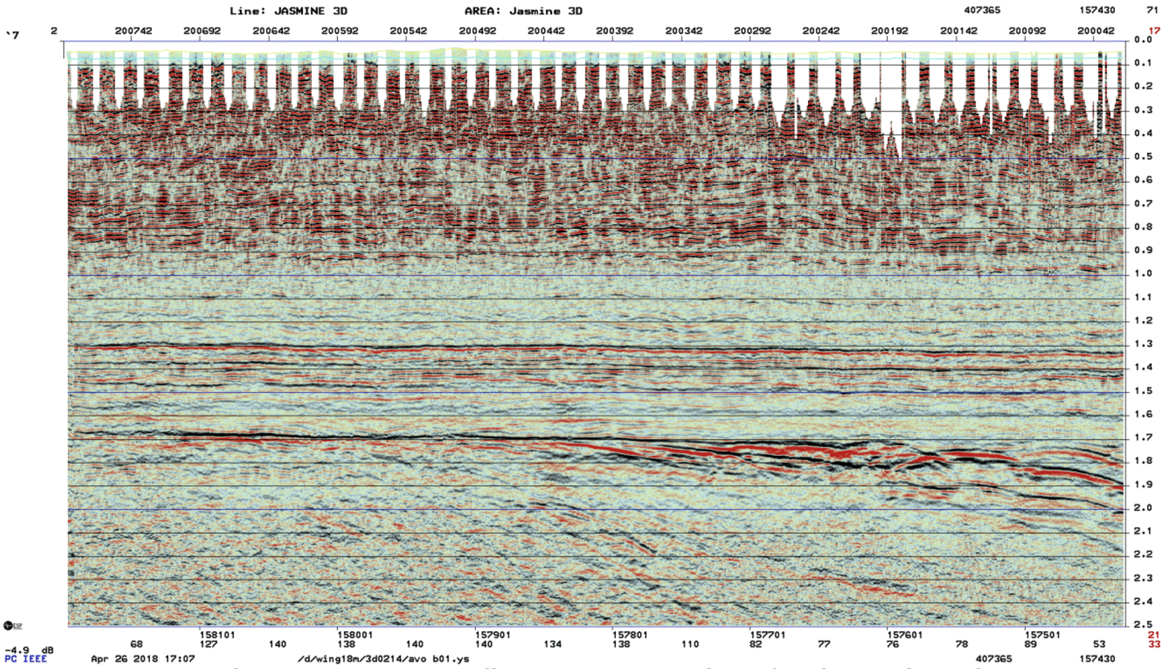


Figure 17: East-West Inline 200, Brute Stack – refraction statics only

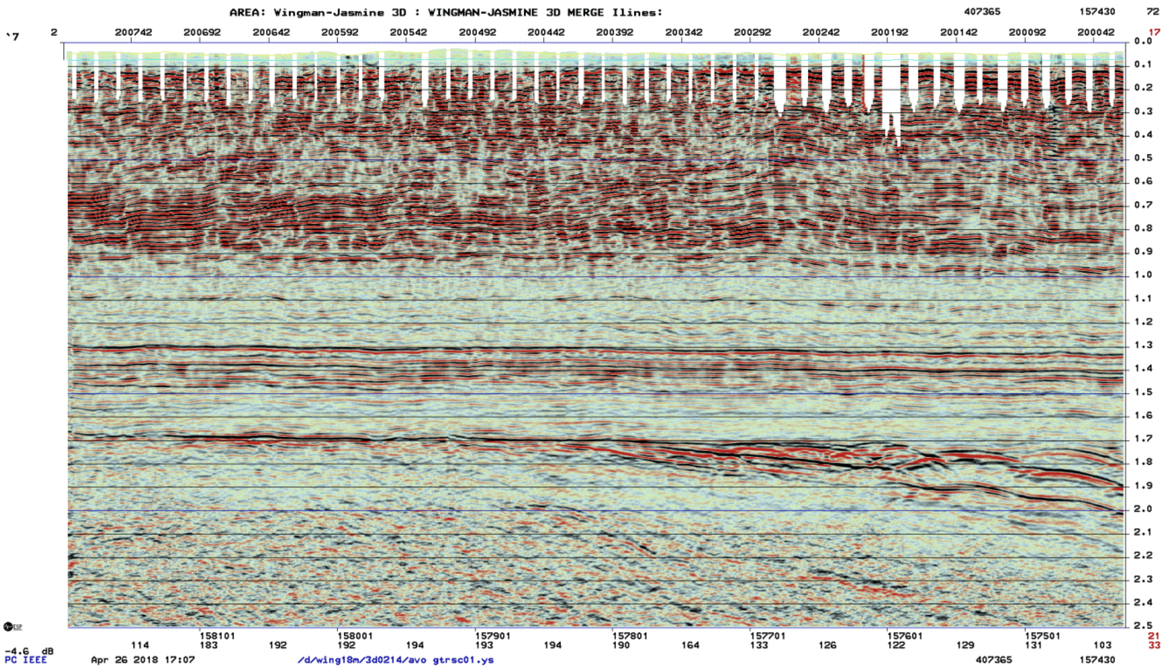


Figure 18: East-West Inline 200, Final Structure Stack after residual statics and final velocities are applied

