Geophysical Investigation for Buried Drums: A Case Study

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Abstract

A vertical gradient magnetic survey was implemented over a 100 acre site to locate isolated buried drums. Clusters of buried drums at the site had been discovered and excavated during the course of previous investigations. The survey was designed and field tested for the ability to detect a single drum buried at a depth of up to 10 feet below the ground surface. Field tests demonstrated that vertical gradient magnetic data collected on five-foot centers would provide the best means for detecting isolated drums. High clay content soils severely limited both electrical and ground penetrating radar methods. Based on the field results and theoretical calculations, a minimum anomaly criterion were established for deciding which vertical gradient anomalies would be investigated. The vertical gradient magnetic contour maps were then inspected and anomalies exceeding these criterion were targeted for investigation. More than 1,000 anomalies were investigated by trenching with a backhoe. Most of the trenched anomalies resulted in the discovery of miscellaneous magnetic debris. Thirty-six of the trenched anomalies resulted in the discovery of drums or drum fragments at depths of up to nine feet. The results of this survey show that isolated drums were easily detectable at depths of 10 feet. Careful management of this investigation was essential due to the large number of anomalies and the complexity of coordinating heavy equipment operations and the magnetometer surveys.

Introduction

An investigation for buried drums was conducted over the majority of a 100 *acre* site (Figure 1) using vertical gradient magnetic data collected with proton precession magnetometers. The survey was designed and field-tested to detect isolated steel drums that might be buried as deep as ten feet below the ground surface. Field testing indicated that a depth of ten feet was close to the practical limit of the method's ability to detect a single drum, especially a drum that might be in a deteriorated condition from having been buried for a period of years. The field testing also indicated that clusters of four or more buried drums could be reliably detected at greater depths. Clusters of buried drums, some which were found to contain volatile organic compounds including methyl ethyl ketone (MEK), cyclohexanone, and iron particles (up to 400 ppm in solution) had been detected and excavated in previous investigations of the site.

The data were used to construct a series of vertical gradient contour maps contoured at three gammas per foot. Anomalies with a vertical gradient amplitude greater than three gammas per foot were generally targeted for field investigation. The following steps were then taken: 1) targeted anomalies were identified by TerraSense personnel on the vertical gradient

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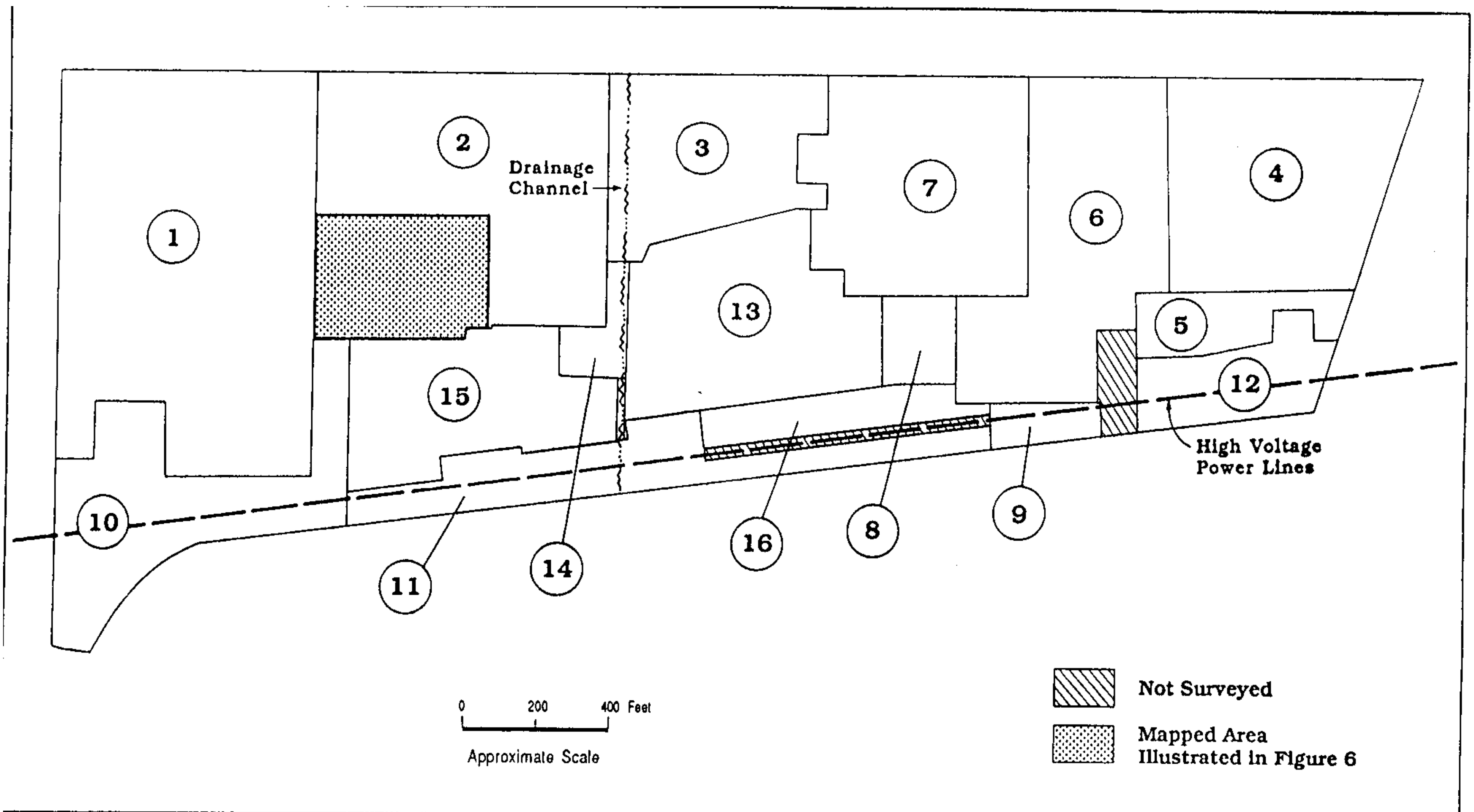


