# Evaluation of one-hundred shots repeated at the same location

John C. Bancroft, Helen Isaac, Dave Henley

## ABSTRACT

One-hundred shots were recorded at the same location to evaluate the repeatability of the shots, the relative amplitude of the shots, and the time repeatability of each shot. The data were recorded at the Priddis test site in Alberta. In addition to the repeatability measurements, the evaluation of random noise was also considered.

## INTRODUCTION

Shot records are assumed to be repeatable at the same location. If we assume the geometry of the source and receiver locations remain the same, we may assume the parameters of each shot would be identical. We would expect the source conditions may vary due to the repeated impact of the source, which in this case, was an assisted weight drop.

Measuring the amplitude was not straight forward. A number of methods were used to identify a reasonable evaluation of the amplitude, but no single method was obvious. Things that were consider when preparing the data include:

- use of gain recovery
- removal of coherent noise
- removal of random noise
- bandpass filtering
- balancing the amplitudes of each receiver
- windowing the data
- scaled for an equal maximum value on each trace

How do we measure the amplitude?
- RMS (root mean squared)
- magnitude
- peak amplitudes

Noise may be either random or coherent. Random noise can be reduced by stacking and is improved with the fold of the data. Coherent noise results from the same source as the seismic data and cannot be removed with stacking. One objective of this project was to evaluate separating the data from random noise. This was especially difficult as most of the energy was coherent surface noise.

For the noise tests, we decided to use radial filtering to remove this coherent noise so that we could see some data.

## PREPARATION OF THE DATA

The data had 100 shots, each with 52 receivers. The sampling frequency was 1,000 Hz, and 3001 sample were recorded for each trace. The data had an initial problem with

one shot record (#42), which had a one second delay. Before any processing or measurements, this record was shifted to a mean time location of the other shots.

Before the noise measurements were made, the data was radial filtered to remove as much of the coherent noise as possible. This process was very successful and reflection evenly became visible on the shot records.

The data was not filtered when estimating the amplitude and statics for each shot.

## THEORY

The method used to define the amplitude is affected by outliers in the noise. Large outliers have more of an effect on the RMS measurements. However, our data did not appear to have any significant outliers so the RMS method was used.

The amplitude of the sum of a coherent signal is proportional to the number of samples within the summation. The amplitude of the sum of random noise increases with square-root of the number of samples. Consequently, the signal to noise ratio increases with the square root of the number of samples. In our data with 100 shots, the stacking of all shots should reduce the random noise by a factor of 10.

We do assume the random noise has a Gaussian distribution.

## RESULTS

### Amplitudes

Figures Fig. 1 to Fig. 3 show the first shot record displayed as raw data, scaled with an analytic offset value, and with an AGC with a window of 201 samples.

Fig. 4 show the amplitudes for all shot records displayed RMS values, and Fig. 5 with magnitude average values. The amplitude of record #42 is lower for the AGC because much of the data is missing from the bottom of the trace due to the large timing error.

Considerable effort went to windowing the data to improve the consistency between the measurement methods to choose a value consistent with the processing objectives. Some results are displayed in Fig. 6 and Fig. 7. We consider the best result, as shown in Fig. 8, used the analytically scaled data; both magnitude and RMS values are displayed.

### Shot static

The amplitude of the traces has little to do with estimating the static shift of each shot. However, the scaled data allows use of all the coherent surface wave data and were used to scale the data for the shot statics test.
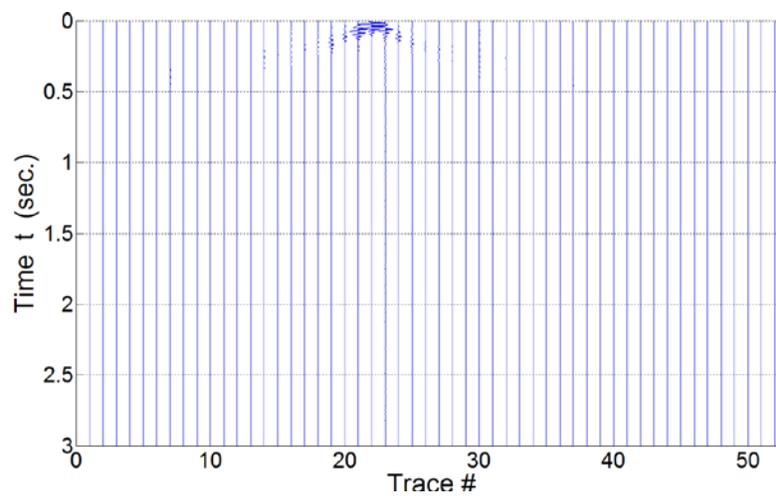
Fig. 1  Raw first shot record
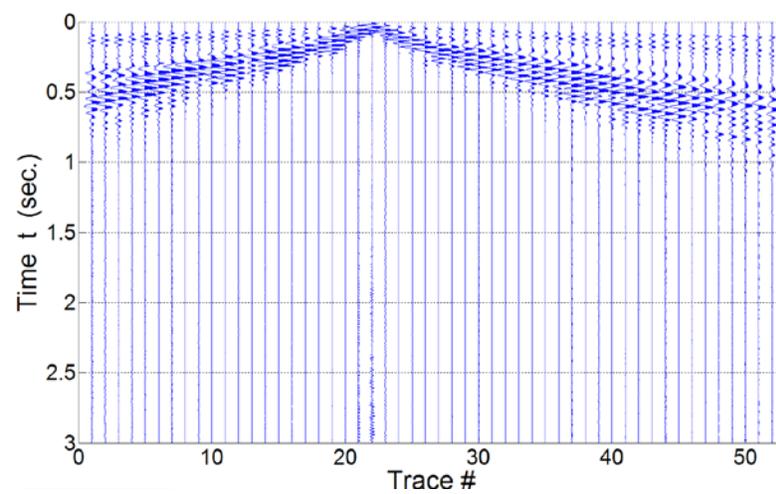


