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SPE 1 Data Quicklook report

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May 31, 2011

Disclaimer

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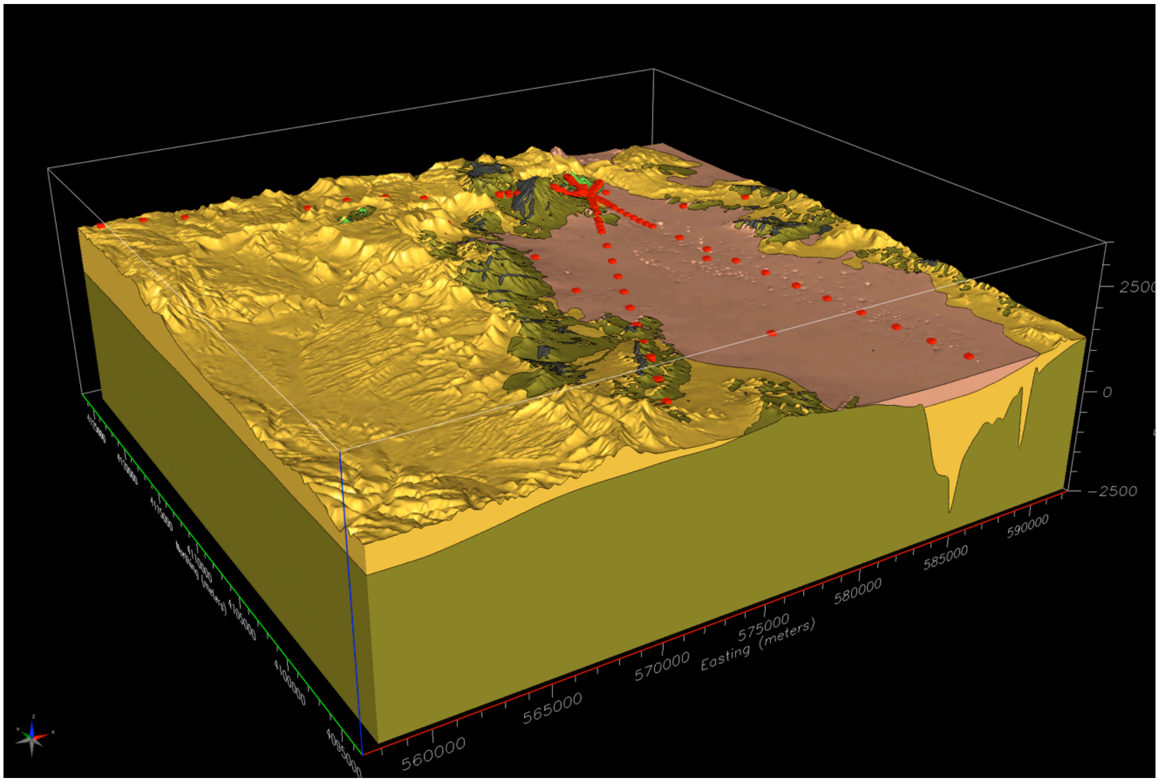
SPE 1 Data* Quicklook report



LLNL SPE Seismic Working Group

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*refers to far-field data

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Summary

The SPE 1 shot was recorded by an extensive set of instrumentation and data return was good. Here we review the far-field data with emphasis on improving data return for the upcoming SPE shots. Initially, the data was checked for instrumentation and metadata problems. Seven sensors appear to malfunctioning, based on data appearance and amplitude. An additional four digitizers may have incorrect channel assignments for the stations. Although not visible on the shot itself, spikes appear periodically in the data and may be related to the solar panel power set-up, although this has not been confirmed.

An assessment of potential clipping for the next shot was carried out with the existing sensor emplacement and rough calculations suggest that clipping appears unlikely. Preliminary comparisons of amplitude versus yield and comparisons with synthetics are shown. A brief discussion of the planned far-field seismic analysis is given.

Instrumentation and data collection review

Pre-shot data analysis. A subset of the instruments (mainly GS11d and S6000) were in place prior to the first shot in two sets of data. One set was on a DVD and the other was continuous data on a portable hard drive. The data was in Reftek format. This was converted to SEGY and then SAC format using the program *ref2segy* and *segy2sac* along with a number of scripts*.* Locations were provided on a spreadsheet and locations of the digitizers were also available from the reftek logs.

A quality check of the data was conducted using the program *clockview* to check GPS timing in the Reftek logs and by examination of the data. Data in the first dataset (Table 1) contained a number of earthquakes (Table 2). The primary problems consisted of bad channels and 'spikes' that occurred intermittently throughout the data. Information about the bad channels was passed on to the installation team.

The origin of the spikes was not as obvious. They appeared to very short in time but were surrounded by smaller amplitude spikes of similar frequency. These smaller spikes resemble the typical response of the DAS anti-alias FIR filters and this suggests that the source is in the signal cable. The best guess is that they are electronic in origin rather than seismic. The timing between spikes was very close to 300 seconds and the spikes were most frequent during the hours of roughly 01-03 GMT and 14-16 GMT. The timing varied with each station and was common across three channels. Overall, this might be caused by the regulator associated with the solar panels and power system, but this remains a guess at this point. While deemed unlikely to interfere with the recording of the shot itself on a large scale, it might present problems for other types of analysis such as ambient noise correlation, which require long time periods of data.

Table 1. Events recorded by pre-shot network.

Name	Date	Lat (N)	Lon (W)	Depth (km)	ML	MT	Time (GMT)
2011041	02/10/2011	38.5337	-118.3776	9.74	3.78	Y	04:55:43.035
2011046	02/15/2011	36.6581	-115.6869	13.42	2.43		11:48:33.227
2011048	02/17/2011	38.4545	-116.4071	0.00	2.30		17:49:08.210
2011026	01/26/2011	38.4913	-117.6524	8.90	3.44		22:29:45.082
2011030**	01/30/2011	*39.2409*	*-120.1134*	*14.86*	*2.28*		*09:36:12.134*
2011039	02/08/2011	37.2559	-117.8335	8.23	3.85	Y	00:28:40.889
2011052	02/21/2011	37.3766	-117.1187	9.56	2.41		00:39:27.981

