APPENDIX C

AIRBORNE GEOPHYSICAL SURVEY SUMMARY

Appendix C
Airborne Geophysical Survey Summary

C.1 Introduction

A low-altitude helicopter geophysical survey was performed over a 2,562 hectare (6,332 acre) portion of the historical Impact Area. The survey did not include the far eastern portion of the historical Impact Area due to the steep terrain. The survey objective was to assess the effectiveness of using airborne geophysical surveying to detect and map surface and buried "UXO". A secondary objective was to identify soil resistivity variations that "might be associated with contaminants." Overall, the work comprised a main survey in the Impact Area and a supplemental survey of another site known as the MRS-16 area (Figure C-1). Additionally, calibration surveying was performed at a special Fort Ord test site where inert UXO items and UXO simulants were intentionally buried at known locations as part of the 2001 Ordnance Detection and Discrimination Study (ODDS).

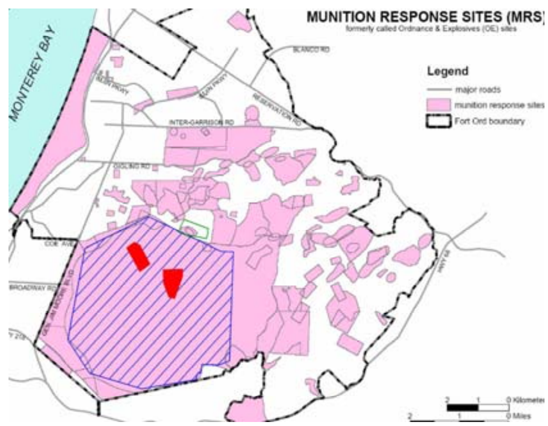


Figure C1 – Airborne Geophysical Survey Areas. Magnetometer survey indicated by blue hatched region; EM survey indicated by red blocks. MRS-16 area outlined in green,

The geophysical survey was performed jointly by Battelle and Oak Ridge National Laboratory (ORNL) between January 29 and February 17, 2005. The geophysical methods used were magnetics and time-domain electromagnetics (TEM). Magnetic surveying was performed over the entire 2,562-hectare (ha) main survey area, while TEM surveying was performed within the main survey area at two smaller areas totaling 72 ha (178 acres) in size (Figure C-1).

C.2 Survey Parameters and Procedures

The geophysical instruments were deployed using the Oak Ridge Airborne Geophysical System (ORAGS) mounted on a Bell 206 Long Ranger helicopter. ORAGS magnetic survey system housed four magnetometers at 1.7-meter spacings in a boom forward of the helicopter and two additional magnetometers in lateral booms on each side of the helicopter for a total of 8 magnetometers. The TEM system comprised a 12- by 3-meter transmitter coil and a pair of 2.7- by 2.7-meter receiver coils inside rigid carbon fiber and Kevlar booms mounted to the underside of the helicopter (Figure C-2). The magnetometer system was used to detect metal objects, while the TEM system was used to both detect metal objects and assess soil resisitivity.

Figure C-2 – ORAGS System

The 12-meter wide magnetometer array was flown at 25-meter line spacing, which provided approximately 50 percent coverage of the 2,562 hectares (6,332 acres) surveyed. The 10-meter wide TEM array was flown with an interleaved line spacing of 5 meters, which provided 100 percent coverage across the relatively small area (72 ha or 178 acre) surveyed using TEM. Aircraft ground speed was maintained at 10 to 15 meters/second (20-35 miles per hour [mph]). Magnetic data were processed to a 120-Hz recording rate, which equates to a down-line sample density of approximately 15 cm at typical survey speeds. TEM data were processed to a 30-Hz sample rate, which equates to a down-line sample density of approximately 60 cm.

Aircraft height was measured using a laser altimeter and ranged from 2 meters to over 6 meters above ground surface, with the median height in the main survey block being 3.5 meters. Additionally, aircraft height was monitored using four GPS antennas incorporated into ORAGS. The GPS and laser altimeter data were combined to produce a digital elevation map (DEM) which was used to assess elevation changes beneath the array swath and calculate the height at each of the eight magnetic sensor locations. For the main survey, aircraft height varied according to topography and vegetative cover. For the calibration surveying the test sites were surveyed at three nominal heights — 2m, 4m, and 5.5m — to better assess the detection capabilities of the magnetic system. The calibration surveying demonstrated the critical dependence of aircraft height on the ability of airborne magnetics to detect potential UXO items.

