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Geophysical Exploration in the U.S. National Parks

Cover Page Footnote
Many archaeologists in the National Park Service have gambled that unproven geophysical surveys might aid their work. These gambles have often been successful. Success or failure, these results have helped to define the applications of geophysical surveys. I thank all of these National Park Service archaeologists for their interest in testing the suitability of geophysical exploration. The results here were first presented at the Middle Atlantic Archaeological Conference in 1994; the session, "Horizons on the Past: Archaeology and our National Parks," was organized by Paul Inashima.

Geophysical Exploration in the U.S. National Parks

Bruce Bevan

Results from several dozen geophysical surveys at national parks in the United States are summarized here. Illustrations from both successful and unsuccessful surveys show the advantages and limitations of geophysical exploration. Ground-penetrating radar and magnetometer surveys have been particularly suitable at sites on the coastal plain of the eastern U.S. While filled cellars can be quite easy to locate, a thinner scatter of rubble from a structure can be difficult to isolate. Cities provide almost impossible conditions for the success of a survey. Accumulations of debris in pits can be located, but privies and wells appear to be more difficult to find. Prehistoric features are almost always harder to locate than historical features; geological features can be too apparent at some sites.

L'auteur résume les résultats de plusieurs douzaines d'enquêtes géophysiques effectuées dans des parcs nationaux des États-Unis. Des exemples tirés d'enquêtes réussies et manquées font voir les avantages et les limitations de l'exploration géophysique. Les enquêtes qui font appel au géoradar et au magnétomètre ont été particuliérement appropriées sur des sites de la plaine côtière de l'Est des État-Unis. Il peut être très facile de localiser des caves remplies, mais il peut être difficile d'isoler un éparpillement plus mince de moellons provenant d'un ouvrage. Dans les villes, l'état des choses rend presque impossible le succès d'une enquête. On peut localiser des accumulations de débris dans des fosses, mais il est plus difficile de trouver des latrines et des puits. Les vestiges préhistoriques sont presque toujours plus difficiles à localiser que les éléments historiques; les caractères géologiques peuvent être trop apparents à certains sites.

Introduction

Archaeologists in the National Park Service have used geophysical exploration in order to estimate the location of underground structures and features. The goal of these geophysical surveys has been one of assisting in the selection of areas for excavation; this may minimize the amount of excavation that is necessary for understanding a site.

Many archaeologists within the National Park Service do geophysical surveys at their sites. Recent surveys have been described by the Southeast Archeological Center (1993), Mid-Atlantic Regional Office (Blades, Hennessy, and Orr 1993), North Atlantic Regional Office (Dwyer and Synenki 1990), and Interagency Archeological Services (De Vore 1990). This is just a small sample of the surveys performed by Park Service archaeologists. John Weymouth, at the University of Nebraska, has performed a particularly large number of high-quality surveys for the National Park Service. While his surveys are all detailed in technical reports, he has also summarized some of them in readily available publications (Weymouth and Huggins 1985; Weymouth 1986).

The following summarizes the results of the geophysical surveys that I have done at National Park Service sites. A list of these sites is given in Table 1. At some of the sites, surveys were done in different parts of large parks during different years; sometimes surveys were conducted over several years at one part of a park.

Most of my surveys have been described only in technical reports; these may be available from the parks listed in Table 1. Geophysical data have been published previously for the following sites: Petersburg National Battlefield (Bevan, Orr, and Blades 1984); Adams National Historic Site and Valley Forge National Historical Park (Bevan 1984); Effigy Mounds National Monument (Bevan 1992); Pictured Rocks National Lakeshore (Bevan 1994a); and Delaware Water Gap National Recreational Area (Bevan 1994b).

The Geophysical Instruments

Sketches of some of the principal geophysical instruments are given in Figure 1. Each of the instruments can be suitable for locating some types of features at some sites. For fur-

Table 1. Geophysical surveys at National Park Service sites, 1973–1995. At some sites, surveys were done in several different years, sometimes in separate parts of large parks. The success of each survey is rated from 1 (poor) to 3 (good).

Site	*Year*																							*State*	*Technique*
	1973	*74*	*75*	*76*	*77*	*78*	*79*	*80*	*81*	*82*	*83*	*84*	*85*	*86*	*87*	*88*	*89*	*90*	*91*	*92*	*93*	*94*	*95*		
Chaco Canyon NHP	1	2	2																					NM	GM
Valley Forge NHP	3	1			2	2				2		3												PA	GMCR
Adams NHS						2																		MA	G
Petersburg Nat'l Battlefield							3	2	1		3							3	3		3			VA	GMCR
Fredericksburg Nat. Mil. Park									2			2	2				3				2			VA	GMCR
Herbert Hoover NHS									1															IA	G
Effigy Mounds NM									3															IA	G
Springfield Armory NHS												1												MA	G
Friendship Hill NHS												2												PA	GM
Women's Rights NHP														2										NY	GMC
Thomas Stone NHS															1									MD	GM
Voyageurs NP															2									MN	GC
Pictured Rocks Nat'l Lakeshore															2									MI	G
Harpers Ferry NHP															2		1							WV	GM
Fort Necessity Nat'l Battlefield																1								PA	GMCR
Salem Maritime NHS																		2						MA	GC
Cape Cod National Seashore																			2					MA	CR
Saint-Gaudens NHS																			2					NH	GM
Colonial NHP																					2	2	2	VA	GMCR
Delaware Water Gap NRA																			2					NJ	GM
Fort Laramie NHS																					2	1		WY	MR
Minute Man NHP																						3		MA	GM
Manassas Nat'l Battlefield Park																							2	VA	GMCR

Technique: G = ground-penetrating radar; M = magnetometer; C = conductivity meter; R = resistivity meter.

NHS - National Historic Site
NHP - National Historic Park
NRA - National Recreation Area
NM - National Monument
NP - National Park

