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REPROCESSING OF SHALLOW SEISMIC REFLECTION DATA TO IMAGE FAULTS NEAR A HAZARDOUS WASTE SITE ON THE OAK RIDGE RESERVATION, TENNESSEE

William E. Doll, Environmental Sciences Division, Oak Ridge National Laboratory,
P.O. Box 2008, MS 6400, Oak Ridge, Tennessee 37831-6400; email: d8e@ornl.gov

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ABSTRACT

Shallow seismic reflection data from Bear Creek Valley on the Oak Ridge Reservation demonstrates that spectral balancing and tomographic refraction statics can be important processing tools for shallow seismic data. At this site, reprocessing of data which had previously yielded no useable CMP stacked sections was successful after application of these processing techniques.

INTRODUCTION

In 1992, shallow seismic reflection data were acquired along six profile lines (three of which formed a larger broken line) adjacent to the Bear Creek Burial Grounds, a hazardous waste site on the Oak Ridge Reservation, Tennessee (Figure 1). The data were acquired in an attempt to image faults and fracture zones that were thought to

Figure 1. Map view of the study area. The inset shows the location of the study area on the Oak Ridge Reservation. Roads are shown as grey lines and streams are shown as dashed lines. Fine lines show geologic formation contacts which dip to the south at about 45°. The locations of five wells are identified by cross symbols. Common midpoint labels on Line 1 correspond to those on Figures 3-5.

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occur in the vicinity and might serve as pathways for migration of dense nonaqueous phase liquids (DNAPLs) (Haase and King, 1990).

Initial processing of these data was attempted with a standard PC-based software package that was available at the time, but this failed to produce satisfactory images along any of the profile lines. The data were dominated by source generated noise, including guided waves (Robertsson and others, 1996), to the extent that no reflections could be clearly identified on shot gathers, and stacked sections indicated only a few weak reflections.

After successfully processing seismic reflection data from other sites on the Oak Ridge Reservation with a workstation software package, the Bear Creek data were reinspected, in the hope that some of the techniques that we had learned from processing other data sets could be used effectively on the Bear Creek data. In this paper, I shall present the results of the reprocessing that was done, and summarize the important elements of this work that could be applicable at other sites.

DATA ACQUISITION

Data were acquired during a 5-day period in July, 1992 by the Kansas Geological Survey (KGS) under the direction of Rick Miller. Acquisition parameters were selected on the basis of a series of walkaway noise tests that were conducted at the beginning of field operations. The two sources that were tested were the .50-caliber downhole gun, and the KGS auger Gun. The auger gun uses a skid-steer loader-mounted hollow stem auger to fire blank 8 gauge shotgun shells at about 0.5 m depth. Both sources showed indications of weak reflections, and resulted in very similar data. The auger gun was selected for production data acquisition because it can achieve a higher rate of production, and because of safety concerns of site managers. Data were acquired at three-meter source and geophone group spacing. Three Mark Products L-28E 40 Hz geophones, wired in series, were placed in a 1 meter in-line group at each receiver station to improve the signal-to-noise ratio. A Geometrics ES-2401X 48-channel seismograph was used to record 500 ms of data at 0.5 ms sample interval with a 500 Hz high cut acquisition filter and a 60 Hz notch filter. Weather conditions were uniformly warm with a few showers during the period of acquisition.

DATA PROCESSING

The unprocessed data are characterized by static problems and ground roll or guided waves (Robertsson and others, 1996) that mask the reflection energy (Figure 2a). Initial processing was conducted with 1992-era PC-based software. Frequency filters and frequency-wavenumber filters were used to try to reduce source generated noise. Static corrections were attempted by applying coherency filters to shot gathers that had been flattened by a linear moveout correction. None of these exercises resulted in identifiable reflections in the shot gathers, or in a satisfactory stacked section.

Subsequent seismic reflection profiling on the Oak Ridge Reservation was more successful (e.g. Doll and others in press, Liu and others, 1997, Carr and others, 1997). In a 1994 source comparison which was conducted about 7 km southwest of the Bear

Creek site (Doll and others, in press), many strong reflections were imaged in data acquired with the same seismic source (KGS auger gun) in the same surface lithology (Nolichucky Shale). The 1994 data were sited in a different thrust sheet where the measured dips were about ten degrees less than at the Bear Creek site, and the water table was higher. Nonetheless, the contrast in these two data sets made the processing difficulties even more interesting and led to a series of attempts at reprocessing.

Processing of these data is still in progress. The most successful processing flow for Line 1 to date consists of:

1. Source and receiver geometry assignment
2. Tomographic refraction statics picking and inversion
3. Spectral balancing
4. Bandpass frequency filtering (80/120/200/250 Hz)
5. Bad trace editing
6. First arrival mute (refraction and direct wave)
7. Surgical mute (air wave and ground roll)
8. Refraction statics correction
9. Common midpoint sort
10. Interactive velocity analysis and application
11. Normal move out correction and CMP stacking
12. Automatic gain control (100 ms)

Further improvements are expected from additional iterations in velocity analysis, further statics corrections, more careful editing and muting, and experimentation with a series of bandpass filters.