Fig. 2:  First record offset scaled.
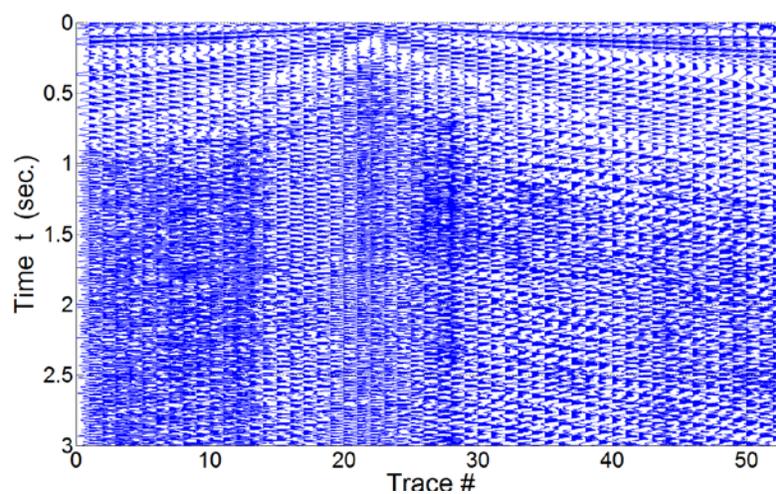


Fig. 3:  First record with AGC.
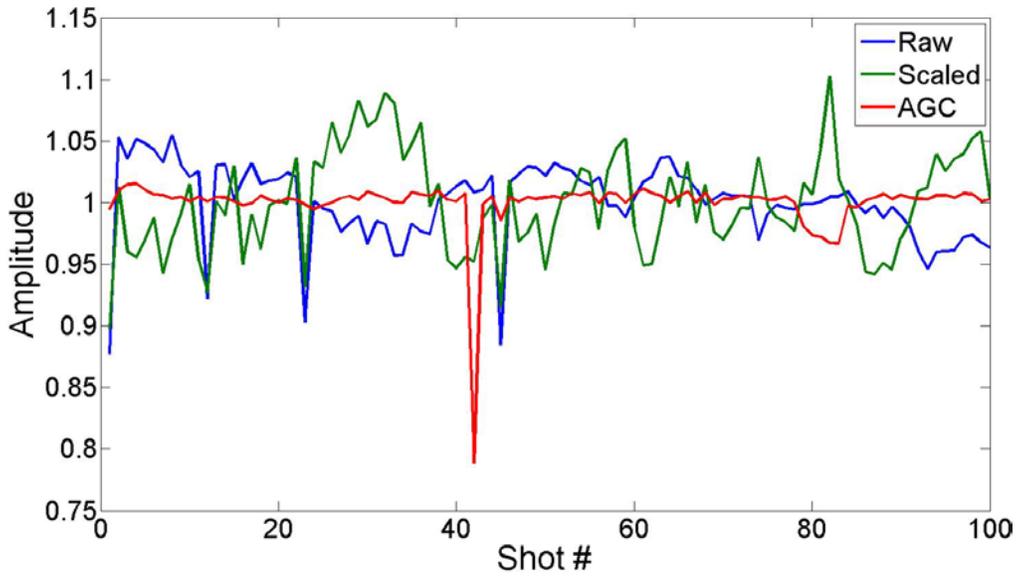
Fig. 4:  RMS amplitudes for all shots for raw, scaled and RMS data.
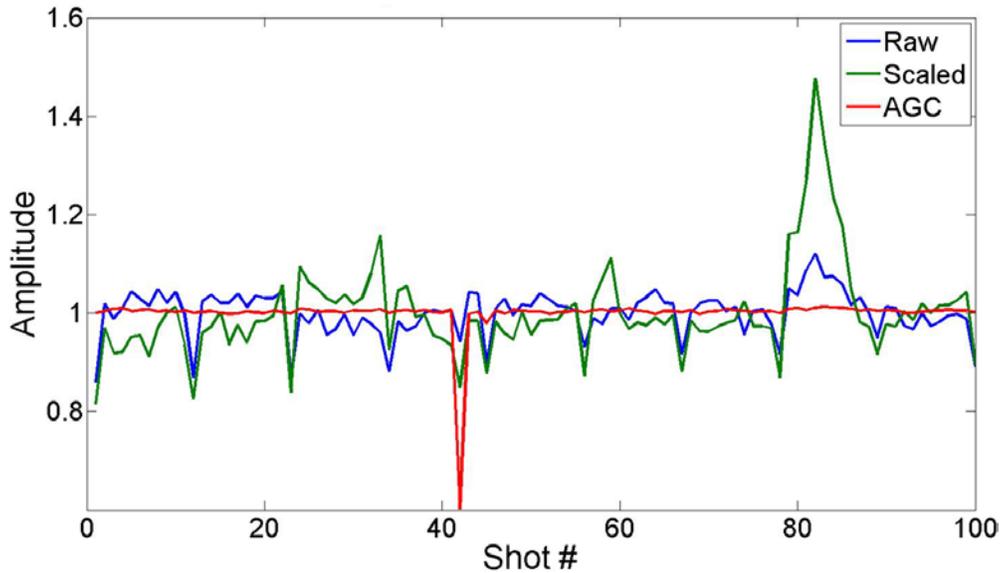


Fig. 5:  Magnitude average amplitudes for all shots for raw, scaled and RMS data.

These amplitude results show the difficulty in choosing an amplitude to scale each shot prior to stacking and cross-correlation.

