Surface Geophysical Investigation of a Chemical Waste Landfill in Northwestern Arkansas

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Abstract

In May 2000, the U.S. Geological Survey performed a surface geophysical investigation on a site used for disposal of unknown types of chemical waste in the 1960's. The site is located near Fayetteville, Arkansas, on the Springfield Plateau of the Ozark Plateaus physiographic province and is about 100 feet by 110 feet in size. The surface is flat lying and characterized by a 40-foot thickness of cherty clay regolith material underlain by the chert-rich, karst limestone of the Boone Formation. Information available about the site's history indicates that as many as six pits were excavated for the disposal of laboratory chemicals in glass containers that may or may not be intact. The objective of the surface geophysical investigation was to use noninvasive methods to delineate possible buried chemical zones. The information collected in this investigation may be useful to locate possible leachate plumes to optimize subsequent sampling and remediation.

Methods used at the site focused on the electrical insulating properties of the nonmetallic (glass) containers, electrical conducting properties of possible leaking fluids, and electromagnetic properties of the disturbed regolith material in the vicinity of the burial zones. The following geophysical methods were used at the site: 1) electromagnetic conductivity, 2) magnetometer, and 3) 2D-DC electrical resistivity survey. The electromagnetic survey was performed in horizontal co-planar mode, measuring both the quadrature and inphase component. The magnetometer survey was performed using a pair of memory magnetometers: one as a roving instrument and one as a stationary instrument continuously measuring the earth's magnetic field. The 2D-DC electrical resistivity survey consisted of 9 profiles of 28 electrodes at a 6-foot spacing with Wenner, Schlumberger, and dipole-dipole array data collected. This combination of geophysical tools was successful in delineating several types of subsurface anomalies consisting of buried metal and discrete high and low resistivity zones at various depths.

Five geophysical anomaly types were categorized and designated as "types A, B, C, D, and E" for reference when describing areas of concern at the site. Anomaly type A is indicated by a discrete high resistivity zone with an associated low resistivity zone below, possibly suggesting buried nonconductive material and leaking conductive fluid below it. Anomaly type B is indicated by a discrete high resistivity zone with no associated low resistivity zone below, possibly suggesting the presence of buried nonconductive material and no leaking conductive fluid. Anomaly type C is indicated by a medium resistivity zone adjacent to a high resistivity zone possibly suggesting the presence of disturbed regolith associated with burial. Anomaly type D is indicated by a zone of high resistivity material with responses from the magnetometer or the electromagnetic survey suggesting nearby buried metal. Anomaly type E is indicated by a discrete zone of high resistivity material underlying a shallow low resistivity zone with a negative electromagnetic response, which indicates the presence of buried metal. These five anomaly types were used to characterize and identify areas of concern that could be possible locations of buried materials at the site. Sampling and source removal plans are being developed based on areas of concern identified from the anomalies.

INTRODUCTION

The U.S. Geological Survey performed a surface geophysical investigation at a chemical waste landfill in May 2000. The chemical waste landfill is located at Latitude 36 deg. 07' 16", Longitude 94 deg. 11' 22" which is in the SW ¼ of the NE ¼ of the NW ¼ of section 28, Township 17N, Range 30W, Washington County, Arkansas (fig. 1) and is about 100 feet by 110 feet in size. Anecdotal accounts by persons present during the placement of the waste suggest that as many as six pits possibly were excavated and used at the site during the 1960's for burial of laboratory chemicals in glass containers. The exact locations and extents of the pits are unknown.

