Shallow Seismic Reflection Survey near a Radioactive Storage Site at the Idaho National Engineering Laboratory

E/G 2.7

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SUMMARY

Seismic reflections can be obtained from the basalts of the Snake River Plain which is a depression filled with several thousand meters of basalt, rhyolite, and sediments of Cenozoic age. The seismic-reflection method was successful in detecting a 3-to-4-m-thick sedimentary layer at 30 m of depth within a basalt-layer/sand-layer sequence near Arco, Idaho. Some shallow reflections on the field files are of exceptional quality. The extreme variation in quality and seismic character observed on the field files recorded along the 500-m-long seismic line is uncommon for such short distances. An end-on source-receiver geometry was used with a source-to-closest-receiver distance of 12 m and a source-to-farthest-receiver distance of 35 m. A 1-m shot-and-receiver group interval resulted in 1/2-m subsurface horizontal sampling interval. The source was a silenced .50-caliber sport rifle fired vertically into the ground. The recording of dominant-reflection frequencies over 150 Hz was partially a result of severe low-cut filtering (220 Hz, 24 dB/octave). Various seismograms along a single 500-meter-long line appear to have come from entirely different geologic locations. This acoustical variability implies coherency on deeper surveys could best be maintained with hundreds of recording channels and small geophone arrays.

INTRODUCTION

This paper is a report on the feasibility of using shallow high-resolution seismic-reflection surveys to characterize structure and stratigraphy near an actively used, over 30-year-old radioactive-materials storage site at the Idaho National Engineering Laboratory. Protecting the environment from possible leaks and developing techniques to mitigate any leaks can be assisted by geophysical analyses of the near-surface materials. The seismic-reflection technique was used here to identify structural and stratigraphic changes in an inter-layered basalt/sand sequence as shallow as 10 m. Detailed knowledge of such shallow subsurface layers is often necessary to evaluate hydrologic flow at waste-storage sites and to assist in developing effective monitoring and/or mitigation procedures.

The study area is located within the central Snake River Plain between Arco and Idaho Falls, Idaho (Fig. 1). The Snake River Plain is a depression which is filled with several thousand meters of basalt, rhyolite, and sediments of Cenozoic age. In some areas within the Snake River Plain, as much as 1 km of interbedded basalt and sediments lies on top of older, rhyolitic volcanic rocks (Walker, 1964). The basalt flows in the upper 150 m of the Snake River Plain are mostly compound pahoehoe flows, 3-to-5-m thick, interbedded with numerous, usually thin, layers of sediments. These sediments are mostly clay and sand with occasional gravel and loess deposits. The use of seismic-reflection techniques to map shallow layers in the repetitive basalt/sand environment of the eastern Snake River Plain has been successful in the 75- to 450-m depth range (Miller et al., 1988).

FIELD PROCEDURES

The seismic reflection data were recorded using a standard CDP acquisition method (Mayne, 1962). An end-on source-receiver geometry was used with a source-to-closest-receiver distance of 12 m and a source-to-farthest-receiver distance of 35 m. A 1-m shot-and-receiver group interval resulted in 1/2-m subsurface horizontal sampling interval. The source was a silenced .50-caliber sport rifle fired vertically into the ground (Steeples et al., 1987). The receivers were three 40-Hz geophones damped to 0.65 of critical, connected in series on 14-cm spikes. The three geophones were in-line and equally spaced over 1-m to reduce the amount of recorded air-coupled waves and wind noise.

Two .50-caliber rifle shots were fired into the same hole and recorded separately at each station location. Reversed-refraction profiles were performed to determine a near-surface velocity and depth model for the weathered layer. The data were recorded on an I/O DHR 2400 seismograph. A record length of 125 ms and a sampling interval of 1/4 ms were used because the primary depth of interest was less than 100 m and the dominant reflection frequencies observed during testing did not exceed 250 Hz. The selected low-cut filters have a -3 dB point of 220 Hz with 24 dB/octave roll-off.

