GEOPHYSICAL SURVEY OF BURIED WASTE AT THE IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY: A CASE STUDY

M.C. Pfeifer, A. W. Glenn, G. E. Matthern*

*Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC, Idaho Falls, Idaho 83415
gtn@inel.gov

ABSTRACT

Intrusive sampling of buried waste sites is expensive and time consuming and it increases the chances of worker exposure to hazardous materials. While noninvasive characterization techniques are not a substitute for invasive sampling, they can focus the sampling effort thereby reducing the number of invasive samples required, decreasing the time required to characterize a site, and reducing the risk of worker exposure to hazardous materials. The results of the use of noninvasive geophysical techniques for the characterization of Pits 2, 3, 5, and Soil Vaults Rows 1–14 in the Subsurface Disposal Area (SDA) are presented as a case study.

The SDA is a part of the Radioactive Waste Management Complex (RWMC), which is located in the southwestern area of the Idaho National Engineering and Environmental Laboratory (INEEL). The SDA is located in a high desert plateau with approximately 20 feet of unconsolidated sediment (mainly weathered basalt) underlain by layers of fractured basalt. The waste pits and soil vault rows were constructed by excavating to the surface of the basalt. Waste was placed directly on the basalt or on top of a thin soil layer placed on the basalt. Disposal of the waste occurred over a period of approximately 20 years starting in the early 1950s. This waste contains radionuclides (cesium, uranium, americium, plutonium, strontium), hazardous compounds (beryllium, asbestos, zirconium fines, sodium and potassium salts, mercury, solvents and degreasing agents, solidified acids and bases), and general debris (metal, wood, paper, cloth, plastic).

Previous characterization activities have included compilation of historical data (photographs, waste disposal manifests), soil and gas sampling, and geophysical surveys that have covered parts of the SDA and provided general information about the sites. However, improvements to geophysical techniques now allow for higher resolution surveys. The purpose of the survey described in this report was to use these improved techniques to better define the location of the waste buried in Pits 2, 3, 5, and Soil Vault Rows 1–14. Better definition of the pit and soil vault boundaries and metallic objects within the pits will help in selection of sites for further investigation. In addition to providing better definition of the pits and vaults, the purpose of this work was to illustrate the power of combining geophysical techniques. The survey was conducted in October of 1999.

A variety of noninvasive geophysical tools can be used to distinguish the boundaries of buried waste sites and provide qualitative data of the contents of those sites. Three geophysical technologies: the Rapid Geophysical Surveyor (RGS), the Geonics EM 61, and the Geophex (GEM2) were used to characterize Pits 2, 3, 5, and Soil Vault Rows 1–14 covering approximately 15 acres in the SDA.

Selection of these technologies was based on the results of previous demonstrations at Brookhaven National Laboratory and the Cold Test Pit at the INEEL. For comparison of the geophysical data to historical data, Geosoft software was used to merge the geophysical data with the CAD rendering of the historical pit, trench, and soil vault row locations. The synthesis of the data from the multiple techniques significantly improved the resolution and compositional detail delivered by the surveys.

Data from the survey provided the locations of geophysical anomalies associated with shallow buried waste. Correlation of these geophysical anomalies to the historical records was done in an effort to better determine boundaries of the pits and soil vault rows and verify the reliability of the historical data. Results of this work will be used to facilitate the selection of sampling locations for contaminants of potential concern and to help locate areas to perform demonstrations of remediation technologies.

Geophysical data from three instruments were analyzed individually and as a group and compared with available historical records to better determine discreet boundaries and the presence and location of buried waste forms in five pits and fourteen soil vault rows. Using the three instruments and a more dense data collection method, information was collected that successfully identified discrete boundaries for most of the pits and soil vault rows and provided enhanced clarity of waste forms over previous surveys. The data collected from this survey was used in evaluating the accuracy of the historical data and provided additional information on the location and content of the pits and trenches. This data will help reduce the number of invasive samples required to characterize the pits and trenches and will assist operations in planning field treatability studies.

INTRODUCTION

Intrusive sampling of buried waste sites is expensive and time consuming and it increases the chances of worker exposure to hazardous materials. While noninvasive characterization techniques are not a substitute for invasive sampling, they can focus the sampling effort thereby reducing the number of invasive samples required, decreasing the time required to characterize a site, and reducing the risk of worker exposure to hazardous materials. A variety of noninvasive geophysical tools can be used to distinguish the boundaries of buried waste sites and provide qualitative data of the contents of those sites. This paper provides a case study, conducted in October of 1999, of the application of multiple geophysical techniques to a series of pits and vaults containing buried wastes.

Pits 2, 3, 5, and Soil Vault Rows 1–14 are located at the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex at the Idaho National Engineering and Environmental Laboratory. The pits and soil vault rows account for approximately 15 of the 80 acres in the SDA. The SDA is located in a high desert plateau with approximately 20 feet of unconsolidated sediment (mainly weathered basalt) underlain by layers of fractured basalt. The Snake River Plain aquifer is approximately 500 feet below the ground surface. The waste pits and soil vault rows were constructed by excavating to the surface of the basalt. Waste was placed directly on the basalt or on top of a thin soil layer placed on the basalt. Disposal of the waste occurred over a period of approximately 20 years starting in the early 1950s. This waste contains radionuclides (cesium, uranium, americium, plutonium, strontium), and hazardous compounds (beryllium, asbestos, zirconium fines, sodium and potassium salts, mercury, solvents and degreasing agents, solidified acids and bases) (1).

Previous characterization activities have included compilation of historical data (photographs, waste disposal manifests), soil and gas sampling, and geophysical surveys that have covered parts of the SDA and provided general information about the sites. However, improvements to geophysical techniques now allow for higher resolution surveys. The purpose of this survey was to use these improved techniques to better define the location of the waste buried in Pits 2, 3, 5, and Soil Vault Rows 1–14. Better definition of the pit and soil vault boundaries and metallic objects within the pits will help in selection of sites for further investigation.

In addition to providing better definition of the pits and vaults, the purpose of this work was to illustrate the power of combining geophysical techniques. Three geophysical techniques were used for this survey and the synthesis of the data from the multiple techniques significantly improved the resolution and compositional detail delivered by the surveys.