### 8.25 Final Velocity Analysis

With all final statics resolved, the velocities were picked approximately at 5 control points per square kilometer using an interactive semblance display with both regular and noise reduced inputs used in the analysis. Velocities were iteratively picked to yield the best stack.

### 8.26 Trim Statics

Trim Statics are non-surface consistent statics that are performed on the stack by cross-correlation to a model trace and applying the time shift that gives the best correlation over a window.

### 8.27 Final Mute

A final stacking mute was decided on and is given in the following offset (meters) and time (ms) pairs:

240 200  1100 850  2000 1700  3600 2400

**The following processes composed the post-stack migration flow:**

### 8.28 Gaussian Weighted Stack

Missing offset information within a CMP is obtained from neighbouring bins and is incorporated based on a Gaussian weighting function. 3x3 bin Gaussian weighted stacks were run and outputted for the post-stack migration flow to limit the amount of acquisition footprint visible in the shallow data.

### 8.29 TXY Decon Noise Reduction

TXY decon noise reduction was designed over 15 traces with a 5-point operator at 100% noise reduction, and was applied to the Gaussian stack prior to migration.

### 8.30 Post-Stack Finite Difference Migration

Omega-X Finite Difference Migration was run with a maximum angle of migration of 65 degrees

**The following processes composed the pre-stack migration flow:**

### 8.31 5D Minimum Weighted Norm Interpolation

The interpolation dimensions are Inline, Crossline, Azimuth, Offset, and time, and in this case were designed to fill in missing traces within the output grid at groupings of 120m out to 3600m offset and 6 azimuths. A maximum of +/- 4ms dip was allowed inline-to-inline. Parameters were optimized to match the data at the known input locations, while giving physically reasonable results where input data did not exist. Gaussian interpolation on the gathers proved to be less effective than 5D interpolation in preserving dips and structure.

