Senex

Senex Energy Limited

Mirage 3D
Processing Report

November 2015

Data Processed by:

EARTH SIGNAL
PROCESSING LTD

Contents

1 INTRODUCTION

Earth Signal Processing Ltd. was chosen to do the processing of the Mirage 3D in the Cooper basin, South Australia, Australia, for Senex Energy Limited. The 3D, which covers approximately 100 km^2, was shot in August 2005.

The main overall objective of the Mirage 3D reprocessing was to obtain the most accurate structural picture possible, particularly at the Cadna-Owie level, as well as improved imaging of the deeper geology.

The processing took place in the processing center of Earth Signal, located in Calgary. The field seismic data, observer reports, and survey information were picked up in Sydney in October 2013. All processing took place from November 2013 - March 2015.

1.1. About Earth Signal Processing:

Earth Signal is a Canadian seismic processing company dedicated exclusively to land data for the past 22 years. We have worked with data from many different parts of the world and we have processed thousands of 2D lines and hundreds of 3D surveys.

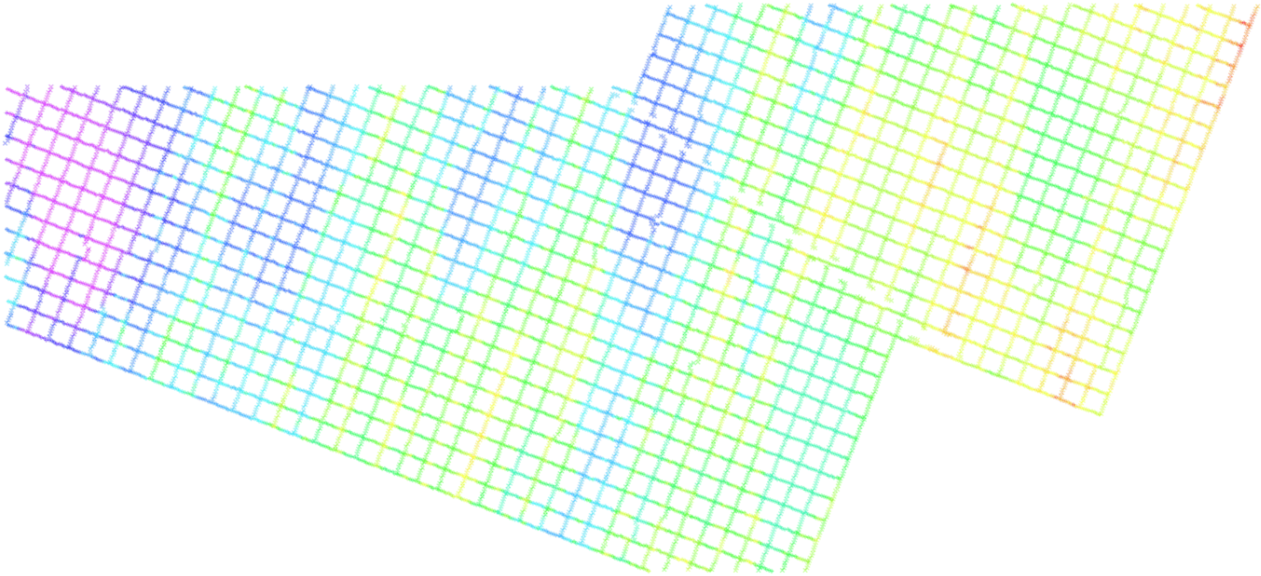
Our processors have processed data from several areas in Australia, such as Queensland, Western Australia, South Australia and Victoria. Our experience working internationally allows us to effectively and efficiently work closely with our clients abroad.

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. ESP's 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 SURVEY LOCATION



4 PROCESSING OBJECTIVES

The primary objectives of the reprocessing were to obtain an accurate structural solution as well as improved imaging of the deeper section. Multiple refraction solutions were calculated and related to the uphole information. It was determined that the refraction model derived from the first breaks was superior to the model derived from the uphole information. Detailed PSTM velocity analysis was an important contributor to the improved imaging in the deeper part of the section.