Inspection of the data indicated that more consistent amplitude estimates would be achieved by using only the first 1000 sample in the traces.  The amplitude tests were repeated with the following results.
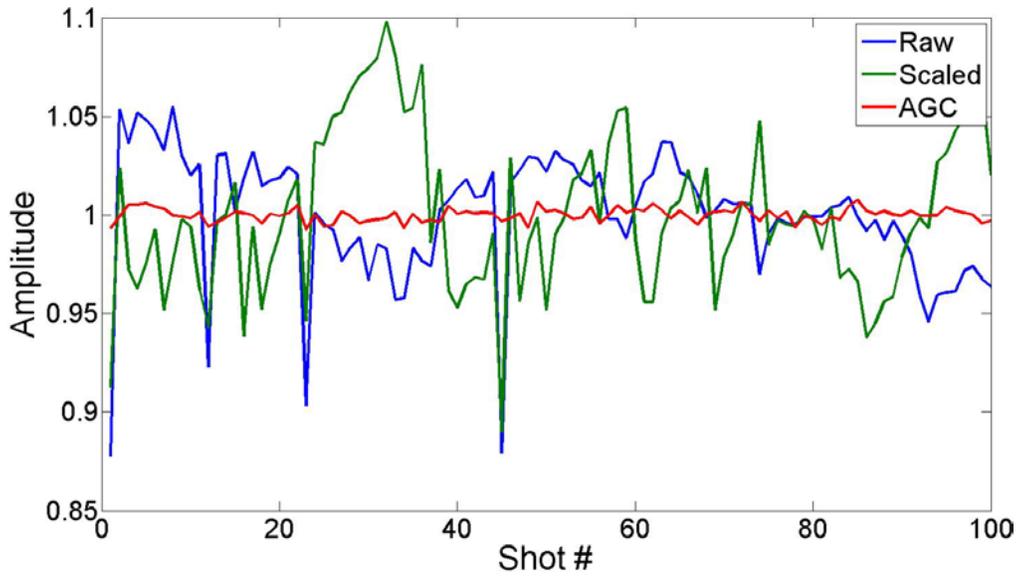
Fig. 6:  RMS amplitudes for all shots for raw, scaled and RMS data using only 1000 samples.
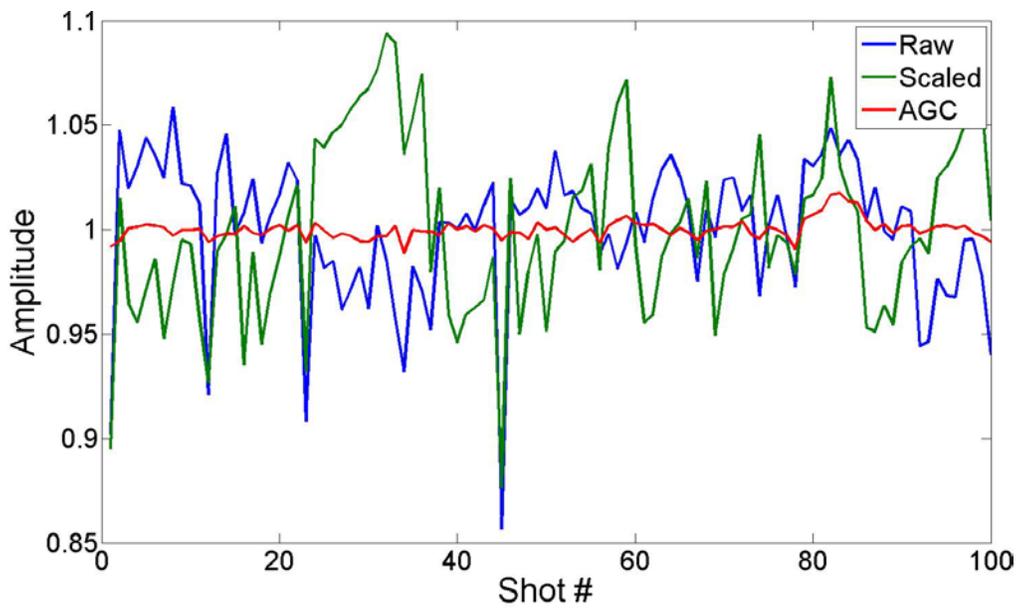


Fig. 7:  Magnitude average amplitudes for all shots for raw, scaled and RMS data using only 1000 samples.
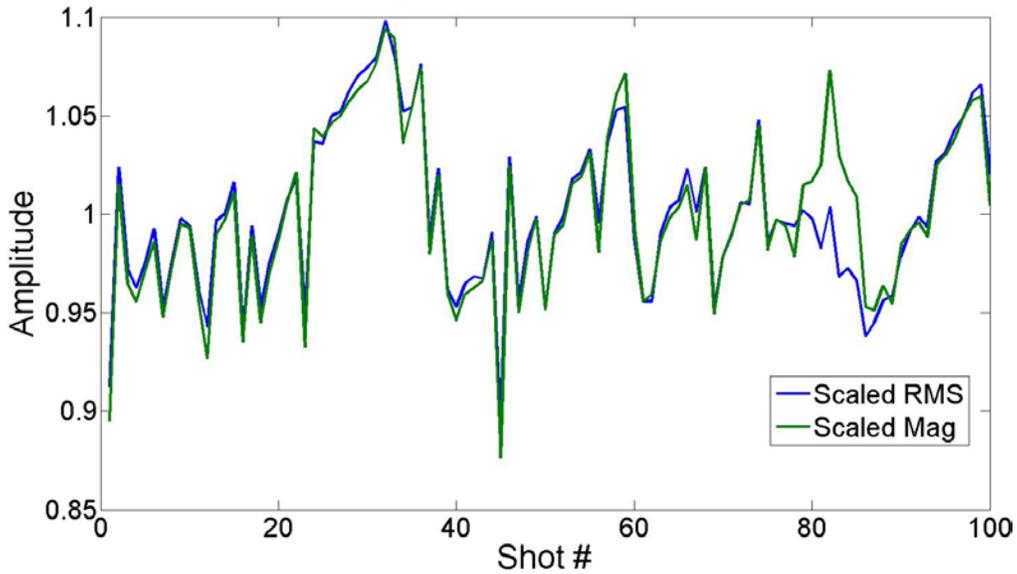
Fig. 8: Comparison of amplitude of the scaled data using RMS and average-magnitudes.

