MAGNETIC AND ELECTRICAL RESISTIVITY SURVEYS OF ARCHAEOLOGICAL SITES IN GREECE

Kathleen E. Donnelly
Trinity University

Introduction

Archaeologists are increasingly turning to geophysical methods to improve their understanding of archaeological sites. Ideally, geophysical methods allow the archaeologist to view the subsurface without destroying the site. Geophysical measurements can also aid in efficient excavations, revealing if and where excavations will be advantageous. The two geophysical methods used in this survey are magnetics and electrical resistivity. They are two of the most frequently used geophysical methods in archaeology (Weymouth, 1986).

Magnetic surveys are perhaps the most efficient geophysical method (Aitken, 1961). The proton precession magnetometer has enabled a relatively large area to be measured in a short amount of time. One problem with magnetic measurements is that a variety of sources, such as geologic or recent human activity, can cause the same anomaly as an archaeological feature. To solve this problem, magnetic measurements are often combined with electrical resistivity measurements (Weymouth, 1986; Young and Droege, 1986; Pattantyus, 1986). Resistivity surveys are more time-intensive than magnetic surveys, and therefore, are less efficient. Another problem with resistivity measurements is that they are strongly affected by the water content in the ground. Thus, an arid climate like Greece is ideal for resistivity surveys. Besides these specific problems, the overall success of both magnetic and resistivity surveys depends on the contrast of physical properties of the archaeological feature and its surrounding material (Young and Droege, 1986).

Three archaeological sites are included in this study: Aghios Nikolas, Emilianos; Paleogla, Dasaki; and Aghia Paraskevi, Asprokambos. The data presented below are selections chosen from the total data collected.

Methods

Two EG&G Geometrics proton precession magnetometers were used to take magnetic measurements. One magnetometer was used in gradiometer mode with the top sensor at a height of 3m and the bottom sensor at a height of 1m. It was discovered after the data were collected that the top sensor was too high to resolve archaeological features. Therefore, only the total field data from the bottom sensor were used. The other magnetometer was reserved to take base station readings at regular time intervals. These base station readings were used to correct for diurnal variation of the earth's magnetic field.

The magnetic data were dumped into a computer after each field day. The program, Magpac, was used to apply diurnal corrections to each measurement and for preliminary analyses. Surface III software was used to grid data at 1m intervals using either slope projections or scaled inverse distance squared projections and to produce final contour maps.

A Bison Instruments earth resistivity system, model 2350, was used to measure apparent resistivities. Collection of resistivity measurements is more time-intensive than collection of magnetic measurements; thus, resistivity measurements were not taken along every magnetic line. Four probes were used in a Wenner array with an A-spacing of 1m. In addition to profiles, two soundings were also measured: one at Emilianos and one at Paleogla.

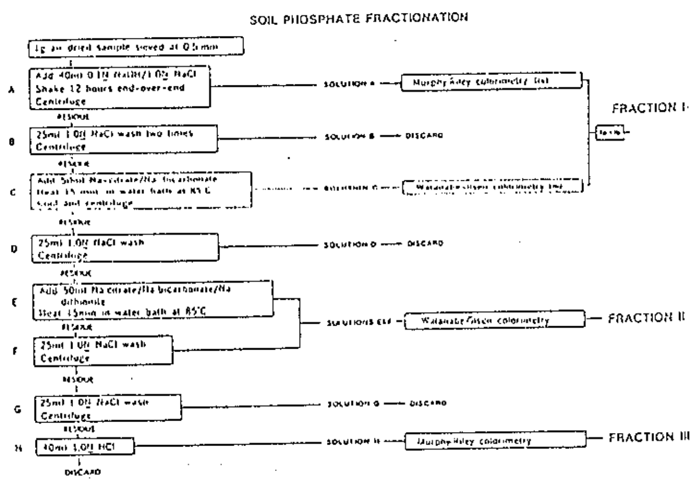
Results by Site

Aghios Nikolas, Emilianos

The first magnetic measurements were taken on a 40m x 50m grid. The lines were oriented north-south with 5m spacing between points and lines. To define an observed linear anomaly in greater detail a smaller grid (10m x 20m) with a spacing of 2m between data points was measured over a portion of the anomaly. The data from the coarse and finer surveys were combined and gridded in Surface III, using slope projection. A contour map of the data shows the linear anomaly of 25 gammas (Figure 1).