C.3 Data Processing and Analysis

The raw magnetic data were processed in several stages to produce a Total Magnetic Field Intensity (Total Field) data set. The processing stages included corrections for sensor time lags, removal of sensor dropouts, compensation for dynamic helicopter effects, removal of diurnal variation, correction for sensor heading error, array balancing, and removal of helicopter rotor noise. The Total Field data were interpolated onto a regular grid at 0.5 meter intervals using GEOSOFT Oasis Montaj geophysical data processing software. Next, vertical magnetic gradient and analytic signal data grid maps were prepared from the Total Field data grid.

TEM data processing included corrections for sensor time lags, removal of aircraft rotor and blade noise using a frequency filter, and "EM response leveling" to correct for instrument drift or (data) offsets between adjacent flight lines. EM response leveling entailed estimating and then subtracting the background response along each survey line. GEOSOFT was then used to prepare maps showing the EM response in millivolts.

The bulk of the interpretation was performed using the magnetic analytic signal map. The analytic signal map was used for interpretation because, for small-object targets like UXO items, the analytic single produces a single positive peak at a metal object location. The single peak provides a better indication of the object's true location and size than the magnetic anomalies exhibited by total field or vertical gradient data. As a further processing step, the analytic signal data were masked according to aircraft altitude to produce separate maps showing only the data collected from 2 meters and lower, from 4 meters and lower, and from 5.5 meters and lower. This step was performed to assess the extent of data coverage for each survey height.

C.4 Results

Magnetic Survey

The magnetic survey results are shown on Battelle Figures 7.1, 7.3, and 7.5, which present Total Field, Vertical Gradient, and Analytic Signal maps, respectively. Additionally, Battelle prepared an "Interpretation Map" (Battelle Figure 7.8) to organize and describe the features exhibited on the magnetic data maps. Finally, Battelle prepared an "Anomaly Density Map" (Battelle Figure 7.9) which "attempts to represent a count of debris pieces." The Anomaly Density Map was used to compare the number of airborne magnetic anomalies with the number of ground magnetic anomalies for the same area.

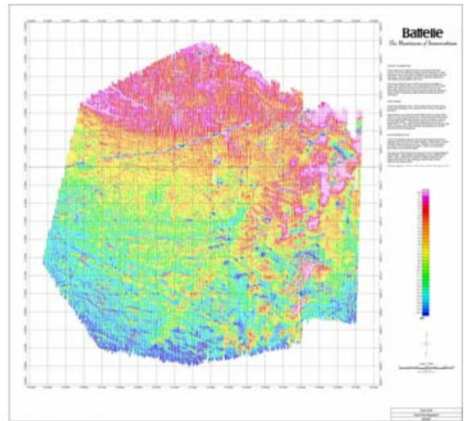


Figure 7.1: Thumbnail of total magnetic field map of the survey area at Fort Ord.

Battelle Report Figure 7.1: Total Magnetic Field; Total field data shows geologic features and locations of ferro-metal objects

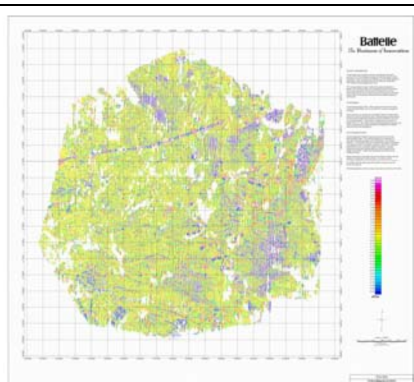


Figure 7.3: Thumbnail of vertical magnetic gradient map of the survey area at Fort Ord for altitudes <5m.

Battelle Report Figure 7.3, Vertical Magnetic Gradient. Gradient processing helps remove geologic trends to highlight locations of ferro-metal objects.

Additionally, MACTEC prepared Plate 13, which presents Battelle's Analytic Signal data on a basemap showing the historical range fans and the locations found ordnance items. Accordingly, Figure Plate 13 facilitates an assessment of the airborne magnetic survey results with respect to known ground features. For convenience, thumbnail versions of the Battelle figures are presented on these pages; however, the Battelle report and the accompanying full-sized figures should be consulted if a more detailed examination of the survey results is wanted.