5 KEY PERSONNEL

The main personnel involved with the project were:

Senex Energy Limited:
    Chuck Briere, Chief Geophysicist
    Irwan Djamaludin, Processing QC

Earth Signal Processing:
    Patrick Tutty, Business Development Manager
    Greg Staples, Senior Processing Advisor

6 DATA ACQUISITION PARAMETERS

Survey	Mirage 3D
Location of Survey	South Australia
Area of Survey	Cooper Basin
Survey Operator	Terrex Seismic
Data Type	Land 3D
Volume	100 km^2
Acquisition Record Length	4 s
Acquisition Sample Interval	2 ms
Source Type	Vibroseis I/O AHV IV
Sweep	3 Vibes, 2 x 5 sec, Sweep 5-90 Hz Linear Upsweep
Receiver Line Interval	320 m
Shot Line Interval	320 m
Shot Spacing	40 m
Receiver Spacing	40 m
Recording Patch	10 x 96
Receiver	Sensor SM4 10 Hz
Recording Filter	Out – 125 Hz.
Recorder	Sercel 388

7 PROCESSING GRID INFORMATION

The data was processed on a 20 m x 20 m bin grid. There were 8005 shots processed with a maximum fold of 38 at 2400 m. offset.

Inline	Crossline	UTM-X	UTM-Y
1	1	484144	686408
1	823	468796	6852300
536	1	480310	6836419
536	823	464962	6842311

8 FINAL PROCESSING SEQUENCE

The processing flow for the 3D is shown below. Parameters were tested along the way to ensure an optimal final product.

- Reformat
- Geometry and QC
- Refraction Analysis
- Replacement Statics
- Trace Editing
- Exponential Scaling
- Surface Consistent Amplitude Scaling
- Frequency Dependant Noise Attenuation
- Vibroseis Designature
- Surface Consistent 5 Component Deconvolution
- Zero Phase Trace Deconvolution
- Coherent Noise Attenuation
- Residual Scaling
- Preliminary Velocity Analysis
- Surface Consistent Statics
- Final Velocity Analysis
- Pre-stack TPXY Noise Attenuation
- 5D Minimum Weighted Norm Interpolation
- Pre-stack Time Migration
- Radon Noise Attenuation
- Final Mute
- Stack
- Multichannel Trace Scaling
- TXY Noise Reduction
- Time Variant Frequency Equalization
- TXY Noise Reduction
- Filter
- Angle Stacks
- Polarity Convention

9 PROCESSING

9.1 Reformat

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

9.2 Geometry and QC

Headers were updated using survey geometry provided. Coordinates were referenced to Zone 54 South, GDA-94. Google Earth was used to QC the survey location against geographical features.

9.3 Refraction Analysis

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. Several iterations of this method were calculated until the difference between iterations was negligible. The crucial thing for FBT was that the first break picks have been picked accurately on good quality data. In this project a one layer refraction solution was used.

9.4 Replacement Statics

A datum elevation of 0 m was used during processing as requested. A replacement velocity of 2000 m/s and weathering velocity of 900 m/s was chosen. All data had a time of first sample of -200ms which is indicated in the EBCDIC headers.

9.5 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. These reverse traces can also be used as an aid in determining correct geometry assignment.

9.6 Exponential Scaling

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

9.7 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 cut-off 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.

9.8 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 20Hz. were examined in this process, with lower frequencies unchanged and left to the ground roll attenuation.

9.9 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

9.10 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 was that it requires minimal processor input compared to similar time domain programs, resulting in more consistent results. 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 (3/6-90/95 Hz.) was selected to be the desired response of the deconvolution, based on the sweep.

9.11 Zero Phase Trace Deconvolution

Frequency domain deconvolution was designed and applied over the design window. This step was to further flatten the amplitude spectrum and in doing so can help combat frequency dependent noise. Zero phase trace deconvolution uses the frequency spectrum of each trace as the input and creates an inverse operator that when convolved with each trace will flatten the spectrum based on the desired response.

9.12 Coherent Noise Attenuation

Ground roll attenuation is applied to further reduce any groundroll that wasn't removed in the deconvolution process. This process works on frequencies below 20 Hz, using the band of 20-60 Hz. as an amplitude guide, as well as velocity criteria. The 20 Hz. cut-off was chosen as the majority of the higher amplitude ground roll fell into this part of the spectrum. If higher low frequency amplitudes that also satisfy the velocity dip criteria are detected over a small sliding window, a localized F-K process is applied to remove this low velocity noise. If no low frequency dipping amplitudes are detected, the data is left untouched. The velocity criterion allows the process to remove undesirable noise while leaving any dipping signal untouched. The velocity limit was set quite conservatively, which does leave in some of the higher velocity ground roll and refracted energy.

9.13 Residual Scaling

FIRST BREAK EQUALIZATION SCALING - The first breaks were equalized using a short window AGC applied upward from the design window.

