ANALYSIS OF LOCALIZED HIGH MAGNETIC SUSCEPTIBILITY ZONES AT JEFFERSON PROVING GROUND, INDIANA

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ABSTRACT

Detection and discrimination of unexploded ordnance (UXO) and landmines with total field magnetic and electromagnetic induction (EMI) sensors can be severely inhibited by large variations in background magnetic susceptibility. Sites in Hawaii, USA, and similar settings have very high magnetic susceptibility over the entire site due to the basaltic soils. The basaltic soils exhibit magnetic viscosity, which is frequency dependence of the magnetic susceptibility. This makes detection of UXO or landmines difficult. There are current efforts to model the influence of magnetic susceptibility variations on geophysical data.

A different situation exists at sites such as Jefferson Proving Ground, IN, USA, where sections of the site exhibit variations in magnetic susceptibility that are of the same spatial wavelength and amplitude as the target UXO or landmines. The JPG soils do not exhibit magnetic viscosity. We have collected total magnetic field data over several grids as well as lines of magnetic susceptibility data with two instruments and at three frequencies over several of the anomalous regions. We have also collected soil samples at three depths at stations along these lines and measured their magnetic susceptibilities in the lab at two frequencies. We have found a correlation between the surface geology, topography, and magnetic susceptibility measurements. Also, the variations in magnetic susceptibility with depth are a function of the variable weathering and mineral transport due to surface water runoff through the areas of lower elevation.

We are currently developing a laboratory measurement system to measure magnetic susceptibility at discrete frequencies from 30 Hz to 100 kHz. This capability will allow us to model the various EMI measurement systems currently in use and filter the background magnetic susceptibility variations. We are developing the capability to model these magnetic susceptibility variations as a function of surface geology (including mineralogy and particle size distribution) and topography. Correlations between the topography, electrical conductivity, magnetic susceptibility, and total magnetic field explain the naturally occurring magnetic anomalies.

1. INTRODUCTION

Detection and discrimination of landmines and unexploded ordnance (UXO) are two important issues to the Army. Landmines are considered the more important of the two due to their direct impact on ongoing Army missions. UXO are also an important issue due to the millions of acres that are contaminated and the potential costs for remediation of these sites. For landmines, the important issue is how to detect the target quickly and reliably in real time for immediate clearance to expedite troop movement. For UXO, the issue is how to detect the target and discriminate what the target is that leads to a reduction in the number of holes dug on a site.

Common detection techniques for both types of targets are total field magnetometry (TFM) and electromagnetic induction (EMI). These sensors exploit contrasts in magnetic susceptibility and electrical conductivity between the target, landmine or UXO, and the surrounding soil to detect the target. Butler (2003) gives an overview of the sensors and problem. This research seeks to analyze soils from many locations that exhibit anomalous magnetic susceptibility, such as very high values, frequency dependence or large variations over small spatial distances. Sites in Hawaii, USA, and similar settings have very high magnetic susceptibility over the entire site due to the basaltic soils. The basaltic

