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Interim Report

The development of enhanced ripple-fire identification methods using high frequency data from Pinedale

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The development of enhanced ripple-fire identification methods using high frequency data from Pinedale

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Abstract

A technique called ripple fire used in quarry blasts produces modulations in the spectra of these events. The Deployable Seismic Verification System (DSVS) was installed at the Pinedale Seismic Research Facility in Wyoming, an area with a lot of mining activity. DSVS records at frequencies up to 50 Hz and these data provides us with a unique opportunity to determine how well we can discriminate quarry blasts and if there are operational benefits from using high frequency (>20 Hz) data.

We have collected a database of 646 events consisting of known earthquakes, known quarry blasts and unknown signals. We have started to calculate preliminary spectrograms to see if we get the time-independent banding from the quarry blasts, and at what frequencies the banding occurs. We also detail what we hope to accomplish in FY1996.

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INTRODUCTION

With a Comprehensive Test Ban Treaty, monitoring smaller and smaller events becomes necessary. When hundreds of events are recorded in a day, a reliable method for quickly determining if an unknown signal is a mining event is important so that these signals can be discarded at the outset. A number of methods for identifying a mining event have been tried. Determining the location of an unknown event can be useful; for example, if the event is from a known mining region. However, these events are so small that they may only be recorded by one station and an accurate location will be difficult. Recently a master event method to identify quarry blasts has been developed (Harris, 1991). Events that look similar and come from a similar direction could be grouped. But the method that has the most promise looks for modulations in the spectrum that result from a technique used in quarry blasting called "ripple-fire" (Park et al., 1987; Baumgardt and Ziegler, 1988; Smith, 1989; Hedlin et al., 1989, 1990; Kim et al., 1994). Ripple fire is a technique that maximizes the amount of rock and product (i.e. coal) fractured while decreasing the ground motion that could cause damage to property and structures. To accomplish this, holes are drilled in the rock face in a pattern, explosives are placed into the holes and then fired sequentially. The modulations in the ripple-fire spectra are time-independent, meaning that a spectrum taken anywhere in the signal will produce the same kind of modulations. Spectrograms, where spectra are taken in a window that moves through the signal, are produced to look at the modulations through time. Hedlin et al. (1989) made a binary spectrogram by comparing an unsmoothed version of the spectra to a smoothed version. The differences between a ripple-fire explosion and a single chemical explosion then become clear (Figure 1).

