Downhole Seismic Imaging for mineral exploration

Norman West 98 Processing Report

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Contents

1 Summary

This report summarizes the processing that was done on the data acquired in Norman West in December 1998 in boreholes N-26 and N-33 (Falconbridge). During the processing of the data, it was discovered that it is possible to process the moderate sized VSP on a Sun Sparc Ultra 1 using DSISoft. Due to problems with ringing present in the data and the relative energy of the channels, it was difficult to rotate the data to maximize the energy in one component and deduce the original receiver orientation with much confidence. The application of predictive deconvolution reduced the effects of ringing in the data but did not eliminate them. Much of the time and effort spent during processing went to trying to fix problems problems with the rotations and ringing present in the data.

2 Background

The data was acquired in Norman West in December 1998. The specific data being processed is the 3-component VSP data acquired from boreholes N-26 and N-33 located on Falconbridge property. The philosophy of VSP processing is to separate the downgoing energy from the upgoing energy. Each borehole had 5 different shot sites leading to a total of 10 distinct datasets. The 2 boreholes and 5 shot sites can be seen in figure 1. In borehole N-33, data was acquired using the 4 level DSI tool purchased from Vibrometrics. Data acquisition in borehole N-26 used both an 8 level Vibrometrics tool and the 4 level DSI tool. The 8 level Vibrometrics tool acquired

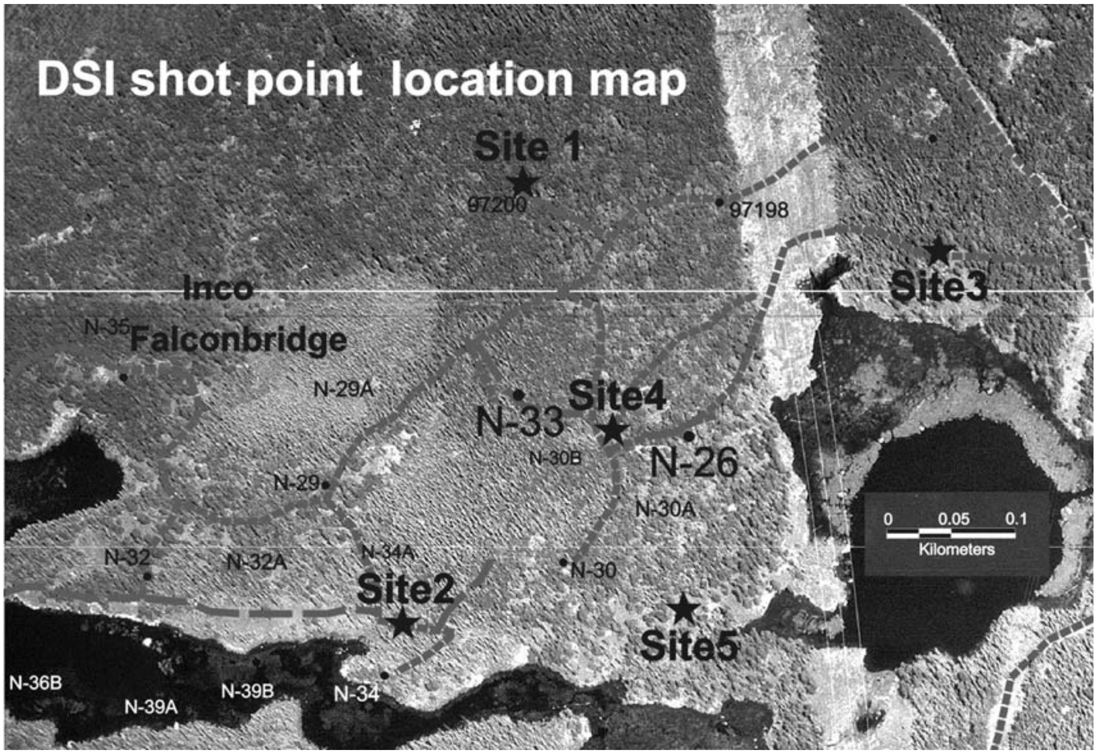

Figure 1: Map of Norman West Site

data to a wireline depth of approximately 920m while the data at deeper wireline depths was acquired with the 4 level DSI tool. The data was processed on a PC and a Sun Sparc Ultra 1 with 256 Mb of ram using only DSISoft.

3 N-26 Processing

The processing of all 10 data sets from Norman West 1998 was done using DSISoft. Most the examples presented in this report will be from borehole N-26.

The first step was to convert the data from seg2 format to DSI format. The data was then sorted into 10 datasets on the basis of borehole-shotsite configuration. Then the geometry was assigned to the headers of the datasets. A datum of 0 m above sea level was used as the datum for the processing of the data.

As can be seen in figure 2, the data recorded by the Vibrometrics tool seem to have a higher level of electrical noise contamination than the data recorded by the DSI tool

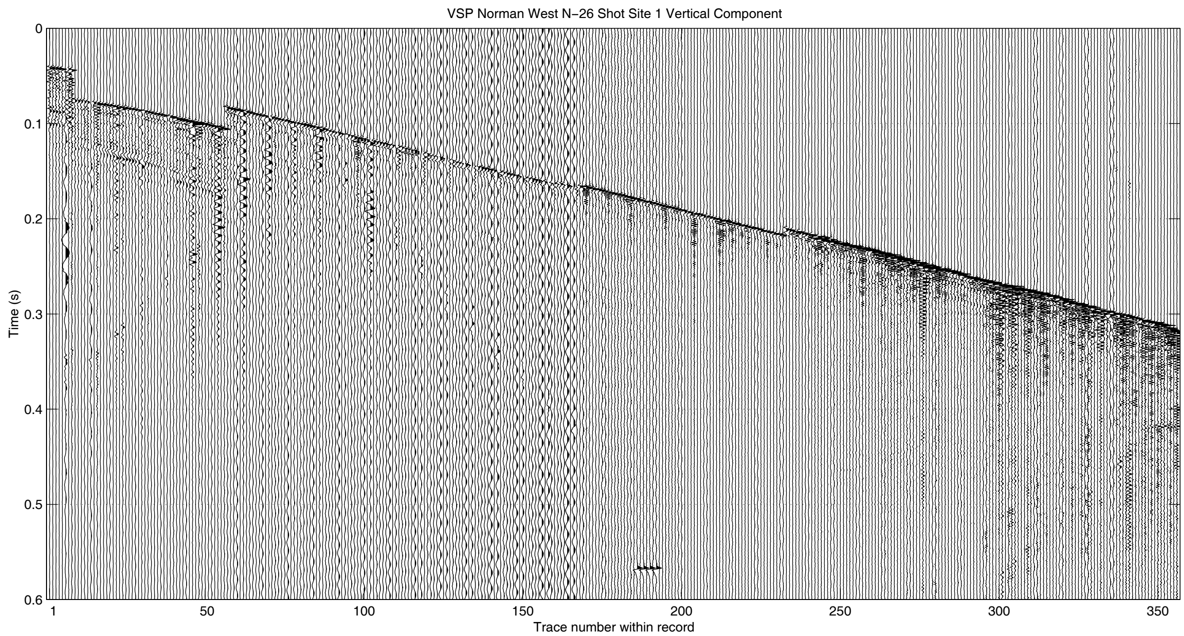

Figure 2: Cross-section of unprocessed data.

and there seems to be a higher amount of ringing in the data collected by the DSI tool. As can also be seen in figure 2, the arrival of the first break energy is jagged and discontinuous. Some of this is caused by drift in the timing clocks of the shooter's boxes.

