

Data Processing Report

for

WesternGeco Land Operations

Area: Silver Peak 2D lines

Esmeralda County, Nevada

Lawson Code: cn76
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1.0 Introduction

The Silver Peak 2D project consists of four independent 2D lines acquired in Esmeralda County, Nevada by WesternGeco US Land crew 1752 using the proprietary QMAS (Q Mini Acquisition System).

The main goal of seismic processing was to image faults along the mountain front that define the edge of the graben, including the faults in the Paleozoic "basement" below the playa sediments in order to help with interpretation of fluid circulation and geothermal well site location in the area. The data was processed using single sensors all the way up to Kirchhoff pre-stack time migration. The refraction tomography method was used for refraction statics calculation. Detailed coherent and random noise attenuation in shot-point, receiver and cmp domains was performed, followed by Surface-Consistent deconvolution and Model Based Wavelet Processing yielding data to zero-phase correction. With the improvement of signal-to-noise ratio, better velocity and statics were obtained. The overall processing effort made it possible to successfully produce pre-stack time migrations of four 2D lines suitable for interpretation.

The project was processed at WesternGeco's Denver Processing Center on a cluster computer platform using the Omega2 Seismic Processing System.

2.0 Seismic Data Processing

2.1 Reformat

The data received at the Denver Processing Center were correlated shot records with source and detector locations existing in the trace headers. The data was correlated and QC'd by crew 1752 infield processors as the lines were acquired. The data was sent in Omega DIO format, and a quick check of the geometry and headers was performed soon after it was received.

	First File	Last File	# of Channels	Total VPs
Line 101	5061	5209	1716	143
Line 201	5211	5310	1452	97
Line 301	5315	5441	1656	122
Line 401	5445	5535	1572	84

2.2 Grid Definition

The data were then updated with the Master Grid information. This places the cell number, inline, crossline, and other 3-D information into the seismic trace headers.

Master Grid – Line 101

	X co-ordinate	Y co-ordinate
MG1	451623.8559	4183099.8687
MG2	440198.0952	439563.6632
MG3	450989.4239	4184996.5753
MG4	439563.6632	4181174.7569

Primary Cell Size:	1.500000
Secondary Cell Size:	1000.000000
First Primary Ordinal:	4000.000000
Last Primary Ordinal:	12032.000000
Primary Ordinal Increment:	1.000000
First Secondary Ordinal:	100.000000
Last Secondary Ordinal:	102.000000
Secondary Ordinal Increment:	1.000000
Maximum Primary Index:	8033
Maximum Secondary Index:	3
Total Number of Cells:	24099
Azimuth in Degrees:	251.505

Master Grid – Line 201

	X co-ordinate	Y co-ordinate
MG1	448516.7841	4179919.3718
MG2	442516.9607	4179965.4020
MG3	448532.1275	4181919.3130
MG4	442532.3041	4181965.3431

Primary Cell Size: 1.500000
 Secondary Cell Size: 1000.000000

 First Primary Ordinal: 4000.000000
 Last Primary Ordinal: 8000.000000
 Primary Ordinal Increment: 1.000000

 First Secondary Ordinal: 200.000000
 Last Secondary Ordinal: 202.000000
 Secondary Ordinal Increment: 1.000000

 Maximum Primary Index: 4001
 Maximum Secondary Index: 3
 Total Number of Cells: 12003
 Azimuth in Degrees: 270.440

Master Grid – Line 301

	X co-ordinate	Y co-ordinate
MG1	448594.6581	4179045.9060
MG2	441094.8170	4179094.7323
MG3	448607.6784	4181045.8636
MG4	441107.8374	4181094.6900

Primary Cell Size: 1.500000
 Secondary Cell Size: 1000.000000

 First Primary Ordinal: 4000.000000
 Last Primary Ordinal: 9000.000000
 Primary Ordinal Increment: 1.000000

 First Secondary Ordinal: 300.000000
 Last Secondary Ordinal: 302.000000
 Secondary Ordinal Increment: 1.000000

 Maximum Primary Index: 5001
 Maximum Secondary Index: 3
 Total Number of Cells: 15003
 Azimuth in Degrees: 270.373

Master Grid – Line 401

	X co-ordinate	Y co-ordinate
MG1	448609.5168	4178512.2557
MG2	441109.5294	4178525.9856
MG3	448613.1781	4180512.2523
MG4	441113.1907	4180525.9823

Primary Cell Size:	1.500000
Secondary Cell Size:	1000.000000
First Primary Ordinal:	4000.000000
Last Primary Ordinal:	9000.000000
Primary Ordinal Increment:	1.000000
First Secondary Ordinal:	400.000000
Last Secondary Ordinal:	402.000000
Secondary Ordinal Increment:	1.000000
Maximum Primary Index:	5001
Maximum Secondary Index:	3
Total Number of Cells:	15003
Azimuth in Degrees:	270.105