During this deployment, three geophysical technologies (the Rapid Geophysical Surveyor (RGS), the Geonics EM 61, and the Geophex GEM2) were used to characterize Pits 2, 3, 5, and Soil Vault Rows 1–14 covering approximately 15 acres in the SDA (see Figure 1). Selection of these technologies was based on the results of previous demonstrations at Brookhaven National Laboratory and the Cold Test Pit at the INEEL (2, 3, 4). For comparison of the geophysical data to historical data, Geosoft software was used to merge the geophysical data with the CAD rendering of the historical pit, trench, and soil vault row locations.

Data from the survey provided the locations of geophysical anomalies associated with shallow buried waste. Correlation of these geophysical anomalies to the historical records was done in an effort to better determine boundaries of the pits and soil vault rows and verify the reliability of the historical data. Results of this work will be used to facilitate the selection of sampling locations for contaminants of potential concern (COPCs) and to help locate areas to perform demonstrations of remediation technologies.

The objectives of this deployment were to:

- Better define and locate the boundaries of Pits 2, 3, and 5
- More accurately locate the Soil Vault Rows 1–14 within the SDA
- Identify areas of metallic concentrations within the pits and soil vaults
- Integrate the geophysical data collected with the available historical database of the SDA
- Attempt to correlate geophysical anomalies with historical data on waste forms to help determine future sampling and/or remediation site locations
- Demonstrate the advantages of using multiple geophysical techniques when surveying a site.

BACKGROUND

Numerous characterization efforts have been undertaken on the SDA. These efforts include SDA inventory evaluation, compilation of historical data, soil and gas sampling, and other geophysical surveys.

In 1977, receiving records for waste shipments and waste disposal records were reviewed to estimate the location of wastes in the SDA (5). The review indicated that significant uncertainty existed about the boundaries of several of the waste pits and placement locations of waste within the pits.

In 1990, geophysical data were collected by EBASCO Geophysical Services using a hand-held magnetometer and a Geonics EM-31 conductivity meter on a 1 × 4-meter grid spacing over the entire SDA. This survey provided general pit and trench locations but could not fully resolve some of the pit and trench boundaries or provide information on the location of individual objects within the waste zones. The geophysical data from this survey were compared to the historical pit and trench locations and numerous discrepancies between the actual and assumed pit and trench boundaries were observed. Although these observations demonstrated the abilities of geophysical technology to detect buried waste at the INEEL, further analysis of the data was not performed due to the limited resolution of the data collected with the two instruments. Improvement in the resolution of geophysical techniques for this survey would have required collecting much larger data sets as well as developing improved methods for processing this data in a timely and efficient manner. At the time of this survey, methods for collection and processing of such data were not available.

Recent developments have improved the resolution of many geophysical techniques. In the area of hardware, there have improvements in the form of increased storage capacity, processing speed and signal generation and collection methods. Developments in software include more efficient algorithms for analysis of geophysical data as well as improvements in methods of integrating geophysical data to other positional data such as site maps. The three technologies used in this deployment (Rapid Geophysical Surveyor (RGS), the Geonics EM-61, and the Geophex GEM2) have incorporated these advancements and have been previously demonstrated at the INEEL.

In 1992, the INEEL demonstrated the RGS at Pit 9 in the SDA (6). This data collection effort demonstrated the improved resolution obtained using a denser sampling grid (0.5 × 1-meter grid). Individual objects marked on the historical records, such as sampling wells and pit monuments could be easily identified and distinguished from waste anomalies. Waste areas within Pit 9 were better defined and could be compared to the historical records of waste burial in the pit to better resolve waste forms. Since 1992, Geonics, LTD., and Geophex, Inc., have also commercialized electromagnetic instruments, the EM-61 and the GEM2 respectively, that can rapidly collect data over a large area.

At Brookhaven National Laboratory, the RGS, EM-61, GEM2, an additional Geonics instrument, the EM-31, and two ground-penetrating radar (GPR) systems were used to locate numerous suspected waste pits in the same manner as described in Roybal et al. (2, 6). This survey integrated all the geophysical data sets with the historical photographs of the site. Data from this survey located pits observed in the photographs as well as additional pits not apparent in the photographs. Analysis of the data clearly demonstrated that the RGS, the EM-61, the GEM2 combined system could be highly effective for the identification of boundaries and waste forms in buried waste pits, trenches and soil vaults, and could be effectively employed at the INEEL. The GPR systems, although successful in the Brookhaven demonstration, have previously been shown to be ineffective at the SDA due to the types of soils prevalent at the INEEL (3, 4).

METHODS

The RGS magnetometer system, Geonics EM-16 time domain induction electromagnetic system, and the Geophex GEM2 frequency domain induction electromagnetic system were used to determine the boundaries of the pits and soil vaults in the areas surveyed. The data collected were also analyzed in an effort to distinguish individual objects or groups of objects in the pits and soil vault rows. After the initial data collection and reduction, the resulting maps were compared to the historical records (5, 7) of the pits in an effort to identify waste streams or waste deposited within the pits and soil vault rows.

The survey was conducted over Pits 2, 3, 5, and Soil Vault Rows (SVRs) 1–14 (Figure 1). The total area surveyed was approximately 15 acres. All surveys were performed following the procedures outlined "Test Plan for the Geophysical Characterization of Pits 2, 3, 5, and Soil Vaults 1–14 in the Radioactive Waste Management Complex" (8) and following the manufacturers operating procedures for each instrument (9).

Of critical importance in each of the following waste characterization surveys is the closeness of the data sample spacing. What is often encountered in buried waste environments is very complex physical fields rather than subtle or low amplitude fields. Complex fields where signals change dramatically over short distances require close data spacing. It is a spatial aliasing issue where widely spaced data causes the responses from nearby objects to become blended into single map features. In order to avoid the combination of signals from closely spaced objects, data must be collected on the scale of the object size or degree to which close objects require discrimination.

Ultimately, the ability to discriminate will be limited by the properties of the instruments and the nature of the field. For each of the following survey methods, a balance was attempted to weigh the limitations of the measurement, the properties of the equipment, and the benefit from additional data.

RGS magnetometer, EM-61, and GEM2 measurements were made using survey grids over each pit. The survey grids consisted of linear profiles with a station spacing of 0.5 meters along each profile line (8). The survey grids were tied to the INEEL RWMC project coordinate system by a series of markers with known coordinates. At least two markers with known INEEL RWMC project coordinates were used to tie each survey grid to the INEEL RWMC coordinate system.