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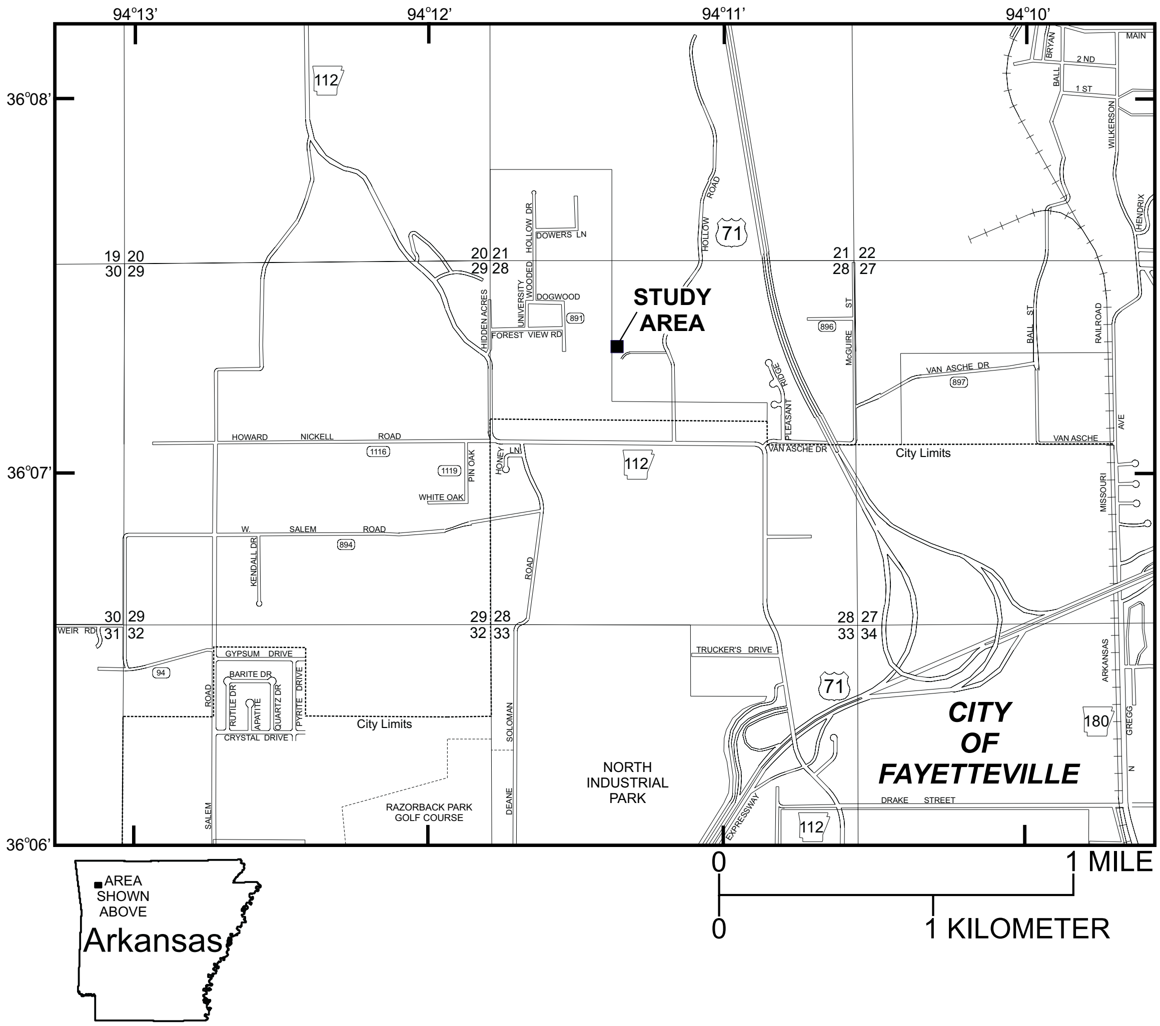

Figure 1. Location of the chemical waste landfill, near Fayetteville, Arkansas.

The site is located on the Springfield Plateau of the Ozark Plateaus physiographic province (Fenneman, 1938). The surface is flat lying and characterized by a cherty clay regolith underlain by the chert-rich, karst limestone of the Boone Formation. Small piles of chert cobbles exist on the northern and southern borders of the site. Depth to the top of the limestone is estimated to be approximately 40 feet, and water levels in local shallow domestic wells completed in the Boone Formation range from 20 to 32 feet below land surface. A seismograph station consisting of a concrete block building was constructed on the site in the early 1970’s. According to personnel involved with the construction and operation of the seismograph station, the building’s foundation is constructed of concrete and metal reinforcement with large pilings beneath it penetrating the cherty clay regolith to the top of the limestone.

The objective of the surface geophysical investigation is to use noninvasive methods to delineate possible buried chemical zones within the site boundary. The lack of historical information about the chemicals buried at the site requires that noninvasive methods be used to minimize the possibilities of causing further damage at the site. The information collected in this investigation may be useful to locate possible leachate plumes to optimize subsequent sampling and remediation. This paper summarizes the surface geophysical investigation performed at the chemical waste landfill.

A 100-foot by 110-foot grid was surveyed and staked on the site. The grid extent is considered to be the full areal extent of the chemical waste landfill and is the area of interest for the surface geophysical investigation.