LATERALLY VARIANT RESIDUAL SCALING - The final scaling was a residual Time-Offset scaling that was designed to more accurately compensate for the spherically spreading wave-front. A long window was allowed to slowly change in both time and offset as well as along the line. This results in a more fair offset contribution, as well as maintaining amplitude through higher noise areas.

9.14 Preliminary Velocity Analysis

Preliminary velocity analysis was done on a 1000 m grid using an interactive semblance display. The semblance analysis was calculated using a 10ms time increment and 50m/s velocity increment. Semblance maxima can be quite easily picked for the majority of the 3D. Well log overlays were used to guide to velocity picking. The data set at far offset showed the classic hockey stick effect of anisotropy (VTI). A horizontal/vertical velocity ratio was picked to better flatten the far offsets, with values around 1.05.

9.15 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 300-1900 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.

9.16 Final Velocity Analysis

With all final statics resolved, the final velocities were picked on a 500 m grid using an interactive semblance display with both regular and noise reduced inputs used in the analysis. The final velocities were quality checked by overlaying the stack section with the RMS and interval function.

9.17 Pre-stack TPXY Noise Attenuation

TPXY noise attenuation was 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 an 11 trace design, allowing +/- 2 ms. dip per trace and 100% noise reduction. After all cross-spreads have been processed, the traces were sorted back to shot gathers for further processing.

9.18 5D Minimum Weighted Norm Interpolation

The TPXY noise attenuated CDP gathers were used as input to the 5D interpolation, with output to common offset common azimuth (COCA) gathers. The interpolation dimensions were Inline, Crossline, Offset, and Azimuth, and in this case were not designed to interpolate to a smaller bin size, but rather fill in missing traces within the output grid. A maximum of +/- 6 ms dip was allowed trace to trace as well as a maximum of +/- 60 ms 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 was no input data. The offset dimension was separated into 60 offsets and the azimuth into 6 azimuths, resulting in 360 fold CDP gathers.

9.19 Pre-stack Time Migration

The interpolated COCA gathers were input into the Kirchhoff summation migration, with output to offset gathers. 60 offsets at a 40 m. increment were output. For better migration results a 2000 m smoother was applied to the velocity field before migration. After migration the velocities were re-analyzed using an interactive semblance program for residual move-out and the final velocity field was recalculated. To minimize migration artefacts, the final migrated gathers were then muted back to an equivalent 5x5 super gather. The effects were most notable at the edges of the 3D.

9.20 Radon Noise Attenuation

Radon noise attenuation was applied to the gathers in an effort to clean up particularly the near offsets prior to any pre-stack inversion work. A forward and reverse transform was used with the transform parameters of +/- 6 ms. This process was quite harsh and designed to be a significant difference from the non-noise attenuated gathers. PSTM gathers were created with and without this process.

9.21 Final Mute

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

240 200   2400 1800

9.22 Stack

Migrated CDP gathers with 2400m offsets (60 offset traces with 40 m. offset interval) were stacked with the final mute applied.

9.23 Multichannel Trace Scaling

This scaling was a slowly changing time and laterally variant scalar with a large design window. This process was allowed to run to the basement of the stack to balance the amplitudes in the deeper section such that any deep faults or structures would be more evident. This scalar has a 500 ms window and because the scaling was applied to the stack and not directly to the gathers AVO effects were maintained.

9.24 TXY Noise Reduction

A post stack TXY noise reduction was applied using an 11 trace design and 100 % noise reduction.

9.25 Time Variant Frequency Equalization

To better flatten the spectrum of the stack, a 3 gated frequency domain deconvolution was designed and applied to each trace of the stack, with event guided crossover times. By separating the trace into three gates the operator was better suited to the frequency content of that portion of the trace. Zero phase trace deconvolution uses the frequency spectrum of each trace as the input and creates an inverse operator that when convolved with each trace will flatten the spectrum based on the desired response.

9.26 TXY Noise Reduction

A post stack TXY noise reduction was applied using an 11 trace design and 100 % noise reduction.

9.27 Filter

An event guided time variant filter was applied. The three filters were 6/10-85/95 Hz, 6/10-75/85 Hz and 6/10-60/70 Hz.

9.28 Angle Stacks

Angle Stacks of 0-15, 0-30, 15-25, 25-35, 35-45, 45-55 were created from the raw PSTM Gathers.

9.29 Polarity Convention

The data were output as SEG Reverse Polarity.

