Case Study Abstract

Wurtsmith Air Force Base
Oscoda, Michigan

Site Name and Location: Wurtsmith Air Force Base Oscoda, MI 48750	**Geophysical Technologies:** Ground penetrating radar Electromagnetic induction Magnetometry	**CERCLIS #** MI5570024278
Period of Site Operation: 1923 - 1993 **Operable Unit:** OT-16b		**Current Site Activities:** None
Point of Contact: Paul Rekowski BRAC Environmental Coordinator AFB Conversion Agency/DD Wurtsmith 3950 East Arrow Street Oscoda, MI 48750 (517) 739-5161 prekowski@afbda1.hq.af.mil	**Geological Setting:** Coastal sand plain consisting of 60 feet of sand and gravel overlying glacial-lacustrine silty clays	**Technology Demonstrator:** William A. Sauck, PhD Department of Geosciences Western Michigan University Kalamazoo, MI 49008 (616) 387-4991 sauck@wmich.edu

Purpose of Investigation:
To better explain/define a GPR shadow zone discovered during an earlier geophysical investigation of a well-established dissolved hydrocarbon plume to the west. This GPR shadow zone was suspected to be a light non-aqueous phase liquid (LNAPL) plume.

Number of Images/Profiles Generated During Investigation:
2700 feet of GPR lines/profiles

Results:
The investigation was a complete success and verified the accidental discovery of the newly named OT-16b LNAPL plume found during a previous GPR investigation of the neighboring FT-02 plume site that was conducted during December 1994. Overall, results indicate that biodegradation of a residual light hydrocarbon product plume and subsequent chemical processes led to changes of the conductivity of soils and groundwater in the capillary fringe. In general, the GPR shadow zone is coincident with the dissolved residual product plume.

EXECUTIVE SUMMARY

Wurtsmith Air Force Base is located in northeastern Iosco County and covers a 5,223-acre area located on the northeastern part of Michigan's lower peninsula, approximately 2 miles west of Lake Huron. The land surface is a five-mile wide plain bounded on the west by 80-foot high bluffs. Several small streams flow from the bluffs and discharge into a swampy area west of the base. The shallow subsurface stratigraphy is known to consist of uniform and well sorted fine to medium sands that coarsen with depth. A sand and gravel aquifer of glacial origin underlies the base. The water table is about 10 to 12 feet below land surface at the OT-16b site.

Three non-intrusive geophysical techniques were used in the characterization of a newly discovered plume. These included electromagnetic (EM) induction, ground penetrating radar (GPR), and magnetometry. An EM survey was chosen to search for any buried metal objects. Magnetometry was used to determine the presence and location of buried magnetic materials that may have been missed by the EM survey. Due to the uniform geologic conditions present at the site, GPR was used to further investigate the newly discovered plume.

The EM survey identified an unmarked utility line and areas where caution should be exercised when drilling wells at the site. The magnetometer survey revealed that no unknown buried steel objects existed at the site. The GPR data identified that the conductive plume is located in the upper portion of the aquifer. Overall, results indicate that biodegradation of a residual light hydrocarbon product plume and subsequent chemical processes led to the generation of a secondary conductive plume in the aquifer. Generally the anomalous GPR zone is coincident with the dissolved product plume.

One of the goals of this investigation was to challenge the conventional model of the geophysical properties of hydrocarbon plumes. The conventional model, based on controlled spill and lab experiments, is that groundwater and soils contaminated with hydrocarbons exhibit lower electrical conductivity and lower relative permittivity than the surrounding uncontaminated media. The alternative model tested in this study is that hydrocarbon spills in the natural environment will change the impacted zone from electrically resistive to electrically conductive over time due to biodegradation of the hydrocarbons.

Geophysical methods at the newly-discovered OT-16b site provided coverage of a large area in a short period of time. The geophysical methods were non-intrusive and were less expensive than drilling wells randomly or on a grid for plume delineation downgradient from the possible source. The results obtained from the three different techniques were complimentary in making conclusions. The exceptional geologic uniformity of this site provided a uniform background resistivity environment for a geophysical investigation where even a subtle shadow effect could be observed. The conductive nature of this plume, totally derived from insulating hydrocarbon fuels, fits the chemical and electrical model for mature plumes undergoing natural attenuation.