** uncertain association, weak signal

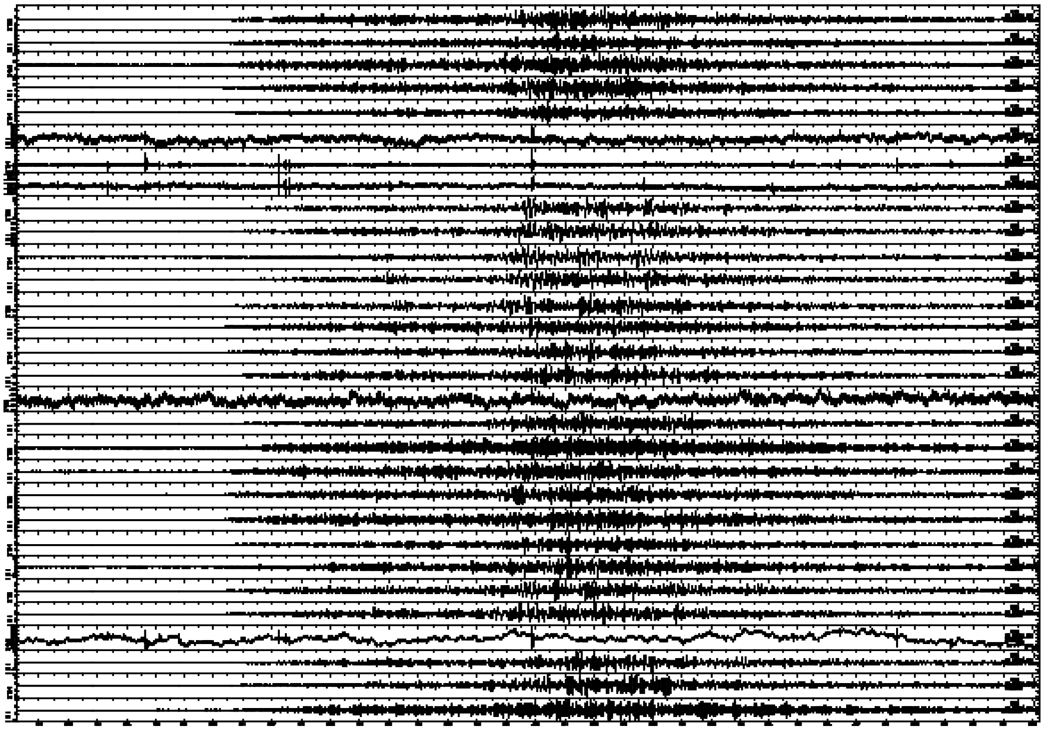

Figure 1. Example earthquake recorded at array.

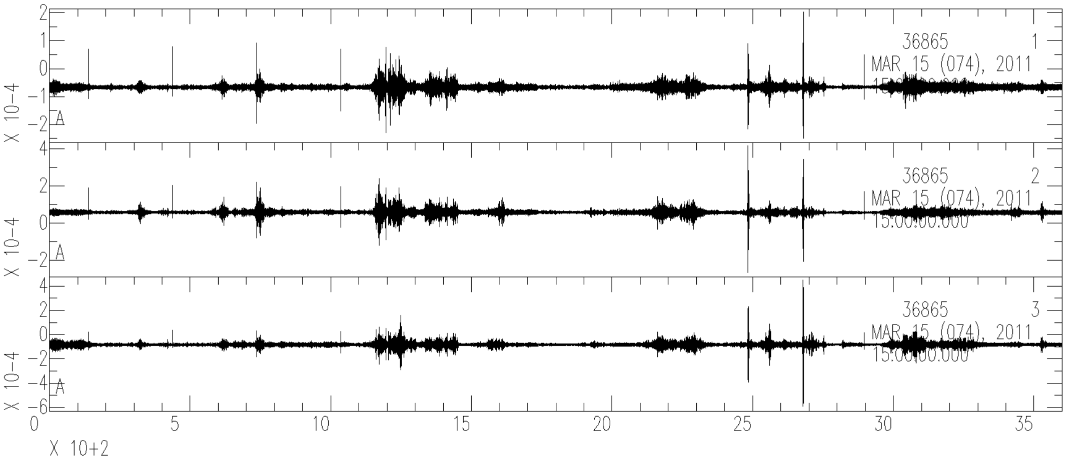

Figure 2. Example of spikes. Note periodicity.

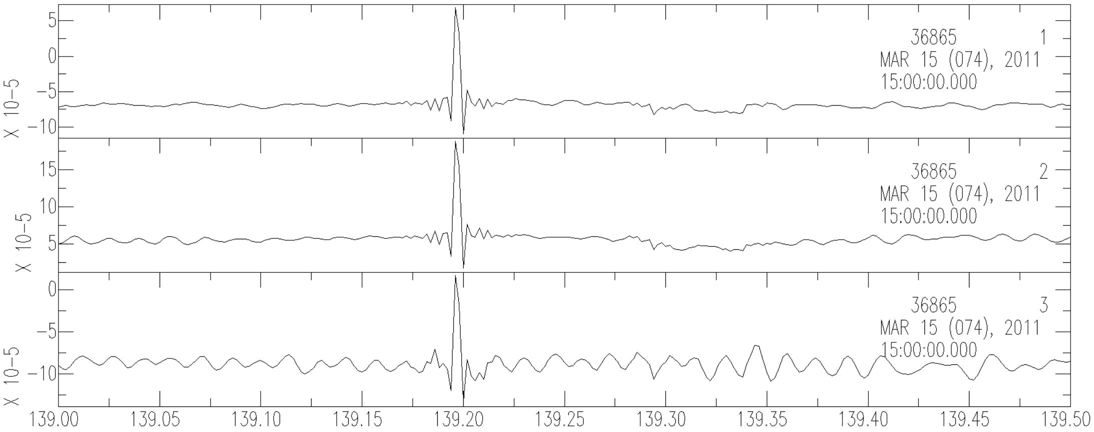

Figure 3. Zoom in spike. Synchronous across channels with ripple before and after.

Shot data review. The shot was on day 123, 2011 at 15:00.0.01137 GMT. The location was at 37.221207, -116.0608674 at a depth of approximately 60 meters. Data was rapidly collected and provided by portable hard drive. Data was also sent to University of Nevada, Reno for re-formatting and construction of metadata. In parallel, data was reformatted into SAC format at LLNL. After completion of the data formatting at UNR and construction of metadata, data including responses was loaded into the database at LLNL.

Initial review of the data revealed that the shot data was mostly good although some problems continued with bad channels, incorrect stations locations (likely due to cable mixups), and apparently non-standard polarity, as the first motion was down at all stations.