Spectral whitening

Figure 2 shows a comparison of two shot gathers with three different techniques for improving the spectral properties of the reflection energy. Figure 2a shows the raw data from these two shot gathers, dominated by low frequency noise, presumably ground roll and guided waves. A common way of enhancing the reflections is to apply a lowcut filter (Steeple and Miller, 1990). Figure 2b shows the data from 2a with a trapezoidal frequency filter applied (85 /120/200/250 Hz). This reveals some narrow band reflections in Shot 105, particularly at about 0.3s, but does not yield any clear reflections in Shot 104.

An alternative to band pass filtering is to apply a technique known as "stretch automatic gain control" (SAGC), as described by Çoruh, 1985 and Doll and Çoruh, 1995. This method sharpens the reflections at 0.3s and brings out reflections at 0.15s as well on both shot gathers (Figure 2c). SAGC is applied by convolving each trace with a synthetic Vibroseis style sweep (8-seconds, 80-250 Hz upsweep in this case), to separate the frequency components of the original trace as a function of time. An automatic gain control is then applied to the stretched trace to equalize the amplitudes of the spectral components, and then the trace is cross-correlated with the synthetic

Figure 2. Comparison of spectral whitening techniques on two shot gathers. a) raw, unfiltered data, b) frequency filtered using a trapezoidal 85/120/200/250 Hz bandpass filter,

Fig. 2 cont. c) result from applying SAGC to the raw data, and d) output from spectral balancing.

sweep to yield a spectrally whitened trace. It is an effective means of reducing ground roll and other source-generated low frequency / high amplitude noise because the spectral whitening is accomplished without making any assumptions about the reflected wavelet. Spiking deconvolution was also attempted with these data, but it did not produce satisfactory results because it requires that assumptions about the reflection wavelet be made from the data.

The spectral whitening technique which was most effective with these data is known as spectral balancing. In this method, the data are decomposed into spectral components over a series of narrow pass bands, and the amplitude at the midpoint of each pass band is used to calculate a scalar correction for that band. The pass bands are recomposited with the scalar corrections to achieve equalization over the spectrum of the data set. Here, I have used ten gates, 20 Hz each, from 40-240 Hz. In the two shot gathers that are shown in Figure 2d, it results in enhancement of several reflections at 0.1- 0.3s depth, particularly in Shot 105.

Refraction Statics

Some of the shot gathers in the data set show irregularities in the first breaks due to variability in near surface conditions. Between CMPs 2000 and 2190, and between CMPs 2450 and 2636, the line was cut through undisturbed forest. Tree roots and a surface organic layer cause scattering and some energy loss. From CMP 2190 to CMP 2450, the surface has been reworked due to development of the hazardous waste burial area to the north. First arrivals were picked on all shot gathers using an interactive routine included in the FOCUS (workstation DISCO) software package. These picks were then used in a tomographic inversion module in FOCUS to calculate refraction statics corrections for the entire line.

CMP Stacked Sections

Figures 3, 4, and 5 show common midpoint stacked sections for a portion of Line 1, following the optimal processing flow, as well as for two alternative flows that demonstrate the importance of the two key processing elements for these data. The preliminary CMP stacked section which incorporates both spectral balancing and refraction statics and follows the flow listed earlier, is shown in Figure 3. When bandpass filtering is used instead of spectral balancing to whiten the spectrum, the resulting CMP stacked section is that shown in Figure 4. Although reflections can be seen between about 0.08s and 0.3s, they are narrow band. When refraction statics are not applied to spectrally balanced data, the section shown in Figure 5 results. The reflection wavelets are sharper than when spectral balancing is not used, but they are more discontinuous and the reflections are more irregular than when both spectral balancing and refraction statics are used (Figure 3). Obviously, when neither of these steps are included in the processing flow, the CMP stacked section is poorer than any of those shown.

SUMMARY

Previous researchers (Steeple and Miller, 1990) have demonstrated that shallow

Figure 3. CMP stacked section for a portion of Line 1 using the 12-step processing flow that is listed in the text.

Figure 4. CMP stacked section for the same portion of Line 1 as in Fig. 3, but omitting Step 3 (spectral balancing).

Figure 5. CMP stacked section for the same portion of Line 1 as in Figs. 3 and 4, but omitting Steps 2 and 8 (refraction statics).

reflection processing requires careful monitoring at each step, and that many routines that have been developed for deeper applications cannot be applied to shallow data. The preliminary results shown here demonstrate that some of the more advanced routines developed for petroleum exploration applications are not only useful, but can make the difference between success and failure. The seismic data shown here, for instance, have been used in conjunction with rock core analysis to identify possible locations of faults that might serve as conduits for migration of contaminants from the site (Hollon, 1997). PC-based software has improved since the original processing of these data. Some of the newer releases have incorporated modules such as spectral balancing and refraction statics. Further research into the application and modification of "petroleum routines" to near surface seismic data could significantly increase the usefulness of and demand for shallow seismic imaging at environmental sites.

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