Figure 1 : SITE PLAN MAP. NUMBERED AREAS INDICATE EXTENT OF AREAS SURVEYED AS LOGICAL MAP UNITS RESULTING FROM A PHASED SURVEY PROGRAM,

contour map(s); 2) the field location of each anomaly was verified using an analog magnetometer and then staked; 3) each anomaly was then numbered and investigated by trenching with a backhoe. The results were recorded by Levine-Fricke personnel and tabulated at the end of the study. Management of the investigation was very important in verifying that all targeted anomalies had been investigated.

Site Geology

The site is located in a low lying bay land plain approximately six miles from the margin of San Francisco Bay. Elevations at the site ranged from 5 to 10 feet above sea-level. The near-surface soils and sediments down to a depth of approximately twenty feet are generally clays and silty clays interbedded with some sandy clay units. Soil descriptions from excavation pits dug to a depth of approximately 15 feet showed that the near-surface soil stratigraphy consisted of four general units that are illustrated and described in Figure 2.

The surface unit was characterized as a brown loamy fill or as a gravelly sandy clay with a medium to high plasticity. The thickness ranged from less than one foot to more than seven feet with an average of approximately four feet. This unit contained an abundance of miscellaneous magnetic debris including pieces of broken concrete with rebar, pieces of mangled wire shopping carts, and other assorted pieces of scrap metal. This unit was generally described as being a surcharge material that was placed at the site for the purposes of building up the land surface. The majority of magnetic anomalies that were investigated by trenching at the site were found to occur in this unit.

The next lower unit was characterized as a dense black clay with high plasticity. This unit probably represented the original land surface prior to the addition of surcharge. The black clay unit was present in most of areas of the site, excepting those areas were it had been cut away. The black unit ranged in thickness from 2.5 to 3.5 feet with an average of approximately 3 feet. The black clay unit has a sharp contact with an underlying brownish clay unit.

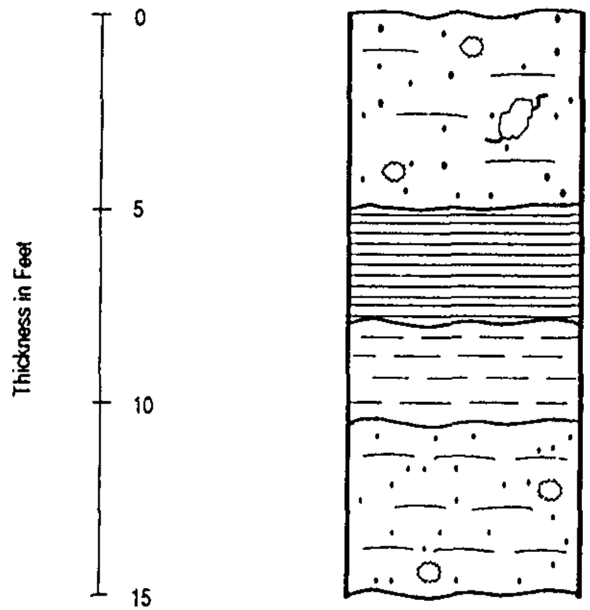
The third unit was described as a brownish clay that graded to a light brownish clay with depth. The brown clay was generally similar in physical characteristics to the overlying black clay. Both units had a high plasticity and were very slippery when wet. This unit ranged in thickness from 2 to 3 feet with an average thickness of approximately 2.5 feet. This unit was observed to have a gradational contact with an underlying sandy gray clay.

The fourth unit encountered in the deepest excavation pits was a sandy gray clay with orange mottling. This unit has a medium plasticity with a trace of gravel. The sand content ranged from an estimated 5 to 15 percent. Ground water was generally encountered in this unit at a depth of approximately 10 to 14 feet below the ground surface.

Field Testing and Evaluation of Geophysical Methods

Three geophysical methods were field-tested and evaluated for their ability to detect a single buried drum. All sources (drums and metal) were buried within the third soil lithology unit (brownish clay) and located in an area with approximately two feet of the top soil unit. The resolution and limitation of each method were tested to determine which method or combination of methods would be most appropriate. The methods tested included: 1) two vertical gradient magnetic surveys using proton precession

SOIL LITHOLOGY



DESCRIPTION

Brown sandy clay with medium to high plasticity with a trace of gravel. This unit contained an abundance of scattered magnetic debris including broken blocks of concrete with rebar, pieces of shopping cads, and miscellaneous pieces of metal. Thickness varied from less than 1 loot to more than 7 feet with an average of approximately 4 feel at most areas of the site. Sharp contact with...

Black clay with high plasticity. Thickness ranged from 2.5 to 3.5 feel with an average of approximately 3 feet. Generally present throughout the site. A good stratigraphic marker. Sharp contact with...

Brown clay with high plasticity. Thickness ranged from 2 to 3 feel with an average thickenss of approximately 2,5 feet. Grades to light brown at base of unit. Gradational contact with...

Sandy gray clay with medium plasticity. Sand content varied throughout the site, ranging from an estimated 5 to 15 percent. Contained a trace of gravel (less than 3 percent) that ranged in size from 1/8 to 1/2 inch in diameter. Ground water was generally encountered in this unit at approximately 10 to 14 feet below the land surface.

