Snowball – Epsilon Merge / Snowball – Odin Processing Report

March 2020

Data Processed by:

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1 INTRODUCTION

Earth Signal Processing Ltd. was chosen to do the processing of the Snowball – Epsilon Merge and the reprocessing of Snowball - Odin in the Cooper Basin, Australia. The Epsilon 3D was reprocessed and merged with the existing Snowball 3D. The Odin 3D was reprocessed as part of the larger Snowball 3D. The Snowball – Epsilon Merge consists of an Epsilon 3D recorded in 1998 and the larger Snowball 3D in 2016.

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 December 2019. All processing took place from December 2019 to February 2020.

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 over 50 different countries spanning the globe and have processed thousands of 2D lines and 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: Universal Transverse Mercator
Projection Zone: UTM South, Zone 54
Geodetic Datum: GDA 94

3 KEY PERSONNEL

The main personnel involved with the project were:

Vintage Energy:

Danny Burns, Exploration Geophysicist
Daniel Gibbins, Exploration Geophysicist

Earth Signal Processing:

Greg Staples, Senior Processing Advisor
Cory Honstein, Senior Processor

4 DATA ACQUISITION PARAMETERS

Survey	Snowball - Epsilon Merge
Location of Survey	Cooper Basin, Australia
Area of Survey	Snowball 3D / Epsilon 3D
Survey Operator	Terrex Seismic/Schlumberger
Data Type	Land 3D
Area	56.4 km^2
Acquisition Record Length	4 s
Acquisition Sample Interval	2 ms
Source Type	Vibroseis Inova AHV-IV / Mertz M26 Sweep: 3 – 99 Hz / 5 – 90 Hz Linear Sweep Length:16 / 4 s
Spread	Orthogonal 28 x 144 m. / 8 x 96 m.
Receiver Line Interval	320 m / 320 m
Shot Line Interval	320 m / 320 m
Shot Spacing	40 m / 120 m
Receiver Spacing	40 m / 40 m
Filters	Out – 200 Hz / 5.5 – 103 Hz
Max Fold	130
Recorder	Sercel 428 XL/ I-O System II

Survey	Snowball - Odin
Location of Survey	Cooper Basin, Australia
Area of Survey	Snowball 3D
Survey Operator	Terrex Seismic
Data Type	Land 3D
Area	53.6 km^2
Acquisition Record Length	4 s
Acquisition Sample Interval	2 ms
Source Type	Vibroseis Type: Inova AHV-IV Sweep: 3 – 99 Hz Sweep Length: 16s
Spread	Orthogonal 28 x 144 m.
Receiver Line Interval	320 m
Shot Line Interval	320 m
Shot Spacing	40 m
Receiver Spacing	40 m
Filters	Out – 200 Hz
Max Fold	138
Recorder	Sercel 428 XL

5 PROCESSING GRID INFORMATION

The Snowball-Epsilon Merge was processed on a 20 m x 20 m bin grid. There were 3383 shots processed with a maximum fold of 130.

	Inline	**Crossline**	**UTM-X**	**UTM-Y**
NW	1	318	510652	6896865
NE	1	1	516992	6896865
SW	444	318	510652	6888005
SE	449	1	516992	6888005

The Odin 3D was processed on a 20 m x 20 m bin grid. There were 4235 shots processed with a maximum fold of 138.

	Inline	**Crossline**	**UTM-X**	**UTM-Y**
NW	1	417	495953	6906798
NE	1	1	504273	6906798
SW	449	417	495953	6897838
SE	449	1	504273	6897838

6 PROCESSING SEQUENCE

The fast track post-stack migration processing flow for the 3D's is shown below.

- Reformat
- Geometry and QC
- Refraction Analysis
- Replacement Statics
- Exponential Scaling
- Surface Consistent Amplitude Scaling
- Frequency Dependent Noise Attenuation
- Anti-Aliasing Anti Leakage Fourier Filter
- Trace Editing
- Vibroseis Designature
- Surface Consistent 5 Component Deconvolution
- Zero Phase Trace Deconvolution
- Ground Roll Equalization
- First Break Equalization
- Laterally Variant Residual Scaling
- CDP Binning on Common Grid and Geometry Application
- Trace Gather
- Processing Datum
- Velocity Analysis
- Surface Consistent Statics
- Overlapping Merge Zones
- TPXY Cross Spread Noise Attenuation
- 5D Minimum Weighted Norm Interpolation
- Pre-Stack Time Migration
- Trim Statics
- RMO Velocities
- Frequency Equalization on PSTM Gathers
- Singular Spectrum Analysis on Gathers
- Final Mute
- Stack
- Frequency Equalization on Stack
- TPX Noise Reduction
- Final Filter and Scaling
- Phase Adjustment to ASEG Polarity (Reverse SEG)

7 PROCESSING SEQUENCE EXPLANATION

7.1 Reformat

The dataset was received in SEG-D, which was reformatted to Earth Signal's internal format before processing.

7.2 Geometry and QC

Geometry assignment entails matching each received data file to the correct shot point identification and position. Headers were updated using survey geometry from supplied coordinates and elevations in UTM Zone 54 from geodetic datum GDA94. Surveys were mapped topographically to confirm location and QC surface conditions.

7.3 Refraction Analysis

An automated picking algorithm was used, with manual modification to areas where the algorithm failed due to low quality first breaks. The initial refraction model used is the slope-intercept method, which is then input into layer-based tomography to arrive at the final near surface model. Layer Based 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. A one-layer solution using the first break picks was calculated to using 180 – 800m of offset, which then was input into a layer-based tomography to calculate the refraction statics.

7.4 Replacement Statics

A datum elevation of 0 m was used during processing, as well as a replacement velocity of 2200 m/s, and weathering velocity of 900 m/s. The time of first sample is -200ms.

7.5 Exponential Scaling

Exponential Scaling is applied to correct for spherical divergence, using a $T^{1.4}$ function.

7.6 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 2400ms.

7.7 Frequency Dependent Noise Attenuation

The frequency spectrum of each trace was split into bands, which were compared in amplitude to surrounding traces in a defined window. If a threshold was reached within a frequency band, the amplitude was brought back to the average of the amplitude for that band. This step was designed to remove glitches from the shot records.

7.8 Anti-Aliasing Anti-Leakage Fourier Filter (ALFF)

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 an 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 and (3) residual energy within the frequency band affected by the noise.

ALFF Parameters	
Ground Roll Noise Cone Bandpass	200/300 ms – 1200/1500 ms
Signal Velocity Cone High Pass Cone	2500/3000 m/s
Noise Band	1/2 - 24/28 Hz

7.9 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.

7.10 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.

7.11 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.

7.12 Zero Phase Trace Deconvolution

Zero phase Trace deconvolution flattens the individual trace amplitude spectra without changing the phase, which results in improved continuity of events. The same design window as the surface consistent scaling is used.

7.13 Ground Roll Equalization

Adaptively scales ground roll represented by frequencies lower than 16Hz to suppress higher amplitudes, and lower frequency noise. Amplitudes of frequencies below 16 Hz are equalized to those between 16 and 60Hz, the expected signal amplitude. Phase is not altered.

7.14 First Break Equalization

This process scales the amplitudes of the first break region above the deconvolution design window to the mean amplitude within the window. This is required because the refracted amplitude spectrum is not the same as the reflected amplitude spectrum.

7.15 Laterally Variant Residual Scaling

Slowly laterally varying residual scaling that is consistent with offset. This is a residual correction to the theoretical spherical divergence compensation and works to give a specified output amplitude level. Statistically preserves amplitudes with offset (AVO compliant).

Up until this step, the Snowball and Epsilon 3D’s have been kept separate. The 3D’s are now merged, and statics and velocities are resolved.

7.16 CDP Binning on Common Grid and Geometry Application

In order to combine the Snowball and Episilon surveys, they needed to be binned on a common grid. A bin grid of 20 x 20 m was chosen, with no angle of rotation. In the Snowball-Epsilon Merge, a maximum fold of 130 is reached. For the merge a maximum offset of 4000m was kept.

7.17 Trace Gather

The shot sorted data is gathered into the CDP domain. Maximum offset kept is 4000m.

7.18 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.

7.19 Velocity Analysis

Velocity analysis was done on a 1km grid using an interactive semblance display. The semblance analysis was calculated using a 10ms time increment and 50m/s velocity increment with semblance maxima quite easily picked down to 2200 ms. An AVO reversal is seen around 22 degrees. Anisotropy (VTI) was observed in the far offsets of the dataset. A horizontal/vertical velocity ratio was picked to better flatten the far offsets, with values ranging from 1.01 to 1.06. Events were also picked on stacks to help the consistency throughout the volume.

7.20 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 300-2400 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 the 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.

7.21 Overlapping Merge Zones

Each 3D is individually is stacked and the overlapping merge zone is checked at each iteration for consistency of phase and static ties. There was no phase rotation or bulk shifts were applied to the 3D’s, the highest correlation between the 3D’s in the overlap zone occurred at 0 degrees.

7.22 TPXY Cross Spread Noise Attenuation

A TPXY noise algorithm using a 15x15 trace operator was applied to the cross spreads for each individual 3D using the final statics and velocities.

7.23 5D Minimum Weighted Norm Interpolation

Common offset (COFF) gathers were interpolated for every 120m offset increment. The interpolation dimensions are Inline, Crossline, Offset and Time. A maximum of +/- 6 ms dip was allowed trace to trace as well as a maximum of -120 to +680 ms over 4000 m in the offset direction. A good interpolated result is one that matches the data at the known input locations and gives physically reasonable results where there is no input data. The interpolation fills in every trace of the COFF gather, and a distance limiting factor is applied to kill off the interpolated traces that are deemed to be too far away from the input data.

7.24 Pre-Stack Time Migration

Kirchhoff summation migration was applied in the offset domain. The input into the PSTM was the COFF gathers after interpolation. At every source and receiver intersection the data was migrated initially using 100% of the smoothed stacking velocities with a 300m smoother. This data was then reanalysed using an interactive semblance program for residual move-out and the velocity field was recalculated.

7.25 Trim Statics

Trim Statics are non-surface consistent statics that are performed by cross-correlation to a model trace and applying the time shift that gives the best correlation over a window. The trim window used was 400-2400ms with a maximum shift of 6ms.

7.26 RMO Velocities

After PSTM the data was reanalysed using an interactive semblance program for residual move-out and the velocity field was recalculated. The stack and gathers were re-run with this updated velocity field.

7.27 Frequency Equalization on PSTM Gathers

Frequency Equalization is applied to the PSTM gathers to help boost and balance the frequencies. A one gate window from 400-2400ms was used, with frequencies of 1/3 – 99/110 Hz being whitened.

7.28 Singular Spectrum Analysis on Gathers

Singular Spectrum Analysis, or Rank Reduction works 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 reserved. This step is applied to the PSTM Gathers to clean them up after the frequency equalization. A rank of 5 was used.

7.29 Final Mute

A final stacking mute was decided on and was given in the following offset (meters) and time (ms) pairs: 319 370 4020 3500.

7.30 Stack

The above mute is applied and the PSTM gathers stacked together to a CDP stack. Angle stacks were also created at 0-22° and 22-45° angle ranges.

