Integrated, Flexible, and Rapid Geophysical Surveying*

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ABSTRACT

Detailed environmental studies associated with landfills, burial pits, vaults, underground storage tanks, contaminant plumes, and unidentified contaminant sources adjacent to buildings at Aberdeen Proving Ground, Maryland, are being conducted. Efficient and innovative data-acquisition procedures are imperative in order to provide complete coverage at a large number of small-sized sites. Because APG is a chemical weapons research and development facility, noninvasive geophysical techniques are a necessity. Real-time data processing and interpretation using computers in a field setting permit rapid changes in the design of the survey and in decision making.

Magnetic and electrical interference caused by metal buildings, power lines, and buried utilities limit applicable geophysical techniques. A pilot study to test a variety of techniques resulted in the selection of horizontal electrical resistivity profiling, magnetic gradiometry, total field magnetics, and ground-penetrating radar.

A systematic geophysical survey was designed that begins with a continuous-coverage magnetic gradiometer sweep, in conjunction with a gridded survey of the total magnetic field. A finer-spaced, more detailed, total magnetic field survey was then conducted around anomalous areas identified by the gradiometer sweep. Horizontal resistivity surveying followed and provided information on the electrical properties of the subsurface to help identify nonferrous metals and contaminant plumes. A modification of traditional horizontal resistivity profiling was developed to allow rapid and extensive data collection around metal buildings. Ground-penetrating radar helped determine the geometry and the approximate depth of anomalies detected by the magnetic and electrical surveys.

The final interpretation depends on separating cultural effects (such as road and construction fill, buildings, buried and overhead utilities) from anomalies that may be potential sources of contamination (such as buried drums, underground storage tanks, pits). Historical aerial photos and utility and site plans are incorporated into the interpretation cycle. Computer software, which superimposes magnetic contours over a color image of the resistivity data was used. This permits the simultaneous interpretation and evaluation of the conductive and magnetic features. Ground-penetrating radar profiles were

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exported from DOS machines to a Macintosh machine to improve the color graphics and figure labeling.

This rapid and flexible approach to a geophysical survey of small sites is still evolving, and techniques are being refined to increase the overall efficiency while retaining data quality and resolution of small anomalies.

1 INTRODUCTION

Aberdeen Proving Ground (APG), in the state of Maryland (Figure 1), is currently managing a comprehensive Installation Restoration Program involving more than 360 solid-waste managing units contained within 13 study areas. The Edgewood area and two landfills in the Aberdeen area appear on the National Priority List under the Comprehensive Environmental Response, Compensation, and Liability Act. Therefore, APG has entered into an interagency agreement with the U.S. Environmental Protection Agency to address the listed areas. The West Branch of the Canal Creek area (Figure 1), located within the Edgewood area, is one of the areas that requires a Source Definition Study because there is an ongoing release of volatile organic compounds into the creek.

A report prepared by EAI Corporation (1989) included a list of 29 potentially contaminated buildings in the Edgewood area. Sixteen of the buildings contain known contaminants, nine buildings contain unknown contaminants, and four of the buildings are potentially clean. The EAI report recommended that a sampling and monitoring program be established to verify contamination levels in and around each building. Thirteen of the potentially contaminated buildings are in the West Branch of the Canal Creek area and are potential sources of volatile organic compounds. Operations have ceased and the buildings have been abandoned, but processing equipment, sumps, drains, ventilation systems, and underground storage tanks remain. These appurtenances may contain liquid, solid, or vapor contaminants of unknown nature.

Aberdeen Proving Ground is proceeding with a program to decommission the buildings, which will eliminate the actual or potential release of contaminants into the environment of the West Branch of the Canal Creek and other sites within the Edgewood area. Argonne National Laboratory has been assigned the task of developing a plan and scope of work for the proposed decommissioning. Argonne has determined that the first step in this decommissioning process, where it is technically feasible, should be a noninvasive geophysical survey around building exteriors.

1.1 Site Reconnaissance

The geophysical survey program design for the exterior of the buildings is based upon results from a pilot study completed in the spring of 1991 for Building E5032 (McGinnis and Miller 1991), which is also located in the Canal Creek area. The initial evaluation was enhanced by visits to each site in November 1991 and by inspection of aerial photos. In addition to evaluating surface conditions at the sites, subsurface characteristics were considered in planning the geophysical surveying:

1. Surficial sediments consist of estuarine silts, sands, and clays that have intermediate resistivities and are nonmagnetic. The underlying soil properties