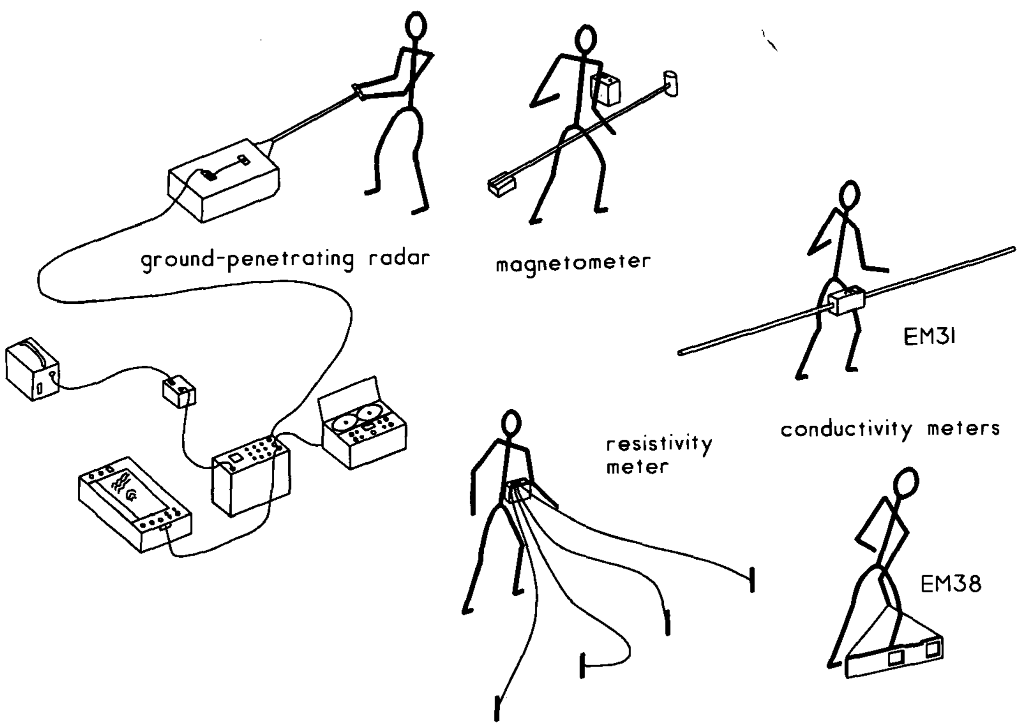

Figure 1. Five geophysical instruments applied to the exploration of archaeological sites.

ther information on geophysical surveys, see Heimmer and De Vore 1995.

The ground-penetrating radar is the most complex and expensive of the instruments, but it can provide the most detailed information about underground features. As Table 1 indicates, the instruments that were most commonly applied at these sites were the ground-penetrating radar and the magnetometer.

A survey may be done in the shortest time using a magnetometer. If iron artifacts or features of fired earth are sought, this is the instrument to use.

The two conductivity meters accentuate features to a maximum depth that is roughly equal to the length of the instruments, which is 1 m or 3 m (3 ft or 10 ft). These instruments are best at locating earthen features, but they also locate metals.

A resistivity meter generally detects features of the same sort that a conductivity meter does. While this instrument can be rather slow, it can also be the least expensive of all of the geophysical instruments.

Does Geophysical Exploration Aid Archaeology?

A geophysical survey is commonly done as a preliminary to the excavation of a site; in such cases, the goal of the survey is to estimate the location of some types of buried features. Excavation units can then be placed deliberately to sample or to miss certain types of features. Also, the total area that needs to be excavated might be reduced. In some cases, the results of the geophysical survey may suggest that there is no need for excavation. Perhaps the geophysical map provides a clear answer to the resource management questions for which the survey was done.

Geophysical surveys may be done with no intention of subsequent excavation. Such surveys aim at obtaining a general understanding of buried features in order to guide the initial planning of modifications to the site for park visitors.

Of the 44 surveys that I have done for the National Park Service, I believe that there has been some excavation done at 19 of the sites. I have received reports describing the findings at 9 of the 19 sites, and these have been my best guide for deciding if the geophysical survey has increased the archaeological understanding of the sites.

Even when I have not received a detailed excavation report, I have usually received an informal review of the successes and failures of the geophysical surveys that I have done. For the unexcavated sites, I have evaluated the clarity of the geophysical data. From all of this information, I have made an estimate of the success of each of the surveys that I have done for the National Park Service. Table 1 lists these estimates as 1, 2, or 3 in order to mark poor, adequate, or good success, respectively.

Of the 44 surveys, I rate the results of 9 as poor. For this 20% fraction of the surveys, the results were probably not worth the money spent on the survey. A few of the sites yielded almost no archaeological information, and the rest yielded little. The poor results are generally caused by the detection of too many unwanted features (those which are natural, geological, or too recent) and these concealed the features of possible archaeological interest. At a few sites, there was little confusion with unwanted features, but the archaeological features were too faint to be detected.

For 25 of the surveys (or 57%), results were adequate. Nothing spectacular was detected, but at least the data from the geophysical survey were probably worth their cost.

For 10 of the surveys (that is, 23%), the results were good. For these sites, I think that the archaeologist received information from the geophysical survey that was worth more than the cost of the survey.

In my judgment, the five most successful surveys were done at the Taylor House (Petersburg National Battlefield, Virginia); the Little Bear Effigy Mound (Effigy Mounds National Monument, Iowa); Appomattox Manor (Petersburg National Battlefield, Virginia); Redoubt Number 5 (Valley Forge National Historical Park, Pennsylvania); and the Widow Tapp House site (Fredericksburg and Spotsylvania County National Battlefields, Virginia).

The success at these sites is caused by several factors. A primary factor that can increase the success of a geophysical survey is the type of soil. It is best that the soil not be rocky, and that it possess a weak natural stratification. Distinct planar stratification can benefit a survey, however, if features intrude into the strata. The second major factor that can aid a survey is the absence of modern intrusive features. If there is recent trash or soil modification at the site, success can still be good if the features that are sought are large and deep.

Difficult Conditions for Geophysical Surveys

Table 2 summarizes some of the site conditions that make it less likely that a geophysical survey will be successful. No single one of these conditions will prevent a successful survey. If any of these conditions are found on a site, however, it will affect the choice of the geophysical instrument to be used. This choice may have to be one that minimizes the effect of the difficult conditions, rather than a selection that allows the best detection of the features that are sought.

Cities have many of these difficulties, and indeed it is difficult to get good geophysical results in urban areas. It is not impossible, however. For a site in a city, the survey must be approached with caution. Small scale but careful testing before a geophysical survey can be a good guide to deciding whether the survey would be worth the expense.

Table 2 lists four classes of difficulties for a geophysical survey. Anything that is in the ground that an archaeologist does not wish to detect can cause a false pattern or anomaly on the geophysical map. A few extra and unwanted features usually cause no difficulties. If there are many, however, the patterns that are sought can be hidden in a clutter of unwanted patterns.

Most geophysical instruments are electronic. Other electrical apparatus in the vicinity (such as machinery or radio transmitters) can interfere with the operation of geophysical equipment. This interference can usually be minimized by making a correct selection of the geophysical instrument to be used at the site.

Geophysical surveys are done by making point-by-point measurements in an area, or by

Table 2. Factors that make geophysical surveys difficult.