10 CONCLUSIONS

The net result of a detailed refraction analysis and careful residual statics was a structural solution that much better tied the existing well control. Noise attenuation played an important role, both pre-stack and post-stack in improving the signal to noise level and allowing the frequency enhancement to boost the signal without significant degradation from the noise. And finally, detailed PSTM residual velocity analysis contributed to good quality imaging through the primary zones of interest.

11 APPENDICES

11.1 Deliverables

DATA SETS	TYPE OF DATA
Filtered PSTM + TXY	SEGY
Un-filtered PSTM + TXY	SEGY
Filtered PSTM + TXY + FREQ + TXY	SEGY
Un-filtered PSTM + TXY + FREQ + TXY	SEGY
Angle Stacks 0-15,0-30,15-25,25-35,35-45,45-55	SEGY
RMS Velocities for PSTM	SEGY
Interval Velocities	SEGY
PSTM Gathers	SEGY
Refraction Shot and Receiver Statics	TEXT
Residual Shot and Receiver Statics	TEXT
Processing Report	PDF

11.2 EBCIDIC Header (example)

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C01 Client: Senex Energy Limited  Bin Geometry: 20 x 20 m.        pmxzxf.ys
C02 AREA: Mirage 3D               Ilines: 536   Xlines: 823
C03 Location: South Australia     GDA94   MGA Zone 54   CM 141
C04
C05 DATA TYPE: Filtered PSTM + TXY DCON + FREQ + TXY DCON
C06 Acquisition: Terrex Seismic       PTY: 402
C07 Shot for: Victoria Petroleum      August 2005      Total Shots: 8005
C08 Spread: Orthogonal 10 x 96    R-Line Int: 320 m.   S-Line Int: 320 m.
C09 Source Interval: 40 m. Receiver Interval: 40 m. Fold: 38
C10 Source: Vibroseis          Sweep: 5-90 Hz.   Linear 2x5 sec.
C11 Receivers: Sensor SM-4   10 Hz.  12 over 20 m.
C12 Instruments: Sercel 388     960 Live Traces Max SEG-D     Gain: Fixed
C13 Record Filters: 0.5 NQ Lin Phase      Notch: Out
C14 PROCESSING:              EARTH SIGNAL PROCESSING LTD.    Date: August 2014
C15 Time of First Sample is -200 ms.            Polarity Convention: SEG Reverse
C16 Expn Scaling: T**p, p=1.4     First Breaks: First Break Tomography (2)
C17 Datum: 0 m.    Replacement Vel: 2000 m/s     Weathering Vel: 900  m/s
C18 Surface Consistent Amplitude Scaling    Frequency Dependant Noise Attenuation
C19 Vibroseis Dephasing: Vibroseis Designature minimum phase equivalent
C20 Surface Consistent Deconvolution: 5 Component (Frequency Domain)
C21 Zero Phase Frequency Domain Trace Deconvolution  Phase Rotation: 90 degrees
C22 First break equalization     Coherent Noise Attenaution below 20 Hz.
C23 Laterally variant residual Scaling Time-Offset
C24 Trace gather: fold = 38                   Processing Datum:  Surface in Time
C25 Velocities: Interactive semblance   Surface Consistent Statics   Velocities
C26 Cross-Spread TPXY Noise Attenuation   100% NR   11x11 trace design   2ms/trace
C27 5D Minimum Weighted Norm Interpolation @ 40m. offset increment, 60 offsets
C28 3D Anti-Aliasing Pre-stack Kirchhoff Time Migration Offset Domain
C29 Remute to 5x5 supergather  Mute Pairs: (d t)  240 200  2400 1800
C30 Stack: 60 offsets          Multichannel Trace Scaling Residual Amplitude
C31 TXY DCON NOISE REDUCTION 11      trace time variant 100    % N.R.
C32 TV FREQ. EQUAL. 3 Window Event Guided
C33 TXY DCON NOISE REDUCTION 11      trace time variant 100    % N.R.
C34 TVF: 6 / 10 - 85 / 95 6 / 10 - 75 / 85 6 / 10 - 60 / 70 Hz.
C35 Midpts.: Event Guided            Mean Scaling: 400    2500 ms.
C36  INLINES: 1 -   536, CROSSLINES: 1 -   823,  (inline,crossline)
C37  NW (    1, 823) @  468796,6852300    NE (    1,1) @  484144,6846408
C38  SW ( 536,  823) @  464962,6842311    SE ( 536,1) @  480310,6836419
C39 Byte 9-12: Inline      Byte 13-16: Crossline      Byte 21-24: CDP
C40 Byte 81-84: UTM X      Byte 85-88: UTM Y          Byte 105-106: TOFS
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