S43A-2210 - Explosion Geophysics II Posters - 1:40 to 6:00 pm

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The Effects of Heterogeneities on Seismic Wave Propagation in the Climax Stock

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Abstract

The Comprehensive Nuclear Test-Ban Treaty requires the ability to detect low-yield (less than 150kton) nuclear events. This kind of monitoring can only be done seismically on a regional scale (within 2000km). At this level, it is difficult to distinguish between low-yield nuclear events and non-nuclear events of similar magnitude. In order to confidently identify a nuclear event, a more detailed understanding of nuclear seismic sources is needed. In particular, it is important to know the effects of local geology on the seismic signal. This study focuses on P-wave velocity in heterogeneous granitoid. The Source Physics Experiment (SPE) is currently performing low-yield tests with chemical explosives at the Nevada National Security Site (NNSS). The exact test site was chosen to be in the Climax Stock, a cretaceous granodiorite and quartz-monzonite pluton located in Area 15 of the NNSS. It has been used in the past for the Hard Hat and Pile Driver nuclear tests, which provided legacy data that can be used to simulate wave propagation. The Climax Stock was originally chosen as the site of the SPE partly because of its assumed homogeneity. It has since been discovered that the area of the stock where the SPE tests are being performed contains a perched water table. In addition, the stock is known to contain an extensive network of faults, joints, and fractures, but the exact effect of these structural features on seismic wave velocity is not fully understood. The SPE tests are designed to seismically capture the explosion phenomena from the near- to the far-field transition of the seismic waveform. In the first SPE experiment, 100kg of chemical explosives were set off at a depth of 55m. The blast was recorded with an array of sensors and diagnostics, including accelerometers, geophones, rotational sensors, short-period and broadband seismic sensors, Continuous Reflectometry for Radius vs. Time Experiment, Time of Arrival, Velocity of Detonation, and infrasound sensors. The focus of this study is two-fold: (1) the geophone array that was focused over the SPE shot and (2) a high-resolution seismic profile that was recently acquired at the field site. The geophone array was placed radially around the SPE shot in five directions with 100m spacing and out to a distance of 2 km. The high-resolution profile was about 475m in length with station and shot spacing of 5m using a 7000lb mini-vibe as a source. In both data sets, the first arrivals will be used to develop velocity models. For the geophone array, 1-D P-wave velocity models will be developed to determine an average apparent velocity of the Climax Stock. The high-resolution data will be used to develop a 2-D P-wave velocity model along the seismic profile. This is in an effort to elucidate the water table in more detail and provide additional information on the near-surface structure. These results will be used in the overall modeling effort to fully characterize the test bed and develop a physics-based model to simulate seismic energy from the SPE events.

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Introduction

The Source Physics Experiment (SPE) was created to develop methods of detecting low-yield nuclear tests. This is a necessary step towards the U.S. ability to uphold the CTBT (Comprehensive Nuclear Test-Ban Treaty), should it become ratified. The CTBTO (Comprehensive Nuclear Test-Ban Treaty Organization) can currently detect high-yield nuclear tests at teleseismic distances, but regional detection of low-yield tests is undeveloped. In transitioning from the far field to the near field, the seismic signal becomes substantially more complex. The detection of lower yield events introduces a decrease in the signal to noise ratio, as the frequency of background events (such as minor earthquakes and mining explosions) increases. One aim of the SPE is to better understand the physical processes involved when an explosion generates a seismic signal, and move understanding beyond empirical evidence and into a physical base (Brunish et al., 2010). Of particular interest are the effects of geological setting, coupling, and S-wave generation (Figure 1).

This project utilizes seismic data recently acquired from the SPE site (Figure 2). One data set was acquired in May 2011 from a HE shot of 100 kg at 60 m depth. These data were recorded on a series of recorders, but this project uses the geophone data that were acquired. The entire data set are primarily being used by the collaborative effort to understand the coupling between the near and far-field seismic data. The second data set was acquired in April 2011 using a mini-vibroseis source and 3-component geophones along a profile parallel to the SPE test bed. This survey was conducted to understand the variation in the weathered layer as well as the water table. Overall, this project intends to further the characterization of the SPE test bed to be utilized by the modelers in the SPE project.

