Project Number:	70052
Title:	Material Property Estimation for Direct Detection of DNAPL using Integrated Ground-Penetrating Radar Velocity, Imaging and Attribute Analysis
Date:	6-1-2001
Lead PI:	John Bradford, (307) 766-3239, johnb@uwyo.edu
Co-PIs:	Scott B. Smithson, (307) 766-5280, sbs@uwyo.edu W. Stephen Holbrook, (307) 766-2427, steveh@uwyo.edu University of Wyoming, Department of Geology and Geophysics Laramie, Wyoming 80271-3006
Graduate Students:	Jake Deeds

Research Objective

The focus of our work is direct detection of DNAPLs, specifically chlorinated solvents, via material property estimation from surface ground-penetrating radar (GPR) data. We combine sophisticated GPR processing methodology with quantitative attribute analysis and material property estimation to determine the location and extent of residual and/or pooled DNAPL in both the vadose and saturated zones. An important byproduct of our research is state-of-the-art imaging which allows us to pinpoint attribute anomalies, characterize stratigraphy, identify fracture zones, and locate buried objects. Implementation and verification of these methodologies will be a significant advance in GPR research and in meeting DOE's need for reliable in-situ characterization of DNAPL contamination.

Chlorinated solvents have much lower electric permittivity and conductivity than water. An electrical property contrast is induced when solvents displace water in the sediment column resulting in an anomalous GPR signature. To directly identify zones of DNAPL contamination, we focus on three aspects of reflected wave behavior - propagation velocity, frequency dependent attenuation, and amplitude variation with offset (AVO). Velocity analysis provides a direct estimate of electric permittivity, attenuation analysis provides a measure of conductivity, and AVO behavior is used to estimate the permittivity ratio at a reflecting boundary. Areas of anomalously low electric permittivity and conductivity are identified as potential DNAPL rich zones. Preliminary work illustrated significant potential for quantitative direct detection methodologies in identifying shallow DNAPL source zones. It is now necessary to verify these methodologies in a field setting. To this end, the project is field oriented and has three primary objectives:

1) Develop a suite of methodologies for direct detection of DNAPLs from surface GPR data
2) Controlled field verification at well characterized, contaminated sites
3) Exploratory contaminant detection in a field setting to be verified through direct sampling

Field experiments are being conducted at the Savannah River and Hanford sites, and five DOD sites (Dover AFB, DE; McClellan AFB, CA; Port Hueneme, CA; Wurtsmith AFB, MI; Hill AFB, UT).

Research Progress and Implications

This section summarizes work after 21 months of a three-year project. Work completed during the first reporting period (ending 6-15-2000) includes:

1) Acquisition of a 3-D GPR survey at the A-014 outfall, A/M area, Savannah River Site, and identification of a radar velocity anomaly consistent with the presence of DNAPL.
2) Integration of three-phase fluid flow and GPR response modeling in preparation for the

controlled injection experiment at Dover AFB.

Continuing our field effort during the current reporting period (6/16/2000 - 6/15/2001) we acquired a 32,000 sq. ft., 3-D multi-offset GPR survey at OU-1, Hill AFB, UT. At the site, 6 - 10 m of gravel to silty sand comprising the Provo Alluvium overly the clays of the Alpine Formation. The Alpine clay acts as an aquitard as the water table fluctuates about the sand/clay boundary on an annual cycle. From the 1952 to 1973 a variety of both LNAPL and DNAPL contaminants were dumped in two chemical disposal pits (CDPs 1 & 2) and burned (1995). A significant quantity of non-combusted liquids leaked from the CDPs to the underlying aquifer and now comprise a free product plume that covers approximately 7 acres with measured thickness as much as 1 ft. The plume is highly heterogenous mixture composed primarily of jet fuel and light lubricating oil with a significant dissolved solvent phase. In addition to the floating pool, the contaminant accumulates in a smear zone that is controlled by water table fluctuation, with the relative amounts of pooled and smeared NAPL dependent on water table elevation. Previous work by Enfield et al. (1998) indicates that contaminated soil at the site has relatively low electric conductivity. We also expect low electric permittivity to be associated with zones of soil contamination.

Our 3-D survey was designed to bound CDP 1 on the east, west and north sides and to extend beyond the known boundary of the free LNAPL plume. Survey objectives included imaging the sand/clay interface and direct detection of the LNAPL plume. Data were acquired using a 50 MHz antenna set, 2 ft source spacing, 1ft receiver spacing, and 25 fold common source gathers. Four adjacent CMPs were combined to proved a 25-fold CMP data set with 2 ft CMP spacing. Using pre-stack depth migration velocity analysis and imaging we were able to extract a detailed map of the sand/clay boundary (Figure 1). Depth to clay interpreted from the processed radar image agrees with the 12 boreholes located within the 3-D patch to within 1 ft with the exception of two boreholes. The radar image indicates that the clay surface topography is significantly more complicated than previously mapped using borehole information alone.