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SURFACE GEOPHYSICS APPROACH AND FINDINGS

Materials buried at the site are believed to be in glass containers that may or may not be intact. Methods used at this site focus on the electrical insulating properties of the nonmetallic (glass) containers, electrical conducting properties of possible leaking fluids, and electromagnetic properties of the disturbed regolith material in the vicinity of the burial zones. Three different types of geophysical surveys were performed on a 10-foot northing/easting grid: 1) electromagnetic conductivity, 2) magnetometer, and 3) 2D-DC electrical resistivity.

References to locations at the site use the surveyed grid as a datum. The grid consists of 12 north-south (N-S) lines at 10-foot intervals designated by alphabetic characters F through Q, and 11 east-west (E-W) lines at 10-foot intervals designated by numbers 6 through 16. Locations outside the grid are designated with alphabetic or numbers characters beyond the limits of the surveyed grid, but retain the established dimensional pattern. Locations between lines are referred to as X.5, such as F.5 being between F and G.

Electromagnetic Conductivity Survey

A Geonics[1] EM-31 unit was used for the electromagnetic conductivity (EM) survey. The EM-31 is a frequency-domain electromagnetic instrument that has a nominal penetration depth of about 18 feet in its horizontal co-planar mode (referring to the orientation of the coils). Disturbed soil generally has a higher porosity than undisturbed soil, with subsequent higher water content and therefore higher conductivity. The soil in a burial zone should appear more conductive unless mixed with less conductive material. Conductivity measurements were recorded for about 423 stations (fig. 2) on the grid with alternating 5-foot and 10-foot spacing using both in-line and broadside orientations (to check for anisotropy) and measuring inphase (to search for metallic debris) and quadrature (to gather stable soil conductivities) components for each orientation (totaling 1,692 measurements). The EM data were contoured using a kriging routine and overlaid on a map of the grid on four separate plots. Kriging is a geostatistical gridding method that produces contour maps that reveal trends in the data.

EM methods have been used effectively elsewhere to map locations of buried metallic objects, disturbed soil, and potential conductive-ion leachate plumes emanating from landfills (Bisdorf and Lucius, 1999). By measuring soil conductivity with the quadrature-phase component, it is possible to detect locations of disturbed moisture-bearing soil and conductive leachate plumes. The inphase component (measured in units of parts per thousand of primary electromagnetic field of the instrument) is primarily used for detection of metal objects, although metal objects also effect the quadrature phase measurements. Negative values usually indicate that the instrument is oriented perpendicular to a highly conductive object (such as iron or steel). Extremely high positive values of conductivity indicate that the metal object is aligned parallel to the orientation of the instrument.

Several anomalous values appear to be associated with buildings and known metal objects at the chemical waste landfill. The quadrature phase (fig. 2) and inphase measurements are affected in some areas by metal objects present at the site, such as two metal signs near F.5-7 and I-7.5, an empty steel drum near K.5-16, and the seismograph station (corners approximately at L.5-11, N-11, N-14, L.5-14). Other extrinsic readings occurred at E-15, associated with a storage building on adjoining property to the west; G.5-4, near some metal strapping on the surface; and a diagonal line of low conductivity extending from the southeast to the northwest from J-14 to H.5-16, probably associated with a buried power cable that surfaces at the west side of the seismograph station. The only conductivity highs that appear on the quadrature phase plot are associated with surface features such as the storage building and the seismograph station.

Several conductivity lows appear to be related to buried materials. A prominent conductivity low appears between I-7.5 and K-7.5 (fig. 2); this is confirmed by a negative inphase response to be caused by buried metal in that area. A similar cause and effect is present at M.5-6 on both quadrature (fig. 2) and inphase plots. There is a large pile of tree and brush debris present at this location that could contain