SITE INFORMATION

Identifying Information

Wurtsmith Air Force Base
Oscoda, MI 48750
Operable Unit: OT-16b
CERCLIS No.: MI5570024278

Background [2, 5, 6]

Physical Description: Wurtsmith Air Force Base (AFB) is located in northeastern Iosco County and covers a 5,223-acre area located on the northeastern part of Michigan's lower peninsula, approximately 2 miles west of Lake Huron. The site is bordered to the north and northeast by Van Etten Lake; to the southeast and east by the Village of Oscoda; to the northwest by State Forest woodlands, and to the southwest by Allen Lake and wooded marshlands. Approximately 1,943 acres of the base are owned by the Air Force, 2,466 acres are leased, and 814 acres are registered as easement tracts.

The land surface is a five-mile wide plain bounded on the west by 80-foot high bluffs. Several small streams flow from the bluffs and discharge into a swampy area west of the base. The Au Sable River, which flows eastward and discharges into Lake Huron, is located less than one mile south of the base. The land between the base and the river is swampy. The altitude of the land surface drops from 750 to 580 feet as it slopes toward the river.

The newly discovered OT-16b plume study area where this geophysical investigation took place is located 450 feet to the east of a former fire training area site known as FT-02, shown in Figure 1.

Site Use: The FT-02 site was used by the Air Force for 24 years as a bi-weekly fire training facility. Typical exercises involved the combustion of several thousand gallons of JP-4 jet fuel and other hydrocarbon fuels. Most but not all of the fuel would burn, which would leave the rest to percolate into the ground along with fire retardant chemicals used to extinguish the fires. In 1982, a concrete fire-containment basin with an oil-water separator was constructed to help reduce the amounts of fuel entering into the subsurface. Until this point, an unknown quantity of fuel had already infiltrated into the subsurface. It was reported that overflows persisted after the separator was installed in 1982.

Release/Investigation History: Fuels used in the fire training exercises at FT-02 were stored nearby in a vaulted underground storage tank (UST) at the OT-16b site. This underground collection and supply tank was removed in 1993, but a concrete pad and steel perimeter posts still mark its location. The protective vault was free of any signs of hydrocarbon spillage. Therefore, the tank was removed and the vault was backfilled. An underground pipeline had been used to transport the waste fuels and solvents from the collection tank to the burning pad at the center of the fire training area (Figure 1). This pipeline passed leak tests at the time it was decommissioned

[6]. Contamination may have occurred in the past from spillage during refilling activities of the UST.

In December of 1994 an integrated geophysical investigation was undertaken at the FT-02 study site 450 feet to the west of OT-16b. This investigation consisted of ground penetrating radar (GPR), electrical resistivity using dipole-dipole profiling and Schlumberger vertical electrical sounding, and self potential methods [6]. The results of several reconnaissance GPR survey lines conducted to examine the background response of FT-02 revealed several strong reflectors. One zone of attenuated GPR reflections was spatially correlated with the area of known hydrocarbon contamination, as determined from soil borings and hydrochemical studies [6]. When the positions of the GPR 'shadow' zones were plotted on a map, the resulting pattern was spatially coincident with the mapped position of the plume from hydrochemical studies [6]. Some of the 'shadow' zones were not coincident with the area of the known FT-02 plume (Figure 1) and caused speculation as to what they represented. The investigator came back in the Spring of 1996 to initiate this geophysical investigation in the area of the OT-16b site to determine what these other 'shadow' zones represented.