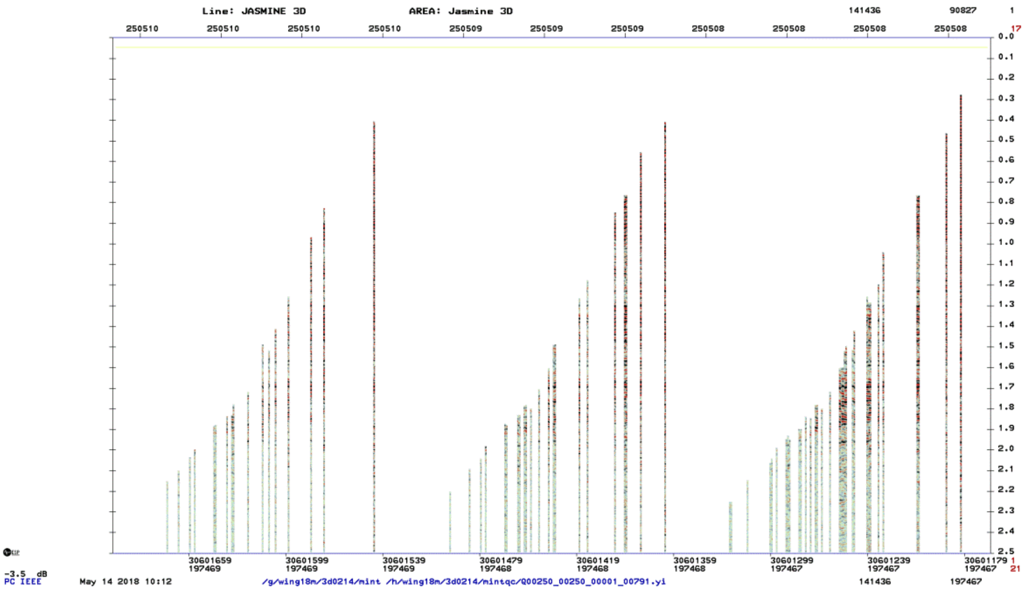



**Figure 19: NMO Corrected CMP Gathers**

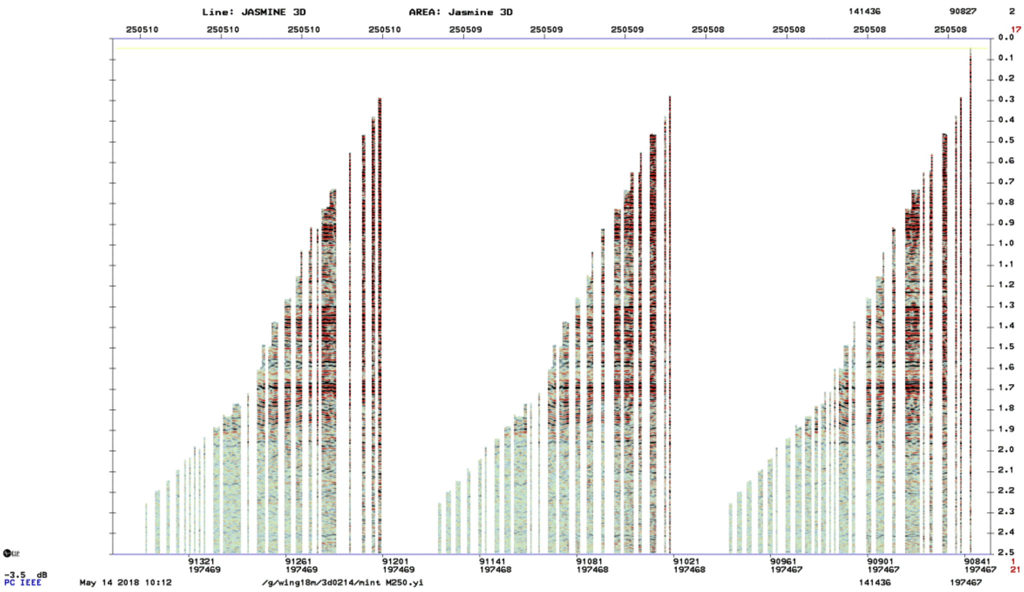



**Figure 20: 5D Interpolated CMP Gathers**

### 8.32 Pre-stack Kirchhoff Time Migration (Gathers)

Kirchhoff summation migration was applied in the offset domain. Data was migrated initially using 100% of the smoothed stacking velocities. This data was then re-analysed using an interactive semblance program for residual move-out and the velocity field was recalculated. The data was then re-migrated and the above steps iterated until a final migration velocity field was determined. To minimize migration artifacts, the final migrated gathers were then muted back to an equivalent 5x5 super gather. A migration aperture of 1500 m and a maximum migration angle of 60 degrees were used.

### 8.33 Singular Spectrum Analysis and Rank Reduction on PSTM Gathers

Singular Spectrum Analysis, also known as Eigenimage Filtering or Rank Reduction was applied. Working in the f-x domain (where 'x' can stand for any number of spatial dimensions), the data is organized into a Hankel matrix. This matrix is then decomposed into its component Eigenimages. Coherent energy ends up in the strongest few images only, which leads to the idea of discarding all other images and then reassembling the data. The result is that with suitable parameter choices, random noise is attenuated and coherent signal is preserved.

### 8.34 PSTM Residual Velocity Analysis

The PSTM gathers were analysed for residual moveout present after migration. These small adjustments were applied to the gathers when creating the PSTM stack.

### 8.35 TXY Decon Noise Reduction on Stack

TXY decon noise reduction was designed over 15 traces with a 5-point operator at 100% noise reduction, and was applied to the Gaussian stack prior to migration.

### 8.36 Final Filter and Scaling

A Final Filter was applied to the data to optimize frequency bandwidth for the volume and remove excess noise outside of the sweep spectra. The filter was based on the vibroseis sweep parameters and narrow band frequency analysis. The following was the final two-gate filter selected for the 3D:

Final Filter: 6/10 – 95/115 Hz

A time residual scalar was applied after the filtering with a rolling window of 500 ms.