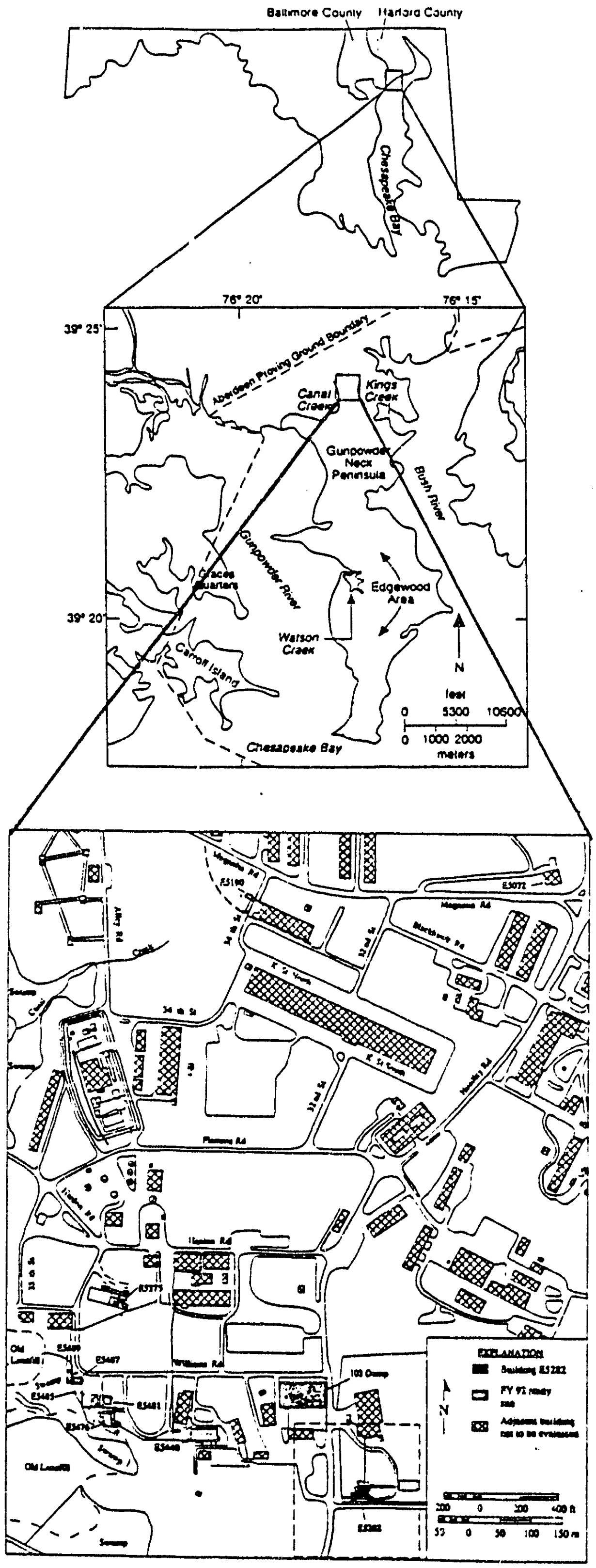

FIGURE 1: GENERAL SITE MAP OF THE CANAL CREEK AREA, ABERDEEN PROVING GROUND, MD

are expected to vary both horizontally and vertically in the proximity of the site, depending on naturally occurring conditions and on the presence of building excavations and operations.

2. Buildings and other attributes of the Edgewood section of Aberdeen, such as radio and radar transmissions, will contribute to interference of magnetic and electrical fields and will cause electromagnetic surveying to be generally inapplicable (AEHA 1989).

3. Multiple sources, such as ferrous and nonferrous conductors, nonmetallic objects, subsurface channels containing contaminants, and plumes of contaminants of variable resistivity, may be present in the subsurface.

Multiple working technologies were utilized in the program design to mitigate interference and to either directly detect or provide inferential data on subsurface characteristics.

1.2 Geology and Physiographic Setting

APG is contained in the topographically low and flat terrain of the Coastal Plain physiographic province. The Canal Creek area is underlain by alluvial and estuarine sands, silts, and clays. A thin veneer of sediments of the Talbot Formation of Pleistocene age overlies unconsolidated sediments of the Potomac Group of Cretaceous age (Oliveros and Gernhardt 1989). The water table is less than 10 ft from the surface, and groundwater contains measurable concentrations of contaminants (USGS 1992).

1.3 Surveys

The following discussion is an example of a typical geophysical survey at one of the buildings scheduled for decommissioning (Thompson et al.,1992). The geophysical phase for Building E5282 was carried out during the period April 6 to May 8, 1992. The original work plan (McGinnis et al. 1992), called for magnetics, ground-penetrating radar (GPR), and horizontal direct-current electrical resistivity (DCER) surveys. An addition to the plan was the use of a magnetic gradiometer/metal detector to ensure detection of anomalies between survey profiles and grid stations. Each technique had its own specific objectives:

- Gradiometer/metal detector sweep — to provide a rapid, 100% sweep of the site;

- Magnetometer measurements — to determine the location of such buried, iron-rich objects such as tanks, pipes, debris, etc.;

- Horizontal DCER survey — to establish the regional conductive nature of the subsurface and to identify contaminant plumes to depths of approximately 10 ft; and

- Ground-penetrating radar survey — to determine the geometry of, and to find the approximate depth to, buried objects.

The following data were acquired at Building E5282 (Thompson, et al., 1992) during field operations: (1) nonpermanent ground markings of magnetic objects, (2) 1,805 magnetic observations, (3) 406 horizontal DCER observations, and (4) 5,605 (linear) ft of GPR profile along 84 lines. See Figure 2 for the boundaries of the geophysical surveys for Building E5282. Field operations required a total of two days for a four-person team. On-site personal computers (both notebook and desktop), interactive software, field equipment designed specifically for Aberdeen, and an all-terrain vehicle (ATV) were used to expedite data acquisition and processing.

2 INSTRUMENTATION

2.1 Magnetic Gradiometer and Cable Locator

The Schonstedt MAC-51B magnetic gradiometer and cable locator is a dual-mode instrument designed for detecting shallow buried iron and steel objects and tracing underground cables and pipes. The system consists of a transmitter and a dual-function receiver designed to detect anomalous magnetic gradients.

Maps or models are not constructed from observations made with the MAC-51B because it is not a calibrated system. The MAC-51B is an audio device used only for rapid detection of magnetic materials for further analysis with complementary instrumentation. Anomalies are identified by changes in sound amplitude and frequency and are marked on the ground surface prior to the initiation of other surveys. If anomalies detected with the MAC-51B cannot be verified with other instrumentation, the anomaly is assumed to be insignificant.