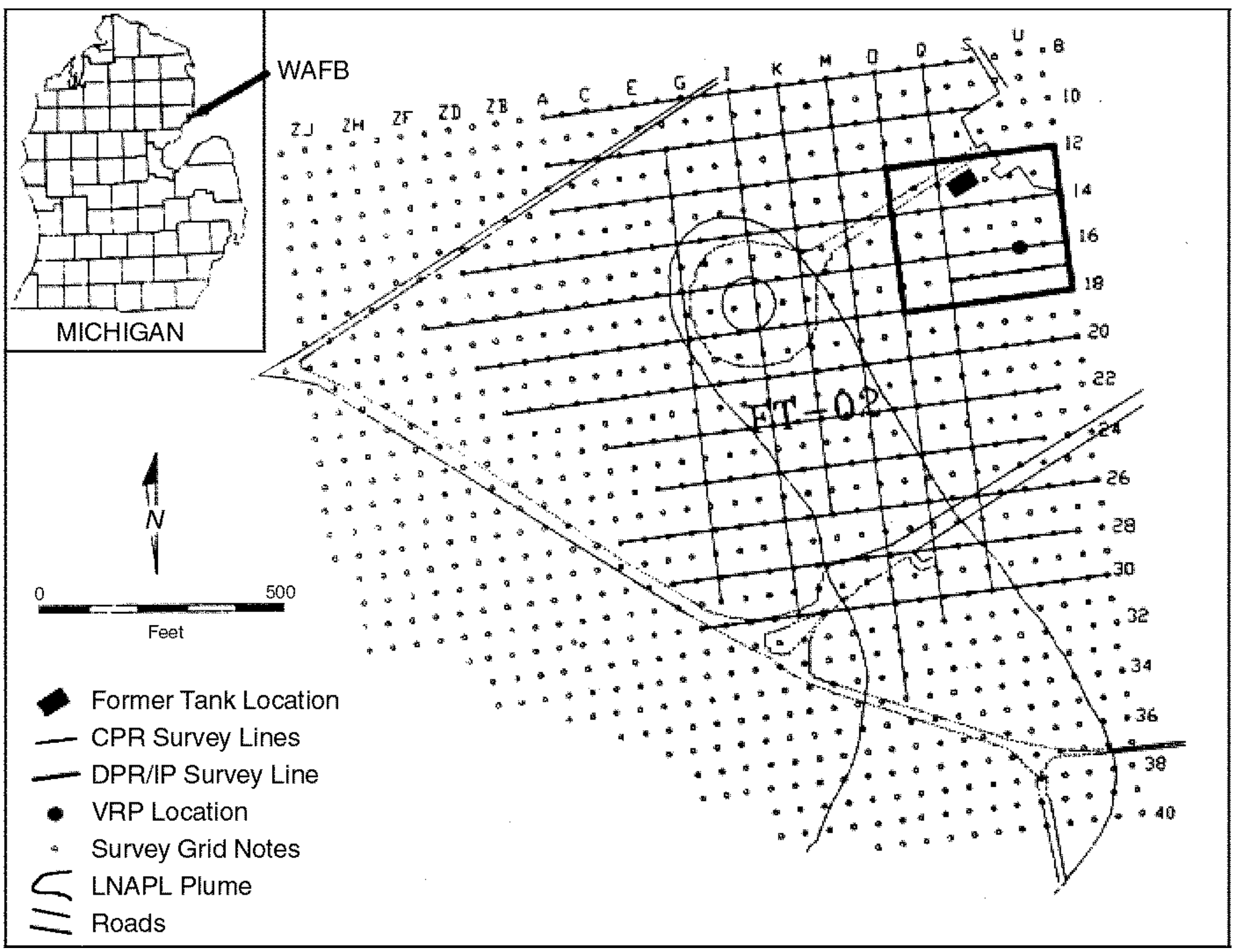

Figure 1: Study area location with GPR profile lines shown. The boxed area to the east of the FT-02 plume site is the OT-16b site. Source: [4, 5].

SITE INFORMATION

Regulatory Context: The site is being addressed through Federal actions. Wurtsmith AFB was proposed to the National Priorities List (NPL) on January 18, 1994, but its addition to the NPL has not yet been finalized. In July 1991, the Base Realignment and Closure (BRAC) Commission recommended the closure of Wurtsmith AFB. On June 30, 1993, the installation closed as scheduled. The BRAC Cleanup Team (BCT) was formed in fiscal year 1994. The BCT consists of representatives of the Air Force, U.S. Environmental Protection Agency (EPA) Region 5, and the Michigan Department of Environmental Quality (MDEQ). The BCT works with a number of other agencies and organizations to complete environmental actions necessary before property at the base can be transferred to the private sector.

Site Logistics/Contacts

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MEDIA AND CONTAMINANTS

Matrix Identification

Type of Matrix Sampled and Analyzed: Groundwater and subsurface soil

Site Geology/Stratigraphy [4]

Based on previous borings completed by the United States Geological Survey (USGS) at the neighboring FT-02 site, the shallow subsurface stratigraphy is known to consist of uniform and well-sorted fine to medium sands that coarsen with depth. A sand and gravel aquifer of glacial origin underlies the base and is comprised of a brown to gray-brown medium coarse sand containing some gravel. The water table is about 10 to 12 feet below land surface at the OT-16b site. The aquifer overlies a thick clay layer found at an average depth of 65 feet. The clay layer is mostly brown to gray, relatively impermeable, and cohesive. Its thickness at the base is not accurately known because no lithologic logs exist that extend to the maximum depth of the clay layer. However, the clay is known to be at least 13 feet thick in one location. At Oscoda and at places east and north of Van Etten Lake, the clay unit is at least 125 feet thick and may be as thick as 250 feet. It slopes downward to the east at 10 to 30 feet per mile. In general, the surface of the unit dips inward to low points in the northeast part of the base and in an area just northeast of Van Etten Lake. Mississippian sandstone, shale, and limestone formations dipping southwest into the Michigan Basin constitute the bedrock beneath the base.