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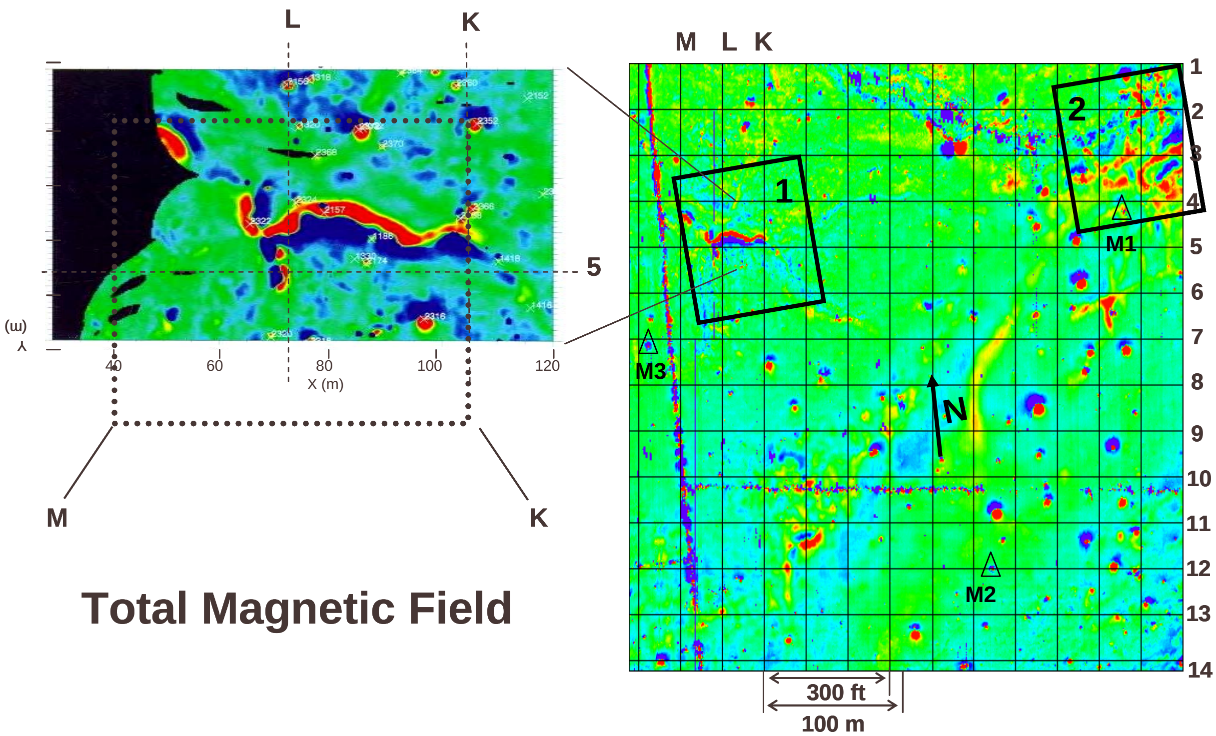

Fig. 1: Map of total magnetic field of a grid at Jefferson Proving Ground (JPG). Note the large magnetic anomaly in Box 1 in the northwest quadrant.

soils exhibit magnetic viscosity, which is frequency dependence of the magnetic susceptibility.

2. CURRENT WORK

Jefferson Proving Ground (JPG), Indiana, USA has been the site of several UXO technology demonstrations. The data presented here was collected during Phase IV of the science and technology component during the period August 1997 to December 1998 (Butler et al 1999). The analysis of the surface geophysical data was presented in Butler et al. (1999). The subsurface soil samples were unable to be analyzed at the time of the publication of the technical report due to constraints on time and funding. This current work has analyzed the subsurface samples due to the interesting results of the surface analysis. Figure 1 shows TFM data collected by the Naval Research Laboratory with the magnetometer multi-sensor towed array detection system (MTADS).

In the northwest corner of the map in Box 1, a large magnetic anomaly can be seen. The amplitude of the anomaly is on the same order of magnitude as the ordnance targets and the spatial extent of the target in the north-south direction is comparable to some of the other targets in the same grid.

The topography of the site can be seen in Figure 2, which shows two drainage features between Lines J and K that meet in the vicinity of Line K. Line K intersects the magnetic anomaly in the coincident location of the drainage feature. This drainage feature is not a current stream bed, but may have significant volumes of water flowing through it during rainstorms. The topography is rather coarsely sampled relative to the other measurements used in this work.

The magnetic susceptibility of Box 1 can be seen in Figure 3 and shows considerable spatial variability. "Soil magnetic susceptibility typically can vary by factors of two to three over distances of 10's of meters (Butler, 2003)." This was not anticipated at this site. Figure 4 is a plot of the magnetic susceptibility and elevation along Line K. There is a large correlation between the minimum elevation and the large variations in the magnetic susceptibility. The displayed magnetic susceptibilities are derived from two instruments: the Bartington MS2 magnetic susceptibility meter and the Geonics EM38 electrical conductivity and magnetic susceptibility meter. The MS2 system has multiple sensors that are designed for either indoor or outdoor use. The MS2D coil which approximates a volume averaged measurement for the upper 10-15 cm of the soil was used for the surface sampling (Dearing, 1994). The MS2B coil was used for the laboratory analysis of the soil samples that were taken at depths from 10 cm to 1 m.