Application of the MAC-51B in its receiver mode was the first geophysical operation following establishment of survey limits. A qualitative description of the site with 100% ground coverage is achieved using the gradiometer, whereas the results obtained with other techniques, although more quantitative, are spatially limited to single-point, survey-grid observations or to continuous readings along spaced profiles.

2.2 Magnetometer/Gradiometer

Total-field magnetics is used to identify buried ferrous objects such as tanks, drums, and small debris. The EDA OMNI IV magnetometer/gradiometer is a total-field, proton-precession, microprocessor-based instrument that can also measure magnetic gradients. To adjust for field changes, the instrument has internal calibration to correct observations made at cross lines and base stations. Repeat readings were used to correct data for diurnal field fluctuations. Internal software permits down-loading directly into an on-site computer.

Total-field magnetic observations were made at 5-ft and smaller intervals along profiles, yielding a grid of data that was contoured using the SURFER V. 4.0 software by Golden, Inc. (1991), to identify potential sources of contaminants and to distinguish them from background.

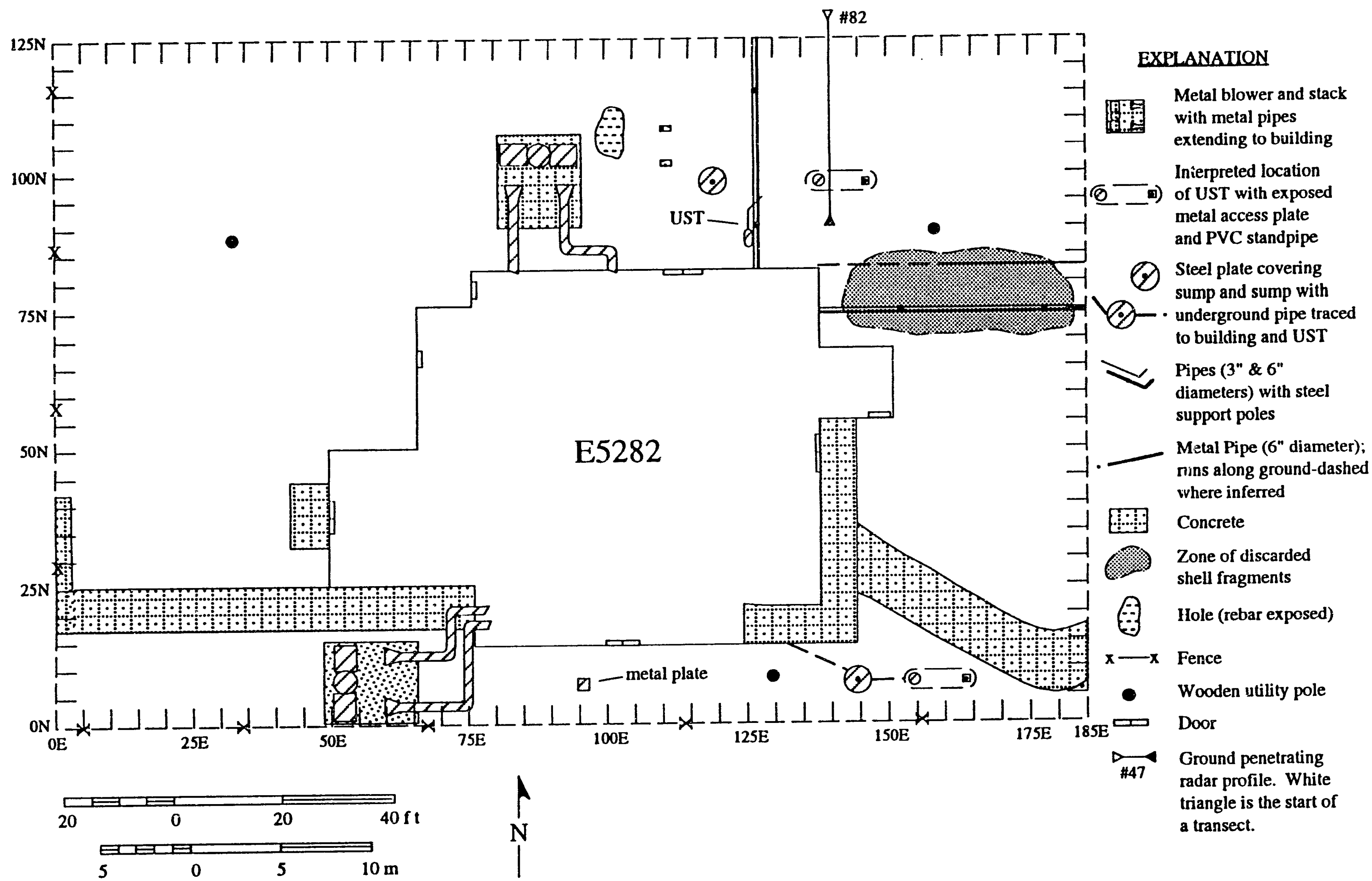

FIGURE 2: GEOPHYSICAL SURVEY BOUNDARIES FOR BUILDING E5282

The SURFER software was incorporated into the field acquisition procedure, so that daily map outputs were available for observation and interpretation.

2.3 Direct-Current Electrical Resistivity Meter

Data on the electrical properties of soils at APG may permit detection of abnormally conductive or nonconductive liquid or solid contaminants. Most of the electrical properties of sedimentary materials are a product of the chemistry of interstitial fluids. Consequently, resistivity data can be diagnostic and complement magnetic and radar measurements.