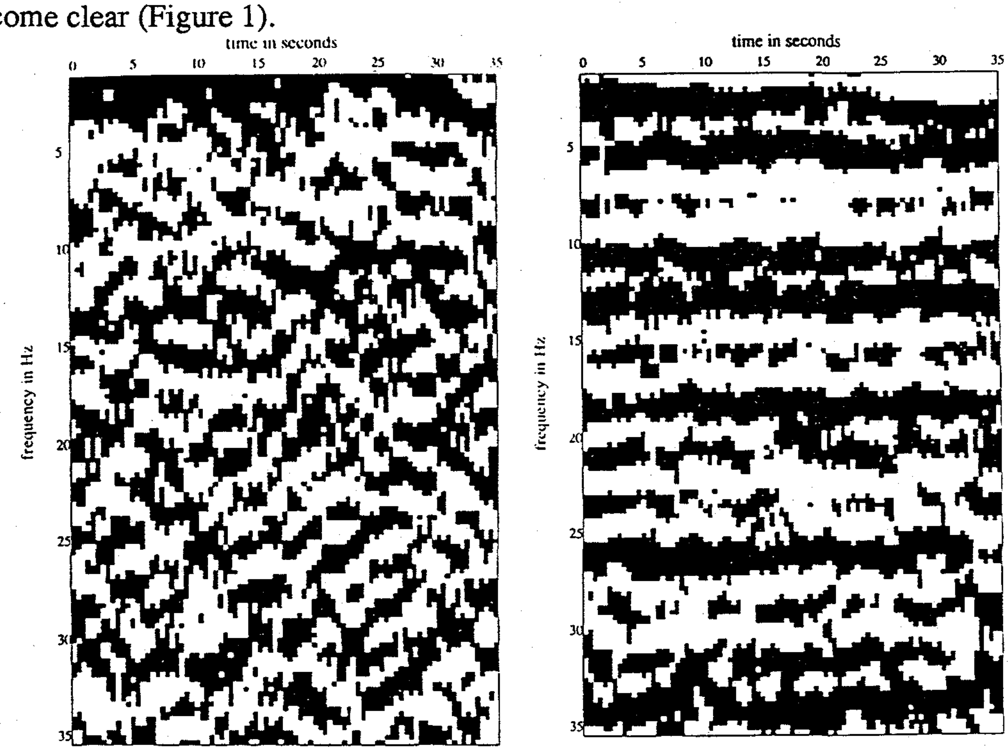

Figure 1. Binary sonograms from Hedlin et al. (1989). The sonogram on the left is from a 20 T calibration explosion. The sonogram on the right is from a ripple fire quarry blast. The banding is evident in the ripple fire blast.

In 1990 a Deployable Seismic Verification System (DSVS) was installed at the Pinedale Seismic Research Facility (PSRF) near Boulder, Wyoming. Wyoming is the number one producer of coal in the nation, so there is a lot of mining activity around this station. DSVS records data up to 50 Hz, and the background noise at PSRF is very close to the USGS-Peterson low noise model (Carr, 1993), so we can examine a large data set of high frequency (HF) data with good signal to noise to see how easy it is to discriminate ripple fire events and to determine if there are any benefits of recording data up to 50 Hz as opposed to 16-20 Hz.

Our goal is to find a method for discriminating ripple fire blasts that can be automated and to determine if there is an operational benefit from using high frequency data in the discrimination process.

PRELIMINARY RESULTS

We started by collecting a database of known earthquakes and ripple-fire explosions that were recorded by DSVS in 1991 and 1992. One hundred eighteen earthquakes located in Wyoming, Idaho, Utah, Montana and Colorado were collected. The timing, locations and magnitudes were found in the Preliminary Determination of Epicenters (PDE) bulletin from the National Earthquake Information Service and the University of Utah Seismic Bulletin. All the earthquakes are within 900 kilometers of PSRF, with the majority between 250 and 450 km. Only ten earthquakes are located east of the station. For the events less than 200 km away, there is good signal to at least 35 Hz. (Figure 2). Only 18% of the earthquakes have poor signal at high frequencies (signal going into the noise at less than 10 Hz). In addition, one event collected from the PDE bulletin was a rockburst in South Dakota. This event had good signal out to 23 Hz and was approximately 500 km away from PSRF.

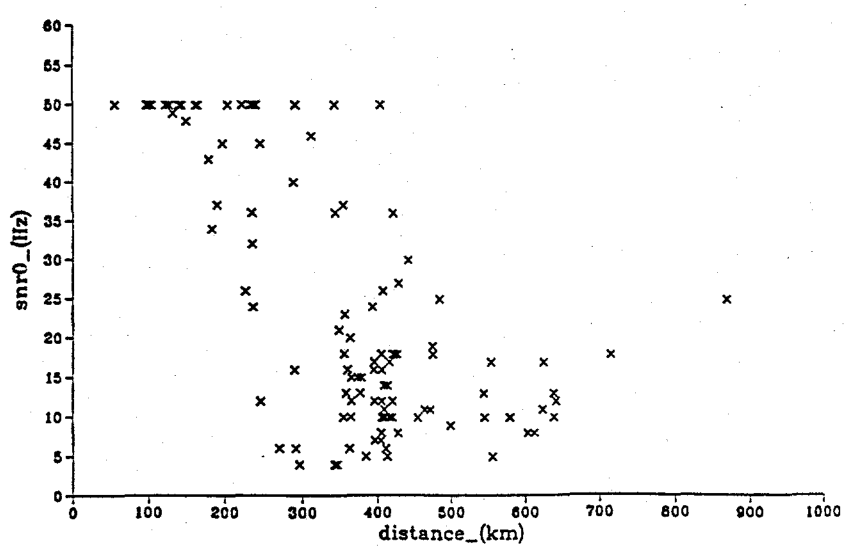

Figure 2. The frequency where the signal goes into the background noise for the 118 earthquakes compared to distance.

