Electrical resistivity variations associated with controlled gasoline spills

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Summary

A number of geophysical surveys were conducted over two controlled releases of about 100 gallons each of gasoline. In order to clearly identify the responses associated with the gasoline plume, measurements were made before, during and after the injection. The two experiments were conducted about three years apart in the same geologic cell at the controlled tank facilities at the Oregon Graduate Institute in Beaverton , OR. The results of high resolution (2.5 cm spacing) downhole electrical resistivity measurements are presented in this paper.

An increase in the electrical resistivity in the capillary zone above the water table was observed with the injected gasoline plume in both experiments. However, the magnitude and shape of the anomaly were considerably different in the two experiments and appear to be associated with the properties of the capillary zone and history of water infiltration prior to the gasoline injection. In order to study longer term responses, measurements were taken 7 months later in the second experiment. These results proved difficult to interpret because considerable rainfall in the area flooded the cell a number of times, causing movement and smearing of the gasoline plume.

Introduction

Electrical geophysical methods have proven to be fairly effective in delineating inorganic contaminants in the subsurface. The mechanism and responses are fairly well understood. Their application for mapping organic contaminants in the subsurface, in particular non-aqueous phase liquids, is not as well accepted nor the mechanisms as well understood. Various surveys have reported results conducted over subsurface organic contamination, however the actual anomaly associated with the organic contamination has been difficult to ascertain over other factors caused by variations in the porosity, degree of saturation, mineralogy, and structure. (Pitchford et al, 1989). For this reason, a number of laboratory studies and controlled spill experiments have been conducted over the past few years in order to evaluate the changes in the physical properties of the geological formations and the associated geophysical responses due the presence of the organic contamination (Greenhouse et al, 1993, Redman et al, 1994, Brewster and Annan, 1994).

As part of this ongoing study , two gasoline spill experiments were conducted in the controlled tank facilities at the Oregon Graduate Institute (OGI) in Beaverton, OR The spills were monitored with a number of geophysical methods: surface and cross borehole ground penetrating radar (GPR), surface and cross borehole resistivity tomography, borehole neutron and dielectric logging, borehole electromagnetic induction logging, downhole video camera logging, high resolution seismic tomography, and high resolution borehole resistivity logging. This paper presents the results of the high resolution resistivity logging. In addition to providing high detailed vertical resolution of resistivity changes associated with the gasoline plume, these measurements provided modeling input for interpretation of the responses of the other geophysical methods, such as the GPR and cross borehole resistivity tomography. Based upon these results, earlier electrical resistivity field surveys that had been conducted over known gasoline plumes are being reanalyzed.

Field spill experiments

The spill experiments were conducted in one of the OGI tanks, which consists of a double steel walled cell about 8m by 8m by 4.5 m deep, that was filled with Columbia River basaltic sand. A high resolution downhole resistivity probe was constructed out of 2 inch PVC pipe. Brass screws were used for electrodes. They were screwed through the pipe and extended 1 cm into the formation, they were spaced 2.5 cm apart down to a depth of 160 cm. A “stealth” resistivity system was constructed with removable wires, to minimize interference with the GPR measurements. The resistivity electrode array (R1) was permanently installed about 1.3 meters from the gasoline injection point, which was in the middle of the cell (see Figure 1.) Wenner array resistivity measurements were made every 2.5 cm with an Abem Tetrameter 3000. This is a synchronous detection instrument and stacking from 1 to 4 cycles showed less than a 0.5% variation. A frequency of 0.1 Hz and current levels of 0.5 to 1 milliamp were used throughout the measurements. The system was calibrated for each run with a known fixed resistance box. The calibration varied a maximum of +/-0.5% throughout the period of all the experiments.

The first spill experiment was conducted in August 1992. The water table was lowered to 91 cm below the surface and repeated measurements with all the geophysical methods were started 8 days before the start of the gasoline spill. However, a number of other experiments were conducted in the cell up to 2 days before the start of the gasoline spill. These included the movement of the water table back up to the surface for an air sparging test, and the injection of about 50 liters of a conductive KCL fluid into the cell about 2 meters from the gasoline injection point. Considerable changes in the electrical resistivity were observed throughout these tests. After the KCL injection, the surface GPR surveys were no longer able to see reflections **from** the water table. Fresh water was sprayed on the surface of the KCL injection area and water was pumped out of well P3 in an attempt to flush out the KCL subsurface plume. However, GPR reflections from the water table were still not observable. The cell was allowed to stabilize with the water table at a depth of 9 1 cm for 18 hours before the start of the gasoline spill experiment. Measurements were made with the downhole electrical resistivity probe Rl about every 4 hours during this time in order to establish any long term temporal drift in the background electrical resistivity. The injection of British Petroleum (BP) unleaded gasoline started on August 28,1992 at 9:05 AM The gasoline was injected in the center of the cell at a depth of about 20 cm below the surface. A total of 104 gallons (394 liters) of gasoline was injected over a period of 8 1 hours at a fairly constant rate of 1.28 gallons/hour. Resistivity measurements were made about every 2 hours at the start of the spill and were extended to about every 8 hours towards the end of the spill when changes occurred slower. Monitoring of the gasoline plume continued for an additional 87 hours after the spill was completed.