7.31 Frequency Equalization on Stack

Amplitude spectrums are analysed and balanced within overlapping time windows based on representative frequencies using a zero-phase frequency deconvolution. A 2-window time variant frequency design window was used for each dataset. A 1000ms crossover taper time was applied between the two-design window, where window 1 and 2 merge.

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	Time (ms)	Frequency (Hz)
Window 1	400 – 1050	4/8 – 85/100
Window 2	950 – 2400	4/8 – 65/75

7.32 TXY Noise Reduction

A post-stack TXY noise attenuation was applied using a 15-trace design window and 100% noise reduction.

7.33 Final Filter and Scaling

A final frequency domain time variant filter was applied to the stack. The filters applied were 5/10 – 80/90 Hz and 5/10 – 60/70 Hz with a crossover time at 1000ms.

7.34 Phase Adjustment to ASEG Polarity (SEG Reverse)

The final output phase rotation was designed from nearby well ties using synthetic seismograms and each dataset was rotated to approximate ASEG (SEG Reverse) Polarity. The well log data used had not been petrophysically corrected and some spikes required manual editing. The resulting phase rotations for each dataset was 270°.

8 APPENDICES

8.1 Figures

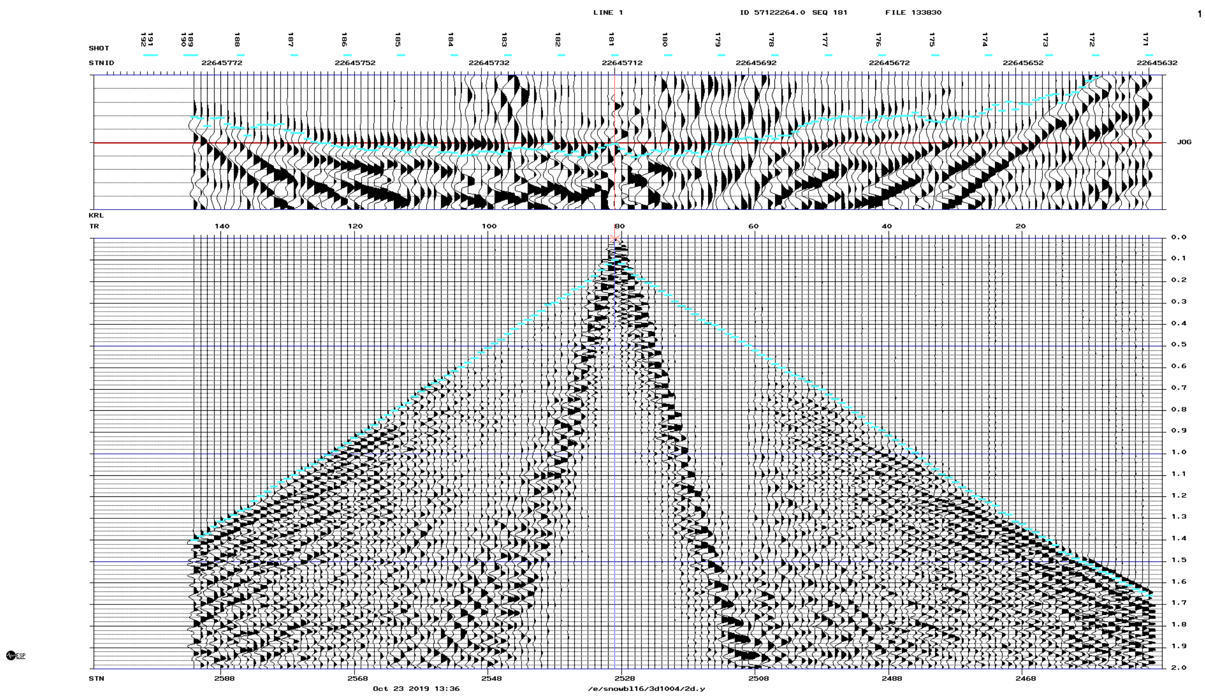

Figure 1. Example of First Break Arrivals from Epsilon 3D

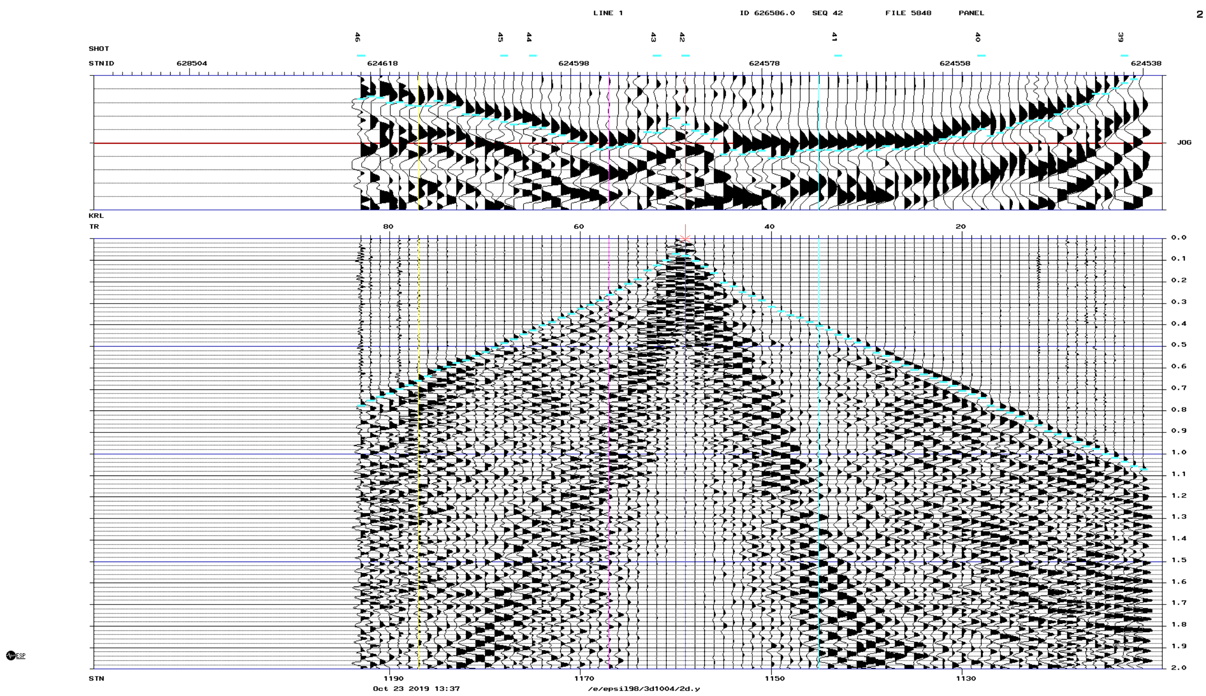

Figure 2. Example of First Break Arrivals from Snowball 3D

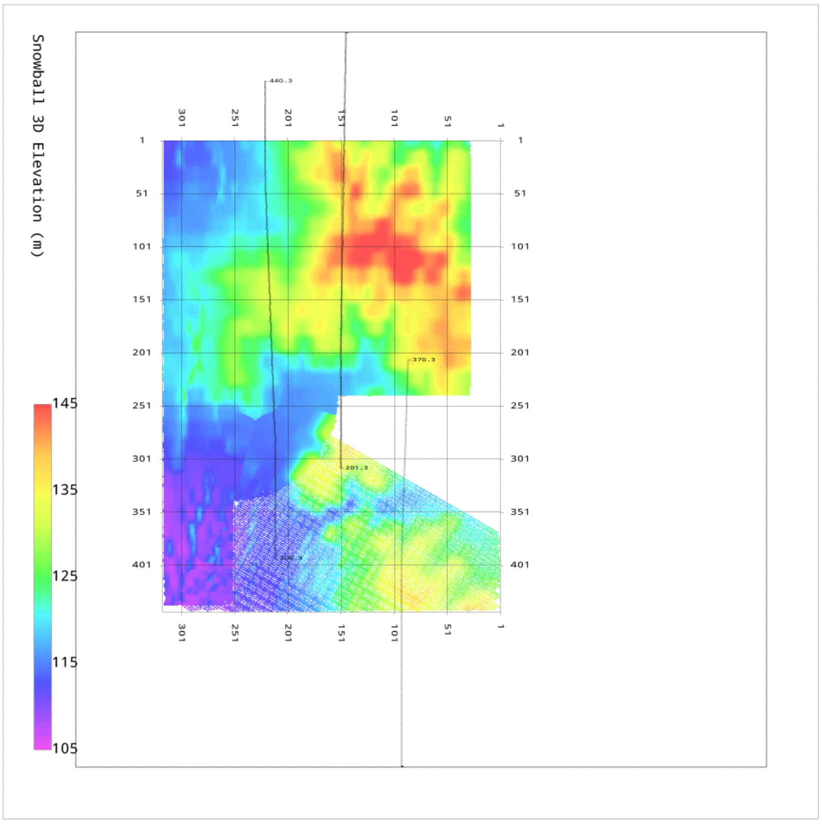

Figure 3: Snowball-Epsilon Merge 3D: Elevation Map

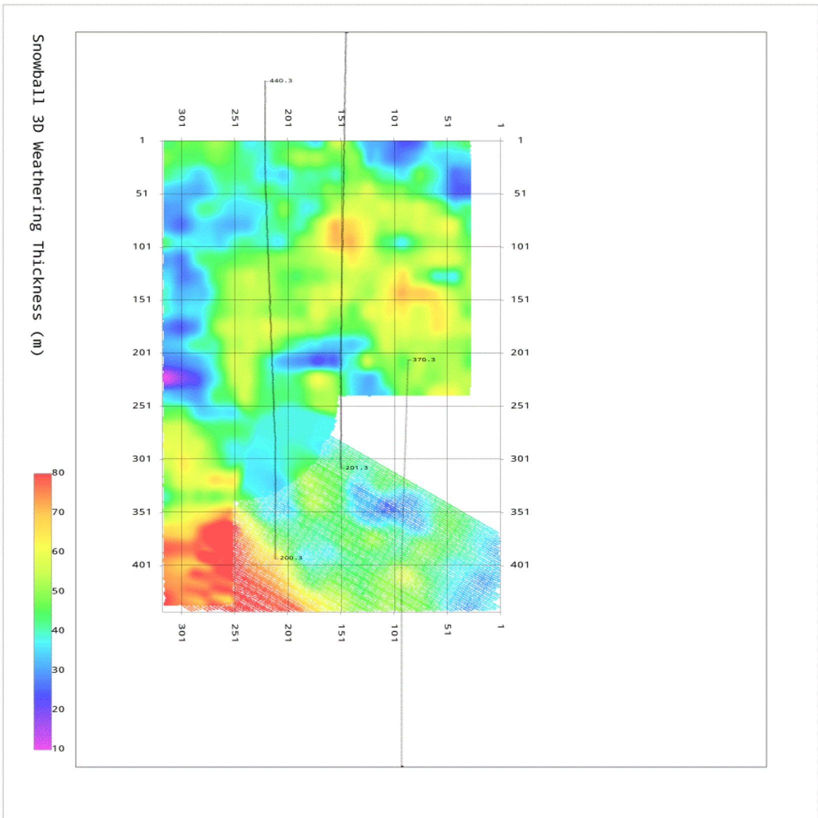

Figure 4: Snowball-Epsilon Merge 3D: Weathering Thickness Map

