1 of 1

PHASE I - FINAL REPORT

**PRDA NO. DE-RA05-910R22000
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Prepared for:

U.S. Department of Energy
Idaho Falls Office
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Idaho Falls, ID 83401-1562

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PHASE I - FINAL REPORT

PRDA NO. DE-RA05-910R22000

**INEL COLD TEST PIT
DEMONSTRATION OF IMPROVEMENTS IN INFORMATION
DERIVED FROM NON-INTRUSIVE GEOPHYSICAL METHODS
OVER BURIED WASTE SITES**

CONTRACT NO. DE-AC07-93ID13215

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1.0 INTRODUCTION

The U.S. DOE, other agencies of the U.S. Government, and our nation's industrial facilities are burdened by a legacy of inadequate disposal practices of radioactive, hazardous, and mixed wastes. These practices often have resulted in contamination of soil and ground water, and in some instances, threaten United States Drinking Water Supplies (USDWS). Various regulatory requirements, records of decision, interagency agreements, and a public desire to improve our environment, are the driving forces to correct this situation. Cleaning up these situations is a complex process that begins with assessing sources and extent of contamination (site characterization). It then proceeds with feasibility investigations of the effectiveness of various alternate clean-up methodologies, design of remediation procedures, and ultimately restoration of a site.

Site characterization itself can be a costly and time consuming process. At present, the most costly component of site characterization are drilling, sampling, and chemical analysis of samples. There is a focused effort at U.S. DOE and other agencies to investigate methodologies that reduce costs and expedite the site characterization. Some of the methodologies being studied and applied are: geostatistics to better deal with the large variations between samples; data fusion to integrate results from diverse sensors and data sources; driving cone penetrometers to reduce drilling and sampling costs, as well as surface and borehole geophysics. The objectives of geophysics are to provide continuity in subsurface information and to optimally locate positions for boreholes, cone penetrometers or soil samples, etc.

The research conducted under this project was focused on improving surface geophysics for detection and characterization of buried wastes. In the past, wastes of all types have been disposed of in controlled landfills, but also in uncontrolled trenches, pits, and random burial sites. Controlled and uncontrolled buried wastes are found at most DOE facilities, DOD installations, and at industrial sites throughout the country. A burial pit or trench may have little or no surface expression because vegetation may have recovered and layers of soils or fill may now cover the site. To locate and characterize a trench or pit of unknown content by intrusive testing is hazardous and would require a dense grid because burial sites are of finite dimensions.

Surface geophysics is a mature science having its origin and development in the hydrocarbon, mineral, and geothermal exploration industries. Using these developed methods for the detection of a steel drum, or an underground storage tank has proven surprisingly difficult. Some of the reasons for this are: (i) measurements must often be made in urban environments with power lines, buried utilities and surface debris; (ii) objects far smaller than the geologic features mapped in resource exploration studies

must be detected; (iii) the required depth of investigation is in the upper 30 ft, considerably shallower than most geologic mapping requirements, and (iv) the users of the information are environmental scientists and engineers not familiar with the common geophysical data presentations and the geophysical jargon built up over 60 years. Also, the search for the holy grail, - the one geophysical method that solves all and can be operated and interpreted by anyone, anytime (long given up by the geophysical community), - still somewhat persists in the environmental arena. The truth is that geologic conditions influence sensor behavior and a sensor that spectacularly performs in one area may fail in a different setting. The geophysical industry has, however, quickly made significant long lasting contributions to environmental geophysics. New instrumentation has been developed specifically addressing common environmental objectives (e.g., ground probing radar, electromagnetic profiling), and the methodologies of environmental geophysics were introduced.

The objectives of this research project were to lay the foundation for further improvement in the use of geophysical methods for detection of buried wastes, and to increase the information content derived from surveys. Also, an important goal was to move from mere detection to characterization of buried wastes. The technical approach to achieve these objectives consisted of:

- (1) Collect a data set of high spatial density. A high data density facilitates applying various filters and other processing methods that may enhance detection and resolution of site objectives.
- (2) Acquire data with multiple sensors and integrate the interpretations inferred from the various sensors.
- (3) Test a simplified time domain electromagnetic system. TDEM has proven the most sensitive method for measuring the geoelectric section in mineral and geothermal exploration. The equipment and quantity of data (20 channels) collected are too cumbersome and costly for detecting shallow metallic buried waste. A simplified instrument for smaller targets was urgently needed.
- (4) Develop imaging and display formats of geophysical data readily understood by environmental scientists and engineers.

Surface geophysical methods are and will remain an indirect method for investigating the subsurface. Information is inferred from known relations between the physical property measured (e.g., total magnetic field) and the object to be detected (e.g., a steel drum). Confidence in geophysics is derived

from verification by intrusive testing or by other ground truth. The existence of the Cold Simulated Test Pit (CTP) at INEL was the reason for acquiring the data for this project there. Not only are the boundaries of the test pit known, but also its contents. The results of geophysical interpretation derived from the R&D reported herein can be directly compared with the as-built design of the CTP.

The breadth of application of this work is far reaching. Not only are uncontrolled waste pits and trenches, abandoned underground storage tanks, and pipelines found throughout most U.S. DOE facilities, but also at military installations and industrial facilities. Moreover, controlled land disposal sites may contain "hot spots" where drums and hazardous material may have been buried. The technologies addressed by the R&D will benefit all of these activities.

2.0 SITE SELECTION

2.1 PURPOSE

Geophysical surveys for delineation of buried waste sites are commonly performed at relatively low station density and with one, or at the most two, methods. The low station density and the absence of multiple datasets often limits full characterization. The purposes of this investigation were to acquire a high density data set over a known buried waste site using multiple geophysical techniques, and to show that this will result in improvements in information content and level of confidence derived from non-intrusive sensors.

2.2 SITE SELECTION

Geophysical methods are an indirect way to derive subsurface data. Inferences from geophysical surveys must be calibrated and verified by ground truth from drilling, testing, and other direct information. Often testing by intrusive verification is the most expensive component of site characterization. At the Cold Simulated Test Pit (CTP) at INEL ground truth is known from as-built design drawings, and the existence of this ground truth was the dominant reason for performing the geophysical survey there. In addition, the waste buried at the CTP trench is similar in form and content to wastes buried throughout DOE and DOD, and some commercial facilities throughout the U.S.

2.3 SITE DESCRIPTION

The CTP is located in an old soil borrow area adjacent to the Radioactive Waste Management Complex (RWMC) outside of the chain link fence. The CTP is about 200 yards south of the fence. Access to the site is via a gravel road outside of the RWMC (Fig. 2-1).

The near surface geology of the INEL-CTP consists of flow basalts and up to 10 ft of fine-grained Snake River Plain sediments. The average depth to basalt from the bottom of the pit is about 2 ft, with a maximum of approximately 6 ft. Some basalt cobbles and boulders are present within the sediments. The characterization cell and retrieval cell floors are set about 3 to 5 ft higher than the original CTP due to higher elevations in the basalt.

The construction of the CTP was completed during two periods. Complete descriptions are provided in EG&G Engineering Design Files (EDF's) from 1988 and 1992 of the Buried Waste Integrated Demonstration (BWID).

The following paragraphs summarize these EDF's.

The original CTP was constructed in 1988 to provide a cold non-radioactive/non-hazardous test bed for demonstrating retrieval and other remedial action scenarios. The test pit was constructed, filled with simulated waste, and backfilled in the same manner in which transuranic waste pits were constructed at INEL between 1953 and 1970. The simulated waste forms included metal scrap, asphalt, concrete blocks, cinder blocks, scrap wood, cloth, paper, glass, and HEPA filters. Simulated waste was loaded by hand and heavy equipment into primarily cardboard 55-gallon drums and cardboard 4' x 4' x 8' boxes. In addition, about 40 metal drums were placed in the pit. Cardboard was used as the simulated waste container material to promote rapid deterioration of the containers. This was done to simulate up to 35 years of burial in shallow land-filled pits in the SDA of the original metal drums and plywood boxes. To further promote deterioration, water was extensively sprayed on the waste forms while being back filled with moist dirt. After emplacing the waste forms moist back fill was used to cover the trenches. After emplacing the waste forms and back filling the pit, a contoured cap of earth was placed over the pit.

The excavated area of the pit was approximately 150 ft long by 50 ft with an approximate depth from the undisturbed level (sage brush level) of about 10 ft. During the survey the pit was compartmentalized into five zones as shown in Figure 2-2. The southern most zone, 30 ft in width, was reserved for large objects. Large tanks, concrete vaults, concrete blocks, and metal drums were organized in this section. Details of this section were eliminated from the EDF's to preserve the blind status of subsurface investigation planned for that section. Going north, the next 30 ft was reserved for the stacked large box zone; this was followed by another 30 ft section designated for stacked 55-gallon drums; the next 30 ft contained randomly dumped drums and boxes; the final 25 ft section was reserved for randomly dumped drums.

Waste Containers

The waste containers consisted of cardboard drums, boxes and metal drums. The dimensions of the cardboard boxes were 4' x 4' x 8' and were constructed of double-wall cardboard material with no weather treatment.

The 55-gallon cardboard drums were constructed of untreated cardboard with a nominal 300 pound payload. The drums were nominally 35" high and 22" in diameter and had a removable cardboard lid with metal rims and lock down mechanism.

Simulated Waste Materials

Based on content code inventories from Rocky Flats Plant (RFP) of the waste that was shipped to RWMC during the period 1971 to 1973, simulated forms were formulated. RFP waste forms in drums consist of plutonium/americium contaminated sludge, grease, cemented sludge, combustibles (paper cloth), metal, concrete, asphalt, dirt, glass, filters and insulation material.

Table 2-1 summarizes the target waste fraction for boxes and drums. Table 2-2 summarizes the contents of the original Cold Test Pit.