This was partially corrected by taking the drift in the timing clocks from the beginning of the day to the end of the day and doing a linear interpolation to determine the time shifts that needed to be applied to the data.

As can be seen in figure 3, the first breaks are still some what discontinuous. Some of the timing clock corrections could not be calculated because the timing clock failed during certain periods of shooting and the drift may not be linear in nature. An analysis of the surface phones was performed to try and determine a more accurate correction. Due to the poor surface phone coupling and the surface phone being moved during the survey, it was not possible to determine a more accurate correction. Due to the failure of the timing clocks during certain periods of shooting, some statics were applied by hand. This can be seen in figure 4.

As can be seen in figure 4, there is some degree of electrical noise contamination in the data. The presence of of electrical noise is due to the proximity of a high voltage power line. The frequency spectrum of the data was analyzed to look for the

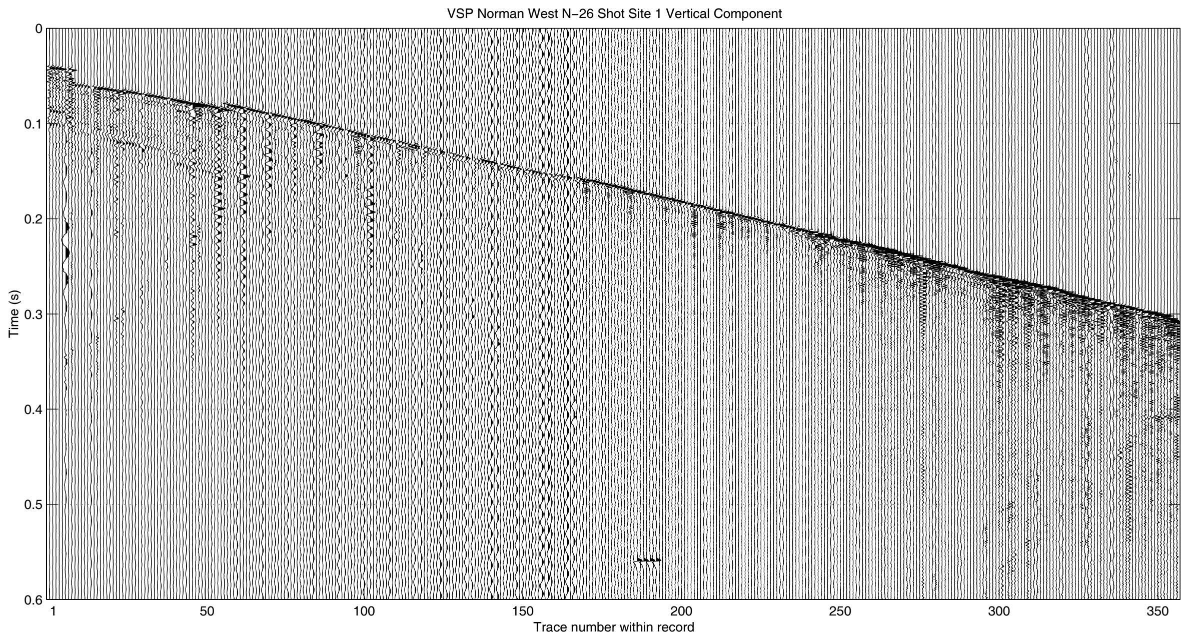

Figure 3: Cross-section of data after application of timing clock corrections.

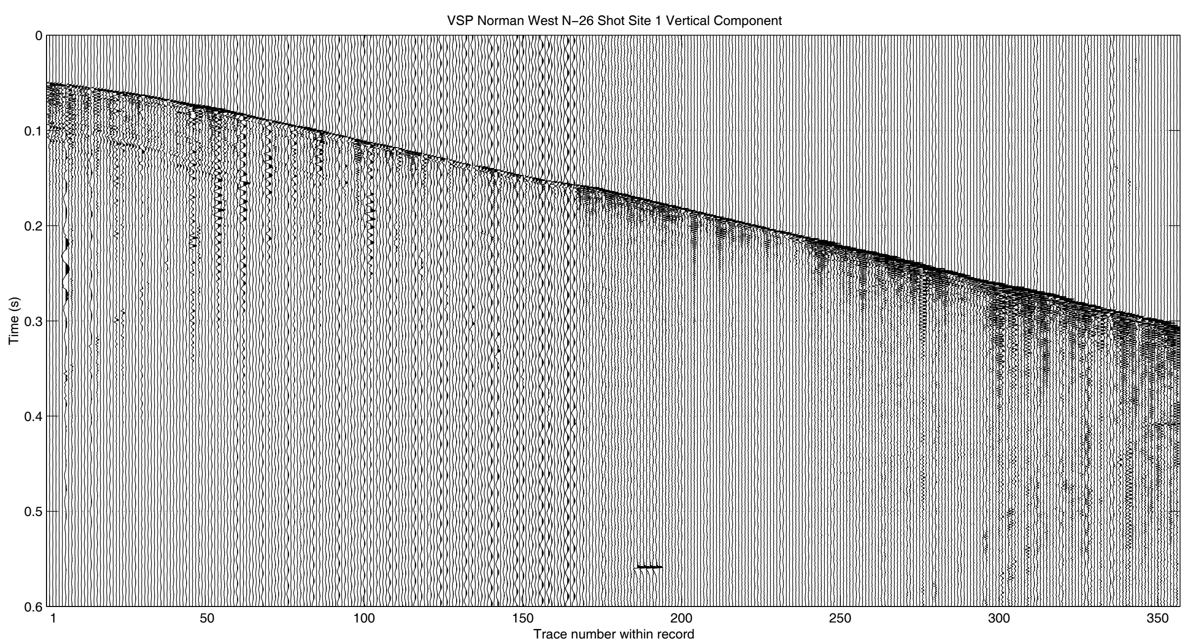

Figure 4: Cross-section of data after application of hand statics.