2.3 Time Function Gain

This process scales trace samples by first raising the time (in seconds) to a user-supplied exponential value, then multiplying the result by the amplitude of the sample at that time. That is:

$$\|A_o(t) = A_i(t)t^x$$

where:

$A_o(t)$ is the amplitude of output trace sample at time t

$A_i(t)$ is the amplitude of input trace sample at time t

t is the time in seconds

x is the value of gain exponent

Parameter values:

Exponent Value : 1.5

2.4 Tomographic Refraction Statics

Surface consistent static corrections were derived by means of a tomographic inversion of the first-break traveltimes. In this implementation, the first arrivals are assumed to be the onset of diving (turning) waves. A linear inversion is performed in x-p domain to generate a near surface velocity model, without the use of explicit ray tracing. Velocity/depth functions are calculated for each surface location, and these functions are used to derive the long-period component of the static corrections. Remaining short-period static corrections are estimated by surface-consistent decomposition of the traveltimes residuals.

Parameter Values:

Datum Plane	: 1600 meters
Correctional Velocity	: 2900 meters/sec
Offset Range	: 10 – 1500 meters
Initial Weathering Velocity	: computed using direct arrival
Velocity Smoothing Diameter	: 900 meters

2.5 Anomalous Amplitude Attenuation

AAA uses the random occurrence and limited bandwidth of noise to separate it and remove it from the seismic signal. Prestack seismic data is transformed to the frequency domain in which a spatial median filter is applied. Any frequency bands that deviate from the median amplitude by a specified threshold are either zeroed or replaced with frequency bands from neighboring traces. AAA is most effective when the input data sort order is such that the noise is random in that domain.

Parameter values:

Number of passes	: 4
Width of Spatial Median Filter	: 31 traces
Frequency range	: 0Hz – 30Hz
Width of Spatial Median Filter	: 50 traces
Frequency range	: 30Hz – 60Hz
Width of Spatial Median Filter	: 71 traces
Frequency range	: 60Hz – 80Hz
Width of Spatial Median Filter	: 60 traces
Frequency range	: 80Hz – Nyquist
Sort order	: Shot

2.6 FX-CNS

FX-CNS is an approach to coherent noise suppression for 3-D shot or receiver data that can handle irregular spatial sampling and noise variability. This is accomplished internally by azimuthally binning the data prior to filtering. Data organized in common azimuths are irregularly sampled 2-D lines radiating from the source. Each azimuth bin is filtered independently. Using frequency-space (f-x) domain fan filters and a least-squares optimization scheme, noise is locally estimated at each receiver for a specified range of apparent velocities. The least-squares estimate is performed for each frequency independently over a specified portion of the bandwidth.

Parameter values: Low Velocity

Number of Traces	: computed
Low stop velocity	: 10 m/sec
Low pass velocity	: 50 m/sec
High pass velocity	: 150 m/sec
High stop velocity	: 200 m/sec
Low stop frequency	: 10 Hz
Low pass frequency	: 20 Hz
High pass frequency	: 30 Hz
High stop frequency	: 40 Hz

Parameter values: High Velocity

Number of Traces	: computed
Low stop velocity	: 150 m/sec
Low pass velocity	: 200 m/sec
High pass velocity	: 290 m/sec
High stop velocity	: 320 m/sec
Low stop frequency	: 6 Hz
Low pass frequency	: 10 Hz
High pass frequency	: 20 Hz
High stop frequency	: 24 Hz

2.7 Surface-Consistent Deconvolution

Spiking surface-consistent deconvolution was applied to the data. Log power spectra were generated from a window of seismic data. These spectra were then decomposed in a surface-consistent manner into source, detector, offset, and, optionally, midpoint components using the Gauss-Seidel method. The minimum-phase inverse filter for each component was calculated and the appropriate operators were applied to each trace.

Parameter values:

Analysis Windows	: 1
Window Start Time	: 300 ms. plus start time.
Window Stop Time	: 2600 ms.
Operator Length	: 160 ms.
Predictive Distance	: 2 ms.
Percent White Noise	: 0.01 %

2.8 Model Based Wavelet Processing

In MBWP, a model is created of the wavelet assumed to be embedded in the seismic data. Known elements of the imbedded wavelet such as the instrument pulse, geophone, and vibroseis sweep are created from analytic responses or recorded by the crew. An estimate of the earth's absorption (Q), and the signal to noise ratio (S/N) is estimated from the data itself. The noise model is assumed to be white.

Putting all the components of the recording system, Q, and S/N together, a model of the embedded wavelet is created. This wavelet is assumed to be the wavelet that has been filtered with the earth's reflectivity before deconvolution.