Figure 2 : GENERALIZED DESCRIPTIONS OF ENCOUNTERED SOIL UNITS

magnetometers on five-foot and ten-foot centers; 2) an electromagnetic survey using an EM-31 instrument on ten-foot centers; 3) and a Ground Penetrating Radar instrument.

The first vertical gradient magnetic survey, measured on five-foot centers, was conducted using two single drums buried at a depth of approximately ten feet in a 60 feet by 100 feet test area. The two drums were buried in separate trenches. One drum was oriented horizontally and the other drum was oriented vertically to evaluate the affect of varying drum orientations. The results of this survey are indicated in Figure 3. The horizontal drum was identified by an anomaly with an amplitude of 12 to 15 gammas per foot. The vertical drum was identified by an anomaly of 9 to 12 gammas per foot. The test drums were standard 55 gallon drums that measured 24 inches by 36 inches.

A second vertical gradient magnetic survey, measured on ten-foot centers, was conducted using the same two buried drums above with the addition of four horizontal drums buried side-by-side in a separate trench at a depth of ten feet, and a piece of scrap sheet metal (approximately 2 feet by 3 feet by 1/8 inch thick) buried horizontally in a separate trench at approximately ten feet. The results of the second test are shown in Figure 4. The single horizontal drum was identified by an anomaly of approximately 6 gammas per foot. The single vertical drum was identified by an anomaly of approximately 9 gammas per foot. The cluster of four drums was identified by a classic dipole anomaly with an amplitude of 24 gammas. The piece of sheet metal was identified by a poorly defined anomaly that ranged up to 12 gammas per foot.

Although the ten foot data still detected the two isolated drums, the wavelengths were longer with lower amplitudes as compared to the five foot survey. The ten foot data would be interpreted to be deeper than the actual depth. Furthermore, the accuracy of an anomaly location is less definitive.

An electromagnetic survey was conducted over the same test site using a Geonics EM-31DL instrument on ten-foot centers. The instrument was operated in the horizontal dipole mode and two readings per stations(90 degree rotation) measured the in-phase and quadrature components. Unfortunately, the digital recorder (Omnidata Polycorder) program contained a bug that did not record the in-phase component when the EM-31 was set to in-phase (i.e. metal detecting) mode. Only the quadrature (i.e. conductivity) component was correctly recorded and contoured. In this geologic environment, the quadrature component will result in slightly less depth penetration than the in-phase component. The test survey covered the same four buried sources as described for the second magnetic test. Inspection of Figure 5 reveals no obvious anomaly pattern for detecting a single drum or even four drums at a depth of ten feet. The electromagnetic method measures the relative conductivity of the ground and the occurrence of highly conductive, moist clay sediment was attributed to be a limiting factor for this geophysical method.

The last geophysical method to be tested was the use of Ground Penetrating Radar (GPR). After sampling the first profile in the area, inspection of the analog chart revealed a maximum depth penetration of about 18 inches. As with the EM-31, soil conditions (high clay content) severely limited the depth penetration of the instrument. This was clearly not an applicable method at this site.

Based on the these field tests, a vertical gradient magnetic survey using proton precession magnetometers was chosen as the method to locate isolated buried drums. Data were measured on five-foot centers to better ensure the probability of detecting a single buried drum, especially if a drum was in an advanced state of deterioration (i.e. low magnetic content).