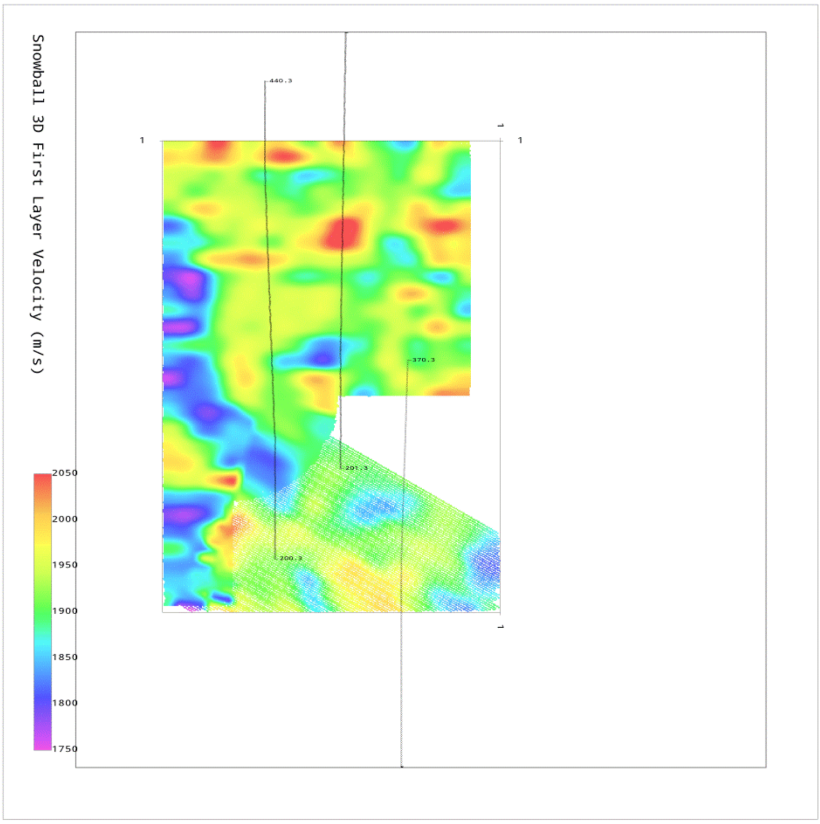

Figure 5: Snowball-Epsilon Merge 3D: First Layer Velocity Map

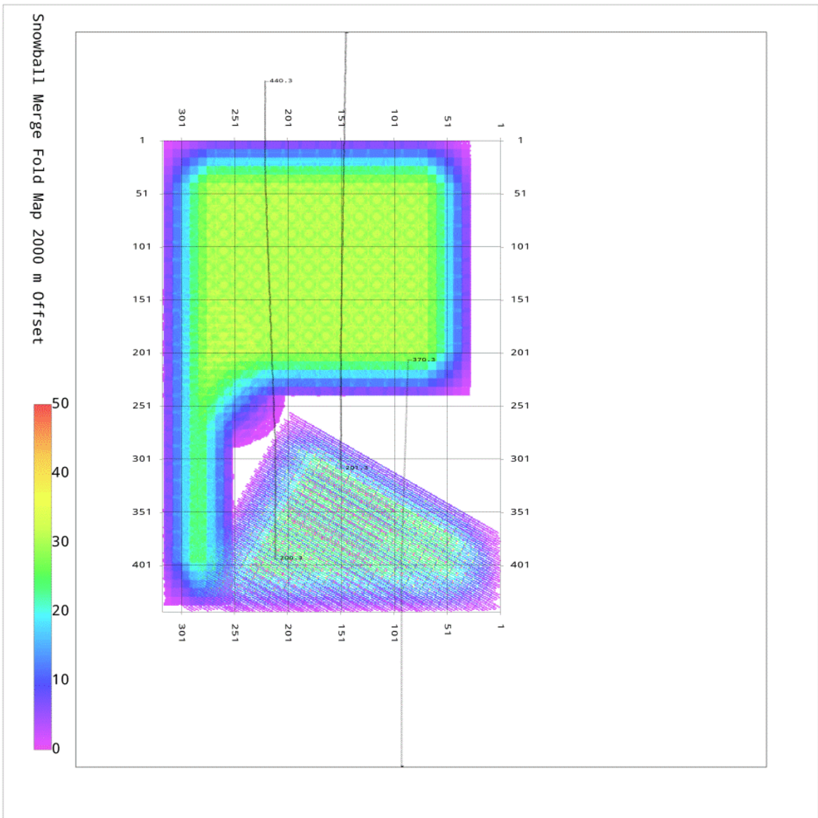

Figure 6: Snowball-Epsilon Merge 3D: Fold Map out to 2000m

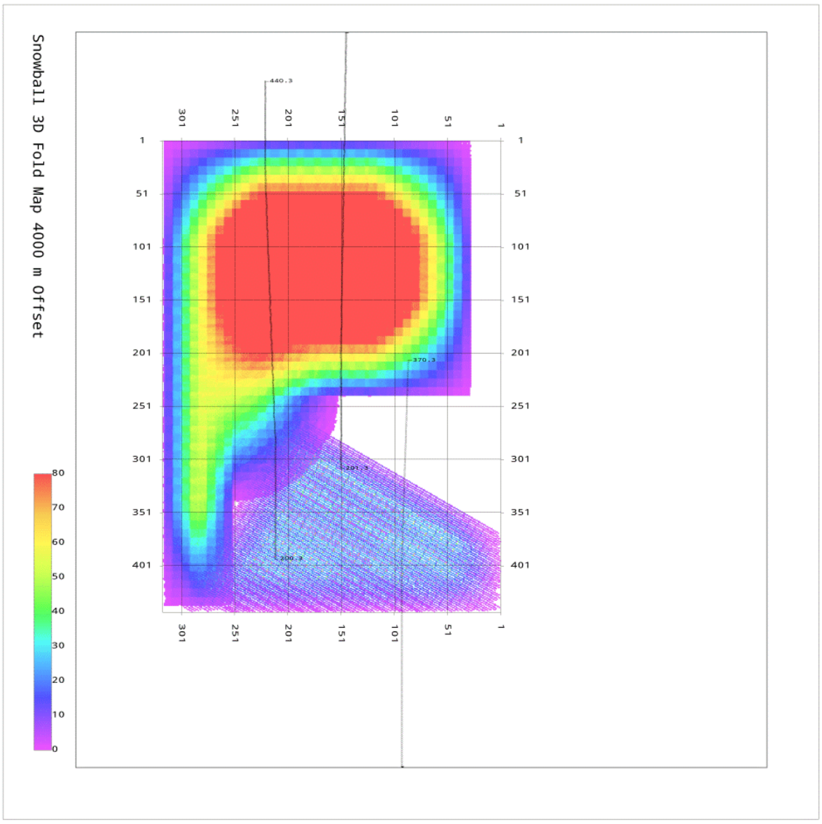

Figure 7: Snowball-Epsilon Merge 3D: Fold Map out to 4000m

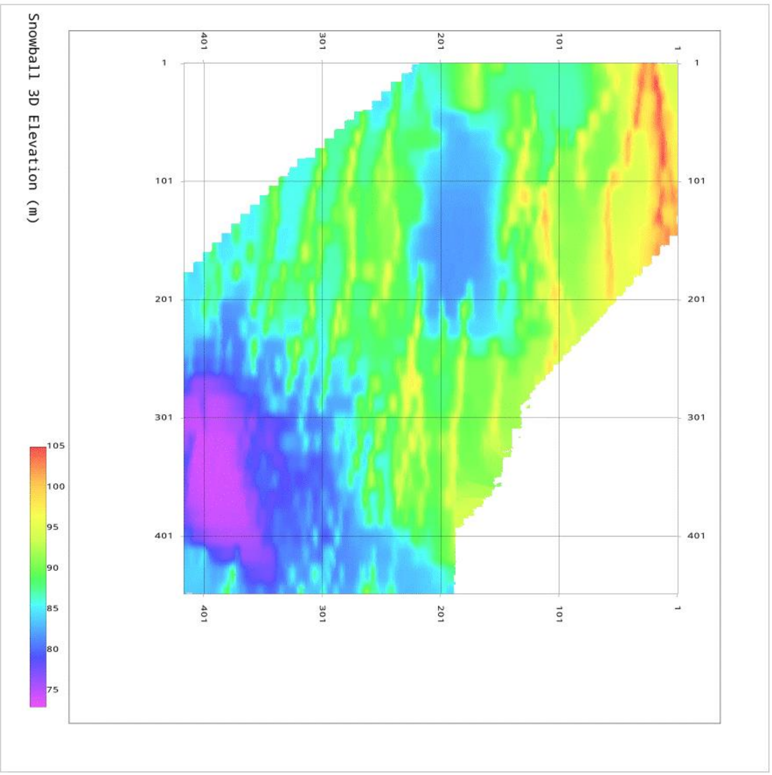

Figure 8: Snowball-Odin 3D: Elevation Map

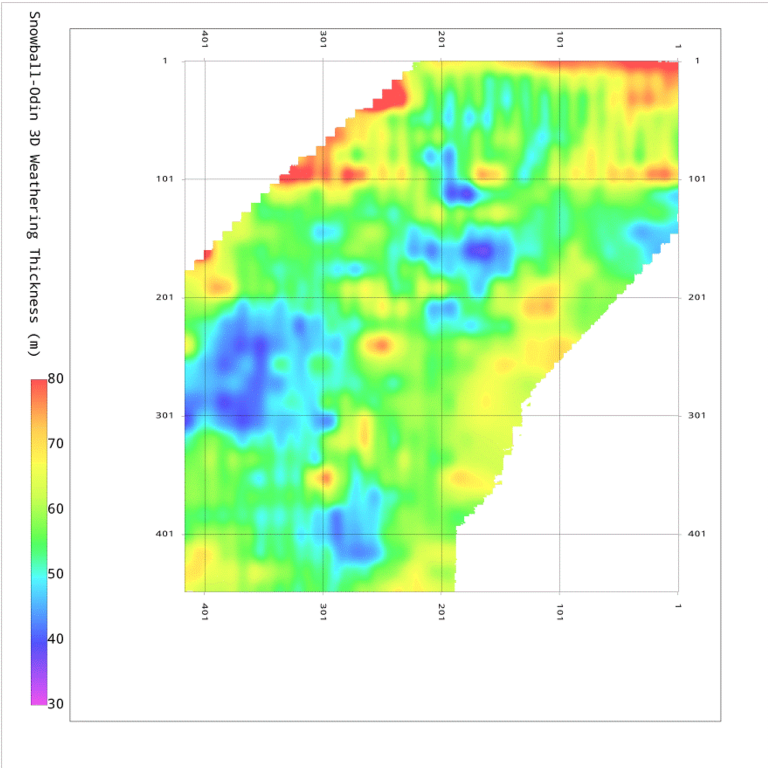

Figure 9: Snowball-Odin 3D: Weathering Thickness Map

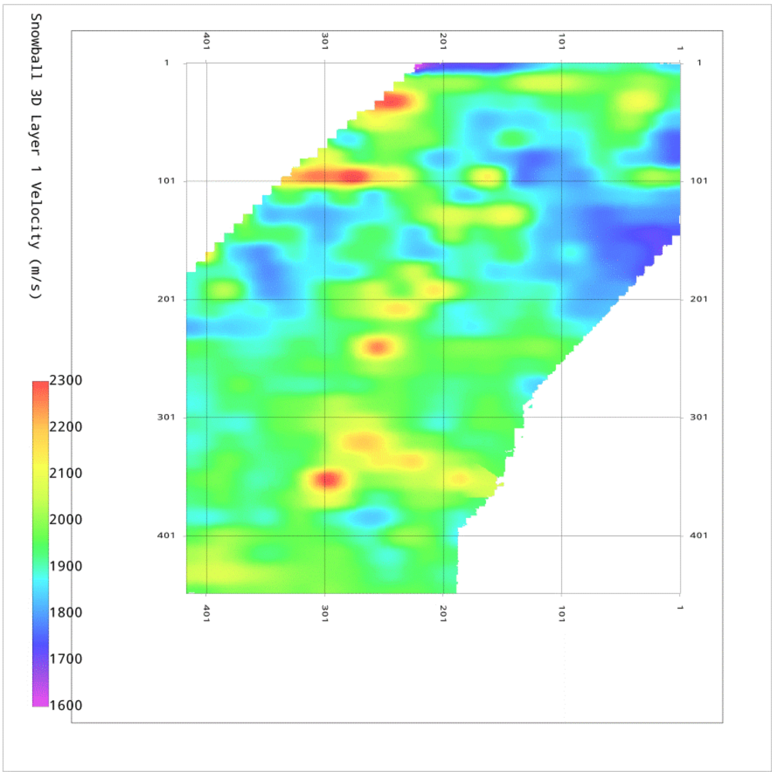

Figure 10: Snowball-Odin 3D: First Layer Velocity Map

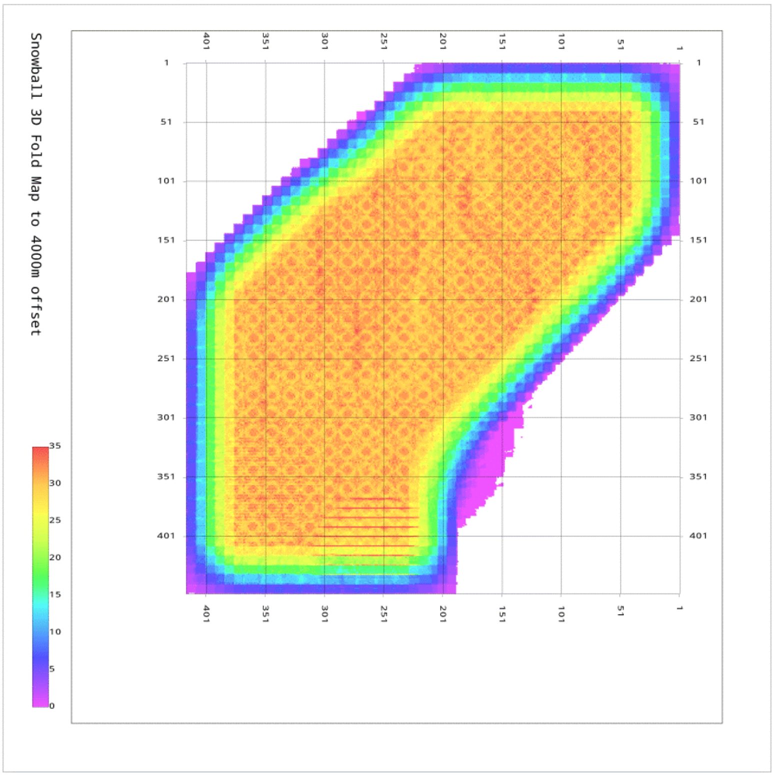

Figure 11: Snowball-Odin 3D: Fold map out to 2000m

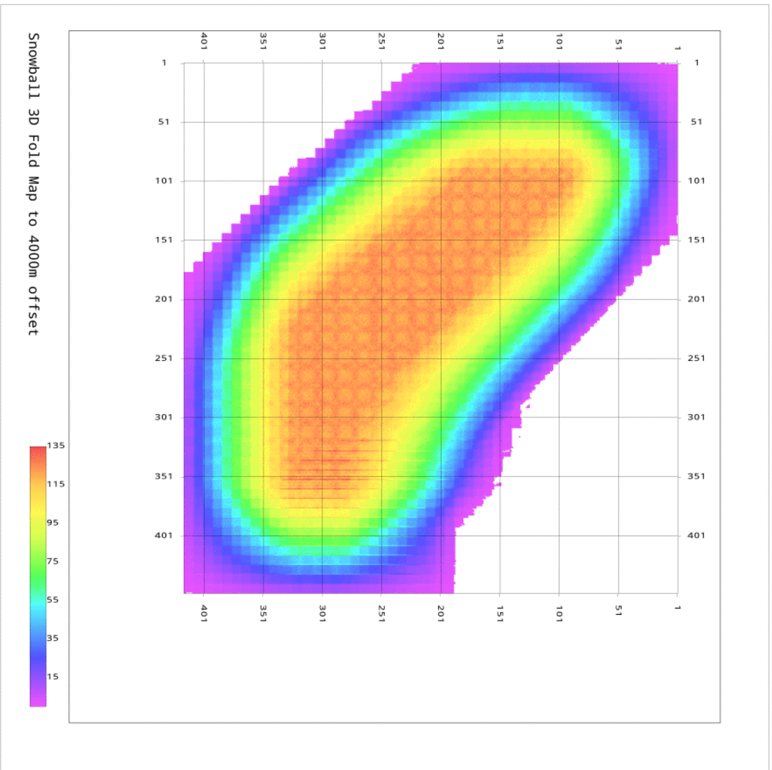

Figure 12: Fold map out to 4000m

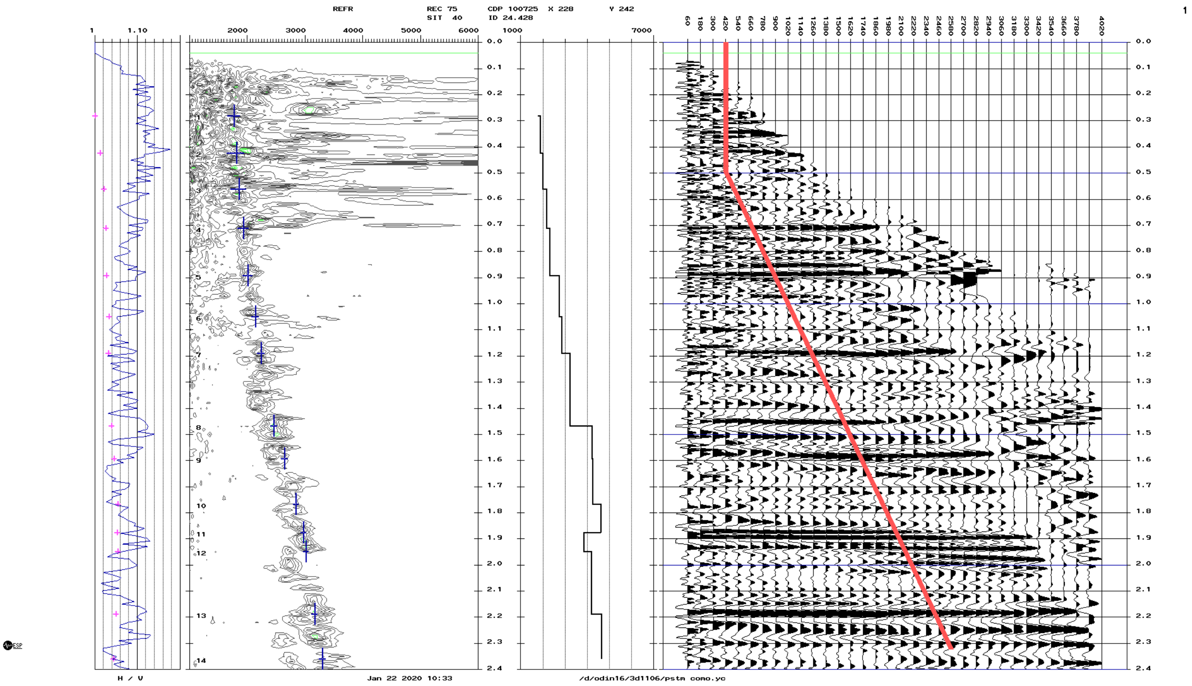

Figure 13: Velocity panel from Snowball-Epsilon Merge.