Because of the variations, ambiguity, and poor responses of a number of the geophysical methods cause by the 1992 pre-spill tests, a repeat gasoline spill experiment was conducted in September 1995. The 1992 gasoline spill was remediated utilizing air-sparging technology. The final phase of the air sparging was completed about 11 days before the start of the 1995 gasoline spill. The water table was initially at the surface. It was then dropped to 240 cm below the surface and the vadose zone was allowed to drain for four days. Two additional high resolution resistivity probes were installed, R2 and R3 (see Figure 1). These were constructed in a similar manner to the initial RI probe installed in 1992. Water was then injected from the bottom upward through wells around the edges of the cell. The water table was raised and allowed to stabilize at a depth of 100 cm over 6 days during which it was monitored with the geophysical measurements. The Rl probe was inspected and tested. It was found to be still in excellent condition. Since no changes had been made to the geology of the cell, data from this probe allowed direct comparison to the 1992 experiment. The injection of 100 gallons (379 liters) of Chevron regular unleaded gasoline started on September 11 at 4:30 PM. The injection was at the same location as the 1992 experiment and occurred over a period of 93 hours at a fairly constant rate of 1.08 gallons/hour. Repeated measurements were made about every 6 to 10 hours with all three probes RI, R2, and R3 throughout the spill and continued for three days afterward.

In order to evaluate the longer term geophysical response of a gasoline plume, measurements were again taken 7 months later , in April 1996. Considerable rainfall had occurred in the Beaverton, OR area in the preceding months. The cell had been flooded and had been pumped down a number of times. Upon arrival, the water table was dropped to about 100 cm, however it was difficult to maintain at that depth since rain showers occurred throughout the measurement period of April 16 to 19, 1996, continuously raising the water table.

Results

Some of the results of the borehole resistivity probe Rl are shown Figure 2. This is a plot of the apparent resistivity as a function of depth at various times with respect to the start of the gasoline spills. Data from both the 1992 and 1995 spills are presented. A prespill , mid-spill, and a measurement at the end of each spill are shown. Considerable difference is observed in the prespill measurements between the two experiments. Assuming an Archie*s law resistivity inverse squared dependance on saturation contend, these results may be interpreted in terms of moisture content . The capillary fringe in the 1992 spill appears to be fully saturated to about 15 cm (75 cm depth) above the water table, compared to a capillary fully saturated zone of about 4 cm in the 1995 spill. At a depth of 80 cm, the moisture contend for the 1995 spill is about 60%, compared to 100% saturation in the 1992 spill. Above this zone, the capillary fringe in the 1992 still appears to contain more moisture than in the 1995 spill. Resistivity measurements from the two spills become about equal at a depth above 50 cm. This difference in the capillary zone moisture contend is attributed the difference in preparation of the water table in the two experiments, in particular to the surface water spraying associated with the KCL flushing in the 1992 experiment. Considerable difference is observed in the electrical resistivity response associated with the gasoline plume in the 1992 and 1995 spill experiments. In both cases resistivity increases are observed in the capillary zone above the water table. However the anomaly in the 1992 spill is considerably larger in both resistivity change and layer thickness. The 1992 data indicate a maximum of 220% resistivity increase with a layer over 30 cm thick, compared to about a 50% increase and a 15 cm thick layer for the 1995 spill. No change in electrical resistivity is observed at or below the water table that can be clearly identified with the gasoline Some changes are observed below 100 cm, but these are attributed to residual trapped air from the air-sparging experiments slowly being released and causing the resistivity to decrease. This becomes clearly evident upon inspect of the long term monitoring data. Based on the resistivity data, it is estimated that about 15% of the pore spaces still had residual trapped air in the formations below the water table at the start of the 1995 gasoline spill. Increases in the cross borehole radar travel times were also observed below the water table and are attributed to this escaping trapped air (Ellefson, 1998). It is believed that this trapped air was a major cause of the poor quality of the seismic cross borehole measurements . The GPR surface measurements were fairly successful in the 1995 experiment. The water table was observed over most of the cell and a bright spot was observed with the presence of the gasoline (Campbell et al, 1996).Computer modeling based upon the resistivity profiles are being conducted in order to understand the difference in the GPR responses from the 1992 to 1995 experiments.