As seen on the analytic signal map (Battelle Figure 7.5), the magnetic data exhibit various linear response features that can be readily attributed to roads, tracks, fences, and pipelines. Additionally, the magnetic data show other linear features that correspond to topographic ridges and troughs and therefore may be geologic in origin. In addition to linear trends, Battelle identified anomaly peaks and grouped them by amplitude into contiguous anomaly "blocks" where possible. The high-amplitude anomaly bocks are shown as grey polygons on the Interpretation Map (Battelle Figure 7.8). According to Battelle, the polygons "should not be taken as physical target boundaries. They are merely an attempt to outline the highest amplitude responses." Battelle further states: "in many cases, dozens or hundreds of individual items may be combining to create a single anomaly that effectively saturates the systems ability to resolve them."

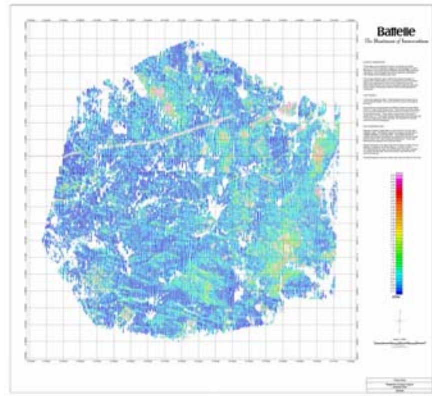


Figure 7.5: Thumbnail of analytic signal map of the survey area at Fort Ord for altitudes <5m.

Battelle Report Figure 7.5, Analytic Signal processed Total Magnetic Field data. Analytic signal processing provides a better indication of the location and extent of ferro-metal objects.

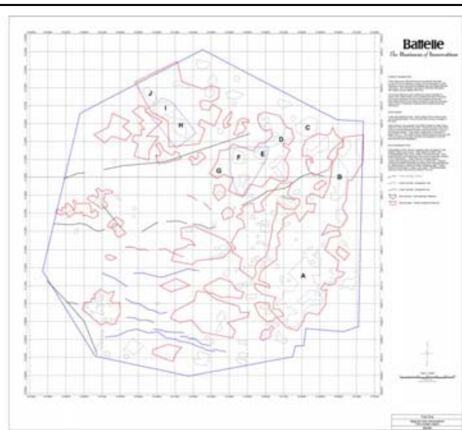


Figure 7.8: Thumbnail of interpretation map for the survey area at Fort Ord.

Battelle Report Figure 7.8: "Interpretation Map." Polygons outline clusters of magnetic anomalies indicative of ferro-metal objects

Battelle has also delineated medium-amplitude blocks that "may be associated with lesser densities of debris (however) the true source …cannot be ascertained without ground follow-up." Battelle labeled 10 high-amplitude anomaly blocks as A through J, further stating that Blocks H-J correspond to "known ranges under remediation." Battelle also states that most of the high-amplitude blocks are contained within a larger medium-amplitude block and suggests this may represent "scattered debris around a central cluster." Further, Battelle states high-amplitude blocks lacking surrounding a medium-amplitude "halo" may represent a single large object. To explain the absence of a medium-amplitude halo around some of the high-amplitude blocks, Battelle states "much of the ordnance expected at this site is below the detection threshold of an airborne magnetometer system." In other words, the metal debris may very well be present but it cannot be detected by the ORAGS.

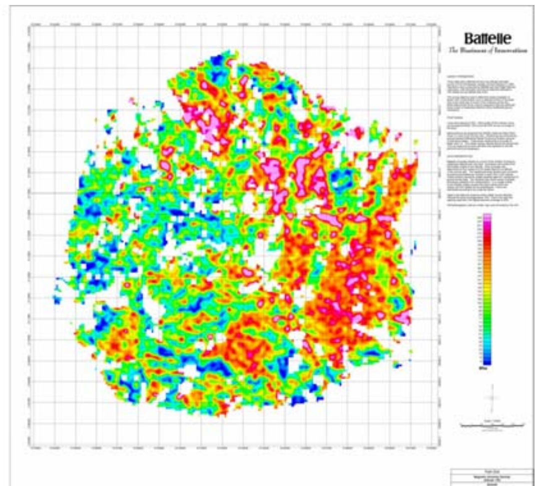


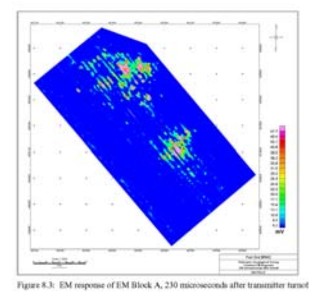
Figure 7.9: Thumbnail of anomaly density map of the survey area at Fort Ord.