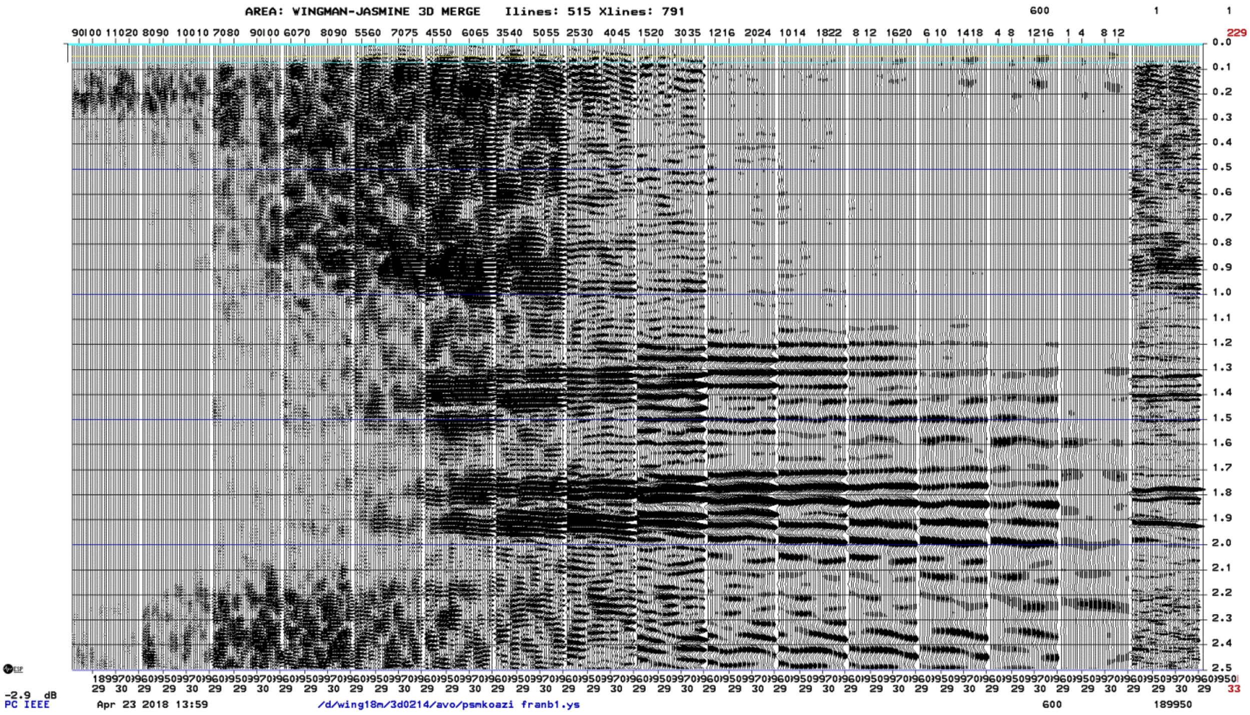


Figure 21: Frequency Analysis Example from Jasmine 3D

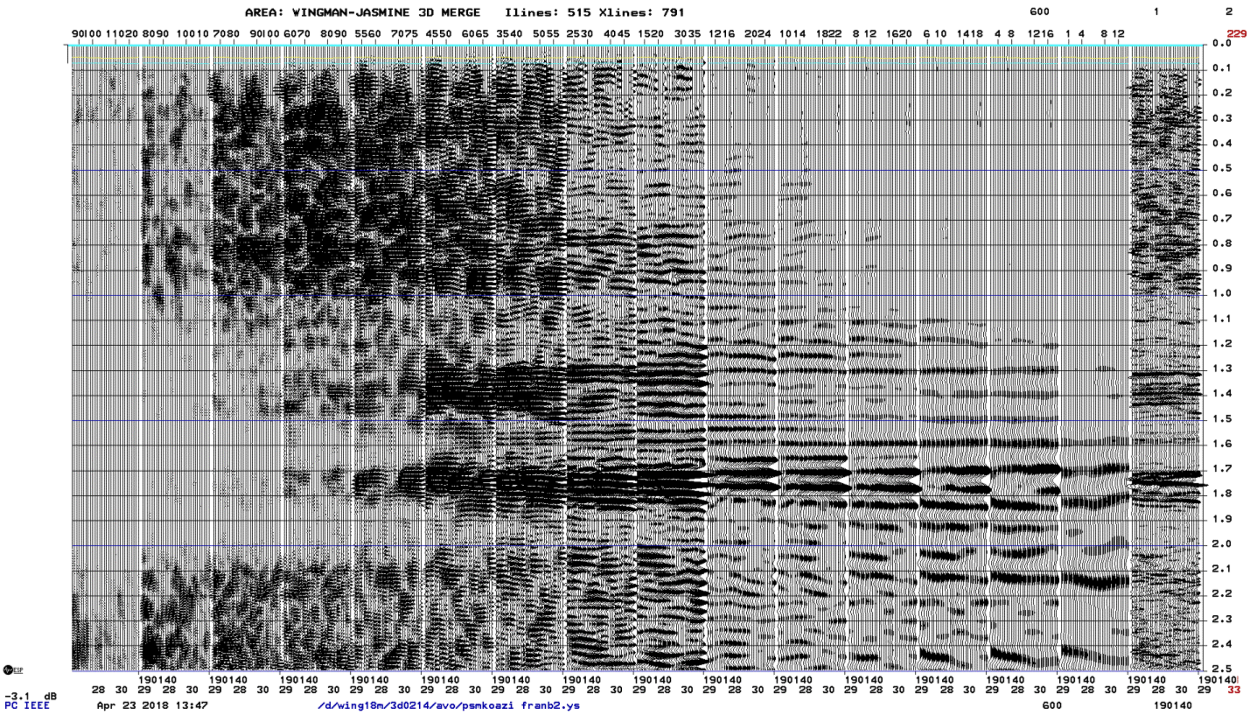


Figure 22: Frequency Analysis Example from Wingman-Jasmine 3D Merge zone