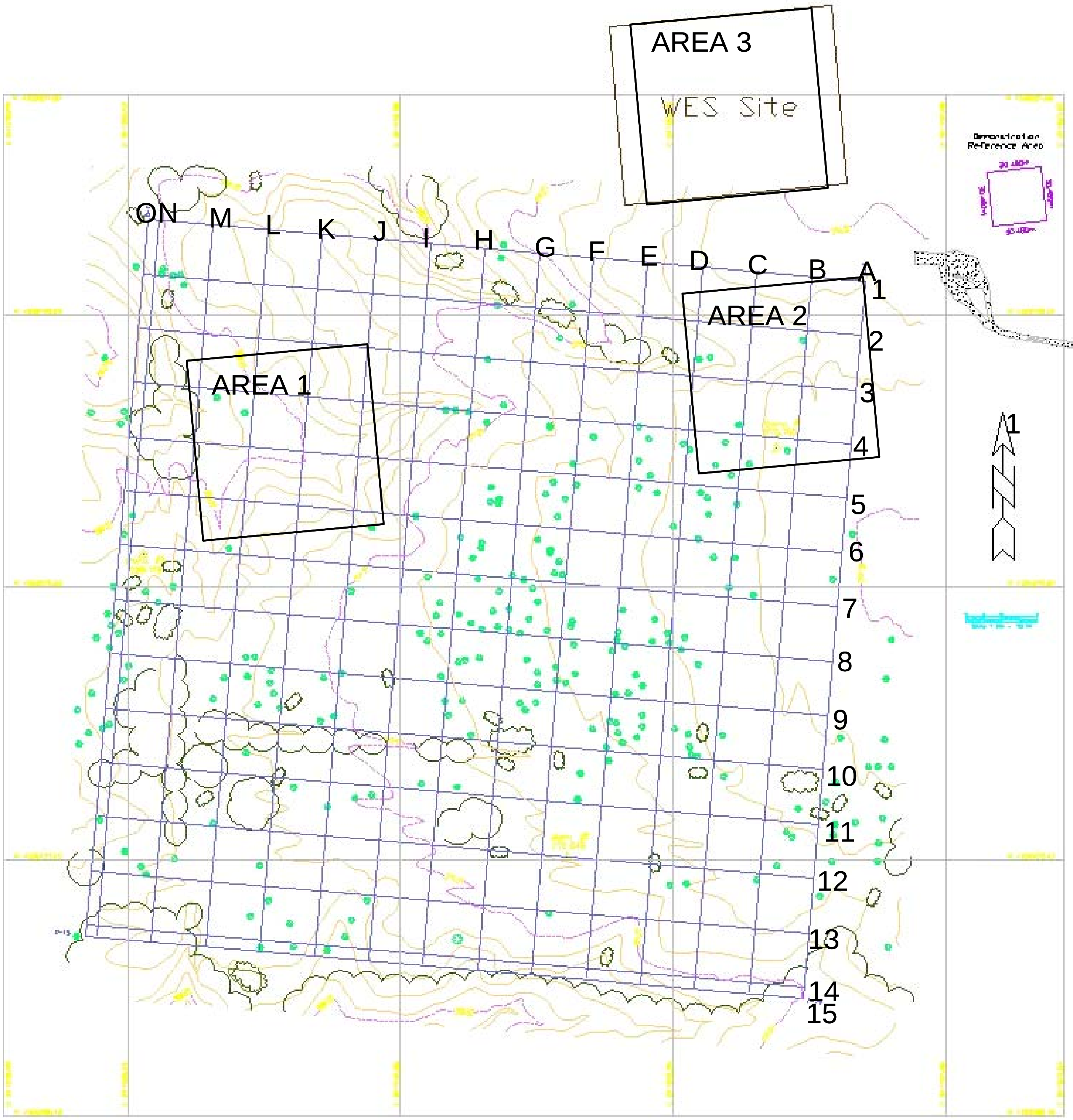

Fig. 2: Topography of grid at JPG. Note the two drainage features that merge near Line K. These drainage features correlate with the magnetic anomaly seen in Figure 1.

The MS2B sensor measures the magnetic susceptibility of a 10 cc sample at two frequencies that are a decade apart. The ability to measure two frequencies allows a determination of the magnetic viscosity of the sample. The EM38 operates at 14.6kHz and approximates a depth-weighted, volume averaged value for the upper 0.5 m of the soil (McNeill, 1986).

