CONF-970344--1

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FEB 12 1997

SEISMIC REFLECTION PROCESSING FOR CHARACTERIZATION OF A HAZARDOUS WASTE SITE

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ABSTRACT

Seismic reflection data have been acquired by the Kansas Geological Survey near the Oak Ridge K-25 Plant on the Oak Ridge Reservation, Tennessee, to assist in the selection of ground water monitoring well locations. The data were recorded in uncorrelated format to allow flexibility in enhancement of stacked images.

During the summer of 1996, five of the thirteen seismic reflection lines acquired were processed. An unconventional correlation procedure, "Vibroseis Whitening" (VSW) (Coruh and Costain, 1983) has been applied to produce improved seismic sections. Refraction statics corrections, which remove the detrimental effect of an irregular weathered layer, have also been utilized to improve the seismic sections. The seismic data were stacked using the velocities obtained from a standard semblance velocity analysis tool. Locations and orientations of faults or fault zones can be interpreted from these stacked sections, and they are in agreement with the interpretations of the surface mapping in the area.

This paper concludes that VSW and refraction statics can be important to near-surface swept source seismic data processing.

INTRODUCTION

MASTER

The K-25 Plant, Oak Ridge, Tennessee, was formerly known as the Oak Ridge Gaseous Diffusion Plant. The K-25 Plant 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. Effective monitoring and remediation requires an accurate geologic and hence hydrologic model.

The K-25 Plant 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 White Oak Mountain Fault. Dips measured at the surface in the vicinity of the plant range from near-horizontal to near-vertical.

Seismic reflection data were acquired by the Kansas Geological Survey to provide three-dimensional control of faults and formation contacts previously mapped at the surface (Lemiszi, 1984) for incorporation into a drilling and ground water monitoring strategy intended to detect any contaminant migration off-site. Between August and December, 1995, approximately 5,000 shot points of seismic reflection data were acquired in the vicinity of the K-25 plant (Doll et al., 1996).

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Doll and Kaufmann began preliminary processing in early 1996. Brute stacks were obtained for all of the seismic lines. Workstation processing started in June, 1996, as Liu's summer internship assignment with Doll at Oak Ridge National Laboratory. The major objective of the processing is to obtain improved stacked sections for the interpretation of faults and horizon contacts which are controls of possible waste migration paths.

DATA ACQUISITION

A total of thirteen CDP seismic reflection lines were acquired by the Kansas Geological Survey in and around areas with geologic features potentially significant to the transport and fate of surface and subsurface contaminants. Figure 1 shows the five seismic lines east of K-25 plant that were processed during the summer of 1996.

The highest signal-to-noise and highest resolution data were obtained with an IVI Minivib, with a 10 second linear up-sweep from 30 to 300 Hz tapered on both ends for 0.25 seconds, (Doll et al., 1996). The data were recorded on two 48-channel, 24-bit Geometrics StrataView seismographs interfaced for simultaneous 96-channel recording. The pilot trace recorded on channel 1 and 95 receiving signal channels were digitally stored at 1 ms sample rate with two seconds of listening time for a total of 12 seconds of uncorrelated data per channel. Three shots were separately recorded for each shot station on the seismograph hard-drive in SEG-2 format. 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. The latter traces can also be used as pilot traces for correlation. Recording the pilot traces and the uncorrelated traces has the advantage that customized correlation procedures can be carried out later during processing in order to produce optimized correlated seismic traces (Doll et al., 1996).

Three Mark Products L28E 40 Hz geophones were wired in series and deployed in a 1 m (3.48 ft) array at each station. The receiver and shot station spacing was 3.048 m (10 ft). The geophone 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.

DATA PROCESSING

A preliminary processing flow for the K-25 seismic lines is shown below. As understanding of the reflection expected from the complex geology at K-25 is obtained through ray trace modeling, the processing flow may be modified.

- (1) Vibroseis Whitening (250 ms AGC)
- (2) Correlation
- (3) Vertical Stacking
- (4) Geometry Preparation and Header Load
- (5) Notch Filtering (60 Hz)
- (6) Band Pass Filtering (30-50-160-250 Hz)
- (7) Trace Editing & Trace Kill
- (8) First Arrival, Air Wave and Ground Roll Mute

- (9) Refraction Statics Prepare & Apply
- (10) CDP Sort and Velocity Analysis in Supergathers
- (11) NMO & CDP Stacking

Vibroseis Whitening

Steps (1)-(3) involve a correlation procedure called Vibroseis Whitening (VSW) (Doll and Coruh, 1995; Coruh and Costain, 1983). VSW is a very attractive and robust means of whitening the spectra of high resolution shallow seismic data. It applies an automatic gain control (AGC) to the swept source data before they are correlated with the sweep. Some of the attenuated high frequency components of the data can be compensated by VSW. The recording of uncorrelated swept trace data makes VSW possible, along with the advantage of allowing choice of correlating sweep length and the type of pilot trace (Doll and Coruh, 1995), resulting in the best correlated traces and hence improved stacked sections.