A groundwater divide cuts diagonally across the base from northwest to southeast. South of the divide, groundwater flows to the Au Sable River; north of the divide, it flows to Van Etten Creek and Van Etten Lake. Groundwater flow ranges from about 0.8 feet per day in the eastern part of the base to about 0.3 feet per day in the western part.

Contaminant Characterization [4]

Primary Contaminant Groups: The primary contaminants of concern at the OT-16b site include fuel related contaminants such as benzene, toluene, ethylbenzene, and xylene (BTEX).

Matrix Characteristics Affecting Characterization Cost or Performance [2, 5]

For the electromagnetic (EM-31) method in the vertical dipole mode, 18 feet is the maximum depth of detection of a highly conductive. Since the contaminant plume found at the site is only moderately conductive, approximately 3.3 times the conductivity of the background aquifer, it is not likely that the EM-31 can effectively discriminate between the weak signature of the contaminant plume below the water table and the conductivity of the uncontaminated groundwater. The depth of the contaminant plume is below the water table (15 feet), which is close to the limit of penetration for the EM-31 instrument. However, results from the EM-31 survey are still useful for other aspects of site characterization, since they clearly indicate where subsurface objects or utilities may exist and caution should be used in drilling future wells at the site.
There were no reported characteristics of the site that affected the magnetometer survey results.

MEDIA AND CONTAMINANTS

However, there are some limitations when using a magnetometer generally. In a relatively "clean" area, a single drum may be theoretically detected to a depth of 20 feet from the surface. In practice, however, numerous smaller, near-surface iron objects will obscure the weaker deep target. A more realistic maximum depth of detection is 5 to 10 feet. Large masses of drums may be detected easily to depths of 10 to 40 feet.

The clarity of Ground Penetrating Radar (GPR) results can be affected by heterogeneous conditions in the subsurface. However, the study site has been noted to have exceptional geologic uniformity. The results of the GPR survey were enhanced by these uniform conditions.

GEOPHYSICAL INVESTIGATION PROCESS

Investigation Goals

Overall, the goal of this geophysical investigation was to use three different geophysical techniques (GPR, magnetometry, and EM) to explore and better define a suspected light non-aqueous phase liquid (LNAPL) plume that was encountered during a GPR investigation approximately 450 feet to the west of the FT-02 plume site [8]. A specific goal of the magnetometer survey was to search for any buried steel objects that might have been missed by the EM induction survey [2, 5]. GPR was then used to delineate the boundaries of the newly discovered plume.

One of the goals of this investigation was to challenge the conventional model of geophysical properties of hydrocarbon plumes. The conventional model, based on controlled spill and lab experiments, is that groundwater and soils contaminated with hydrocarbons exhibit lower electrical conductivity and lower relative permittivity than the surrounding uncontaminated media. The alternative model tested in this study is that hydrocarbon spills in the natural environment will change the impacted volume from electrically resistive to electrically conductive over time due to biodegradation of the hydrocarbons. Conductivity is enhanced by the leaching of inorganics from the soil and aquifer materials by organic acids and carbonic acid produced by microbial activity during degradation of the hydrocarbons. This model suggests that the conventional model can not be applied uniformly to all hydrocarbon plume sites and the geoelectrical signature of a plume will vary with time and position [7].

Geophysical Methods [2, 5]

The investigation took place over several days in May 1996. The EM induction method is often used to explore for metal objects based on the principle of EM induction. This induction technique uses two coils: a transmitter and a receiver. EM surveys detect variations in the conductivity of subsurface materials. Buried objects, conductive fluids, and geologic discontinuities can be detected by artificially applying known electric fields to the ground surface by means of the transmitter, and the receiver records the presence of disruptions to the known field. These disruptions, termed EM anomalies, can result from geological changes or the presence of metallic objects, such as pipes, drums, cables, tanks, etc., in the subsurface.