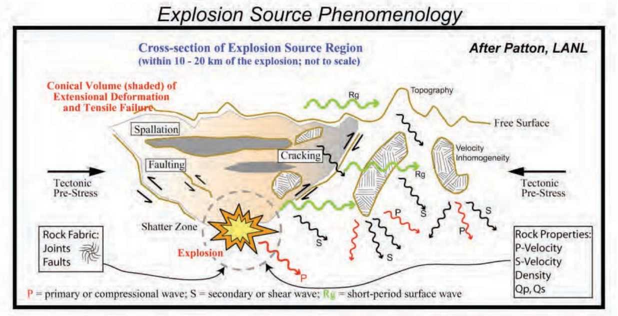

Figure 1. Schematic of the source region. Characterization of the test bed is imparative to discern the the differences in the character of the waveforms generated from the seismic source.

Figure 2. Aerial view of the SPE test bed in Area 15 at the NNSS.

Geologic Setting

The SPE site is located in Area 15 of the Nevada National Security Site (NNSS), which is located in the Mojave Desert in southern Nevada within the Basin and Range (Figure 3). During the Precambrian and into the Paleozoic era, marine sediment was laid down in the region (Ekren et al., 1968). In the late Mesosoic, an orogeny caused uplift and erosion, followed by folding, thrust faulting, and strike-slip faulting (Winograd and Thordarson, 1975). Later in the Mesosoic, three granitic intrusions occurred, two of which, the Climax and Twinridge stocks, are believed to be connected at depth (Maldonado, 1977). The Climax Stock intruded into the Pogonip group of Ordivician limestone, dolomite, and shale (Maldonado, 1977). During the Tertiary, rhyolitic volcanism covered much of the region with thousands of feet of ash-flow and ash-fall tuff (Wilder and Yow, 1984). Approximately 17 mya, a north- striking normal fault system initiated and cut through the Climax stock during Basin and Range extension; this is when Yucca fault formed (Ekren et al., 1968). More recently, high angle normal faults formed, probably due to subsidence in the Yucca Flat area (Hinrichs, 1968).

The Climax stock is a cretaceous pluton of quartz monzonite and granodiorite where the SPE test bed is set. The contact between these two compositions is thought to be nearly vertical (Orkild et al., 1983). The pluton formed approximately 100 mya (Orkild et al., 1983). The outcrop spans about 4 square km, and the size of the stock increases with depth; it is known to reach at least 100 km2 at depths of several km (Wilder and Yow, 1984). Drilling has revealed perched water tables in the stock at depths between 30 and 244 m. (Orkild et al., 1983). There are three major faults in the Climax Stock area: the Boundary Fault on the South East, the Tippinip Fault on the West, and the North-striking Yucca Fault (Wilder and Yow, 1984). Eight prominent joint sets have been identified (Wilder and Yow, 1984). The uppermost part of the stock has been weathered down to a depth between 8 and 46m (Orkild et al., 1983).