Table 2-1
Target Waste Fraction for Boxes and Drums

Content	Fraction of the Total Number of Containers in a Given Zone
Drums	
Sludge	0.30
Combustibles (paper, cloth)	0.50
Metals	0.08
Concrete Asphalt	0.10
Filter wood glass	0.02
	1.00
Boxes	
80% Metal	
20% Concrete/glass/asphalt/wood	

Table 2-2

Contents of Original Cold Test Pit

Cell	Total Drums/Weight	Total Boxes/Weight	Comments
Stacked Boxes (2)	-0-	60/174,200	boxes ranged from 1,500 lbm (metal) to 6,200 lbm (concrete); machine loaded metal boxes averaged 1,600 lbm; hand loaded metal boxes averaged 2,500 lbm; concrete/asphalt boxes averaged 5,000 lbm
Stacked Drums (3)	sludge - 208 drums/118,900 lbm combustibles - 352/48,149 lbm metals - 56/10,000 lbm concrete/glass - 72/34,400 lbm filter/wood - 12 / 2,300 lbm <u>700 / 213,749</u>	-0-	8 sludge drums made of metal; sludge drums averaged 571 lbm; 8 combustible drums are metal; combustible drums averaged 140 lbm; 8 metal drums made of metal, metal drums averaged 178 lbm; concrete/glass averaged 478 lbm; filters/wood average 191.16 lbm
Random Dump Drums and Boxes (4)	sludge - 40/23,700 combustibles - 64/9,530 metal - 12/2,150 concrete/glass - 16 / 8,400 <u>132 / 43,780</u>	12/28,510	one of the boxes contained used HEPA filters; 8 sludge drums made of metal; boxes average 2,375 lbm; sludge drum average 592 lbm; combustible drums average 149 lbm; metal drums average 179 lbm; concrete average 525 lbm
Random Dump Drums (5)	sludge - 104/57,600 combustibles - 164/25,570 metals - 28/5,450 concrete/glass - 32/15,800 filters/wood - 8 / 800 <u>336 / 105,220</u>	-0-	8 sludge drums made of metal; sludge drums averaged 554 lbm; combustible drums average 156 lbm; metal drums average 195 lbm; concrete/glass drums average 494 lbm; filters/wood drums average 100 lbm

Addition to Cold Test Pit

The addition to the CTP was built to provide an additional test area for BWID characterization and retrieval activities for FY1993. Figure 2-2 also shows the basic addition layout and dimensions based upon the EDF and conversations with BWID personnel concerning the position of the addition with respect to the original CTP.

The new addition is located on the north end of the existing CTP. The total size of the new addition is 40 ft in width, by 29 ft in length, by 12 ft in depth. The addition consists of two cells; a characterization cell and a retrieval cell. A third cell has been removed. The characterization cell is 40 ft x 13 ft x 12 ft. The retrieval cell is separated from the characterization cell by a 40 ft x 6 ft x 12 ft soil berm. The dimensions of the retrieval cell are 40 ft x 10 ft x 12 ft.

Details of Characterization Cell Construction and Waste Forms

Figure 2-3 is a detailed top view schematic of the characterization cell as-built adjacent to the retrieval cell. The cell is 40 ft x 13 ft x 12 ft. The cell contains 10 separate waste forms placed at strategic locations. A detailed statement showing the characteristics of each waste form is shown in Table 2-3.

Table 2-3
Detail of Waste Forms Placed in the Characterization Cell (Cell 6)

Item Id.	Waste Form Type	Dimensions	Net Wt. (kg)	Contents
A	55 gal. Drum w/liner	24" dia. x 36"	380	Concrete
B	30 gal. plastic drum	18" dia. x 28"	105	Saltwater
C	55 gal. Drum w/liner	24" dia. x 36"	1.5	Foam
D	Wood Box	2' x 4' x 4'	54	Wood and Paper
E	2-Wood Boxes Stacked	2' x 4' x 4' ea.	E1 = 44 E2 = 411	E1= Wood and Paper E2= Ferrous Metals
F	Wood Box	2' x 4' x 4'	252	Mixed Metals
G	Wood Box	2' x 4' x 4'	405	Non-Ferrous Metals
H	Wood Box	2' x 4' x 4'	991	Dense-Pack Metal
File 1	5-Drawer Metal File Cabinet	14" x 28" x 57"	25	Empty
File 2	5-Drawer Metal File Cabinet	14" x 28" x 57"	25	Empty

Figure 2-4 shows a photograph of the characterization cell as-built. The drums are placed in position on their sides. All of the waste forms were placed at equal distances and centered on the instrumentation access pipes.

An 8 ft by 10 ft area of the characterization cell was backfilled with sand and gravel to provide a different soil media in the test area as shown in Figure 2-3. The remainder of the characterization cell is backfilled with typical INEL/RWMC soil taken from the lake bed area near the RWMC. The same soil was used to fill the pits and trenches of TRU contaminated wastes throughout RWMC. In addition, a 5 ft by 5 ft notch was cut in the west wall to provide a irregular pit boundary to test the ability of non-intrusive sensors to define pit boundaries.

Retrieval Cell Construction and Waste Form Placement

Figure 2-4 shows a photograph of the retrieval cell with the characterization cell in the background. The retrieval cell is separated from the characterization cell by a 6 ft soil berm. The purpose of the retrieval cell is to provide a test area for the SEA vehicle. The SEA vehicle is a remotely operated excavator. This vehicle will be tested during FY93 to determine its ability to excavate waste forms in different positions and configurations. To this end, the retrieval cell is divided into four waste zones. Each waste zone contains a different waste form type and configuration designed to mimic actual waste form configurations found in the pits and trenches at the SDA in RWMC.

Figure 2-3 also shows a top view of the retrieval cell. Waste Zone 1 contains a mixture of random dumped 55-gallon (11) and 30-gallon (11) cardboard drums and 4 metal 55-gallon drums. These drums contain wood, paper, cloth, plastic, metal, sludge and soil.

Waste Zone 2 contains two desks stacked one on top of the other. Waste Zone 3 contains 24 metal 55-gallon drums and 23 metal 30-gallon drums dumped randomly, containing a similar variety of materials as Zone 1. Waste Zone 4 contains 17 cardboard 55-gallon drums, 17 cardboard 30-gallon drums, 2 metal 55-gallon drums, and two metal 30-gallon drums also containing similar materials as Zones 1 and 3.

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AREA LOCATION MAP

U.S. DOE Idaho Nat. Eng. Lab
DOE CONTRACT NO: DE-AC07-93ID13215

PROJECT NO: 6803-001

Figure 2-1

FIGURE 2-2

TOP VIEW RETRIEVAL CELL

TOP VIEW CHARACTERIZATION CELL

4 inch dia. AIS corner marking pipe

SCALE 1" = 10'

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SCHEMATIC DRAWING
ADDITION TO COLD TEST PIT

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GEOPHYSICAL DEMONSTRATION

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FIGURE 2-3

Photo of Characterization Cell looking Southeast

Photo of Retrieval Cell with Characterization Cell in background looking South

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PHOTOGRAPHS OF CTP ADDITIONS

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FIGURE 2-4

3.0 LOGISTICS AND DATA ACQUISITION METHODOLOGIES

3.1 GENERAL

The geophysical surveys were conducted by a CEES-BGD crew consisting of two geophysicists and one geologist. A grid was laid out over the CTP based on Engineering Design Files provided by EG&G and using surface features such as pipes protruding out of the characterization cell and the excavation along the west wall outside the north end of the pit. A schematic drawing of the CTP is shown in Figure 2-2 based on the engineering design files provided by EG&G. The layout of the grid is given in Figure 3-1 showing the location of grid control points and the CTP as interpreted from the geophysical survey and additional input from the EDF's. Instrument access pipes into the characterization cell were the only physical feature to tie the geophysical grid to. Two orange capped markers were also tied to the grid. These markers were later found to be EG&G project coordinates. The survey lines were marked using either wooden stakes or wooden golf tees at 5 ft intervals. A declination of 14 degrees east was used on the compasses. USGS 1972 topographic maps indicate a declination of 17.5 degrees while the new USGS Geomag program calculates the true declination 1993 to be 15.3 degrees. All data are based upon grid coordinates.

The geophysical instrumentation used included:

- Magnetics - GEM GSM 19 Magnetometer/Gradiometers (2),
- Magnetics - GEM GSM 19 Base Station (1),
- FDEM - Geonics EM31 and EM34,
- TDEM - Geonics EM47 (Profiling),
- TDEM - Geonics EM61 (Metal Detection),
- GPR - GSSI SIR-10 w/100 MHz, 500 MHz, and 300 MHz Antennas.

The data acquisition portion of the geophysical demonstration was conducted during the period May 3 through May 21, 1993, including mobilization and demobilization.

3.2 QUALITY CONTROL

Each instrument manufacturer has developed specifications on instrument set up and calibration, and their procedures were adopted prior to initializing daily data acquisition. In addition, where applicable, a base station was occupied and recorded. Data for each instrument was stored in solid state

memory loggers and subsequently transferred daily to computer disks. All data was checked and verified daily. The procedures included generation of computer screen plots of data acquired, and thus scanning for errors such as missing data points, erratic data points, data with wrong sign or other errors. If an error was found, lines were rerun.

Magnetic Survey

Two roving magnetic gradiometers were used on this survey measuring both total field and vertical magnetic gradient. The lower (total magnetic field) sensor was positioned 52 cm above the ground, and the upper sensor was positioned 104 cm above the ground. Therefore, the vertical magnetic gradient was calculated using a sensor separation of 52 cm. A base station magnetometer was used to monitor the diurnal drift of the magnetic field and correct the data of the roving instruments at the end of the survey day.

Data was highly influenced by local basalt flows in the southern portion of the grid area (0 to 30N). The data incorporated in this study includes data taken between Lines 30N and 300N with a line and station spacing of 2.5 ft.

FDEM - EM31 and EM34 Surveys

EM31 data were collected in the vertical dipole mode using two transmitter/receiver boom orientations at 2.5 ft line and station intervals. The data was collected over the entire grid first in an east-west orientation and then north-south. Two independent maps for each component and orientation were produced from the data.

The EM34 data was collected along selected lines over each cell at 10 ft station intervals. The horizontal dipole mode was used at a 10 m coil separation.

TDEM - EM47 Profiling Survey

The random dumped drum and box cell was selected for a detailed high density TDEM profiling survey. Due to the time consuming nature of this type of survey, dense station spacing of 2.5 ft along lines over the cell were occupied and measured on 5 and 10 ft line spacing as time permitted. Additional data was collected along Line 60N to obtain background (halfspace) data and also on the berm between the characterization cell and the random dumped drum cell. The transmitter loop for this portion of the

survey was placed about 40 ft outside the CTP along the east side as shown in Figure 3-2 along with lines surveyed. The loop was 460 ft by 160 ft with the long axis of the loop parallel to the CTP.

A second transmitter loop was placed on the south end of the CTP with the "near" wire along Line 40N as shown in Figure 3-2. Data were collected along line 65E from 70N to 275N.

The base frequency used in this survey was 300 Hz with a current of 1 ampere. A multi-turn air cored receiver coil (31.4 m² effective area) was placed on the ground and attached via a cable to the receiver console. The receiver measured the electromotive forces (emf's) due to the secondary magnetic field caused by the ground eddy currents from three receiver orientations (x, y and z).