The RGS magnetometer and EM-61 surveys were conducted by moving the instruments along the profile lines at walking speed. Position along each profile was obtained by monitoring the rotation of the system wheel/axle supporting the equipment as it passed over the survey area.

The location of each profile was established in the field using fiberglass survey tapes tied to a local grid. The start of each profile line was marked by a traffic cone and flags. Grid coordinates were assigned to the readings by prorating the coordinates of the beginning and end of the lines using the data recorders on each piece of equipment.

The survey using the hand-held GEM2 system was conducted by collecting data at timed intervals while the system operator walked at a steady pace between the line start and end points. After a line was completed, coordinates of the reading points were determined in the same manner as for the RGS and EM-61.

A line spacing of 1.0 meters and the station spacing along lines of 0.5 meters was used for each area surveyed. To ensure data collection consistency and accuracy, data acquisition was repeated on 5% of all lines. Also, functionality tests were performed at the start of each data collection session. No malfunctions of the instruments were encountered during the duration of this survey. Data repeatability was consistently within the limits set forth in the test plan (8).

The RGS magnetometer system was used to detect ferrous metallic objects within the areas surveyed. The RGS allows the operator to collect high density data that improves the resolution of individual magnetic field anomalies created by ferrous metal objects. The detection of these objects was used to better estimate the boundaries of the pits and soil vaults.

Shallow time domain electromagnetic methods are effective metal detectors that respond to a range of metal types. A transmitter generates an electromagnetic pulse that induces eddy currents in metallic objects. The eddy current decay produces a secondary magnetic field measured by the receiver coil. By taking a measurement at a relatively long time after the start of the decay, the current induced in the ground has fully dissipated and only the current in the metal is still producing a secondary field. The secondary field response is sensed and recorded.

The Geonics EM-61 is a coincident loop time domain electromagnetic system that uses two 1 meter by 1 meter square antennae, offset by 0.7 meters and rigidly mounted on a two-wheeled cart that is pushed or pulled along the lines by the operator. The system electronics and data recording equipment are carried by the operator and activated by a signal from an odometer connected to one of the wheels on the cart.

The GEM2 system is a frequency domain electromagnetic induction device. This system is operated with coplanar transmitting and receiving coils whose plane can be oriented either horizontally or vertically and can be aligned parallel or perpendicular to the line direction. The sensor exploits the relationship between electric fields, magnetic field, and electrical current to detect changes in subsurface conductivity. Depth of penetration for electromagnetic methods is affected by the target's size, orientation, and burial depth, as well as the soil conductivity.

DATA INTERPRETATION

The RGS magnetometer, EM-61, and GEM2 data were initially interpreted individually using standard methods. The data were graphically displayed on the CAD drawings of the SDA and visual inspection was used to determine the extent of the metallic objects within each survey area. The pits were defined by the presence of broad relatively large amplitude anomalies, caused by closely placed metallic objects, which rapidly decrease in strength at the boundaries of the pits. The soil vault rows were defined by moderately sized anomalies associated with the waste in the soil vault rows. Each soil vault row consists of a series of individual vaults that were constructed in a straight (more or less) line. Unlike the trenches where waste was placed all along the trench line, waste was placed in individual vaults or in discrete areas along the soil vault row. These moderate sized anomalies generally are aligned with the long axis of the soil vault rows and suggest that metal made up part of the waste placed in the individual vaults. Small anomalies were interpreted to be shallow objects not associated with the buried waste in the pits and the soil vault rows. Data from the three instruments were then compared. The anomalies associated with the buried waste correlated well across each data set and boundaries of the pits and vaults were determined using the three data sets. Boundaries determined by the data were drawn conservatively so that they define the maximum areal extent of the waste. The two components of the three frequencies collected with the GEM2 data were then compared to the RGS and the EM-61 data to detect areas containing nonmetallic conductors that might be associated with contamination or increased soil depth. The results are discussed further in the data analysis section.

DATA ANALYSIS

At the completion of the survey, Sage Earth Sciences and Geophex, Ltd., produced field reports consisting of the raw field data reduced to one of three plant coordinate systems. All data collected using the RGS, EM-61, and GEM2 systems were reduced and displayed in map form using the Geosoft mapping system. Figures 2 through 4 show the location of each survey with the RGS, EM-61 and one component of the GEM2 data superimposed upon the SDA map. The magnetic data collected using the RGS was the vertical gradient magnetic field as indicated on each map of RGS data. The 1,050 Hz GEM2 data was chosen for display because it is representative of the three frequencies; maps of the other components can be found in the Geophex field report (9). Additional maps of each area and for each technique have been produced and are available in the full report on this work (9).

The locations of known sources of anomalous magnetic fields such as cultural features (e.g., power lines, pipes, fences, etc.) and geologic features (e.g., berms, ditches, etc.) were noted on the maps to aid in interpretation. Information from the IWITS database indicates that the metallic waste is spread throughout the pits and vaults so that the extent of the pit and vault boundaries can be inferred using the metallic waste signal. Therefore, the waste pit and vault boundaries determined from this survey were defined based on the extents of the metallic objects present. Estimations of waste depth—distance from the surface to top and bottom of waste material—are very difficult to determine due to limitations of the geophysical instrumentation and the imaging software and to the subsurface characteristics at the INEEL. Available data is useful to estimate the depth to the top of metallic waste forms only and cannot detect contaminated overburden. Depth to top of the waste can be reasonably estimated to only +/- 30% (10). This estimation would not be a significant improvement over estimates of overburden depths from the historical records. The depth to the bottom of the waste can be determined either by using refraction seismic techniques or drilling records from holes in and around the SDA. The depth to the basalt for the pits and vaults survey is approximately 20 feet and was determined from historical records and nearby boreholes.

Metal objects in the buried waste zones generate high magnetic field responses, which dominate the signals. Thus no subtle conductivity anomalies could be detected in the presence of the metal objects within the pits. Some anomalies associated with nonmetallic conductors were observed with the GEM2 instrument, which could not be easily interpreted. These anomalies lie at the edges of the survey areas and could be associated with a thickening of the soils above the basalt. Depth to basalt information is needed to better determine whether these anomalies are actual waste forms.