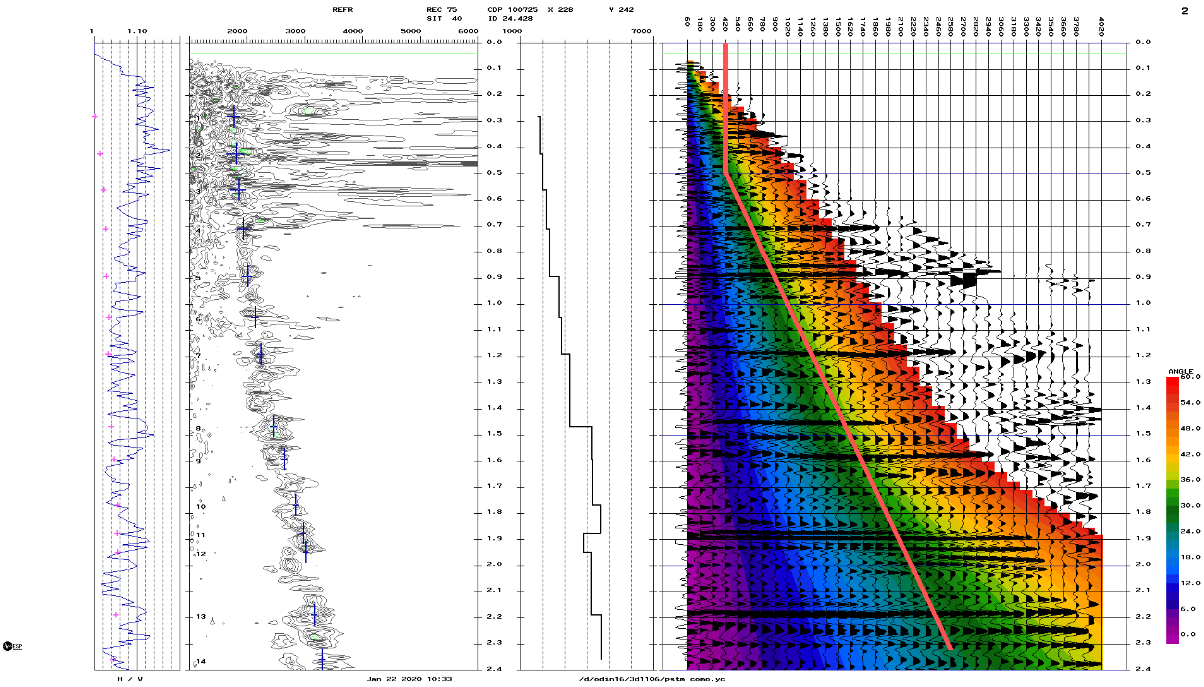

Figure 14: Velocity Panel from Snowball-Epsilon Merge with angles overlain

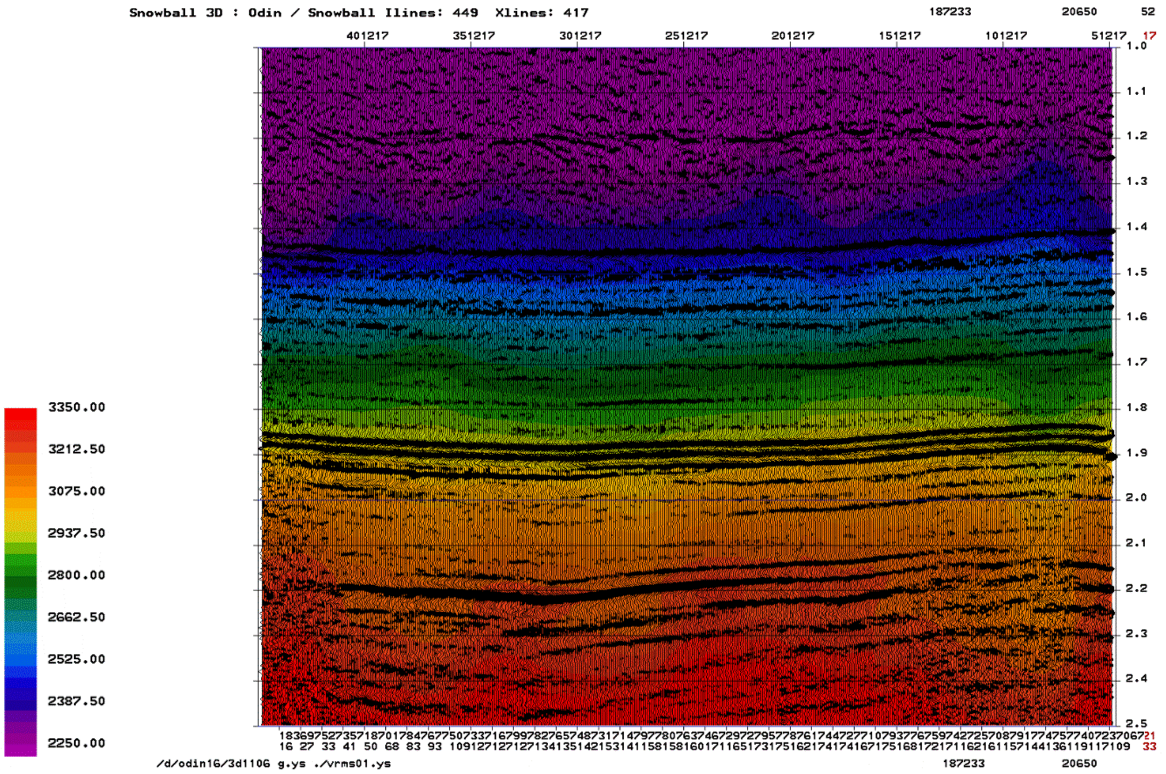

Figure 15: Snowball-Odin 3D: Crossline 217. Structure stack with RMS velocity underlain.

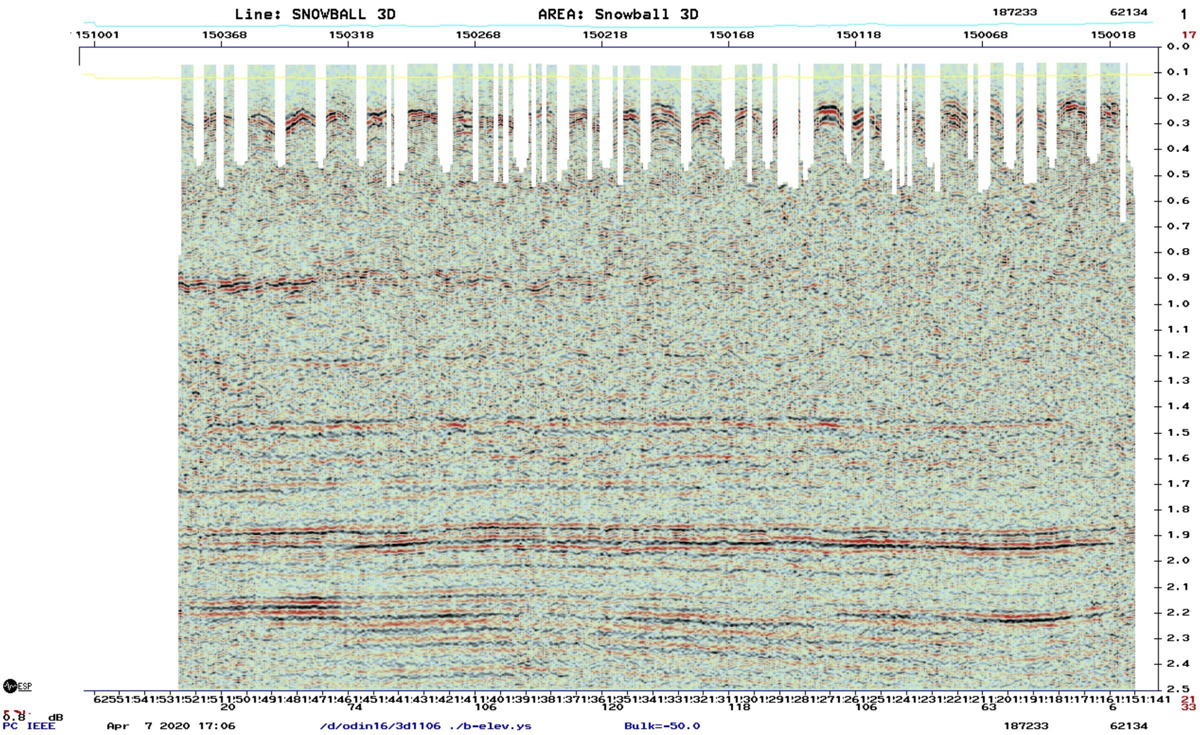

Figure 16: Snowball-Odin 3D: Inline 150. Elevation Stack

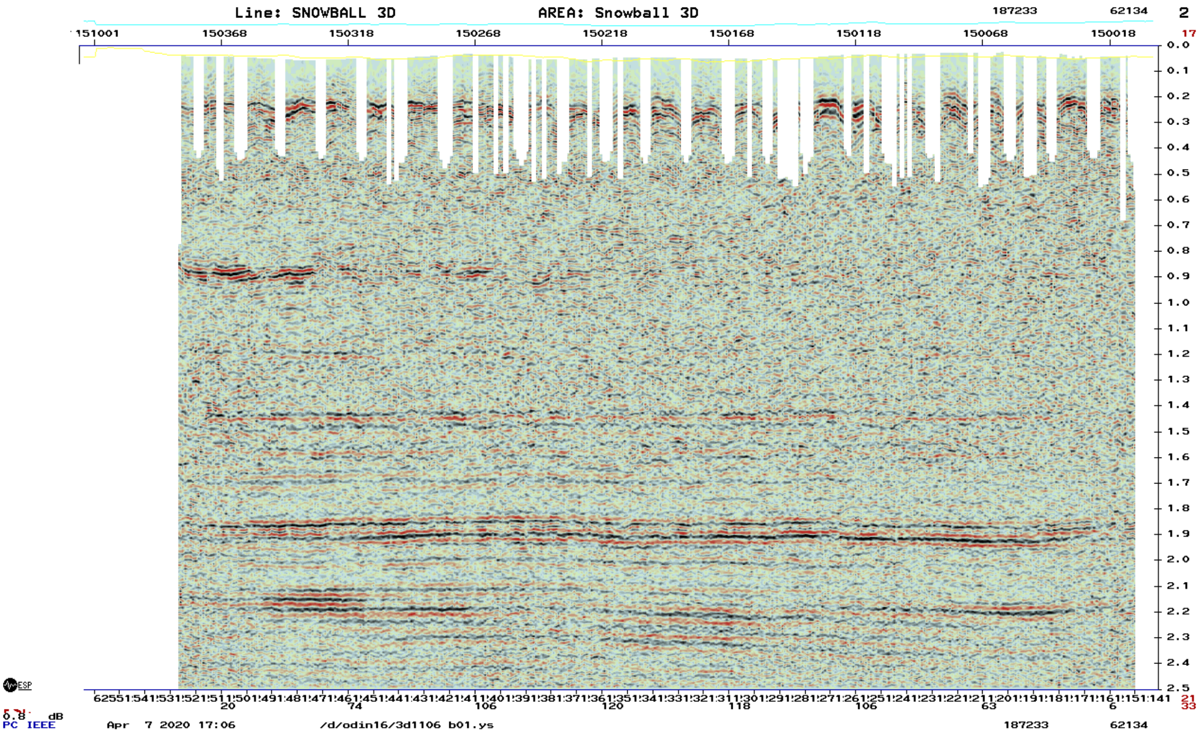

Figure 17: Snowball-Odin 3D: Inline 150. Refraction Stack

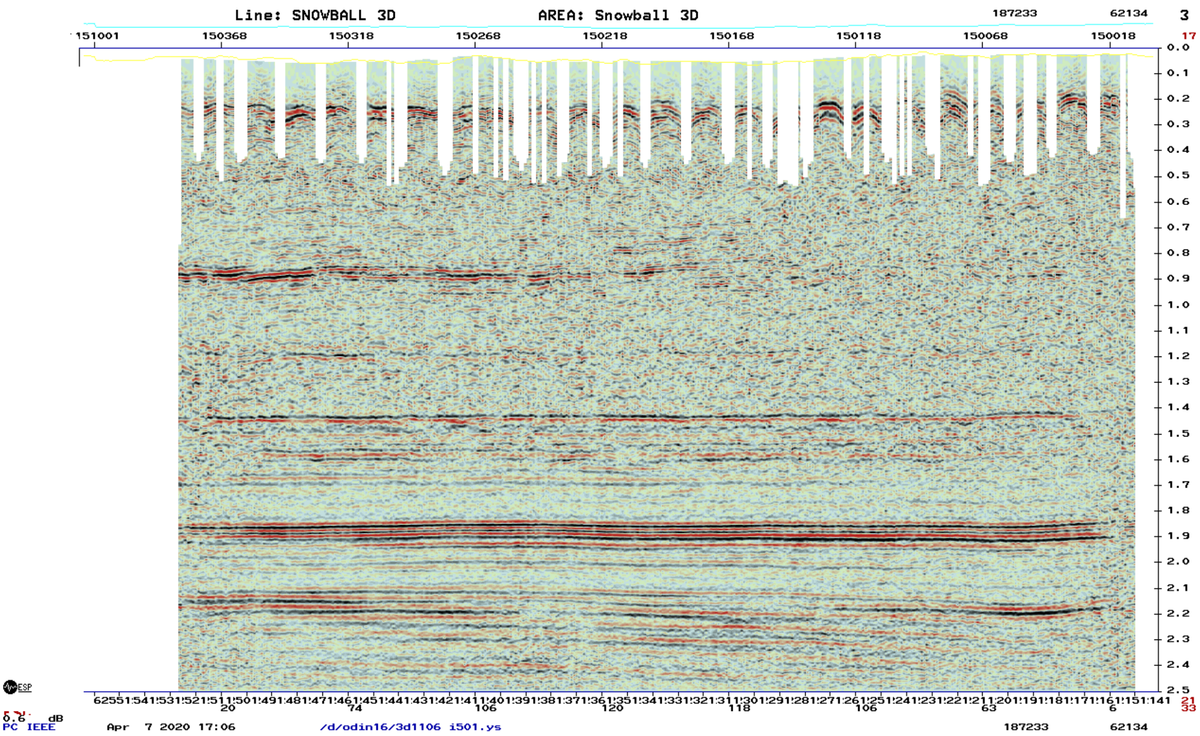

Figure 18: Snowball-Odin 3D: Inline 150. Stack with residual statics and updated velocities