Resistivity equipment used on the Aberdeen project consisted of an ABEM Terrameter and Booster, model SAS 300C, that utilized a variety of electrode configurations. Direct-current earth resistivity surveying, one of the classical technologies used in the study of the subsurface for groundwater, engineering, and the environment, is rapidly being replaced by electromagnetics (EM) because its application is labor intensive, time-consuming, and therefore, where hundreds of observations are required, costly. EM techniques developed for rapid acquisition of data in airborne mineral exploration are effective in areas formerly the domain of resistivity; however, these techniques will not work in close proximity to conductive metallic buildings or in areas subject to intense radio frequency transmissions.

To overcome limitations in both EM and resistivity surveying, an electrode array, referred to as the "Octapod," for horizontal ground resistivity applications was constructed for this project. The Octapod, described by McGinnis and Tome (1992), can be used in either the Wenner or Schlumberger mode. It was constructed to eliminate the cumbersome and time-consuming procedure for horizontal surveying whereby four conducting electrodes, two potential and two current, arranged in a linear pattern, are hand-carried and driven into the ground at locations where knowledge of the electrical properties of the earth is required. In order to stabilize the array during transit and at the same time, decrease electrode-to-ground resistance, it was decided to construct the electrodes in a paired system such that four current electrodes, two left and two right, are fixed at the two ends of the array, and four potential electrodes are spaced, two left and two right, in a symmetrical pattern between the four current electrodes. The distance between the left and right electrodes can be varied depending on the needs of the survey.

The electrodes consist of aluminum dishes of a size that maintains contact with the ground while towing over uneven terrain or lawn by ATV. When required, coupling between dishes and ground is enhanced with a gravity feed watering system connected to the aluminum dishes with flexible tubing. Electrical coupling between electrodes and ground is further enhanced with copper-coated, steel grounding rods, inserted through a conductive metal shaft attached to the center of the dish electrodes. Resistivity readings are made by properly connecting the array to the resistivity meter.

Versatility of the array is improved through the construction of a switch box that permits readings to be made in several modes.

1. Apparent resistivity can be determined using only electrodes on the left side of the Octapod;

2. Apparent resistivity can be determined using only electrodes on the right side of the Octapod; or

3. Apparent resistivity can be determined using both left and right electrodes connected in parallel, thus halving the contact resistance between electrodes and ground and resulting in a mean apparent resistivity beneath the array.

A modified, eight-electrode Wenner array was the configuration selected for use at Aberdeen. Profiles were coincident with GPR and magnetic lines, and data were recorded at 5-ft intervals along the lines. Consistency of repeat observations over a test profile and over known electrical anomalies provided assurance of relative data quality and variations. Data were contoured using SURFER software as described in the magnetics section.

The Octapod has been field-tested at APG and has shown itself to be robust and field-worthy, requiring little maintenance. Operation of the Octapod requires only one person. Repeat observations at different statics can be made in several tens of seconds rather than the former five to ten minutes required using conventional electrical resistivity surveying techniques.

Electrical depth-sounding curves using a Schlumberger electrode array were also determined in the Canal Creek area to add a three-dimensional view to horizontal mapping. Each sounding curve was interpreted using the RESIX PLUS software package written by Interpex (1988).

2.4 Ground-Penetrating Radar System

Ground-penetrating radar surveying was accomplished using a Geophysical Survey Systems, Inc. (GSSI), model SIR-3 radar connected to a transceiver with a cable approximately 300 ft long. Data were recorded on a digital audio tape to permit playback and computer processing. The control unit/graphic recorder was located in the transport vehicle. An IBM-compatible processing computer was located in a field office, so that the radar operator could down-load, check data-tape quality, and do preliminary processing after a day's run. Radan I computer software written by GSSI was used for processing the GPR data.

Wave-velocity characteristics of materials to be found at the Aberdeen/Edgewood area were derived from known positions of buried objects. Internal calibration was run at least twice each day to ensure that the graphic record of the range setting was consistent. Studies conducted during the 1991 field season suggest wave velocities of $6\text{-}7 \times 10^{-9}$ s/ft for near-surface sediment at Aberdeen; however, characteristics vary with the heterogeneity of the subsurface.

Ground-penetrating radar is probably the best method available to determine depth and geometry of objects buried near the surface. The weakness of the method is its limited depth of exploration due to wave-propagating constraints imposed by the electrical properties of soils. The maximum depth of penetration with GPR at Building E5282 was approximately 8 ft below the ground surface.

3 GEOPHYSICAL MEASUREMENTS AND SURVEYS

3.1 Magnetometer Measurements

Total magnetic-field observations were made at 1805 stations for use in construction of the magnetic map shown in Figure 3. Station spacing was normally 5 ft; however, where the pre-survey scan identified anomalous zones, stations were read at intervals as small as 1 ft. Readings were not made within 5 ft of a security fence to minimize interference with the magnetic observations. Peaks and troughs of positive and negative anomalies were truncated to permit a clearly displayed visual representation of the magnetic field. Thus, anomaly interiors are depicted as "white-outs." Because of surface interference caused by pipes, metal racks, exhaust stacks, and fences, considerable caution should be observed when viewing anomalies on the north, east, and south. The fence at the far west end of the survey site is not associated with an anomaly of high amplitude, although a north-south lineament on the west is probably fence-related.

In general, the west and northwest margins of the building, essentially that area outlined by a low topographic terrace composed of fill material, are underlain by multiple magnetic sources scattered within the building fill. Anomalies produced by these sources are, for the most part, defined by one or two magnetic stations. One north-south, elongated, multistation anomaly (survey coordinates 45E,70N) is centered approximately 20-25 ft west of Building E5282. This anomaly has a size and shape consistent with that of an underground storage tank (UST); however, it is not associated with such surface features as vents, fill pipes, or mounds that would support a UST interpretation. The anomaly may be caused by buried pipe oriented in a north-south direction and by clusters of magnetic sources that appear as a single magnetic anomaly.