[1] Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

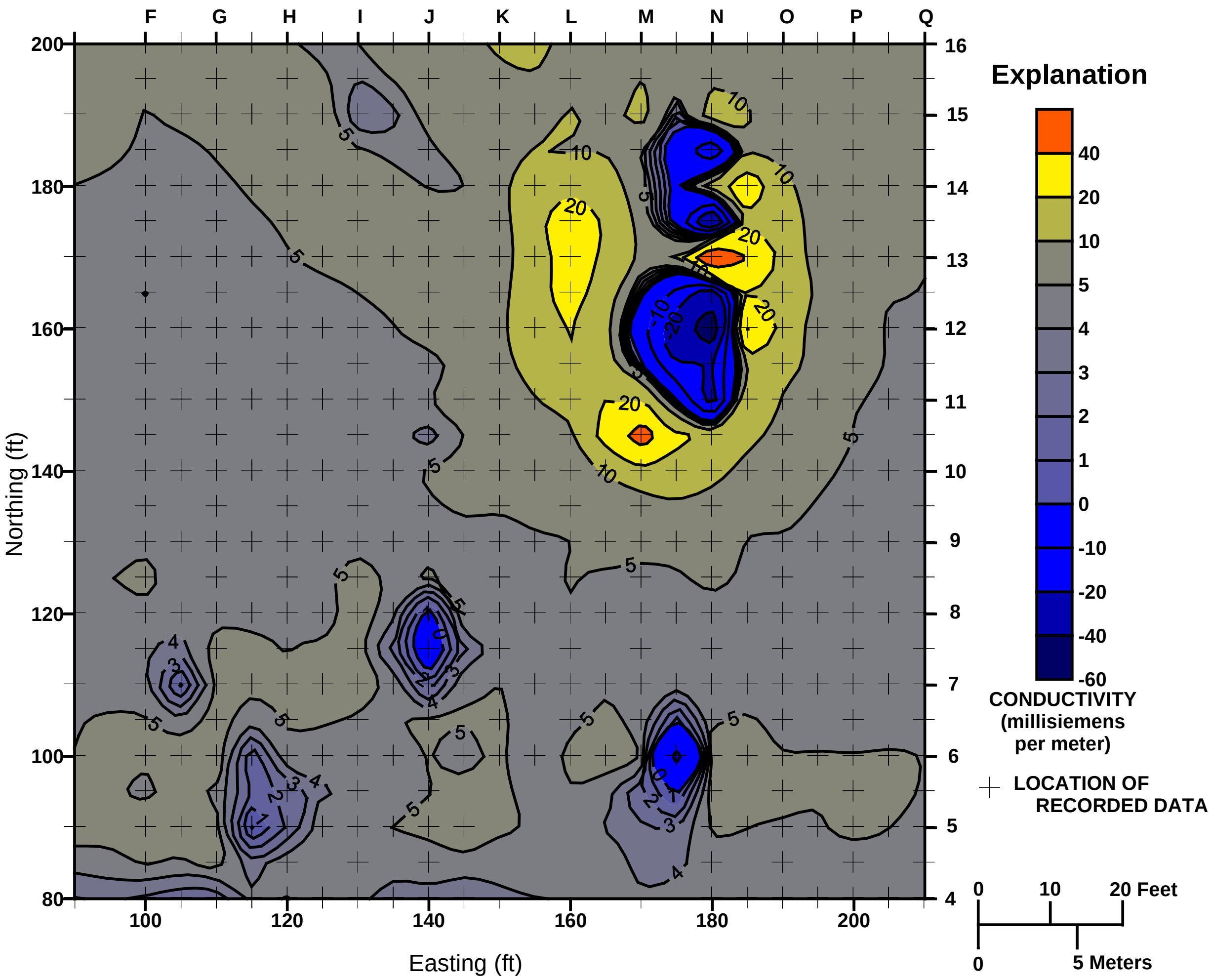

Figure 2. Electromagnetic conductivity (north-south orientation) quadrature phase component survey.

some metal. At J-10.5, an anomaly of slightly low conductivity is present on the quadrature phase plot, especially in the N-S orientation (fig. 2), possibly indicating a nonconductive mass aligned east-west. This is supported by the lack of anomalies on the inphase plots at J-10.5 or I.5-11.

Magnetometer Survey

The magnetometer survey was performed on the morning of May 13, 2000. The magnetometer system comprised a pair of Geometrics G-856 memory-magnetometers, which measure magnetic intensity in units of nanoteslas. One was used as a roving instrument which recorded measurements at stations on the surveyed 10-foot grid, and one was placed nearby at an off-site location as a base station to continuously record the earth's magnetic field. The magnetic data were downloaded to a laptop computer and the base station record was used to correct the roving station data for diurnal drift. The measurements were then contoured using a kriging routine and overlaid on the grid (fig. 3). The natural magnetic intensity at the base station location near the chemical waste landfill on the day of the survey was about 52,800 nanoteslas.