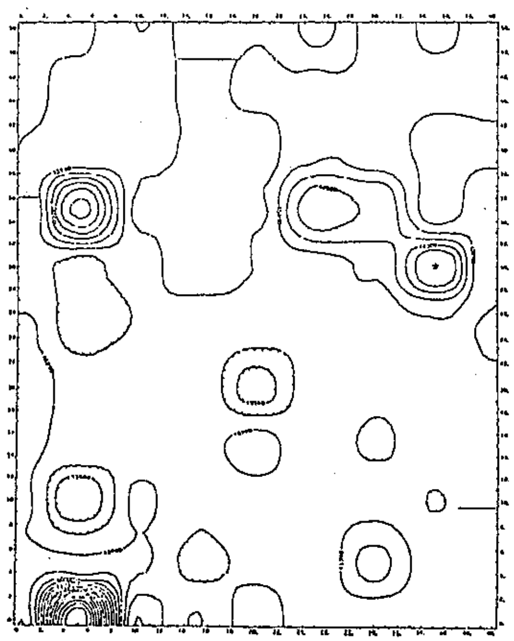
Apparent resistivity readings were also measured over the linear magnetic anomaly. The data points were taken at a 5m spacing. A contour map of the data shows a strong anomaly with a dramatic increase in apparent resistivity (Figure 2). The center of this anomaly is approximately 5m north of the magnetic anomaly's center. Daly (1994) used an auger to dig a hole at x=35m, y=30m. Small fragments of pottery and pieces of charcoal were found in the upper 10cm, and at depths of 50-80cm a red layer was present, possibly the remains of decomposed pottery or roof tile (Daly, 1994).

Both the magnetic and electrical resistivity surveys reveal an anomaly with centers along the north-south profile, x=35m. The magnetic anomaly center is shown to be at y=30m, while the resistivity anomaly center is 5m to the north of this (Figures 1 and 2). The positive peak would be expected to be displaced to the south of



Asprokambos	Ring value	Agios Nikolaos	Ring value	Potamia	Ring value	Paleogla	Ring value
In situ	3	Auger 1	4	MS 6	3	OB28	n/a
vert. profile	4	(see fig. 5)	4		4	(also known	n/a
(horizons	5		4		4	as PG1...)	n/a
1-8)	4		5		4		4
	5	Below site	3		1		4
	5		4		0		5
	5		2	MS5	4		4
	3		2		4		3
Auger 1	4	On site	3		4		4
(at 3rd	4	(NE corner of	4		3		4
transect pt.)	3	site)	3		3		4
	4		4		4		5
Auger 2	3		4	Off-site till	2		
	4		3		2		
	3		5		2		
	3	(Auger 1)	4		1		
	4		4		1		
Transect	2				2		
(N-S, 45m,	3				1		
5m intervals)	4				1		
	3				1		
	3						
	3						
	2						
	2						
	1						
	1						

Figures 3-6 (clockwise from upper left). 3. Flow chart of soil fractionation procedure outlined and developed by Eidt (1977). 4. Chart of qualitative values collected at each of the four sites through Eidt's rapid field test. Zero indicates a low phosphate concentration, while five indicates a very high phosphate concentration. 5. Magnetic survey map of Emilianos (agios Nikolaos); the star indicates the site of Auger 1.
6. Chart of preliminary quantitative values collected for two horizons at Potamia (MS5 and osc) and one at paleogla (PG1). Zeroes indicate that testing has not been completed.



Horizon		con. frac 1a	#1a+#1b	conc. #2	conc. #3	Total
MS5	1	6.4833E-08	9.6574E-08	0	2.7702E-08	0
	2	1.5431E-07	1.7399E-07	3.8975E-09	0	1.7789E-07
	3	9.0611E-08	9.8425E-08	0	1.9686E-08	0
	4	1.5431E-07	0	0	5.6427E-08	0
	5	1.4488E-07	0	0	-3.5571E-06	0
osc	2.	1.4488E-07	0	0	6.0619E-08	0
	2.2	1.6385E-07	0	0	9.9397E-08	0
	2.3	1.0828E-07	1.0828E-07	0	6.4833E-08	0
	2.4	2.447E-07	0	0	8.1923E-08	0
	2.5	6.0619E-08	6.0619E-08	0	9.9397E-08	1.6002E-07
	2.6	8.1923E-08	0	0	9.0611E-08	0
	2.7	2.7733E-07	2.7733E-07	0	6.9071E-08	0
	2.9	2.0322E-07	0	0	6.4833E-08	0
pg	1.6	1.3333E-06	1.3451E-06	0	4.8111E-08	0
	1.7	6.3835E-07	0	0	5.6427E-08	0
	1.9	7.1246E-07	0	0	7.8146E-09	0