TDEM Metal Detector - Geonics EM61

The EM61 transmitter/receiver, mounted on a 2-wheel trailer (Fig. 3-3), measures automatically while the operator pulls the instrument along. For this survey measurements were obtained from lines 60N to 305N at 2.5 ft line intervals and about every .6 ft along the line. Two channels are measured at a time gate of 450 microseconds from two coils, channel 1 (80 cm from the ground) and channel 2 (40 cm from the ground).

GPR Survey

Due to the enormous quantity of data collected with the other geophysical methods mentioned, only 10 radar records were collected from the survey. Various antennae (100 MHz, 300 MHz and 500 MHz) were used at nominal and low gain. The lines were selected so as to cover the characterization cell and the middle of the original CTP from north to south. No records were obtained indicating the presence of objects within the CTP.

Magnetometer
Base Station

●
EG&G
Project
Coordinates
N668099.22
E266613.21

●
EG&G Project Coordinates
N668099.22 E266828.21

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

LEGEND:

- Survey Monument

FIGURE 3-1

INEL USDOE
GEOPHYSICAL DEMONSTRATION
COLD TEST PIT GEOPHYSICAL GRID MAP CONTRACT# DE-AC07-93ID13215
CEES-BLACKHAWK Project#6803-001

FIGURE 3-2

HARNES MODE

TRAILER MODE

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EM-61 EQUIPMENT LAYOUT

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PROJECT NO. 6803-001 FIGURE 3-3

4.0 BASIC PRINCIPLES OF GEOPHYSICAL METHODS

4.1 MAGNETICS

The Earth's magnetic field can be represented as a magnetic dipole at the center of the earth with the negative or south magnetic pole directed toward the geographic north pole (Fig. 4-1). Measurements of the strength of the magnetic field are commonly obtained with total field magnetometers. These instruments measure the magnitude of the Earth's magnetic field vector independent of its direction as a scalar quantity. The magnetic field is presented in units of gammas (nano teslas). The strength of the Earth's magnetic field is about 60,000 gammas near the poles where it is vertical to the Earth's surface, and about 25,000 gammas near the equator where it is parallel to the Earth's surface. In magnetic surveys perturbations in the Earth's magnetic field are measured. These perturbations may be caused by geologic features or the presence of buried ferrous-metallic objects. These features can be inferred from careful analysis of the measured data.

Magnetic surveys have traditionally been designed for geologic applications, such as locating fault zones or ore bodies often of considerable depth (i.e., > 100 ft). The main variable is the distribution of magnetic minerals (hematite, magnetite).

Burial of ferromagnetic objects causes local perturbations in the Earth's magnetic field. The Earth's magnetic field induces a magnetic moment per unit volume in ferromagnetic material, and this induced magnetization is parallel with and proportional to the Earth's local magnetic field. Therefore, the intensity and shape of perturbations caused by a buried drum or a basalt boulder varies across the Earth (Fig. 4-2). At the magnetic poles this anomaly could be a simple peak, at the magnetic equator a negative anomaly may occur. This assumes that a body is magnetized in the direction of the earth's field. For this site we are near an inclination of 68° .

Typically, magnetic field measurements are made with a proton precession magnetometer (Fig. 4-3). The proton precession magnetometer utilizes the precession of spinning nuclei of the hydrogen atom in a hydrocarbon fluid to measure the total magnetic intensity. The spinning protons in a sample of water, kerosene, alcohol, etc., behave as small, spinning magnetic dipoles. These magnets are temporarily aligned by application of a uniform magnetic field generated by a current in a coil of wire. When the current is removed, the spin of the protons causes them to precess about the direction of the ambient or earth's magnetic field. The precessing protons generate a small signal in the same coil used to align them. The frequency of the signal is proportional to the total magnetic field intensity and independent of the orientation of the magnetometer sensor. A proportionality constant relates frequency to field intensity and

is a well known atomic constant called the gyromagnetic ratio of the proton. Typically, the total magnetic field intensity is determined with an accuracy of 1 gamma, and in special cases to an accuracy of about 1 part in 50,000 parts (Breiner, 1973).

The Earth's magnetic field generally drifts slowly over time (typically a few gammas per hour), but it can also have large diurnal variations. In fact, during geomagnetic storms these variations can be so large as to preclude meaningful magnetic field measurements. To continuously record this drift in the magnetic field, a base station magnetometer was set out in a stationary position near the CTP. The readings from two roving magnetometers were corrected for the drift observed at the base station.

4.2 FREQUENCY DOMAIN ELECTROMAGNETIC (FDEM) PROFILING

The FDEM profiling technique measures the conductivity of the subsurface (terrain conductivity). Electrical conductivity of the subsurface can be measured by a number of different techniques. EM methods are attractive because they require no contact with the ground and have a high survey productivity.

The FDEM system consists of a transmitter and a receiver. Two common instruments used in environmental investigations are the Geonics EM31 and EM34 (Fig. 4-4). The transmitter generates an electromagnetic field (primary magnetic field) which induces eddy currents in the subsurface (Fig. 4-5). The intensity of these eddy currents is a function of ground conductivity. The eddy currents in turn cause a time-varying secondary magnetic field that is measured as a voltage in the receiver.

The search depth of these instruments depends on a number of factors, such as

- spacing between transmitter and receiver,
- frequency of operation,
- orientation of transmitter or receiver magnetic dipoles,
- ground conductivity.

Geonics EM31

In the Geonics EM-31 the frequency of operation and spacing has been selected so as to make search depth relatively independent of ground conductivity. Typical search depth for the EM31 is about 15 ft when utilizing a vertical dipole orientation, and about 10 ft using the horizontal dipole mode.

Moreover, the frequency of operation and spacing between transmitter and receiver are selected so that there is a linear relation between apparent ground conductivity and voltage measured over a large range of ground conductivities. The instrument meter provides a direct read-out in apparent conductivity.

The secondary magnetic field caused by eddy current flow in the ground has an in-phase and quadrature phase (90° out-of-phase) component with reference to the current waveform driven through the transmitter, and both components are small over ground with conductivities less than 100 millimhos/m (typically less than 1 part in 10^4 parts), and it is only the quadrature phase component that can be measured to such accuracies.

Over metallic objects, which have extremely high conductivities, both quadrature and in-phase components can reach values of several tens of percent of the primary field. Thus, the in-phase component is useful for mapping metallic debris. Combining the interpretations made from the quadrature phase data with those from the in-phase data will often provides a more complete picture of sources of wastes buried at a given site. It is, therefore, common with the Geonics EM-31 to record both quadrature and in-phase components. The anomalies in the EM field caused by metallic objects can show both positive and negative values.

Geonics EM34

The Geonics EM34 operates under the same principles as the EM31, and it can be operated at three different intercoil spacings (10, 20 and 40 m). The EM34 only measures the quadrature phase (conductivity) component, because the in-phase information is used to set proper coil separation. The search depth obtainable with various configurations of the EM34 are given in Table 4-1.

Table 4-1
Exploration Depths For Various EM34 Intercoil Spacings

Intercoil Spacing (meters)	<u>APPROXIMATE EFFECTIVE EXPLORATION DEPTH (Meters)</u>	
	Horizontal Dipoles	Vertical Dipoles
10	7.5	15
20	15	30
40	30	60

Applications and Limitations

EM surveys have their main application in site assessment for:

- searching large areas for uncontrolled waste pits and trenches of unknown location,
- determining boundaries of landfills, sludge lagoons, and other burial sites,
- locating buried drums, UST's, and other metallic buried objects.

Some of the advantages of EM surveys for these objectives are:

- EM measures changes in conductivity, and can therefore map the boundaries of areas filled with non-metallic as well as metallic debris,
- EM can detect waste with ferromagnetic debris, as well as waste containing non-ferromagnetic metals (aluminum, copper, etc.),
- the effective search depth is relatively independent of soil or rock type, and can be up to 50 ft (with the EM34),
- high survey productivity can be maintained in difficult terrain and through narrow walking trails in brush.

Some of the limitations of EM surveys are:

- metallic structures, such as buildings, buried utilities, metal fences and reinforcements in concrete, interfere with measurements; EM-31 measurements should be made at least 10 ft away from such infrastructures,
- in areas with extensive metallic debris scattered over the surface, no distinction can be made between surface debris and buried debris,
- in areas of extremely high conductivity (i.e., greater than 100 mmhos/m) the relationship of quadrature (conductivity) component and conductivity are no longer linearly proportional and data would require corrections.

4.3 TIME DOMAIN ELECTROMAGNETICS

In addition to frequency domain electromagnetic profiling with the Geonics EM31 and Geonics EM34, two time domain electromagnetic (TDEM) instruments were used over the CTP. The principles of time and frequency domain electromagnetics are in many ways similar. Both instruments consist of a transmitter and a receiver, and with both instruments a time varying electrical current is driven through a transmitter. This time varying current causes a time varying (primary) magnetic field (Fig. 4-6), and this field induces electrical eddy current flow in the subsurface. These eddy currents in turn result in a secondary magnetic field that is measured by a receiver coil. From this secondary magnetic field the geoelectric section (lateral and vertical resistivity variation) of the subsurface can be derived.

The difference between time domain and frequency domain is the system waveforms used, and Figure 4-7 shows the system waveforms of both systems. In frequency domain systems, the current driven through the transmitter is harmonic-varying, and the induced electromotive force (emf) and the secondary magnetic field due to the eddy currents in the subsurface also are harmonic-varying. In time domain systems a half-duty cycle waveform is employed, and the emf due to eddy current flow in the subsurface is measured during transmitter off time.

This difference in system waveforms has a major impact on accuracy of measurements. In frequency domain systems, the secondary magnetic field must be measured in the presence of the primary magnetic field (due to currents in the transmitter). This primary magnetic field contains no information about the subsurface. Thus,

$$\text{emf}_t = \text{emf}_p + \text{emf}_s \quad [1]$$

where subscripts t, p and s refer to total, primary and secondary magnetic fields, respectively.

In most common situations emf_p is several orders of magnitude larger than emf_s , and this limits the accuracy to which the secondary magnetic field can be measured. Figure 4-7 shows that in time domain systems the emf due to the secondary magnetic field is measured during transmitter off time, i.e., in the absence of a strong primary field. In time domain EM the only fields measured are the secondary magnetic field and any fields due to ambient EM noise. Hence, the principle difference between frequency and time domain systems is measurements in the presence of a primary field in frequency domain and in the absence of the primary field in time domain. Although, in many physical situations, frequency and time domain systems are equivalent and related by the Fourier transform, - they are not equivalent in the

practice of geoelectric prospecting, because the strong primary field limits the accuracy of measuring the secondary magnetic field in frequency domain systems.