Battelle Report Figure 7.9: Anomaly Density Map, which shows a count of the number of anomaly peaks per hectare. Counts range from zero (blue areas) to a high of over 300 (pink areas).

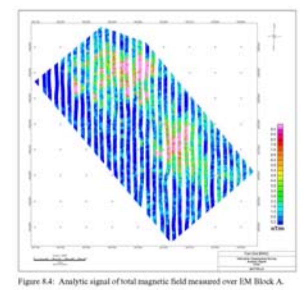
The "Airborne Anomaly Density Map" (Battelle Figure 7.9), displays the number of anomaly peaks in units of counts per hectare. Anomaly peaks were defined by Battelle as those analytic signal peaks exhibiting an amplitude at least 2.5 times background measurements. The density of airborne anomalies was compared to ground magnetic anomaly density figures for the same areas as provided by Parsons Engineering through the Corps of Engineers. The ratio of ground anomalies to air anomalies ranged from 2:1 to 9:1. Battelle notes that the Airborne Anomaly Density Map shows a strong correlation with the medium-amplitude polygon "blocks" on Figure 7.8. Battelle also notes that the dominant feature of the Airborne Anomaly Density Map is the very high anomaly density found in the vicinity of Range 43 and 48.

Electromagnetic Survey

ORAGS-TEM data were collected in two areas designated Block A (35 ha/86 acres) and Block B (37 ha/92 acres). Battelle figures 8.3 through 8.6 show maps of TEM and magnetic data obtained over the same areas. In general, the TEM anomaly locations correspond to magnetic anomaly locations, however the TEM anomalies are more localized, i.e., smaller in extent. Battelle states that the "analytic signal appears more sensitive to smaller items than does the EM system…Ordnance concentrations can be well-located using the Fort Ord EM data (however) it is the small individual ordnance items that are difficult for EM to define…" Battelle further states "the ORAGS-TEM system…shows even more height dependence that to the magnetic systems." Additionally, the ORAGS-TEM exhibits more noise that the ORAGS-MAG system. The noise is evidenced by the corrugated or striped appearance of the EM data maps. Battelle attributes the noise to small changes in helicopter roll, which, given the 10 meter separation between the EM sensors, can cause enough difference in sensor height to result in a "100 percent difference in EM response between the port and starboard sensors." Finally, the Fort Ord EM data exhibited a "variable period oscillation," the source of which has not yet been ascertained. In some cases the oscillation is substantial—over 10 millivolts—and could hide small anomalies produced by individual ordnance items.



Battelle Report Figure 8.3: EM response at Block A

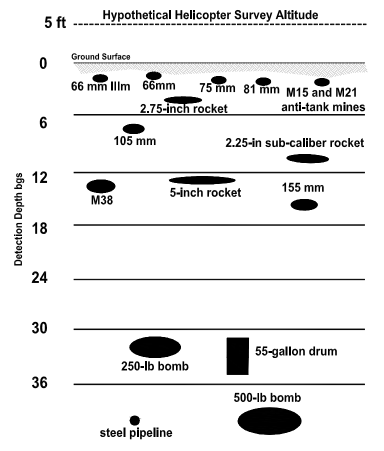


Battelle Report Figure 8.4: Magnetic Analytic Map, Block A.

A secondary objective of the ORAGS-TEM survey was to identify soil resistivity variations that "might be associated with contaminants." However, "neither of the EM survey blocks shows unambiguous responses from soil cover." "The mean millivolt response at 2 meters height is virtually indistinguishable from the high altitude response." Accordingly, Battelle concludes that it is not possible to use the ORAGS-TEM data for ground conductivity mapping.