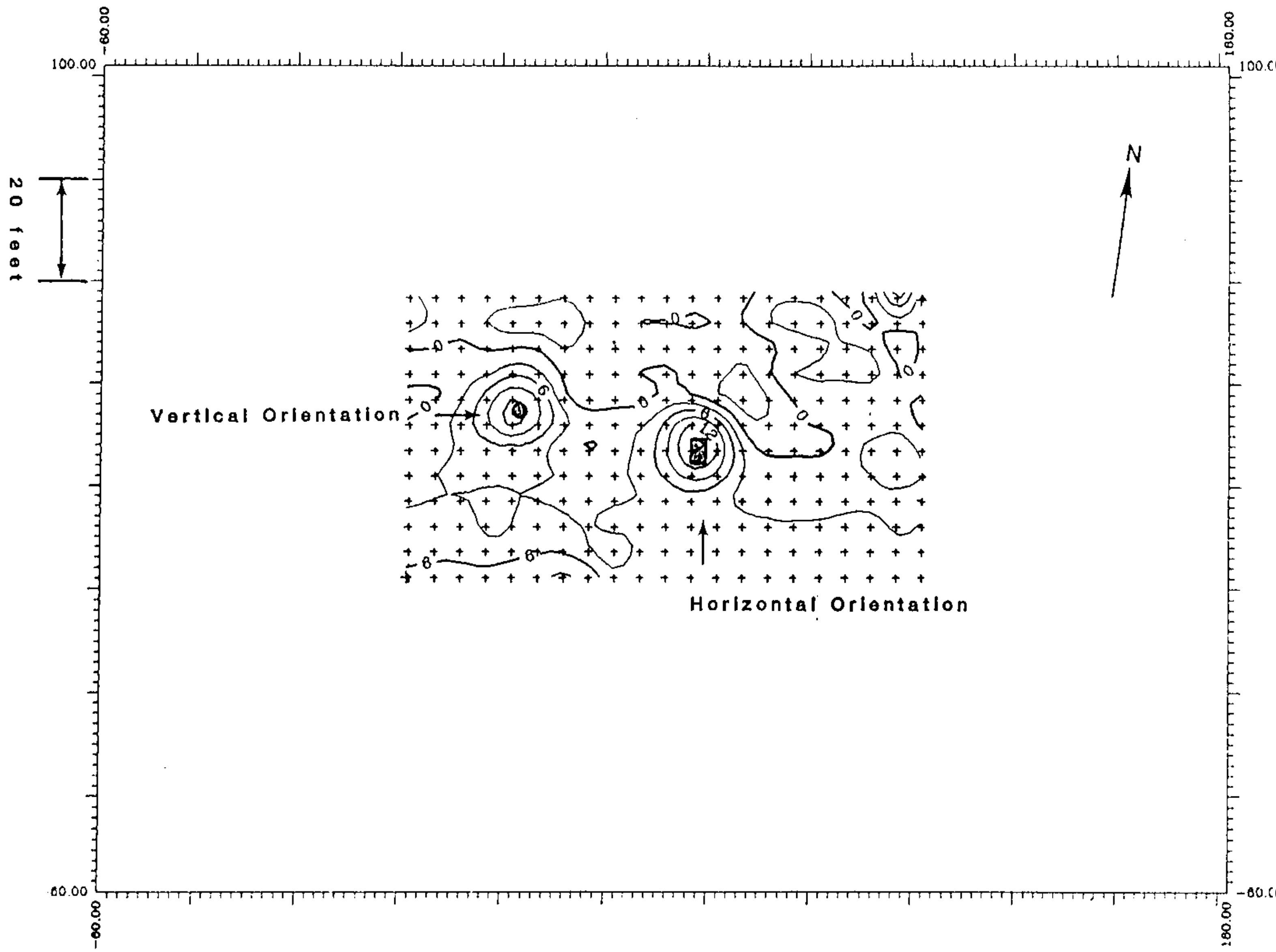


Figure 3 - Vertical Magnetic Gradient Contour Map of the First Field Test. Contour interval - 3 gammas/foot

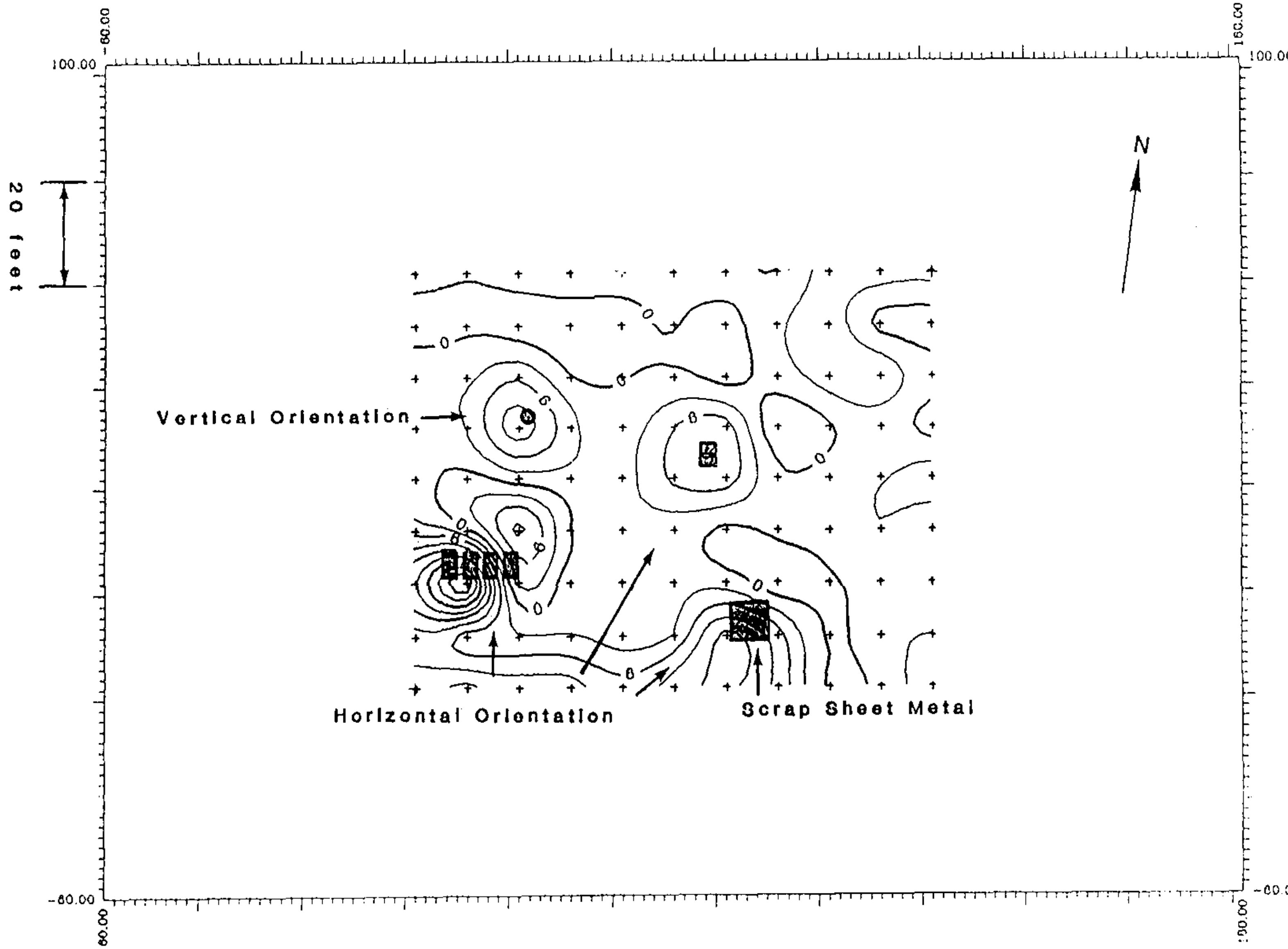


Figure 4 – Vertical Magnetic Gradient Contour Map of the Second Field Test contour Interval - 3 gammas/foot