Based upon these results, earlier electrical resistivity field surveys that had been conducted over known gasoline plumes are being re-analyzed. An increase in electrical resistivity appears to be associated with these gasoline plumes, even after the gasoline has been in the ground for more than a year (Pitchford et al, 1989).

Conclusions

The use of high resolution downhole resistivity measurements gave considerable insight to the distribution and migration of subsurface gasoline plumes in the controlled spill experiments. In addition, the resistivity measurements provided useful high resolution information of the changes in the formation properties, such as residual trapped air and variations in the moisture content of the formations.

The electrical resistivity was observed to increase with the presence of gasoline in both the 1992 and 1995 spills. However, the changes were considerable different in the two experiments even through data were compared from the same location, same formation and with the same resistivity probe. All the resistivity changes associated with the gasoline plumes occurred in the capillary fringe above the water table and appear to be highly dependent upon the properties of the capillary fringe and history of moisture infiltration.

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References

Brewster, Michael, and A. Peter Annan, 1994, Ground-penetrating radar monitoring of **a** controlled DNAPL release: 200 MHz radar, Geophysics, Vol. 59, No. 8, August 1994, p. 1211-1221.

Campbell, D.L., J. E. Lucius, K. J. Ellefsen, and M. Deszcz-Pan, 1996, Monitoring of a Controlled LNAPL Spill Using Ground-Penetrating Radar, Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 1996, p. 5 1 l-5 18.

Ellefsen, Karl J., 1998, An Analysis of Crosswell Radar Data Collected during and Experimental Gasoline Spill, USGS Open File Report 98-225, 36 p.

Greenhouse, John, Michael Brewster, George Schneider, David Redman, Peter Annan, Gary Olhoeft, Jeff Lucius, Kathy Sander, Aldo Mazzella, 1993, Geophysics and Solvents: The Borden Experiment, The Leading Edge, April 1993, p. 261-267.

Pitchford, A.M., A.T. Mazzella, and K.R. Scarbrough, 1989, Soil-Gas and Geophysical Techniques for Detection of Subsurface Organic Contamination, Final Report, Air Force Engineering and Services Center Report, ESL-TR-87-67, 172 p.

Redman, J.D., S.M. DeRyck, and A.P. Annan, 1994, Detection of LNAPL pools with GPR- theoretical modelling and surveys of a controlled spill: Proceedings of the Fifth International Conference on Ground Penetrating Radar, sponsored by The Waterloo Center for Groundwater Research and the Canadian Geotechnical Society, June 1216,1994, Kitchener, Ontario, Canada, p. 1283- 1294.

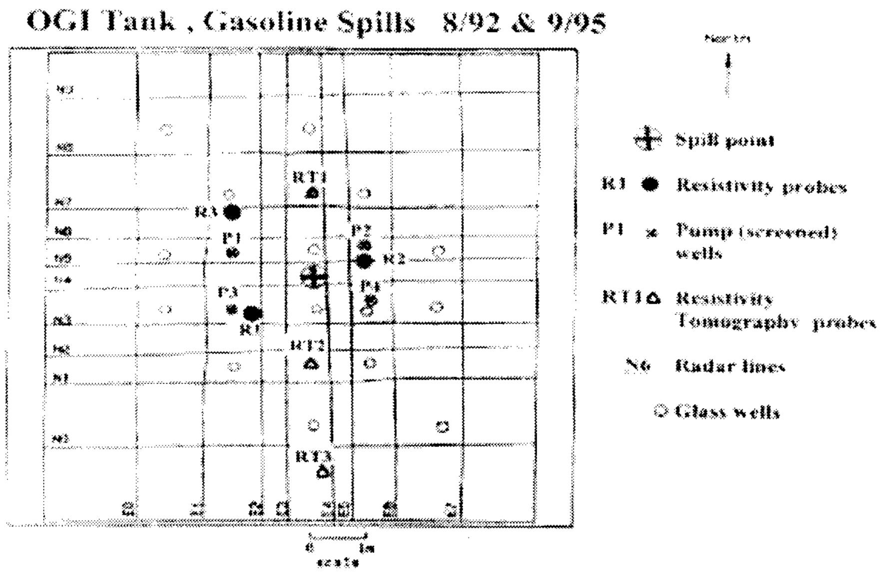

Figure 1. Schematic of OGI tank layout showing the location of various geophysical surveys, monitoring wells and borehole probes that were used for the gasoline spills conducted in August 1992 and September 1995.