	False Anomalies	*Interference*	*Access*	*No data*
Steep slopes			x	
Brush			x	
Large trees	x		x	
Flower beds or crops			x	
Multiple landscaping	x			
Rocky soil				
Clayey or saline soil				x
Fences	x		x	
Brick walls	x		x	
Near buildings	x			
Prior or current excavations	x		x	
Surficial trash	x			
Pavement				x
Buried pipes or wires	x			
Power lines		x		
Nearby trains		x		
Radio transmitters		x		
Passing vehicles		x		

making traverses across an area along parallel lines. The spacing between these measurements or traverses is usually about 1 m to 5 ft. At some sites, it is not possible to walk to each point where a measurement is wished; buildings or trees may block the way. If there are too many gaps in the survey, the results are more difficult to interpret; the survey also takes longer, even if fewer measurements are made. Table 2 shows these conditions as access difficulties.

Metal-reinforced pavements can be opaque to almost all geophysical instruments; the measured data will reveal nothing about what is below the pavement. For the ground-penetrating radar, clay or saline soil can result in radar profiles that show nothing. It is possible to get no data from sites like these.

While geophysical surveys can detect features of any size, they cannot detect features that are both small and deep. As a general guide, a geophysical survey usually cannot detect a feature at a depth that exceeds the size of the feature. This is one of the reasons why prehistoric features are usually much more difficult to locate than historical features. If there are historical features at a site, they are likely to be shallower and much easier to locate than the deeper prehistoric features; the strength of the geophysical anomalies caused by the historical features will probably hide the anomalies resulting from the presence of prehistoric features.

Illustrations of Difficult Geophysical Surveys

The following case studies illustrate sites where the geophysical surveys were not successful at locating the features that were sought. This failure was generally caused by the fact that the archaeological features were detected much more faintly than were other features that were unwanted.

Grant's Cabin

During the Civil War siege of Petersburg, General Grant had his residence and headquarters at a log cabin in Hopewell, Virginia. This cabin was removed after the war but parts of it were preserved. David Orr (Mid-Atlantic Regional Office) wished to locate the underground remnants of this cabin so that the whole cabin could be replaced at the site.

I surveyed the possible area of the cabin with both ground-penetrating radar and a

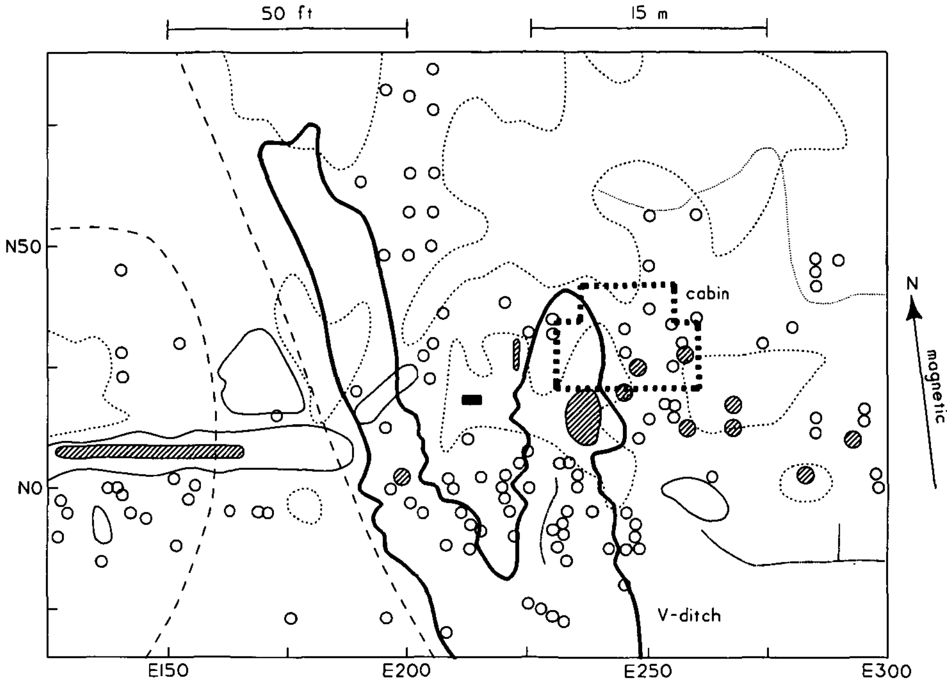

Figure 2. The search for remnants of General Grant's cabin at City Point, Virginia. These radar and magnetic anomalies did not reveal it, and its actual location as found by excavation is marked with a broken line. The filled rectangle in the figure marks an above-ground fireplace.

magnetometer.[1] The interpretation of this survey is shown in Figure 2. Hachured areas show iron or brick objects that were detected by the magnetic survey. The other patterns in Figure 2 show features detected by the radar. The geophysical data do not isolate any particular area as being the likely location of the cabin. In fact, the geophysical evidence suggested that there was a trench that could have obliterated the cabin's remains; this V-shaped feature is marked with a broad line. Later excavations in this area exposed the remnants of the cabin; its location is approximated in Figure 2 by a rectangular shape with a broad dashed line. This survey was unsuccessful primarily because the remnants of the cabin were too small and detected too faintly in comparison with the other features in the vicinity.

[1] The ground-penetrating radar for this November 1981 survey, and all of the other surveys illustrated here, was a SIR System-7, made by Geophysical Survey Systems. Two radar antennas were used: an intermediate resolution model 3105 (180 MHz) antenna and a high resolution model 3102 (315 MHz) antenna. The electrical resistivity of the soil at this site was about 100 ohm-m; the velocity of the radar pulse in the soil was estimated to be 11 cm/ns.

Thomas Stone House

The Thomas Stone House is located near La Plata, Maryland; this 1771 house was the residence of one of the signers of the Declaration of Independence. As part of the preparation of this site for visitors, an archaeological search was done for buried features in its vicinity. The geophysical survey that I performed for David Orr (MARO) tested around all sides of the house with both a magnetometer and a ground-penetrating radar.

In the front of the house, the radar delineated a trench-like feature. While it had some of the characteristics of a sunken road, excavation showed that there was no archaeological feature at this location. The source of this pattern must be a natural soil contrast of unknown origin.

The radar also isolated an oval area that had the characteristics of a former garden plot, or even a cellar. Excavation tests revealed nothing of archaeological importance, however. It appears that my interpretation of the radar data was fooled by natural features in the soil. There is nothing visible at the surface