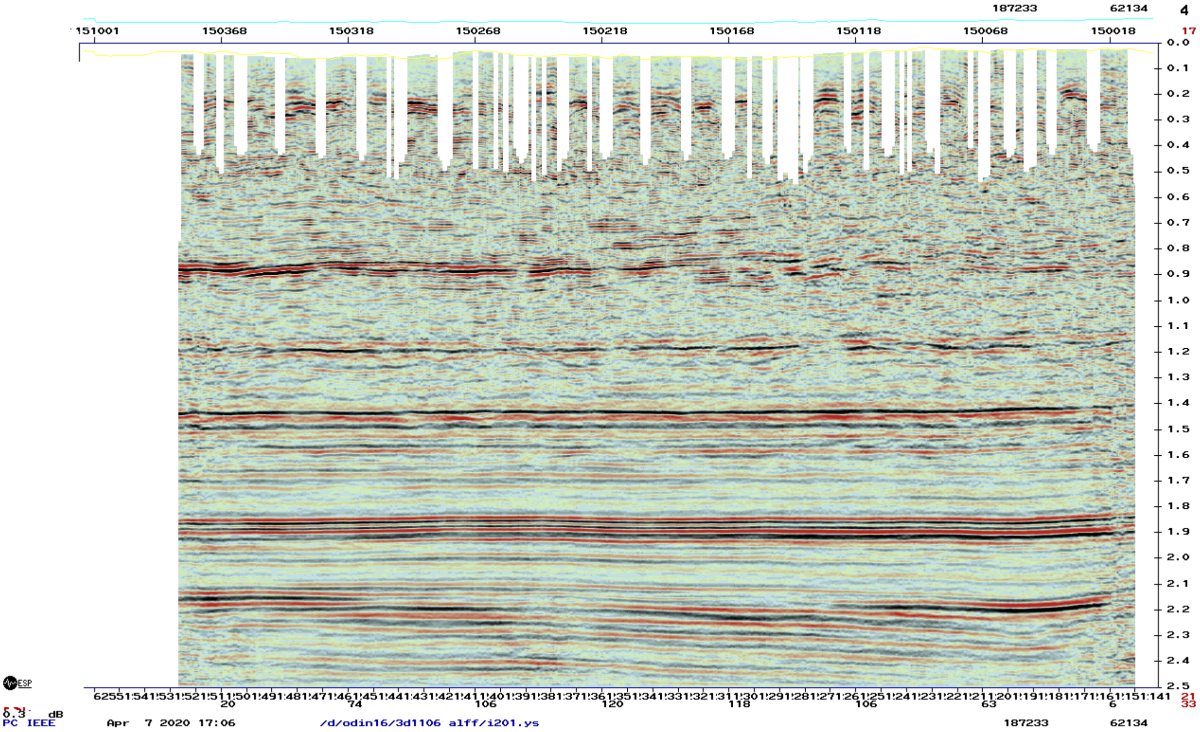

Figure 19: Snowball-Odin 3D: Inline 150. Stack after TPXY noise attenuation.