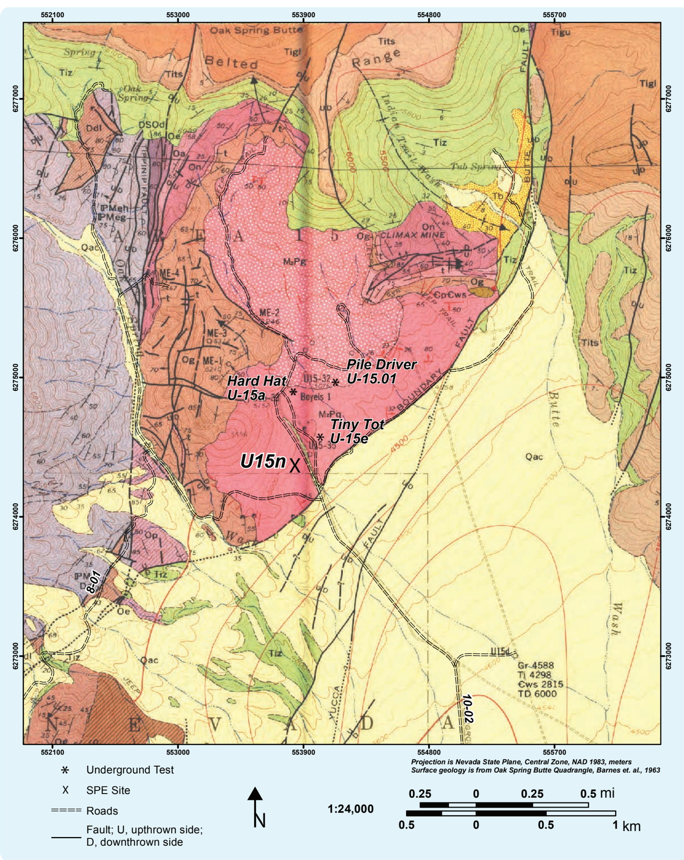

Figure 3. Geologic map of the SPE site (X). Previous nuclear tests are located (*). Pink colors are the granite.

Previous Work

From 1962 to 1966, three nuclear tests were performed in the Climax stock, providing legacy data that were used to determine the current study location (Figure 3). The Hard Hat, Tiny Tot, and Pile Driver tests revealed that these nuclear tests generated S-waves. The exact mechanism for this has yet to be determined, although it is hypothesized that the activation of faults in the vicinity of the test could be the cause.

The SPE test bed has been characterized using a high-resolution seismic refraction survey, which indicated the base of the weathered layer at about 23 m. In addition, geophysical logs were acquired in the GZ (ground zero) hole as well as the 6 instrumentation holes (Figure 4). Core was acquired from the GZ and has been used for materials testing to determine physical properties of the granite. Fracture analysis was conducted to determine the preferential orientation of the fracture sets within the granite. While this work was being conducted, a perched water table was discovered within the Stock. The fractures and water led to the high-resolution mini-vibe survey, which is the focus of this study.

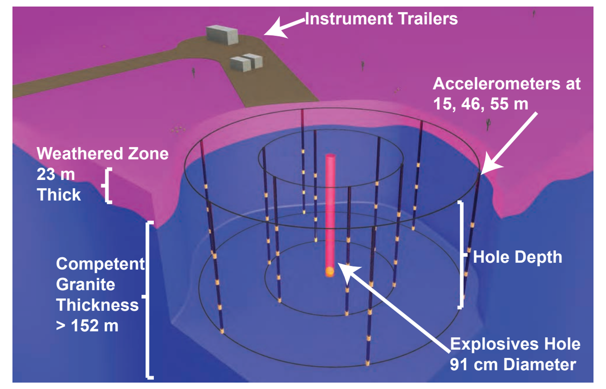

Figure 4. Cartoon of the SPE test bed layout. The red line is the GZ and the black line are the down hole accelerometer instrumentation holes. This diagram shows the thickness of the weathered zone as defined by the previous refraction survey.

Data & Methods

High-resolution seismic characterization
A mini-vibe survey was conducted to further characterize the SPE test bed (Figure 5). This was conducted to further define the water table boundary and weathered layer. In addition, the data acquired was 9-component, which is to be processed by Sandia National Laboratories to further understand the anisotropy within the Stock. The details of the survey are described in Table 1.

SPE – Source Physics Experiment
The SPE is designed to understand the formation of S-waves at the explosive source and how those waves propagate from the near-field into the far-field. A 3-component geophone array was deployed in 5 radials from GZ at 100 m station spacing (Figure 6). Details of the survey are described in Table 2.

Processing
These data were processed in SPW (Seismic Processing Workshop) and modeled using MacRay and MacR1D (Table 3). The data for both surveys had high signal-to-noise (Figures 7 & 8). First arrival picking was conducted on both data sets (Figure 7).

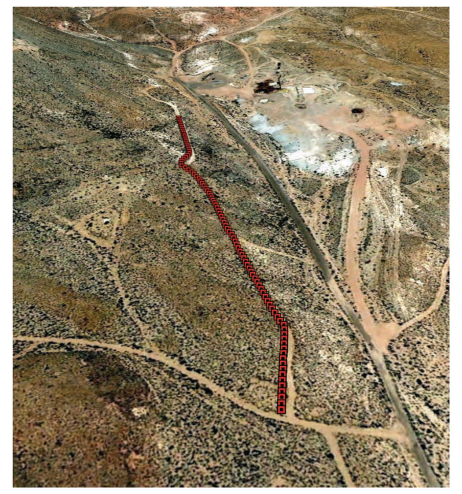

Figure 5. Google map image of the mini-vibe survey location.

