Enhancement of swept source near-surface seismic reflection data at a hazardous waste site

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Summary

Seismic reflection data have been acquired on the Oak Ridge Reservation, Tennessee, to assist in the selection of groundwater monitoring well locations. An IVI MiniVib swept source was chosen for the aquisition on the basis of comparison tests. Pre-correlation ("Vibroseis Whitening") and post-correlation spectral whitening techniques cause significant improvements in stacked sections. Correlation of the raw (uncorrelated) field data with alternative sweeps is also investigated.

Introduction

Between August and December 1995, approximately 5,000 shotpoints of seismic reflection data were acquired in the vicinity of the Oak Ridge K-25 Site (formerly known as the Oak Ridge Gaseous Diffusion Plant) on the Oak Ridge Reservation (ORR). Tennessee. The facility is located in the Valley and Ridge province of the southern Appalachians, in an area of folded and faulted Cambrian through Ordovician sedimentary rocks in the footwall of the Whiteoak Mountain fault. Dips measured at the surface in the vicinity of the plant range from near-horizontal to near-vertical. The K-25 site was constructed in the 1940s and used for enrichment of uranium hexafluoride until 1985. The enrichment procedures and related activities generated nonhazardous, hazardous. radioactive, and mixed wastes that have been stored, treated, or disposed in the vicinity of the plant. The seismic survey was designed to provide three-dimensional control of faults and formation contacts previously mapped at the surface (Lemiszki. 1994) for incorporation into a drilling and groundwater monitoring strategy intended to detect any contaminant migration off site. Microgravity data were also acquired as part of this activity (Kaufmann, 1996), to locate places where karstified carbonate rocks might allow enhanced pathways for contaminant migration.

Effective monitoring and remediation of contaminants requires an accurate geologic and hence hydrologic model. Transport and fate models for site remediation planning have been accurately developed by incorporating borehole data and surface seismic reflection surveys (Burow and Miller, in review; Daniel et al., 1996). An effective seismic reflection survey requires optimized acquisition and processing parameters and equipment selections (Steeples and Miller, 1990: Hunter et al., 1984). Seismic survey design for K-25 production profiles were based on an extensive comparison test conducted at three sites prior to the beginning of acquisition, and on a more thorough source comparison conducted during November 1993 at a site on the Oak Ridge Reservation a few kilometers away (Doll et al., 1994). The highest signal-to-noise and highest resolution data were acquired with a vibratory source, relatively high fold(nominal48), groups of geophones with high output and low spurious noise, and pre-correlation processing. Equivalent test data sets from around the ORR suggest that delineation of units as shallow as 25 m and at