Magnetometer readings are expected to be erratic in the presence of disturbed soil and ferrous materials, both of which may be present at the chemical waste landfill. The major feature present on the magnetometer plot between gridlines L and N and 11 and 14 is the magnetic intensity extreme associated with the seismograph station building. Unfortunately, the effect from this building masks any subtle differences in magnetic intensity that could be present within 20 feet of the building, thus making this area of the survey invalid toward the objective of the investigation. Other extrinsic responses include the two metal signs near locations G-7 and I-8 appearing as lower

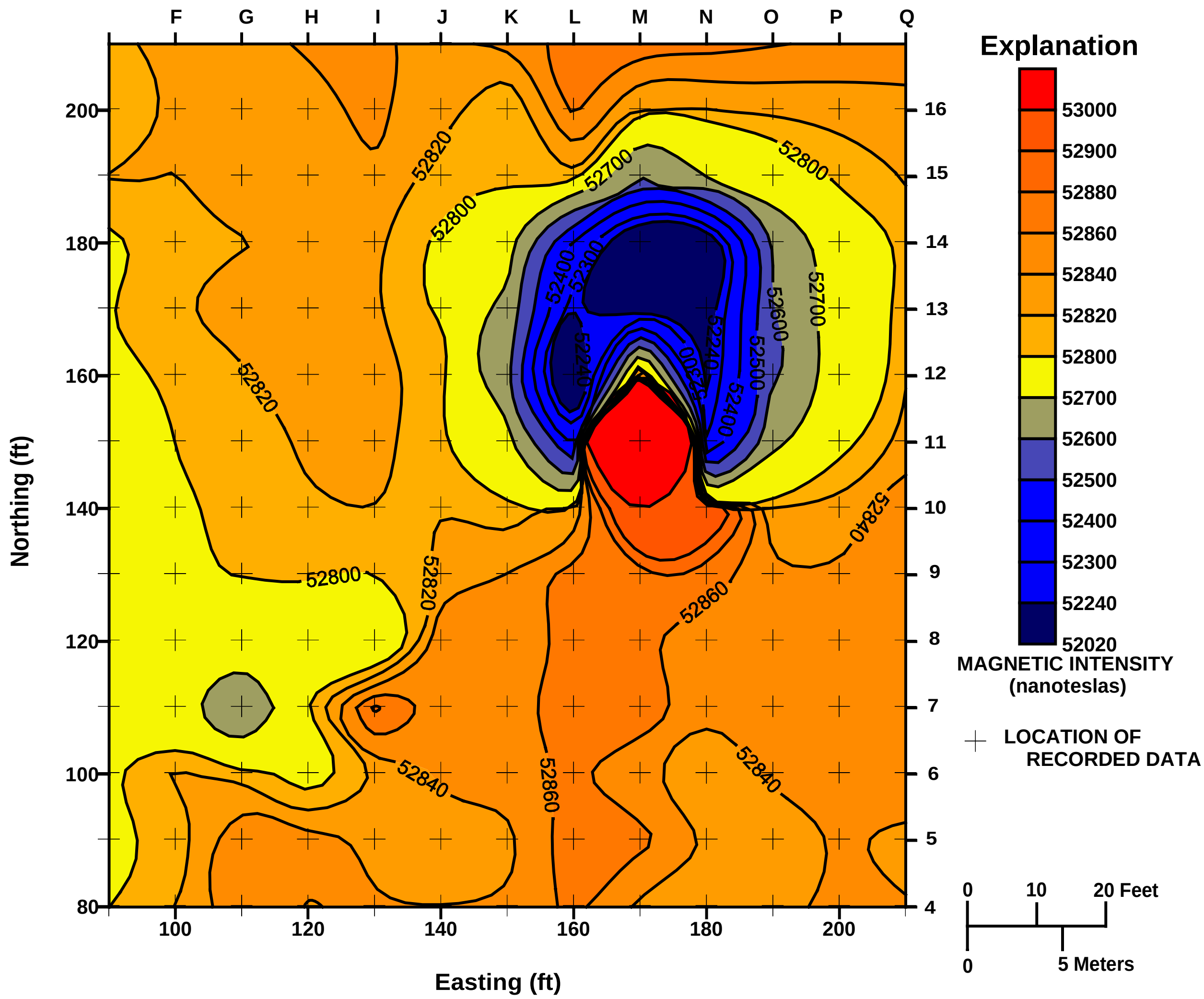

Figure 3. Magnetometer survey.

intensity on the magnetometer survey plot (fig. 3) and the empty steel drum near L-16 appearing as higher intensity.

A response of concern is located near I-7 to I.5-7 (fig. 3), which is an increase of magnetic intensity probably associated with the metal detected with the EM at J-7.5. The shifted nature of the magnetic anomaly with respect to the EM anomaly is typical of a magnetic field of a monopole object buried at an angle from horizontal. A monopole has lines of equal magnetic field that point radially in or out from the positive or negative monopole respectively (Briener, 1973). The object is probably shallow (1-3 feet deep) as indicated by the limited extent of the anomaly.