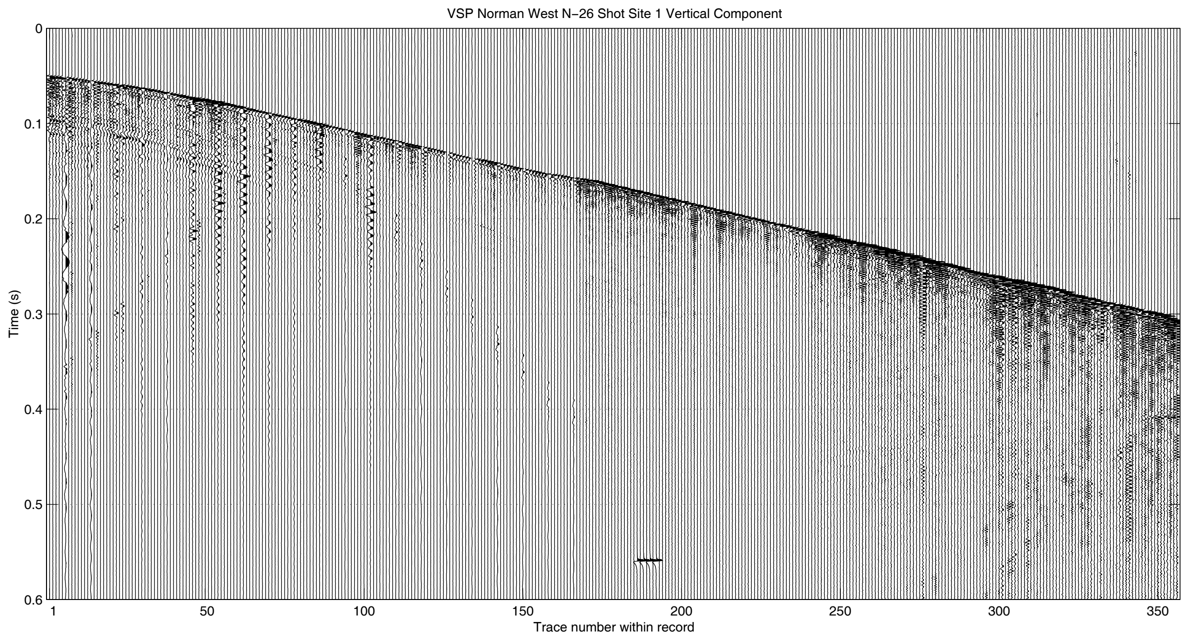

Figure 5: Cross-section of data after elcctrical noise removal.

electrical noise frequencies to be removed. The unwanted frequencies are removed using an adaptive filtering module (Adam and Langlois, 1995). The data with the electrical noise removed can be seen in figure 5.

There was still some wavering in in the firstbreak energy so some residual statics were applied to the data. Originally, the data was further processed and the data rotated to maximize the energy on the H1 component but problems were encountered with the rotation. It was suggested that the average energy per channel be analyzed to see if there was a bias in the energy. The DSI tool has 4 receiver levels with 3 geophones per receiver level. This gives a total of 12 channels to be analyzed. Channels 3, 6, 9, and 12 are the channels for the vertical component receivers, these channels should have a higher energy than the horizontal component receivers. Channels 1, 4, 7, and 10 are the channels for the H1 component receivers because of geophone geometry. Channels 2, 5, 8, and 11 are the channels for the H2 component receivers. If one assumes that the orientation is statistically random when a sample of all depths is taken, then the average energy for the H1 and H2 receiver channels should be equal. Figure 6 shows the average energy per channel for VSP N-26 shot site 1 for all depths where data was taken by the DSI tool. As can be seen in figure 6, this is not the case. The H2 component receiver channels consistently have a higher energy by a factor of 3 to 7 when compared with the H1 receiver components. The average back-

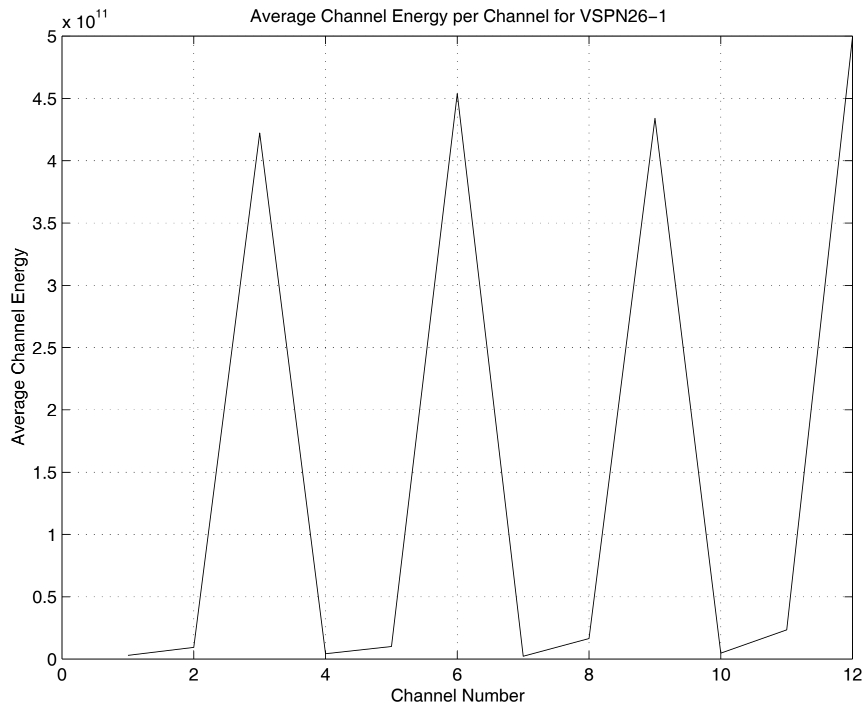

Figure 6: VSP N-26 Shot Site 1 Average Energy per Channel (H1, H2, Z)

ground energy per channel was then calculated from 0 milliseconds to 25 milliseconds to determine if there was any problems with the preamps in the tool. The average noise energy per channel can be seen in figure 7 for shot site 1. The data was energy balanced so that the average energy per channel for H1 and H2 were the same. The data was then rotated to try and maximize then energy on the H1 component but the results were not satisfactory. Due to ringing problems and amplitude imbalance in the receiver components, it was quite difficult to calculate the rotation angles of the data (Mah, 1999a). Without being able to calculate the original orientation of the data, it is extremely difficult to determine where reflected energy is coming from in the horizontal components of the data.

The data was then lowpass FIR filtered with a passband frequency of 400 Hz and a stopband frequency of 1000 Hz in order to get rid of the high frequency noise (Mah, 1999b). As mentioned earlier there is ringing present in the data. This can be seen in figure 8 which a sample trace from VSP N-26 Shot Site 1.