"+" Denote Station Locations

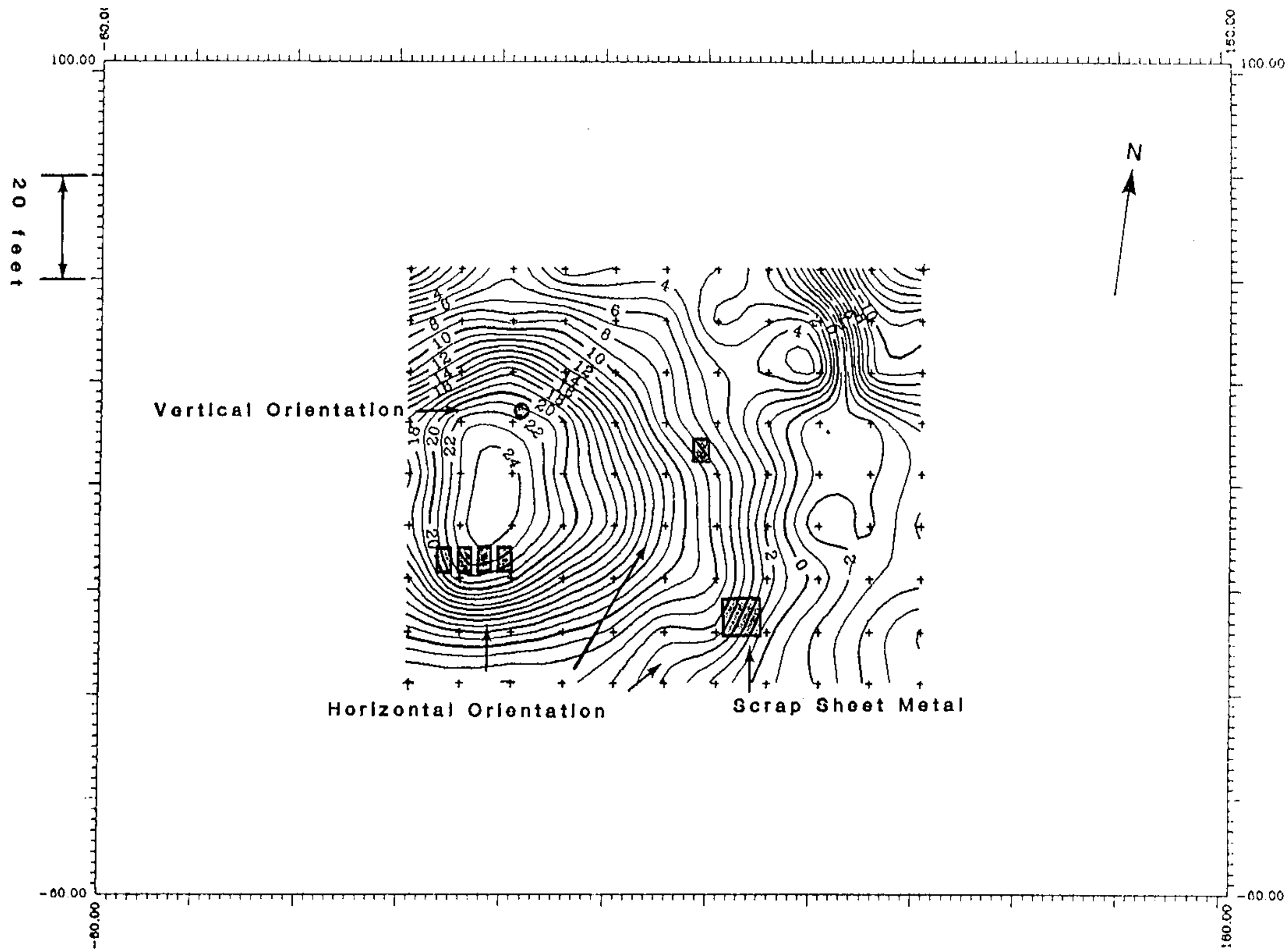


Figure 6 – Conductivity Contour Map of the Second Field Test

Contour interval - 1 mmhos/meter

"+" Denote Station Locations

The use of a vertical gradient survey, as opposed to a total field survey, was preferred for two reasons. The first is that the vertical gradient can resolve finer details in the earth's magnetic field, such as subtle distortions due to the magnetic material in small objects like drums. The second reason is that the vertical gradient is free of time-varying fields that occur as a result of the complex interactions between the earth's ionosphere and the solar wind. (S. Breiner, 1973). These time-varying fields can be so severe as to render a total field survey useless, especially surveys that are implemented in phases over an extended period of time.

Magnetic Field Limitations

No additional tests were performed to determine the maximum depth of detection of a single drum. However, theoretical calculations can be presented. The attenuation of anomaly amplitude with distance, or fall-off rate, is the fundamental criterion for calculation of magnetic field values at varying distances. In general, a drum can be treated as a point source and thus the fall-off rate is $1/(r^3)$ (r is distance) for total field values and $1/(r^4)$ for gradient field values (Telford and others, 1976). Results of the test surveys demonstrated, for these particular drums, that $1/(r^3)$ is a reasonable value for the fall-off of total field values. This was evaluated by computing the top sensor total field value from the bottom sensor total field value over each anomalous source and comparing with the measured top sensor value(see Table 1). With this in mind, the vertical gradient at ten and 20 feet below the ground level were calculated and are shown in Table 2. It should be understood that these calculations are only approximate, depending on the magnetic characteristics of each drum and the orientation.

Due to the magnetic materials in the top soil unit, the noise level of the test survey data ranged between one to two gammas per foot. Using this limitation, theoretical calculations show that a single drum could not be detected at 20 feet, and a group of four drums would barely be detectable. Using these results and the anomaly characteristics resulting from the field tests, it was decided to investigate anomalies using the following criteria: 1) three gammas per foot minimum amplitude; 2) wavelengths longer that five feet. This criterion would theoretically detect a single drum at 15 to 18 feet.