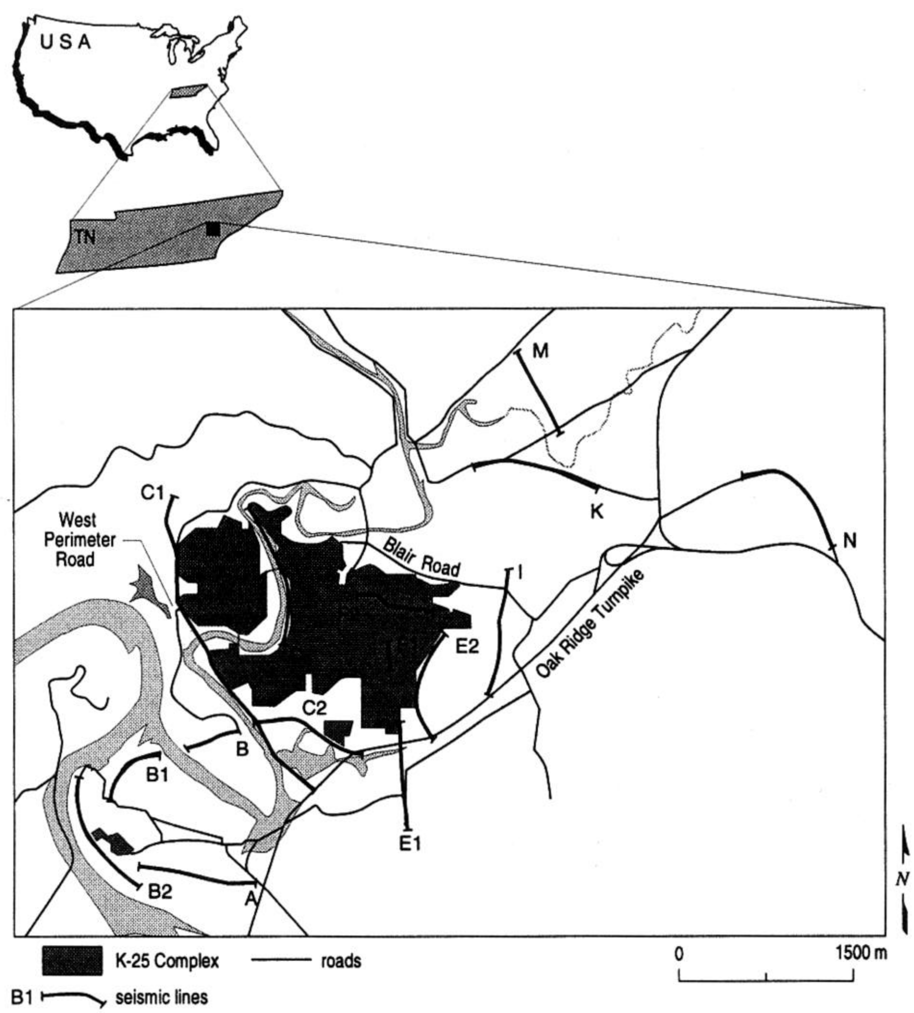

Figure 1. Site map showing line locations relative to permanent facilities around the K-25 site at Oak Ridge, Tennessee.

least as deep as 500 m is possible with reflection frequencies as high as 100 Hz.

Acquisition

A total of thirteen CDP seismic reflection profiles were acquired in and around areas with geologic features potentially significant to the transport and fate of surface and subsurface contaminants (Figure 1).

The data were recorded on two 48-channel, 24-bit Geometrics StrataView seismographs interfaced for simultaneous 96-channel recording. The 10 second pilot trace recorded on channel 1 was digitally stored with the other 95 traces which recorded 12 seconds of uncorrelated data. Three shots were recorded for each shot station and digitally stored separately. The pilot trace saved with the uncorrelated data was the calculated ground force. The vibrator computer retained the synthetic, base plate accelerometer, and mass accelerometer data separately. By retaining the accelerometer traces, customized correlation routines can be developed. This analysis is currently in progress. For each shot station three shots were independently stored on the seismograph hard drive in SEG2 format. Data for each shotpoint exceeded 14 MB with the entire 5,000 shotpoint survey requiring just over 70 GB of storage space.

The source was an IVI MiniVib which delivered a linear upsweep from 30 to 300 Hz tapered on both ends for 0.25 seconds. The vibrator was configured to deliver the maximum available down pressure of about 7,000 Ibs through the mid-range of the spectra. The ground force pilot calculated in real time at the vibrator was a function of the mass and baseplate weights and accelerometer outputs. The pilot was then telemetered to the seismograph.

Three Mark Products L28E40 Hz geophones were wired in series and deployed in a 1 m array at each station. The receiver and shot station spacing was 3 m, The geophones conditions ranged from gravel road bed to manicured grass lawn. The use of 14 cm spikes and removal of the loose surface material was critical to the amplitude and frequency response of the geophones.

Processing

The data were processed to generate the optimum CDP stacked section, consistent with impulsive shallow seismic data sets (Steeples and Miller, 1990). The uncorrelated records were correlated, edited, and vertically stacked so each shot station was represented by a single shot gather. Pre-correlation processing was evaluated and applied to much of the data. As is always the case, extreme care was taken to ensure that refractions and direct wave were not present on the CDP stacked sections. Migration was effective in improving apparent signal-to-noise and in suppressing diffraction tails and bow tie features. The most unique aspect of the data processing flow was the extreme amount of out-of-the-plane and scatter type noise present.

Sweep Data Reduction

For each shot, the digitized sweep, base plate accelerometer, mass accelerometer, and a ground force calculation derived from the accelerometers and physical characteristics of the mass/base plate were recorded on a database in the vibrator computer. Recording uncorrelated shots allowed enhancement of the correlation process, using different sweeps (either one of those recorded, or a synthetic sweep, such as ground force, that can be calculated from the recorded sweeps on the basis of certain assumptions), and allowed pre-correlation processing such as Vibroseis Whitening (VSW) (Doll and Coruh, 1995; Coruh and Costain, 1983).

VSW is a very attractive means of whitening the spectra of high resolution shallow seismic data because it requires no assumptions about the wavelet, is very simple to apply, and is quite robust. It involves applying an automatic gain control (AGC) to the swept source data before they are correlated with the sweep. Comparison of shot gathers and stacked sections from the 1993 source comparison indicated that the highest quality results were obtained when a two-step pre-processing sequence was followed. This sequence consisted of VSW using a 250 msec AGC before correlation, followed by spiking deconvolution after correlation (Doll and Coruh, 1995). It is possible this type of AGC applied to the ground force pilot might improve the shot gather as well. We have found that occasionally correlation with a synthetic pilot produces a shot gather with greater bandwidth than correlation with a calculated ground force. Classic ground force calculations may not be adequate for high frequency shallow data.