The area of relatively higher magnetic intensity (greater than 52,860 nanoteslas) south of the seismograph station building (fig. 3) does not correlate with any EM anomalies and therefore is probably associated with natural variations of magnetic intensity of the regolith present at the site.

The EM anomaly present at M.5-6 (fig. 2) does not appear in the magnetometer survey, which indicates that the metal present is not of sufficient mass or does not contain enough ferrous metal to change the magnetic intensity. The fact that it affected the EM readings so drastically, combined with the lack of magnetometer response, indicates that a small light metal object was very near the EM instrument, possibly in a nearby brush pile.

2D-DC Electrical Resistivity Survey

Electrical resistivity surveys are commonly used for hydrogeological, mining, and geotechnical investigations, and environmental surveys (Loke, 1999a). Subsurface electrical resistivity is related to buried materials and various geological and hydrogeological parameters such as the mineral and fluid content, porosity and water saturation.

A 2D-DC (two-dimensional, direct-current) electrical survey was performed at the chemical waste landfill to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface could be estimated. The resistivity directly measured in the field survey is not the true resistivity of the subsurface but an "apparent" resistivity value. The apparent resistivity value equals that of the resistivity of a homogeneous ground measured from the same electrode arrangement. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values must be performed (Loke, 1999a). The result is a contoured representation of the apparent and inverse modeled "true" resistivity in a cross-sectional format. In this format, the insulating quality of the glass containers thought to be present at the site are expected to appear as higher resistivity values among the lower resistivity values of the disturbed regolith. The heterogeneity of the regolith material made some interpretations difficult.

The 2D-DC resistivity system used at the chemical waste landfill was the Sting/Swift resistivity system by Advanced Geosciences, Inc. Of the three different arrays (Wenner, Schlumberger, and dipole-dipole) that were used initially, the dipole-dipole was the most successful because of its detailed resolution near the land surface. Based on the anomalies observed, the nine dipole-dipole profiles, which were collected at 6-foot electrode spacings, were further evaluated. They were located along the following grid lines: 6, 7, 8, 9, 16, F, G, J, and O (fig. 4). Because of the trapezoidal geometry of the dipole-dipole cross-sectional profiles, the lines were extended beyond the surveyed grid to optimize subsurface coverage.

There are several steps involved in producing a cross-sectional profile of "true" resistivity of the subsurface. The field measurements are spatially related to positions in the cross section and recorded by a datalogger. The field data are subsequently downloaded to a computer and input into the finite-difference model RES2DMOD (Loke, 1999), which inverts the data and creates a contoured profile of field apparent resistivity. This apparent resistivity profile is used to create a simplified integrated model of the cross section, which is subdivided into discrete blocks with specific resistivity values. The finite-difference model is run on the interpreted model grid and the resulting modeled resistivity profile from the inversion is compared to the apparent resistivity profile. Through a trial-and-error process, the interpreted model is improved to create a modeled resistivity profile that closely resembles the field apparent resistivity profile. The interpreted model is then considered to have produced a representation of "true" resistivity of the subsurface when a close match is made between the modeled resistivity profile and the apparent resistivity inversion profile. The nine 2D-DC resistivity dipole-dipole profiles were evaluated in detail and the results were used in conjunction with results from the electromagnetic conductivity and magnetometer surveys to delineate areas of concern.

In the southwest corner of the site (fig. 4), an area of concern was identified through the analysis of 2D-DC resistivity profiles along gridlines 6, 7, 8, 9, F, and G. Three types of anomalies are present in this area. The first type, designated as type A, corresponds to a high resistivity zone above a low resistivity zone. This could be caused by nonconductive containers buried 6 to 9 feet deep with a conductive substance leaking below. The type A anomaly in this area is most prominent on east-west trending gridline 6, between gridlines F and G. Another anomaly type similar to the type A, without the associated conductive zone below the high resistivity zone (designated as type B), is present near grid location F.5-7 to G-9. It is unclear if this is in response to the possible buried nonconductive material present along gridline 6 or if this is a zone of higher resistivity regolith material such as a greater concentration of chert. The type B anomaly possibly suggests the presence of buried nonconductive material without leaking conductive fluid. The third type of anomaly present in this area, referred to as type C, is characterized by a medium resistivity zone adjacent to a type A or B anomaly. This type of anomaly is indicative of disturbed regolith. Type C anomalies in this area are located along gridlines F and G. Affected sections of the profiles are indicated on figure 4.