the sources' true location (Breiner, 1973). Another factor that might be contributing to the offset of anomalies is the wide spacing (5m) between resistivity measurements. Magnetic measurements were taken every 2 meters. The actual resistivity peak may not have been measured and may actually be to the south of the peak on the contour map. Thus, the magnetic and resistivity anomalies appear to have the same source.

The source is believed to be archaeological because it is relatively shallow and its anomaly is linear. A wall or foundation floor are good candidates because of their linear nature. Both would likely give a high resistivity reading, relative to their surrounding material. Since the anomaly is produced by induced magnetism, its amplitude is dependent on the material in the wall or floor. Piles of rounded sandstone blocks are found on the surface and are hypothesized to be the material in this buried wall. A sandstone sample was collected along with soil samples and their magnetic susceptibilities determined by Rob Sternberg and Aaron Sheaffer at Franklin and Marshall College. The sandstone had a relatively high susceptibility, 1.5×10^{-4} emu, while soil samples were lower by an order of magnitude, 1.75×10^{-5}- 6.42×10^{-5} emu. A wall made of this sandstone would contrast strongly with the soils at this site.

The modeling program, Magnetics, was used to model a source with the wall in mind. One of the limitations of this program is that it can only model 2D features, while the actual source is not infinitely long. A body with a rectangular cross section and located at x=31.6m models the observed data well (Figure 5). The dimensions of the model cross section are 3.3m x 1.8m. The depth of the model's center is approximately 1.7m, and its susceptibility is 3.0×10^{-4} emu. The obvious difference between the model and the observed profile is the dramatic negative trough that is calculated for the model but which is not present in the observed data. According to Breiner (1973), only a slight negative trough should be present in a field with Grevena's inclination, 56.5°. A spherical body (radius=1.2m, depth=1.5m, susceptibility=3×10^{-4}) was also used to model the observed data (Figure 5). Unlike the 2D model, this profile shows a small negative trough. The observed data are bracketed by the 2D model and the 3D sphere. This indicates the source is slightly elongate.

The susceptibility used in the models is twice as large as that of the measured sandstone. This difference may be accounted for by several factors. The sandstone measured may have a variable susceptibility (Sharma, 1986). Magnetic susceptibility is largely a function of magnetite content; a trace element that would be expected to be variable in concentration throughout a sandstone. An alternative explanation is that other materials such as roof tiles and/or a building floor may also be present, adding to the overall magnetic anomaly. Although there is no evidence that a fire destroyed the site, a fire would produce a remnant magnetism in the direction of the earth's current field. The source of the anomaly may be a wall that is not composed of the measured sandstone. Finally, the source may not be archaeological, but the linear shaped anomaly and shallow depth are characteristic of an archaeological source.

Paleogla, Dasaki

Measurements at this site were not taken over a grid because of the topography and dense foilage; profiles were measured instead. Magnetic and resistivity profiles were measured over a known wall (1-1.5m wide). The depth is uncertain, but estimations can be made from an outcrop in a roadcut to the southeast of the profile. The section exposed is 2-3m tall and is composed of several, smaller blocks of sandstone. The actual wall is located at 9-10.5m along the profile (Figure 3).

The results from Paleogla are important because the profiles are over a known archaeological feature. Therefore, the effectiveness of the two methods, electrical resistivity and magnetics, can be compared. The profile of apparent resistivity, using 1m spacing, clearly shows the presence of a subsurface feature (Figure 3). It has a significantly higher apparent resistivity, over 600 ohm-meters higher, than the surrounding material. The anomaly is distinctive because it has a double peak, or a low in the center of the peak. The double peak is typical in Wenner array profiles over walls (Clark, 1990). Thus, the use of electrical resistivity was successful because it shows both the higher resistivity and the double peak expected from a sandstone wall. The magnetic profile, on the other hand, was unsuccessful. The profile did not distinguish between the wall and its surrounding material. The explanation for its failure is that the sandstone's magnetic susceptibility is very similar to that of its surrounding material, unlike the sandstone at Emilianos.