Source	7000lb MiniVibe
Source Location	Climax Stock, Area 15
Date	3/17/11-3/24/11
Time Delay of Source	23.1msec
Depth of source	surface
Receiver	96 geophones
Receiver location	475m line with 5m spacing of geophones
Pros	Minivibe source provides shots in both directions to determine slope, and actual velocity profile. Closer spacing means higher resolution, ability to detect variations in stock and water table
Cons	Smaller range of data, data set has lower signal/noise ratio due to nearby drilling

Table 1. Parameters of the mini-vibe survey.

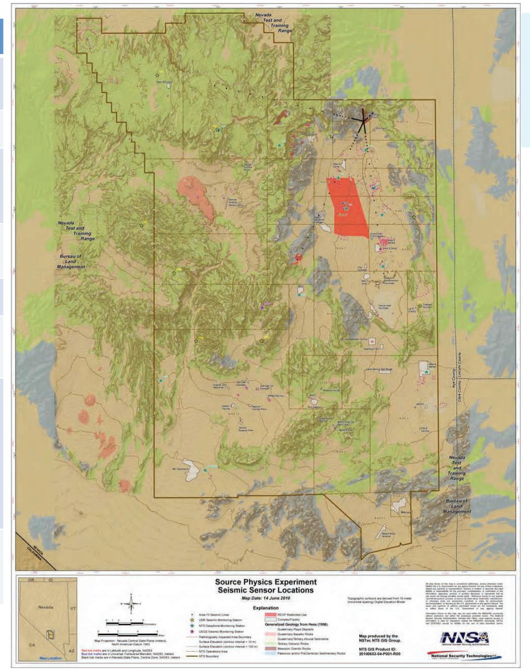

Figure 6. GIS map of the SPE seismic array.

Source	SPE1: 100kg TNT equivalent of chemical Explosives
Source Location	Climax Stock, Area 15
Date	May 2011
Depth of source	55m
Receiver	≈ 96 geophones
Receiver location	4 2km lines and 1 1.6 km line extending radially from ground zero, 100m spacing between sensors
Pros	Long range of sensors, get velocity average of entire stock
Cons	Low resolution, only one shot direction; cannot determine slope, only apparent velocity

Table 2. Parameters of the SPE experiment.

Program	SPW	MacR1D	MacRay
Use	Pick first arrivals in refraction data	Create 1D velocity model of Climax Stock	Create 2D Velocity model of Climax Stock
Data Set Used	SPE1 and MiniVibe	SPE1	MiniVibe
Method	Pick first peak in signal (AGC 300 ms)	Forward model P-wave velocities, compare generated travel-time curve to picked data	Forward model P-wave velocities and positions of layers, compare generated travel-time curve to picked data

Table 3. Parameters for processing and modeling of data.