**Cross-correlation**

A model shot record was created by stacking all the shots. A cross-correlation patch was created for all shots relative to the stacked shot. The cross-correlation window was three traces wide and 11 samples in time. The zero lag point was chosen to be in the center. All time sample and traces, except for those at the boundaries were included when computing the CC. The CC patch for the first shot is shown in Table 1.

Table 1  Cross-correlation patch Scale factor = `1.0e+04 *`

| | | |
|---|---|---|
| -0.7693 | 4.0532 | -1.1421 |
| -0.9306 | 4.4234 | -1.1947 |
| -1.0636 | 4.6951 | -1.2154 |
| -1.1657 | 4.8587 | -1.2032 |
| -1.2351 | 4.9079 | -1.1576 |
| -1.2707 | **4.8401** | -1.0792 |
| -1.2723 | 4.6567 | -0.9691 |
| -1.2404 | 4.3641 | -0.8293 |
| -1.1765 | 3.9731 | -0.6625 |
| -1.0826 | 3.4978 | -0.4719 |
| -0.9615 | 2.9543 | -0.2617 |

The data in the central column is much greater than the side values indicating there is virtually no lateral shifting of the different shots. This is as expected since they are entirely due to the physical layout geometry, which remained fixed.

The central value in time, highlighted in red, is the zero lag in time, and is not the maximum value, indicating a time shift from the average shot record (static). A parabolic curve was fitted to the maximum point and the two points either side. The peak of the

parabolic curve was used to define the static and has a resolution much finer than the sample interval. The statics for each shot are displayed in Fig. 9. The statics appear larger for the first 40 shots, and then tend to converge for the last 40 shots. Shot 42, which had an initial time delay, shows a static error due to the correction. An explanation of the behavior of the static variation with increasing shot number remains elusive. However, the low frequency trend may result from the compaction of the material around the shot location.
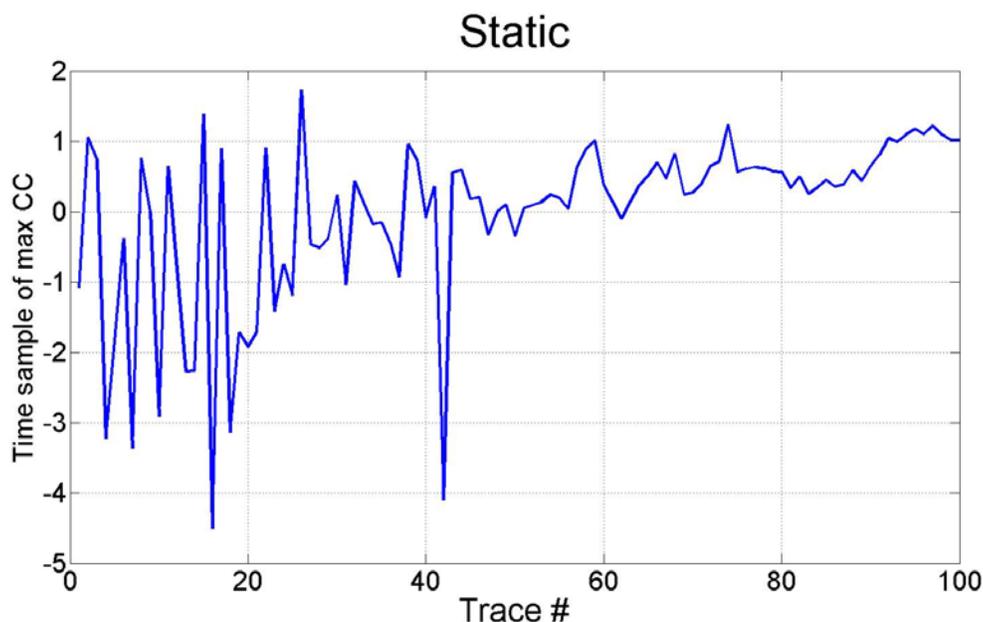


Fig. 9: Static of each shot relative to the model shot.

## EVALUATION OF RANDOM NOISE ON SHOT RECORD

The data was processed to remove the coherent surface noise using radial filters. The result of the first shot is displayed in Fig. 10. The following figure shows and AGC of the first shot.

The AGC'd shot records were then stacked and displayed in Fig. 12. Note the noise in the central band has been reduced; indicating much of the noise in this band was random, or had noise greater than any signal.

This stack shot record was then AGC'd and displayed in Fig. 13 to see if any coherent reflection energy was visible. The next two figures, Fig. 14 and Fig. 15 were filtered with a smoother of 20 and 40 samples, and show the effect of applying high cut filters of 100 and 50 Hz.

The ringing area in the stacked shot of Fig. 12, that is bound by traces 12 to 22 and from 1 to 2 sec., appears to be coherent residual noise remaining from the radial filtering. This noise is also visible in Fig. 13 and Fig. 14. The low cut filter result in Fig. 15 appears to have reduced this noise, and some coherent reflection energy may be visible.

I did have to try another AGC, and that result is in Fig. 16. I leave an explanation of the coherent energy up to you.