Pit 2

Pit 2 (see Figure 1) encompasses Pit 1, which is located in the north central portion of Pit 2. Therefore, data collected from Pit 2 includes the boundaries of Pit 1. The pits are well defined by the geophysical data. The northern edge of Pit 2/Pit 1 extends farther north than indicated in the historical records. In this area, the anomalies associated with Pit 2/Pit 1 merge into the anomalies associated with Trench 9 (see Figure 1) from the western edge of Pit 2/Pit 1 through the central portion of Pit 2/Pit 1. A survey with a greater areal extent may be necessary to clearly delineate these anomalies. The eastern edge of Pit 2 is located farther east (approximately 50 feet) than indicated in the historical records. The southern boundary of Pit 2 straddles the anomaly associated with Trench 10 (see Figure 1). It is, therefore, difficult to delineate the anomalies due to their proximity. Without a more detailed survey, these areas should be considered as one. The western edge of Pit 2 as shown in the historical drawings, is consistent with the boundary determined using the geophysical data.

The most prominent feature in Pit 2 is the remains of the foundation of a waste retrieval building straddling Pit 1 and Trench 9 in the northern section of Pit 2 (see Figures 2-4). The area within this foundation area is difficult to interpret. The GEM2[a] and EM-61[a] data show relatively low conductivity indicative of a reduced metal content in this area. However, the RGS[a] data indicate that the magnetic anomalies are still present but at a reduced strength under the foundation area. Former SDA personnel have reported that this area was excavated and the waste retrieved. The magnetic anomaly may be due to the basalt underlying the area or there may be ferrous metal remaining in the area at depths not as detectable as in the EM-61 or GEM data. While the metal within Pit 2 is distributed throughout the pit, there are areas with larger concentrations of metal in the western portion of the pit, along the southern boundary, and the area directly west of the foundation. The area between the eastern edges of Pit 1 and Pit 2 appears to be devoid of metallic objects or of any abnormal conductivity anomalies. This either represents an area devoid of waste material or the waste consists of objects with a similar conductivity to the soils of the SDA (e.g., paper, wood, contaminated soils, glass, or any other nonmetallic materials) and little or no metal.

Pit 3

Pit 3 is clearly defined in the geophysical data although there are several discrepancies in the locations of the pit corners between the historical records and the geophysical data. The northern edge of the pit either does not contain any metallic waste or the locations of the two northern corners as determined by historical records are inaccurate and are actually located more to the south and east by a significant amount (between 25 and 50 feet to the south). From an inspection of the IWITS data, the metal waste appears to be located throughout the pit indicating that the boundaries of the pit can be represented by the metal waste distribution. Based on interpretation of the geophysical data, the northwest and northeast corners of the pit appear to be actually located to the southeast of the historical locations.

The southern edge of the pit is more difficult to place because the GEM2[a] data does not agree with the RGS[a] or EM-61[a] data. All three data sets indicate that the southern edge of the pit is not parallel to the road as shown in the historical data. The southwestern corner appears to be accurate but the geophysical data indicate that the southeastern corner is located to the northeast of the coordinates indicated by historical data. The eastern edge of the pit also appears to be offset to the east in the southern half of the pit but is consistent with the historical data in the northern part of the boundary. Data for the western edge of the pit is consistent between the historical records and the geophysical data.

The metal within the pit is concentrated in the southern two thirds of the pit. The largest concentration of metal appears to be located in the southwestern corner of the pit. The northern portion of the pit appears to contain less metal. This conclusion is based on a smaller change in conductivity and magnetic field response relative to background measurements.

Pit 5

Pit 5 data[a] are presented in Figures 2 through 4. The boundaries of Pit 5 are well defined by the geophysical data but are not consistent with the historical boundaries. The historical boundaries enclose an area larger than that indicated by the geophysical data.

The most prominent feature observed in the geophysical data is the anomaly associated with the large above-ground pipe transecting the pit from the northwest corner to the southeast corner. However, this anomaly is easily distinguished from the anomalies associated with the deeper waste within the pit. There is a large concentration of metallic waste in the southeastern portion of the pit as indicated by the hot pink colors in Figures 2 and 4. The metallic waste is fairly evenly distributed in the pit. However, two areas located in the south central and north central sections of the pit contain less metallic waste as indicated by the green regions in Figure 3 (EM-61 data[a]) and the light orange areas of Figure 4 (GEM2 data[a]). Figure 2 (RGS data[a]) is consistent with this; notice there is less pink in the mottled features in these regions than in other areas of the pit. Although lower in magnetic field response and conductivity, these areas are well above the background levels and most likely contain some waste forms. The IWTS database indicates that the metallic waste is distributed throughout the pit. Therefore, the areal extent of the eastern and western pits can be inferred by the extent of the anomalies detected by the geophysical surveys. Another interesting feature seen in the Pit 5 data is the effect of the soils and basalts surrounding Pit 5. The effect of the basalt can be clearly seen in the magnetic data because of the relatively high magnetic response of the basalt compared to the conductivity measurements. The areas around the pit where the magnetic field is relatively high, are areas were the basalt is probably nearer the surface. The areas with increased conductivity as seen in the GEM2 data are most likely areas of deeper soils (basalt farther away from the surface). These areas do correlate to some extent (especially on the western side of the pit) across each of the data sets.

Soil Vault Data Interpretation

Soil Vault Rows (SVRs) 1 through 5 are located near Pit 14 in the southeastern area of the SDA. These SVRs are small compared to the pits and other SVRs investigated in this study. The geophysical data from these areas were difficult to interpret because of anomalies created by areas of relatively high metal content surrounding the SVRs. The RGS data provides the best resolution of the boundaries of these SVRs. All five SVRs showed relatively low response to the instruments, indicating a lack of metal within the SVRs. The anomalies within these SVRs appear in most cases to merge together and, therefore, are generally treated as a single block. (see Figure 1).

SVR 6, 8, 11, and 14 are all located south of Pit 13 (Figure 1) and were surveyed as a group. The data along with the historical boundaries are shown in Figures 2 through 4. The SVRs are best delineated by the RGS[a] data but are also apparent in the GEM2[a] and EM-61[a] data. Their positions appear to be consistent with the historical boundaries however, they appear to have relatively low metallic content.