Deconvolution is then performed on this wavelet in the same manner as the actual seismic data. The result of this deconvolution is the wavelet that is assumed to be imbedded in the data after deconvolution. This is the so-called residual wavelet. The phase spectra of the residual wavelet can be examined and a phase only inverse filter can be created that when filtered with the residual wavelet will yield a wavelet with zero phase. The phase only inverse filter is called the residual filter, or the MBWP operator. If the model is correct, filtering the seismic data with the MBWP operator will yield zero phase data (that is data whose imbedded wavelet is zero phase). Although the data is, in general, not exactly zero phase, it is believed that it is much closer to zero phase than without MBWP applied.

The filter coefficients for the MBWP operators are listed in appendix 4.4. As part of model-based wavelet processing, a -90° phase rotation was applied in addition to the filter coefficients.

2.9 Surface-Consistent Amplitude Compensation (SCAC)

SCAC compensates for amplitude variations that are caused by near-surface conditions rather than by sub-surface geology.

The amplitude of a given time window is determined for every trace using either a root-mean-square (RMS) or a mean-absolute amplitude criterion. The amplitudes measured can then be decomposed into surface-consistent terms. Taking the logarithm allows the amplitude to be expressed as a sum of these terms which, in turn, allows the surface consistent terms to be computed using a Gauss-Seidel algorithm. Surface-consistent scaling factors are then applied to each trace.

Parameter Values:

Amplitude Criterion	: RMS amplitude
Time Window	: 500ms to 3000ms
Terms used for application	: Source, Receiver

Due to the high amplitudes on traces near the shots, SCAC was applied in order to balance the amplitudes for further noise reduction using AAA.

2.10 FX-CNS

FX-CNS is an approach to coherent noise suppression for 3-D shot or receiver data that can handle irregular spatial sampling and noise variability. This is accomplished internally by azimuthally binning the data prior to filtering. Data organized in common azimuths are irregularly sampled 2-D lines radiating from the source. Each azimuth bin is filtered independently. Using frequency-space (f-x) domain fan filters and a least-squares optimization scheme, noise is locally estimated at each receiver for a specified range of apparent velocities. The least-squares estimate is performed for each frequency independently over a specified portion of the bandwidth.

Parameter values:

Number of Traces	: 211
Low stop velocity	: 100 m/sec

Low pass velocity	: 200 m/sec
High pass velocity	: 225 m/sec
High stop velocity	: 275 m/sec
Low stop frequency	: 1Hz
Low pass frequency	: 2 Hz
High pass frequency	: 4 Hz
High stop frequency	: 12 Hz

Parameter values:

Number of Traces	: 211
Low stop velocity	: 75 m/sec
Low pass velocity	: 100 m/sec
High pass velocity	: 125 m/sec
High stop velocity	: 175 m/sec
Low stop frequency	: 6 Hz
Low pass frequency	: 12 Hz
High pass frequency	: 16 Hz
High stop frequency	: 28 Hz

Parameter values:

Number of Traces	: 211
Low stop velocity	: 5 m/sec
Low pass velocity	: 25 m/sec
High pass velocity	: 75 m/sec
High stop velocity	: 100 m/sec
Low stop frequency	: 2 Hz
Low pass frequency	: 4 Hz
High pass frequency	: 20 Hz
High stop frequency	: 60 Hz

Parameter values:

Number of Traces	: 211
Low stop velocity	: 250 m/sec
Low pass velocity	: 275 m/sec
High pass velocity	: 350 m/sec
High stop velocity	: 375 m/sec
Low stop frequency	: 24 Hz
Low pass frequency	: 34 Hz
High pass frequency	: 48 Hz
High stop frequency	: 60 Hz

2.11 Anomalous Amplitude Attenuation

AAA uses the random occurrence and limited bandwidth of noise to separate it and remove it from the seismic signal. Prestack seismic data is transformed to the frequency domain in which a spatial

median filter is applied. Any frequency bands that deviate from the median amplitude by a specified threshold are either zeroed or replaced with frequency bands from neighboring traces. AAA is most effective when the input data sort order is such that the noise is random in that domain.

Parameter values:

Number of passes	: 1
Width of Spatial Median Filter	
Frequency range	: 4Hz – Nyquist
Frequency range	: 0 – 14 Hz
Sort order	: CMP, sorted by offset

Parameter values:

Number of passes	: 2
Width of Spatial Median Filter	
Frequency range	: 0Hz – 20Hz
Frequency range	: 20Hz - Nyquist
Sort order	: Receiver, sorted by shotpoint number

2.12 FX-CNS

FX-CNS is an approach to coherent noise suppression for 3-D shot or receiver data that can handle irregular spatial sampling and noise variability. This is accomplished internally by azimuthally binning the data prior to filtering. Data organized in common azimuths are irregularly sampled 2-D lines radiating from the source. Each azimuth bin is filtered independently. Using frequency-space (f-x) domain fan filters and a least-squares optimization scheme, noise is locally estimated at each receiver for a specified range of apparent velocities. The least-squares estimate is performed for each frequency independently over a specified portion of the bandwidth.