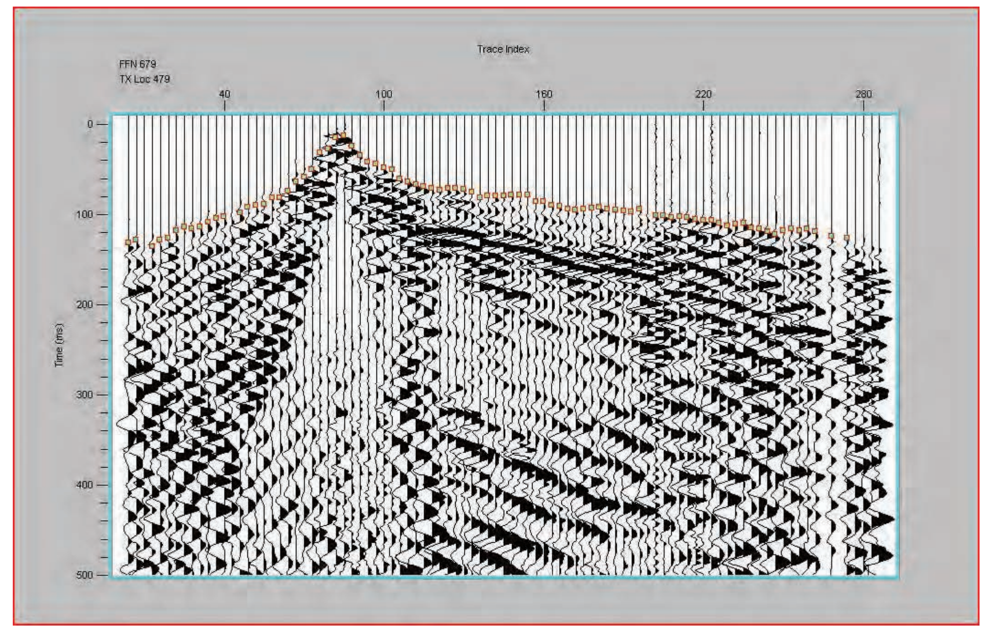

Figure 7. Seismic record section from the mini-vibe survey with first arrival picks overlain.

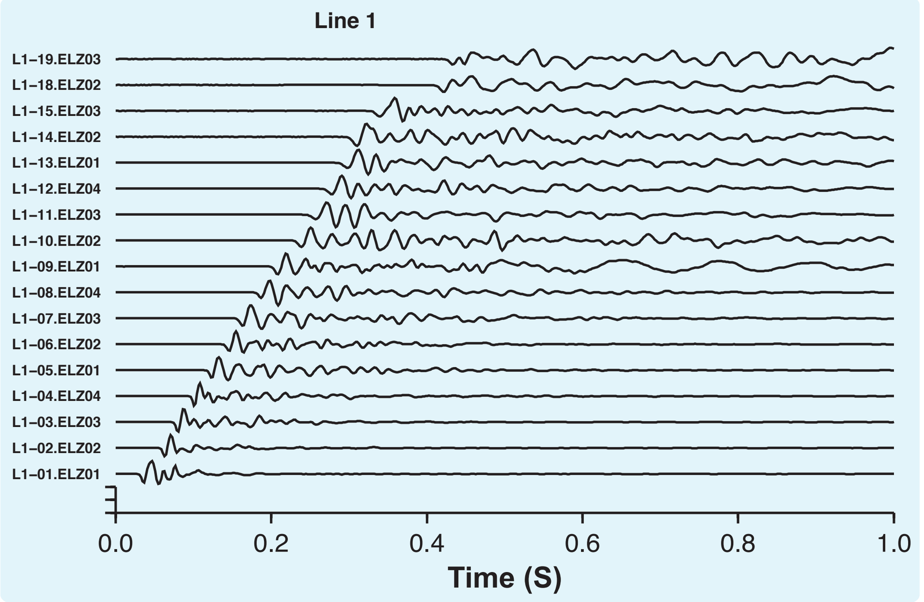

Figure 8. Seismic record section from the SPE geophone array Line 1

Results

2-D P-wave velocity model
Three distinct layers were modeled with these data (Figures 9 & 10). The weathered layer ranges in velocity from 0.8 to 1.5 km/s; the perched water table ranges in velocity from 2.2 to 2.5 km/s; and the fractured granite ranges in velocity from 4.0 to 4.5 km/s. The water table does not appear to be pervasive throughout the model and it is suggested that there is a structure that impedes the flow of water at about 200 m within the model.

1-D P-wave velocity model
As the SPE-1 were un-reversed, it was not possible to develop 2-D models for the profiles. As a result, a 1-D generalized model was developed for the gross P-wave velocity. The model shows an interface at about 60 m with velocities ranging from 4.1 to 5.0 km/s and an interface at 300 m with velocities ranging from 5.0 to 6.2 km/s (Figure 11). Interface 1 is consistent with the boundary of the weathered layer. Interface 2 maybe indicating the tranistion between highly fractued granite to more competent material.