The anomalies for SVR 6 and SVR 8 merge with those of Pit 13 to the north and separate boundaries cannot be clearly delineated. The anomalies for SVR 11 and SVR 14 also merge and individual boundaries cannot be clearly delineated. SVR 18 is located south of SVR 14 (see Figure 1) within the area surveyed. The CAD drawing of the SDA indicates that this SVR is present at the SDA but was never filled**.** The geophysical data appear to confirm this; however, the RGS[a] data indicate that the anomaly from SVR 14 overlaps this area in the eastern area. SVR 7 is located in the far southwest corner of the SDA (Figure 1). The geophysical data are displayed in Figures 2 through 4. Boundaries of SVR 7 are well defined in the geophysical data. Data indicate that this vault has waste distributed along its entire length. The location of SVR 7 boundaries is consistent with the historical records. The anomalies within the vault appear to be somewhat separated but are close enough together in many areas for the images to merge especially in the central region of SVR 7. The central region shows a broader response in the EM-61[a] and GEM2[a] data indicating that the metallic objects present may contain more nonferrous metal than ferrous metal. The anomalous region to the south of SVR 7 (seen in Figures 2 and 3) is not part of SVR 7 and no indication as to the cause of these anomalies is given on the historical CAD rendering. They could be due to power lines, buried utilities, a buried cable or other feature not recorded on the CAD drawing. No overhead object was recorded in the field notes during the survey but the anomalies continue past the end of the survey area and probably represent the presence of a utility line.

SVR 9 and 10 are located to the south and north of Trench #3 respectively and just south of Pit 2 (Figure 1). Both SVRs are well defined by the three geophysical data sets. Trench #3 is also well defined and can be easily distinguished from the two SVRs. Both the RGS[a] data and the EM-61[a] data provide a clear view of individual objects within the pit. The SVRs are approximately 15 to 20 feet apart with anomalies measuring approximately 5 feet in diameter. They appear to contain individual metallic objects (or small groups of objects) buried with nonmetallic low conductivity backfill between the objects. The geophysical anomalies created by the objects in Trench #3 appear similar to those associated with objects in SVR 9 and 10. The GEM2[a] data shows that the conductivity between these anomalies is low. All of the anomalies for SVR 9 and 10 seem to lie within the historical boundaries of the SVRs.

SVR 12 is long and straddles a fence surrounding the active pit disposal area. Therefore, the center of the SVR 12 could not be surveyed. Thus, for discussion purposes, the SVR 12 has been separated into two areas: SVR 12 west and SVR 12 east. The geophysical data for both sides of SVR 12 are displayed in Figures 2 through 4. SVR 12 is clearly defined by the geophysical data[a]. The geophysical data are consistent with the historical records and indicates the metallic waste within the vaults. The waste forms in SVR 12 west appear to be discrete metallic objects or are small groupings of small metallic objects with soil between them. There appear to be four metal-based anomalies in the western portion of SVR 12 west with the remaining area devoid of metallic objects. SVR 12 east may also contain discrete metallic objects but the signatures are slightly obscured by the anomalies associated with a trench located to the south of the vault but not directly in the survey area and by anomalies due to utilities to the north of the row. Both geophysical data and historical records indicate that the western section of SVR 12 east is devoid of metallic objects. The geophysical data, however, indicates that SVR 12 extends approximately 25 feet farther to the east than indicated in the historical records.

SVR 13 is located south and west of Pit 5. Boundary data collected with the RGS[a] and the EM-61[a] do not agree with data collect with the GEM2[a] instrument for this SVR. Therefore, absolute boundaries could not be determined with any degree of certainty. However, several observations can be made. SVR 13 boundaries and anomalies are well defined in the individual data sets despite the lack of agreement between the instruments concerning the boundaries. All three data sets indicated that the vault is shifted south relative to the historical SVR. Unlike the other SVRs, in which waste appears to have been placed in straight rows, SVR 13 appears to have a slight bend in the middle of the row. The eastern portion of SVR 13 is relatively free of metallic waste, while waste in the western portion appears to be composed of discrete metal objects.

CONCLUSIONS

Geophysical data from three instruments were analyzed individually and as a group and compared with available historical records to better determine discreet boundaries and the presence and location of buried waste forms in five pits and fourteen soil vault rows. Using the three instruments and a denser data collection method, information was collected that successfully identified discrete boundaries for most of the pits and SVRs and provided enhanced clarity of waste forms over previous surveys. The data collected from this survey also provided knowledge to enhance the limited historical data.

The data are of sufficient quality and fidelity to clearly detect anomalies associated with the pits and SVRs. Geophysical data for the SVRs generally agreed with historical data; however, boundaries for Pit 3 and 5 were overestimated in the historical data as compared to the geophysical data. It is unclear whether the boundary for Pit 2 is overestimated in the historical records or merges with Trench 9. The RGS magnetic measurements detected the utilities with better accuracy allowing the effect of these utilities to be recognized in the EM-61 and GEM2 data. Based on homologous responses of the RGS, ferrous metal detector, and the EM-61 and GEM2, ferrous and nonferrous metal detectors, no significant concentrations of nonferrous metals are present in the pits and trenches. However, the instruments were able to distinguish areas with lower metal content within the pits as seen in Pit 5.

The data show that there are discrete zones of waste within the pits and SVRs. The RGS and the EM-61 provided the clearest images of the metallic waste associated with the pit boundaries while the GEM2 system provided information on areas with limited metal content (e.g., the northern area of Pit 3). Therefore, combining these instruments clearly provides enhanced imagery and detection of buried waste forms over individual instrumentation data.

The three geophysical technologies respond to the waste and surrounding areas differently, each providing additional data about the materials within the waste and the surrounding areas. An example of this is the effect of the basalt surrounding Pit 5. The basalt has a clear magnetic signature in the RGS data, but is not visible in the EM-61 or GEM2 data. Individual metallic objects could be clearly detected within the waste areas and distinguished from nonmetallic waste.

Geophysical techniques can be a valuable tool in characterizing the extent and composition of buried wastes. Invasive sampling of buried wastes is a costly, time consuming and potentially hazardous. Geophysical surveys combined with existing historical records can reduce the costs and risks by allowing a more focused approach to sampling. Geophysical techniques continue to be refined with the goal of improving the resolution of subsurface debris location and developing the capability of detecting contaminant plumes.

ACKNOWLEDGEMENTS

The work described in this article was supported by the United States Department of Energy through Contract DE-AC07-99ID13727.