A north-south elongated anomaly, centered at survey coordinates 100N,105E (approximately 20 ft north of the building), also has the size and shape of a UST-derived magnetic anomaly, but again this anomaly is not associated with such expected surface features as vents, fill pipes, or access plates. Rebar and concrete fragments exposed in a shallow pit 5 ft west of this anomaly suggest an alternative source.

A magnetic high centered at survey coordinates 95N,135E is caused by a UST that is oriented with its long axis east-west. The center of this magnetic high is offset approximately 7 ft west of the presumed center of the UST. Surface features such as vents and fill pipes support this UST interpretation, as does GPR profile data.

A large and complex anomaly, with an amplitude of several thousand gammas, is centered approximately 25 ft east of the eastern-most projection of the building. This anomaly is caused by ordnance fragments that were scattered at the surface and by aboveground pipes and the structural braces supporting these pipes. If any subsurface sources were present, they would be masked by this dominant anomaly.

Six smaller anomalies located near the southwest corner of the surveyed area are probably caused by a drainage pipe oriented north-south that underlays a cement sidewalk. A large anomaly near the southwest corner of the building is produced by an aboveground complex of fans, blowers, exhaust pipes, and associated plumbing.

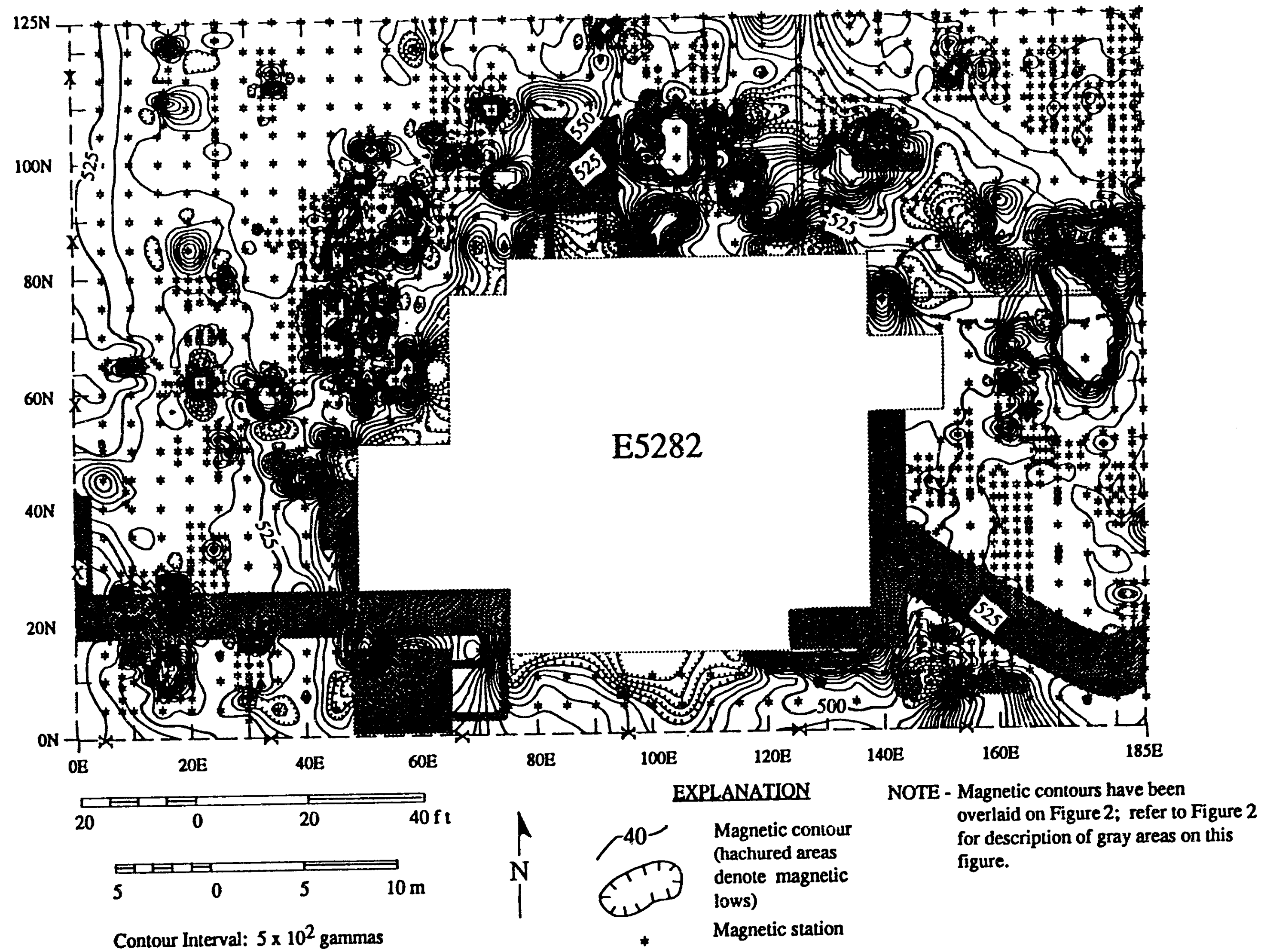

FIGURE 3: TOTAL INTENSITY MAGNETIC MAP OF BUILDING E5282

Three isolated anomalies are observed near the southeast corner of the surveyed area. Of these, the east-west elongated anomaly centered at 156E,7N is caused by a UST. Vents, fill pipes, and steel access plates located on the anomaly support this interpretation.