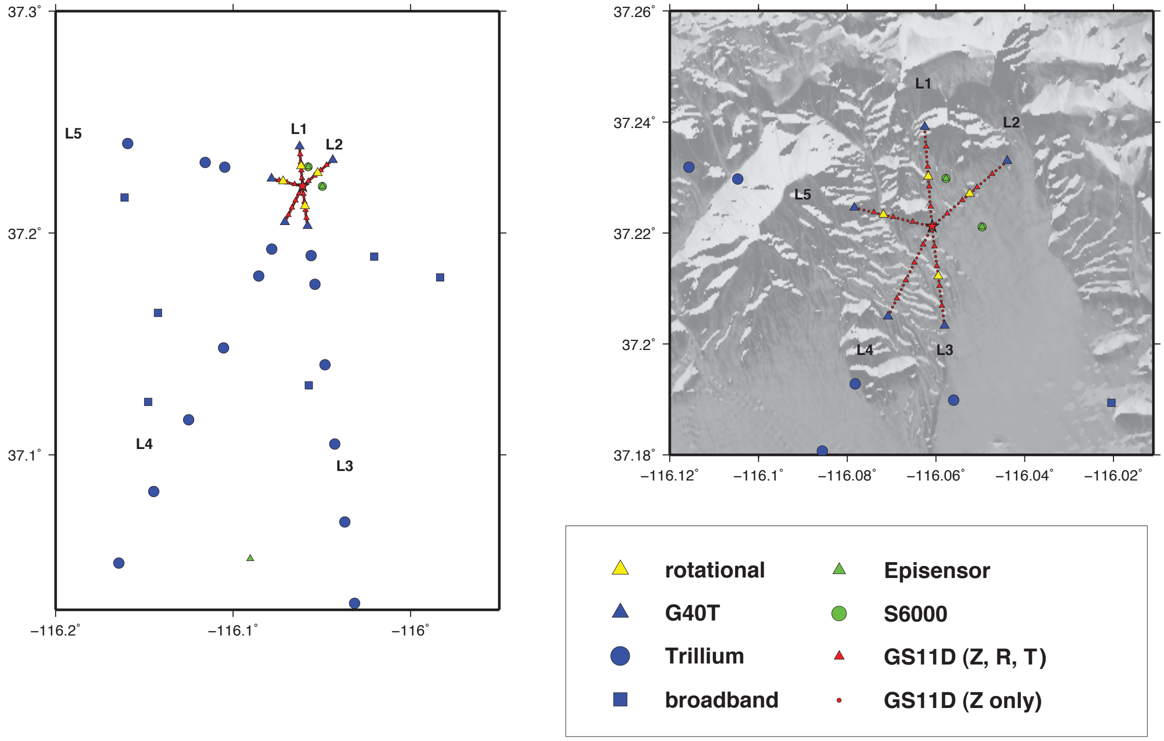

Figure 4. Map of deployment (as of May 5)

This section evaluates the data for moveout consistency and timing. A review of the Reftek logs using *clockview* indicated no significant problems.

Line L1, from station 1 to station 19 is shown below for the GS11D vertical geophones.

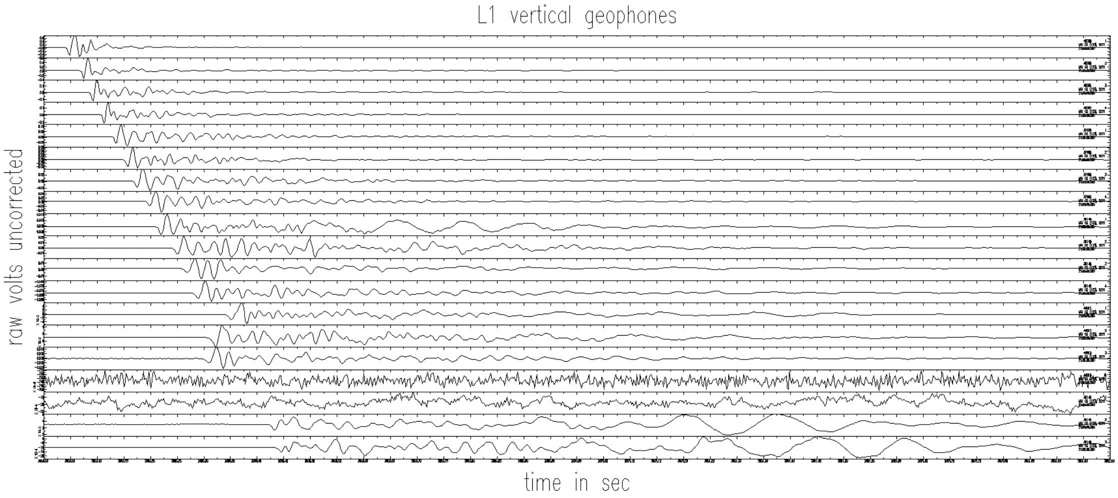

Figure 5. Line L1

We note two moveout problems:

1) probable reversed wiring order on L1-13, L1-14, L1-15
2) bad geophone or cable at L1-16 and L1-17

Line L2, from station 1 to station 19 is shown below for the GS11D vertical geophones.

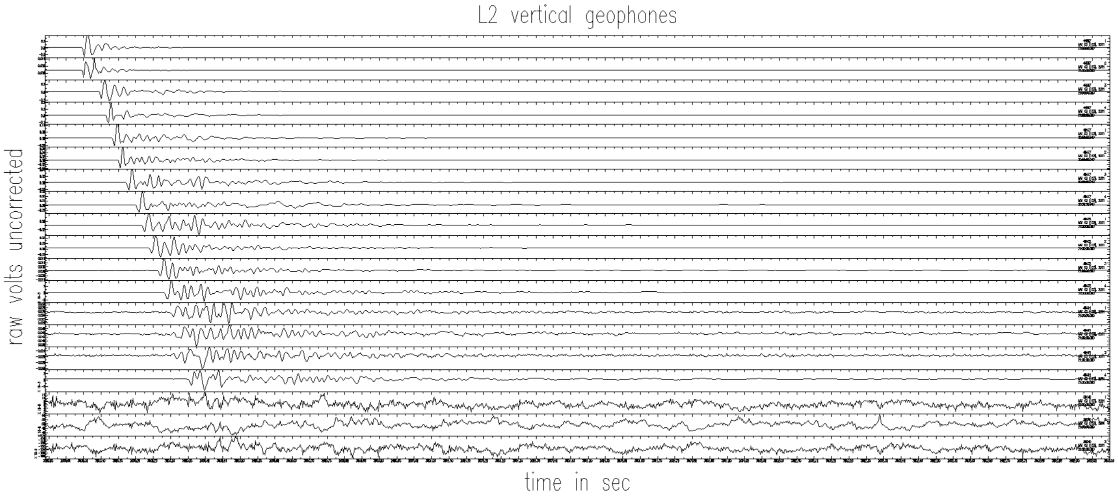

Figure 6. Line L2

We note one moveout problem:

1) no signal on L2-17, L2-18, L2-19, probably a problem at/near the station L-20 recorder (bad connection to Reftek)

Line L3, from station 1 to station 19 is shown below for the GS11D vertical geophones.