Aghia Paraskevi, Asprokambos

Asprokambos is a large site, so surveying was limited to magnetics. Three large grids (50m x 50m) with a 5m spacing between data points were initially measured. From these grids a smaller area was chosen for a denser survey, which used 1m spacing on a 20m x 20m grid. Two dipole anomalies are observed on the contour map of the data (Figure 4). Their orientations are similar, striking almost east-west. The eastern dipole is smaller in areal extent and exhibits the typical dipole configuration, with a shallower negative trough curving around the positive peak of the dipole. The western dipole is larger in areal extent and atypical in shape.

The dipoles measured at this site reveal information about their sources. The first observation is that both dipoles are strong anomalies (over 40 gammas), striking approximately east-west (Figure 4). Thus, the sources must have a strong remnant magnetism. This strong remnant magnetism could not have been acquired *in situ* because to our knowledge the earth's magnetic field has never been east-west. It is curious though, that there is more than one dipole that strikes east-west. It seems unlikely that two objects, archaeological or not, would be oriented such that their remnant magnetisms match. The other peculiarity in this contour map is the atypical shape of the western dipole (Figure 4). It is unusual for the negative trough to have a larger areal extent than the positive peak. Modeling has yet to be done, since programs such as Magnetics do not model remnant magnetism. The possible sources range from a burned archaeological object to a piece of metal, possibly from a plow. Further modeling will hopefully resolve these questions.

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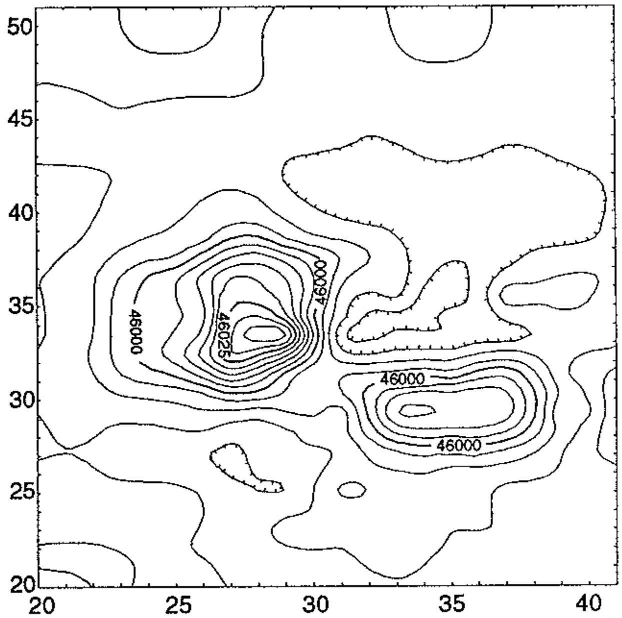

Figure 1. Contour map of magnetic data from Emilianos site. The contour interval is 5 gammas.

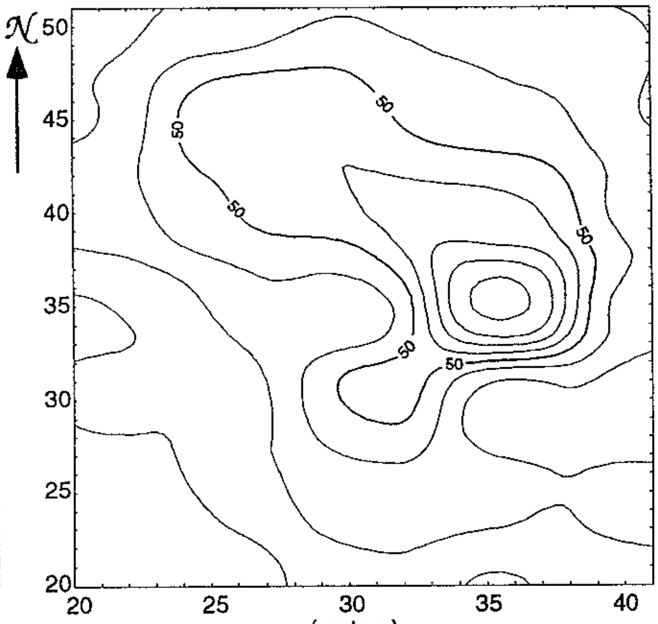

Figure 2. Contour map of resistivity data covering the same area at Emilianos as in Figure 1. The contour interval is 10 ohm·meter.