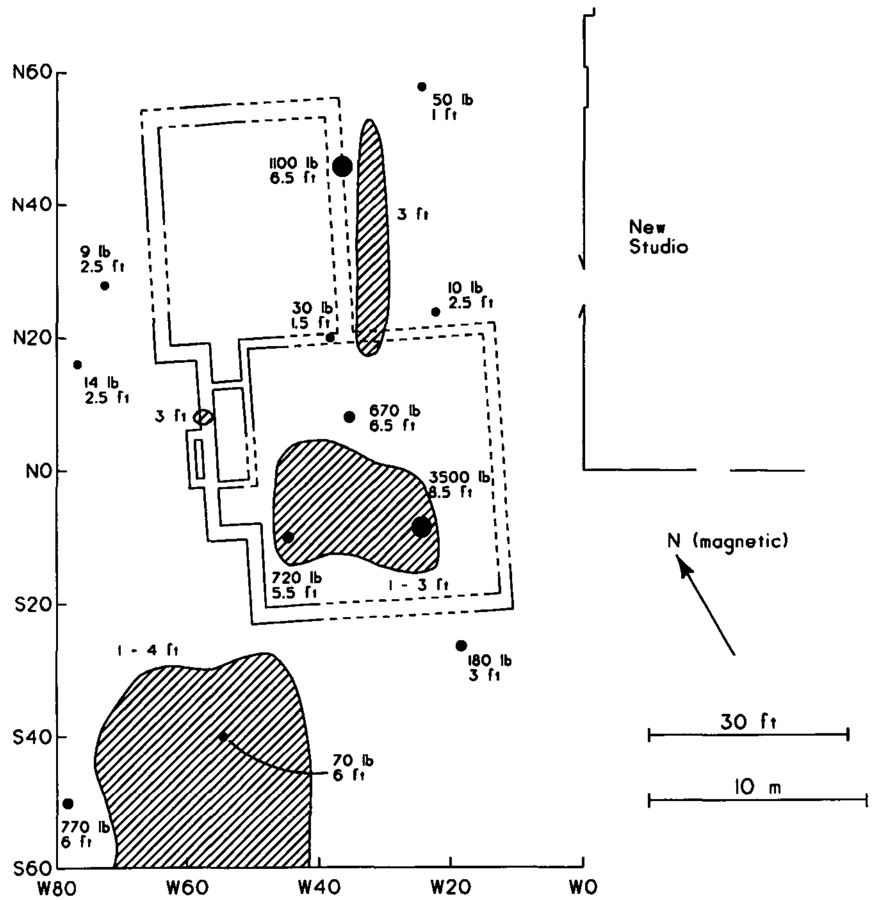

Figure 3. The early sculpture studio of Saint-Gaudens. The ground-penetrating radar could not isolate the foundation and cellar that were found by later excavation. On the basis of the magnetic survey, the weight of buried iron was estimated in pounds; multiply those numbers by 0.45 to convert to mass in kilograms. The depths are given in feet; multiply those values by 0.3 to convert them to meters.

that suggests that the site is a difficult one for a geophysical survey.

Saint-Gaudens National Historic Site

In Cornish, New Hampshire, the Saint-Gaudens National Historic Site preserves the studio of a 19th-century bronze sculptor. Two earlier studios at this location were destroyed by fire. James Mueller (Applied Archeology Center, Maryland) wished to relocate these earlier structures. The interpretation of the radar and magnetic surveys that I did at this site is given in Figure 3. The magnetic survey suggested that there could be over a ton (1000 kg) of iron buried in this area; filled circles in the figure locate specific concentrations.[2] The iron that was detected by the magnetic survey may be structural iron from the molds of the sculptures; fired earth could also contribute to the magnetic anomalies.

The ground-penetrating radar survey could detect nothing of the cellar and foundations that were later revealed by excavation (Balicki 1991); the foundations are marked with straight lines on the left side of Figure 3.

[2] The electrical resistivity of the soil was over 400 ohm-m and the pulse velocity of the radar was 11 cm/ns. The interpreted depth and mass of each iron object is more likely to be too large than too small. All of the magnetic surveys that are discussed here were made with magnetometers that measured the total flux density of the magnetic field.

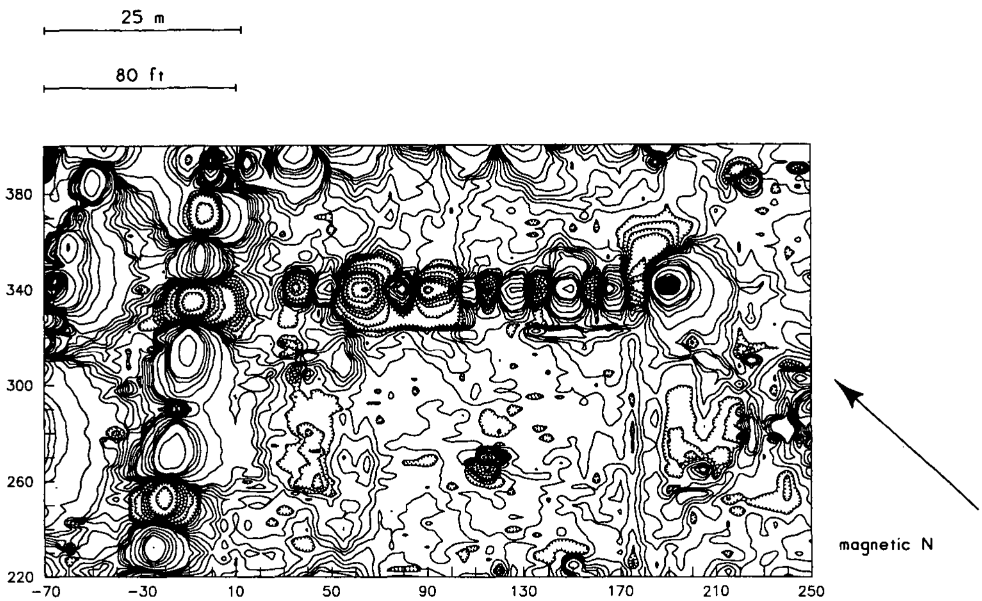

Figure 4. The magnetic effect of underground pipes at Fort Necessity. The bead-like patterns shown on this map are caused by four iron pipes. Magnetic lows are indicated with hachured contours.

The hachured areas mark planar soil interfaces detected by the radar; these appear to be modern fill.

The radar could not even trace most of the buried pipes and wires that are thought to pass through the area. The failure to detect the utility lines and also the archaeological features is probably caused by the stoniness of the soil. Large stones, or clusters of stones, can cause radar echoes; if there are many stones, their chaotic radar echoes will conceal the echoes of archaeological features.

Fort Necessity

During the 18th century, it is possible that soldiers camped in the vicinity of the fort at Fort Necessity National Battlefield, in Pennsylvania. David Orr (MARO) asked me to do a geophysical search for traces of these French-and-Indian-War-period encampments.

The tall grass in the area would have caused problems for resistivity, conductivity, or radar surveys. A magnetic survey was selected for this search because it has little difficulty with grass.

The magnetic map of the area of survey is given in Figure 4. The dominant patterns in that map are the alignments of circles.[3] These just mark the path of buried iron pipes at the site; there are four of them. The magnetic field is seen to alternate between high and low values along each pipe; these anomalies mark pipe segments.

While the heated rocks and fired earth at a hearth can cause a distinctive magnetic pattern, it is likely that most of these anomalies of archaeological interest would be hidden by the large anomalies caused by the pipes. These pipes were unexpected at the site, and the purpose of most of them is unknown.