Refraction Statics

Step (9) will correct the time shift caused by irregular distribution of weathering layer velocity and thickness. The refraction statics is computed tomographically (Taner, 1994) with the FOCUS (Cogniseis) software. There are four steps: (1) Pick first arrival times from shot gathers; (2) Assign refractors; (3) Solve for refraction statics; (4) Apply refraction statics correction to data. It is our impression that first arrival time picking and refractor assignment are site specific, time-intensive, and often require a learning experience. However, doing refraction statics can be rewarding in defining correct structural images, as compared with doing no statics or only elevation statics correction. The advantage of a tomographic approach of refraction statics over conventional refraction solution is that the former does not require a separate refraction survey.

Deconvolution

In our processing, predictive deconvolution has been used to reduce the guided waves which appear as events parallel or sub-parallel to the first arrivals in some of the shot records. This option is inserted into the processing flow before the band pass filtering.

A prediction operator produces a time-advanced form of the input time series. The coefficients of the operator are solved from a matrix equation consisting of autocorrelation of the seismogram to be filtered. A prediction error filter can be constructed. Convolution of the prediction error filter with the seismogram will remove the predictable part of the wavelet from the seismogram. Multiples and reverberative energy can be reduced using predictive deconvolution (Yilmaz, 1991).

Other studies based on seismic reflection data from the Oak Ridge Reservation indicate that spiking deconvolution is a very useful tool for spectral whitening of Minivib data (Doll et al., 1996; Doll and Coruh, 1995). To maintain the focus on VSW and refraction statics, we will not discuss spiking deconvolution in this paper.

Other Processing

A standard, semi-automatic, semblance velocity analysis, has been applied to all five seismic

lines to obtain the velocities needed for NMO. Super-gathers around a CMP point have been used for velocity spectrum analysis and automatic velocity picking.

Since the reflections for far offsets beyond the air wave and ground roll cone are good for the K-25 data, surgical mute has been applied to the near-offset air wave and ground roll cone. First arrivals have been muted.

PROCESSING RESULTS

Both VSW and refraction statics have been included in the regular processing flow for all five seismic lines discussed here. We present comparison with or without these options. Readers are referred to Doll and Coruh, 1995; Coruh and Costain, 1983 for details about VSW.

An example of refraction statics for K-25 Line I is shown in Figure 2. A weathering layer exists between the ground surface and the refractor (top panel). The weathering layer thickness changes across the section of Line I. The refractor velocity also changes (middle panel). The time shifts caused by these changes should be corrected to obtain the correct structural imaging of the reflectors below. The tomographic solution of refraction statics results in long wavelength statics (L. Statics) and short wavelength statics (R. Statics), (bottom panel). A long wavelength statics problem causes a time shift in the stacked image, such as an undulating image for a planar reflector. A short wavelength statics problem causes the reflection events in a NMO corrected CMP gather to be mis-aligned, resulting in poor stack quality such as broader waveform and lower signal-to-noise ratio for the stacked trace.

Figures 3A through 3D show CDP stacked sections of Line I with different processing options. Figure 3A is the CDP stacked section without VSW, but with the conventional correlation. Refraction statics are included. Figure 3B is the CDP stacked section with both VSW and refraction statics included. The correlation processed stack (Figure 3A) does not image well on both ends of Line I. Reflection events are not continuous. On the other hand, the reflection image on the VSW and refraction statics processed section (Figure 3B) from CDP 330 to 550 shows higher resolution and better image continuity.

Figure 3C shows the CDP stacked section with VSW, but without refraction statics. The imaging quality of Figure 3C looks close to that of Figure 3B, especially on the south side of the Line I, perhaps due to the fact that the short wavelength statics is small. However, the undulation of the reflectors on the south side (from CDP 570 to 900) on Figure 3C can be easily seen and may be caused by a long wavelength statics problem. The imaging of reflectors on the north side from CDP 300 to 550 does not show as much detail and continuity as the counterparts in Figure 3B. This is due to the fact that the short wavelength statics are large in the north side (Figure 2). Applying refraction statics correction results in a flatter reflector image as in the southern part of Figure 3B, from CDP 570-890, time 130-180 ms. Better reflection resolution and continuity is obtained for CDP 300-530, time 50-200 ms by doing the refraction statics (Figure 3B).

From the comparison of Figures 3A, 3B, and 3C, it can be seen that including both VSW and refraction statics in the processing flow will result in an optimal structural image, Figure 3B.

PRELIMINARY INTERPRETATION

The purpose of this paper has been to compare the effect of alternative processing steps on the continuity and time-resolution of line I.