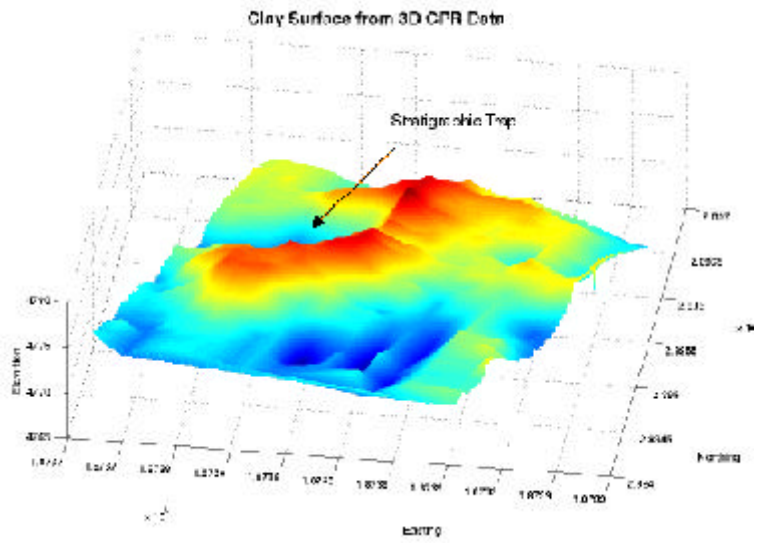

Figure 1 Surface of the sand/clay interface interpreted from the 3-D GPR survey. The trough to the northwest may act as a stratigraphic trap. Analysis of the GPR data indicates that physical properties of sediments filling the trough are consistent with elevated NAPL concentrations.

We found a significant ridge and trough on the clay surface that was not previously identified. The trough lies beyond the known location of the free LNAPL plume, but may act as a stratigraphic trap. Sediment within the trough was not previously sampled so it is not currently known if it contains elevated NAPL concentrations. Our data show a zone of anomalous reflectivity directly above the trough that does not appear geologic in nature. Additionally, velocity analysis indicates that the zone of anomalous reflectivity is associated with a very large velocity anomaly. Both of these effects are consistent with an accumulation of low permittivity LNAPL. Additionally, preliminary AVO analysis indicates that the anomalous reflectors have a large AVO gradient. This is consistent with

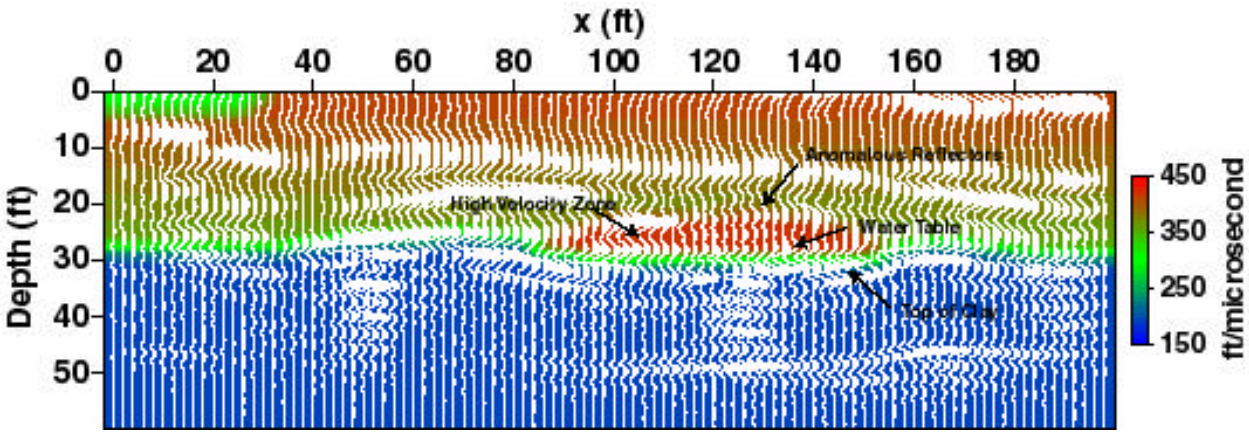

Figure 2 Pre-stack depth migrated image along Line 14 in the 3-D GPR survey. The water table and sand/clay interface are well imaged, as well as a zone of anomalous reflectivity. The anomalous zone is associated with high radar velocities which may indicate the presence of NAPL.

the velocity analysis results. If the trough is verified as a NAPL rich zone, this information will be used to modify the NAPL plume parameters and may used in future remediation planning.

At both the Savannah River and Hill AFB sites, we located both physical property anomalies and stratigraphic features that were not previously identified and are consistent with NAPL rich zones. This is an interesting turn of events, as these sites were originally chosen to represent highly controlled sites that had been extensively studied using direct sampling methods. As it turns out, experiments at both sites have both a controlled component, and an exploration component. This being the case, we have begun our verification effort to investigate radar anomalies. At the Savannah River site, two boreholes have been completed, with two additional holes to be completed in June, 2001. At Hill AFB, 5 holes are scheduled to be completed in June, 2001. All holes are being logged for lithology, and subsampled for chemical analysis. Additionally, a total of 6 are being cased with PVC tubing which will act as access tubes for deployment of downhole electric permittivity and conductivity probes to verify the results of radar velocity, attenuation and AVO analysis.

Additional work completed during this reporting period includes implementation of a non-linear algorithm for computing the permittivity ratio at a reflecting boundary from GPR AVO data, and continued development of GPR specific AVO analysis software suitable for application to exploration scale data volumes. Also, we have completed reporting requirements required for state approval of the controlled PCE injection experiment at Dover AFB, DE.

Planned Activities

In July, 2001, we complete the controlled injection experiment at Dover AFB, DE. The injection will consist of two, 50 l PCE injections. The first will be within the saturated zone and the second will be within the vadose zone, approximately 2 m above the water table. PCE migration will then be monitored for up to 30 days using surface GPR and downhole probe measurements. Upon completion of the GPR effort, the site will be extensively sampled using a variety of Geoprobe based methods. This experiment has been delayed over a year, primarily due to the state permitting process. In August through September 2001, we will conduct experiments at the Hanford Site, WA, the former Wurtsmith AFB, MI, McClellan AFB, CA, and Port Hueneme, CA.

References

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Montgomery Watson, 1995, Hill Air Force Base, Utah: Comprehensive remedial investigation report for Operable Unit 1 - Volume 1; Salt Lake City.