[3] The coordinates are those of Harrington (1978). Two of the pipes are along the left and upper sides of the survey area. The sensor for the proton magnetometer was at an elevation of 2 ft (0.6 m) above the ground. The interval between contour lines is at three different levels: 2, 20, and 200 nT (nanotesla); changes in the density of the lines show the break between these three contour levels. Recorded traverses were made going toward grid north (upwards in the figure); measurements were made at intervals of 2.5 ft (0.8 m) along these lines. Parallel traverses were spaced by 5 ft (1.5 m). The temporal shift of the magnetic data was corrected with a base station magnetometer that made measurements at intervals of 2 minutes.

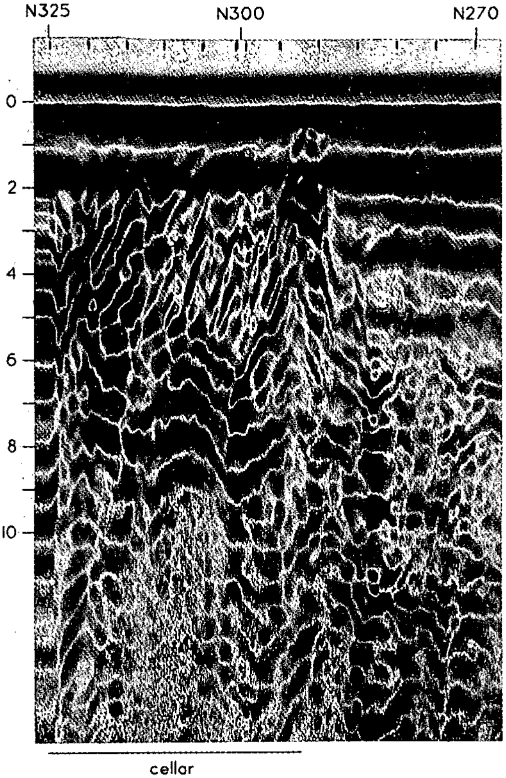

Figure 5. A ground-penetrating radar profile made at the Springfield Armory. My interpretation was that there might be a cellar shown on the right half of this profile; the cellar was actually on the left side. The length of the profile is 55 ft (17 m) and the bottom of the depth scale is 10 ft (3 m).

Springfield Armory

The Springfield Armory in Massachusetts was a center for the manufacture of military weapons from 1794 through 1968. There was a drainage problem at this site, and Dana Linck (Applied Archeology Center, Maryland) had me do a ground-penetrating radar survey in the vicinity of the main building of the Armory. As part of that survey, radar traverses crossed the estimated location of the Master Armorer's Quarters.

Figure 5 is an illustration of one of these radar profiles.[4] Tick marks near the top of the profile indicate intervals of 5 ft (1.5 m) along the traverse. An estimated depth scale is on the left. Note the extreme horizontal compression of the image; a horizontal distance of 55 ft (17 m) has the same length as a depth of 10 ft (3 m). This compression exaggerates the inclination of interfaces detected by the radar.

At the left side of the profile, in a depth range of 2–5 ft (0.6–3 m), a series of lines are seen to dip down toward the left; the actual dip angle is about 27 degrees. These echo bands are caused by stratification contrasts in the soil; these contrasts are missing from the right-hand part of the profile. My interpretation of this profile was that the dipping stratification seen on the left indicated natural, undisturbed soil, while the right side of the profile showed the effect of unstratified fill soil, probably within a cellar of the former building. I had this interpretation backward. Excavations by Louana Lackey and Richard Sacchi (American University, Washington, D.C.) showed that the cellar of the Master Armorer's Quarters was actually on the left side of this profile.

Perhaps if this profile had been extended to a greater length, I would have recognized the local character of the cellar; perpendicular profile lines would also have helped to define the extent of the anomaly and would have helped in suggesting the true location of the cellar.

Examples of Successful Geophysical Surveys

Geophysical surveys are most successful for detecting features that are larger than 2 m (6 ft) in size or that are quite different from the surrounding soil. At each of the following sites, these types of features were located by the surveys.

Appomattox Manor

While the radar surveys at Springfield Armory and the Saint-Gaudens site could not identify the cellars that were there, cellars are generally easy features to locate with a geophysical survey. At Hopewell, Virginia, David Orr (MARO) wished to locate an early house at Appomattox Manor in the Petersburg

[4] This survey was done with a model 3105 antenna. The electrical resistivity of the soil at this site was over 1000 ohm-m; the depth scale on the radar profile assumes that the velocity of the radar pulse was 14 cm/ns.

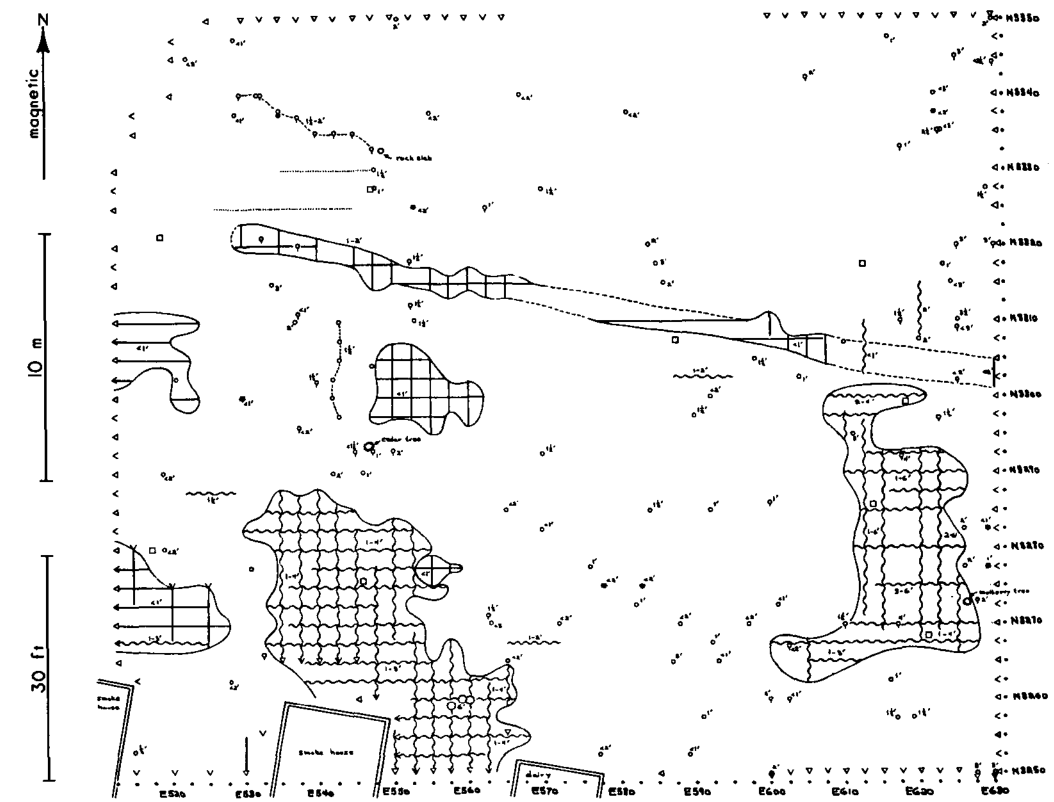

Figure 6. A radar echo map made at Appomattox Manor, Virginia. The cellar of an early building was found near the lower right corner of this area, where the radar detected distinctive echoes. Numbers in the map show the depth of the echoes, in feet; multiply these numbers by 0.3 to convert them to meters.