DATA PROCESSING

The key to interpreting true geologic structures or stratigraphy from processed shallow CDP seismic data is the clear identification of reflection energy on raw, unprocessed field files. The hyperbolic time-distance moveout of reflection energy can be identified on most field files across the entire line (Fig. 2). The raw field file from near well 88 has several relatively strong reflection arrivals. The event at approximately 55 ms is interpreted as a reflection from the approximately 3-4-m thick sedimentary layer at about 30 m identified on geophysical logs of well 88 (Fig. 3). Due to the extreme variability of the near-surface geology along the line, correlating that reflection event from field file to field file is impossible over a horizontal distance of more than about 30 m. The velocity, apparent structure, and general reflection character of the seismic data on the raw field files vary greatly as the survey moved from one basalt-flow lobe to another. The general variability in the raw data emphasizes the need for care during the computer processing of data.

The velocity structure at this site is complicated by basalt flow irregularities, non-uniform sedimentary deposition, and a variable thickness of near-surface material characteristic of volcanic environments. The brute stack section which includes preliminary velocity analysis, spectral analysis, and surface-consistent statics lacks coherent reflection information (Fig. 4). Reflection information can be confidently identified on field records across the entire expanse of the profile. However, sufficient variability in both velocity and near-surface conditions exists within the length of the 24 channel spread that conventional velocity analysis inhibited the selection and eventual assignment of the correct normal moveout velocity.

In order to confidently and accurately select the correct moveout velocity and static corrections, all non-reflection information that could be identified was removed by surgically separating the data into two sets: (1) seismic reflections that could be identified on the field plots, and (2) everything else. The velocity analysis and surface-consistent statics computation were done on the reflection-only information so as to avoid the influence of coherent noise or other non-reflection signal present on the seismograms. The corrections derived from this computation were then applied to both the previously extracted exclusive reflections and to everything else. After the corrections were applied to the two data sets independently, they were merged, CDP sorted, and stacked.

RESULTS

The dominant frequency of much of the raw data is easily in excess of 150 Hz. The average interval velocity of the weathered layer was calculated to be approximately 500 m/s overlying an approximately 2000 m/s bedrock. Using a one-forth wavelength minimum vertical resolution criterion (Widess, 1973) and a normal moveout velocity of 1000 m/s, vertical-bed resolution is on the order of 1.7 m. The horizontal sampling interval was 0.5 m, providing over 15 samples within the first Fresnel zone in the upper 30 m, surpassing the suggested 4-sample minimum of Knapp and Steeples (1986). Minor distortion in interpreted geologic structure can occur in some situations as a result of oversampling the first Fresnel zone (Myers et al., 1987). The geologic setting, in association with the characteristics of the seismic data, suggests that the effects of the defocusing of reflected seismic energy as a result of oversampling, could cause some minor smoothing of interpreted geologic structure at this site. It is also noteworthy that oversampling of Fresnel zones was necessary to maintain coherency of the reflections in this highly heterogeneous environment.

The stacked section (Fig. 6), with the reflection and noise portions processed separately and then recombined, were compared with the reflection-only stack (Fig. 5) to more accurately interpret the reflection data. The stacked reflection section is of sufficient quality to confidently interpret the sedimentary layer at 30 m (Fig. 6). The acquisition and processing of this entire data set was focused on recording and enhancing the sedimentary reflector identified on field files at about 50 ms (40 ms after static correction on the stacked sections.) The obvious reflections present on the stacked sections are restricted to a relatively narrow time window between about 30 and 70 ms. This narrow time-window appearance of the data is due to the very precise and focused acquisition and processing parameters as well as the limitations of our seismograph.

The apparent major long-wavelength synclinal structure and the multiple localized structural lows, observable in the 40-ms-deep sedimentary layer, are either real geologic features that could be drill verified with two or three holes, or they are processing artifacts (Fig 6). The long-wavelength synclinal structure located between CDP's 250 and 860 has a maximum relative depth of about 15 m. The multiple apparent localized structural lows, generally no more than 20 to 30 m across, have a maximum relative depth of no more than 10 m. Any structure interpretable on the stacked sections that appears to mimic the refraction-derived bedrock map and the stacked refraction arrivals on the processed noise sections are probably artifacts of the refraction statics process.