Ripple fire data was collected using 1991 and 1992 blasting records from four coal mine operations in Wyoming. Only one mine was willing to give us pattern and timing information of the blasts, but all assured us that the events were ripple fired. Sixty four explosions are from mine #1, located approximately 359 km from PSRF at an azimuth of 75°. One small explosion came from a mine 379 km east of PSRF at an azimuth of 61° (mine #2). Mine #4 is also east of PSRF, at a distance of 330 km and 90° azimuth. Thirty seven explosions are from this mine. Seventy four events are from mine #3 which is located 235 km northwest of the station at an azimuth of 339°. In addition there are six explosions from 1994 from other mines in Wyoming for a total of 183 ripple fired explosions. The amount of high frequency signal from the explosions varied depending upon the mine (Figure 3), but the majority of events had good signal up to at least 20 Hz.

In addition to the known events, we also have 351 events of unknown origin. These events were found when scanning the data looking for ripple fire shots. We plan to use this data set as a test bed for testing any methods we believe would be able to discriminate ripple fire explosions.

Along with collecting events, we also have researched the literature on methods used to discriminate ripple fire events. We chose to focus on the program developed by researchers at UCSD (Hedlin et al., 1989, 1990). In doing their research, Hedlin et al. used techniques from previous papers (Baumgardt and Ziegler, 1988; Park et al., 1987) that they felt were valuable, such as using an adaptive multitaper algorithm for spectral estimates to help minimize leakage from outside a pre-specified bandwidth. They also introduced the use of a binary sonogram (Figure 1), which may be a first step toward automating the discrimination process. Hedlin and his colleagues at UCSD were very willing to send us a copy of the program, and we are in the process of implementing the program on our system and modifying the input parameters to take the information from the DSVS data files. We plan to have the program running by late November.

While modifying the program, we have done some preliminary work looking for modulations in the spectra of the ripple fire explosions. We have used a program in MATLAB® called specgram that generates a spectrogram of a time series. It does not have the multitaper algorithm used by Hedlin et al., but is good enough to see peaks in the spectrum. We do see time-independent banding from known mining shots (Figure 4). For some events we see peaks at certain frequencies: 26, 38 and 48 Hz; in both the signal and in the noise prior to the signal. When looking at background noise at PSRF, Carr (1993) found peaks at these frequencies which were believed to be due to wind blowing on the antenna and fence and causing them to resonate. The ripple-fire explosions with peaks in both signal and noise at these frequencies were found to have occurred when the average wind speeds were over 10 mph. These speeds correspond well to the wind speeds that caused the large peaks in the noise data.