National Battlefield park. Historical research suggested that this building was located close to the present standing structure.

My geophysical survey used both a magnetometer and ground-penetrating radar. This combination of geophysical instruments has been particularly suitable for locating a wide variety of features. The features found by the two instruments are generally different, which makes the data from the two instruments quite complementary. Figures 6 and 7 are radar and magnetic maps of the same area at Appomattox Manor; this area is just north of the standing Eppes Mansion.[5] On the radar map areas that have similar echoes are outlined (FIG. 6). The long band in the middle of the map is probably caused by a buried path. Most of the patterns outlined on the left half of the map are caused by shallow features.

[5] This survey area is to the west of that shown in Figure 2. Both the model 3105 and 3102 antennas were used for the profiling. In Figure 6, echoes marked with straight lines indicate planar strata, while undulating lines indicate other irregular strata. The electrical resistivity of the soil here was about 100 ohm-m; the radar pulse velocity was measured to be 10 cm/ns. Magnetic measurements were made at intervals of 2.5 ft (0.8 m) with a sensor height of 1.8 ft (0.5 m). Three different contour intervals are shown in Figure 7: 10 (dashed), 100, and 1000 nT (broad); this contour map was drawn by hand. The temporal change in the magnetic field was about 22 nT during the survey, but this shift has not been corrected. Magnetic traverses were made going toward the north. The surveys were done in May 1983.

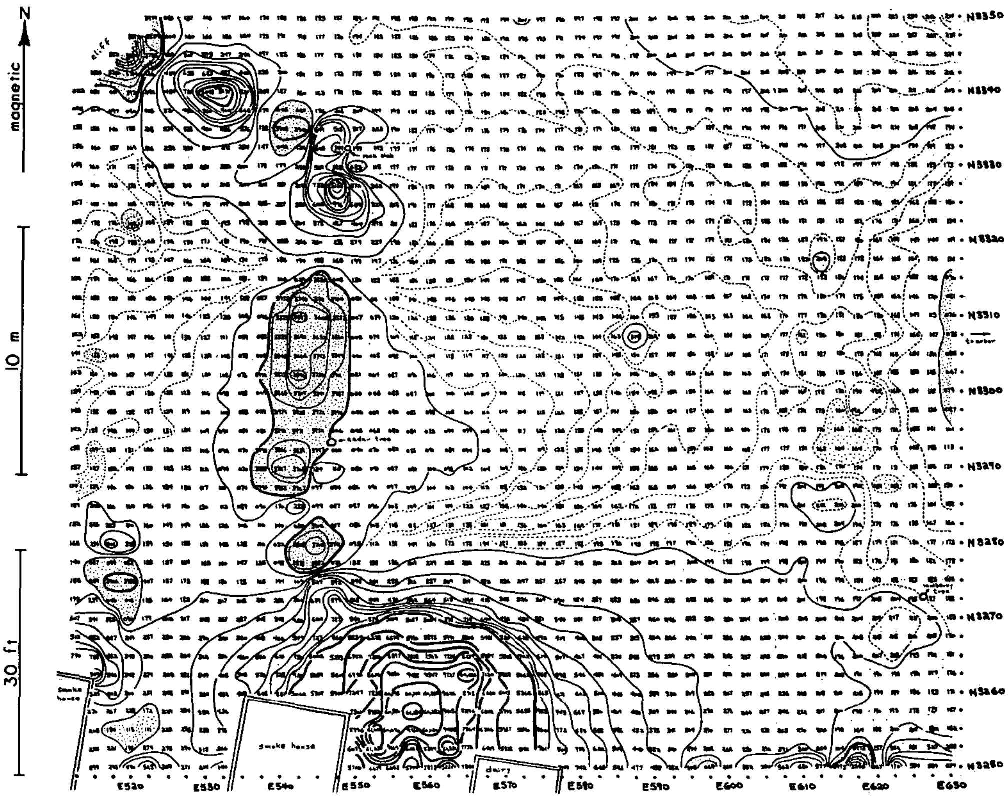

Figure 7. A magnetic map that covers the same area as Figure 6. While the predominant pattern is caused by the base of a former windmill and an iron pipe, there are also faint anomalies at the location of the cellar near the lower right corner of the map.

The magnetic map shown in Figure 7 gives a very different picture. The most distinctive anomaly is at the bottom of the figure. There was once a steel-framed windmill at this location, and the four stumps of the tower's legs are underground; there is also a large amount of iron within the well at the middle. The linear cluster of magnetic anomalies that extend upwards in the figure are evidently caused by an iron pipe going away from the windmill; segments of this pipe were also delineated by the radar.

The remnant of the windmill, the well, and the water pipe are the dominant features in the magnetic map. At the lower right corner of the radar map (FIG. 6), however, there is a cluster of radar echoes that extend from a depth of 1 ft (0.3 m) to as much as 6 ft (2 m) underground. Some of the radar profiles suggest that there is a rather flat lower surface at this point. In this same area, there are three rather faint magnetic anomalies, each of which could be caused by roughly 5 lb (2 kg) of iron or several hundred pounds (100 kg) of brick. Excavation in this area resulted in the discovery of the cellar of the former mansion.