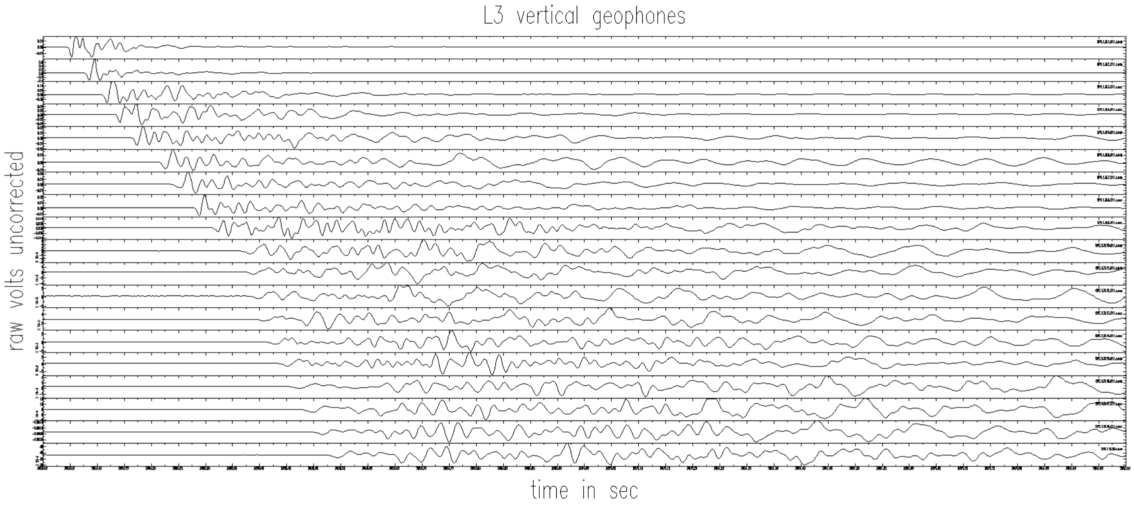

Figure 7. Line L3

We note no moveout problems on L3.

Line L4, from station 1 to station 19 is shown below for the GS11D vertical geophones.

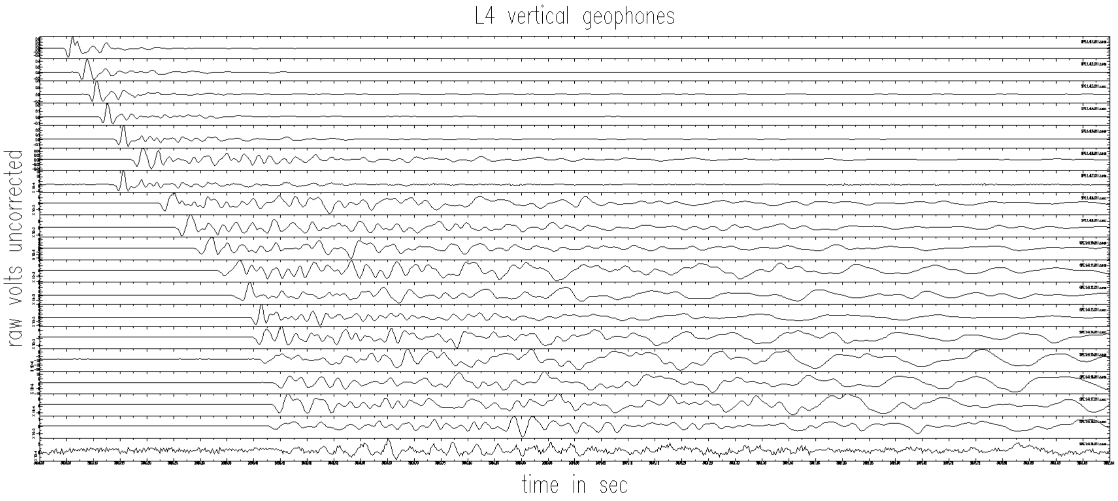

Figure 8. Line L4

We note one moveout problem:

1) probable reversed wiring order on L4-5, L4-6, L4-7

Line L5, from station 1 to station 19 is shown below for the GS11D vertical geophones.

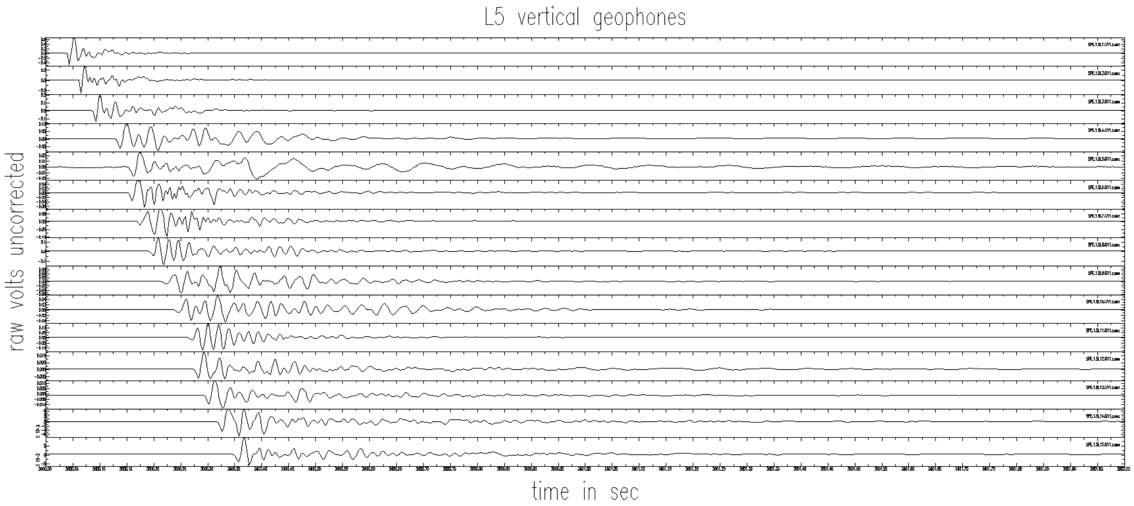

Figure 9. Line L5

We note no moveout problems on L5.

Checking the rings for moveout consistency we see an anomalously slow L3 line. The three plots below show the signal arrivals at the 300m ring, the 1 km ring, and the 2 km ring. Different sensor types and digitizers were used at each ring. Given the different instrumentation, the consistent result, and the lack of timing errors in the Reftek log, this probably reflects a significant difference in the L3 path geology.

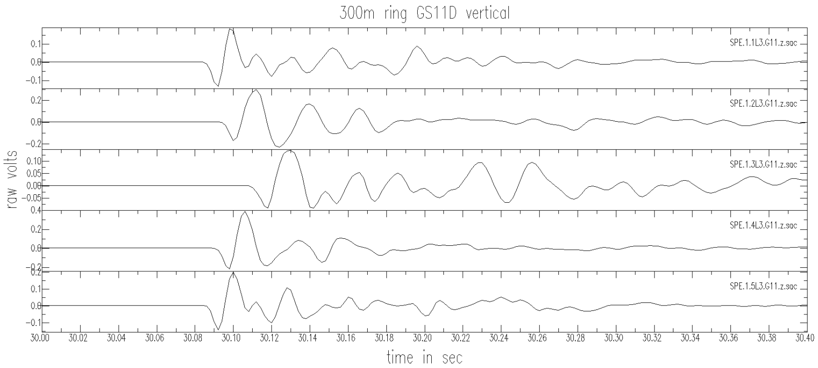

Figure 10. Comparison of moveout across lines (300 m).