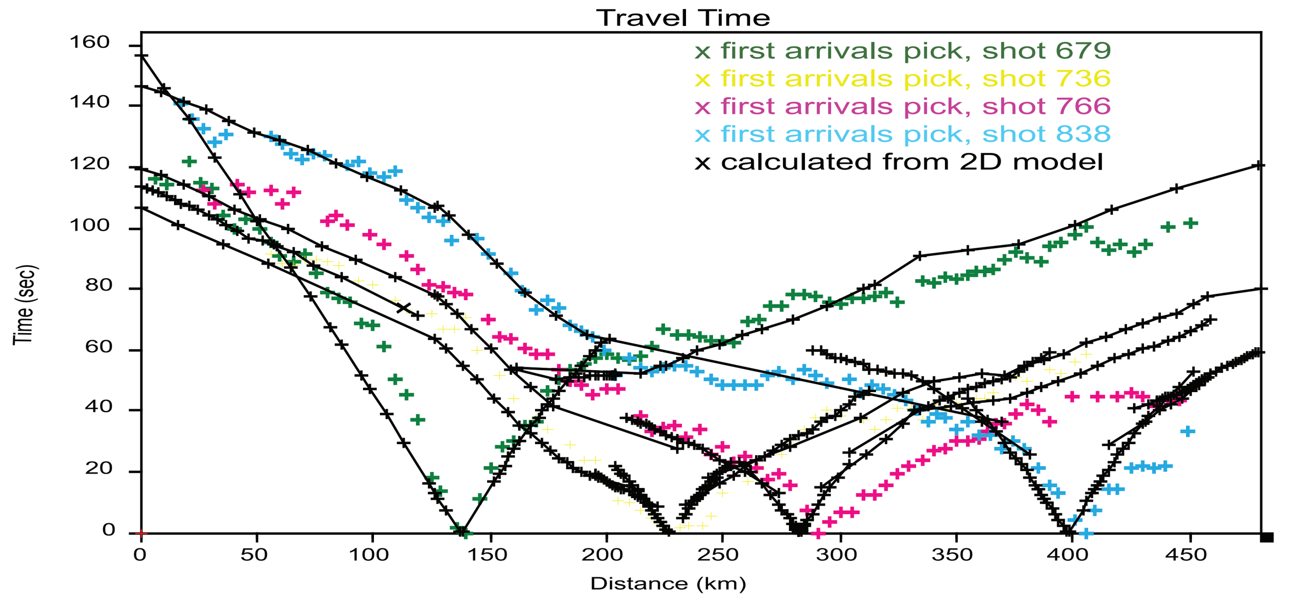

Figure 9. First picks and fits for the mini-vibe profile from selected shots. Overall the fits are very good.