FOOTNOTES

a. Enlarged plots of the data for each pit and group of soil vaults are available in M. C. Pfeifer, A. W. Glenn, and G. E. Matthern, "Geophysical Characterization of Pits 2, 3, 5, and Soil Vaults in the Radioactive Waste Management Complex", INEEL/EXT-2000-01030, August, 2000.

REFERENCES

1. "Addendum to the Work Plan for Operable Unit 7-13/14 Waste Area Group 7 Comprehensive Remedial Investigation/Feasibility Study," DOE/ID-10622 (1998)
2. G.S. SCHNEIDER and M.C. PFEIFER, "Final Report on Non-Intrusive Characterization of the Chemical Animal Pits and Glass Hole Areas at Brookhaven National Laboratory," DOE, Idaho Operations Office (1996)
3. M.C. PFEIFER, "INEEL Letter Report on EMR," (1999)
4. L. PELLERIN, D.L. ALUMBAUGH, and M.C.PFEIFER,"The Electromagnetic Integrated Demonstration at the Idaho National Engineering Laboratory," Proceedings of the Symposium on the Application of Geophysics to Engineering and Environmental Problems, Environmental and Engineering Geophysical Society, March 23-27 (1997)
5. D.H. CARD, "History of Buried Transuranic (TRU) Waste at INEL, Work Plan Remedial Investigation Feasibility Study," March 1 (1977)
6. L.G. ROYBAL, G.S. CARPENTER, and N.E. JOSTEN, "Rapid Geophysical Surveyor," Proceedings of the Symposium on the Application of Geophysics to Engineering and

Environmental Problems, Environmental and Engineering Geophysical Society, April 18-22 (1993)

7. IWITS - Integrated Waste Tracking System waste stream database. The IWITS database contains information regarding the waste streams placed in each of the pits and soil vault rows. The database also provides a disposal location relative to a marker placed somewhere near the pit or soil vault being filled. However, physical evidence of many of the markers is no longer available. Thus, only general information about the waste streams can be inferred and no attempt to correlate the geophysical anomalies to actual waste forms was made.

8. M.C. PFEIFER, "Test Plan for the Geophysical Characterization of Pits 2, 3, 5, and Soil Vaults 1-14 in the Radioactive Waste Management Complex," Idaho National Engineering and Environmental Laboratory (1999)

9. M.C. PFEIFER, A.W. GLENN, and G.E. MATTHERN, "Geophysical Characterization of Pits 2, 3, 5, and Soil Vaults in the Radioactive Waste Management Complex," INEEL/EXT-2000-01030, August (2000)

10. N. JOSTEN, "Geophysical Investigation Report Subsurface Disposal Area Pits 4, 6, 10," Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID (1999)

ACRONYM LIST

CAD	computer-aided drawing
COPCs	contaminants of potential concern
CTP	Cold Test Pit
DOE	Department of Energy
EM	electromagnetic
EM-61	Electromagnetometer-61
GEM2	Geophysics Electromagnetometer2
GPR	ground penetrating radar
INEEL	Idaho National Engineering and Environmental Laboratory
IWTS	Integrated Waste Tracking System
LMITCO	Lockheed Martin Idaho Technologies Company
RGS	Rapid Geophysical Surveyor
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
SVR	soil vault row

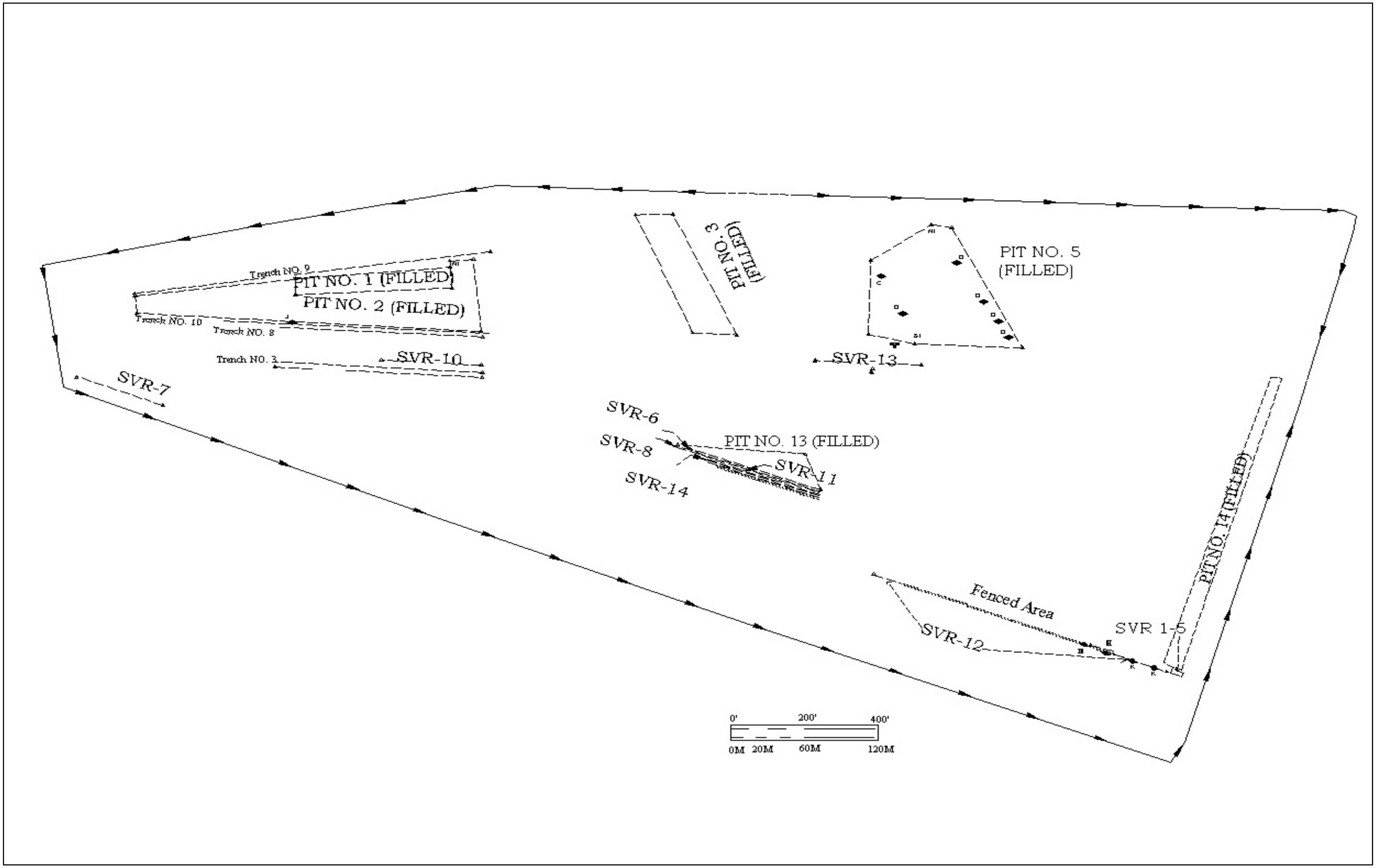

Fig. 1: SDA Location Map for Pits 2, 3, 5, and Soil Vault Rows 1-14. Figure orientation with North at top.