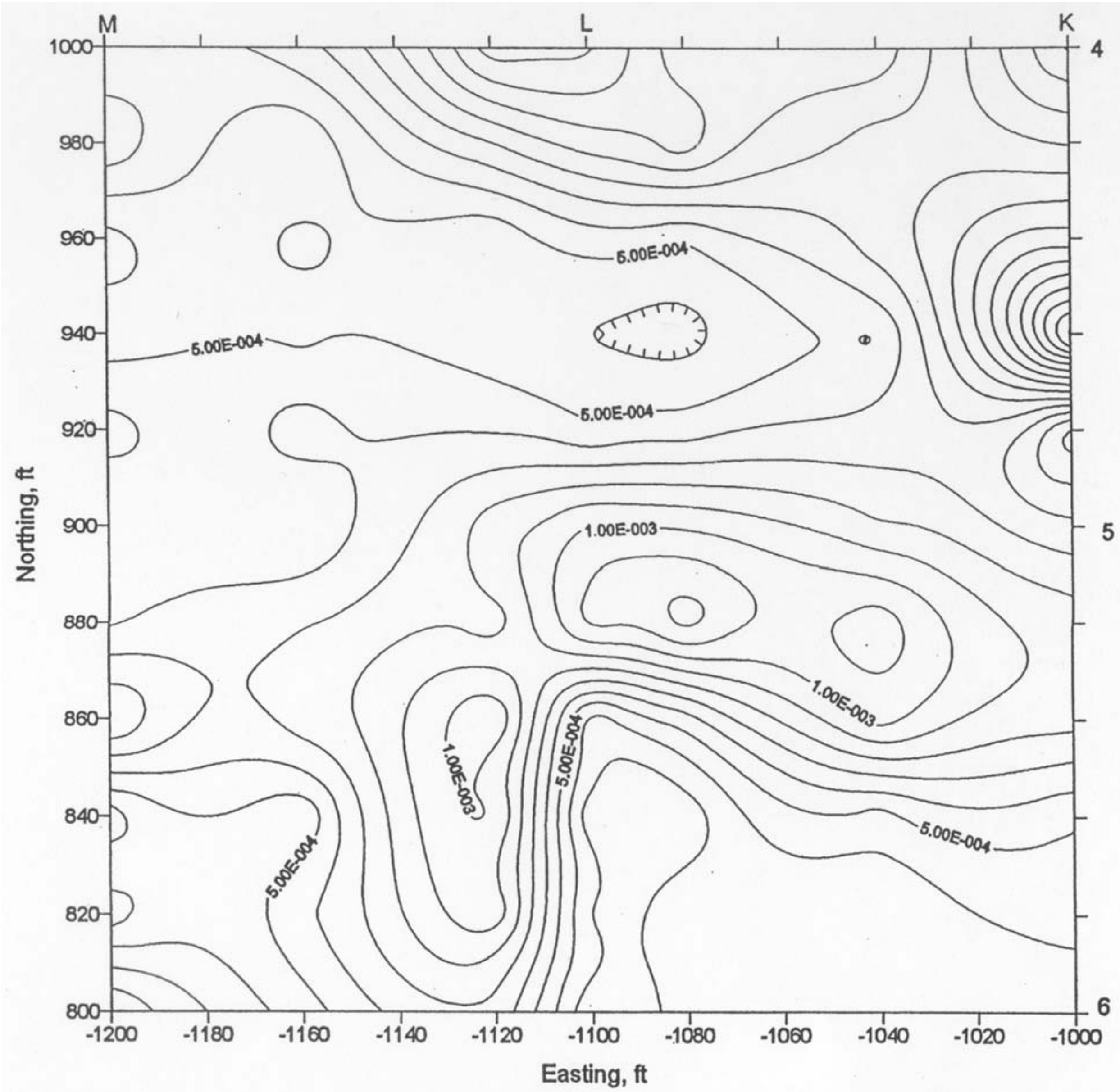

Fig. 3: Magnetic susceptibility map of grid at JPG. Note the rapid changes on the right side of the plot in the top half; this is the area of the magnetic anomaly.

3. FUTURE WORK

The future work for this research project involves developing an understanding of the geologic origins of variations in magnetic susceptibility and developing techniques to predict magnetic susceptibility distributions as a function of geology. The ability to improve detection and discrimination of UXO and landmines in magnetically complex soils is another area that will receive additional attention.