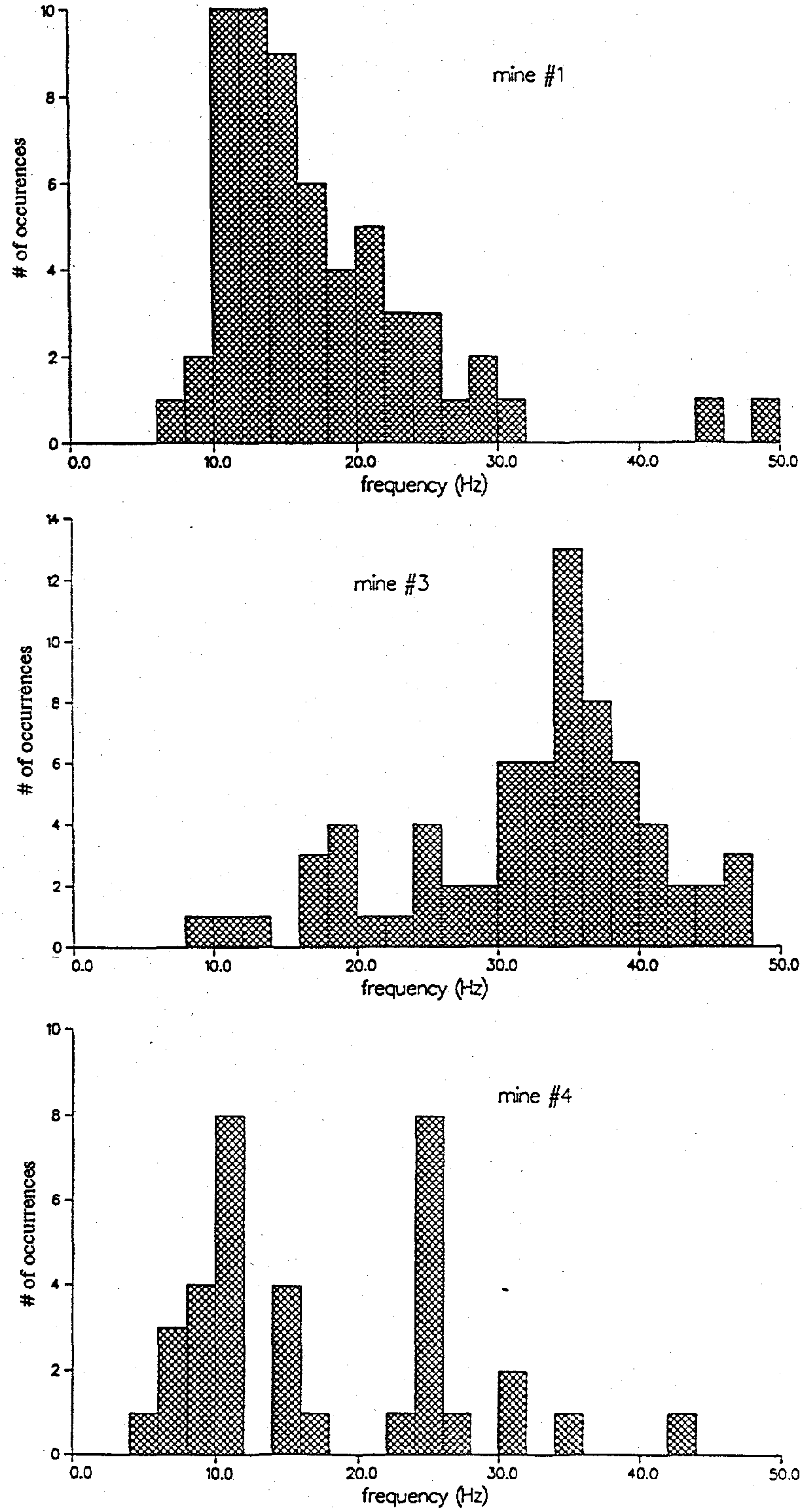

Figure 3. The frequency where the signal goes into the background noise for the quarry blasts from the three major mines.