Survey Implementation

As illustrated in Figure 1, the site covers approximately 100 acres and has a slightly irregular rectangular shape. The site was divided into 16 logical map areas that were investigated in the order in which the areas became available. A logical map area is one that could be surveyed without interruptions due to heavy equipment operations and field conditions. The vertical gradient survey (sampled on five-foot centers) was implemented in 100-foot by 100-foot data collection blocks and tied together by four overlapping coordinate systems that covered the entire site.

Each area was prepared for the survey by using mass grading equipment to smooth the surface and by removing surface debris and stockpiles of soil. In some areas, the ground surface had been built up with several feet of surcharge soils. Where appropriate, the surcharge soils were stripped away so the survey would be closer to the original ground surface (i.e. closer to buried drums).

Vertical gradient data was collected in all areas where acceptable quality data could be obtained. Magnetic interference from high voltage overhead power lines on one side of the site resulted in the acquisition of unreliable

Table 1

Buried Magnetic Source	Measured Bottom Sensor	Measured Top Sensor	Computed $1/(r^3)$ Top Sensor
Horizontal Drum	70 gammas	30 gammas	38 gammas
Vertical Drum	80 gammas	40 gammas	44 gammas
Group of Four Drums	180 gammas	100 gammas	98 gammas

Table 2

Source Anomaly	Measured at eight feet	Computed $1/(r^4)$ at ten feet	Computed $1/(r^4)$ at twenty feet
Vertical Drum	12 gammas/ft	10 gammas/ft	1.2 gammas/ft
Group of Four Drums	24 gammas/ft	17 gammas/ft	2.3 gammas/ft

data in a corridor approximately 50 feet on either side of the power lines. Magnetic data sampled within 20 feet of cyclone fences and reinforcedconcrete walls were also unreliable.

The vertical gradient survey was implemented in three phases over a period of eight months in 1989. The first phase was conducted in April and May; the second phase was conducted in August; and the third phase was conducted in November. The first phase covered approximately 80% of the site including Map Areas 1 through 12. The second phase covered Map Area 13 and the third phase covered Map Areas 14, 15, and 16. The third phase also included a QA/QC (quality assurance/quality control) review. The purpose of the review was to evaluate if within each of the Map Areas where acceptable quality data had been obtained, all targeted anomalies had been trenched and/or evaluated for possible buried drums. A total of 132,845 station measurements were acquired. During all three phases, coordination of heavy equipment operations was essential in acquiring accurate measurements.

Magnetic data were collected with proton precession gradiometers with a sensitivity of 0.1 gammas per foot (EG&G Geometrics Model G856A). The data were stored in digital form, up-loaded to a PC, and then transmitted to a Sun 3/280 computer for processing. The vertical gradient data were interpolated using a minimum curvature interpolator and plotted as a contour map at a scale of 1 inch equals 30 feet. The contour interval was 3 gammas per foot.

Vertical gradient anomalies on the contour maps exceeding the anomaly criterion were identified and numbered. The identified anomalies were carefully located and staked in the field using an analog magnetometer (EG&G Geometrics Model G816). The staked anomalies were then investigated by trenching: 1) until an apparent magnetic source was found; 2) to the depth at which significant ground water was encountered; 3) or to a depth of ten feet below the ground surface. Trenching was generally halted upon encountering ground water in order to minimize the problems associated with properly backfilling excavation pits. Targeted anomalies with no apparent source were over-trenched by digging a large pit (with some pits measuring 20 feet by 30 feet or larger) and/or sometimes extending below ten feet.

The results of trenching *were* recorded in a field notebook and were tabulated. The recorded information included a brief description of what was found, the depth at which an apparent magnetic source was discovered and any other significant observations including: evidence of discolored soils, odors, or readings on a photoionization detector (PID) which indicated the presence of vapors from volatile organic compounds (VOCs).

Survey and Investigation Results for Map Unit No. 2

Survey results for a small portion of the site (see the shaded portion of Map Unit No. 2 in Figure 1) are illustrated in the vertical gradient contour map of Figure 6. The area covers approximately 212,000 square feet, or slightly less than 5 acres. Part of this area had been cleared of magnetic debris and buried drums following a fluxgate magnetometer survey conducted in 1988. As shown in Figure 6, the results of the 1989 survey show that the area contained 18 anomalies and 2 additional anomalies attributed to monitoring wells. The 18 anomalies were investigated by trenching with a backhoe. The trenching results are reported in Table 3. Three of the anomalies (11,14,16) contained drums or drum fragments while another three (3,9,17) showed no apparent sources. The lack of an apparent source may be explained by one of the following reasons: 1) magnetic sources may have been too small to be discovered with the backhoe method; 2) in trenches where VOCs in soils were encountered, trenching was halted, and the excavation and removal of the