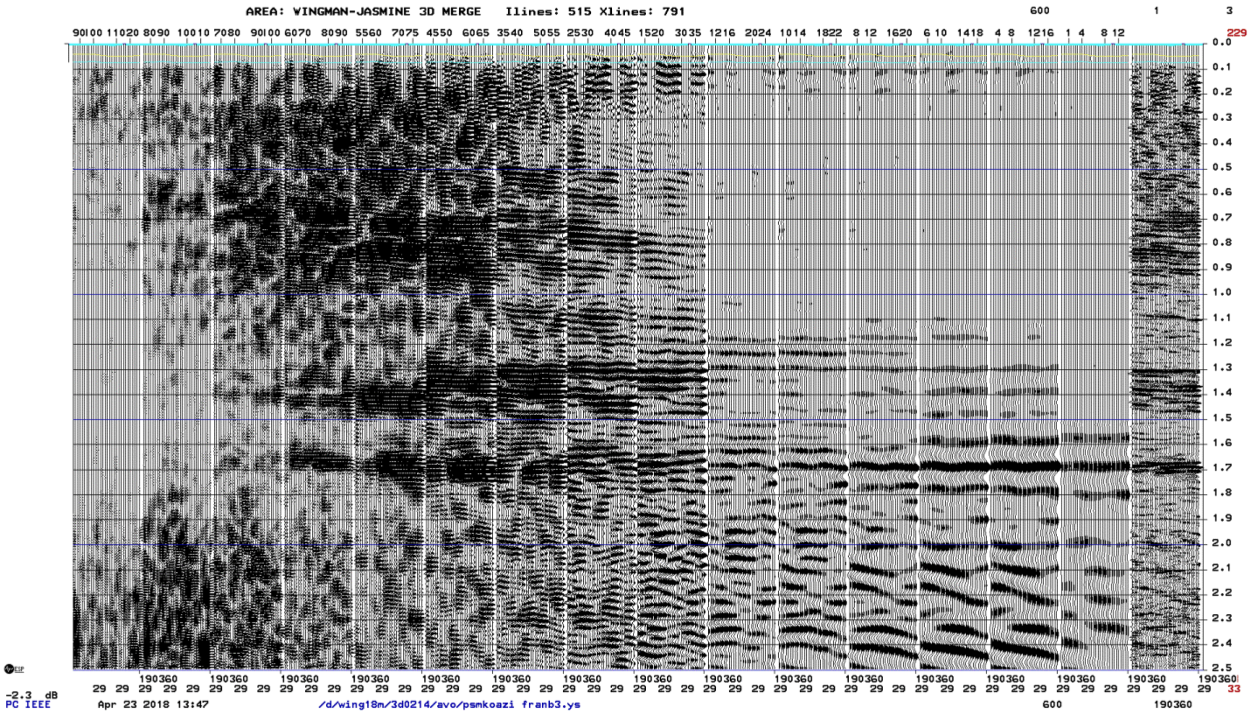



**Figure 23: Frequency Analysis Example from Wingman 3D**

The following figures display the final post- and pre-stack migrations:

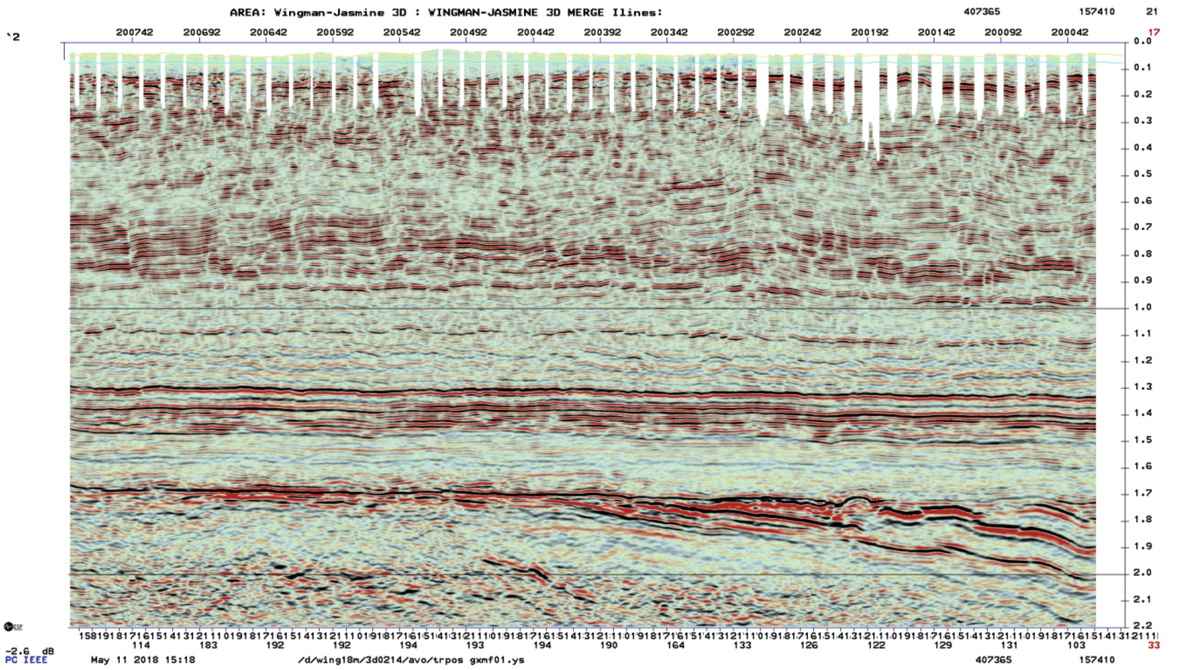



**Figure 24: Southeast-Northwest Inline 200, Filtered Post-Stack Migration with TXY Decon**

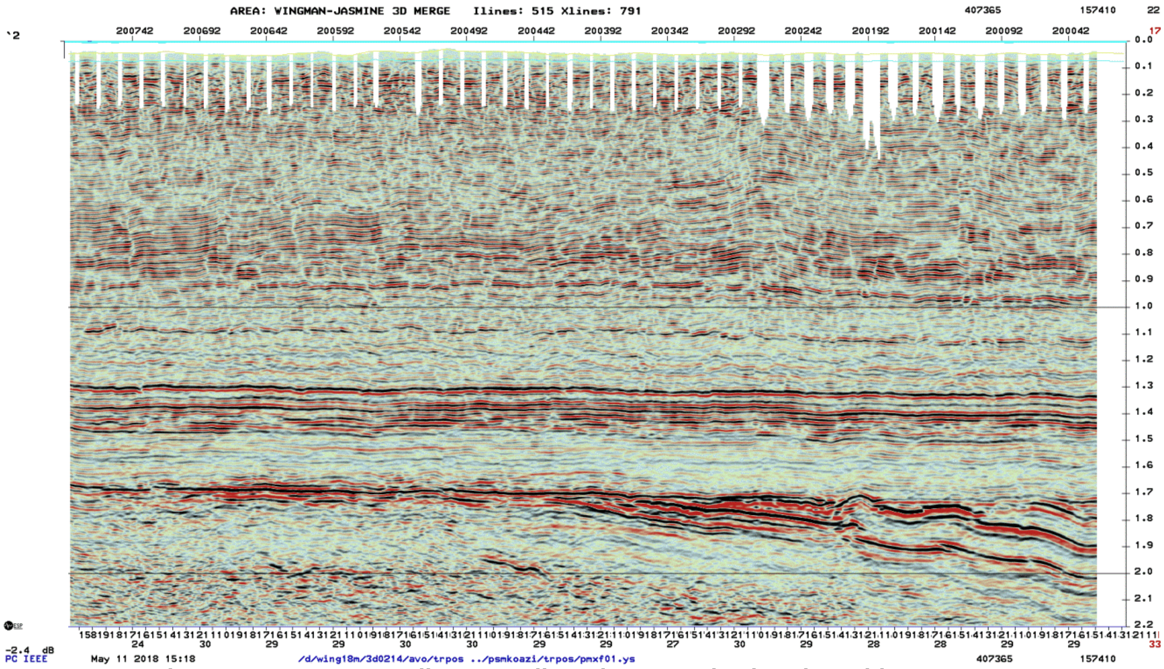


Figure 25: East-West Inline 200, Filtered Pre-Stack Migration with TXY Decon

## 8.37 Event-Guided Scalar Factors

To bring out subtle amplitudes in the zone of interest, scalar factors of 1.5 and 2.1 were applied to the final filtered stacks.