Time domain systems find use for determining conductivity stratification in near horizontally layered ground, as well as for detecting localized highly conductive objects. In mineral exploration these highly conductive zones often are massive sulfide ore bodies. In environmental site assessments the conductive targets are metallic drums, underground storage tanks, exploded and unexploded ordnance. Figure 4-8 can be used to explain the effectiveness of time domain systems in detecting highly conductive targets, where a conductive target is seen buried in surrounding soils of finite conductivity. The primary field of the transmitter will induce eddy current flow both in surrounding soils and in conductive targets. If our objective is to detect the target, the secondary field due to currents flowing in surrounding soils is noise, and the field due to currents in the target represents useful signal. Immediately after current turn off, eddy currents are induced both in the surrounding soils as well as in metallic targets. The currents in the soil will decay faster with time than the currents in the metallic object, because currents are trapped in the target and decay much slower with time. Thus, it can be shown that in time domain EM there always is a range of time where the ratio of signal due to the target and that due to surrounding soils is maximum (Fig. 4-9).

In summary, time domain measurements have potentially three advantages over frequency domain systems that can be exploited:

- (1) Mitigating ambient electrical noise. The duration of on-off pulses is measured in microseconds, so that many transients can be stacked in a short measurement period to mitigate against noise due to power lines, meters, radio stations, etc.
- (2) Improving accuracy of secondary field measurements. Because measurements are made in the absence of a primary field, the secondary field (in-phase component) can be more accurately measured.
- (3) Better conductive target recognition. Signal due to metallic objects can be enhanced by measurements over a time range where signal due to surrounding soils has largely decayed (Fig. 4-9).

Two time domain instruments were employed for the survey over the CTP - the Geonics EM47 and EM61. In the EM47 the transient decay is measured during off-time in 20 channels with the center time of the gates equally spaced on a logarithmic scale of time. At each station, therefore, a large quantity

of data is collected (60 data points if 3 components of the magnetic field are measured). The amount of data processing required will in many situations be too complex for surveys for buried wastes. Also, the equipment and field operations (e.g., separate transmitter and receiver) may be too involved for rapid shallow surveys.

The EM61 is a greatly simplified time domain system specifically designed for detecting metallic objects in the upper 20 ft. The transient is recorded in two receiver coils spaced 40 cm apart at a time which is optimized, so the ratio of signal due to shallow buried metal versus surrounding soils is maximum. The lower coil of the instrument is used for both transmitting and receiving.

Two modes of surveying are commonly employed for detecting conductive targets, and they are shown in Figure 4-10. Both modes were employed over the CTP. A relative large loop was laid outside the trench, and profiles with receiver stations at 2.5 ft intervals were run across the trench. The Geonics EM47 was employed for the profiling measurement. The Geonics EM61 was used for measurements with both roving transmitter and receiver co-located.

4.4 GROUND PENETRATING RADAR (GPR)

A GPR system measures the two-way travel times of electromagnetic pulses to reflecting boundaries in the subsurface. Reflecting boundaries are interfaces across which changes in dielectric constant occur. Such interfaces can be caused by changes in water content, changes in density, voids, boulders, and foreign objects buried below ground.

The basic components of a GPR system are shown in Figure 4-11 consisting of a transmitter-receiving antenna, and receiver control. Because EM pulses of high frequency (10^2 megahertz to 10^3 megahertz) are employed, attenuation of GPR signals is high and site specific, depending on water content, clay content and uniformity. Antennas with center frequencies of 100 MHz, 300 MHz, and 500 MHz were employed.

The GPR survey is performed by pulling the antenna over the surface. A continuous recording is made of the two-way travel time from the antenna to reflectors in the subsurface versus time. The time along a profile is correlated to distance along the profile by the operator inputting fiducial markers at specified distance intervals.

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ILLUSTRATION OF THE EARTH
AS A MAGNET
AND ITS MAGNETIC FIELD VECTORS

INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 4-1

THE SOURCES AND NATURE OF MAGNETIC ANOMALIES

Variation in form of anomaly in total magnetic intensity of a sphere with change in magnetic latitude. (From Nettleton, 1962: by permission of the American Association of Petroleum Geologists.)

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TOTAL MAGNETIC ANOMALY
FOR VARIOUS INCLINATIONS

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FIGURE 4-2

GEM

SYSTEMS

ADVANCED MAGNETOMETERS

Shown in Backpack
Sensor Mode

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PROTON PRECESSION
MAGNETOMETER/GRADIOMETER

INEL-01-001-001-001 FINAL REPORT
GEOPHYSICAL DEMONSTRATION

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FIGURE 4-1

GEONICS EM31 CONDUCTIVITY METER

GEONICS EM34-3 CONDUCTIVITY METER HORIZONTAL DIPOLE MODE

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SCHEMATIC DIAGRAM OF
EM-31 AND EM-34

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FIGURE 4-4

Primary Field

Eddy Current Flow

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EDDY CURRENT FLOW IN
SUBSURFACE FROM EM
INDUCTION INSTRUMENT

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FIGURE 4-5

Currents Immediately After Turn Off

Homogeneous Earth

Eddy Current Flow

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SCHEMATIC DIAGRAM OF TDEM CURRENTS

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FIGURE 4-6

SYSTEM WAVEFORMS OF TIME DOMAIN AND FREQUENCY DOMAIN EM

FREQUENCY DOMAIN

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SYSTEM WAVEFORMS OF TIME DOMAIN
AND FREQUENCY DOMAIN EM

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FIGURE 4-7

Also Refer to Figure

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TDEM AS USED FOR DETECTION
OF CONDUCTIVE TARGETS

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FIGURE 4-8

Schematic illustration of the fact that in transient EM there is a range of time where ratio of useful signal and geologic noise is optimum

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ILLUSTRATION TDEM TIME RANGE
OF MAXIMUM TARGET DETECTION

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FIGURE 4-9

(a)

(b)

- a) Fixed transmitter-moving receiver
- b) Constant Separation

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TDEM SURVEY ARRAYS

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FIGURE 4-10

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GPR SYSTEM COMPONENTS

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FIGURE 4-11

5.0 DATA PROCESSING

5.1 OBJECTIVES

The objective of the data processing was to obtain additional information from the data sets collected over the CTP. The acquisition of high spatial density data sets allowed application of processing techniques not feasible with data collected at low density. These techniques includes high pass filtering, Euler deconvolution of magnetic data, de-corrugation filtering and 3-D gridding of EM-47 data sets. The following sections will describe the motives for application of the data processing, the methods used and summarize the results obtained from the data processing.

5.2 PROCESSING TECHNIQUES EMPLOYED

5.2.1 Gridding and Contouring

Problem description

For application of many of the processing techniques described below, as well as color or grey scale display and contouring of the data sets, the algorithms require a regularly spaced grid of values. The value at a grid location must correspond very closely to a measured value at the same location. In order to do this a gridding algorithm must be used.

Gridding algorithms

A variety of different gridding algorithms exist to create regularly spaced grid values from data points which may or may not be regularly spaced. For data which is collected along lines which are roughly parallel, a process is employed which fits a spline function along each of the survey lines. Then along each line of grid nodes, roughly perpendicular to the original data lines, a spline is fitted which fits the values at each survey line intersection with a value calculated according to the splines along the survey lines. At each grid node along the line of grid nodes, the fitted spline is then evaluated to arrive at the value for the node. This method offers two major advantages over other gridding algorithms:

- Increase in speed, provided that the data sets are sorted by lines, because no searching through the data sets for all the nearest data points is required. For large data sets, this offers a magnitude decrease in processing time and memory required.

- The co-located grid nodes and data values have the exact same values. The spline functions used exactly fit the input data.

To create grids using this method, the Geosoft program BIGRID was used.

In the case of the EM-47 data, where a 3-D dataset was available, a different gridding algorithm was used. To generate a 3-D display of the EM-47 data, a regularly spaced grid in three dimensions is required. For the data collected over the CTP, the x and y axes of the cube corresponded to horizontal distance. The z value corresponded to time after turnoff. The value at the cube grid nodes corresponded to the emf at each time gate. To generate this cube the Dynamic Graphic's Program *ev3_grd* was used. This algorithm calculates a value at each grid node such that the volume simulated by the 3-D grid has the minimum curvature(or tension) in the isovalue surfaces of the volume. It does this by starting with a coarse grid (4x4x4) and determining the values using an inverse distance least squares algorithm. Then a new grid is interpolated using a spline function which minimizes curvature (or tension). The spline only fits the grid node values and not the data points. At each new grid node, the value of the node is compared against nearby data points. If the difference between the closest grid node and the data points is not decreasing, the grid node is recalculated. The process of interpolating and recalculating the grid is repeated until the grid reaches the final user specified grid spacing, and the error at each grid node doesn't decrease any more. This process has the effect of creating smoothly varying grids that very closely fit the observed data.

5.2.2 De-Corrugation

Problem description

A number of the data sets exhibited an effect known as corrugation where there were small misties between adjacent lines. This was noted in the magnetic data (especially the vertical gradient) as well as the EM-31 data. The causes of this noise are related to the fact that adjacent lines were acquired with the operators and instruments facing opposite directions(i.e. one line acquired North-to-South and the next acquired South-to-North). An example of data where line-to-line corrugation is found is shown in Figure 5-1.

In the case of magnetic data, a likely cause for this noise is a very small amount of ferrous metal on the operator or within the instrument. Although the magnetic anomaly due to that object will remain the same, regardless of operator orientation, the position of the sensor within the anomaly will change. This noise has not been noted in prior magnetic surveys performed by CEES-Blackhawk because typical

line spacings have been on the order of 5-10 ft, and the magnetic field variations from one line to another were much larger than the corrugation noise. However, this type of noise is often seen on high resolution aero-magnetic surveys acquired for mineral exploration, and processing techniques developed for those surveys were used to remove the noise for this survey.

The EM-31 corrugation noise was likely due to two factors, one of which is a slight variation in the distance from operator to the transmitter coil vs. the receiver coil. Thus, when the operator stands at the survey location, the instrument is not exactly centered over the survey point. When the operator orientation is reversed, the instrument center will be moved. The other cause of the corrugation noise in the EM-31 is the delay of the instrument in reaching equilibrium. This means the instrument will always be reading a value which is indicative of the sub-surface which the operator has just passed over. Again this type of noise has not been noted before most likely due to the wider line spacing and therefore larger line-to-line signal variation, generally employed in environmental geophysical surveys.

Filtering applied

Two types of filtering were applied to the data, i) 1-D low-pass filtering of gridded data sets in a direction perpendicular to the directions of data acquisition and ii) A combination of Fourier domain high pass filtering and directional cosine filtering. The second combination of filtering was generally found to be more effective at removing the corrugation noise while still preserving the high frequency data.

