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Investigation of the shallow subsurface near the Paducah Gaseous Diffusion Plant using SH-wave seismic methods

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Summary

Over 17 km of shallow, high-resolution SH-wave reflection and refraction data were collected near the Paducah Gaseous Diffusion Plant (PGDP) in Paducah, Kentucky (Fig. 1). The data have been used to characterize the shallow subsurface structure neighboring the PGDP. This study indicated that the subsurface structure influences the flow of groundwater in the study area. The study also revealed that deformation is present in the Quaternary Lower Continental deposits, which includes the regional gravel aquifer (RGA). Of interest to the characterization of the structure within the area is the presence of a graben, imaged in the Mississippian bedrock over a distance of roughly 0.8 km. The trend of this graben follows that of the Fluorspar Area Fault Complex (FAFC) and of several faults in southernmost Illinois that also display evidence of Quaternary deformation.

Introduction

Shallow seismic reflection and refraction imaging are indispensable tools for studying near-surface geology. This is particularly the case in the northern Jackson Purchase region; here, bedrock is overlain by at least 90 m of poorly consolidated sediments. However, bedrock reflections can be identified and correlated on profiles throughout the study area.

This study was sponsored by the Department of Energy as part of their effort to understand the nature of the shallow subsurface near the PGDP. In the early 1980s, two contaminant plumes containing TCE and Tc-99 were discovered in the RGA. Based on monitoring well data, it was determined that the plumes were migrating away from the PGDP in a northeastwardly direction. It is believed that the Lusk Creek and other segments of the FAFC extend into Kentucky, near PGDP, along the same trend (Nelson et al., 1997). As a result, it was hypothesized that if faulting extended upward into the Quaternary sediments of the RGA, then the direction of the migrating plumes was fault controlled. The goal of the resulting seismic investigation was to determine if the Mississippian bedrock was faulted, and if the faults extended up through the unconsolidated Cretaceous sediments, at least to the base of the RGA. This paper presents some of the results of the study.

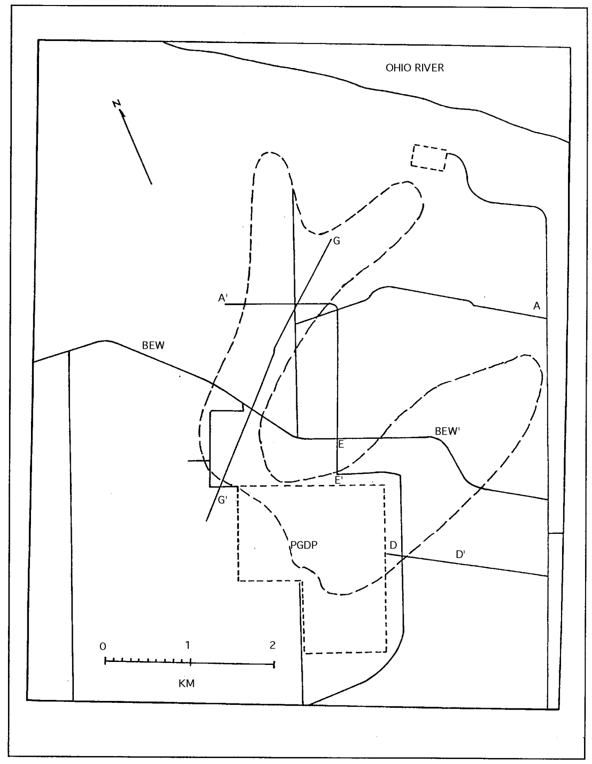

Figure 1. Area map of PGDP and vicinity. Contaminant plumes are shown by long dashed lines.

Geological Setting

Paducah, Kentucky is located along the Ohio River in the northernmost tip of the Mississippi Embayment. The local stratigraphy includes poorly consolidated sands, clays and gravels of Cretaceous to Recent age (Olive, 1972). These sediments unconformably overlie Mississippian limestone, which is roughly 90 to 100 m in depth. An erosional unconformity occurs near the plant, where the ancestral Tennessee River cut into Paleocene and Eocene sediments (Olive, 1972). Pliocene and Pleistocene sediments unconformably overlie Cretaceous through Eocene sediments. A veneer of Pleistocene loess as well as Pleistocene to Recent alluvium rests atop the Lower Continental deposits.