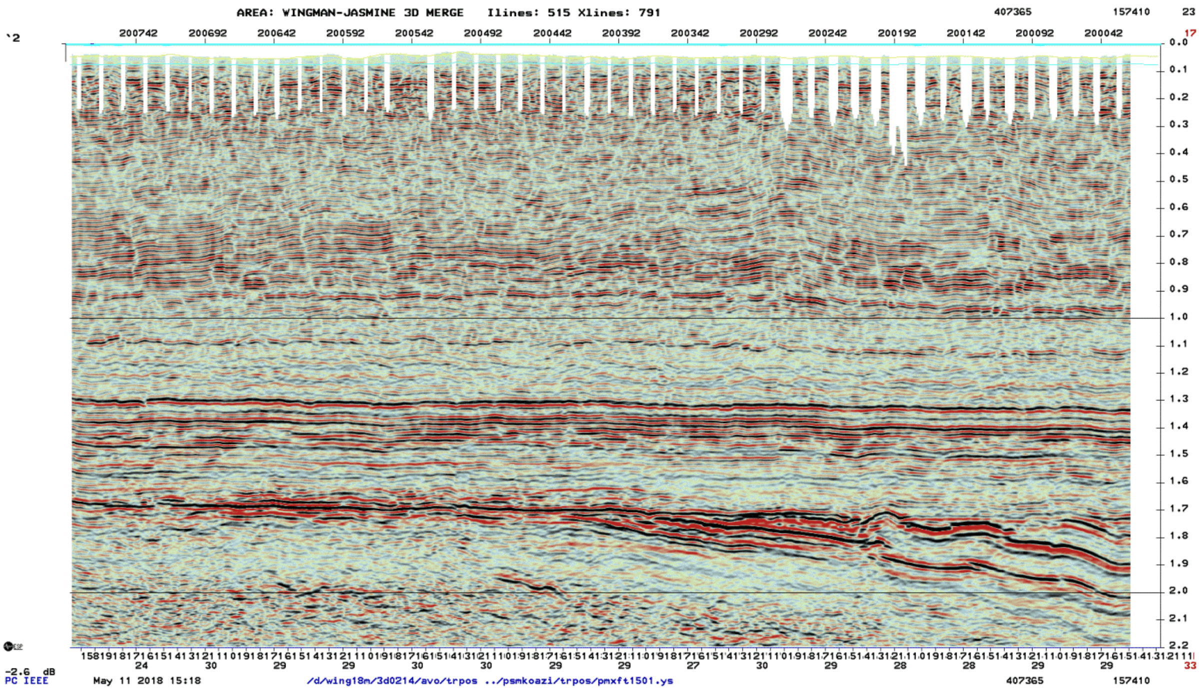


Figure 26: East-West Inline 200, Filtered Pre-Stack Migration with TXY Decon and Scalar Factor of 1.5