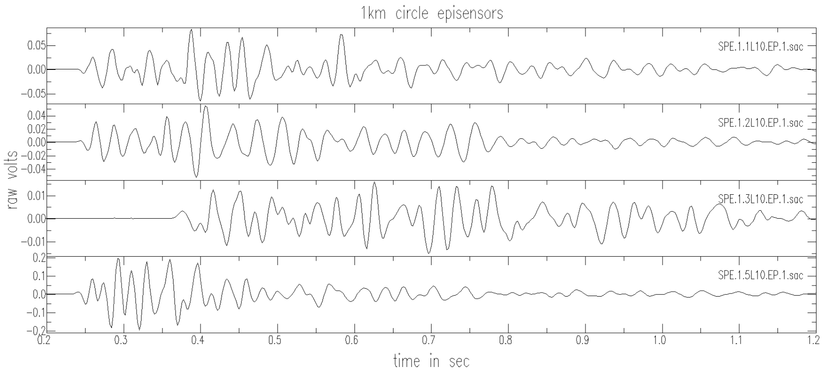

Figure 11. Comparison of moveout (1km)

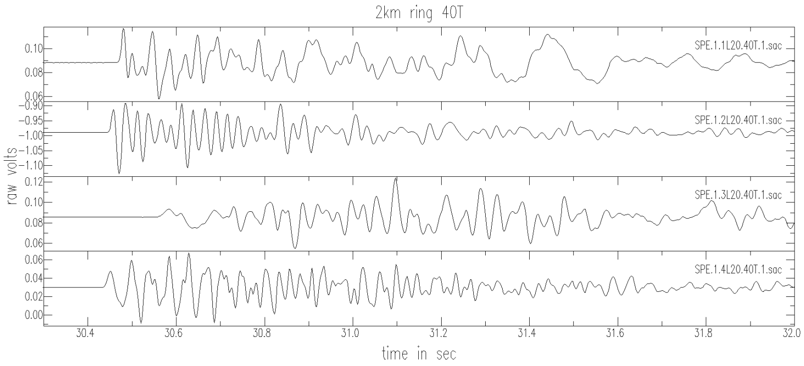

Figure 12. Comparison of moveout (2 km ring)

The moveout for the outer Trilliums on L3 is shown below.

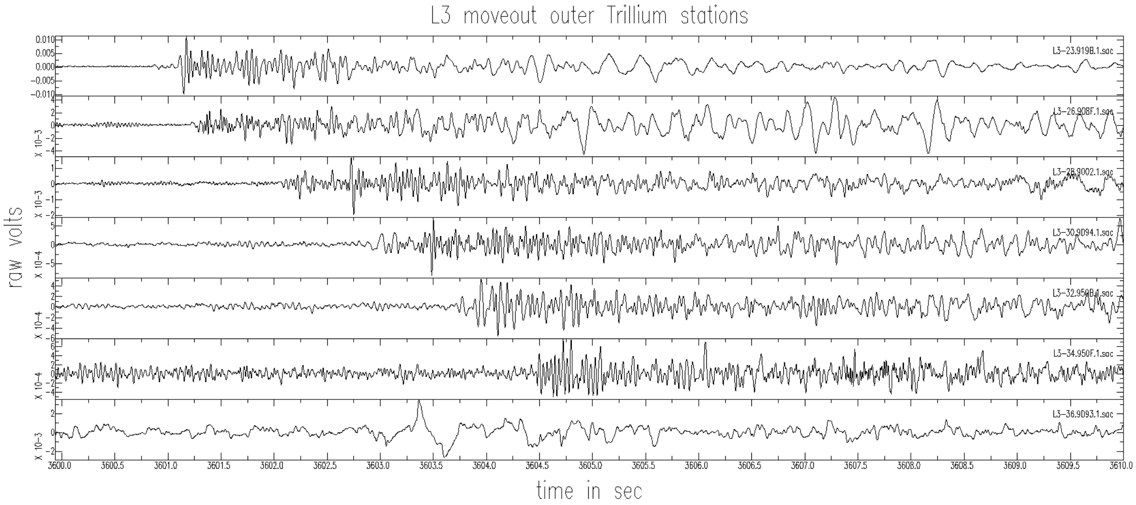

Figure 13. Comparison of moveout (Line 3 Trilliums)

The moveout appears reasonable except the sensor at station L3-36 is not functioning.

The moveout for the outer Trilliums on L4 is shown below.

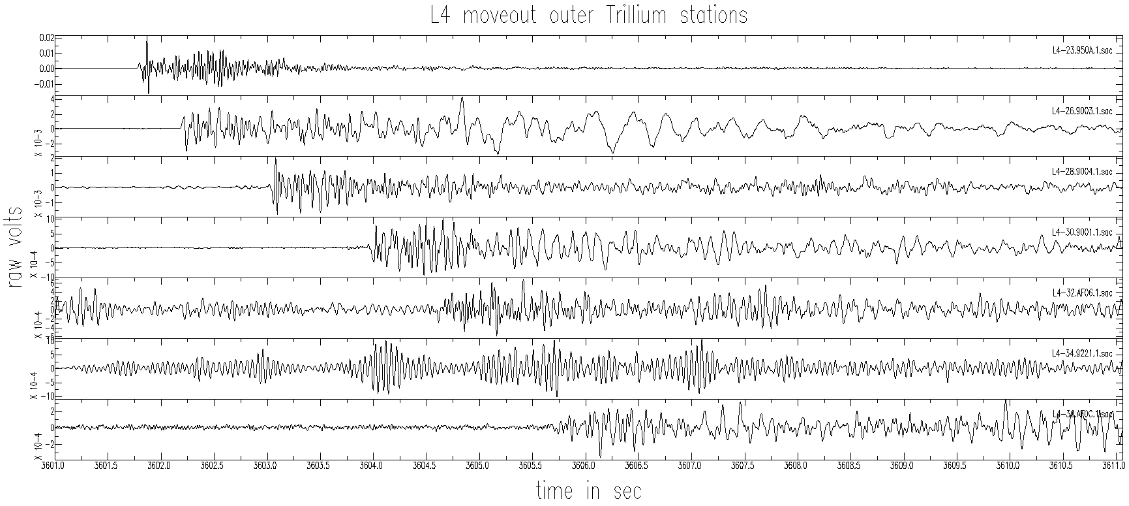

Figure 14. Line 4 Trilliums

The moveout appears reasonable except the sensor at station L4-34 is not functioning.