## Shot 1 Radial Filtered
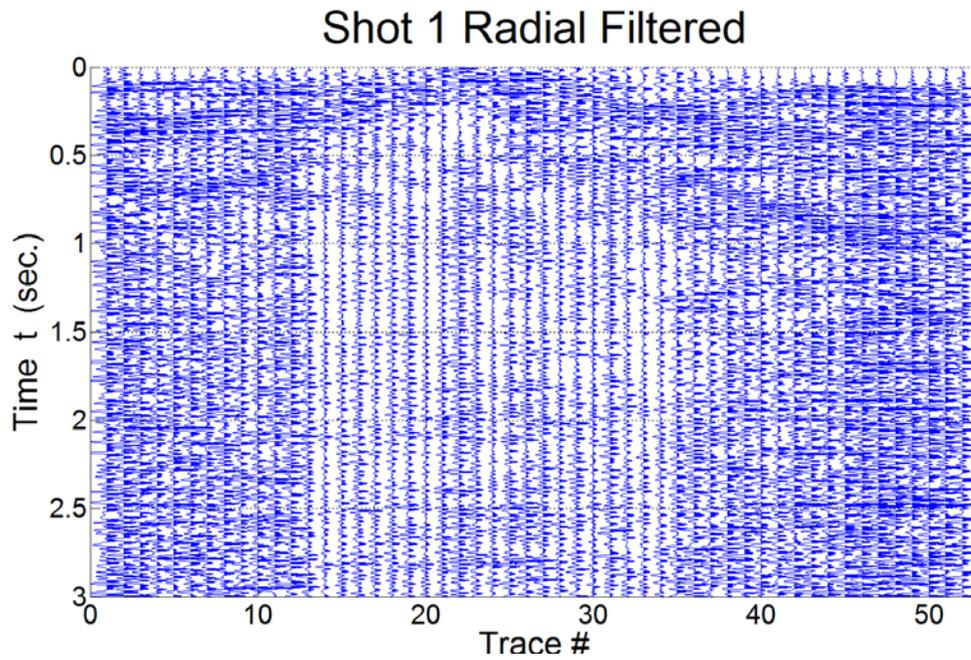


Fig. 10: Shot #1 that has been radial filtered.
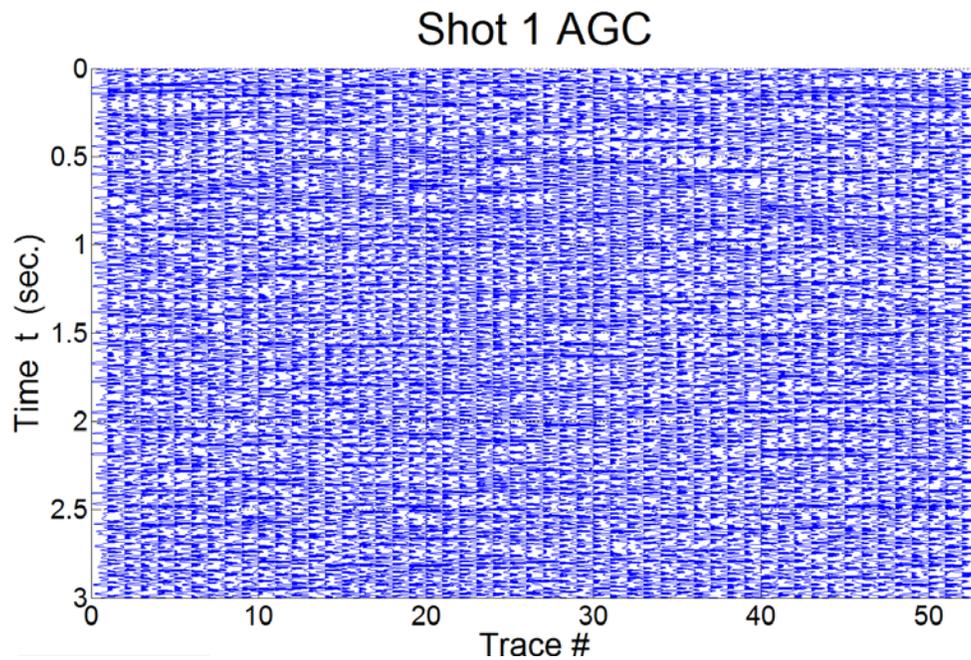
## Shot 1 AGC