Parameter values:

Number of Traces	: 21
Low stop velocity	: 50 m/sec
Low pass velocity	: 100 m/sec
High pass velocity	: 800 m/sec
High stop velocity	: 900 m/sec
Low stop frequency	: 5 Hz
Low pass frequency	: 12 Hz
High pass frequency	: 32 Hz
High stop frequency	: 35 Hz

Parameter values:

Number of Traces	: 21
Low stop velocity	: 50 m/sec
Low pass velocity	: 100 m/sec
High pass velocity	: 800 m/sec
High stop velocity	: 900 m/sec
Low stop frequency	: 0.5 Hz

Low pass frequency	: 1 Hz
High pass frequency	: 18 Hz
High stop frequency	: 20 Hz

2.13 Time Variant Filter

A zero-phase TVF (Time Variant Filter) was applied to the data. The filter passbands were described by low- and high-cut frequencies and associated dB/octave cutoff slopes. The specified cutoff frequencies are located at the half-power (-3 dB in amplitude) response points and the slopes at these frequencies are equal to the respective dB/octave values. The slope is an approximate cosine squared function in the amplitude domain. The filters were normalized so that the output amplitudes were the same as the input amplitudes for frequency components within the passband.

Parameter values:

Filter Centre Time (ms)	Low-cut Frequency (Hz)	Low-cut Slope (dB/octave)	High-cut Frequency (Hz)	High-cut Slope (dB/octave)
500	n/a	n/a	85	57
1500	n/a	n/a	65	54
3000	n/a	n/a	50	42
5000	n/a	n/a	40	38

Note: The times are those at the centre of the filter where the full effect of the filter is attained
The first filter was applied from the beginning of the trace to the first filter centre time
Intermediate filters were linearly tapered and blended with the preceding and succeeding filter between the filter centre times
The last filter was applied from the last filter centre time to the end of the data

2.14 Anomalous Amplitude Attenuation

AAA uses the random occurrence and limited bandwidth of noise to separate it and remove it from the seismic signal. Prestack seismic data is transformed to the frequency domain in which a spatial median filter is applied. Any frequency bands that deviate from the median amplitude by a specified threshold are either zeroed or replaced with frequency bands from neighboring traces. AAA is most effective when the input data sort order is such that the noise is random in that domain.

Parameter values:

Number of passes	: 1
Width of Spatial Median Filter	: 201 traces
Frequency range	: 30Hz – 90Hz
Sort order	: Shotpoint

Parameter values:

Number of passes	: 1
Width of Spatial Median Filter	: 41 traces
Frequency range	: 0Hz – 85Hz
Sort order	: Shotpoint

2.15 Preliminary Velocity Analysis

Velocity analysis was performed using WesternGeco's Interactive Velocity Analysis (InVA) package which displays all the relevant information on an X-terminal controlled by a UNIX- based workstation. This is an integrated velocity interpretation and QC system. This package has been designed to handle both 2D and large 3D surveys effectively.

NMO processed CMP gather data were input to velocity analysis. From these data Multi-velocity Function (MVF) stacks and velocity semblance displays were computed. For each velocity location the gathers, MVF data and semblances are displayed in separate windows on the workstation. Changes made to one window are automatically applied to all other windows. Velocities can be picked from either the MVF or semblance display. When velocities are interpreted at a location a velocity database is updated and the CMP gather is displayed with the NMO correction. To aid velocity picking, x and y co-ordinate information for each velocity location was loaded to InVa. This enables all the picks within a user-defined radius to be superimposed on the display. This is especially beneficial with 2D data in areas where lines intersect, to ensure consistency in the velocity interpretation.

After the velocities had been interpreted they were QC'd using a range of tools available in InVa, including iso-velocity displays and horizontal contours. Interpreted velocities were then used to generate a velocity model for subsequent processing.

Parameter Values:

Analysis Spacing	: 1500 meters
Number of CMPs per Analysis (MVF Stack)	: 11
Number of CMPs per Analysis (Semblance Display)	: 14

2.16 Residual Statics (1st pass)

Surface consistent reflection residual statics were calculated from pre-processed CDP gathers. The process is split into two phases – the first (termed XPERT) picks the time shifts for each prestack trace and the second (termed MISER) computes surface consistent statics from these picks.

In the XPERT program, one or more time and space variant gates that contain reflection events are defined. A model trace is generated by performing a rolling average of the stacked traces within the time gate and then, for each CMP gather, unstacked traces are cross-correlated with the model trace. The peaks of these cross-correlations are picked and the differential times between the peak time and the zero lag computed. These represent the sum of the residual shot and receiver statics plus any structural and residual moveout terms.

In the MISER (Modular Iterative Statics Evaluation Routine) program, an iterative Gauss-Seidel decomposition technique is used to derive the individual components of the time shift, that is, Source, Receiver, Midpoint and Residual NMO terms. The static values for each trace are written into that trace's header so that they are available for subsequent processing.