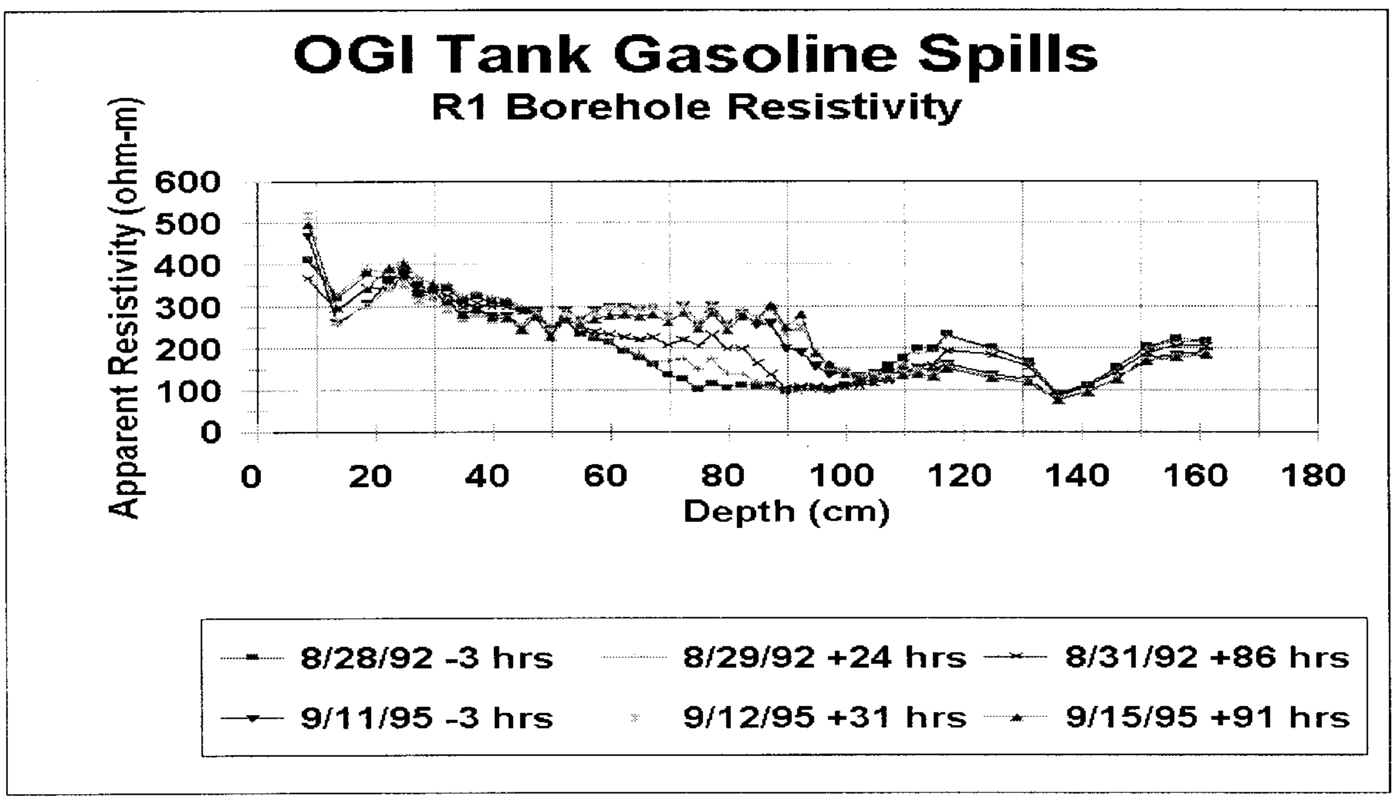

Figure 2. Plot of apparent resistivity verses depth for various times for the 1992 and 1995 gasoline spills. Times (hrs) are in reference to the start of the respective gasoline spills. The water table was at a depth of 91 cm for the 1992 spill and at 100 cm for the 1995 spill. The gasoline response occurs in the capillary zone above the water table. Resistivity changes below the water table are associated with trapped air being released.