3.2 Direct-Current Electrical Resistivity Measurements

The results of the DCER survey are illustrated in Figure 4. The electrode spacing was 2 m, a configuration that provides an average resistivity for materials lying between the surface and a depth of about 3 m. As known from the log for the borehole nearby, these materials would include fill; an orange-brown material with asphalt and wood; and most of the thickness of the Upper Confining Unit (Oliveros and Gernhardt 1989), which is a silty clay.

From previous work (McGinnis and Miller 1991), background resistivities for these fine-grained, organic-rich, clayey materials were found to range from 50 to 150 Ω-m. Electrical depth-sounding curves collected for background in the Edgewood area indicate that resistivity values normally decrease with depth, probably due to increasing saturation and concentrations of dissolved solids. Where anomalous materials are present, this generalization is not valid. Measurements made along an east-west line at an electrical depth-sounding station centered at survey coordinates 195E,140N, with electrodes expanded outward to a maximum spacing (AB/2) of 60 m, are inverted to give an interpreted earth-model having surficial resistivities of 108 Ω-m in the upper 40 cm. From 40 cm to a depth of 4.5 m, about the combined thickness of fill and the Upper Confining Layer, resistivities average 244 Ω-m. Resistivities drop back to 95 Ω-m below 4.5 m depth.

Apparent resistivity values in the surveyed area of Building E5282, acquired using horizontal profiling techniques, range from a minimum of 80 Ω-m near the north central wall of the building to a high value of 600 Ω-m centered about 25 ft east of the building. The high resistivities observed at this location might be attributed to the presence of asphalt and wood (known from the drillers report) or gravel and unreinforced concrete. Another cause may be the presence of nonconductive liquids, which are known to be in the area (USGS 1992). However, the causes cannot be known with certainty without subsurface sampling.

The extremely high resistivity values observed to the east of the building were located in an area where gravel, cobbles, and rusted metallic debris (ordnance fragments) were found lying at the surface. Dry, shallow, construction fill material may be part of the cause of these extremely high resistivities, although the fill material west of the building is associated with relatively more conductive and magnetic zones.

3.3 Ground-Penetrating Radar Measurements

Ground-penetrating radar measurements around the building perimeter were made at 5-ft intervals over 5,605 ft of traverse along 84 individual profiles, coincident with magnetic and resistivity profiles. Prior to running the production lines for the survey, replicate runs were made to determine which of the three transceivers — the 80-, 300-, or 500-MHz antenna — was best suited to study the terrain surrounding the site. The transceiver providing the best penetration and resolution of buried objects was the 300-MHz unit. Different range settings were also tested over the same transect to determine the optimum resolution and depth of penetration. A range