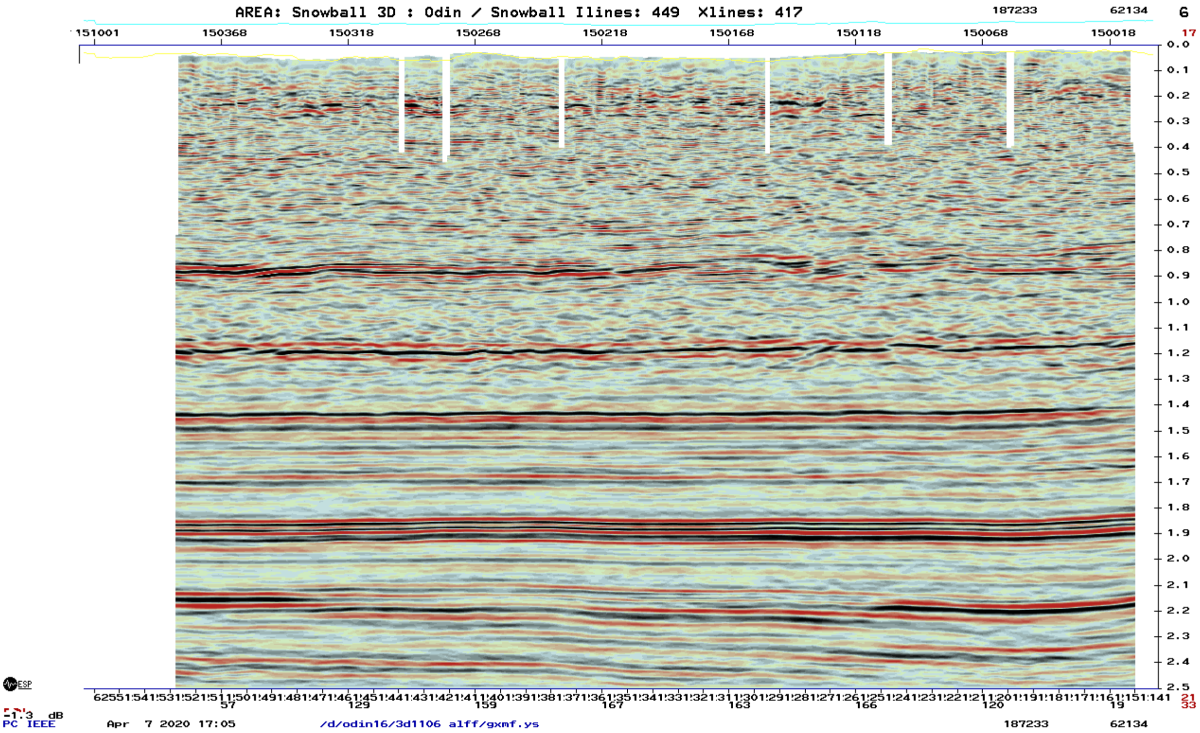

Figure 20: Snowball-Odin 3D: Inline 150. Post Stack Migration

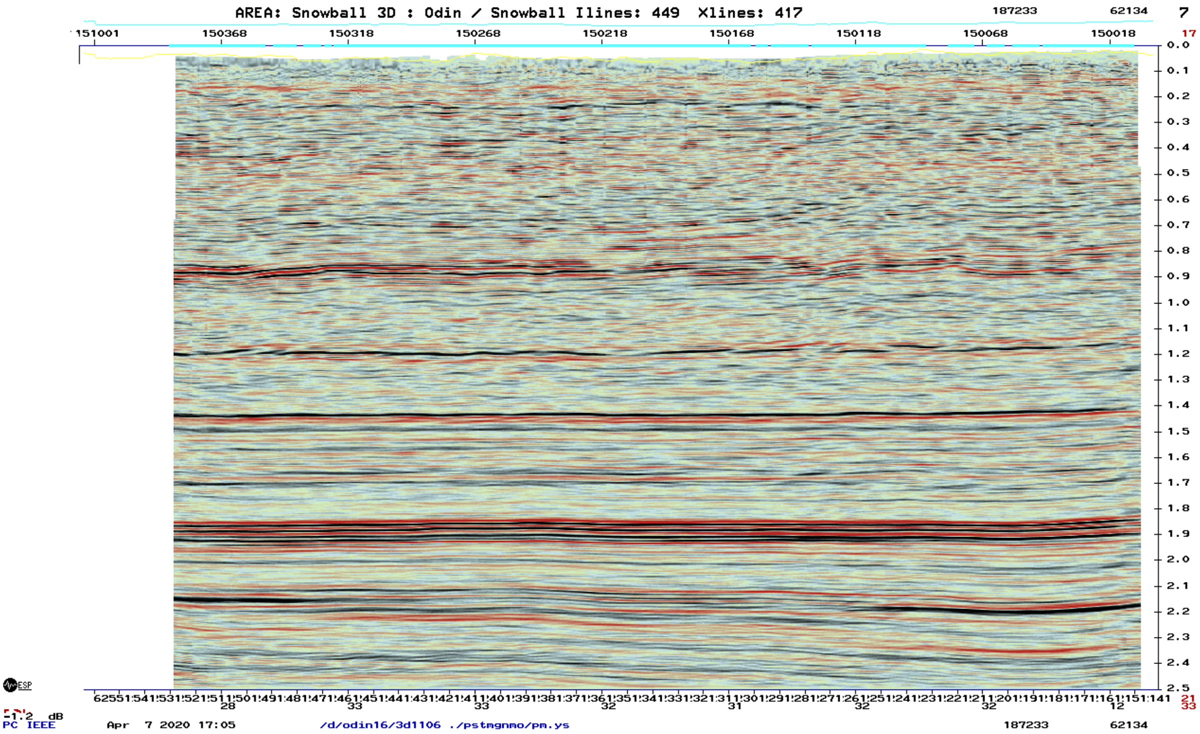

Figure 21: Snowball-Odin 3D: Inline 150. PSTM

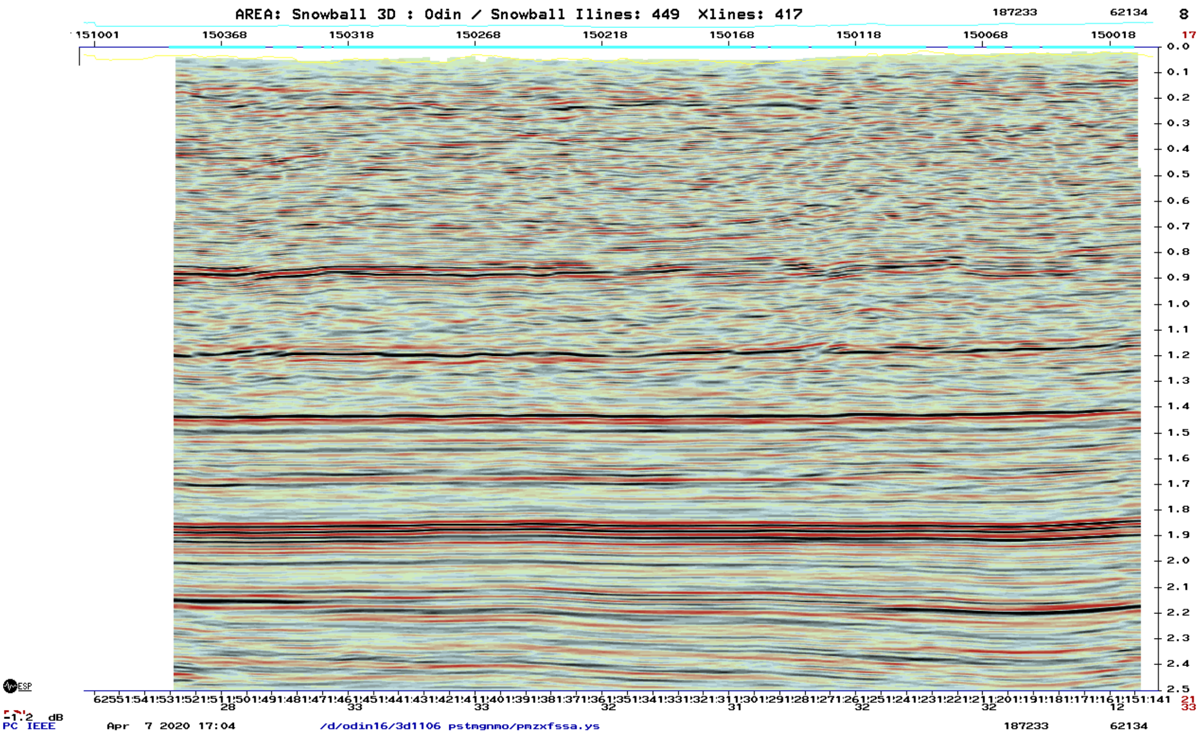

Figure 22: Snowball-Odin 3D: Inline 150: Frequency Enhanced PSTM

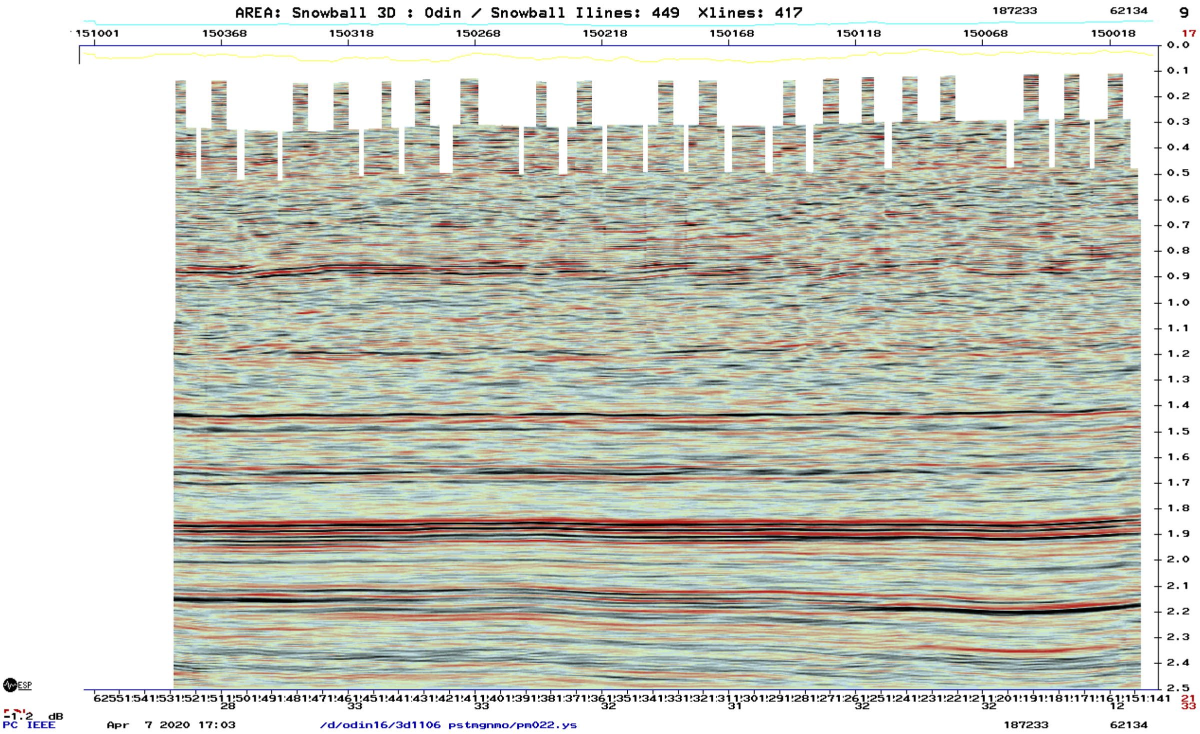

Figure 23: Snowball-Odin 3D: Inline 150: PSTM 0-22 Degrees

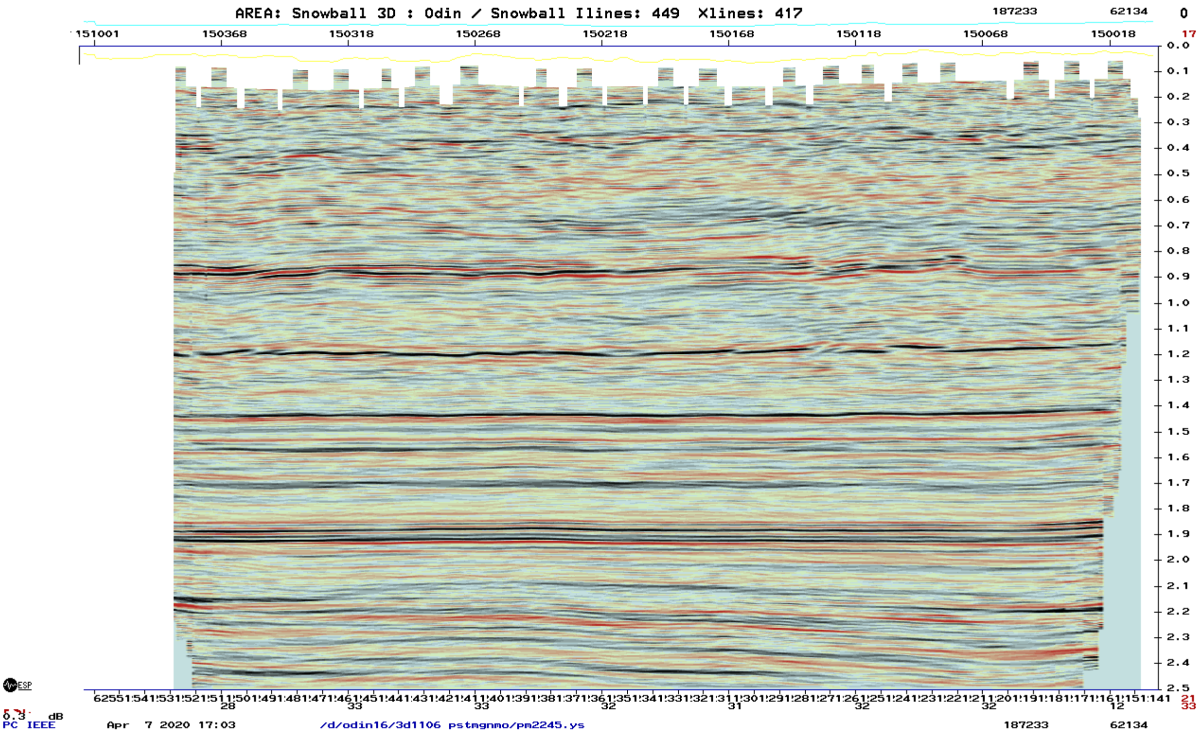

Figure 24: Snowball-Odin 3D: Inline 150. PSTM 22-45 Degrees

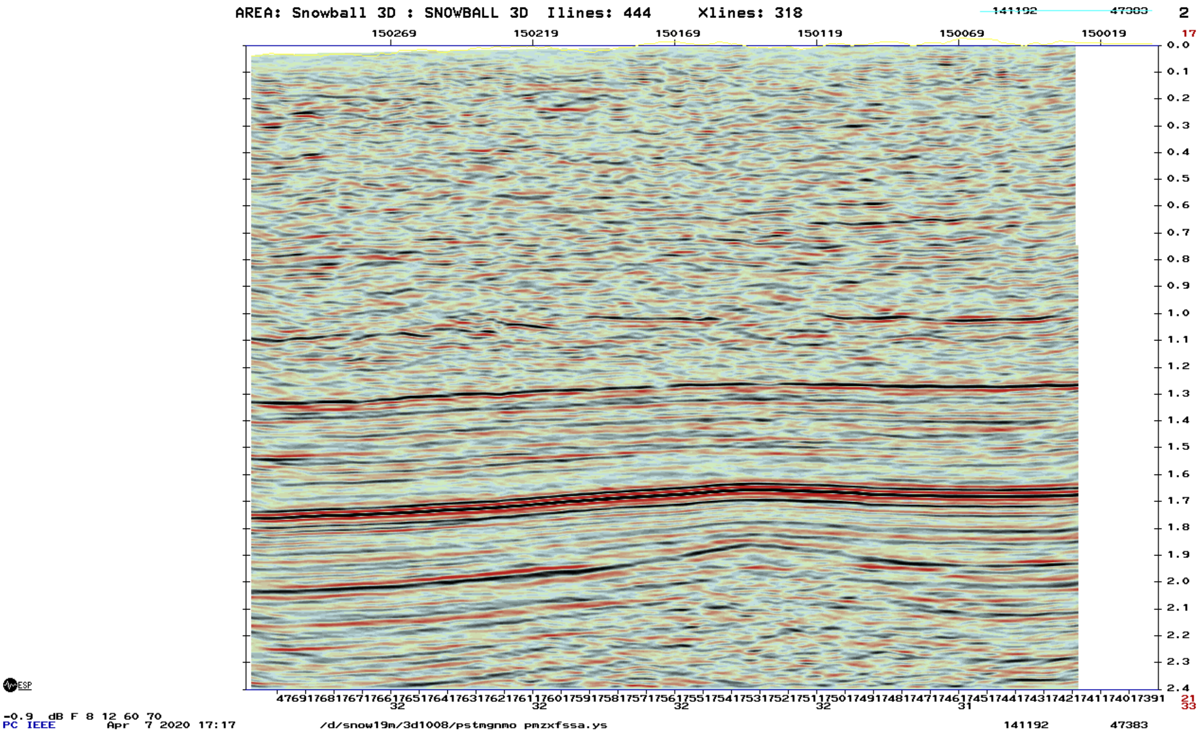

Figure 25: Snowball-Epsilon Merge: Inline 150: Frequency Enhanced PSTM

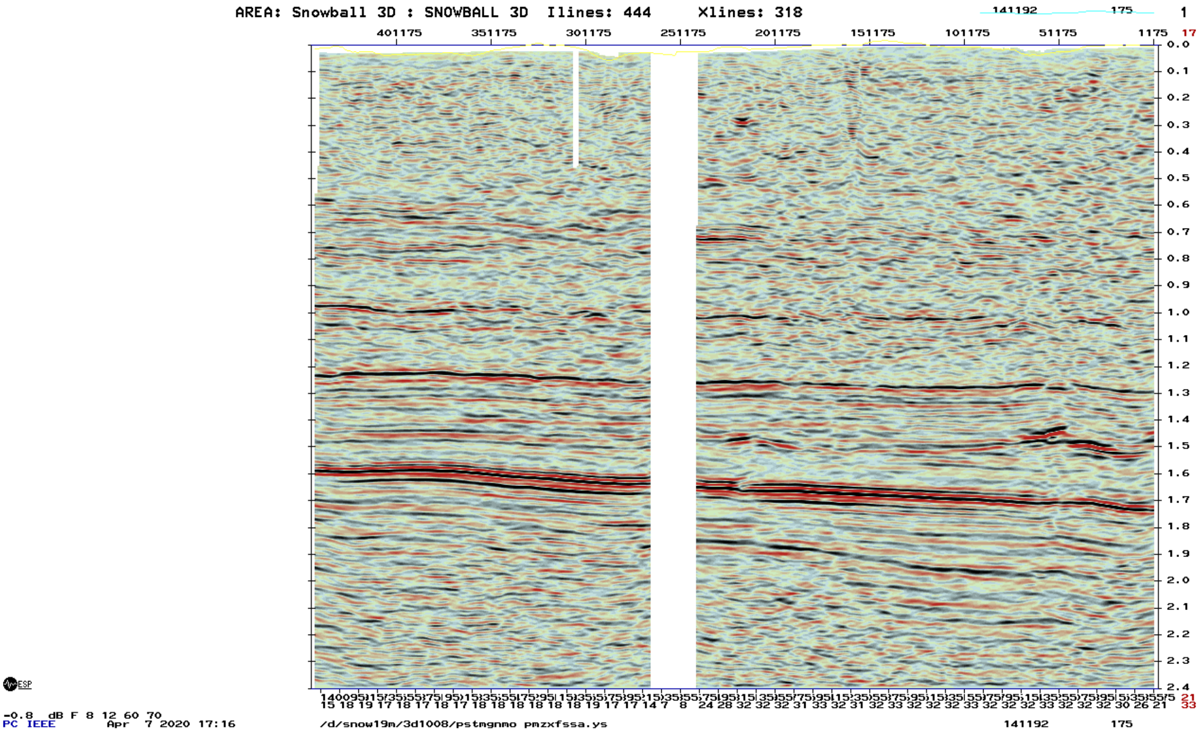

Figure 26: Snowball-Epsilon Merge: Crossline 175. Frequency Enhanced PSTM

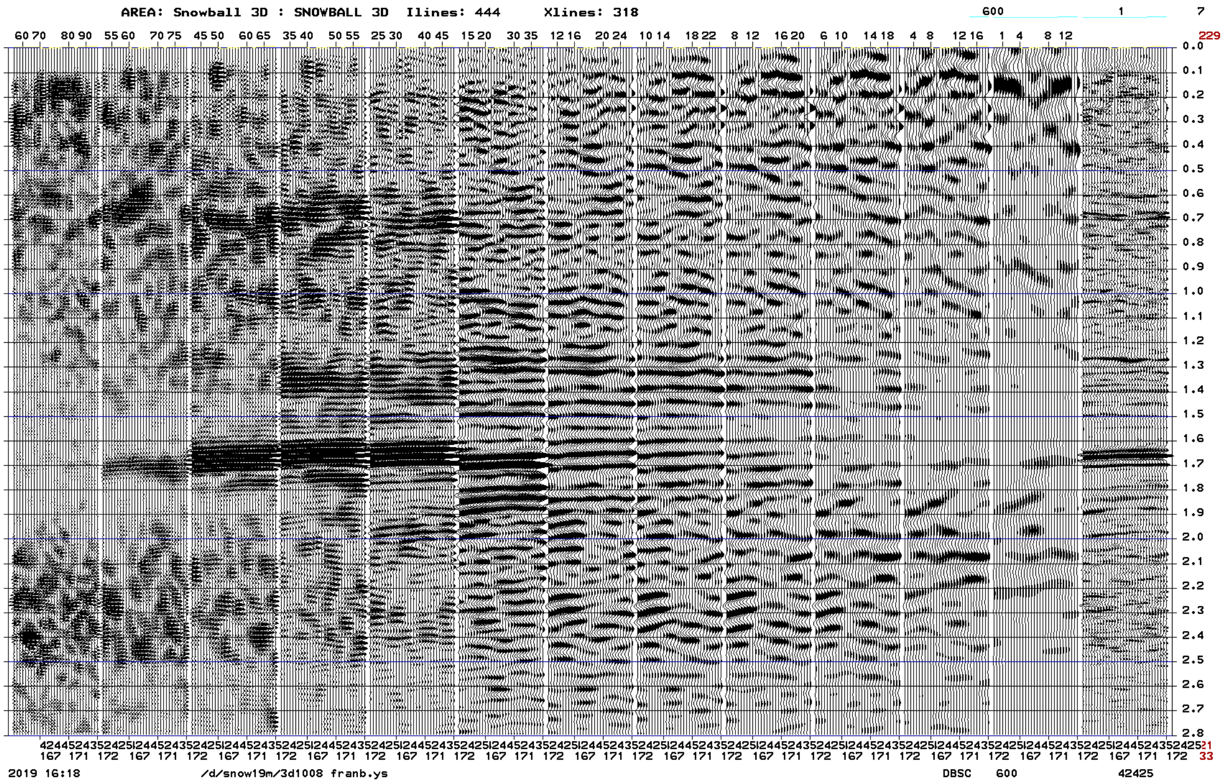

Figure 27: Snowball-Epsilon Merge Frequency Analysis Panel

8.2 Deliverables

All SEGY and text files for the stacks were delivered via FTP. The processing report was emailed and uploaded to the FTP site.

List of Deliverables:

- Stacks (Structure, Migrated and Whitened Migrated)
- Angle Stacks (0-22° and 22-45°)
- Static Text Files (Shot Point and Station)
- RMS Velocities
- Processing Report

Below is a detailed list of all the deliverables for each dataset:

2016_SNOWBALL_ODIN_3D.FPSMIGRX.SGY
2016_SNOWBALL_ODIN_3D.FPSMIGRZX.SGY
2016_SNOWBALL_ODIN_3D.UPSMIGR.0-22DEGREE.SGY
2016_SNOWBALL_ODIN_3D.UPSMIGR.22-45DEGREE.SGY
2016_SNOWBALL_ODIN_3D.UPSMIGRX.SGY
2016_SNOWBALL_ODIN_3D.UPSMIGRZX.SGY
2016_SNOWBALL_ODIN_3D.VRMS.SGY
2019_SNOWBALL_EPSILON_MERGE.FPSMIGRX.SGY
2019_SNOWBALL_EPSILON_MERGE.FPSMIGRZX.SGY
2019_SNOWBALL_EPSILON_MERGE.UPSMIGR.0-22DEGREE.SGY
2019_SNOWBALL_EPSILON_MERGE.UPSMIGR.22-45DEGREE.SGY
2019_SNOWBALL_EPSILON_MERGE.UPSMIGRX.SGY
2019_SNOWBALL_EPSILON_MERGE.UPSMIGRZX.SGY
2019_SNOWBALL_EPSILON_MERGE.VRMS.SGY
Odin_Snowball-Spt-Statics.txt
Odin_Snowball-Stn-Statics.txt
SNOWBALL_3D-Spt-Statics.txt
SNOWBALL_3D-Stn-Statics.txt

8.3 EBCDIC Header (example)

```
C01 Client: Vintage Australia        Bin Geometry: 20    x 20    m.
C02 AREA: Snowball 3D : Odin / Snowball Ilines: 449  Xlines: 417
C03 Location: Cooper Basin, Australia    UTM ZONE: 54   GDA 94
C04
C 5 DATA TYPE:  Filtered PRESTACK TIME MIGRATION + FREQ + TXY DCON
C06 Acquisition: Terrex Seismic        PTY: A2