The ringing in the data obscured events near the firstbreaks of the data. It is therefore necessary to try to remove this ringing to see any events near the first

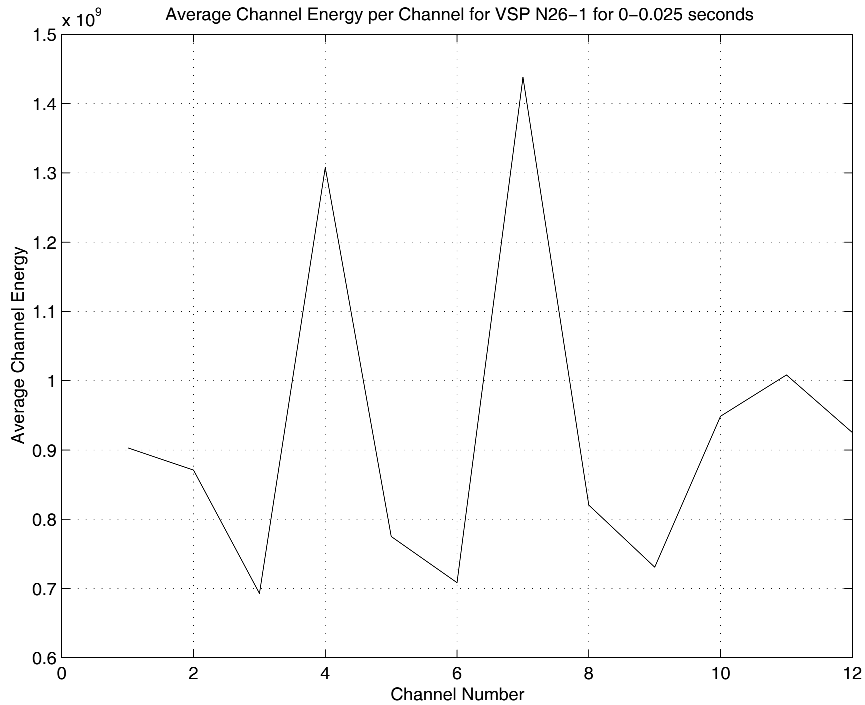

Figure 7: VSP N-26 Shot Site 1 Average Noise Energy per Channel (H1, H2, Z)

breaks. One possible way of doing this is to apply a predictive deconvolution (Mah, 1999c). After predictive deconvolution was applied to the data, ringing was greatly reduced in the data as can be seen in figure 9. Two different sets of parameters were used for the predictive deconvolution. One set was used for the vertical components of the data while another set was used for the horizontal components of the data because the vertical components of the data had a different type of ringing than the horizontal components of the data. A cross-section of the data after predictive deconvolution and after trace editing can be seen in figure 10. The data was median filtered to remove the down going P-waves and the down going S-waves which can be seen in figure 11.

There was still a significant amount of down going energy present in the data. So it was decided to apply an f-k filter the data in order to reduce or remove the unwanted signal. The f-k spectrum of the data can be seen in figure 12 where the energy contained in the black polygon will be removed. There was still some remanent of a tube wave present in the data. The data was f-k filtered in order to reduce the tube wave. The f-k spectrum of the data can be seen in figure 13. The energy contained in the black box is that of the tube wave and an alias of the tube wave.

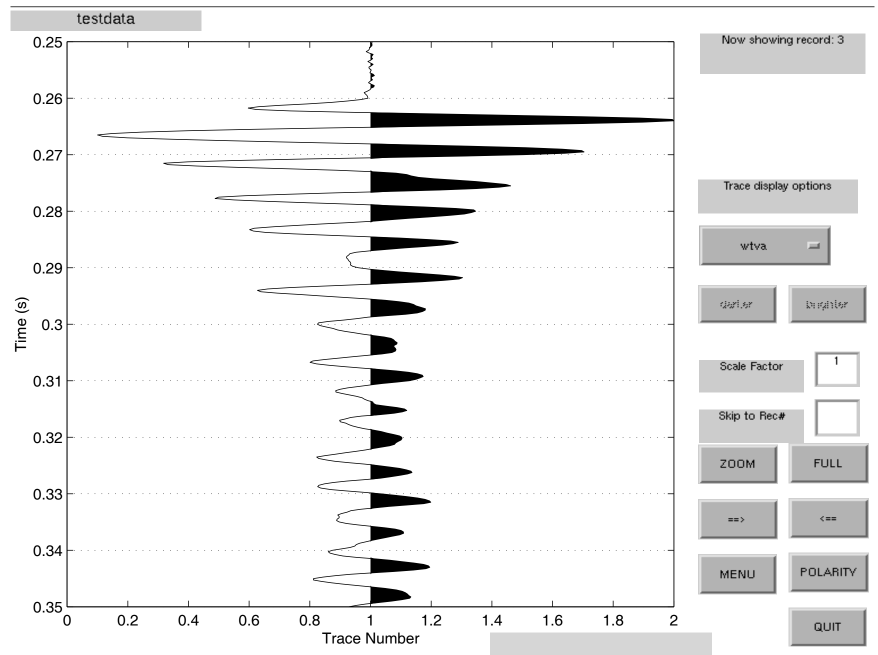

Figure 8: Sample Trace

After f-k filtering, the frequency spectrum of the data was analyzed and the data was then bandpass filtered to remove low and high frequency noise. Figure 14 shows the data after f-k filtering and bandpass filtering.

Table 1 is a summary of the processing stream with the parameters used for the processing of VSP data collected in N-26.

4 N-33 Processing

The processing flow for N-33 was almost exactly the same as for N-26 except for the additional energy balancing and the extra f-k filtering. The extra f-k filtering was necesary to further reduce the amount of tubewave energy present. Figure 15 shows VSP N-33 Shot Site 1 after it has been finished processing.

In table 2 is a summary of the processing stream with the parameters used.

5 Conclusions

In conclusion, it is possible to process the moderate sized VSP on a Sun Sparc Ultra 1 using DSISoft. If a larger data set is to be processed, a machine with more

Geometry	
Sort	Wireline Depth
Timing clock corrections	
Monofrequency electrical noise removal	Adaptive filter (60, 180, 300, 360, 420, 540, 660, 780 Hz)
Residual statics	Hand Picked
Energy balancing based on average channel energy	2 msec before first breaks to 4msec after first breaks window
Rotation to maximize energy in H1	Based on energy from 2 msec before first breaks to 4 msec after first breaks
Lowpass filtering	Passband frequency = 400 Hz Stopband frequency = 1000 Hz
Predictive deconvolution of vertical component	Start of window = 50 msec before firstbreaks End of window = 150 msec after firstbreaks Operator lag = 2.75 msec Operator length = 3 msec Prewhitening = 1%
Predictive deconvolution of horizontal components	Start of window = 0 sec End of window = 2 sec Operator lag = 7.50 msec Operator length = 3 msec Prewhitening = 1%
Resample	Sample rate = 0.5 msec
Energy balancing	0 to 0.75 sec window
Trace editing	
Removal of downgoing P-wave	median velocity filter (13 points)
Removal of downgoing S-wave	median velocity filter (23 points)
Removal of other downgoing energy	f-k velocity filter
Removal of tubewave energy	f-k velocity filter
Bandpass filtering	35Hz-85Hz-225Hz-325Hz

Table 1: Summary of processing flow for N-26.