The moveout for the outer Trilliums on L5 is shown below.

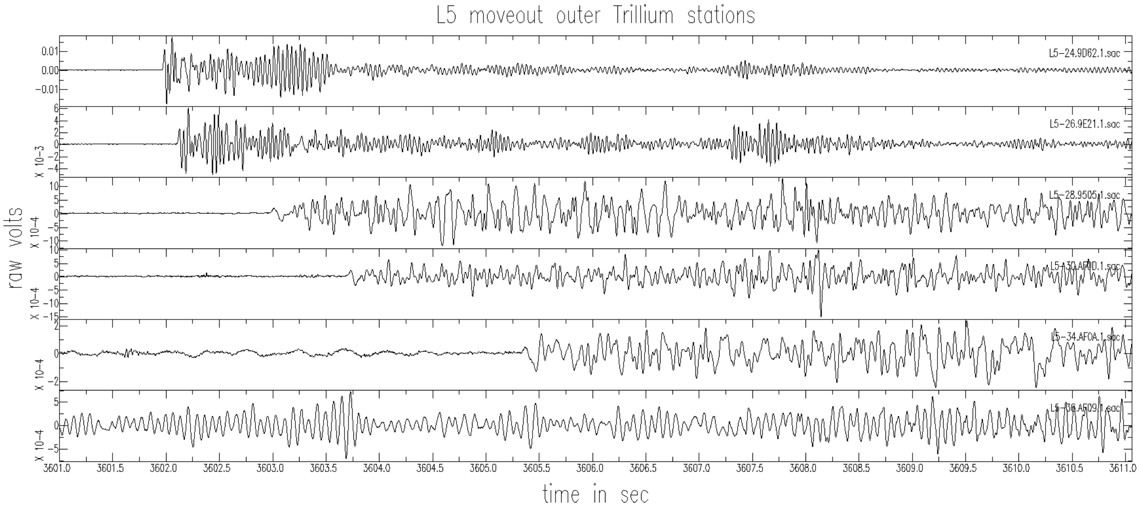

Figure 15. Line 5 Trilliums

The moveout appears reasonable except the sensor at station L5-36 is not functioning.

Preliminary quicklook analysis

Clipping Predictions for SPE2

Clipping on the 1km ring: episensors and rotational seismometers

The 1 km ring was instrumented with episensors and rotational seismometers at 4 stations: L1-10, L2-10, L3-10, and L5-10. The table below shows the R1 amplitudes in raw volts of the peak signal. Note the bad R1 at station L3-10.

Station	Channel	Amplitude (Volts)
L1-10	1	0.0068
	2	0.0057
	3	0.0108
L2-10	1	0.0192
	2	0.0301
	3	0.0224
L3-10	1	----
	2	----
	3	----
L5-10	1	0.0150
	2	0.0305
	3	0.0115

The soft clip level (nonlinear distortion above given value) for the R-1 is 2.0 volts (Nigbor, 2009). The hard (physical) clip level is 2.5 volts. If the SPE2 has a 10x yield, and we conservatively estimate square root scaling of R1 amplitudes, the maximum output would be 0.1 volts, over an order of magnitude below the soft clip level. The sensors can remain in place for SPE2.

The episensors on the 1 km ring have a clip level of 4 g's and will be well below clip level on SPE2.

Clipping on the 100m and 200 m rings: vertical geophones:

Below is the 100 meter ring of GS11D vertical geophones. The y-axis scale is the same for each waveform. Clearly there is a signal amplitude problem with the L3-1 geophone.

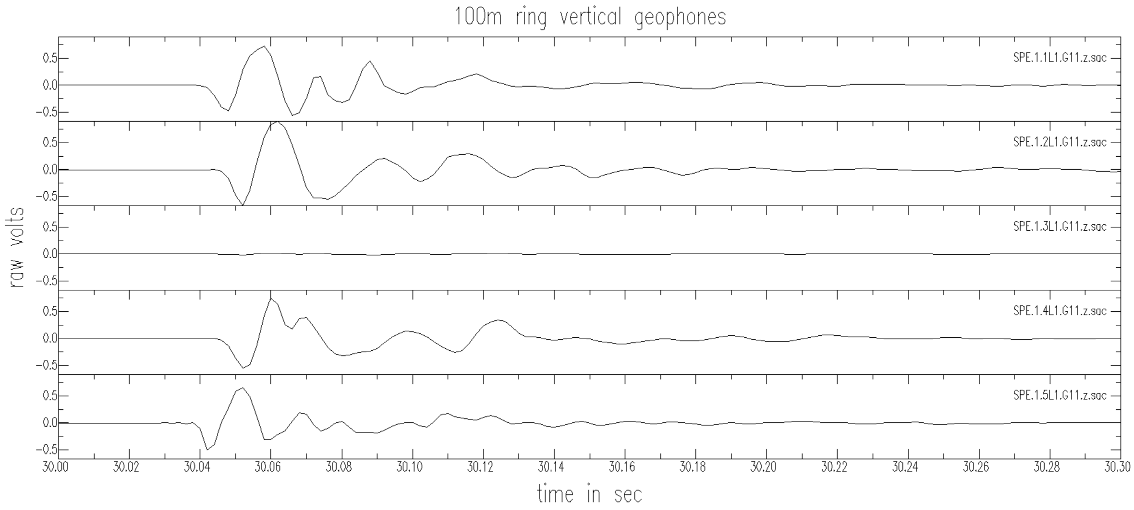

Figure 16. Anomalous geophone.

Below is the 200 meter ring of GS11D vertical geophones. The y-axis scale is the same for each waveform. Clearly there is a signal amplitude problem with the L2-2 station.

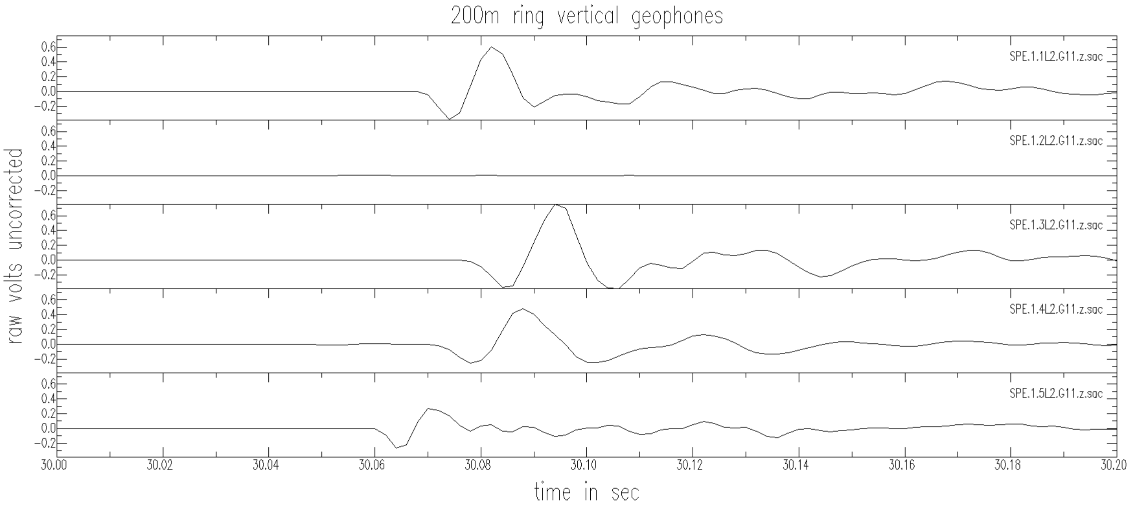

Figure 17. Anomalous geophone.