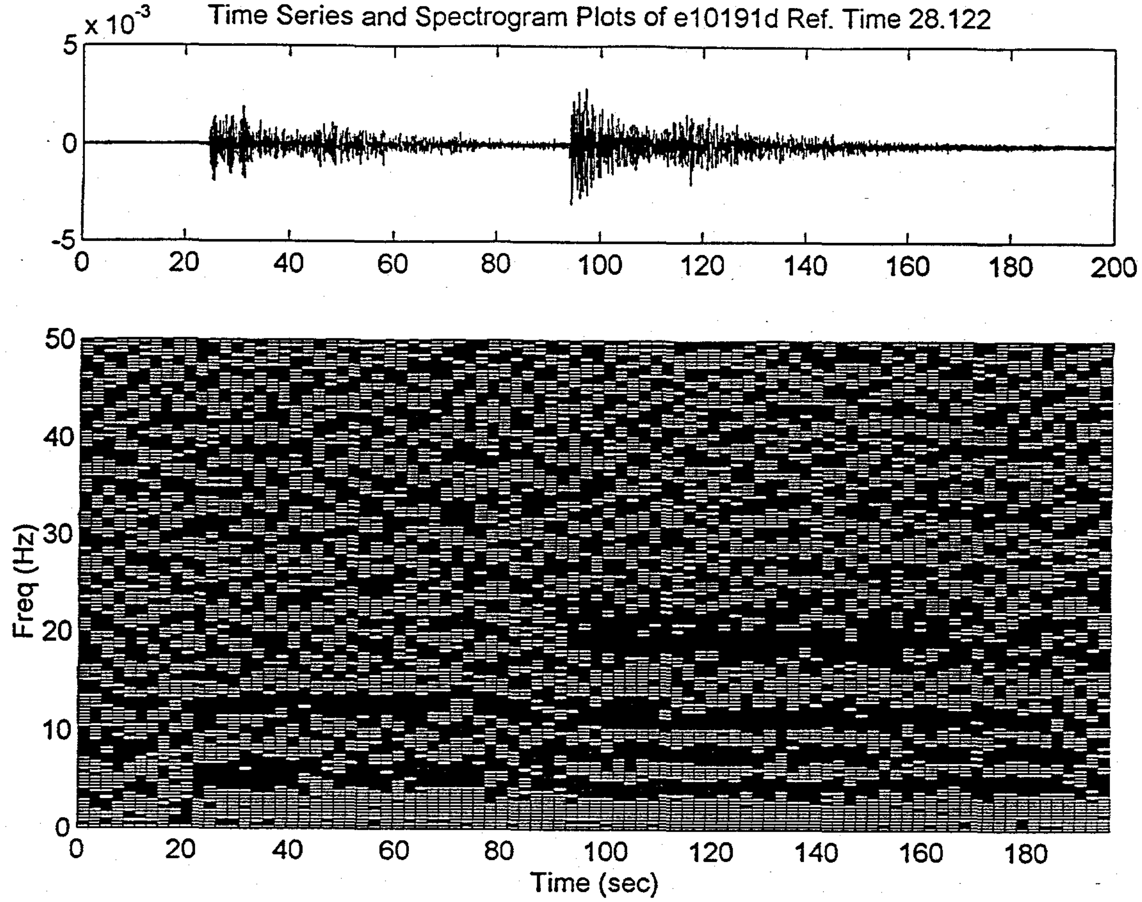

Figure 4. Time series and binary spectogram of two ripple fire explosions. The light areas are peaks and the dark areas are troughs. Spectral banding is seen at frequencies under 25 Hz.

Spectrograms for fourteen events from mine #3 were looked at to see how the banding seen was affected by where the signal went into the background noise. Events with good signal out to 50 Hz were compared to events with good signal only out to 16 or 17 Hz. For all of the explosions there is banding seen between 1.5-3 Hz and 5.5-7.5 Hz. A peak or band near 13-15 Hz can also be seen on nine events, two of which only have good signal out to 16 Hz. At higher frequencies there are no bands that are seen on all the events. Bands at 17-18 Hz, 20-21 Hz and 28-29 Hz are seen on at least two of the fourteen mining explosions. This preliminary look indicates that recording signals at frequencies of at least 20 Hz may be of value. Although there are spectral bands at frequencies over 20 Hz for some of the events, they are not as striking as the bands at lower frequencies.

The same kind of spectrograms for five earthquakes ranging in distance from 100 to 400 km were also computed. For two of these events, there appeared to be banding in the spectrogram, similar to that seen from the mining explosions. Further work needs to be done to determine if this event is actually an explosion that was misidentified in the bulletin as an earthquake, or if earthquakes in this region can show some banding.

REMAINING WORK

The major focus of the next few months will be to get the program from UCSD running. Then we will do a blind test on all the events in the database using both the MATLAB® program and the UCSD program to determine how well we can discriminate ripple-fire explosions from earthquakes. We will start with what we consider to be reasonable parameters; a 2.5 second window with a 25% overlap. This test will tell us if we need the multitaper algorithms to get good discrimination or if a simple procedure, like that in MATLAB® will work as well. Also, we will find out the value of the high frequency (>20 Hz) data. For any of the events we cannot discriminate well, we will do the following to try to improve results:

1. Change the parameters used to produce the spectrograms (i.e window).
2. Look at the non-binary output.
3. Add the horizontal components to the vertical.
4. Add in other discrimination methods (location, master event).

Once these four points are answered, we will test our unknown events to see how well the discriminant works. Finally we plan to do a similar study with high frequency data from Tennessee, to determine if what we find at PSRF can be applied to another geological region.

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