In the 1-D filtering technique, a regularly spaced grid is generated from the acquired data, the grid is then rotated so that the grid data is stored in vectors oriented perpendicular to the direction of data acquisition (i.e., if the data was acquired in North-South lines, the grid is stored so that the vectors are oriented East-West). Then a 1-D low pass filter is designed to reduce the high spatial frequency signal along the lines. For the data sets acquired over the CTP, a low pass filter with a cut-off of 12 ft was found to provide the best trade-off between removing the corrugation and preserving the signals from the buried objects. The advantage of this method is that it can be done rapidly and doesn't require the transformation of the grid into the Fourier domain

The second filtering method requires the transformation of the grid into the Fourier domain. This is done so that applying a filter does not require a point by point multiplication of each filter coefficient, but instead the transformed grid can be multiplied by an analytically derived grid of the same dimensions, resulting in much reduced processing time. A grid which has been Fourier transformed is now a grid of complex values with x,y dimensions which correspond to spatial wave numbers with units of

1/distance and the value at each node corresponding to the phase and amplitude of the signal at that particular wave number.

The first filter applied was a high pass Butterworth filter, with a cut-off wavelength at 0.1 cycles/ft and an order of 8. The cut-off wavelength was determined by using the wavelength of the corrugation noise(5.0 ft, twice the line-to-line distance) and the determination of a cut-off wavelength which would effectively remove that noise. A Butterworth filter is known also as a maximally flat filter. It is used routinely in many applications because of its smooth transition between pass and reject regions. The fact that it doesn't alter the phase of the signal in the pass band and very smoothly changes the phase in the transition band is another advantage of its use. The Butterworth Filter is defined as follows:

$$L(r) = \frac{1}{\left[1 + \left(\frac{r}{r_c}\right)^n\right]}$$

Where:

r = wave number(radians per meter)

r_c = central wave number of filter

n = degree of the filter function

This high pass filtered data was then filtered using a directional cosine filter. The formula for the directional cosine filter is as follows:

$$L(\mu, \nu) = 1 - \left| \cos^n\left(\alpha - \theta + \frac{\pi}{2}\right) \right|$$

where:

n = the degree of the cosine function

α = the direction of the filter in degrees from North

μ, ν = coordinates in the wavenumber domain

$$\theta = \tan^{-1}\left(\frac{\mu}{\nu}\right)$$

The degree of the cosine filter controls how sharp the pass region of the filter is. The lower the number, the sharper the pass region. In the case of the decorrugation filtering, a degree of .5 is used.

This filter is useful in isolating trends which occur in specific directions. In this case we enhanced the corrugation noise by passing only signal which trended in the parallel to the direction of data acquisition. This Fourier domain grid was then inversely transformed back into the spatial domain and resulted in a grid which contained mainly the corrugation noise. This grid was then subtracted from the original grid. The resulting grid contained the signals from subsurface objects, but almost no corrugation noise (Fig. 5-1).

5.2.3 High Pass Filtering

Problem description

The signals from buried objects as well as the signals from geology occur over a wide range of spatial wavelengths. Sometimes, the information in the data can be enhanced by only looking at a subset of those wavelengths where the signals due to the buried objects are strongest relative to the geologic signal. Another reason may be to decrease the spatial width of the signal due to a buried object by looking at only the higher spatial frequencies.

In order for high pass filtering to be effective, the measured signal must contain information about buried objects at high spatial frequencies of a higher amplitude than geologic signal and instrument noise. Of the data sets obtained, only the EM-61 data fulfilled this criteria.

Filtering applied

A Butterworth high pass filter was used to perform the high pass filtering, for the same reasons as stated above in the de-corrugation filtering section. A 6th order filter with a central wave number of .04 was used. The results are shown in Figure 5-2, which shows only the characterization cell, and the objects within the cell. Individual objects within the cell are clearly more recognizable after the high pass filter has been applied. Furthermore, there is no appreciable increase in the random noise visible in the data. High pass filtering was also applied to the magnetic and EM-31 data, with no significant improvement in information.

5.2.4 Euler Deconvolution

Problem description

Determining the location of buried objects which cause anomalies in the magnetic data is a difficult process. One approach is to attempt to match a calculated response from a reasonable model for each individual anomaly, a time consuming approach requiring extensive input from the interpreter. Other simplified approaches include estimating the depth of the object, using the anomaly width, and placing the object below the center of the anomaly. These and many other approaches require significant manual input from the interpreter. Furthermore, they generally simplify the problem to a great extent including ignoring any remnant magnetization of the object. Euler Deconvolution automates a significant amount of the interpretive process and greatly speeds up the interpretation of magnetic data.

Description of method

Euler Deconvolution is a method for determining the location of magnetic bodies which result in the magnetic anomalies seen in the data. Euler's deconvolution is based on the Euler's Homogeneity relationship, which relates the magnetic field and its x,y, and z gradient values to the source of the anomaly. The algorithm uses a sliding window which proceeds over the grid(usually about 10x10 grid cells) and determines the x,y,z location of a magnetic object which minimizes the least square error of the difference between the computed and observed magnetic field. The use of Euler's equation has several key advantage's over other methods of magnetic inversion, they include:

- insensitivity to the inclination and declination of the Earth's magnetic field,
- insensitivity to remnant magnetization of the ferro-metallic body,
- automated application of the algorithm to gridded data sets in the form of GRIDDEPTH™, a package offered by Geosoft Mapping Systems.

The insensitivity of the solutions to the Earth's magnetic field and any remnant magnetization in the body are due to the fact that the deconvolution technique is dependent on the gradients of the magnetic field and is not tied to any geologic model. A more detailed description along with examples and further references can be found in Yaghoobian, 1993.

Procedures

The steps involved in processing the data using the GRIDDEPTH™ algorithm are:

1. Construct a suitable total magnetic field grid. This may involve filtering or upward continuation of the data. Furthermore, the cell size of the grid should be such that a 10 by 10 square of grid cells approximately covers an entire anomaly, and doesn't include anomalies from more than one object.
2. Calculation of the x, y, and z gradient grids. The horizontal gradients(x,y) can be calculated using either a Fourier domain calculation or a simple spatial domain filter. The vertical(Z) derivative can either be obtained from the gradient measurements or by a calculation in the Fourier domain.
3. Input the total field grid and three gradient grids to the Euler Deconvolution algorithm. Along with these grids, several parameters must be specified including: the structural index (SI) and several distance and error tolerance parameters. One of the key parameters is the SI. This parameter relates to the shape of the object, and can vary from an index of 1 to 3. The value of this index corresponds roughly to 3 (for magnetic data) minus the number of "large" dimensions of the object. For instance, a pipe has one "large" dimension, and therefore has a SI of 2. A sphere has no large dimensions and therefore has an SI of 3. The other key parameter is the maximum error for an acceptable solution. For drums and metal filled boxes an SI of approximately 2.5 was used.
4. Plot the output of the GRIDDEPTH™ algorithm. Often different sizes or colors of the plotting symbols can be keyed to different depths for the solutions.

Analysis of results

The GRIDDEPTH™ algorithm was run several times in order to evaluate the different inputs to the algorithm. An example of the output over the characterization cell is shown in Figure 5-3. The solutions should be analyzed in terms of how well the solutions are clustered together in terms of x,y,z location. Therefore the scattered solutions that don't fall into clusters are not likely to correspond to the location of an actual ferro-metallic object. Many different locations of objects are found, however, there does not appear to be much correlation between the locations calculated using GRIDDEPTH™ and the

known location of the ferro-metallic objects (Objects E2, F, H and the two file cabinets). This is likely due to several factors including:

- Presence of strong magnetic anomalies arising from the basaltic flows underlying the CTP. These provide magnetic anomalies which are superimposed on-top of the buried waste anomalies.
- Ferro-metallic objects are situated too close together to allow for only a single complete magnetic anomaly in a window. This has the effect of distorting the computed location of the objects.

It should however be noted that the location of one of a group of objects identified using GRIDDEPTH™ in the area of the file cabinets in the characterization cell, corresponds closely with the location of anomalies in the EM-61 data. This could perhaps indicate that the filing cabinets are not in the location that they were originally placed. This shifting may have occurred in the process of filling in the cell with soils.

5.2.5 Reduction-to-Pole

Problem description

Reduction-to-pole is a technique commonly applied in mineral exploration, to enhance the interpretability of magnetic data. It is intended to compensate for the fact that the Earth's magnetic field is not vertical at any location not at the magnetic poles and therefore the anomaly induced in a ferro-metallic object will have a dipolar shape. By mathematical manipulation, the data can be transformed as if it were acquired at the magnetic North pole, and therefore all the induced anomalies will be a single peak. The assumption made when performing this transform is that all magnetic anomalies are due to induced fields in ferrometallic objects and there are no magnetic anomalies due to remnant magnetization of an object.

Filtering applied

The operation is performed in the Fourier Domain using the following calculation on the total magnetic field data.

$$L(\theta) = \frac{1}{[\sin(I_a) - i \cos(I) \cos(D + \theta)]^2}$$

Where:

I = geomagnetic inclination, 68° at INEL

Ia = inclination for amplitude correction (same as I for latitude at INEL)

D - Geomagnetic declination

The results of the reduction-to-pole are shown in Figure 5-4. Many of the magnetic anomalies have been transformed from a dipolar anomaly to a single peak. This makes the x,y location of the data, somewhat easier to determine. However, there was no increase in the resolution obtainable from the magnetic data. Furthermore, there were several anomalies for which the reduction-to-pole accomplished very little, indicating that there was a significant amount of remnant magnetization of the object. This was especially true of some of the anomalies likely due to basalt flows outside the CTP.

5.2.6 Depth conversion of EM61

Problem description

Viewing EM-61 data in a map or 3-D projection surface provides information only of the x,y location of possible objects. One of the objectives of this program was to obtain information about the objects in a 3-D manner which requires information on the depth to the object. By utilizing the ratio of response between the upper and lower coils of the EM-61, an estimate to the distance of the object can be obtained.

Processing applied

The relative response of an EM-61 coil to an object is defined as follows:

$$\begin{aligned} f1(z) &= \sqrt{(h+z+11)^2 + 2 * a1^2} + [(h+z+11)^2 + a1^2] \\ f2(z) &= \sqrt{(h+z+12)^2 + 2 * a1^2} + [(h+z+12)^2 + a1^2] \\ R(Z) &= k * \frac{f1(z)}{f2(z)} \end{aligned}$$

where:

$f1, f2$ = response of lower and upper coils

z = depth of object in cm

h = radius of the EM-61 wheel

$l1, l2$ = height of lower and upper coils above wheel axes

$a1$ = geometric factor

$k = 2.8$.