Harpers Ferry

While resistivity surveys are rather slow, they can be very good for locating traces of former buildings. At Harpers Ferry, West Vir-

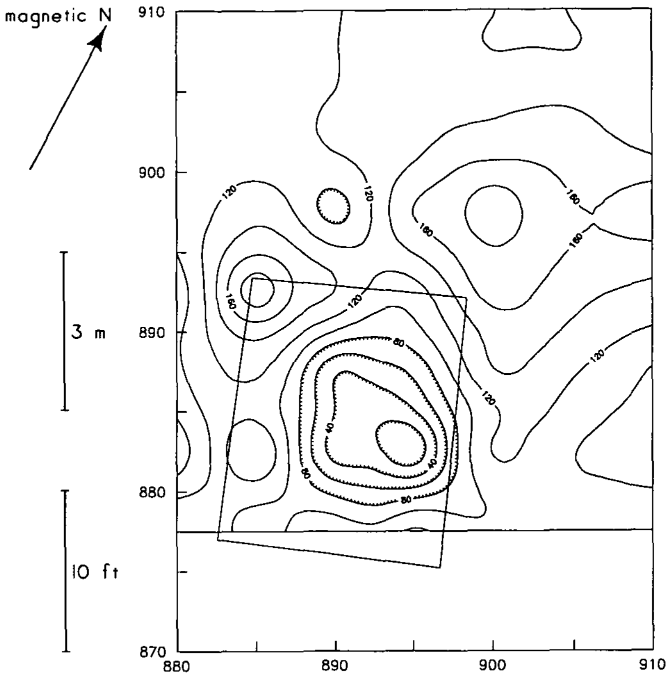

Figure 8. A map of electrical resistivity at Harpers Ferry. The low values coincide with the location of a shed which is seen on Sanborn maps from the years 1902 through 1933; it is marked with a rectangle.

ginia, a resistivity survey detected a clear anomaly at the location of a 20th-century shed.

Figure 8 shows part of a resistivity map that was measured by Susan Winter, Paul Shackel, Ellen Armbruster, and John Ravenhorst (Harpers Ferry National Historical Park).[6] A distinctive area of low readings is contoured with hachured lines. Sanborn maps show that there was once a shed in this area; the rectangular shape in the figure approximately locates this shed. The historical records (Shackel 1993) also indicate that there was once a stable in the right-hand two-thirds of the shed shown in Figure 8. It is possible that manure is the cause of this low resistivity.

Each year, a National Park Service training course on the methods of remote sensing and geophysics is coordinated by Steven De Vore (Interagency Archeological Services). As part of these courses, resistivity surveys have been done at a pair of 19th-century stage stops in southern Colorado. These surveys have shown that lower resistivity is found in the areas of former corrals (Heimmer and De Vore 1995: 106). As in the example above, the low resistivity is probably caused by a combination of chemical salts and the vegetation that is found in manure. These corrals and the stable would probably have also been detected by measurements of phosphate in the soil.

Stevens House

Historical maps can be very valuable for indicating the location of former structures. During the Civil War battle at Fredericksburg, Virginia, the Stevens House was on the front line of the fighting. While that house no longer

[6] The contour interval is 20 ohm-meters. The Wenner configuration of electrodes was used with the array oriented in a northerly direction; the spacing between the electrodes was 5 ft (1.5 m). I did a conductivity survey in this same area with a Geonics EM38. While this instrument indicated that there was metal underground in the area of the low resistivity anomaly, the resistivity survey gave much clearer information. The area is south of the Provost Office, and the coordinates of the archaeological survey were used.

exists, it appeared on maps made in the early part of this century.

David Orr (MARO) and Noel Harrison (Fredericksburg and Spotsylvania National Military Park) asked me to help find out if there were underground traces of the former building at the site. While the historical maps approximate the location of this building, there is nothing visible on the surface to suggest whether anything might remain in the soil.

The ground-penetrating radar survey located a rather diffuse area where the soil strata had a greater complexity than elsewhere; this complexity can be caused by rubble in the soil. Excavation in a small part of this area definitely located the Stevens House.

Widow Tapp Farm House

Later in the Civil War, another house stood on the front line between the Union and Confederate armies during the Battle of the Wilderness. This was the Widow Tapp Farm House, located in Virginia. Once again, all above-ground traces of this house have disappeared, and there are no good historical maps for the site. Wilson Greene (Fredericksburg and Spotsylvania National Military Park) and David Orr (MARO) requested that a geophysical survey be done in an attempt to locate this building.

For the survey, I used a magnetometer and a Geonics EM38 conductivity meter and tested an area of 150 by 250 ft (45 by 75 m), making measurements at intervals of 5 ft (1.5 m). In one corner of this area, both instruments indicated anomalies, but they were not particularly clear. This interesting area was resurveyed with measurements at intervals of 2 ft (0.6 m). Both the magnetic and the conductivity surveys detected a cluster of metallic objects. Excavation in this area resulted in the discovery of concentrations of artifacts, suggesting that this might have been the location of the house.

Elizabeth Cady Stanton House

At the Elizabeth Cady Stanton House in Seneca Falls, New York, I was asked by Dick Ping Hsu (North Atlantic Regional Office) to search for traces of structures and features around the historic house, which is within the Women's Rights National Historical Park. Magnetic and radar maps of the front yard of this house revealed an anomaly. Upon excavation, this was found to be a brick-lined well, although there was an error of 3 ft (1 m) in the location predicted by the geophysical survey.

Historical records had suggested the location of the well. Without this information, the geophysical instruments would have detected the same patterns, but the interpretation would have been simply that an unknown feature was detected, and it probably would not have been identified as a possible well. It is always easier to detect features with a geophysical survey than to identify them.

Wells are readily detected if a significant amount of metallic trash has been put in their fill. The brick lining of a well can also be detectable with a magnetic survey. The fill soil of a well can be very different from the surrounding soil, and a radar survey may detect this difference. Wells, however, have a small cross-section and are not generally easy to find.

Valley Forge

Historical records hint at the approximate area of Redoubt No. 5 at Valley Forge National Historical Park in Pennsylvania, but no trace of it has ever been found. In 1979, during an examination of aerial photographs of the area, Helen Schenck (University of Pennsylvania Museum) (personal communication) found a light-toned circular pattern that had a size and location that would be reasonable for the missing fort. Later, in 1984, road construction was planned in the vicinity of this feature, and David Orr (MARO) asked me to try a geophysical search in the area.[7]

I used a ground-penetrating radar survey for the search, and it revealed the interesting

[7] Prior to the radar survey, a resistivity survey was done here by David Orr, Doug Campana, and Brooke Blades (Mid-Atlantic Regional Office) and by Helen Schenck and Michael Parrington (Helen Schenck Associates); the resistivity map showed a distinctive area of low resistivity at the location of the stratification basin. The electrical resistivity of the soil here was about 80 ohm-m. A model 3105 antenna was used and the pulse velocity was estimated to be about 8 cm/ns. The survey area is just east of Highway 363, south of Highway 23, and west of the County Line Expressway. My radar survey was done November 1984.