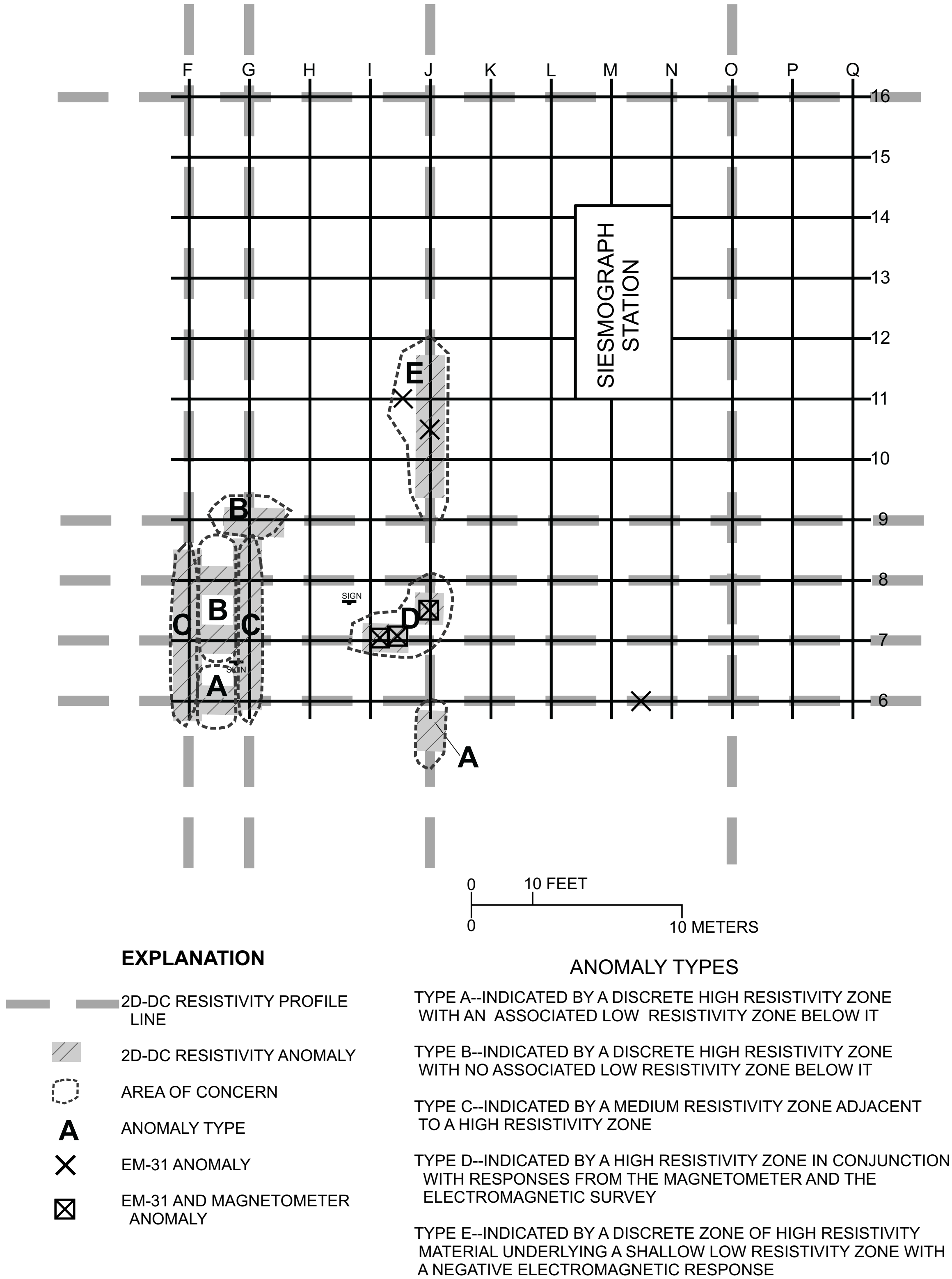

Figure 4. Locations of anomalies and areas of concern.

An additional type A anomaly indicated by 2D-DC resistivity is present just south of grid location J-6 on gridline J. This area of concern is areally less extensive than the type A anomaly in the southwest corner of the site, but appears at the same approximate depth. It appears as a discrete zone of high resistivity 6 to 9 feet deep above a zone of low resistivity. This could be indicative of nonconductive containers buried 6 to 9 feet deep with a conductive substance extending below. The affected section of the profile is indicated on figure 4.