Parameter Values:

Model Window(s)	: 300 ms to 3500 ms
Maximum Correlation Shift	: 32 ms
Inline and Crossline Model Extent	: 7

2.17 Velocity Analysis

Velocity analysis was performed using WesternGeco's Interactive Velocity Analysis (InVA) package which displays all the relevant information on an X-terminal controlled by a UNIX- based workstation. This is an integrated velocity interpretation and QC system. This package has been designed to handle both 2D and large 3D surveys effectively.

NMO processed CMP gather data were input to velocity analysis. From these data Multi-velocity Function (MVF) stacks and velocity semblance displays were computed. For each velocity location the gathers, MVF data and semblances are displayed in separate windows on the workstation. Changes made to one window are automatically applied to all other windows. Velocities can be picked from either the MVF or semblance display. When velocities are interpreted at a location a velocity database is updated and the CMP gather is displayed with the NMO correction. To aid velocity picking, x and y co-ordinate information for each velocity location was loaded to InVa. This enables all the picks within a user-defined radius to be superimposed on the display. This is especially beneficial with 2D data in areas where lines intersect, to ensure consistency in the velocity interpretation.

After the velocities had been interpreted they were QC'd using a range of tools available in InVa, including iso-velocity displays and horizontal contours. Interpreted velocities were then used to generate a velocity model for subsequent processing.

Parameter Values:

Analysis Spacing	: 750 meters
Number of CMPs per Analysis (MVF Stack)	: 11
Number of CMPs per Analysis (Semblance Display)	: 14

2.18 Residual Statics (2nd pass)

Surface consistent reflection residual statics were calculated from pre-processed CDP gathers. The process is split into two phases – the first (termed XPERT) picks the time shifts for each prestack trace and the second (termed MISER) computes surface consistent statics from these picks.

In the XPERT program, one or more time and space variant gates that contain reflection events are defined. A model trace is generated by performing a rolling average of the stacked traces within the time gate and then, for each CMP gather, unstacked traces are cross-correlated with the model trace. The peaks of these cross-correlations are picked and the differential times between the peak time and the zero lag computed. These represent the sum of the residual shot and receiver statics plus any structural and residual moveout terms.

In the MISER (Modular Iterative Statics Evaluation Routine) program, an iterative Gauss-Seidel decomposition technique is used to derive the individual components of the time shift, that is, Source, Receiver, Midpoint and Residual NMO terms. The static values for each trace are written into that trace's header so that they are available for subsequent processing.

2.19 Extended Stolt Migration

The data were migrated using an Extended Stolt F-K migration algorithm. The method is capable of accurately migrating stacked data to 90 degrees in areas where there is temporal velocity variation but little or no lateral velocity variation.

Conventional Stolt migration deals with temporal variations in velocity by preconditioning the input data. This preconditioning, known as Stolt stretch, is a dynamic time shift that can be thought of as a form of depth conversion. The main purpose of this stretch is to make all events appear as though they had traveled through a constant-velocity medium, for which the algorithm would yield perfect results. This pseudo-depth conversion also helps the algorithm deal with minor variations in lateral velocity. Additionally, a constant known as the W-factor is applied to the wave equation to further correct for inaccuracies resulting from the simplistic nature of the dynamically stretched input.

The Extended Stolt algorithm deals with larger temporal velocity variations by cascading Stolt stretch migrations. Each stage uses a different velocity function and the output from the previous stage in the cascade is used as the input to the next stage. After the completion of a stage, m , the data appear to have been migrated with a cumulative interval velocity function given by:

$$v_m^2(t) = \sum_{j=1}^m v_j^2(t)$$

where:

V_i is the interval velocity function for the n th stage

$V_m(t)$ is the true migration interval velocity for the final cascade

In implementing Extended Stolt migration a Fourier transform is used to convert from time-CMP ($t-x$) to frequency-wavenumber ($f-k$) coordinates. Frequency-, velocity- and depth-dependent phase shifts are then computed and applied to each wavenumber column. Finally, inverse temporal and spatial Fourier transforms are used to convert back to time-CMP coordinates. This process is repeated for each stage of the cascade.

There are a variety of time-migration algorithms and methodologies that will yield accurate, steep-dip results. However, the goal of accurate time migration, in the presence of lateral velocity variations, has always presented a challenge. The main reason: time migration and laterally varying velocities do not mix well. One methodology provided is termed "Full-field Extended Stolt Migration". This is a "hybrid" time migration and has been an option since the program was originally developed. In this approach, lateral velocity variations are accommodated via preconditioning the stacked data. It involves:

Time to Depth conversion with the full field

Depth to Time conversion with the average function

Migration with the average function

Time to Depth conversion with the average function

Depth to Time conversion with the full field

Although such preconditioning is an approximation, it is surprisingly robust. The reason this approach is called a "hybrid" time migration is that the preconditioning partially corrects for lateral velocity variations in a manner analogous to depth migration. For this reason, the result is a better-focused, more accurately placed image than conventional forms of time migration.