Fig. 11: AGC of radially filtered shot #1.
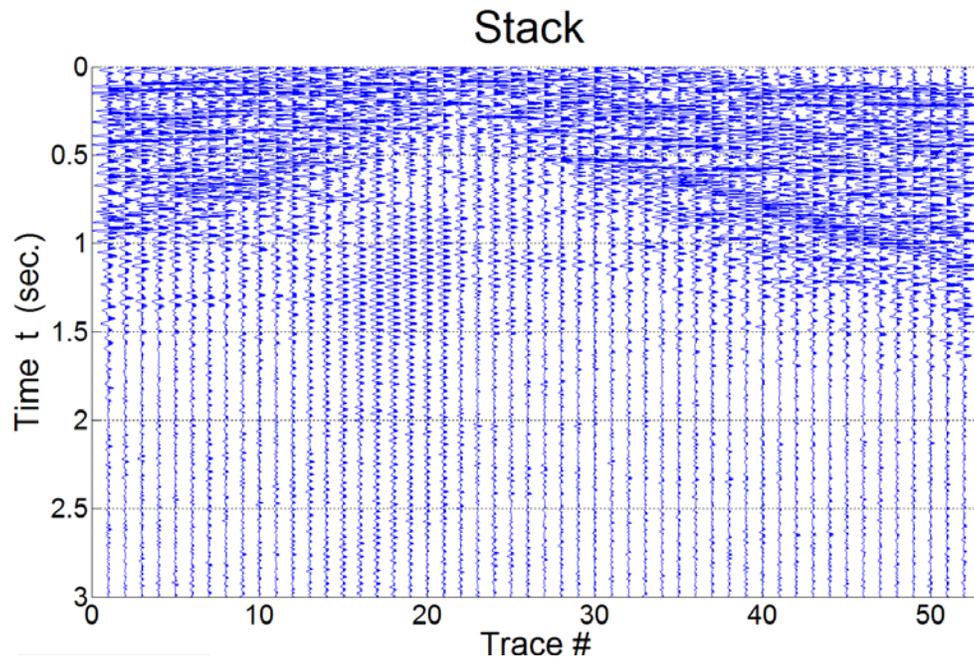
Fig. 12:  Stack of the 100 shots
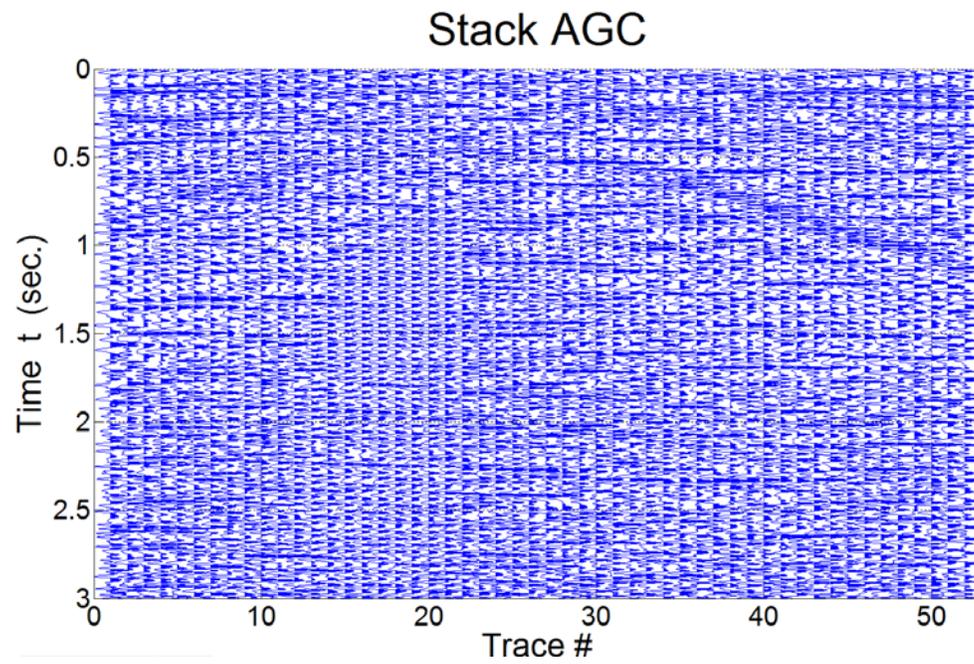


Fig. 13:  AGC of the stacked shot.
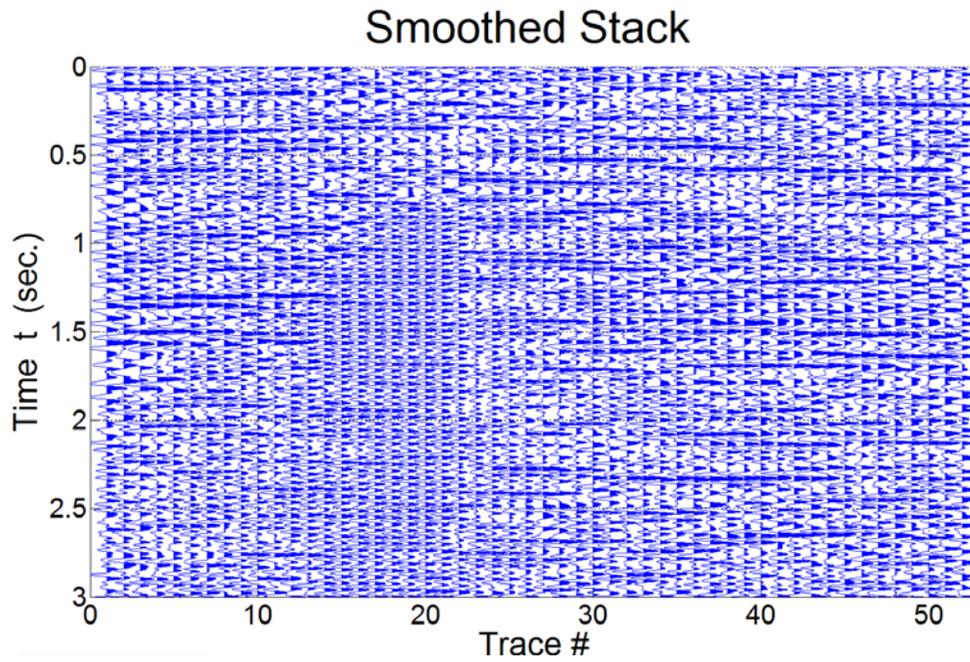
Fig. 14: Smoothed with 20 samples, of the AGC stacked shot.