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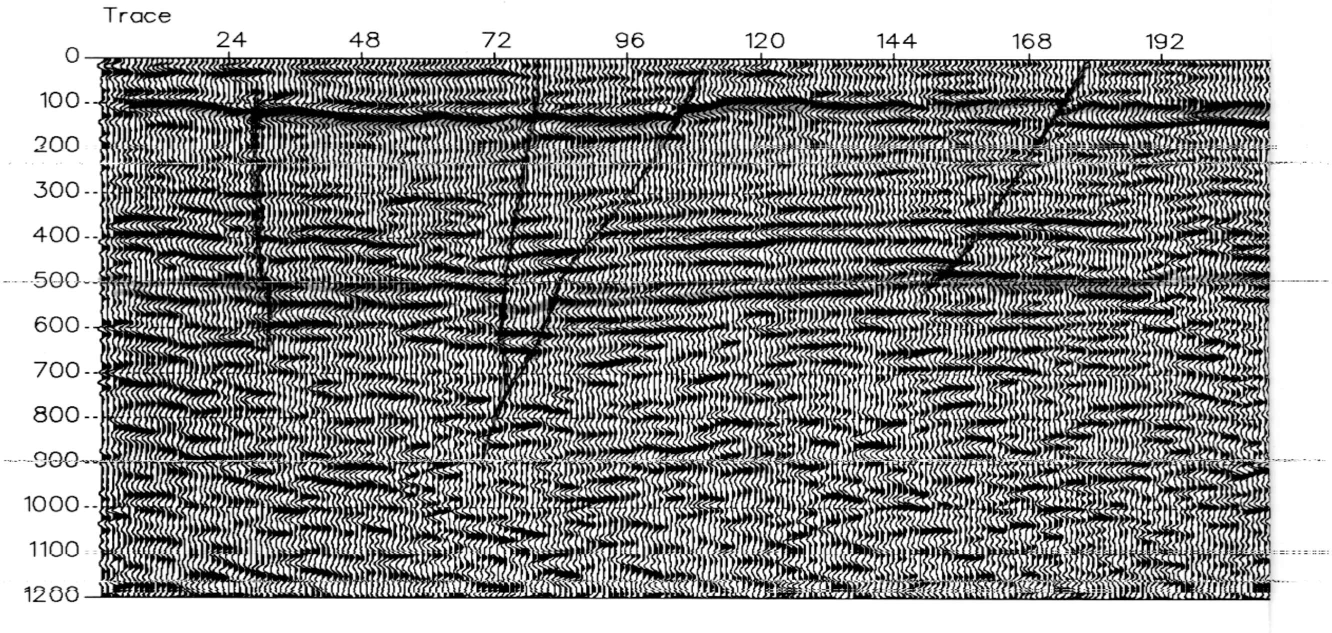

Figure 2. Seismic section for line D-D'. Note faulting throughout section that interrupts reflectors at ~150 and ~500 ms.

Method

Based on field tests using seismic hammers and a vacuum-assisted weight drop, it was determined that SH-waves generated by a seismic hammer resulted in the optimum signal-to-noise ratio for imaging the bedrock and unconsolidated sediments in the study area. The energy source consisted of a 5.4-kg sledgehammer striking a 12-kg section of I-beam perpendicular to the geophone spread. The hold down weight of the I-beam, including the hammer swinger standing on the beam, was approximately 85 kg. Coupling of the energy source to the ground was enhanced by embedding the I-beam against the edge of a blacktop road when possible; otherwise, the edge of the I-beam was embedded in a small slit trench.

An in-line spread of 48, 30-Hz, horizontally-polarized, shear-wave geophones, spaced at 4 meter intervals, was used. A zero offset was used with the energy source, and records were generally stacked six times at each shotpoint. To ensure proper identification of SH-wave events at each end of the spread, hammer hits were recorded from both sides of the I-beam energy source. The polarity was then reversed at each end of the spread to effectively cancel any P- or SV-waves and to ensure proper identification of the SH-waves generated. After recording the first 24 shotpoints, the corresponding geophones were moved downline to become geophones 25 through 48 of the next spread, thus ensuring 12-fold data.

SH-wave CDP data used in this study were collected with a 48-channel, 24-bit, IFP engineering seismograph, and recorded at a sampling rate of 0.5 ms. Acquisition parameters included low-cut and high-cut bandpass filters of 10 and 250 Hz, respectively. A notch filter of 60 Hz was used in the study to negate the effects of low-lying, high-voltage power lines in the area. Processing of data was done on a PC using the software package VISTA (Seismic Image Software Ltd., 1992).