On the south side, the gently north dipping event (at about 150 ms on CDP 730) might be a sideswipe from the K-25 fault (Figure 1). The north side is more difficult to interpret because of the presence of shallow faults beneath Line I. There are several possible interpretations for the north side of Line I at this preliminary interpretation stage.

One interpretation considers that the south dipping events (Figure 3B, Line I) from CDP 330-574, time 50-150 ms, are the reflections from the two thrust faults, KF-1 and KF-2, (Figure 1). This interpretation is consistent with the generalized geologic map of Lemiszki (1994). This interpretation is best shown by Figure 3B.

Another interpretation considers the apparent south dipping events to be noise and are guided waves. Predictive deconvolution is selected to reduce the guided waves that appear as events parallel or sub-parallel to the first arrivals in some of the shot gathers of Line I. Figure 3D shows the CDP stacked section with the predictive deconvolution, in addition to the VSW and refraction statics processing. The data were processed by applying an 80-120-250-300 Hz trapezoidal high pass filter and a predictive deconvolution with a gap of 10 points and operator length of 50 points (or ms). The stacked section is much more ringy. However, notice that the amplitude for the south dipping events in the window 50-175 ms from CDP 470-570 is reduced in Figure 3D as compared with Figure 3B. Thus the south dipping events in Figure 3B are now attenuated by applying the high pass filtering and the predictive deconvolution. The apparent dips for the first 150 ms are now reversed. This is consistent with the dips measured through surface mapping, around CDP 506 (Figure 1). This interpretation is best shown by Figure 3D.

The two interpretations for the first 150 ms on the north side of Line I seem to be discordant. We recognize that seismic reflection processing cannot be independent of available geologic data. This is an excellent example of a dataset in which contradictory results can be reached by minor changes in processing. We are currently investigating this issue by modeling and additional processing tests. Seismic modeling can help to determine whether the 50-150 ms events are noise or they are indeed reflections. A three dimensional framework, incorporating the other lines in Figure 1, together with all available structural information and generalized cross-sections, must be established to have a better understanding of the K-25 geology. A ground roll filtering technique is under development by Liu to improve the imaging of the very near-surface (first 100 ms). Eventually, we anticipate that a decision can be made whether to include predictive deconvolution in the processing sequence.

CONCLUSION

Different processing options have been included and compared in our processing flow. VSW and refraction statics have improved the quality of stacked sections of swept source data of K-25. The result for the first 200 ms seem to agree with the generalized cross section, as indicated by the thrust faults in the area, surface mapped through previous geological work. We have applied predictive deconvolution in an attempt to improve the stacked sections by reducing the guided waves from shot gathers. Some of the south dipping events are removed from the stacked section and north dipping events are obtained for the very near-surface using high-pass

filtering. Further study will help to determine whether deconvolution produces stacked sections that are more or less consistent with geology.

We recommend that both VSW and refraction statics be carried out to improve the quality of the stacked sections for the swept source data. Further work that will be important and helpful for the imaging of the complex geology in K-25 include, seismic modeling, ground roll filtering, and more complete velocity analysis.

ACKNOWLEDGEMENT

The research described in this paper was supported in part by the summer internship program provided by the Oak Ridge National Laboratory and the K-25 plant, administered by the Oak Ridge Institute for Science and Engineering of DOE. The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-96OR22464. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution or allow others to do so for U.S. Government purposes.

We would like to thank the Kansas Geological Survey, especially Rick Miller, for collecting the seismic data. Ron Kaufmann of Oak Ridge National Laboratory did some preliminary processing. Peter Lemiszki helped to relate the seismic data to the geology of K-25. Brad Carr clarified some issues in the processing. Roger Young of the University of Oklahoma made some critical suggestions. We would like to thank them all for their helps and suggestions.

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Figure 1 Site map of the five processed seismic lines east of the K-25 Plant, Oak Ridge, Tennessee. Numbers alongside of the seismic lines denote CDP numbers, with 5 ft CDP spacing. Dip symbols and numbers indicate dips and strikes measured at the outcrops.

Figure 2 Refraction statics solution of line I. Top panel: Elevation of the ground surface and the refractor. Middle panel: Velocity of refractor. Bottom panel: Long wavelength statics and short wavelength statics.

Figure 3 Comparison of stacked sections processed with various processing options.

(A) no VSW; Refraction Statics; (B) both VSW and Refraction Statics;

(C) VSW; no refraction statics; (D) VSW, Refraction Statics, Predictive Deconvolution.

Figure 3 Comparison of stacked sections processed with various processing options.
 (A) no VSW; Refraction Statics; (B) both VSW and Refraction Statics;
 (C) VSW; no refraction statics; (D) VSW, Refraction Statics, Predictive Deconvolution.