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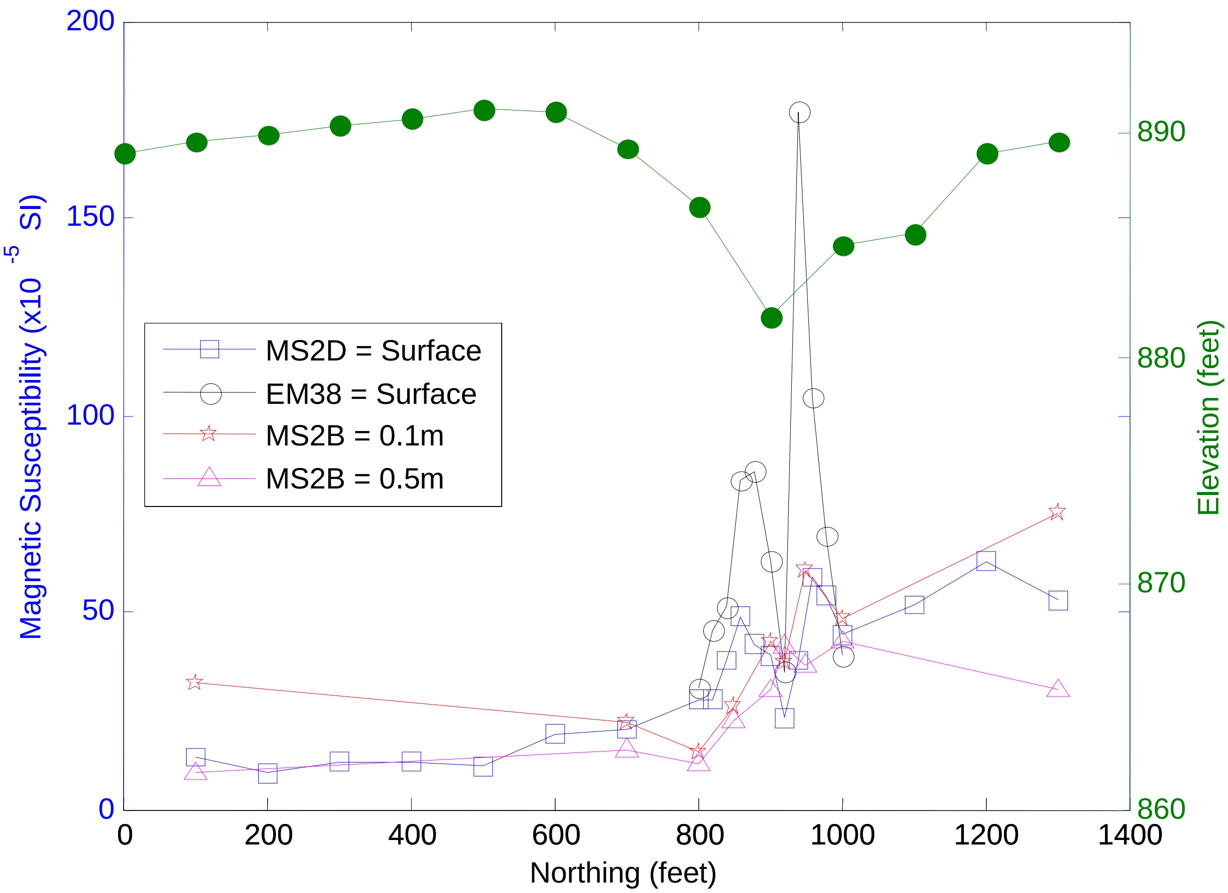

Fig. 4: Plot of Line K from grid at JPG. A northing of 0 corresponds with station 14, while a northing of 1400 corresponds with station 0. The rapid spatial changes in susceptiblity are located near the minimum in the elevation profile.

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CONCLUSION

The magnetic anomaly in the northwest quadrant of the grid does appear to be of shallow geologic origin. It can be attributed to one of two possible scenarios, the two drainage features that join near Line K may be depositing magnetite that leaches down in the soil, or the station sampling was too coarse and the sample that has been analyzed is not representative of the surrounding soils. It is very interesting that the susceptibility value at 0.5 m depth at Northing 900 is greater than that at 0.1 m depth. A more thorough analysis can only be completed with more detailed elevation data and denser spatial sampling of the soil samples at depths from the surface to one meter.