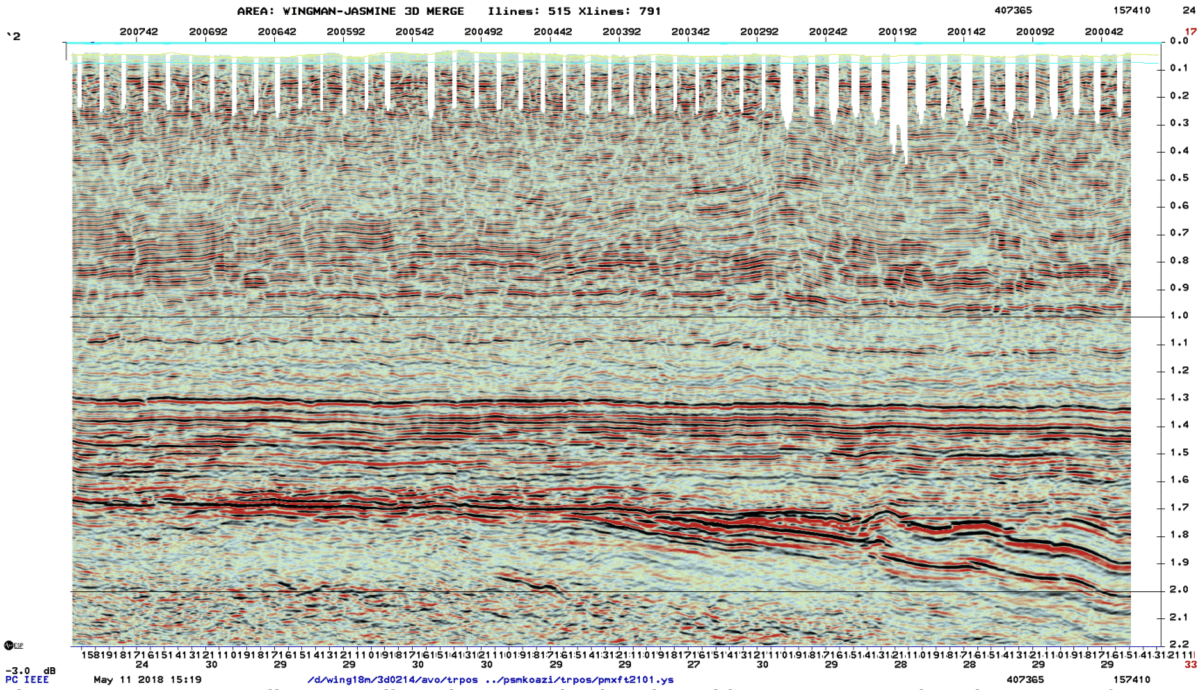



**Figure 27: East-West Inline 200, Filtered Pre-Stack Migration with TXY Decon and Scalar Factor of 2.1**

# 9 APPENDICES

## 9.1 Deliverables

- Filtered AVO Compliant Post-Stack Migration
  - TXY DCON + Migration
- Filtered AVO Compliant PSTM
  - PSTM + TXY DCON
  - PSTM + TXY DCON with Scalar Factor of 1.5
  - PSTM + TXY DCON with Scalar Factor of 2.1
- Unfiltered AVO Compliant PSTM Angle Stacks
  - Near 0-15 degree
  - Mid 15-30 degree
  - Far 30-45 degree

## 9.2 EBCDIC Header (example)

```
CHEAD

C01 Client: Terra Nova Energy Ltd.   Bin Geometry: 20 x 20 m.
C02 AREA: WINGMAN-JASMINE 3D MERGE   Ilines: 515 Xlines: 791
C03 Location: Australia                                    MGA ZONE: 54  GDA 94
C04
C05 DATA TYPE:  Filtered PRESTACK TIME MIGRATION + TXY DCON
C06 Acquisition: Terrex Seismic  PTY: 402 / A2
C07 Shot for: Terra Nova/Senex Energy  June 2013/March 2015   Total Shots: 17542
C08 Spread: Orthogonal 14 x 160/20 x 192   R-Line Int: 320m.  S-Line Int: 320m.
C09 Source Interval: 40 m. Receiver Interval: 40 m. Fold: 153
C10 Source: Vibroseis    Type: I/O AHV IV     Sweep: 4-100 / 4-90 Hz.  Linear
C11 Receivers: SM-24     10 Hz.  12 over 40 m.
C12 Instruments: Sercel 428      3425 Live Traces  Max SEG-D  Gain: Fixed
C13 Record Filters: Out - 200 Hz.                  Notch: Out
C14 PROCESSING:         EARTH SIGNAL PROCESSING LTD.   Date: April 2018
C15
C16 Expn Scaling: T**p, p=1.4    First Breaks: First Break Tomography (2)
C17 Datum: 100 m.   Replacement Vel: 2000 m/s  Weathering Vel: 700  m/s
C18 Surface Consistent Amplitude Scaling  Trace Edits
C19 Frequency Dependent N.A.  Anti-Aliasing Anti-Leakage Fourier Filter (ALFF)
C20 Surface Consistent Amplitude Scaling  Surface Consistent Deconvolution
C21 First break equalization              Frequency Dependent Noise Attenuation
C22 ALFF  Surface Consistent Amplitude Scaling  TPXY NR on X-Spreads
C23 Surface Consistent Amplitude Scaling   Trace gather: fold = 153
C24 Frequency Dependent Noise Attenuation  Processing Datum:  Surface in Time
C25 Velocities: Interactive semblance      Surface Consistent Statics
C26 Velocities: Interactive semblance      Trim statics: cmp cross correlation
C27 Mute Pairs: (d t)  1    240 200  1100 850  2000 1700  3600 2400
C28 5D MWN Interpolation: 120 m Offsets   3D Anti-Aliasing PSTM   Rank Reduction
C29 TXY DCON NOISE REDUCTION 15     trace time variant 100    % N.R.

C31 Filter:  6 / 10 - 95 / 115 Hz. Mean Scaling window: 400   2500 ms.



C36  INLINES: 1 -  515, CROSSLINES: 1 -  791,  (inline,crossline)
C37  NW (   1, 791) @  374159,6993627   NE (   1,1) @  389958,6993622
C38  SW ( 515, 791) @  374155,6983347   SE ( 515,1) @  389955,6983342
```