The response of the instrument vs. depth of an object is shown in Figure 5-5. This curve was least-squares fitted using a 6th order polynomial to give a formula which computes depth as a function of the ratio of response between the two channels. The fitted curve is also shown in Figure 5-5.

Figure 5-5

The depth was then computed using this polynomial relationship on each data point and the computed depth was then gridded. In order for a depth to be computed a threshold value of 20 millivolts had to be read in channel 2. The computed response over the characterization cell is shown in Figure 5-6. Directly over the objects which cause large anomalies such as Box E2 and the file cabinets, reasonable depths appear to be computed. The depth to the box E2 (Ferrous Metals) was computed as 2.3 m (7.5 ft); the stated depth to the top of the box is 2.13 m (7 ft). The depth to the file cabinet was computed as 1.65 m (5.4 ft). The stated depth to the top of the file cabinet is 1.29 m (4.25 ft) assuming the file cabinet was moved during soil emplacement, but remained upright. However, in other areas of the CTP the depth is calculated to be over 5 m, which is due to the large number of metallic objects within the pit. The computed depth over the entire CTP is shown in Figure 5-7. By using the threshold of 20 millivolts, the depth response can be used to provide an approximation of the plan trench boundaries in areas where metallic objects are present in the trench.

When the sensor is directly over an object and the object is on the order of the size of the coils (1m x 1m) then the distance can be interpreted as the depth to the object. However, when the objects are not directly underneath the instrument then the value computed is the distance to the object. For large objects the average distance to the object is computed. Both of these cases have the effect of computing a value which is larger than the depth to an object. This can be seen in Figure 5-7., where a large majority of the CTP is computed to have a depth of over 5 m(16.4 ft).

5.2.7 Normalization of EM-47 Data

Problem description

To create a 3-D volume of the EM-47 data that could be visualized, a data set needed to be created which reduced the dynamic range of the data values as well as the time values. In order to do this the emf values were normalized based on the rate of decay expected from a half space response and the log of the time values was used as a coordinate.

Processing of EM-47 data for 3-D display

The measurements recorded by the EM47 polycorder data logger represent the time rate of change of the magnetic field, dB/dt, normal to the plane of the receiver coil, amplified by the system electronics. This data is transferred to a PC and visually checked in an editing program. Particular attention is given to data fields containing transmitter turn-off, effective receiver coil area, time of first gate, frequency, transmitter current, and area of transmitter loop. Data that was recorded, but judged bad by the operator, is so marked in the data file so it is not used in calculations.

The recorded raw data is then transformed into a normalized nanovolts/per ampere meter squared value for further processing.

In order to create a 3-D grid of the voltages measured from the EM-47 survey, the data was transformed into suitable input for the gridding algorithm. The transforms included:

1. Normalization of the voltage measured by using the late time decay rate for a half space($t^{-5/2}$ for z component, t^{-3} for the x,y components). The normalization for the horizontal components was as follows:

$$V_{ni} = V_i * \left(\frac{T_i}{T_1} \right)^3$$

Where:

V_{ni} = normalized voltage at EM-47 gate i

V_i = measured voltage at EM-47 gate i

t_i = time after turnoff at center of EM-47 gate i

t_1 = time after turnoff at center of EM-47 gate 1(.0069 ms)

For gates 8-20 on the EM-47 this appeared to correct the data so that at least the voltages were on the same order of magnitude. Gates 1-7 appeared very noisy, likely due to galvanic currents(McNeill, 1993) and so effort was made to normalize the values at those gates to a useful value. No correction was applied to account for the change in voltage that occurs with increasing distance from the loop. For the loop size and distance traversed in this survey, this correction was not necessary.

2. Taking the natural log of the time gate. This transforms the data into approximately equally spaced values along the depth axis allowing more reasonable grid cell size selection.

A display of the 3-D grid for the z component over the random dump drums and boxes cell is shown in Figure 5-8. The negative anomalies inside the cube correspond to the location of the random dump drums and boxes cell.

FIGURE 5-1

INEL USDOE
GEOPHYSICAL DEMONSTRATION
COLD TEST PIT EXAMPLE OF DE-CORRUGATION FILTERING DOE CONTRACT # DE-AC07-93ID13215
CEES-BLACKHAWK Project # 6803-001

EM-61 CHANNEL 2 RAW DATA

EM-61 CHANNEL 2 HIGH PASS FILTERED

CONTRACT # DE-AC07-93ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

EM-61 CHANNEL 2 OVER
CHARACTERIZATION CELL
FILTERED VERSUS UNFILTERED
INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 5-2

Euler Deconvolution Depth Solutions

- 12 to 10 ft
- 10 to 7 ft
- 7 to 5 ft
- 5 to 3 ft
- 3 to 1 ft

CONTRACT # DE-AC07-03MD13215

BLACKHAWK GEOSCIENCES DIVISION

**OBJECT LOCATION DERIVED FROM
EULER HOMOGENEITY DECONVOLUTION
OVER CHARACTERIZATION CELL**
INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 8803-001

FIGURE 5-3

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

FIGURE 5-4

INEL USDOE

GEOPHYSICAL
DEMONSTRATION

NO TEST PIT

THE MATERIALS FIELD RESEARCH CENTER
INTEGRATED # DE-AC07-93OR13215

CEES-BLACKHAWK Project # 6803-001

CONTRACT # DE-AC07-83ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

DEPTH TO OBJECT DERIVED FROM
RATIO BETWEEN EM-61 CHANNELS IN
CHARACTERIZATION CELL

INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 6-6

0 20 40 60 80 100 120 140

300

280

260

240

220

200

180

160

140

120

100

80

60

500
484.8485
469.697
454.5454
439.3939
424.2424
409.0909
393.9394
378.7879
363.6364
348.4848
333.3333
318.1818
303.0303
287.8788
272.7273
257.5757
242.4242
227.2727
212.1212
196.9697
181.8182
166.6667
151.5152
136.3638
121.2121
106.0606
90.90909
75.75758
60.60606
45.45454
30.30303
15.15152
0

Depth
(cm)

CONTRACT # DE-AC07-93ID13215

INEL USDOE

Geophysical
Demonstration

Cold Test Pit
Depth Derived From Ratio
of EM 61 Channels

CEES-Blackhawk

FIGURE 5-7

CONTRACT # DE-AC07-93D13215

CEES BLACKHAWK GEOSCIENCES DIVISION

3-D

DISPLAY OF TDEM DATA Z COMPONENT

INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 6-3

Z COMPONENT RESPONSE - EM - 47 INEL CTP - RANDOM DRUMS AND BOXES

6.0 RESULTS

6.1 GENERAL

A large quantity of data was collected over the CTP. To systematically evaluate the results of each individual data set, several criteria were applied. These are:

- the accuracy in determining pit boundaries,
- the accuracy in determining boundaries between cells within the pit,
- the ability to detect individual objects within the pit. In evaluating this criterion we mainly focused on the characterization cell where the position of objects was known,
- the ability to characterize objects, e.g., metallic versus non-metallic.

In Section 5.0 various processing techniques were described and evaluated for their improvements in mapping the objectives listed above. In this section, contour maps and line profiles of the processed data that best accomplished the objectives are shown.

6.2 MAGNETIC SURVEY

6.2.1 Survey for the Entire CTP

The results of the magnetic survey data are given in Figure 6-1 (total magnetic field), Figure 6-2 (total magnetic field, reduced -to-pole), Figure 6-3 (de-corrugated vertical magnetic field gradient), and in Figure 6-4 (Euler deconvolution of magnetic field data). On each data set the best information about pit boundaries and cells is superimposed. Next, the accuracy and ability of the magnetic survey data to accomplish the objectives is analyzed.

Determining pit boundaries

All three sets of magnetic data show the largest anomalies (about 2,500 gammas) over ferrometallic targets, such as those buried in the large object pit (cell 1) and in the random drum and boxes cell (cell 4). The boundaries of the pit and between cells within the pit are not well delineated, for the reason that some wastes are non-ferrometallic and have no magnetic signatures, as well as the strong magnetic signatures of the underlying basement basalts.

Determining cell boundaries within the pit

For the same reason as stated above, the magnetic survey did not well delineate cell boundaries. The boundaries of some cells containing ferromagnetic debris (e.g., cell 4) are delineated to an accuracy of ± 5 ft.

Optimum data display format

Reduction-to-pole of the total magnetic field data appears to better delineate larger metallic objects. The reduction-to-pole (Fig. 6-2) also allows better location of zones of burial, because it typically results in one positive single anomaly rather than a positive and negative anomaly. The existence of a positive and negative anomaly makes interpretation of the placement of the object ambiguous. The Euler deconvolution did not improve detection. The presence of basalts with high magnetite content under the site at varying depths is believed to be part of the reason for unsuccessful application of Euler Deconvolution.

6.2.2 Characterization Cell

Figure 6-5 shows the characterization cell and a table describing its waste forms. The results of the magnetic survey over the characterization cell are given in Figures 6-6 (total magnetic field), Figure 6-7 (total magnetic field, reduced-to-pole), Figure 6-8 (vertical magnetic field gradient), and Figure 6-9 (Euler deconvolution solutions). In these figures results after application of a high-pass filter are given.

Some anomalies in the magnetic data are caused by geologic variation in the basalts which complicate delineation of the buried objects. The basalts obscure definition of the objects. Also, ferrometallic objects in the retrieval cell, north of the characterization cell, cause large magnetic anomalies which interfere with anomalies within the characterization cell.

The Euler deconvolution process appears to show a cluster of solutions approximately halfway between objects E₂ and F, which both contain ferrous metal. The computed depth is less than 3 ft. This spurious location may be due to the insufficient separation between the objects. The Euler deconvolution is unable to separate the anomalies, so the best least square fit is one shallow object approximately halfway between them. Object A (metal drum) shows a cluster of solutions within 3 to 4 ft of its location at a depth of 3 to 5 ft. Object C, also a metal drum, doesn't have any corresponding cluster. There do appear to be two separate clusters of solutions corresponding to the location of the file cabinets at depths

between 2 to 7 ft. Their locations are within 3 to 4 ft of the positions determined by the EM61 data. Box H, which contained 991 Kg of steel parts, had only a very weak cluster of metallic object solutions at depths between 5 to 7 ft. This would indicate that the metal contained in the box is only weakly magnetically susceptible, although this is unlikely.

The Euler deconvolution solution in Figure 6-9 is one of many possible sets of solutions, all of which can differ significantly. Therefore, it is difficult to determine the confidence to place on the solutions at the CTP. The presence of very strong magnetic anomalies from the underlying basalts is likely a strong contributor to this problem. The requirement for the entire anomaly of an individual object to be spatially separated from an anomaly of a different object also caused Euler deconvolution to produce inaccurate results.