C07 Shot for: Santos                    January - August 2016 Total Shots: 4235
C08 Spread: Orthogonal 28 x 144  R-Line Int: 320 m.  S-Line Int: 320 m.
C09 Source Interval: 40       m. Receiver Interval: 40      m. Fold: 138
C10 Source: Vibroseis      Type: Inova AHV-IV Sweep: 3-99 Hz.
C11 Receivers: SM-24     10 Hz.   6 phones bunched, centred on peg
C12 Instruments: Sercel 428XL    3909 Live Traces Max SEG-D         Gain: Fixed
C13 Record Filters: Out- 200 Hz.    Notch: Out
C14 PROCESSING:          EARTH SIGNAL PROCESSING LTD.   Date: December 2019
C15
C16 Expn Scaling: T**p, p=1.4    First Breaks: First Break Tomography (1)
C17 Datum: 0 m.  Replacement Vel: 2200 m/s  Weathering Vel: 900 m/s   TFS=-200ms
C18 Surface Consistent Amplitude Scaling          Trace Edits
C19 Vibroseis Dephasing: Vibroseis Designature minimum phase equivalent
C20 Anti-Aliasing Anti=Leakage Fourier Filter     TURN  270 DEGREES
C21 Surface Consistent Deconvolution: 5 Component (Frequency Domain)
C22 Zero Phase Frequency Domain Trace Deconvolution  First break equalization.
C23 Ground roll equalization: Below 16 Hz.  Laterally variant residual Scaling
C24 Trace gather: fold = 138                 Processing Datum:  Surface in Time
C25 Velocities: Interactive semblance  Surface Consistent Statics   Trim statics
C26 TPXY X-Spread Noise Attenuation 5D MWNI Interpolation
C27 Mute Pairs: (d t)  1   319 370  4020 3500
C28 3D Anti-Aliasing Kirchhoff PSTM.   Frequency Equalization SSA Rank Reduction
C29 TV FREQ. EQUAL. 400 - 1050 ms. 950 - 2400 ms. ms. Crossover: 1000 ms.
C30 TXY DCON NOISE REDUCTION 15     trace time variant 100    % N.R.
C31 Time Variant Filter: 5 / 10 - 80 / 90 5 / 10 - 60 / 70 Hz.
C32 Filter crossover midpt.: 1000 ms.    Mean Scaling window: 400   2400 ms.
C33
C34  INLINES: 1 -  449, CROSSLINES: 1 -  417,  (inline,crossline)
C35  NW (    1, 417) @ 495953.0,6906798.0   NE (    1,1) @ 504273.0,6906798.0
C36  SW ( 449, 417) @ 495953.0,6897838.0   SE ( 449,1) @ 504273.0,6897838.0
C37  Byte 9:Inline  Byte 13: Crossline   Byte 109: Time of first sample
C38  Byte 81: CDP UTM X * 10  Byte 85: CDP UTM Y * 10  Byte 91: 1st Layer Vel
C39  Byte 93: Replacement Vel Byte 95: Weathering Depth Byte 99: SPT Refrac Stat
C40  Byte 101:STN refrac stat Byte 233: Total CDP stat. Byte 237 Total STN stat.
```