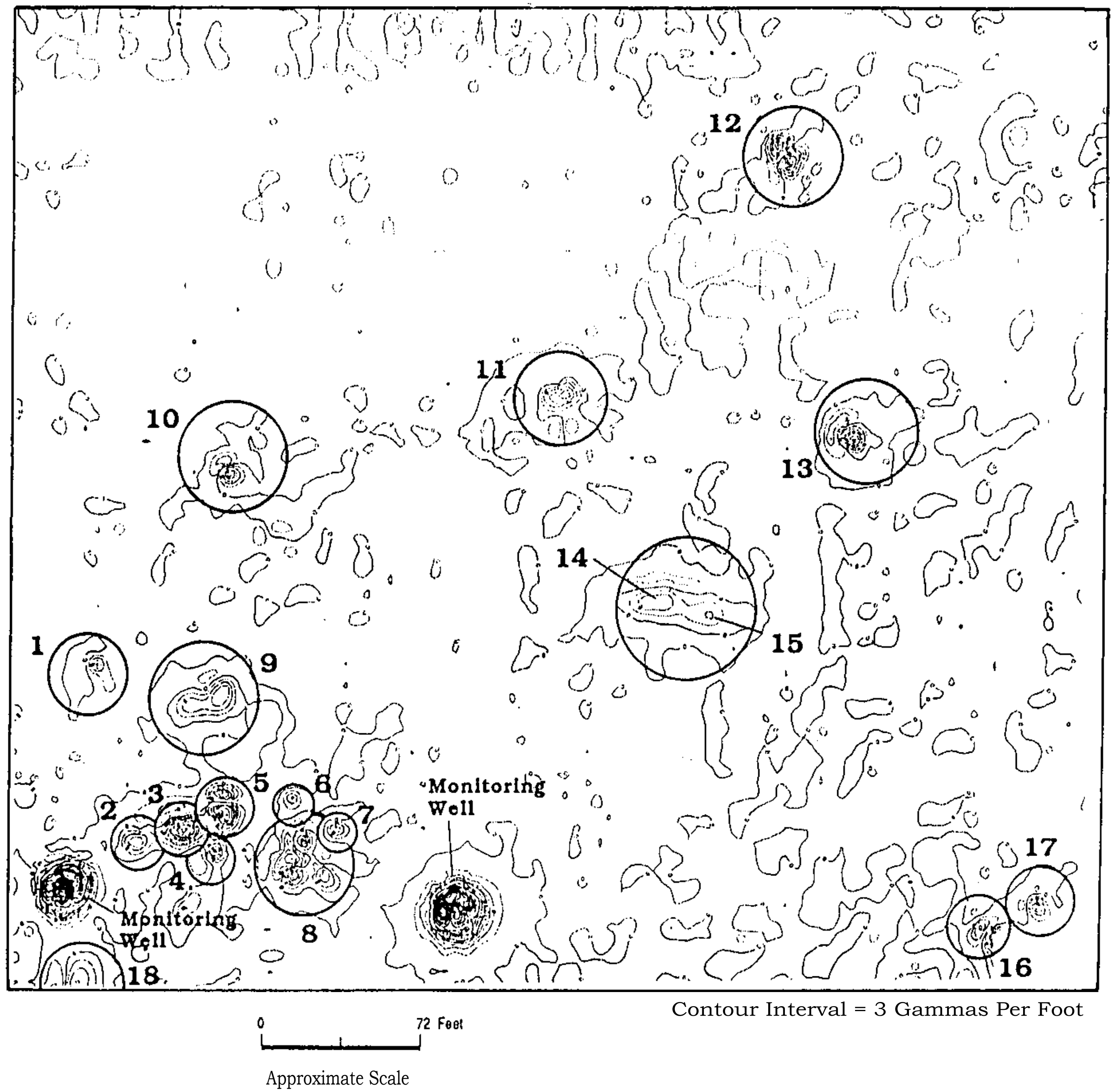


Figure 6 : VERTICAL GRADIENT ANOMALY MAP. INVESTIGATED ANOMALIES ARE CIRCLED AND NUMBERED. RESULTS OF THE INVESTIGATION BY TRENCHING OF EACH ANOMALY ARE REPORTED IN TABLE 3.

TABLE 3

RESULTS OF INVESTIGATION OF MAGNETOMETER ANOMALIES

AS ILLUSTRATED AND NUMBERED IN FIGURE 6

Anomaly Number	Area and Depth of Trench Lx W x D	Apparent Source of Anomaly	Depth of Apparent Source	Field Comments
1	Not Trenched	Shopping cart wheel	0'	Exposed at surface
2	8' x 14' x 8'	Shopping cart debris	2'	Pit has odor with 12 ppm on PID' re
3	8' x 14' x 6'	Recorded as no apparent so Stopped excavation to wait removal of affected soils	Not Recorded	Odors with 18 ppm PID reading Affected soils excavated and remove
4	8' x 12' x 8'	Shopping cart debris	2'	No odors
5	8' x 12' x 8'	One large bundle of crushe shopping cart debris	2'	Slight odor with 8-12 ppm PID readi discolored soil
6	8' x 10' x 8'	One large piece of twisted p about 3' long, 2" diameter	2'	No odors and/or readings on PID
7	8' x 12' x 10'	One big piece of shopping cart debris	2'	No odors and/or readings on PID
8	8' x 12' x 8'	One large piece of shopping cart debris and one large concrete block 3'x3'x2'	Surface	No odors and/or readings on PID
9	3' x 12' x 12'	Recorded as no apparent so Stopped excavation to wait removal of affected soils	Not Recorded	Strong odors, PID readings as high a Affected soils excavated and remove
10	6' x 3' x 3'	One large piece of rebar	Not Recorded	
11	8' x 10' x 10'	One crushed drum	6'	PID reading of soil is 120 ppm Affected soils excavated and remove
12	15' x 15' x 8'	Scrap sheet metal	4 - 5'	
13	12' x 8' x 10'	Coat hanger, shopping can	Not Recorded	
14	12' x 8' x 10'	Two drum fragments	Not Recorded	PID readings near 1000 ppm Affected soils excavated and remove
15	8' x 10' x 4'	No apparent source		No odors or readings on PID
16	8' x 10' x 6'	One crushed drum	2'	PID reading of 54 ppm
17	8' x 10' x 3'	Recorded as no apparent so Stopped excavation to wait removal of affected soils	Not Recorded	Excavation halted because of strong PID reading 640 ppm increasing to 9 15 minutes later Affected soils excavated and remove
18	10' x 10' x 8'	Concrete debris with rebar	4 - 6'	No reading on MD

*PID = Photoionization Detector

affected soils would have included the removal of the magnetic source; 3) iron particles (up to 400 ppm in solution) had been found in previously excavated drums and leakage may have contributed to the source of the magnetism. A review of the anomalies in Figure 6 and the results in Table 3 shows that a buried drum or drum fragments were easily detectable. However, the anomaly characteristics could not be used to predict if the source was a drum or some other metal object.