Frequency and phase anomalies at several places on the seismogram inhibit attempts to confidently correlate the sedimentary reflector across the line (Fig. 6). Between CDP's 350 and 400 and between CDP's 625 and 700, the reflection frequency varies as much as 25 percent, making correlating through the area speculative. Abrupt horizontal variations in phase angle of as much as 120 degrees in correlated reflection arrivals are observable at CDP's 200, 525, 770, and 975. Near-surface variations, changes in the geology at or near the depth of the reflector, or phase distortion due to severe low-cut filtering in the amplifiers are responsible for these phenomena. Without drilling information, confident determination of the geology in these areas and, therefore, the source of the phase and frequency distortion cannot be identified.

Much of the slightly disjointed appearance of the reflector is a result of extreme fluctuation in stacking velocity from point to point. The overall coherency and consistent appearance of the event on the processed sections support the overall geologic interpretation.

CONCLUSIONS

Seismic reflections can be obtained from the basalts of the Snake River Plain. The seismic-reflection method was successful in detecting a 3-to-4-m-thick sedimentary layer at 30 m of depth within a basalt-layer/sand-layer sequence. Some reflections on the field files are of exceptional quality with dominant frequencies in the 150- to 200-Hz range. The extreme variation in quality and seismic character of the field files along the 500-m-long seismic line is uncommon for such short distances. Much of the variability evident on the seismic data can be attributed to the complicated composite depositional structure of the different lobes of the basalt flows and to the near-surface unconsolidated layer, which varies from zero to approximately 8 m in thickness.

The extreme variability of the seismograms suggests that static corrections for deeper surveys could be very significant in processing data from deeper in the geologic section. A small group interval, coupled with small geophone arrays (2-3 m across), would allow much better static corrections as well as preserve coherency of deeper reflections, particularly if a seismograph system with several hundred channels were used.

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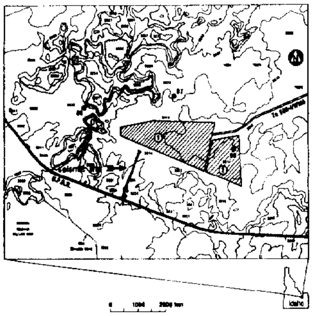

FIG. 1. Site map indicating 500 m-long seismic-reflection line and well 88.

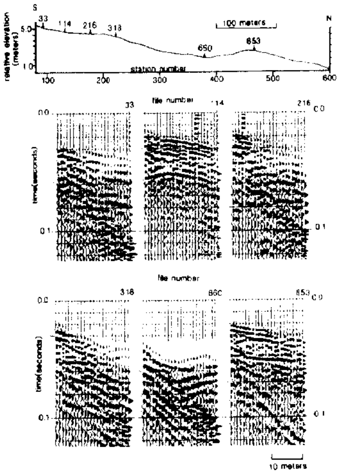

FIG. 2. Raw field files from various places indicate variability in near-surface.

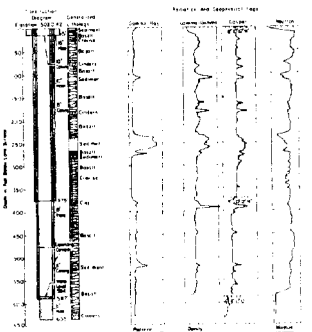

FIG. 3. Well construction and geophysical logs for well 88 (EG&G, Idaho).