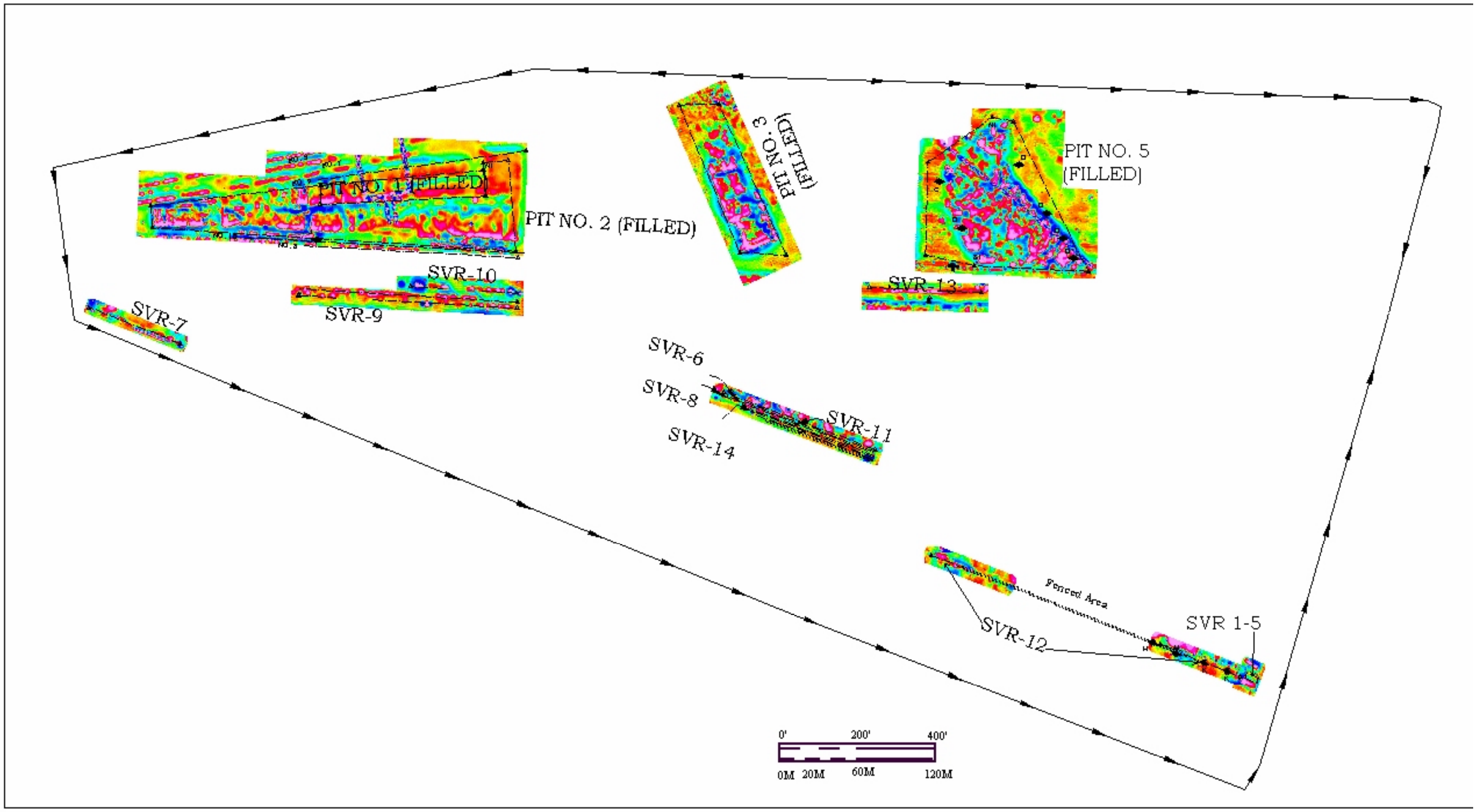

Fig. 2: SDA location map of the vertical gradient magnetic field data for Pits 2, 3, 5, and SVR's 1-14. Figure orientation with North at top. Data provided by Sage Earth Sciences.