Geometry	
Sort	Wireline Depth
Timing clock corrections	
Monofrequency electrical noise removal	Adaptive filter (60, 180, 300, 360, 420, 540, 660, 780 Hz)
Residual statics	
Energy balancing based on average channel energy	2 msec before first breaks to 4msec after first breaks window
Rotation to maximize energy in H1	Based on energy from 2 msec before first breaks to 4 msec after first breaks
Lowpass filtering	Passband frequency = 400 Hz Stopband frequency = 1000 Hz
Predictive deconvolution of vertical component	Start of window = 50 msec before firstbreaks End of window = 150 msec after firstbreaks Operator lag = 2.75 msec Operator length = 3 msec Prewhitening = 1%
Predictive deconvolution of horizontal components	Start of window = 0 sec End of window = 2 sec Operator lag = 7.50 msec Operator length = 3 msec Prewhitening = 1%
Resample	Sample rate = 0.5 msec
Energy balancing	0 to 0.75 sec window
Trace editing	
Removal of downgoing P-wave	median velocity filter (13 points)
Removal of downgoing S-wave	median velocity filter (23 points)
Energy balancing	0 to 0.60 sec window
Removal of other downgoing energy	f-k velocity filter
First pass at removal of tubewave energy	f-k velocity filter
Second pass at removal of tubewave energy	f-k velocity filter
Bandpass filtering	35Hz-85Hz-225Hz-325Hz

Table 2: Processing flow for N-33.

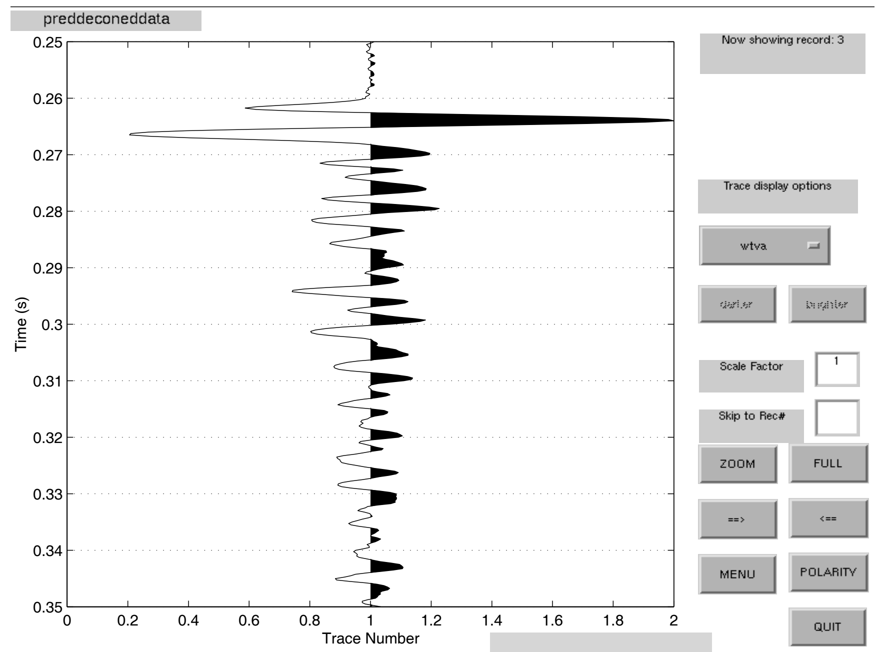

Figure 9: Sample Trace after application of Predictive Deconvolution.

memory and CPU power will be needed. Due to problems with ringing present in the data and the relative energy of the channels, it is difficult to rotate the data to maximize the energy in one component and deduce the original receiver orientation with much confidence. This leads one to believe that there is very little, if any, useful information contained in the horizontal data. The application of predictive deconvolution will reduce the effects of ringing in the data but not eliminate them. Much of the time and effort spent during processing went to trying to fix problems with the rotations and ringing present in the data. It must be mentioned that this process or method is successful at removing enough of the downgoing energy so that upgoing energy, i.e. reflections, is seen.

6 Recommendation

It is recommended that the problems with the ringing and the relative amplitudes in the various channels be examined and possible solutions determined. It is also recommended that a few rotations of the data be done out in the field to see if the orientation of the receivers can be deduced.

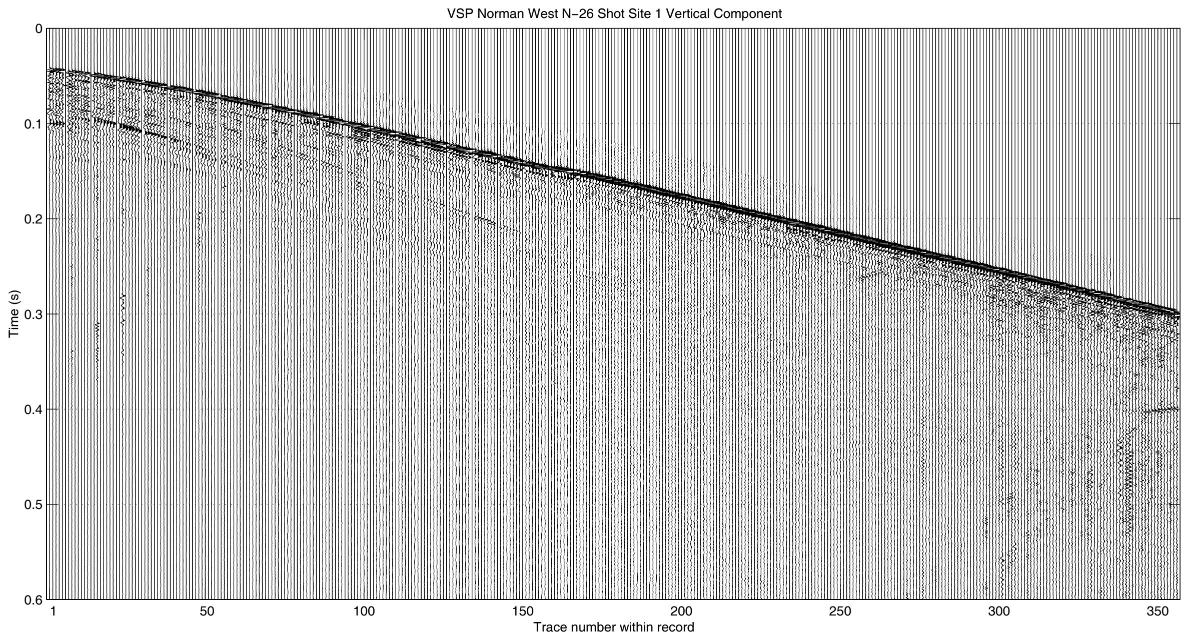

Figure 10: Cross-section of data after predictive deconvolution.