Smoother = 40
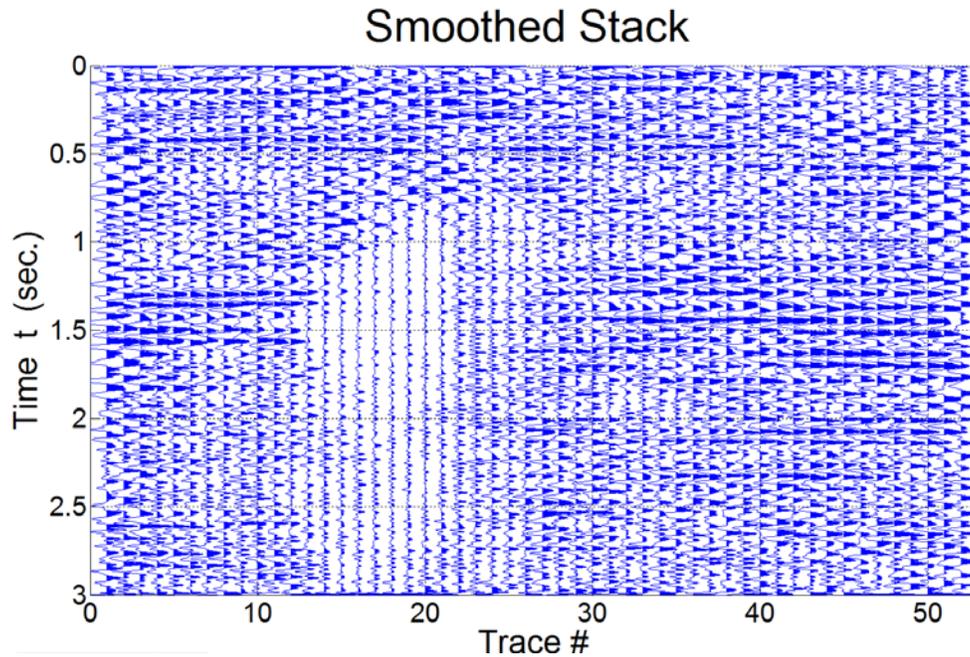


Fig. 15: Smoothed with 40 samples of the AGC stacked shot.

## AGC of smoothed AGC Stack
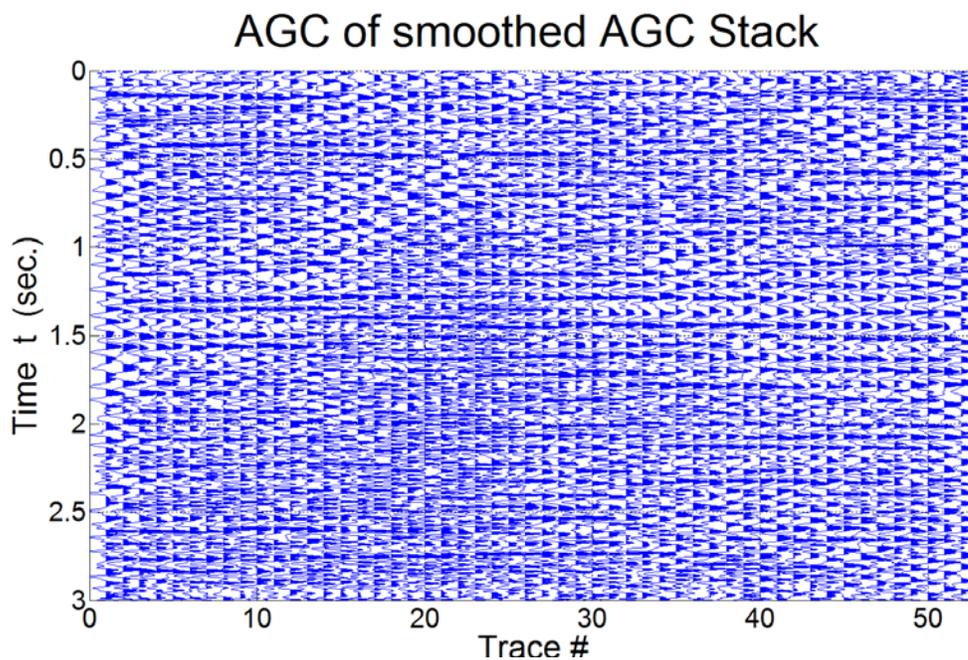


Fig. 16: An AGC of the smoothed data in Fig. 15

## SPECTRAL NOISE ANALYSIS

Each trace in the radially filtered data $D\left(ism,itr,ish\right)$ was Fourier transformed

$$F\left(if,itr,ish\right) = \text{FFT}\left\{D\left(ism,itr,ish\right)\right\} \tag{1}$$

where **ish** is the shot number, **itr** is the trace number in each shot, **ism** is the time sample number, and **if** is the frequency sample number. The average shot spectrum $F_{Stk}$ was found from

$$F_{Stk}\left(if,itr\right) = \frac{1}{Ns}\sum_{ish}F\left(if,itr,ish\right), \tag{2}$$

and the RMS shot spectrum from

$$F_{RMS}\left(if,itr\right) = \sqrt{\frac{1}{N_{shots}}\sum_{ish}\left|F\left(if,itr,ish\right)\right|^2} . \tag{3}$$

These amplitude spectra of the first trace in the respective shot spectra are found in Fig. 17.

An estimate of the shot noise spectrum $F_{noise}$ is found from

$$F_{Noise}\left(if,itr\right)=\left|F_{RMS}\left(if,itr\right)\right|-\left|F_{Stk}\left(if,itr\right)\right|,\qquad(4)$$

allowing an estimate of the SNR of the shot to be found from

$$SNR\left(if,itr\right)=\frac{\left|F_{Stk}\left(if,itr\right)\right|}{F_{Noise}\left(if,itr\right)}.\qquad(5)$$

Figure 18 shows the SNR for the first trace, while Figure 19 shows the SNR for all traces in the shot record.