Parameter Values:

Model Window(s)	: 300 ms to 2000 ms
Maximum Correlation Shift	: 16 ms
Inline and Crossline Model Extent	: 7

2.20 Kirchhoff Summation Prestack Migration – velocity locations

Migration was performed prestack, using Kirchhoff summation. In this method, the migrated image is constructed by summing weighted amplitudes along diffraction curves. These diffraction curves are determined by two-way travel times from the surface to subsurface scatterers that are computed from the supplied velocity field. Ray bending and topography corrections are included in the travel time computation. The entire dataset was input to the migration, and fully migrated velocity analysis locations were output from this step.

Parameter Values:

Trace spacing	: 1.5 meters
Maximum dip filter	: 45 degrees, 1 degree taper
Maximum aperture	: 1000 meters
Spatial antialiasing frequency	: unlimited
Number of offsets	: 61
Offset increment	: 72 meters

2.21 Velocity Analysis

Velocity analysis was performed using WesternGeco's Interactive Velocity Analysis (InVA) package which displays all the relevant information on an X-terminal controlled by a UNIX- based workstation. This is an integrated velocity interpretation and QC system. This package has been designed to handle both 2D and large 3D surveys effectively.

NMO processed CMP gather data were input to velocity analysis. From these data Multi-velocity Function (MVF) stacks and velocity semblance displays were computed. For each velocity location the gathers, MVF data and semblances are displayed in separate windows on the workstation. Changes made to one window are automatically applied to all other windows. Velocities can be picked from either the MVF or semblance display. When velocities are interpreted at a location a velocity database is updated and the CMP gather is displayed with the NMO correction. To aid velocity picking, x and y co-ordinate information for each velocity location was loaded to InVa. This enables all the picks within a user-defined radius to be superimposed on the display. This is especially beneficial with 2D data in areas where lines intersect, to ensure consistency in the velocity interpretation.

After the velocities had been interpreted they were QC'd using a range of tools available in InVa, including iso-velocity displays and horizontal contours. Interpreted velocities were then used to generate a velocity model for subsequent processing.

Parameter Values:

Analysis Spacing	: 375 meters
Number of CMPs per Analysis (MVF Stack)	: 11
Number of CMPs per Analysis (Semblance Display)	: 14

2.22 Migration Velocity Preconditioning

Proper conditioning of the velocity field is critical to the migration process. By introducing interval-velocity constraints and proper smoothing criteria, a sophisticated flow is established for creating geologically realistic velocity fields appropriate for the Kirchhoff PSTM migration method.

Parameter Values:

Analysis point spacing	: 375 meters
Velocity scaling	: 100%
Interval-velocity constraint	: 500 – 6000 m/sec
Spatial smoothing radius	: 750 meters

2.23 Time Variant Filter

A zero-phase TVF (Time Variant Filter) was applied to the data. The filter passbands were described by low- and high-cut frequencies and associated dB/octave cutoff slopes. The specified cutoff frequencies are located at the half-power (-3 dB in amplitude) response points and the slopes at these frequencies are equal to the respective dB/octave values. The slope is an approximate cosine squared function in the amplitude domain. The filters were normalized so that the output amplitudes were the same as the input amplitudes for frequency components within the passband.

Parameter values:

Filter Centre Time (ms)	Low-cut Frequency (Hz)	Low-cut Slope (dB/octave)	High-cut Frequency (Hz)	High-cut Slope (dB/octave)
0	n/a	n/a	65	78
2000	n/a	n/a	55	66
4000	n/a	n/a	45	54
6000	n/a	n/a	25	30

Note: The times are those at the centre of the filter where the full effect of the filter is attained
The first filter was applied from the beginning of the trace to the first filter centre time
Intermediate filters were linearly tapered and blended with the preceding and succeeding filter between the filter centre times
The last filter was applied from the last filter centre time to the end of the data

2.24 Instantaneous Gain

User-specified time windows were used to derive and apply scale factors to each data sample. These multipliers were calculated by centering the window over a sample, taking the average absolute amplitude of the window, defining a multiplier to make this average 0.9 times the desired output rms amplitude and applying it to the sample. The window centre was then moved down one sample and a new multiplier calculated and applied. In this way, multipliers were computed and applied to each sample from the first window application point to the last window application point. Note: The times specified are the time of the first sample to be included in the first window and the time of the last sample to be included in the last window. The multiplier for the first window was applied constantly back to the first sample The last multiplier calculated was applied constantly until the last live sample

Parameter values:

Length of AGC Window	: 500ms
Begin Time	: 0ms
End Time	: 6000ms

2.25 Kirchhoff Summation Prestack Migration

The migration was performed prestack, using Kirchhoff summation. In this method, the migrated image is constructed by summing weighted amplitudes along diffraction curves. These diffraction curves are determined by two-way travel times from the surface to subsurface scatterers that are computed from the supplied velocity field. Ray bending and topography corrections are included in the travel time computation.