In summary, magnetic data were not effective in accurately locating or characterizing individual objects within the characterization cell. Part of the reason is that both ferromagnetic and non-ferromagnetic objects were buried, and another reason is that the variation in magnetite content of the basalts complicated anomaly shapes caused by magnetic objects.

6.3 FREQUENCY DOMAIN ELECTROMAGNETICS (GEONICS EM31 AND EM34)

6.3.1 Survey of the Entire Pit

The results of electromagnetic profiling with the Geonics EM31 are given in Figures 6-10 through 6-13, and the Geonics EM34 results are given in Figure 6-14. Table 6-1 describes the various figures.

Table 6-1
Information Displayed on Figures 6-8 through 6-12

Figure #	Tx - Rx Orientation	Component Measured
6-10	E - W	EM31, Conductivity (Quad-Phase)
6-11	E - W	EM31, In-Phase
6-12	N - S	EM31, Conductivity (Quad-Phase)
6-13	N - S	EM31, In-Phase
6-14	E - W	EM34, Conductivity (Quad-Phase), 10 m spacing

Determining pit boundaries

Again, superimposed on the figures is the best information about pit boundaries. Observation of the figures indicates that the EM31 in-phase component delineates pit boundaries within ± 2.5 ft. The eastern and western boundaries are not accurately delineated with the Tx-Rx orientation in a N-S direction. The southern and northern boundaries are most accurately delineated with a Tx-Rx orientation in an E-W direction.

Large conductivity variations around the CTP (some probably caused by soil disturbance and fill), are the cause of poor definition of the pit boundaries from the EM31 conductivity measurements. This also applies to EM34 conductivity measurements. The conductivity measurement appears to map surficial and near surface geology well. For example, basalt is known to outcrop in the southwest corner of the grid where low conductivities are observed, and lower conductivities in the northern portion of the CTP suggests the basalts are approaching the surface.

Determining cell boundaries within the pit

The berms between the characterization cell 6 and cell 5, and between cells 5 and 4 are best seen in the EM31 in-phase data. In fact, the berms are difficult to observe in the conductivity data.

6.3.2 Characterization Cell

The detailed results over the characterization cell with the Geonics EM31 are given in Figure 6-15 (conductivity) and Figure 6-16 (in-phase). (Refer to Fig. 6-5 for a table of characterization cell waste forms). There is considerable object definition in the in-phase data:

- i) Object A (metal drum), object B (plastic drum with salt water), and object C (metal drum) are defined by negative in-phase responses in the east-west data; only object A is defined in the north-south data. This likely is due to the fact that the drums are oriented with their long axis in the E-W direction resulting in better coupling when the berm is oriented parallel to the object;
- ii) the two metal filing cabinets occur as one negative anomaly in both sets of data;
- iii) Object E₂ is defined as a relative low ppt anomaly.

The large anomaly, apparently associated with the large concentration of drums in the adjacent retrieval cell, dominates the response for objects F, G and H, although some distinct response is seen associated with object H (wooden box with dense packed metal) with both orientations, but it is influenced by the response from the file cabinet area. The effect of the file cabinets on the EM31 data is less than the effect on the EM61 data, resulting in better definition of Box H by the EM31. The fact that a buried conductive target can have either a positive or negative anomaly in the EM31 data complicates the interpretation of the data. The size, sign and amplitude of the anomaly depend on a variety of factors including depth of burial, size and conductivity of the object, as well as orientation relative to the instrument.

Definition of objects is poor for the conductivity component of the EM31.

6.4 EM61 METAL DETECTOR

6.4.1 Survey for the Entire CTP

Although the primary objective in the design of the EM61 was metal detection, both contour maps in Figures 6-17 (channel 1) and 6-18 (channel 2) define the exterior CTP boundaries within ± 2.5 ft. Part of the good diagnostic of the EM61 arises from its low background values outside the pit. Individual zones of metallic objects within the pit are well defined. The lower amplitude anomalies suggest less metallic concentrations (i.e., the stacked drums; cell 3 area).

Determining cell boundaries within the pit

In both channels 1 and 2 the berms between cell 6 and cell 5, 5 and 4, and 4 and 3 are defined.

Determining pit boundaries

The primary objective in the design of the EM61 was to detect metal objects, and to be insensitive to changes in ground conductivity. Therefore, the EM61 was not expected to provide much information on the boundaries of the CTP or the cells within it. However, in most cases it was able to define the boundaries with ± 5 ft. This may be due to some sensitivity to ground conductivity or the fact that enough metal objects existed within the CTP. In some areas, such as the NE corner of the Random Dump Drums and boxes cell (cell 5), the CTP boundary is underestimated, whereas in the SW corner of the Large Object pit (cell 1), the boundary is overestimated, likely due to the presence of large metal objects very close to the CTP walls.

Determining cell boundaries within the pit

Both of the EM61 channels showed significantly reduced response within the berm zones, although the data didn't return to background levels. This is probably due to the fact that the EM61 detected the presence of metal at distances of over 7 ft, and because the berms were approximately 10 ft wide, the instrument was responding to metal objects in adjacent cells while it was directly over the berm.

6.4.2 Characterization Cell

The results of the EM-61 survey and processing over the characterization cell are provided in the following figures:

- Figure 6-19 Unfiltered and High Pass Filtered Contour Map of EM61 Channel 2 Data
Figure 6-20 Profile Plot of Filtered EM61 Data Over Objects in Characterization Cell
Figure 6-21 Plot of Objects with Computed Depth from EM61 Superimposed.
(Refer to Fig. 6-5 for a description of the characterization cell waste forms).

From the contour map in Figure 6-19, it appears as though the lateral location of all containers which had significant metal content could be interpreted to within ± 1 ft. This assumes that the file cabinets were shifted somehow during backfilling operations. In particular objects E2, F,G, A and C were well defined. Object B(plastic drum filled with saltwater) and Box D(wooden box filled with wood and paper) were not evident on either the contour plot or the profile plot, because they didn't contain significant amount of metallic objects. The signal from Box H is not particularly evident, because of its proximity to the suspected shifted file cabinet. This is somewhat unexpected, because it contains nearly 1,000 kg of metal, and one would expect that the signal from Box H would be larger. The reasons for this decreased response are believed to be: i) the EM-61 response is a function of the surface area of the metal. If the metallic objects are not electrically well coupled, then all the objects within the box will result in a signal which is the summation of a large number of small objects rather than one large object. The EM-61 response increases geometrically with size of the object, therefore the summation of many small objects doesn't equal the response of a single large object. This situation could result from either a coating on the metallic objects which has an electrical conductivity less than metal, or if rusting of the objects prevents good electrical contact between the objects. ii) the depth at which the box was buried(7 ft at the top) was much more than the depth to the top of the file cabinet(4.25 ft). The signal from a file cabinet would therefore be significantly higher than the signal from Box H.

The ability of the EM-61 to detect objects such as a single metal drum is due to the fact that there is very little noise in the EM-61 response. Variation of the signal in areas away from the trench is on the order of ± 2 mv. The signal from objects A and C which are single 55 gallon drums buried approximately 8 ft. deep is 8-15 mv (Fig. 6-19). This would be a clear indication of buried metal. In contrast, the signal over the file cabinets was about 200 mv and the signal from the largest object in the pit was over 1,000 mv. This presents a problem in the visual interpretation of the EM-61 data because the dynamic range of the data is very high. An interpreter may miss small anomalies which would still indicate buried metal. Therefore in order to locate all the buried objects, it is necessary to look at profile plots (Fig. 6-20),

because visually small anomalies are easier to detect in profile. It was useful in interpretation to first grid the data, then subsequently extract profiles from the grid in arbitrary directions for analysis, rather than looking at profiles of the acquired data.

Another important feature of interpretation of the EM-61 data is the fact that the signal due to a buried magnetic body is always a simple positive peak. This is in contrast to the EM-31 in-phase data which may have both positive and negative peaks over metallic objects. This greatly simplifies the interpretation of the data and would allow some automated analysis of peaks within the data by determining the location of all local maxima.

Further analysis of the EM-61 data over a portion of the Retrieval Cell (Cell 7) showed an apparently good correlation with photographs of the contents of that cell (Figure 2-4). The sections of the cell which should contain drums or desks appear to show correlation with available photographs.

Computed depth analysis

Directly over the objects which cause large anomalies, such as Box E2 and the file cabinets, reasonable depths appear to be computed. The depth to the box E2 (Ferrous Metals) was computed as 2.3 m (7.5 ft); the stated depth to the top of the box is 2.13 m (7 ft). The depth to the file cabinet was computed as 1.65 m (5.4 ft). The stated depth to the top of the file cabinet is 1.29 m (4.25 ft) assuming the file cabinet was moved during soil emplacement, but remained upright. However, in other areas of the CTP the depth is calculated to be over 5 m, which is due to the large number of metallic objects within the pit. Figure 6-21 shows the position of objects E1, E2, F, G and H, and calculated depth.

A summary of the larger objects interpreted to be located within the large object pit is shown in Table 6-2.

Table 6-2
Large Object Pit Interpreted Waste Forms and Calculated Depth

Object	Location	Calculated Depth
1	Northern Edge of Cell, 17 ft from Western Edge	Shallow (<3 ft.)
2	Long Linear Object Oriented N-S along Eastern Edge of Cell	Deep (> 7 ft.)
3	Diagonally oriented object, 8 ft from Southern Edge, 15 ft from Western Edge, Possibly two closely Located Objects.	Medium (Between 3 and 7 ft)
4-6	Three Objects in South-Western Corner	Deep (> 7ft.)

6.5 TIME DOMAIN ELECTROMAGNETICS (TDEM)

With the Geonics EM47, a number of 3-component TDEM measurements were made along profiles across the trench from a transmitter laid to the side of the CTP (Fig. 6-22) and one profile was made from a transmitter at the south end of the CTP. The data were reported in the Field Operations Plan and Project Status Report. Additional data is expected to be collected in the next field period, and will be subject to detailed analysis. This is not discussed further here.

6.6 GROUND PENETRATING RADAR (GPR)

A limited number of GPR lines were run over the CTP. The results were similar to those reported by others, who reported high attenuation in the fill placed over the pit, preventing observation of reflections from buried objects within the pit. Therefore, no useful information about pit boundaries, cell boundaries or buried objects was obtained from the GPR survey.