a) Average amplitude
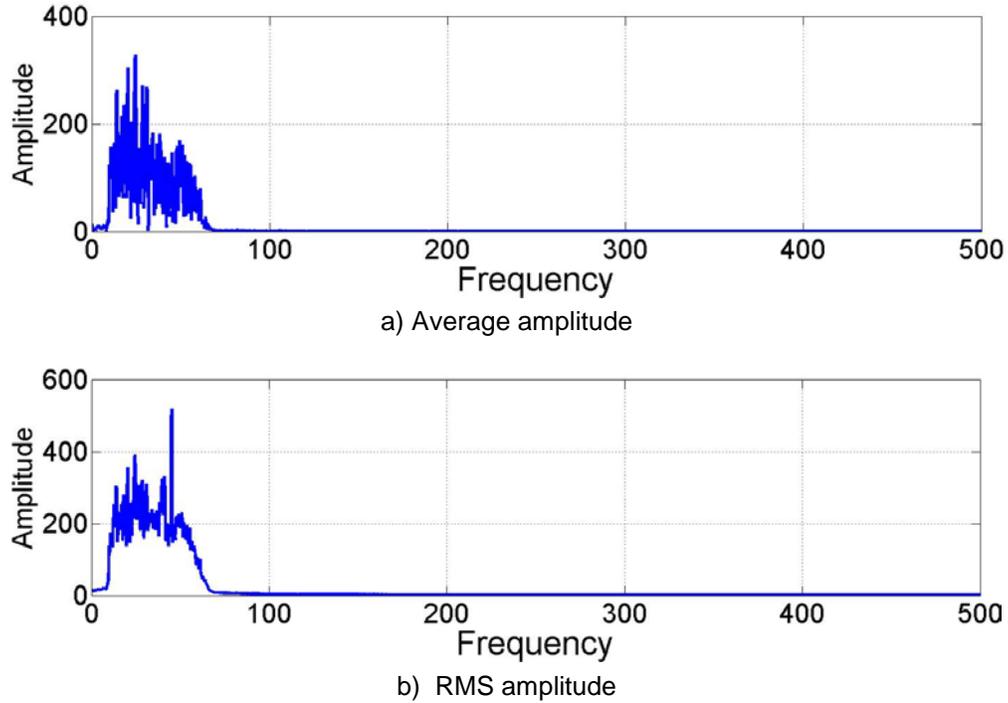
b) RMS amplitude

Fig. 17:  Amplitude spectrum of the first trace a) using the average, and b) the RMS methods.
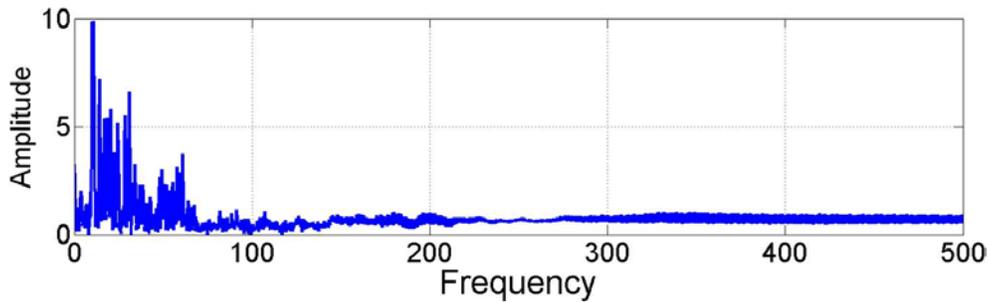
Fig. 18:  SNR of the first trace in the "shot".
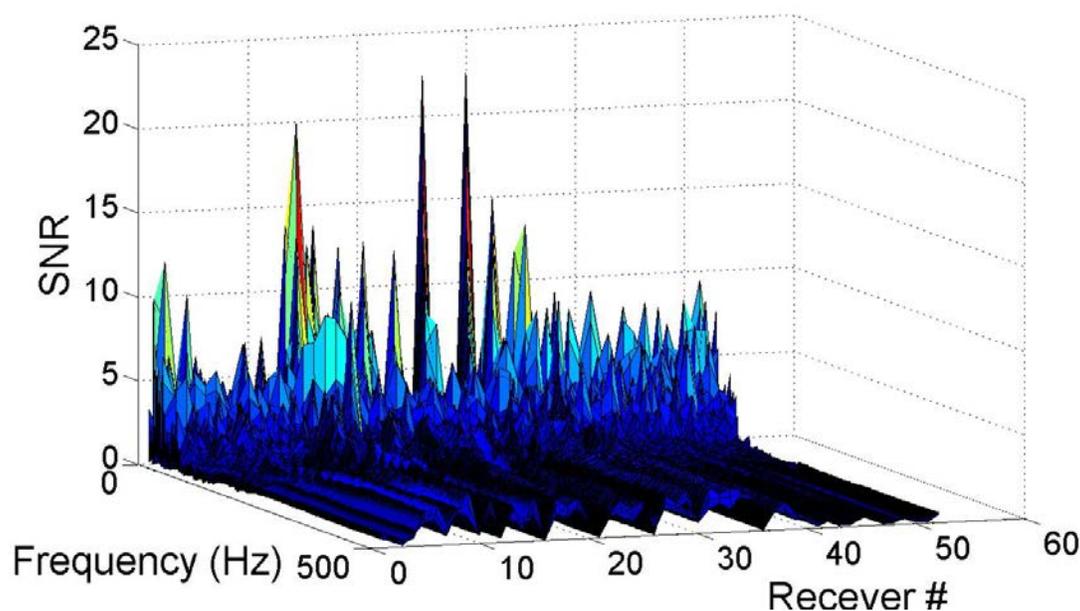
Fig. 19: SNR of all traces in the stacked shot record.

## COMMENTS AND CONCLUSIONS

The 100 shots displayed amplitudes that varied by as much as 10 percent from an average value.

The static for each shot showed unusual variation that was approximately 4 ms. for the first 30 shots, and then seemed to stabilize towards 1 ms. for the remaining shots. A slight low frequency trend may be attributed to the compaction of the surface at the shot point.

The exercise in evaluating noise required the data to be radially filtered. An AGC of the radially filtered data produced data where the noise was relatively constant. Stacking the 100 shots produce a portion of the section with low amplitude indicating that part of the data was predominantly random noise. Lowpass filtering and another AGC revealed coherent energy towards the bottom of the record at 3 sec.

Fourier transforms of the traces in the radial filtered data were stacked using average and RMS methods to estimate a SNR of data. Even though a number of AGCs were required, this test indicated it is possible to obtain a SNR for a given shot location.

## ACKNOWLEDGMENTS