Examples

Seismic sections for lines D-D' and E-E' (Fig. 1) are shown in Figures 2 and 3, respectively. These sections present data typical of that obtained throughout the study. Prominent reflections show up at ~500 ms and ~150 ms on each section. Refraction data, along with drillhole data and velocity estimates from a previous study (Sykora and Davis, 1993), indicate that the reflector at ~150 ms is the base of the RGA, whereas the reflector at ~500 ms is the top of the Mississippian bedrock. Faulting is evident on both profiles, clearly extending from the top of the bedrock into the base of the RGA. The locations of these fault zones coincide with the northwest and southeast edges of the northeast contaminant plume, as shown in Fig. 1.

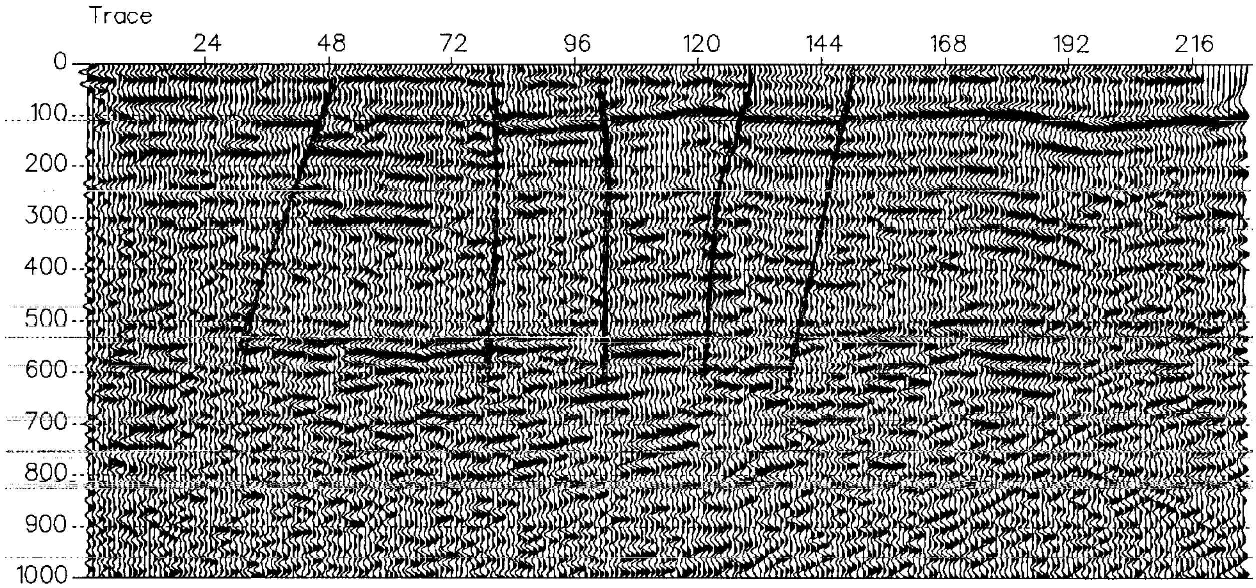

Figure 3. Seismic section for line E-E'. Faulting here also appears to offset reflectors at ~150 and ~500 ms.

While collecting data for this study, a larger structure was recognized at the western terminus of line BEW. Additional seismic lines were then ran farther west where a graben was identified within the Mississippian bedrock. Reprocessing of existing data along the western end of A-A' and the northern termination of line G-G' (Fig. 1) clearly showed that the graben crossed these lines in a northeastwardly fashion. The trend of the graben is nearly identical to the trend of the faults identified along sections D-D' and E-E', and to the trend of the faults within the FAFC as mapped by Nelson et al (1997).

Conclusions

The high-density array of seismic profiles in the area of the PGDP provide overwhelming data which support the hypothesis that contaminant plume migration is structurally controlled. Faulting that extends into Quaternary strata has been imaged throughout much of the study area. Many of these structures coincide with proposed contaminant plume boundaries; therefore, faulting is likely presenting preferential flow paths for contaminant migration. Such structures were complementarily imaged using refraction data. Thus, the northeast-trending plumes parallel the trend of structure surrounding PGDP. Additionally, largely due to the results of this study, a remediation plan has been implemented in order to control the migration of the contaminant plumes.

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