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

FIGURE 6-1

INEL USDOE
GEOPHYSICAL
DEMONSTRATION

CEES-BLACKHAWK Project # 6803-001

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

FIGURE 6-2

INEL USDOE
GEOPHYSICAL DEMONSTRATION
ALL TEST PIT TOTAL MAXIMUM ELEVATION 5005 FT LINE CONTRACT # DE-AC07-93ID13215
CEES-BLACKHAWK Project # 6803-001

FIGURE 6-3

GRADIENT
GAMMA T/M

INEL USDOE
GEOPHYSICAL
DEMONSTRATION
SCALE 1:4
100 feet

INEL USDOE

GEOPHYSICAL
DEMONSTRATION

COLD TEST PIT
DE GRADIENT VERTICAL MAGNETIC GRADIENT
LINE CONTRAST # DE-ACCT-G3115175

CEES-BLACKHAWK Project # 6803-001

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

GRIDEPTH LEGEND:

- 3 - 7 feet
- 0 - 3 feet

FIGURE 6-4

INEL USDOE
GEOPHYSICAL DEMONSTRATION
COLD TEST PIT EULER DECON. OF TOTAL MAG. FIELD DOE CONTRACT # DE-AC07-93ID13215
CEES-BLACKHAWK Project # 6803-001

Scale 1:120

Item Id.	Waste Form Type	Net Wt (kg)	Contents
A	55 gal. Drum w/liner	380	Concrete
B	30 gal. plastic drum	105	Saltwater
C	55 gal. Drum w/liner	1.5	Foam
D	Wood Box	54	Wood and Paper
E	2-Wood Boxes stacked	E1= 44 E2= 411	E1= Wood and Paper E2= Ferrous Metals
F	Wood Box	252	Mixed Metals
G	Wood Box	405	Non-Ferrous Metals
H	Wood Box	991	Dense-Pack Metal
File 1	Metal Cabinet	25	Empty
File 2	Metal Cabinet	25	Empty

CONTRACT # DE-AC07-93ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

INEL COLD TEST PIT LOCATION OF
OBJECTS IN COLD TEST PIT
CHARACTERIZATION CELL
INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 6-5

TOTAL MAGNETIC FIELD

HIGH PASS FILTERED TOTAL MAGNETIC FIELD

CONTRACT # DE-AC07-93ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

RAW & FILTERED TOTAL MAGNETIC
FIELD OVER

CHARACTERIZATION CELL

INEL U.S. DOE PHASE I FINAL REPORT

GEOPHYSICAL DEMONSTRATION

PROJECT NO 6803-001

FIGURE 6-6

TOTAL MAGNETIC FIELD REDUCED TO POLE

TOTAL MAGNETIC FIELD REDUCED TO POLE THEN HIGH
PASS FILTERED

CONTRACT # DE-AC07-93ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

REDUCED TO POLE TOTAL MAGNETIC
FIELD OVER CHARACTERIZATION CELL
(FILTERED & UNFILTERED)

INEL U. S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT 6803-001

FIGURE 6-7

VERTICAL MAGNETIC GRADIANT - DECORRUGATED

Scale 1:120
 5 0 5
 (feet)

CONTRACT # DE-AC07-83ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

**VERTICAL MAGNETIC GRADIANT
 OVER CHARACTERIZATION CELL**

**INEL U.S. DOE PHASE I FINAL REPORT
 GEOPHYSICAL DEMONSTRATION**

PROJECT NO. 8803-001

FIGURE 6-8

Euler Deconvolution Depth Solutions

- 12 to 10 ft.
- 10 to 7 ft.
- 7 to 5 ft.
- 5 to 3 ft.
- 3 to 0 ft.

Scale 1:120

CONTRACT # DE-AC07-83ID13215

CHES BLACKHAWK GEOSCIENCES DIVISION

OBJECT LOCATION DERIVED FROM
EULER HOMOGENEITY DECONVOLUTION
OVER CHARACTERIZATION CELL
INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 8809-001

FIGURE 6-9

← →
East - West Coil Orientation

FIGURE 6-10

INEL USDOE
GEOPHYSICAL
DEMONSTRATION

CEES-BLACKHAWK Project # 6803-001

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

East - West Coil Orientation

FIGURE 6-11

INEL USDOE
GEOPHYSICAL DEMONSTRATION
FIELD TEST PIT EMRI, F. A. M. PHASE, DE-2, BRIDGES LINE # 1, TRACT # 11, AREA 1, 1000000
CEES-BLACKHAWK Project # 6803-001

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

FIGURE 6-12

INEL USDOE
GEOPHYSICAL DEMONSTRATION
FILE # 6803-001
CEES-BLACKHAWK Project # 6803-001

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

North - South Coil Orientation

FIGURE 6-13

INEL USDOE
GEOPHYSICAL DEMONSTRATION
COLD TEST PIT EMERGENCY RESPONSE, DECONTAMINATION OPERATION CONTRACT # DE-AR07-00013010
CEES-BLACKHAWK Project # 6803-001

Map made by
PIT

FIGURE 6-14

INEL USDOE
GEOPHYSICAL
DEMONSTRATION

CEES-BLACKHAWK PROJECT # 6803-001

DECORRUGATED EM 31 CONDUCTIVITY NORTH SOUTH

DECORRUGATED EM 31 CONDUCTIVITY EAST WEST

CONTRACT # DE-AC07-93ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

COMPARISON EM 31 CONDUCTIVITY
DECORRUGATED EAST WEST
VERSUS NORTH SOUTH DATA

INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO 6803-001

FIGURE 6-15

DECORRUGATED EM 31 IN PHASE NORTH SOUTH

DECORRUGATED EM 31 IN PHASE EAST WEST

CONTRACT # DE-AC07-93ID132

CEES BLACKHAWK GEOSCIENCES DIVISION

COMPARISON EM 31 IN PHASE
DECORRUGATED EAST WEST
VERSUS NORTH SOUTH DATA

INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 6-16

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

FIGURE 6-17

INEL USDOE
GEOPHYSICAL
DEMONSTRATION

CEES-BLACKHAWK Project# 6803-001

- 1 large object pit
- 2 Stacked boxes
- 3 Stacked drums
- 4 Random dump drums and boxes
- 5 Random dump drums
- 6 Characterization Cell
- 7 Retrieval Cell

FIGURE 6-18

INEL USDOE
GEOPHYSICAL
DEMONSTRATION

CEES-BLACKHAWK Project# 6803-001

EM-61 CHANNEL 2 RAW DATA

EM -61 CHANNEL 2 HIGH PASS FILTERED

CONTRACT # DE-AC07-93ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

EM-61 CHANNEL 2 OVER
CHARACTERIZATION CELL
FILTERED VERSUS UNFILTERED
INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 6-19

NOTE: Scales Differ

CONTRACT # DE-AC07-83ID13215

CEES BLACKHAWK GEOSCIENCES DIVISION

EM 61 CHANNEL 2 PROFILE DATA
ALONG LINES THROUGH OBJECTS
IN CHARACTERIZATION CELL

INEL U.S. DOE PHASE I FINAL REPORT
GEOPHYSICAL DEMONSTRATION

PROJECT NO. 6803-001

FIGURE 6-20

LEGEND:

 Computed Depth Estimate

CONTRACT # DE-AC07-93ID

CEES BLACKHAWK GEOSCIENCES DIVISION

ACTUAL OBJECT LOCATIONS WITH
DEPTH ESTIMATES FROM
COMPUTED EM-61

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FIGURE 6-21

Scale: 1" = 100' App.

CONTRACT # DE-AC07-93ID13215

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TDEM TRANSMITTER LOOPS

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FIGURE 6-22

7.0 CONCLUSIONS

General

The ability of the various sensors tested over the CTP and characterization cell to meet the objectives of the survey are summarized in Table 7-1. The two sensors that performed best were the frequency domain system (the Geonics EM31) and the time domain metal detector (Geonics EM61). The magnetic survey met with limited success mainly because the basalts underlying the test site showed large lateral variation in magnetization, complicating anomalies caused by buried objects. The signals of the GPR system were highly attenuated in the fill placed over the trench, preventing the recording of reflections from objects in the trench. Also, measurements were made with the Geonics EM47 transient system. The large amount of data required to be collected with that system limits its effectiveness for trench and metal detection. Further analysis of the TDEM data is planned.

Table 7-1
Summary of Instrument Capabilities at the INEL CTP

Geophysical method and instrument	Mapping pit boundaries	Mapping boundaries between cells within pit	Delineating individual objects	Characterizing objects - depth determination
Frequency Domain EM Geonics EM31	good, ± 2.5 ft with in-Phase	good	fair	poor
Time Domain EM Geonics EM61	good, ± 2.5 ft	good	good	fair
Magnetics	poor	poor	poor	poor
GPR	not effective	not effective	not effective	not effective

Geonics EM31 Frequency Domain EM Profiling

With the Geonics EM31, both the in-phase and quadrature phase components were measured. The in-phase component was more effective in delineating pit boundaries, berms between the cells within the pit, and major metallic buried objects. The in-phase component delineated pit boundaries with an accuracy of ± 2.5 ft. The conductivity component (quadrature phase) was less effective mainly because of large background variation. Data processing procedures, such as high-pass and decorrugation filters, enhance pit wall positions and objects. The large amount of metal buried in the retrieval cell just north of the characterization cell influenced the readings, obscuring detection of some objects in the characterization cell.

Geonics EM61

The Geonics EM61 provided the best definition of all sensors employed. It was particularly effective in detecting and characterizing individual objects placed within the characterization cell. Three features of the EM61 facilitate detection of pit boundaries and objects within the pit:

- 1) Background values due to ground conductivity can be muted by recording the ratio of emf's between two coils separated by about 40 cm.
- 2) The volume of the subsurface influencing a measurement is considerably less than with the EM31 and magnetometer thereby improving lateral resolution.
- 3) Some information on the depth to the larger objects can be obtained using the ratio between the two channels.
- 4) The simple nature of the EM61 anomalies, high spatial resolution of the instrument, and almost negligible amount of background value result in the successful use of high pass filtering techniques to further enhance the resolution of the EM61.

The variation in amplitude over a pit with objects of different sizes and buried at different depths can be three orders of magnitude. This may make effective visualization of data for all objects in one display difficult, and to bring out all features in the data may require several display formats.

Overall Summary

The results over the CTP are good illustrations of the influence of geologic settings in sensor behavior. The local geology caused the GPR to be ineffective, caused substantial geologic noise in the magnetic survey data, and caused variations in the conductivity data from the Geonics EM31. These factors prove the importance of employing multiple-sensors for buried waste detection.

Because of the large geologic noise and interferences from the retrieval cell (on magnetic and EM31 conductivity data), integrated interpretation using all sensor data needs more work. Attempts will be made to remove data trends caused by variations in magnetic data caused by basalt and nearby objects in the retrieval cell, and variations in the EM31 conductivity data caused by variations in thickness of overburden and interference from the retrieval cell.

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