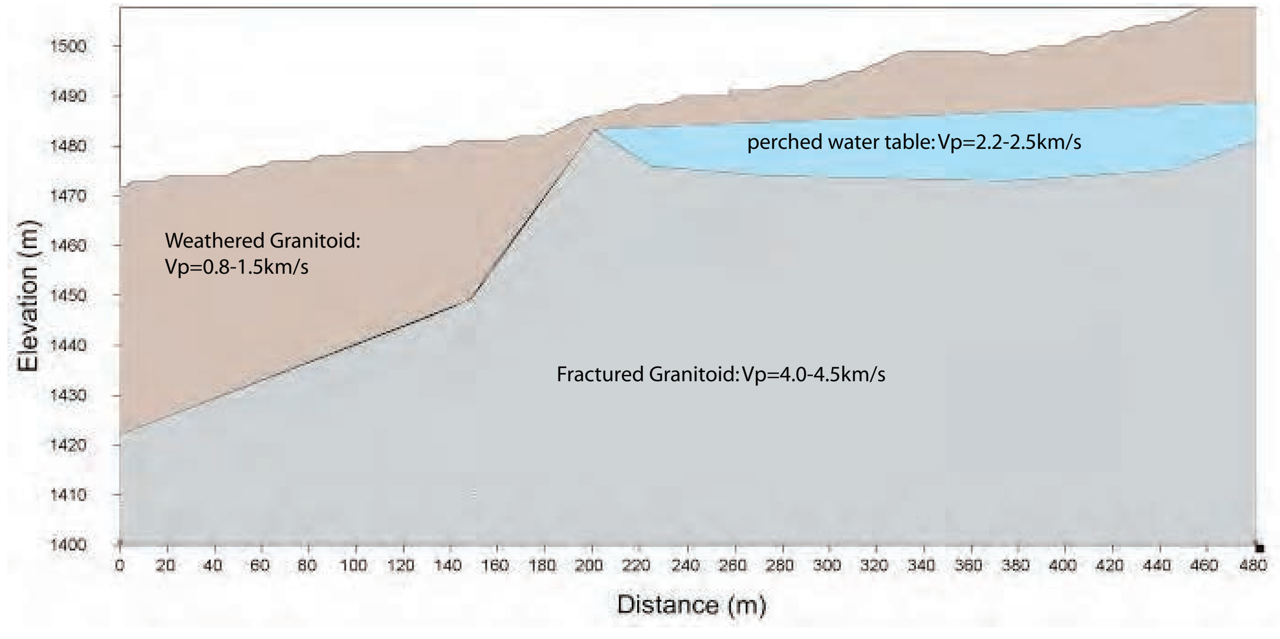

Figure 10. P-wave velocity model for the mini-vibe profile. Elevation is relative to the surface above sea level. Velocity is in km/s.

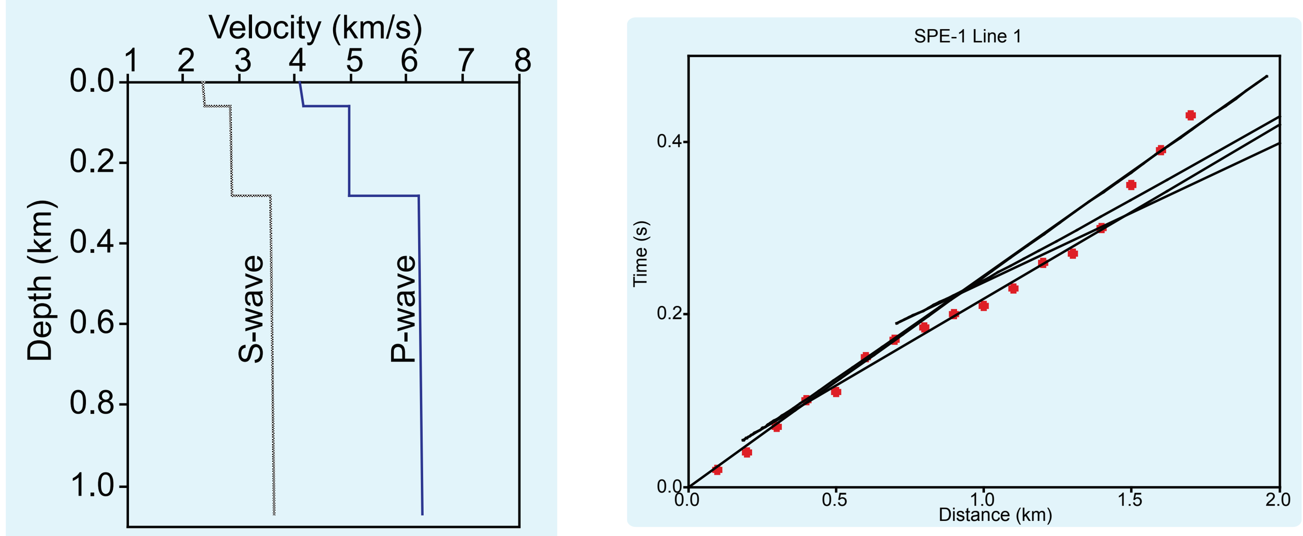

Figure 11. 1-D P-wave velocity model for the SPE-1 Line 1 data. Left panel is the velocity-depth profile. Right panel is the travel-time fits.

Future Work

The SPE-1 shot was a calibration shot in preparation for future shots in the same shot hole. SPE-2 used 1000 kg of chemical explosives that were placed at a depth of 46m. Following SPE-2, SPE-3 will consist of an identical shot fired in the same hole; the data will be used to determine the effects on the seismic signal in a damaged zone. SPE tests will continue shooting in the same hole, moving the shot to progressively shallower depths until it generates surface effects. After a thorough study of the explosion physics as seen in the Climax stock, SPE testing will move to a more complex geology. The planned second test bed is in U16b, a tunnel located in a Pennsylvanian limestone formation in Area 16 of the NNSS. The effects of change in geologic setting in the seismic wave generation and propagation will then be examined.

Acknowledgements
Many hands have helped make the project successful, we would like to thank those people that have been involved from the inception to the execution of the experiment. Thanks to IRIS and NNSA for funding that contributed to this research project. Thanks to IRIS PASSCAL and UNLV AGC for instrumentation support.

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