Results

Confident identification of reflections on field files is not only necessary to properly process shallow seismic reflection data, it is also of the utmost importance in differentiating reflections on a CDP stacked section from stacked refractions and other coherent noise events. Reflections interpreted on shot gathers from this site are easily interpreted, and on some files reflections can be correlated directly to particular geologic units present on well logs and interpolated from surface geology in this area.

The nominal dominant frequency of reflections from around this site is about around 90 Hz on filtered field files. The variability of the near-surface and extreme dip on surface exposures of some rock units in this area is evident on most shot gathers.

Stacked sections display a complete sequence of high confidence reflections from about 80 msec to over 600 msec (Figure 2). Casual observation shows that the reflection bandwidth increases with VSW. The coherence of reflections and apparent structures are consistent with that inferred from surface mapping. The improved resolution allows significant geologic detail through a depth window significant to movement of surface or shallow subsurface contaminant.

Enhancement of reflection data at waste site

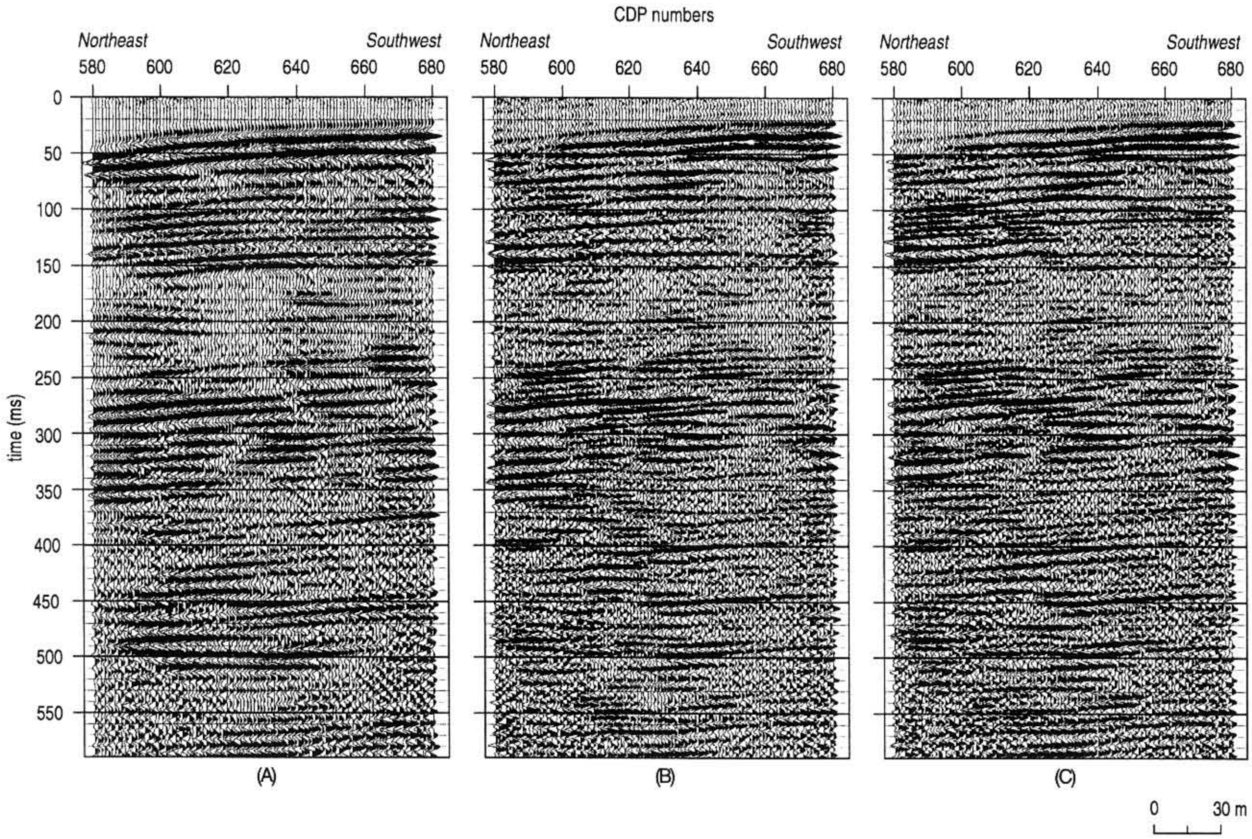

Figure 2. CDP stacked sections: A) standard processing, B) deconvolution, and C) pre-correlation whitening and deconvolution.

Conclusion

Enhancement of shallow seismic reflection data that were acquired to assist with contaminant isolation and remediation procedures at DOE's K-25 site neat Oak Ridge Tennessee was accomplished through both the recording of high quality resolution uncorrelated data that allowed for pre-correlation processing and careful attention to the subtle aspects of both acquisition and processing.

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