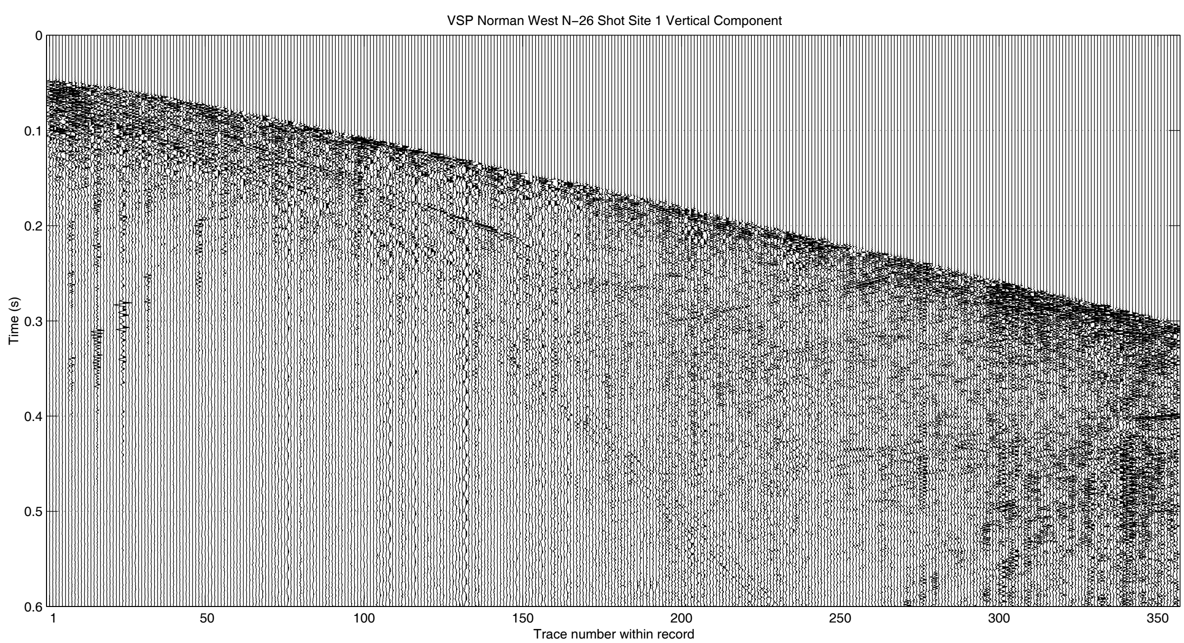

Figure 11: Cross-section of data after median filtering to remove downgoing energy.

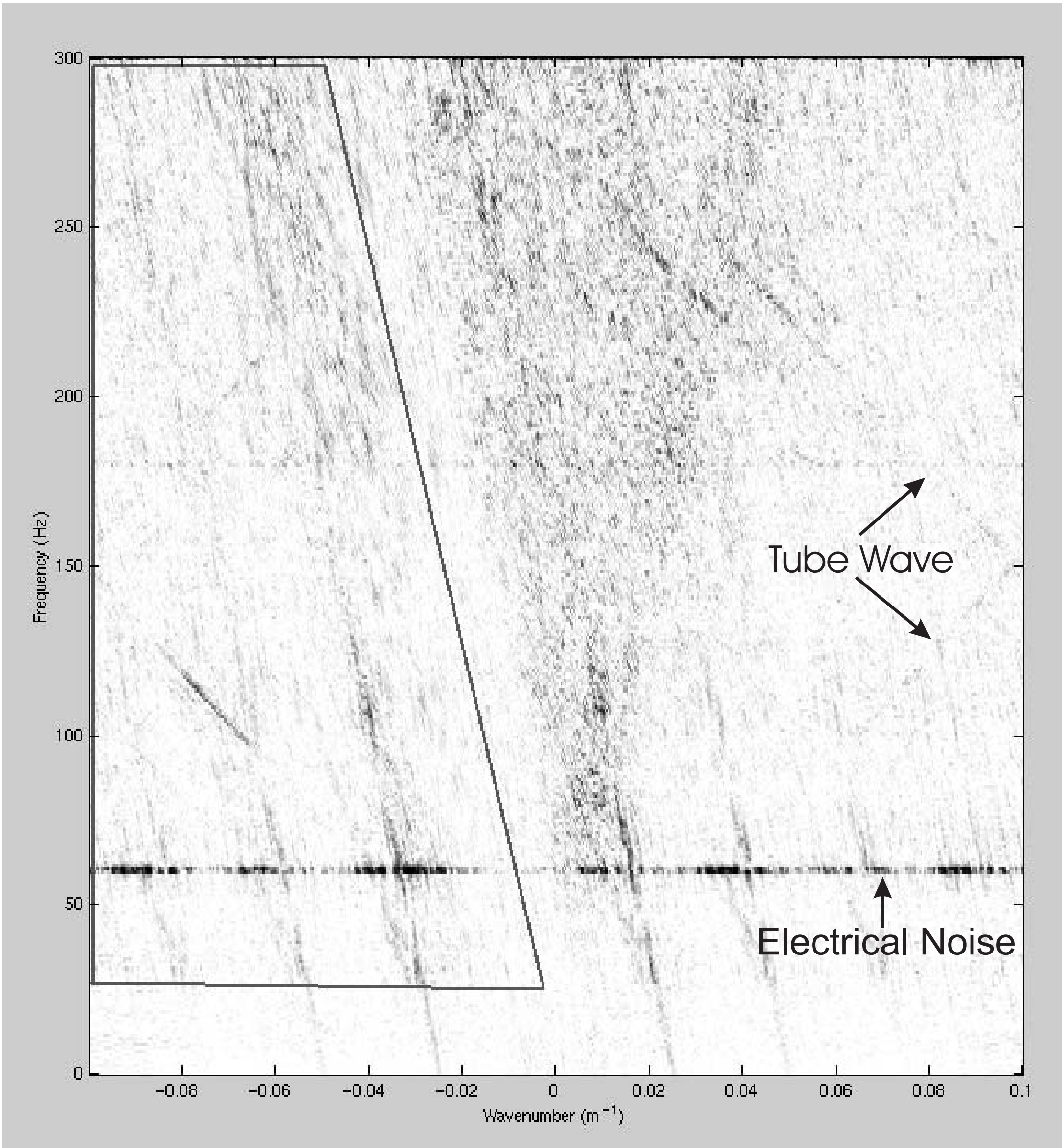

Figure 12: FK spectrum of VSP N-26 Shot Site 1.

7 References

Adam, E. and Langlois, P. 1995 Elimination of Monofrequency Noise from Seismic Records. Lithoprobe Seismic Processing Facility Newletter, Vol. 8, No. 1, pp. 59-65.
Mah, M. 1999a. Rotation of Norman West VSP N-26. DSI Consortium Internal Report, Geological Survey of Canada.