The table below shows the amplitude in raw volts for 100 m and 200 m ring vertical geophones.

Line	100m ring (volts)	200m ring (volts)
L1	.72	.60
L2	.90	.01
L3	.02	.76
L4	.75	.48
L5	.65	.26

If we look at the dominant frequency, about 50 Hz, and take the GS11D nominal transduction constant of 98.4 volts /m/sec then the largest output in the table (0.9

volts) becomes 9.15 mm/sec velocity. At 50 Hz, this corresponds to a mass displacement of 0.065 mm. The physical clip level of the GS11D (maximum mass excursion from center) is 0.9 mm. If we conservatively assume square root scaling, we expect a mass displacement of about 0.2 mm in SPE2. If we further assume that the dominant frequency will be lower, say 20 Hz, then we can expect a maximum mass displacement in SPE2 of 0.46 mm. If the dominant frequency is 10 Hz, we can expect to be on the fringe of clipping on the 100m ring. It is not likely that clipping will occur in SPE2 at the 100m ring and very unlikely beyond that. The sensors can be left in place for SPE2.

Amplitudes versus expected yield

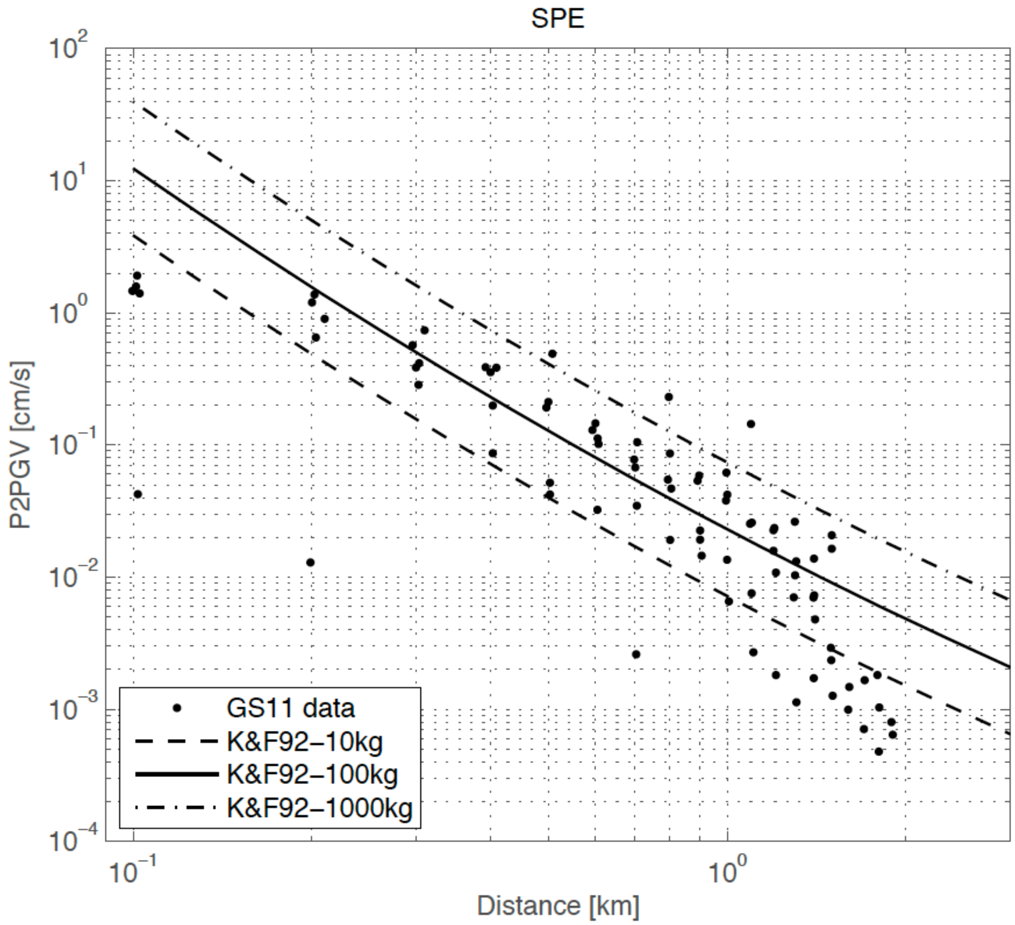

Figure 18. GS11 amplitudes versus distance. Lines indicate expected values for various weights of ANFO (Kohler and Fuis, 1992).

We compare first peak-to-peak particle velocity using a nominal response for the GS11 geophones to the Kohler and Fuis (1992) predictions for three different yields in figure 18. The comparison to the 100kg yield is very good overall but the differences beyond about 1.5 km will need further investigation to understand.

Effect of varying velocities and comparison with synthetics

One of the goals of the experiment is to test the effect of the lateral heterogeneous velocity model and compare with synthetics. Here we show some very preliminary comparisons for stations at equal distance but differing azimuths.