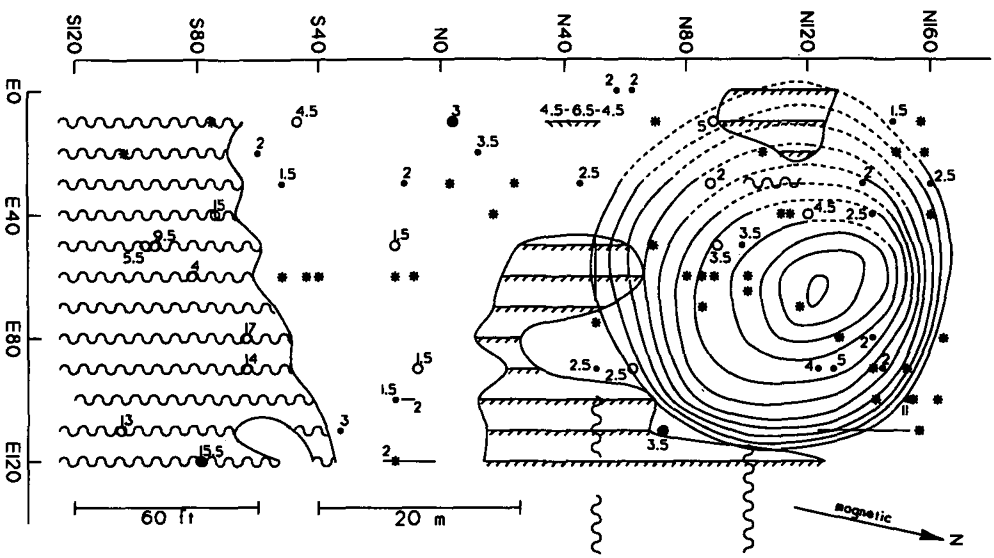

Figure 9. A basin-like soil feature at Valley Forge. This was found during a search for an earthen fort. The circular contours are at depth intervals of 0.5 ft (0.15 m) and range from 3 to 8 ft (1 to 2.4 m) deep.

stratigraphic anomaly shown in Figure 9. The circular lines at the top of the figure show the depth contours of a distinctive soil interface. This feature appears to be a soil basin about 100 ft (30 m) in diameter. The radar could not locate any evidence of filled-in ditches in the vicinity. It is likely that this feature is a natural depression. Since bedrock is composed of limestone here, this soil lens could mark the subsidence at a sinkhole; no excavation tests have been made at this location.

Jamestown Island

As part of an archaeological re-evaluation of Jamestown Island, I tested several geophysical instruments at the 17th-century settlement, part of the Colonial National Historical Park. The archaeological work was directed by Marley Brown III and Andrew Edwards (Colonial Williamsburg Foundation), and the project was administered by David Orr (MARO).

A part of the magnetic survey is mapped in Figure 10. After this survey was finished, three excavation units were placed in this area; these are shown as rectangles. A concentration of brick was found in the lower excavation, and two brick clamps (simple, at-surface brick kilns) were found at the northern two excavations.[8]

While iron is always easy to find with a magnetic survey, brick and fired earth can also be readily located with a magnetometer. After bricks are moved from a kiln to construct a building, the bricks in the building are less magnetic than they were in the kiln; this is because the orientation of the bricks changed when they were removed from the kiln. Fired earth features that have never moved from their location of firing are much more magnetic than a structure made of separate bricks.

A magnetic survey can be excellent for locating kilns and furnaces, although I had not predicted that there would be brick at these three locations at Jamestown. Instead, I had predicted that there would be iron objects there. My estimate was that the iron mass

[8] The sensor was at an elevation of 0.8 m (2.6 ft) and measurements were made at intervals of 1 m (3 ft) along east-west lines. The contours have three different intervals. The broad lines indicate intervals of 50 nT, the thin lines show 10 nT, and the broken lines indicate 2 nT. Temporal correction was done with a base station magnetometer. An iron water pipe causes the strong anomaly at the right-hand side of this map.

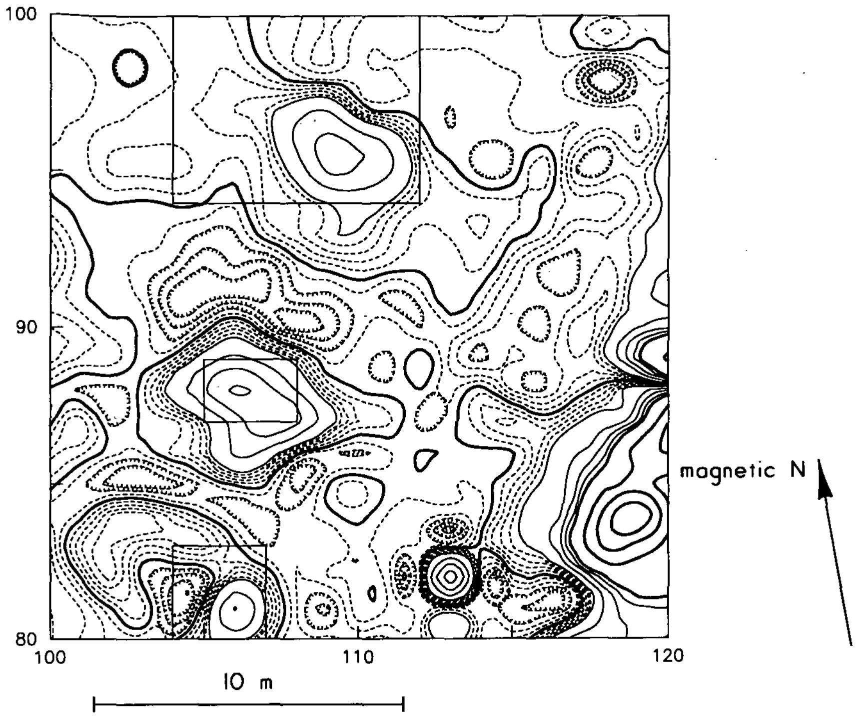

Figure 10. Jamestown Island. On the basis of this magnetic map, excavations were placed at the three rectangular areas shown here; kilns or concentrations of brick were found at each excavation.

could range from 1 to 15 kg and that the depths could be between 0.4 and 1.8 m. The actual depth of the brick and fired earth was only about 0.3 m. This overestimate resulted from the fact that shallow and broad features can cause the same magnetic pattern as small, deep features. Also, one cannot generally distinguish metallic iron from fired earth with a simple magnetic survey.

Conclusion

These examples, from National Park Service sites, are a representative sample of the capabilities of geophysical exploration in the eastern part of the United States. This discussion of prior work may assist archaeologists in deciding whether a geophysical survey might be suitable at a given site. While perhaps a quarter of the surveys described here have not been successful, the knowledge gained from unexpected failures can be as important (for geophysical purposes) as the findings of very successful surveys.

The likelihood of a successful geophysical survey at a site is reduced if the soil is rocky, the features are small, or the site is in a city. A survey is more likely to be successful if the desired feature is large, such as a cellar or a lens of debris. Metallic artifacts and kilns are generally easier to find with a geophysical survey.

Acknowledgments

Many archaeologists in the National Park Service have gambled that unproven geophysical surveys might aid their work. These gambles have often been successful. Success or failure, these results have helped to define the applications of geophysical surveys. I thank all of these National Park Service archaeologists for their interest in testing the suitability of geophysical exploration.

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