Parameter Values:

Trace spacing	: 1.5 meters
Maximum dip filter	: 45 degrees, 1 degree taper
Maximum aperture	: 1000 meters
Spatial antialiasing frequency	: unlimited
Number of offsets	: 61
Offset increment	: 72 meters

2.26 Final Velocity Analysis

Velocity analysis was performed using WesternGeco's Interactive Velocity Analysis (InVA) package which displays all the relevant information on an X-terminal controlled by a UNIX- based workstation. This is an integrated velocity interpretation and QC system. This package has been designed to handle both 2D and large 3D surveys effectively.

NMO processed CMP gather data were input to velocity analysis. From these data Multi-velocity Function (MVF) stacks and velocity semblance displays were computed. For each velocity location the gathers, MVF data and semblances are displayed in separate windows on the workstation. Changes made to one window are automatically applied to all other windows. Velocities can be picked from either the MVF or semblance display. When velocities are interpreted at a location a velocity database is updated and the CMP gather is displayed with the NMO correction. To aid velocity picking, x and y co-ordinate information for each velocity location was loaded to InVa. This enables all the picks within a user-defined radius to be superimposed on the display. This is especially beneficial with 2D data in areas where lines intersect, to ensure consistency in the velocity interpretation.

After the velocities had been interpreted they were QC'd using a range of tools available in InVa, including iso-velocity displays and horizontal contours. Interpreted velocities were then used to generate a velocity model for subsequent processing.

Parameter Values:

Analysis Spacing	: 375 meters
Number of CMPs per Analysis (MVF Stack)	: 11
Number of CMPs per Analysis (Semblance Display)	: 14

2.27 NMO Compensation

Hyperbolic moveout was applied to the data. This corrected the reflection events to their zero offset position by:

$$t_o = \sqrt{t^2 - \frac{X^2}{V^2}}$$

where:

t is the traveltime at offset X

t_o is the zero offset traveltime

X is the absolute value of the source-to-detector offset distance

V is the moveout velocity

As the input trace samples were moveout corrected, they were stretched across a longer output time, so distorting the original data. The effect of this distortion was limited by limiting the amount of moveout compensation applied to the data according to a limiting stretch value, that is (where this value is represented by the variable N) the output interval was restricted to stretching $N/100$ times the input interval when the output interval exceeded $N\%$ of the input interval.

Parameter values:

Limiting Stretch Value : 2

2.28 Outer Trace Mute

An outer (long offset) trace mute was applied to the data in order to suppress direct arrivals, refractions and wide angle reflections.

The data were tapered from zero to full amplitude over a taper zone.

Parameter values:

Taper Zone Length: 64 ms (starting from the mute times detailed below)

Source-to-Detector Offset (meters)	Mute Time (ms)
351.50	99.78
654.50	237.55
1075.40	726.44
3385.00	2535.33

Note: Mute times were linearly interpolated between the specified offsets and extrapolated for

offsets larger than the last offset specified.

2.29 Stack

The migrated CMP gathers were stacked to form the final image volume.

3.0 Post Migration Processing

3.1 Band-Pass Filter

A band-pass filter was described by low- and high-cut frequencies and associated dB/octave cutoff slopes. The specified cutoff frequencies are located at the half-power (-3 dB in amplitude) response points and the slopes at these frequencies are equal to the respective dB/octave values. The slope is an approximate cosine squared function in the amplitude domain. The filter was normalized so that output amplitudes were the same as input amplitudes for frequency components within the passband.

Parameter values:

Low-Cut Frequency	: None
Low-Cutoff Slope	: None
High-Cut Frequency	: 65
High-Cutoff Slope	: 48

3.2 Instantaneous Gain

User-specified time windows were used to derive and apply scale factors to each data sample. These multipliers were calculated by centering the window over a sample, taking the average absolute amplitude of the window, defining a multiplier to make this average 0.9 times the desired output rms amplitude and applying it to the sample. The window centre was then moved down one sample and a new multiplier calculated and applied. In this way, multipliers were computed and applied to each sample from the first window application point to the last window application point. Note: The times specified are the time of the first sample to be included in the first window and the time of the last sample to be included in the last window. The multiplier for the first window was applied constantly back to the first sample The last multiplier calculated was applied constantly until the last live sample

Parameter values:

Length of AGC Window	: 1000ms
Begin Time	: 0ms
End Time	: 3800ms

3.3 Spectral Whitening

This process time-variantly flattens the amplitude spectra of seismic traces over a user-defined frequency band. Amplitudes at frequencies outside this band are suppressed. The action on each trace is similar to a single-channel, time-variant, zero-phase deconvolution.

An input trace is passed, in parallel, through a number of different zero-phase filters spanning the desired output frequency passband. The filter specifications are generated automatically based on the defined output frequency passband and on the number of filters required to cover this band. Each of the filtered versions of the input trace are then AGC scaled. More precisely, the scale factors are computed on the amplitude envelope of the trace. To stabilise the process, white noise is added to the envelope before computing the scalar. This addition of white noise prevents exaggeration of weak signal frequencies.