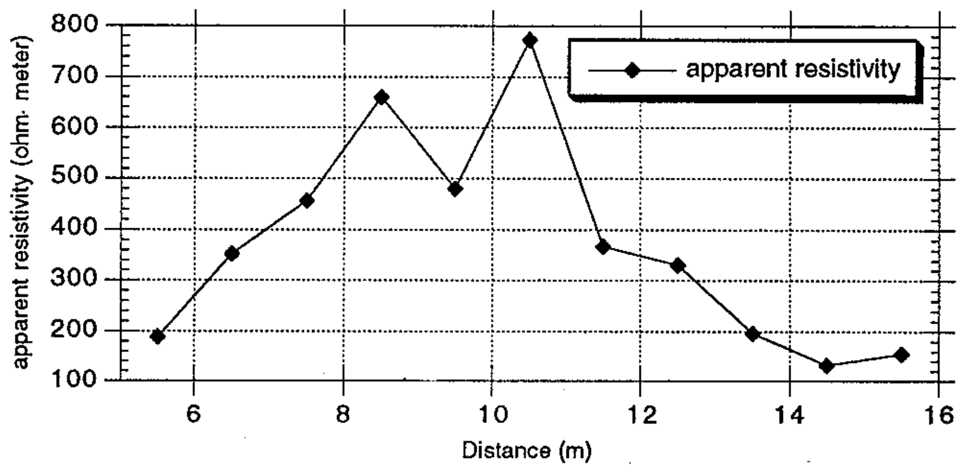

Figure 3. Resistivity profile over a known wall at the Paleogla site. The wall is located at 9-11m.

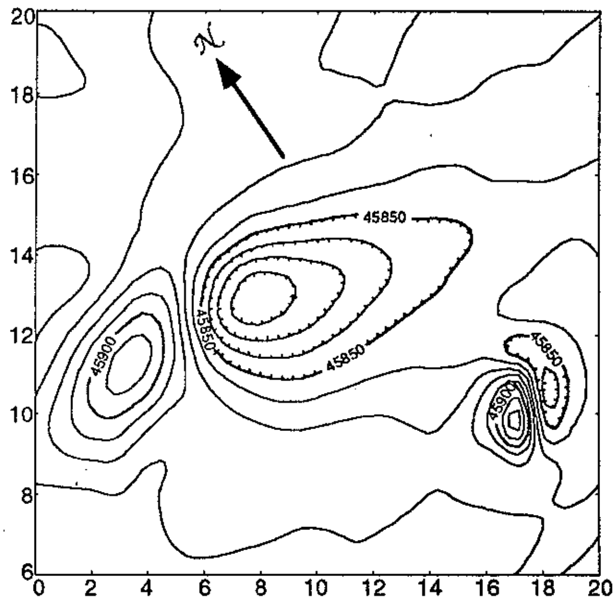

Figure 4. Contour map of data from the Asprokambos site, showing two distinct dipole anomalies.

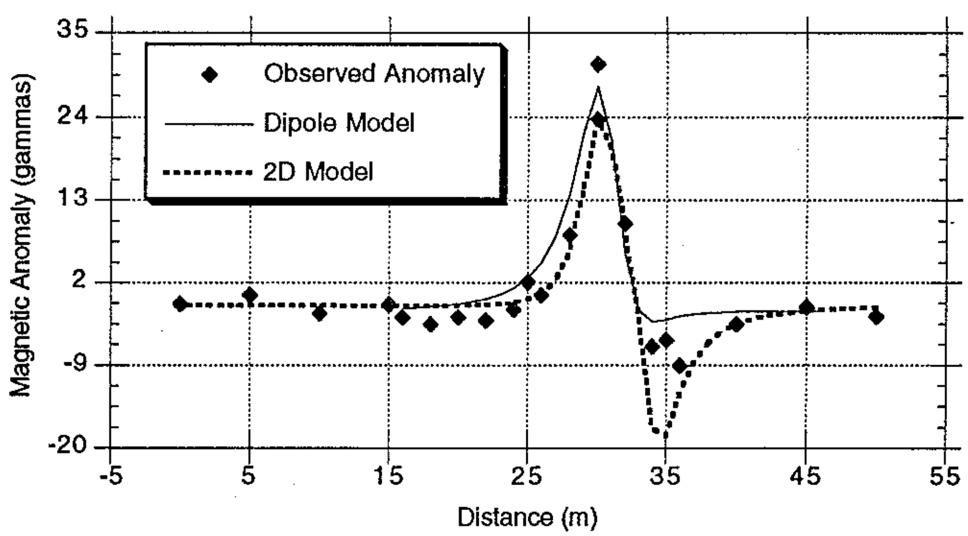

Figure 5. Model of magnetic anomaly at Emilianos. The observed data are plotted over the two models: 2D rectangle (3.3m x 1.8m, depth=1.7m, susceptibility =3×10^{-4}) and sphere-dipole (radius=1.2m, depth=1.5m, susceptibility =3×10^{-4}).