For the EM survey, a Geonics EM-31 was carried at waist level using the vertical dipole mode. A grid of 25 feet by 50 feet was established and results from the survey were plotted using Geosoft™ software.

The second method used in this investigation was the magnetometry survey. Magnetometers measure variations in the magnetic field of the earth, and local disruptions to the earth's field, the presence of naturally occurring ore bodies, and man-made iron or steel objects such as buried drums, tanks, or ordinance. Whether on the surface or below, iron objects or minerals cause local distortions or anomalies in this field. Originally designed for mineral exploration, magnetometers are now used in the environmental field for locating buried steel drums, tanks, pipes, and iron debris in trenches and landfills. A magnetometer's response is proportional to the mass of iron in the target. The magnetometer can only sense ferrous materials such as iron and steel; other metals like copper, tin, aluminum, and brass are not ferromagnetic and cannot be located with a magnetometer. The effectiveness of magnetometry results can be reduced or inhibited by interference (noise) from time-variable changes in the earth's field and spatial variations caused by magnetic minerals in the soil or iron debris, pipes, fences, buildings, and vehicles. Many of these problems can be minimized by careful selection of the type of instrument and field procedures used for the survey.

Magnetometry was used in this investigation to determine the presence and location of buried magnetic materials using a 50 feet by 50 foot grid, which had already been established for the EM survey, magnetic data were collected using a Geometrics G-858 cesium vapor magnetometer. Using this data, a magnetic field intensity map of the area was produced for interpretation.

The third geophysical method used in the OT-16b site geophysical investigation was ground penetrating radar (GPR). GPR uses high-frequency radio waves to determine the presence of subsurface objects and structures. A GPR system radiates short pulses of high-frequency EM energy into the ground from a transmitting antenna. This EM wave penetrates into the ground at a velocity that is related to the electrical properties of subsurface materials. When this wave encounters the interface of two materials having different electromagnetic properties (i.e., soil and water), a portion of the energy is reflected back to the surface, where it is detected by a receiver antenna and transmitted to a control unit for processing and display. The major principles involved for GPR are similar to reflection seismology, except that EM energy is used instead of acoustic energy, and the time scale for GPR is a million times shorter than that of seismic phenomena.

For this investigation a Geophysical Survey Systems, Inc. (GSSI) Subsurface Interface Radar (SIR) System-10 GPR system along with 100 MHZ antennae recording for a scan time of 400 nanoseconds (ns) was used. The 100 MHZ Transmitter-Receiver pair were operated with a separation of 1.45 meters between mid-points. The site was traversed in the west to east and south to north directions along lines spaced 50 feet apart, using a van to tow the antennae. No post-processing was done other than horizontal scales normalization. This GPR system used fixed gain vs. depth function. No gain equalization or automatic gain control processing were used.

GEOPHYSICAL FINDINGS

Technology Calibration [8]

For the EM-31 the only calibration necessary is setting the zero on the instrument. A region of very resistive ground was identified and its conductivity was accurately measured using conventional techniques. GPR readings were taken in the same location and the instrument gains were set at this point. No further calibration was reported to be necessary for the GPR or magnetometer used in this investigation.

Investigation Results [2, 5]

The EM survey revealed a linear alignment of anomalies extending from a manhole located at coordinate S18 to coordinate P12 (Figure 1), and at least three other anomalies parallel to this alignment. These anomalies were attributed to communication or electric cables buried in the ground. No anomalous regions associated with the suspected conductive groundwater plume were visible on any of the interpretive maps produced from the EM survey. The lack of EM-31 response from the conductive plume just below the water table at 15 feet was attributed to the plume being nearly at the limit of depth penetration for the instrument. One unmarked utility line was discovered. The results indicated where caution should be taken when drilling wells at the site. A strong anomaly beneath the old taxiway in the northeast corner of the map was detected but the source is unknown.

The magnetic survey revealed that there was a strong low in the magnetic field in the vicinity of the old UST vault. The UST vault (still in place, but now filled) had been surrounded at the surface by 20 steel posts filled with concrete. The posts were attached to a flat slab of concrete. The strong low was attributed to the potential for the steel having a strong reversed remnant magnetization. The magnetic survey revealed no other buried steel objects at the site. This was an indicator that the buried cables found by the EM-31 survey are nonmagnetic but electrically conductive. A strong magnetic low found beneath the asphalt taxiway in the northeast corner of the map remains unexplained.