Finally, the filtered and gained versions of the input trace are summed and the whole scaled so that the amplitude envelope of the output is equivalent to the envelope of the input trace. In this way, relative amplitude is broadly preserved.

Parameter values:

Filter Specification : Automatic
 Number of Filters Generated : 8
 Gain Window Length : 500ms
 Percent White Noise : 1.0

Filter Number	Frequency (Hz)	Amplitude
1	5	0.01
	10	1.0
	50	1.0
	65	00.1

3.4 Time Variant Filter

A zero-phase TVF (Time Variant Filter) was applied to the data. The filter passbands were described by low- and high-cut frequencies and associated dB/octave cutoff slopes. The specified cutoff frequencies are located at the half-power (-3 dB in amplitude) response points and the slopes at these frequencies are equal to the respective dB/octave values. The slope is an approximate cosine squared function in the amplitude domain. The filters were normalized so that the output amplitudes were the same as the input amplitudes for frequency components within the passband.

Parameter values:

Filter Centre Time (ms)	Low-cut Frequency (Hz)	Low-cut Slope (dB/octave)	High-cut Frequency (Hz)	High-cut Slope (dB/octave)
0	8	12	60	57
1000	8	12	45	46
4000	8	12	30	33

Note: The times are those at the centre of the filter where the full effect of the filter is attained
 The first filter was applied from the beginning of the trace to the first filter centre time

Intermediate filters were linearly tapered and blended with the preceding and succeeding filter between the filter centre times
The last filter was applied from the last filter centre time to the end of the data

3.5 Radial Predictive Filter

A weighted summation of adjacent traces that have been time variantly shifted to line up at the angle of maximum coherency is used to enhance the most coherent signal within a range of specified dip angles and suppresses both random noise and coherent energy outside that range.

Parameter values:

Spatial Filter Width : Automatic
Correlation Filter Width : 21
Number Of Traces To Stack : 21
Gate Length : 300ms

CMP Control Point	Fan Start Time	Upper Edge Cutoff	Lower Edge Cutoff
1	2	-13	13
	6000	-13	13

3.6 Time to Depth conversion

After post migration processing, the sections were converted to depth using a vertical time-to-depth conversion with a smoothed time-velocity function.

4.0 Personnel

4.1 WesternGeco

Scott Totten	NAM Land Operations Manager
Jeff Thompson	Project Geophysicist (Survey Design)

WesternGeco, Denver Office DP

Zhanna Jackson	Processing Supervisor
Adrian Montgomery	Team Leader
Greg Wimpey	Area Geophysicist
Patrick Hall	Seismic Analyst

5.0 Appendices

5.1 Acquisition Parameters

5.1.1 General Information

Surface geometry	
Source Point Interval	36 meters
Detector Point Interval	3 meters
Recording Parameters	
Spread type	Static Spread, all channels live
Recording Instrument	Q-Land Mini Acquisition System (QMAS)
Sample Interval	2 msec.
Record Length	6 sec., correlated
Low Cut Filter	3Hz, 18dB/Octave, Butterworth
High Cut Filter	Out
Notch Filter	Out
Tape Format	SEGD 8036 REV 2.0
Source Parameters	
Source type	Vibroseis
Sweep segments	1
Starting frequency	6 Hz
Ending frequency	120 Hz
Sweep Length	18 sec.
Listening time	6 sec.
Sweep type	Proprietary (Maximum Displacement)
Force level	70%
Number of sweeps per VP	1
Number of vibs per group	2
Nominal array	linear, parallel to source line direction
Nominal vib spacing in array	12.5 meters
Vibrator type	AHV-IV, 64,000 lbs
Binning and Fold	
Bin size	1.5 meters inline
Bin Density	
Nominal Fold	
Nominal Fold Tolerance	

Auxiliary Trace 1	Timebreak
Auxiliary Trace 2	True Reference
Auxiliary Trace 3	Radio Reference
Auxiliary Trace 4	Radio Similarity

5.2 Model Based Wavelet Operator

This is a list of the MBWP wavelet coefficients.



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5.3 List of Deliverables

The final SEGY seismic sections were small enough to be able to sent to Bob Will using the Drop File Box utility on the Schlumberger Hub. These files were also written to a DVD and sent to Bob Will for his archive.



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Line 101 final
transmittal

5.4 Data Examples

5.4.1 Noise Attenuation



D:\Projects\
CN76_Reese_River\p

5.4.2 Statics and Velocities



Silver_Peak_2D_Stack
k_displays_Statics_Vel

5.4.3 Kirchhoff Prestack Time Migration Velocity Analysis



Silver_Peak_kpstm_v
elocity_analysis_exa

5.4.4 Kirchhoff Prestack Time Migration Stacks with Depth Stretch



Silver_Peak_kpsm_s
tacks_with_depth_st