C.5 Conclusions

The Battelle report states that the airborne survey data are "suitable for use…in a variety of characterization, screening-level, and removal actions associated with determination of the extent of potential UXO-related contamination…." Additionally, the survey "was successful in delineating areas of greater and lesser ordnance contamination…." However, the report also states that "airborne data are NOT suitable for declaring an area free of contamination as some ordnance types fall below the detection threshold of the system and only a percentage of other ordnance types will be detected." Battelle notes that flying the 12-meter wide magnetometer array at 25-meter line spacing meant that only half of the area of interest was surveyed; accordingly, the survey was not intended to detect all items within the survey area. Battelle also notes that airborne geophysical surveying at Fort Ord is complicated by rough topography and tall vegetation, which forced aircraft height above 5 meters in some areas. The increased survey height lowered the ORAGS system's sensitivity in those areas and further reduced the overall survey coverage. Battelle also reports that the lack of a uniform survey height complicates the data analysis and further reduces the effectiveness of airborne surveying at Fort Ord. Despite the above limitations, Battelle concludes that "clusters of ordnance…represent a legitimate target for this technology…" because such clusters allow for "interpolation between (survey) lines and across gaps caused by increased flight height."



Battelle Report Figure 4.3: Maximum detection depths for typical ordnance types at a nominal 1.5-meter survey altitude.

The calibration data obtained at the ODDS test site as part of the ORAGS survey indicate that targets larger than 90mm can be detected by magnetics with a high degree of certainty if they are surveyed at a low height of 2 meters; however, this low height was achieved only rarely during the Fort Ord survey (1 percent of the time). The median height of the main survey was 3.5 meters. Calibration test survey data from a height of 4 meters showed that only pipes, presumed clusters, and the largest of the single targets are clearly visible, yet data from this altitude and lower comprise only 61 percent of the total survey block.

Battelle's report includes a figure (Battelle Figure 4.3) that shows "reliable detection depths for common ordnance types" when surveyed by magnetics from a height of 1.5 meters (5 feet). The figure shows that many common ordnance types can be detected to a depth of 6 feet below ground surface when surveyed from a height of 5 feet. However, the figure also shows that many of these same items, including 81mm projectiles, 2.75-rockets, M15 and M21 anti-tank mines, cannot be detected when surveyed from the median height of the Fort Ord survey (3.5 meters or 11.5 feet). Figure C-4 presents a version of Battelle Figure 4.3 that has been revised to reflect the median Fort Ord survey height. Items shown above the ground surface on Figure C-4 cannot be reliably detected from the median survey height of the Fort Ord Airborne survey.

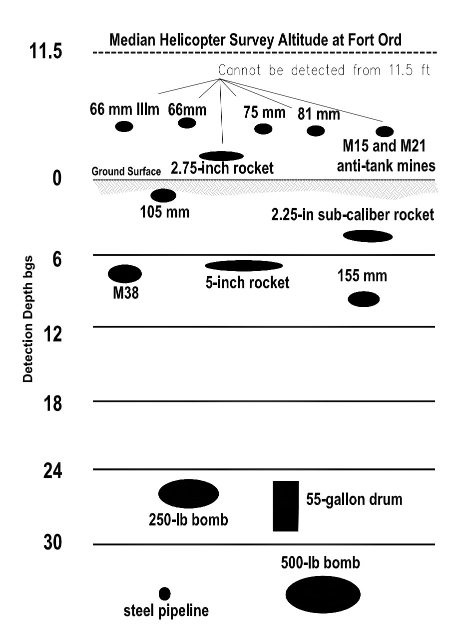


Figure C-4 Detection depths for common ordnance items from airborne magnetic survey performed at a height of 11.5 feet. Items shown above ground surface cannot be reliably detected from 11.5 feet.

Comparison of the Fort Ord ORAGS-TEM data with ORAGS-MAG data from the same area shows that the MAG system is more sensitive to metal objects than the TEM system and therefore is the preferred system for airborne geophysical surveying at Fort Ord. However, the Fort Ord airborne magnetics survey's lack of sensitivity to many common ordnance items calls into question the usefulness of airborne geophysical surveying for ordnance detection and mapping at the Fort Ord Impact Area. The airborne survey's lack of sensitivity is demonstrated by the fact that ground magnetic surveys detected from two to nine times as many magnetic anomalies as did the ORAGS-MAG system. Battelle's report states, "It must be recognized that if the ODDS test grid is indicative of the ordnance types and densities over the rest of the Fort Ord site, the airborne magnetometer system is not sufficiently sensitive to detect all discrete ordnance items that may be present." It is MACTEC's opinion that this would be the case even if a fully-interleaved, 100% coverage airborne magnetic survey were flown at Fort Ord.