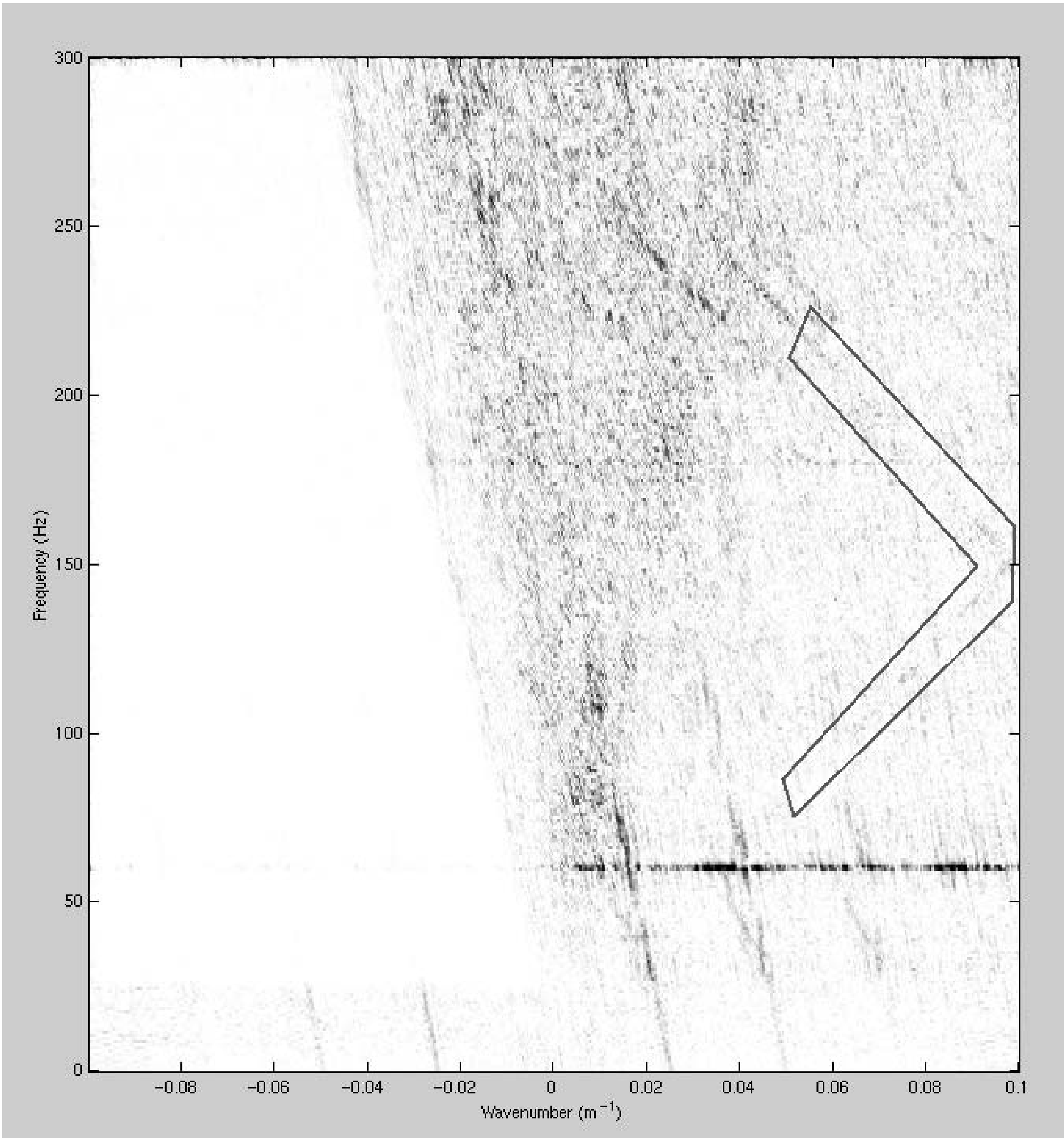

Figure 13: FK spectrum of VSP N-26 Shot Site 1.

Mah, M. 1999b. Finite Impulse Response Filtering Report. DSI Consortium Internal Report, Geological Survey of Canada.
Mah, M. 1999c. Predictive Deconvolution Report. DSI Consortium Internal Report, Geological Survey of Canada.