At grid location I-7 to J-7, the EM and magnetometer indicated probable buried metal in the area and the 2D-DC resistivity indicated a zone of moderately high resistivity present 3 to 6 feet deep. This type of anomaly is designated as a type D anomaly. It is unclear if the high resistivity is caused by an increased concentration of chert or by buried nonconductive material. Another type D anomaly, present at J-7.5, could be a continuation of the one at I-7 to J-7. Affected sections of the profiles are indicated on figure 4.

At grid locations J-9 to J-12, a discrete zone of high resistivity underlies a low conductivity zone near the surface at J-10, which is corroborated by an indication of buried metal from the EM data. This is designated as a type E anomaly. The affected section of the profile is indicated on figure 4.

The areas described herein represent the possible areas of concern delineated by the surface geophysics investigation within the limits of interpretation of the collected data. Any drilling or excavation at the site may result in exposure of potentially hazardous materials. Additional areas of concern may exist on the site that are beyond the limits of detection of the methods and equipment utilized. Within reasonable limits, every effort was made to delineate possible burial zones applying widely used methods and standards.

SUMMARY

In May 2000, the U.S. Geological Survey performed a surface geophysical investigation on a site used for disposal of unknown types of chemical waste in the 1960's. The site is located near Fayetteville, Arkansas on the Springfield Plateau of the Ozark Plateaus physiographic province and is about 100 feet by 110 feet in size. The surface is flat lying and characterized by a 40-foot thickness of cherty clay regolith material underlain by the chert-rich, karst limestone of the Boone Formation. Information available about the site's history indicates that as many as six pits were excavated for the disposal of laboratory chemicals in glass containers that may or may not be intact.

The objective of the surface geophysical investigation was to use noninvasive methods to delineate possible buried chemical zones. The information collected in this investigation may be useful to locate possible leachate plumes to optimize subsequent sampling and remediation. Methods used at the site focused on the electrical insulating properties of the nonmetallic (glass) containers, electrical conducting properties of possible leaking fluids, and electromagnetic properties of the disturbed regolith material in the vicinity of the burial zones. Several areas of concern at the chemical waste landfill appear to have been impacted through burial of various types of material.

The areas of concern were discovered though electromagnetic, magnetometer, and 2D-DC resistivity surface geophysical methods and are suspected to contain buried materials. The electromagnetic survey was performed in horizontal co-planar mode, measuring both the quadrature and inphase component. The magnetometer survey was performed using a pair of memory magnetometers, one as a roving instrument and one as a stationary instrument continuously measuring the earth's magnetic field. The 2D-DC electrical resistivity survey consisted of 9 profiles of 28 electrodes at a 6-foot spacing with Wenner, Schlumberger, and dipole-dipole array data collected. This combination of geophysical tools was successful in delineating several types of subsurface anomalies consisting of buried metal and discrete high and low resistivity zones at various depths.

Five geophysical anomaly types were categorized and designated as "types A, B, C, D, and E" and were used to delineate areas of concern at the site. Anomaly type A consists of a discrete high resistivity zone with an associated low resistivity zone below, possibly suggesting buried nonconductive material and leaking conductive fluid below. Two type A anomalies were found, one along gridline 6 between gridlines F and G, and the other south of gridline 6, along gridline J. Anomaly type B consists of a discrete high resistivity zone with no associated low resistivity zone below, possibly suggesting the presence of buried nonconductive material without leaking conductive fluid below. A type B anomaly exists between gridlines F and G at gridlines 7 and 8 and another exists near grid

location G-9. Anomaly type C is indicated by a medium resistivity zone adjacent to a high resistivity zone possibly suggesting disturbed regolith associated with burial. Two type C anomalies are evident on the eastern and western sides of the type A and B anomalies mentioned above. Anomaly type D is indicated by a zone of highly resistive material in conjunction with responses from the magnetometer or the electromagnetic survey suggesting buried metal nearby; this anomaly is located near grid locations I-7 to J-7. Anomaly type E is indicated by a discrete zone of high resistivity material underlying a shallow low resistivity zone with a negative electromagnetic response, which indicates the presence of buried metal; this anomaly is located near grid locations J-9 to J-12. These five anomaly types were used to characterize and delineate the possible locations of buried materials at the site. Sampling and source removal plans are being developed based on delineations of the anomalies.

The areas described herein represent the possible areas of concern delineated by the surface geophysics investigation within the limits of interpretation of the collected data. Any drilling or excavation at the site may result in exposure of potentially hazardous materials. Additional areas of concern may exist on the site that are beyond the limits of detection of the methods and equipment utilized. Within reasonable limits, every effort was made to delineate possible burial zones applying widely used methods and standards.

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