The GPR data revealed that there is a particularly strong reflector representing the water table at approximately 10 to 12 feet (five meters) shown on Figure 2 as an inverted triangle. This was caused by the sharp change in the relative permittivity in the transition from unsaturated to saturated sand. The central areas of the pair of two-dimensional profiles show pronounced signal attenuation, creating an amplitude shadow zone (between “R” and “T” on line 14 in Figure 3, and between “S” and “U” on line 16 in Figure 4). The conductive zone causing the attenuation is at the tops of these shadows. The shadow begins at or just below the water table, so the conductive plume is located in the upper part of the aquifer. This same phenomenon was seen along all other lines crossing the plume area. This conductive plume in the groundwater below the highly resistive hydrocarbon liquids fits the alternative geoelectrical model proposed for mature plumes [7].

GEOPHYSICAL FINDINGS

The investigator's recognition and understanding of the significance of the GPR shadow zone below the FT-02 plume led to the discovery of the new contaminant plume. From the shadow zones on the GPR profiles, it was possible to create a map that showed the extent of the conductive plume at the OT-16b site (Figure 2). The broad proximal end of the plume is possibly due to the spillage of fuel on the asphalt taxiway, as well as possible surface spillage during refilling operations at the former underground collection tank location. Another result of the GPR

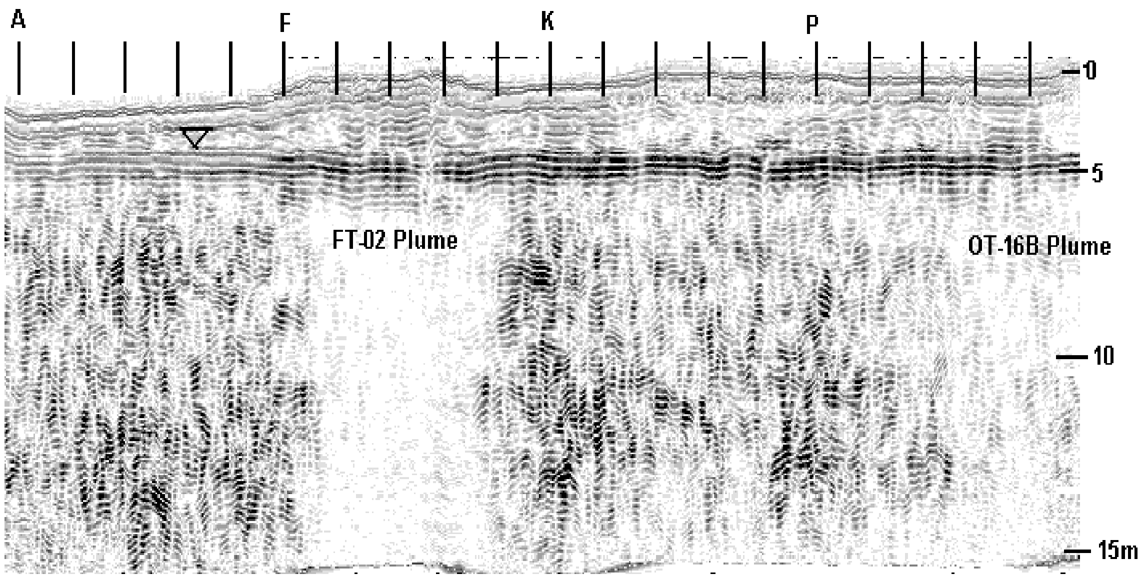

Figure 2: Ground penetrating radar profile of Line 14 showing the strong amplitude shadow caused by the proximal end of the neighboring FT-02 plume, and the somewhat weaker shadow at the right end caused by the OT-16b plume. Source: [8]

investigation was the observation of some paleo-dune morphologies that underlie the area at a depth of approximately 40 feet (Figure 4 at location "Q").

Overall, results indicate that biodegradation of a residual light hydrocarbon product plume and subsequent chemical processes led to the generation of a secondary conductive plume in the aquifer that is coincident with the dissolved product plume. This coincides with the newly developed hypothesis that hydrocarbon spills in the natural environment cause changes from electrically resistive to electrically conductive over time due to biodegradation of the hydrocarbon impacted zone. Conductivity is enhanced by the leaching of inorganics from the soil and aquifer materials by organic acids produced by microbial activity during degradation of
the hydrocarbons [7]. Generally the GPR shadow zone is coincident with the dissolved product plume (Figure 2).