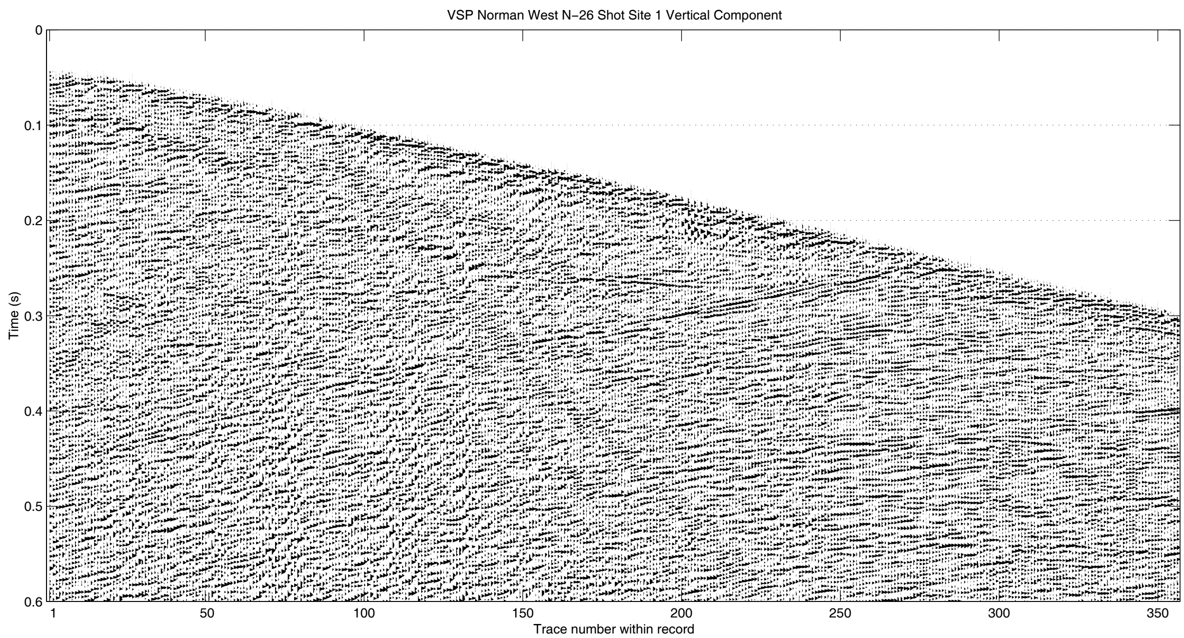

Figure 14: Cross-section of data after FK filtering and bandpass filtering. N-26

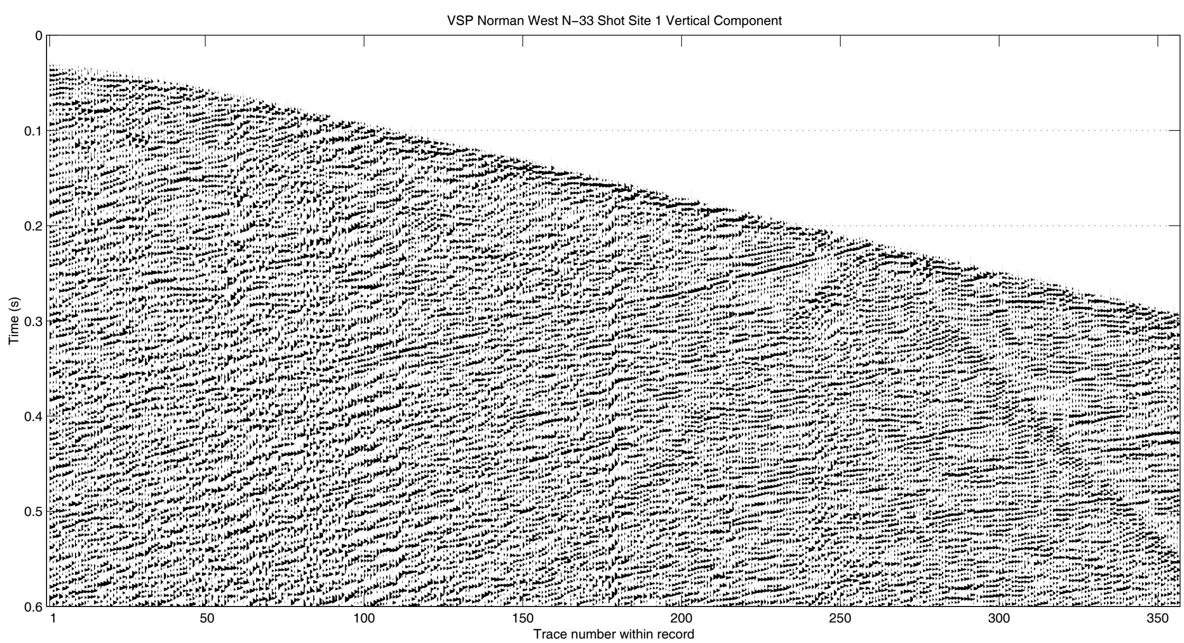

Figure 15: Cross-section of data after FK filtering and bandpass filtering. N-33

8 Appendix

The following is a summary of the scripts used in the processing of VSP N-26 shot site 1.

pre_proc1_26a.m
The data was read into Matlab using the seg2mat command. The files were read in according to a text file which contained the seg2 filenames of the files which contained traces taken from vspn26-1. The original trace number (1) and the FFID (2) was set by the seg2mat command. Some geometry was then applied. The recording component (4), shot point number (26), shotsite number (48), and the wireline depth (56) was applied to the headers. The data acquired from the Vibrometrics and the DSI tool was combined and sorted first by recording component (4) then by wireline depth (56).
The output of this program is vspn26-1.mat

pre_proc1_26b.m
The program loads in vspn26-1.mat
More geometry is applied to the data. The recording day (30), recording time in secs (32) and the shooting box number (34) is applied to the data.
The output of this program in vspn26-1.mat

pre_proc1_26c.m
The program loads in vspn26-1.mat
A datum of 375 metres above sea level was decided on to which the data was to be processed. The receiver coordinates are determined and set in the headers. The receiver easting (37), the northing (35), and the depth below datum (39) was set. The datum elevation (51) was set to 375 metres and the bore hole collar elevation (50) was also set.
The output of this program is vspn26-1.mat

pre_proc1_26d.m
The program loads in vspn26-1.mat
The source northing (29), source easting (31), and source depth below datum (33) was set. The shot depth (54) was set to 5 metres.
The output of this program in vspn26-1.mat

pre_proc1_26e.m
The program loads in vspn26-1.mat
The program assigns the shot-receiver azimuth (9) and the shot-to-receiver offset (53) to the data.

The output of this program is vspn26-1.mat

pre_proc1_26h.m
The program loads in vspn26-1.mat
The program just to extract the ffid out of vspn26-1.mat so a x-section of the surface phones can be made.
The output of this program is vspn126jan27.wk1

pre_proc1_26i.m
Creates a cross-section of the surface phones
The output of this program is surf126method2.mat

pre_proc1_26j.m
The program loads in vspn26-1.mat
This program shifts the traces to try and correct for the drifts of the clocks. It uses a linear interpolation of the drift time of the data.
The output of this program is vspn126shft.mat

pre_proc1_26k.m
The program loads in vspn126shft.mat
This program will extract header information from vspn126shft.mat This header info will be put into surf126method2.mat to see what affect it has on the surface phones
We want to extract a lot of info such as:
trace header word 21 (shot static)
trace header word 26 (shot point number)
trace header word 30 (date)
trace header word 32 (time)
trace header word 34 (shooting box)
trace header word 48 (shot site number)
trace header word 56 (wireline depth)
The output of this program is surf126cor.mat

pre_proc1_26l.m
This program applies hand statics to the data.
The output of this program is vspn126shft2.mat

repre_proc1_26a.m
The program loads in vspn126shft2.mat
It then removes 60Hz,180Hz,300Hz,360Hz,420Hz,540Hz,660Hz,780Hz electrical noise from the data using harmon_new
The output of this program is vspn126harmon2.mat

repre_proc1_26c.m
The program loads in vspn126harmon2.mat and vspn126subpfb.mat
It applies a polynomial fit to the data and corrects the data to the least squares fit. These corrections are also applied to the first break picks so that the won't have to be redone. Next, it applies energy balancing based on a window around the first breaks. It uses the sum of all 3 components to determine the energy, however due to problems with the average channel energy as pointed out in rotation report, the average channel energy was determined and corrected.
The output of this program is vspn126ener2.mat

repre_proc1_26d.m
The program loads in vspn126ener2.mat
It then uses rot3c to rotate the traces to maximize on component 1.
It uses a window of 2msec before and 4 msec after firstbreaks.
The output of this program is vspn126rot.mat

repre_proc1_26e.m
The program loads in vspn126rot.mat
It first applies a lowpass FIR filters with a passband frequency of 400Hz and a stopband frequency of 1000Hz to get rid of high frequency noise.
It then performs a predictive deconvolution on the vertical component of the data.
It then performs a predictive deconvolution on the other 2 horizontal components of the data.
It then swaps the polarity of the 2nd and 3rd component to make it of standard configuration.
It then resamples the data from 0.25msec to 0.50msec.
The output of this program is vspn126resamp.mat

repre_proc1_26f.m
The program loads in vspn126resamp.mat
It removes some spikes in the data and energy balances the data using all 3 components and a window from 0 to 0.75sec.
It then mutes out the bad Vibrometric traces.
The output of this program is vspn126resamp.mat

repre_proc1_26g.m
The program loads in vspn126resamp.mat
It pads the end of the data with another second of zeros to prevent loss of data.
It then median filters the data to try and remove the P-waves.
It then median filters the data to try and remove the S-waves.

It then removes the 1 second of padding added
The output of this program is vspn126med.mat

repre_proc1_26h.m
The program loads in vspn126med.mat
It applies an f-k filter to all 3 components to remove some down going energy.
The output of this program is vspn126fk.mat

repre_proc1_26i.m
The program loads in vspn126fk.mat
It applies an f-k filter to all 3 components to remove tube waves.
The output of this program is vspn126fk2.mat

repre_proc1_26j.m
The program loads in vspn126fk2.mat
It then bandpass filters the data (35Hz-85Hz-225Hz-325Hz).
It then mutes the data above the first breaks.
The output of this program is vspn126bp.mat

repre_proc1_26k.m
The program loads in vspn126bp.mat
It changes some of the geometry to make it look like it was processed with a datum of 0 metres above sea level.
The output of this program is vspn126final.mat