MAGNETIC SUSCEPTIBILITY AND RESISTIVITY OF COLLUVIAL UNITS AT THREE SITES IN GREVENA, GREECE

Mary K. Greene
Department of Geology
Beloit College
Beloit, WI 53511

Introduction

Colluvial units containing cultural debris are found at the sites known as Potamia, Aghia Paraskevi, and Paleogla in the county of Grevena, Macedonia, Greece. The materials relating to human habitation that are most common in these colluvial units are potsherds from different time periods. Fragments of charcoal, burned mudbrick, and roof tiles are also found in the colluvium The purpose of this study was to determine whether the soil horizons containing evidence of human habitation differed in their geophysical properties from those horizons that are devoid of cultural materials. Such a relationship would allow sites in Grevena that are not *in situ* to be located using geophysical prospecting methods. The Grevena Project, for whom this study was undertaken, has been documenting sites throughout the county of Grevena since 1987.

Previous Work

Tite and Mullins (1971) and Thompson and Oldfield (1986) documented a correlation between elevated magnetic susceptibility of soils and human occupation levels at archaeological sites. Magnetic susceptibility is dependent on grain size and parent material of the soil. Mullins (1977) stated that magnetic enhancement of topsoil is a widespread phenemenon due to conversion of particles of iron oxide from a weakly magnetic form to a strongly magnetic form. Tite and Mullins (1971) found that fires and increased concentrations of organic materials at human habitation sites aid and enhance the natural processes of iron oxide conversion. Clark (1990) explored the relationship between cultural remains and resistivity anomalies. He stated that resistance of the earth is controlled by the amount and distributionof moisture in a unit. Cultural materials, as well as the porosity of the soil, will affect resistivity and create resistivity highs if the cultural remains are consolidated (e.g a wall) or resistivity lows if mositure is prevalent throughout the unit (e.g. in a ditch).

Field Work

We attempted to measure magnetic susceptibility of the colluvial units in the field using a Bartington susceptibility meter, but due to equipment problems, this was impossible. The samples were collected at measured intervals within given horizons in each soil profile. Stainless steel dental instruments were used to free the samples from the profile face. Soil was scraped from the profiles into plastic boxes about 8 cm^3 in volume. These samples were taken back to the United States for analysis. In November 1993, measurement of the magnetic susceptibilities was completed using a Bartington Susceptibility Meter with an MS 2B probe. The probe has a 36-mm inner diameter sample cavity. Measurements may be taken at two different frequencies, 0.46 kHz and 4.6 kHz; one measurement at each frequency was taken in order to observe the effect grain size might have on susceptibility of the sample. The masses of each sample were recorded, and the readings given by the MS 2B were converted into mass specific susceptibility measurements.

Resistivity was measured using different techniques at each site. The Wenner electrode configuration was used to test resistivity of the colluvial units in outcrop. This technique was experimental, but it was employed at Potamia and Paleogla with some success. A profile over approximately 60 m of colluvial unit MS5 at Potamia was also completed, as well as a mini-profile into the outcrop face of MS6. At Aghia Paraskevi, a sounding was completed along 50 m above soil profile OB53. A profile was also run on the outcrop face of this unit. At Paleogla, resistivity testing consisted entirely of soundings into the outcrop face of several different colluvial units. Results of the soundings were plotted on a bilogarithmic scale and matched with theoretical resistivity curves to obtain apparent resistivity values for the units measured (Orellana and Mooney 1972).

Results

Magnetic Susceptibility

Table 1 lists the susceptibilities of each of the units containing cultural debris from each of the sites studied. The susceptibilities of the soils from both profile MS5 and MS6 are similar. The anomalous unit in this group of soil horizons is horizon AB, with a susceptibility that is remarkably higher than all of the