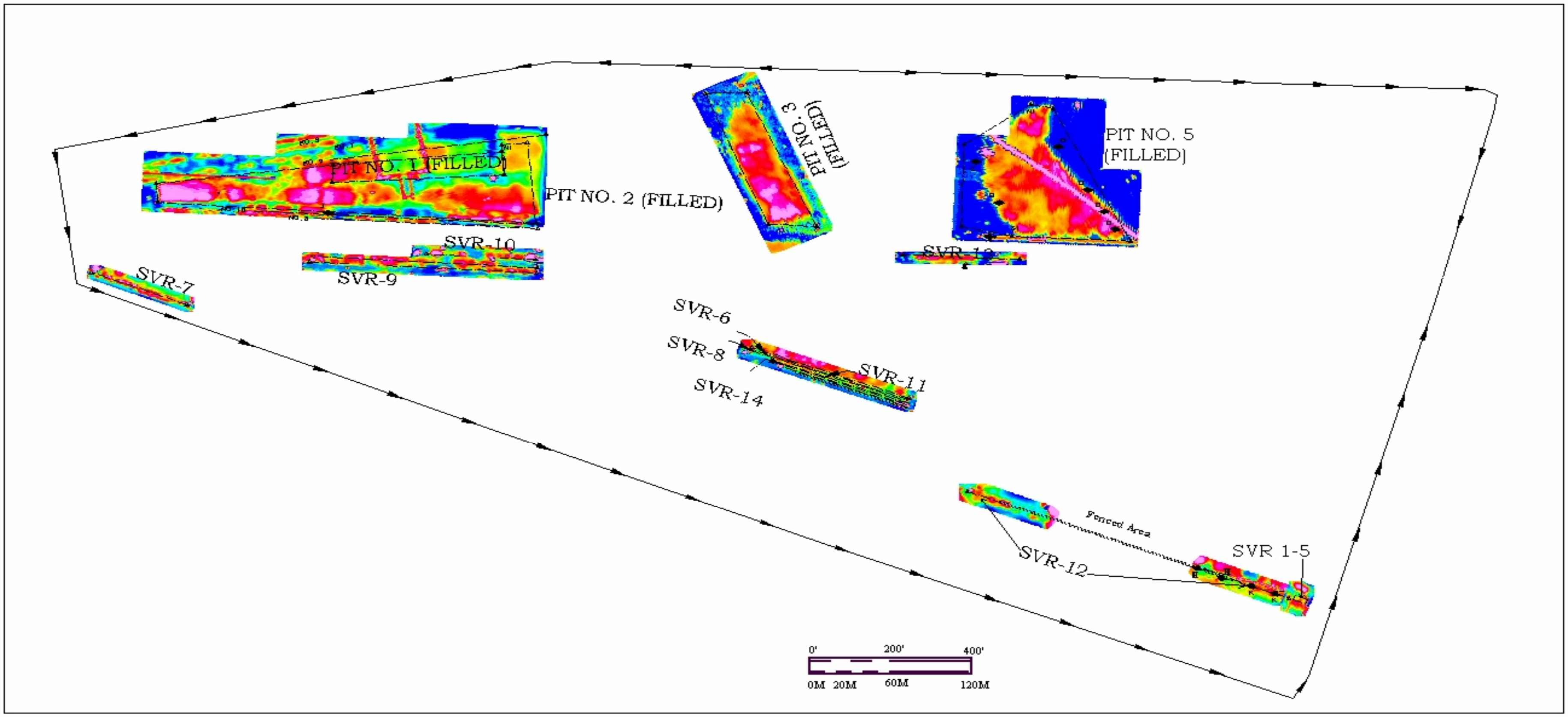

Fig. 3: SDA location map of the Geonics EM-61data for Pits 2, 3, 5, and SVR's 1-14. Figure orientation with North at top. Data provided by Sage Earth Sciences.

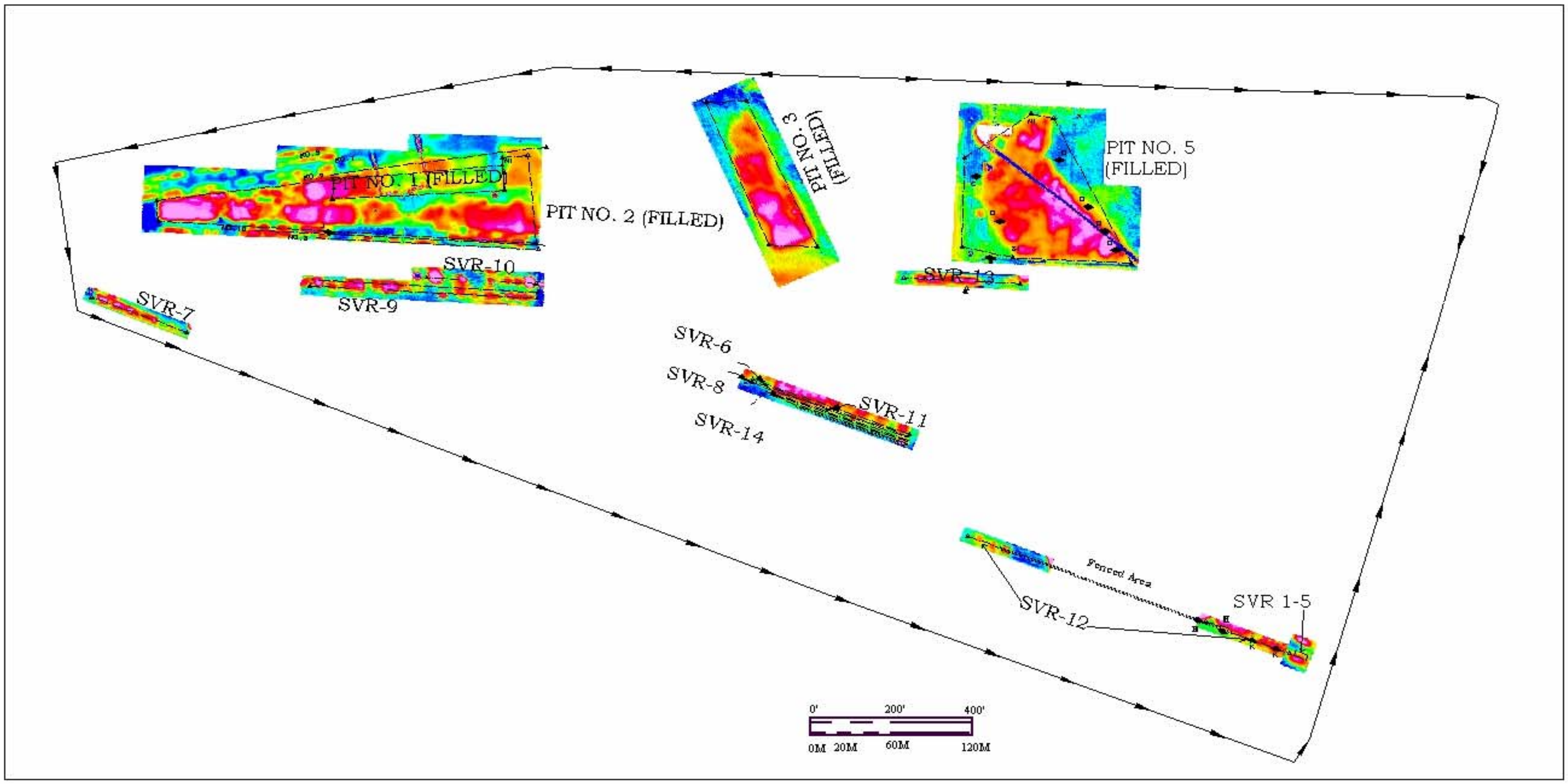

Fig. 4. SDA Location Map of the GEM Inphase 1050 Hz Data for Pits 2, 3, 5 and SVR's 1-14.