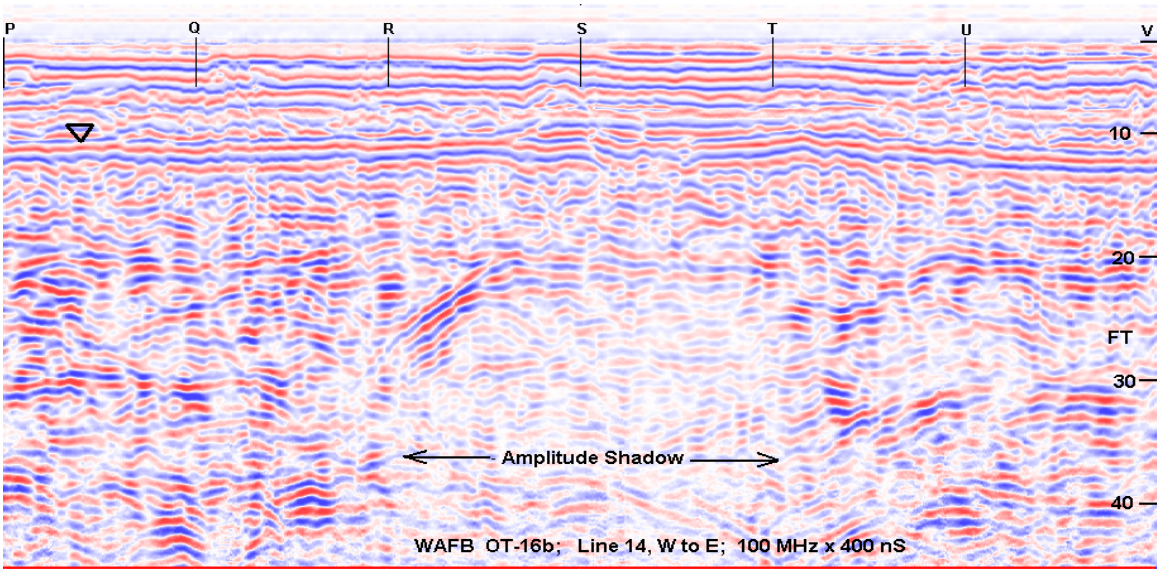

Figure 3: 100 MHZ GPR profile for line 14 (at 150 feet N coordinate on Figure 1) oriented with west to the left. Scan length is 400 ns, showing amplitude shadows starting below the water table (about 70 ns or 12 feet); horizontal scale is 50 feet between marks. Source: [2, 5]