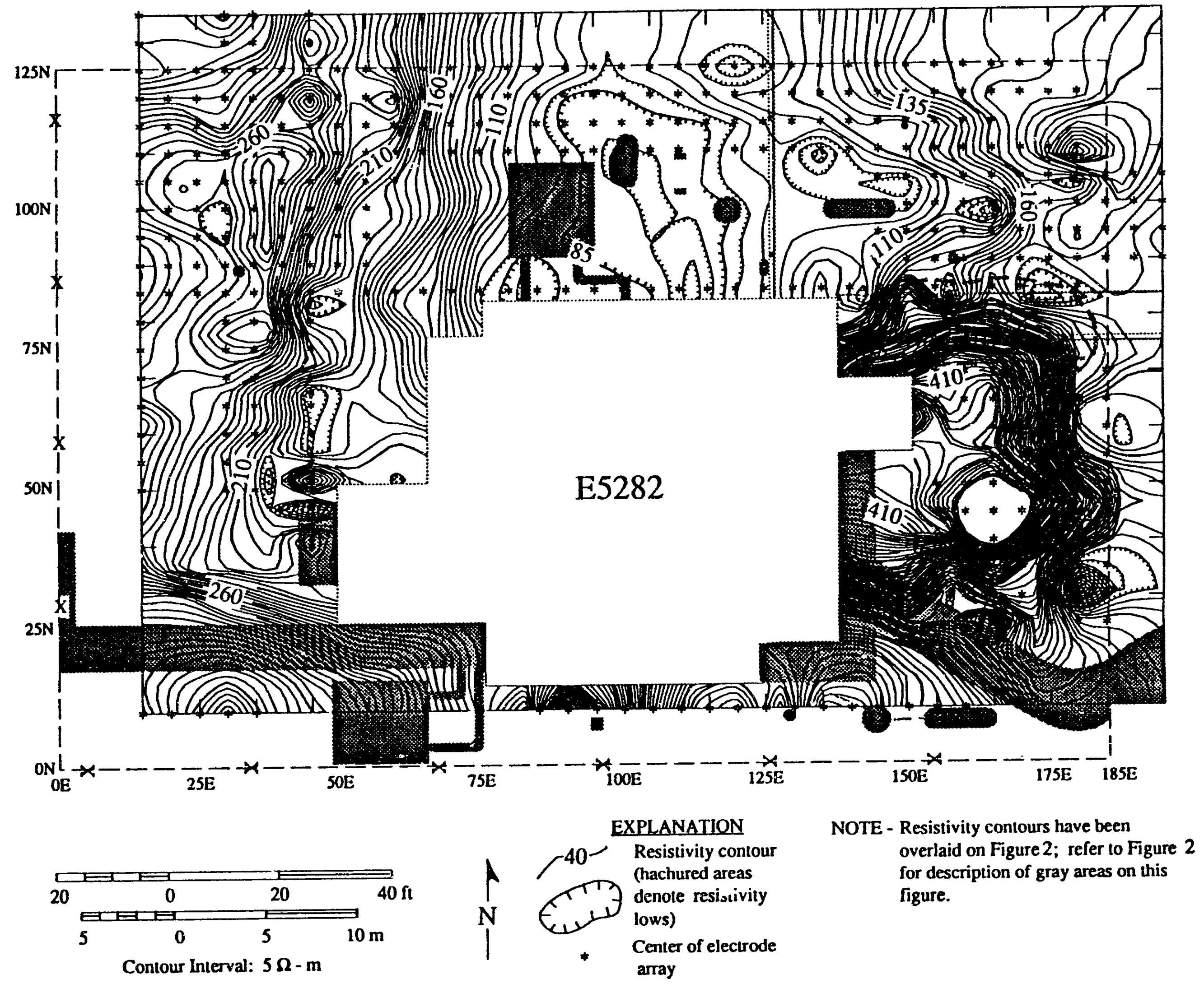

FIGURE 4: APPARENT RESISTIVITY MAP OF BUILDING E5282

setting of 90 ns was used for the entire survey at scan rates of both 16 and 32 scans/s. However, some additional profiles were collected at a range setting of 70 ns over selected anomalies around Building E5282. Antennas were pulled by hand at approximately 3 ft/s.

Most of the profiling was done in the areas north, east, and west of the building; some lines were run in the narrow space between the building and the fence to the south. Perimeter profiles were designed to detect buried objects extending radially from the building. Figure 5 shows one of the GPR profiles. The vertical scale is shown on the right side of the profile, whereas lines are marked at 10-ft intervals for the horizontal scale. Without verification by another technique or by passing the antenna over a known buried object, characteristics of radar anomalies may only be inferred. However, where GPR anomalies coincide with magnetometer or electrical anomalies, a more specific interpretation of the radar anomaly is possible.

Good penetration was observed over most of the site, with resolution down to about 8 ft below the ground surface. The major findings of the GPR survey around Building E5282 are as follows:

1. Building E5282 appears to be built over 2-3 ft of engineered fill that contains scattered metallic debris. GPR profiles collected on the west side of the building show the western edge of this fill at approximately 40E. A small diameter pipe buried at a depth of approximately 3 ft was also discovered in a few GPR profiles. This pipe corresponds with a magnetic anomaly shown in Figure 3.

2. The GPR profiles collected to the north and east of Building E5282 show many shallow objects in the upper 1-2 ft. In areas where this debris is very concentrated, radar signal penetration is poor. This is especially true in the area east of the northeast corner of the building, where ordnance was found at the surface. The debris to the north of the building does not appear to extend beyond a distance of 30 ft.

3. The presence of the two USTs was confirmed with the GPR. The two tanks are centered at coordinates 98N,142E and 8N,158E. Both of the tanks are oriented east-west, and each is approximately 12 ft long. Figure 5 clearly shows the UST north of the building at coordinates 98N,140E. The GPR signature of the UST southeast of the building is nearly identical. The profiles collected over the USTs show that both are buried at depths of approximately 3.5 ft and confirm that each tank is connected by a pipe to a round sump located to its west. The GPR profiles also revealed a pipe that extends from the sump at the southeast corner toward Building E5282.

4. GPR profiles collected on the east side of the building show a prominent flat-lying reflector that starts at 63N and extends to 35N. This feature is also visible on east-west GPR lines. The feature tends to lose its flatness and becomes much more intermittent toward the north. It is characterized by two reflectors, one at 2.5 ft and a second, more prominent one, at 5.0 ft below the ground surface. This anomaly could be produced by such buried debris as concrete without steel reinforcement; by layered, coarse fill; or by a highly reflective liquid.