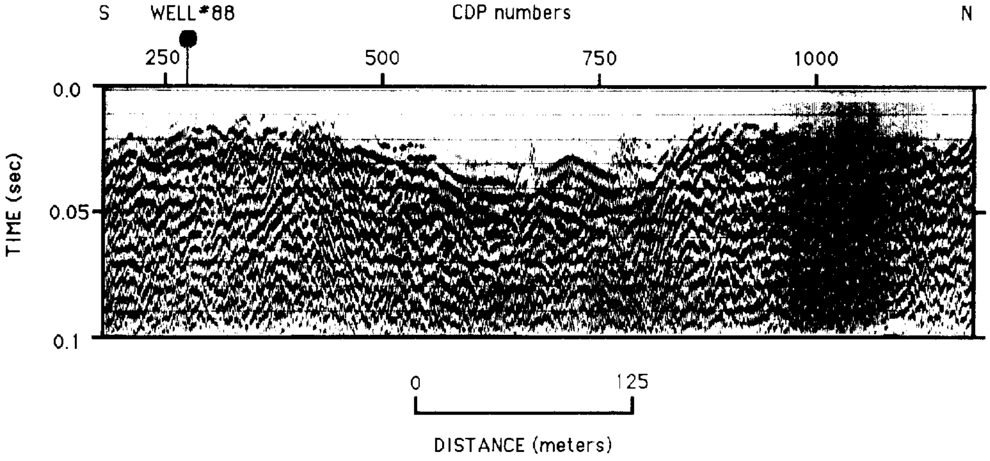

FIG. 4. Brute-stacked seismic section from 500 m-long line.

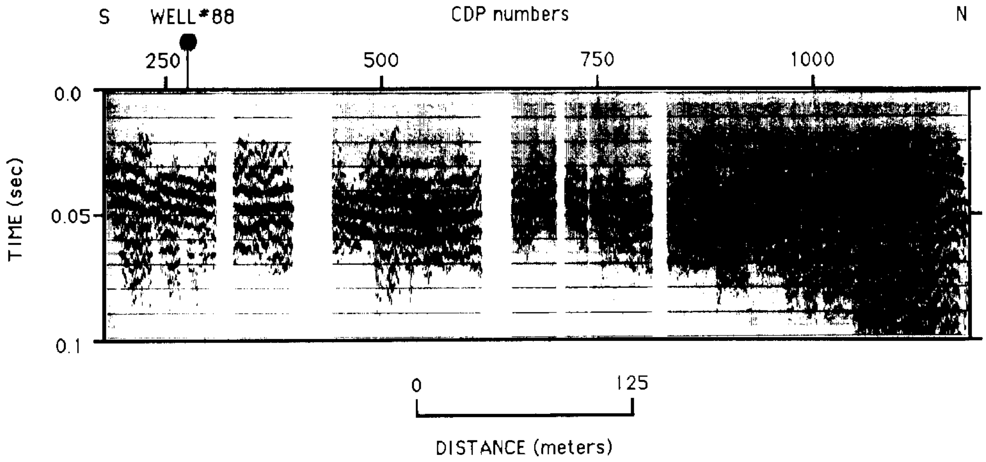

FIG. 5. 12-fold CDP-stacked seismic data of shot 1 reflection only.

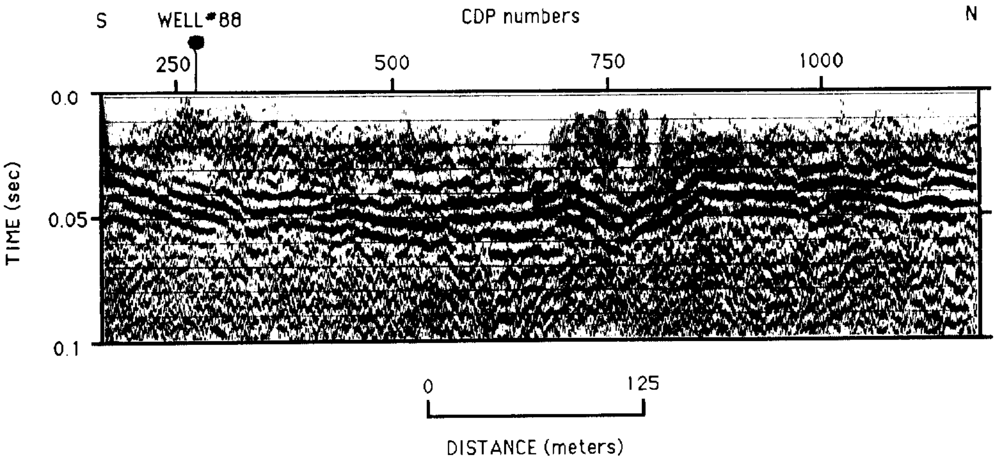

FIG. 6. Combination of reflection data (Figure 5) without identifiable reflections.