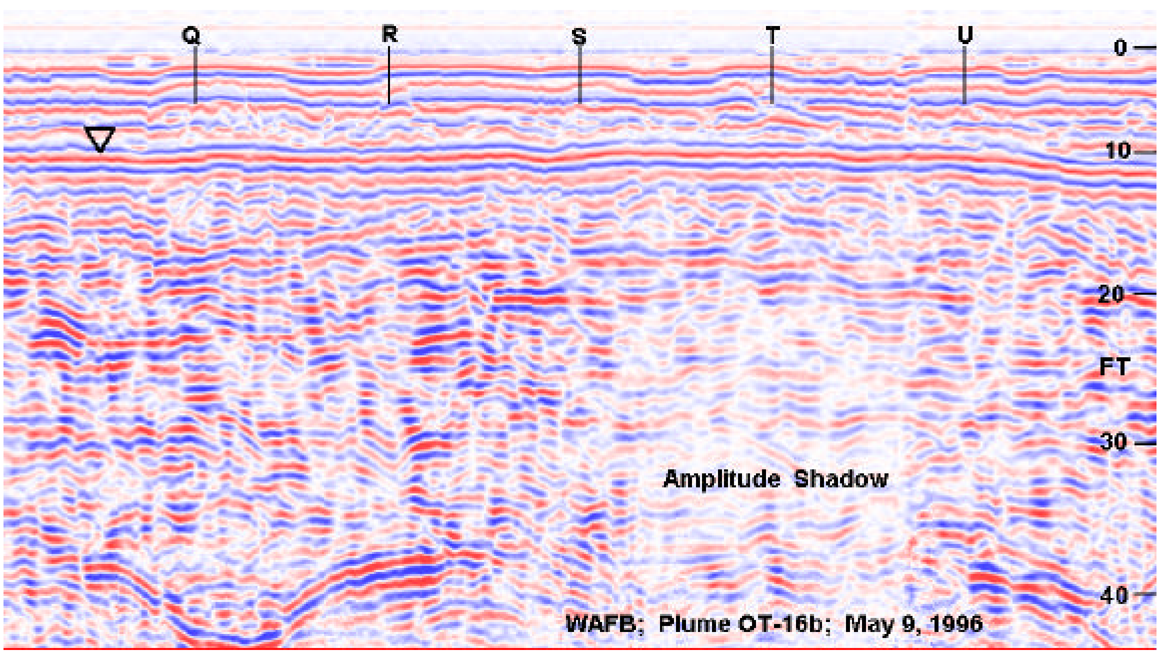

Figure 4: 100 MHZ GPR profile for line 16 oriented with west to the left. Scan length is 400 ns, showing amplitude shadows starting below the water table (about 70 ns or 12 feet); horizontal scale is 50 feet between marks. Source: [2, 5]

Results Validation [2, 5]

Several months after the initial geophysical investigation took place in May of 1996, borings were taken at three locations on the newly discovered OT-16b plume. Soil and groundwater samples were taken at various depths. One soil sample revealed approximately 16 inches of a dark, viscous residual hydrocarbon product near the water table. The conductivities of the aquifer water were at a maximum at the top of the saturated zone and then diminished to background levels at depths of 10 feet below the water table. This indicated that the anomalous conductive zone was less than 10 feet thick and the water samples had a conductivity contrast of 2.5 to 3.3 above background levels.

In addition, after the geophysical investigation was completed, a review of Wurtsmith AFB air photo archives led to the discovery that a maintenance building occupied the site area until the 1970's. The UST was installed later, after the building was removed. When the UST was removed there was no evidence of soil contamination. This indicates that the source of the newly discovered contaminant plume was probably as a result of the drainage of solvents and fuels from the floor of the maintenance building.

LESSONS LEARNED

Lessons learned at the Wurtsmith site include the following:

- Geophysical methods at the newly discovered OT-16b site provided coverage of a large area in a short period of time. The geophysical methods were non-intrusive and were less expensive than drilling wells randomly or on a grid for plume delineation downgradient from the possible source. The investigation was considered a complete success and, using purely surface geophysical methods, verified the 1994 initial "blind" discovery of a new groundwater contaminant plume [2, 5].

- The use of more than one geophysical method provided synergy, as each technique was responsive to a different property. Therefore, the results obtained using the different techniques were complimentary. The GPR outlined the conductive groundwater plume and also revealed the details of the sand stratigraphy. The shallow EM discovered a complex of buried electrical utility lines where only one line had been previously known. Finally the magnetic survey revealed no buried steel objects, which was helpful in characterizing the site as "tank-free [2, 5]."

- The conductive nature of this plume, totally derived from insulating hydrocarbon fuels, fits the chemical and electrical model for mature plumes undergoing natural attenuation [7]. The anomalous geophysical response is due to the electrically conductive ionic nature of the plume, not due to any direct response to residual or dissolved hydrocarbons. The investigators would not extrapolate these results to investigations of dense non-aqueous phase liquid spills [2, 5].

- It is clear that at this site biodegradation of a residual light hydrocarbon product plume and subsequent chemical processes led to changes of the conductivity of soils and groundwater in the capillary fringe and underlying aquifer. The broad proximal end of the plume is potentially due to fuel spillage on the asphalt taxiway, as well as possible surface spillage during refilling operations at the former underground collection tank location and the floor of the maintenance building [2].

- The exceptional geologic uniformity of this site provided a uniform background environment for a geophysical investigation where the shadow effect could be observed [8]. The amplitude shadow is not visible if the GPR scan length or range can only reach the water table. The shadow will also be destroyed if automatic gain control or other gain equalization is applied during either acquisition or post-processing of data. Therefore the appropriate setting of field acquisition parameters and careful post-processing are necessary to record and preserve the GPR amplitude shadows [2, 5].

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8. Personal Communication with Dr. William A. Sauck of Western Michigan University. November 20, 1998.

9. Personal Communication with Dr. Michael J. Barcelona of the University of Michigan. November 20, 1998.

10. Personal Communication with Phil Sirles of Microgeophysics Corporation. Wheat Ridge, CO. December 10, 1998.