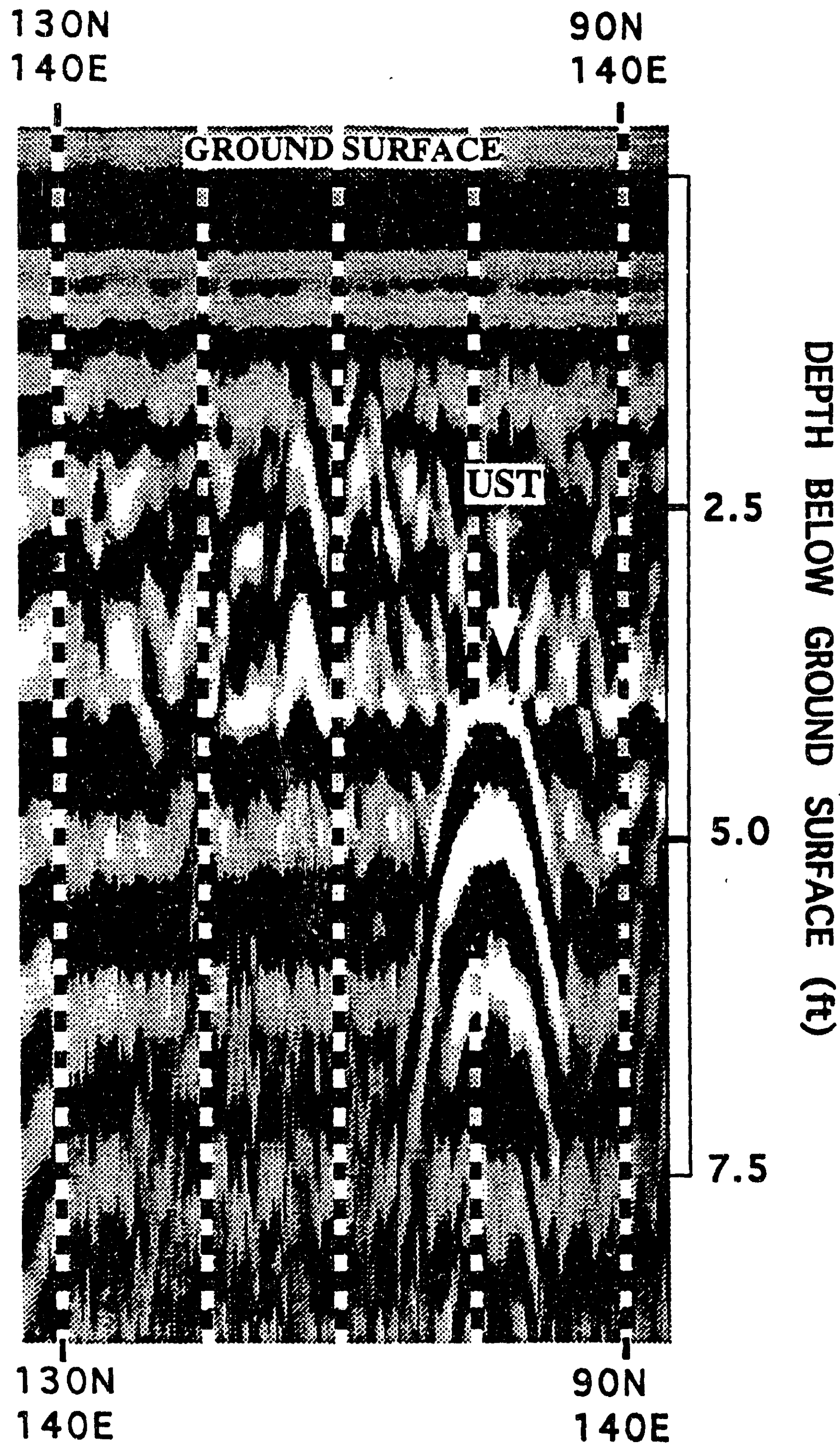

FIGURE 5: GROUND PENETRATING RADAR PROFILE NORTH OF BUILDING E5282. THE PROFILE IS ORIENTED NORTH-SOUTH. THE LOCATION OF THIS PROFILE IS SHOWN IN FIGURE 2 AND LINE #82

4 DISCUSSION

In order to develop a more complete interpretation, the electrical resistivity and the magnetic data should be overlaid. Computer software that superimposes magnetic contours over a color image of the resistivity data was used. However, for the purposes of this paper, color figures are not included. In general, electrically conductive areas conform with positive magnetic anomalies, where both data sets are complete. This relationship is most pronounced west of the building, where electrical gradients outline a broad cluster of high-intensity magnetic anomalies. Conductive and highly magnetic areas to the north and southeast of the building also have a common source. No resistivity data were acquired in the anomalous magnetic zone in the southwest corner of the surveyed area. The extremely high resistivity region east of the building is not associated with a similar magnetic feature, but does coincide with a strong reflector in the GPR data. A broad magnetic positive anomaly north of the resistivity anomaly is caused by aboveground debris and plumbing and is therefore not represented by a coincident electrical anomaly.

The integration of data from all the geophysical measurements performed around Building E5282 further enhances the interpretation. The GPR profiles anomalies are supported by both the magnetics and the electrical resistivity data. The magnetic anomalies and electrical gradients associated with building fill west of the building are apparent in the GPR data. The concentration of magnetic anomalies that trend from south to north also coincide with a pipe anomaly seen in several GPR profiles.

The magnetic and GPR data show two large anomalies that are the results of USTs. These USTs are centered at coordinates 98N,142E and 8N,158E. Both of the tanks are oriented east-west, and each is approximately 12 ft long. The GPR profiles over both tanks show the tops at approximately 3.5 ft below the ground surface. The GPR profiles also show pipes extending from each tank to round sumps located to the west of each. A pipe that extends from the sump at the southeast corner toward Building E5282 was also revealed.

5 CONCLUSIONS

Specific conclusions drawn from the site surveys of Building E5282 are the following:

- Isolated magnetic and GPR anomalies west of the building are due to small, scattered, metallic debris that probably poses no environmental hazard.
- Electrically conductive zones west and north of the building outline areas of increased metallic debris in construction fill.
- Two underground storage tanks, one near the southeast corner of the building and a second near the northeast corner, are associated with magnetic anomalies and a GPR image.
- A circular, high-intensity, high-resistivity anomaly measuring about 25 ft in diameter is centered approximately 25 ft east of the building and is in line with east-facing, steel double-doors. The feature spreads out to the north and south away from the building and is not associated with a magnetic anomaly

or with any surface feature. GPR imaging in this area indicates a prominent, horizontal reflector lying 5 ft below the surface. The source of the anomaly may be a concrete slab without steel reinforcement; layered, high-resistivity construction fill; or high-resistivity liquid above the water table.

Generalized conclusions from studies conducted in 1992 are the following:

- The development of the Octapod allowed rapid acquisition of data on the electrical properties of the subsurface. Resistivity measurements using the Octopod can be a valuable substitute for electromagnetics in areas with cultural interference (i.e. metal buildings and radio transmissions)

- The use of color maps and color GPR profiles is very helpful for interpretation.

- ANL is in the process of acquiring a new continuously recording proton procession magnetometer, which will further speed up data acquisition.

- There is still a great need for research on improving data quality, software, and speed of acquisition.

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