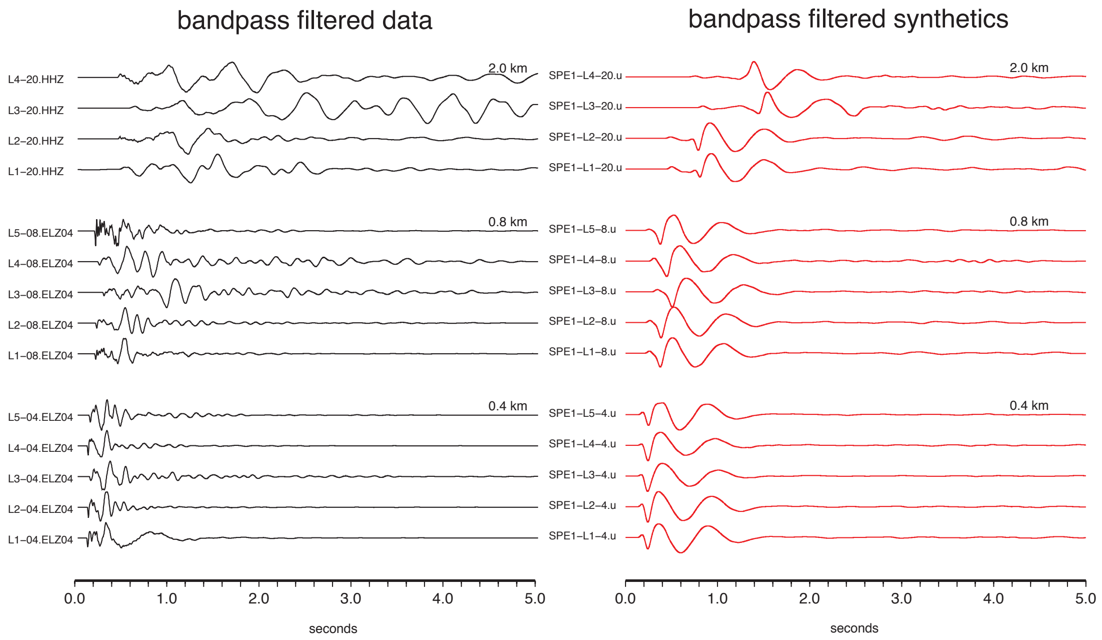

Figure 19. Normalized and bandpassed data (left) with preliminary velocity synthetics (also normalized and filtered). Data have not been corrected for instrument response. In general, relative moveout is similar. Instruments at location 20 (Guralp GT40) have different responses than for location 04 and 05 (geophones).

Planned Far-field Data Analysis

A principle goal for the SPE is to develop a more complete and physics-based understanding of how explosions generate S-waves. Toward this goal, and with appropriate funding, we will be performing a variety of analysis techniques on the far-field seismic data from all of the SPE shots as the data becomes available. In addition we will collect and compare SPE explosion data to local earthquake data from the region. Earthquake data offers a different source mechanism and depth for comparison to the explosions. Improving our understanding of physics-based differences between earthquakes and explosions may lead to new event discrimination techniques potentially improving nuclear explosion monitoring. Earthquake and explosion data from seismic stations deployed during the SPE will be loaded into the LLNL database, along with appropriate metadata, where we can take advantage of a number of software analysis tools we have previously developed.

Rotational seismometer data analysis

Analysis of the rotational-seismometer data for explosions is a new frontier. Rotational seismograms will be compared from station-to-station and between SPE shots. Rotational data will also be used in conjunction with conventional seismometers to better characterize the seismic wave field.

Measuring P and S wave spectra, amplitudes and P/S ratios

Arguably the most pressing research issue concerning the generation of S-waves from explosions is the frequency dependence of explosion S-wave signals. The ratio of regionally recorded P-wave to S-wave energy is typically used to discriminate explosions from earthquakes, but the effectiveness of this method is dependent on frequency. Lower frequencies commonly contain the highest signal-to-noise portion of the spectrum for regional recordings, but the P- to S-ratio usually only discriminates between earthquakes and explosion at higher frequencies (>~4 Hz). We will use our in-house database tool RBAP (Regional Body-Wave Amplitude Program) to measure body wave amplitudes. We will then evaluate those amplitudes to elucidate source behavior. We will also compare to earthquake and explosion spectral models. One of the outcomes of the SPE is intended to be an improved P- and S-wave explosion spectral model that can be used in explosion monitoring for a much wider range of geologies and emplacement conditions than what is currently available.

Surface wave amplitudes

Surface waves are believed to contribute to S-waves from explosions through scattering (e.g. Myers et al. 1999). Surface waves also play a key role in the Ms:mb discriminant. We will make use of our database software tool SWAP (Surface-Wave Amplitude Program) to measure surface wave amplitudes and timing of surface-wave group arrivals.

Cross-correlation and accurate location analysis

Correlating waveforms for each of the SPE shots will be used to determine extremely precise relative arrival times. Location estimates with precision on the order of 100 m are possible with this type of analysis. The known location of the PSE shots enables the testing and evaluation of new small event sparse station location algorithms important for explosion monitoring. Waveform correlation will also be useful for quantifying differences in the far-field signals for the SPE shots.

Comparison to synthetic data

The larger research question is the relative contribution of each S-wave generation mechanism and whether that contribution can be quantitatively predicted. In preparation for the SPE shots we created synthetic seismograms described in the report by *Rodgers et al.* (2010). We will compare data and synthetics and work to improve both the source model and the path model. The source model work will be done in close collaboration with the Near-field modeling (described by Antoun et al., manuscript in preparation). The path model will make use of the earthquake data as well to refine the geological boundaries and properties (e.g. velocity, density, attenuation) to improve the match of the synthetics and data. It is by matching data that we ultimately can improve and validate our physics-based source and path models.

Comparison to historic data

The far-field (and near field) measurements will be readily comparable to any other seismic source. Part of the effort we would like to eventually undertake will be to locate, digitize, and load seismic recording of the Pile Driver and Hard Hat nuclear explosions, and compare the nuclear and chemical shots. To improve nuclear explosion monitoring we need to tie our chemical results back to nuclear data and tests.

Remote-sensing data

We are exploring the use of remote sensing data (e.g. hyperspectral and radar data) to characterize the effects of the shot on the ground surface and to improve understanding of the source with independent constraints.

Conclusions and recommendations for SPE2

Field Recommendations

- Rotational sensor on L3-10 is not functioning, replace sensor.

- Bad amplitude for L3-1 vertical geophone.

- Bad amplitude for L2-2 geophone.

- Check wiring order on digitizer, channels 1-3, station L1-16. Suspect that order is reversed.

- Check GS11D geophones at station L1-16 (channel 4) and L1-17 (channel 1). Suspect that geophones or cables failed.

- Check channels 1-3 on L-20 recorder. Suspect cable/connector problem or problem with Reftek on channels 1-3.

- Check wiring order on L4-8 digitizer. Suspect wiring order reversal, channels 1-3.

- Check Trillium seismometer at station at L3-36 for functionality

- Check Trillium seismometer at station at L4-34 for functionality

- Check Trillium seismometer at station at L5-36 for functionality

- Provide information to map each Reftek channel to locations in spreadsheet (locations were provided but it was not clear how which channels corresponded to which channels where a single Reftek recorded adjacent stations).

- Identify source of ‘spikes’ (possibly by changing solar panel setup) and correct, if possible.

Acknowledgements

We thank all who participated in the field deployment for their work and patient response to our questions. Robert White, Robert Abbott, and Catherine Snelson-Gerlichter were particularly helpful. The UNR group led by Ken Smith deserves praise for rapid data processing.

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Rodgers, A. J., J. Wagoner, N. A. Petersson, and B. Sjogreen, Preliminary pre-shot simulations of far-field ground motions for the Source Physics Experiment (SPE) explosions at the Climax Stock, Nevada National Security Site.

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