Results of Anomaly Investigations

A total of 1086 anomalies were considered to be of sufficient magnitude to investigate by exploratory trenching (Table 4). 36 of the trenched anomalies resulted in the discovery of drums or drum fragments at depths ranging from 1 foot to 9 feet. 990 trenched anomalies resulted in the discovery of miscellaneous magnetic debris including pieces of broken concrete with rebar, mangled pieces of wire shopping cart debris, pieces of cyclone fences and barbed wire, pieces of scrap sheet metal, and other magnetic materials. The smallest items included the wheel of a shopping cart and pieces of rebar that were six inches long. The largest items included manhole covers, car transmission casings, and large chunks (2-3 three feet in diameter) of concrete debris with rebar. These magnetic materials were recovered at depths ranging from less than 1 foot deep to 12 feet.

The remaining 60 anomalies resulted in the discovery of no apparent source, i.e., nothing apparently magnetic was found. As mentioned earlier, there are several explanations for why an apparent magnetic source may not have been found during trenching.

Results of Quality Assurance and Quality Control Review

A quality assurance and quality control (QA/QC) review was conducted on the investigation results. The review was done to determine if all potentially suspect anomalies had been excavated or otherwise evaluated for potential buried drums. Due to the large number of targeted anomalies, this review was essential for evaluating the accuracy and completeness of the investigation.

The QA/QC review identified 51 targeted anomalies that had not been trenched but were of sufficient amplitude and wavelength to warrant additional investigation. These anomalies were subsequently resurveyed by the magnetometer field crew. If each anomaly could still be located, it was re-investigated by exploratory trenching. None of these anomalies resulted in the discovery of drums or drum fragments.

The QA/QC review of the trenched anomalies included a review of anomalies with no apparent source. Those anomalies were further evaluated for potential buried drum(s) by considering the following: 1) results of the initial exploratory trenching; 2) vertical gradient anomaly amplitude and wavelength; 3) size and depth of the initial exploratory trench; 4) the occurrence of ground-water at the bottom of the trench; 5) the occurrence of discolored soils and/or odors or readings on a PID indicating the presence of VOCs; 6) and whether or not drums containing VOCs were found in any near-by area. As a result of this review, 5 anomalies were considered to be suspect and were targeted for reinvestigation. Four of these anomalies were relocated by the magnetometer field crew and reinvestigated by exploratory trenching. The remaining anomaly could not be relocated by the magnetometer and thus was considered to be a small, near-surface source that had been removed by previous trenching. None of these anomalies resulted in the discovery of drums or drum fragments.

TABLE 4

SUMMARY OF RESULTS OF INVESTIGATION AND TRENCHING OF MAGNETIC ANOMALIES

DESIGNATED EXPLORATION AREAS MAP NUMBER/DESCRIPTION	NUMBER OF ANOMALIES IDENTIFIED FOR INVESTIGATION	RESULTS OF TRENCHING		
		TRENCHES WITH DRUMS OR DRUM FRAGMENTS	TRENCHES WITH NON-DRUM SOURCES	TRENCHES WITH NO APPARENT SOURCE
Map Unit 1	187	0	157	9
Map Unit 2	42	5	29	8
Map Unit 3	68	1	58	8
Map Unit 4	136	2	122	12
Map Unit 5	29	0	25	4
Map Unit 6	179	1	157	3
Map Unit 7	172	2	163	6
Map Unit 8	9	0	7	2
Map Unit 9	7	0	7	0
Map Unit 10	49	0	46	3
Map Unit 11	23	3	16	1
Map Unit 12	32	1	7	1
Map Unit 13	91	8	82	1
Map Unit 14	38	2	36	0
Map Unit 15	58	9	43	0
Map Unit 16	21	2	17	2
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TOTALS	1,086	36	990	60

NOTES:

- "Non-drum sources" refers to apparent magnetic sources discovered by trenching that were not drums or drum fragments. This category included pieces of broken concrete with rebar, wire shopping cart debris, pieces of scrap metal, and other magnetic sources.
- "No apparent source" means that no readily apparent magnetic source was encountered during trenching.

Conclusion

The purpose of the site investigation was to locate all isolated drums buried to a maximum depth of ten feet. After field testing three geophysical methods, a vertical gradient magnetic survey was chosen. High clay content soils severely limited both electrical and ground penetrating radar methods. Based on the field results and theoretical calculations, a minimum anomaly criterion were established for deciding which anomalies would be investigated. 1086 anomalies were investigated: 990 were due to a large variety of magnetic materials; 36 were due to drums or drum fragments at depths of 1 to 9 feet; 60 had no apparent source. Some of these "no apparent source" anomalies may have been associated with soils containing iron particles in solution. The results of the magnetic survey show that the survey design and anomaly characteristics criterion were sufficient for locating isolated drums and drum fragments at depths up to ten feet. The success of this investigation was dependent on two important elements: 1) accuracy and completeness of the magnetometer survey; 2) careful management of the trenching program and scheduling of the heavy equipment operations with the magnetic survey of each Map Area. Due to the size of this investigation, failure to properly execute both elements would have resulted in not discovering some of the drum materials.

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