ASSESSING FEATURE FUNCTION AND SPATIAL PATTERNING OF ARTIFACTS WITH GEOPHYSICAL REMOTE-SENSING DATA

William A. Martin, James E. Bruseth, and Robert J. Huggins

Magnetic surveys and electromagnetic conductivity surveys were conducted at several sites during the course of field work at the Richland/Chambers Reservoir in north-central Texas between 1982 and 1985. Much of this work was conducted at the Bird Point Island site (41FT201J, which was used as a proving ground to test the effectiveness of various remote-sensing techniques. Two devices, a Geometrics proton precession magnetometer and a Geonics Limited EM-38 electromagnetic conductivity sensor were tested. The data produced by the EM-38, although initially successful for locating large archaeological features. were less useful for site interpretation than those yielded by the magnetometer.

Replicative experiments were conducted to test hypotheses related to feature function and to identify the sources of magnetism present in features. After an experimental hearth and a pit were created on an off-site area, a magnetic survey was conducted and the results were compared with the magnetic responses obtained from archaeological features. Remarkably similar magnetic responses were observed between the experimental features and certain classes of prehistoric archaeological features. Fire-cracked rock, consisting of small fragments of iron-enriched sandstone and ironstone, was identified as the primary source of magnetism.

In addition to identifying locations of features, the magnetic data also provided information regarding whether or not features had been subjected to multiple episodes of disturbance and reuse. Episodes of recurrent use were indicated by irregular symmetry and unusual magnetic polarity. Several large pit features. which archaeological evidence indicated had been reused, exhibited anomalies with multiple peaks of strong magnetic highs surrounded in several directions by peaks of weak to moderate magnetic lows. In contrast, hearths and pits lacking archaeological evidence of major disturbance or reuse were associated with anomalies that exhibited the normal dipolar signature associated with cultural features—a strong magnetic high with a strong magnetic low immediately to the north. The results of this study demonstrate that the magnetometer has a great potential for aiding in the interpretation of archaeological features in addition to its traditional use as a tool for identifying feature locations.

Durante trabajos de campo realizados en el Richland/Chambers Reservoir en el norte-centro de Texas entre 1982 y 1985 se efectuaron prospecciones magnéticas y de conductividad electromagnética en varios sitios arqueológicos. La mayor pane de este trabajo fue realizado en el sitia Bird Point Island (41 FT201), que fue utilizado como prueba de la eficiencia de diversas técnicas de prospección. Se pusieron a prueba dos dispositivos, un magnetómetro de prececión de protones Geometrics y un sensor de conductividad electromagnética *Geonics Limited EM-38. Los datos producidos por el EM-38 fueron inicialmente capaces de localizar grandes estructuras arqueológicas pero tuvieron menos utilidad para la interpretación que los proporcionados por el magnetómetro.*

Se condujeron experimentos replicativos para poner a prueba hipótesis relativas a la función de las estructuras y para identificar las fuentes de! magnetismo presente en las mismas. Luego de crear un fogón y un pozo experimentales fuera del area del sitio, se efectuó una prospección magnética y los resultados fueron comparados con respuestas magnéticas notablemente *semejantes entre las estructuras experimentales y ciertas cases de estructuras arqueológicas prehistóricas. Rocas fragmentadas al fuego. incluyendo pequeños fragmentos de arenisca y hierro, fueron identificadas como la principal fuente del magnetismo.*

Además de localizar estructuras, los datos magnéticos proporcionaron información sobre múltiples episodios de perturbación y reuso de las mismas. Episodios de uso recurrente fueron señalados por la simetría irregular y polaridad magnética inusual. Varios pozos de considerable tamaño. que habían sido reutilizados de acuerdo a la evidencia arqueológica. exhibieron anomalías con múltiples picos de alto magnetismo rodeados en varias direcciones por picos de magnetismo moderadamente bajo. Por el contrario, fogones y pozos carentes de evidencias arqueológicas de perturbación o reuso estuvieron asociados con anomalías que exhibían la señal dipolar normal característica de estructuras culturales—un fuerte pico de magnetismo elevado con un fuerte pico de magnetismo bajo inmediatamente hacia el none. Los resultados del presente estudio demuestran que el magnetómetro posee un gran potencial para auxiliar la interpretación de estructuras arqueológicas además de su uso tradicional en la localización de estructuras.

The research discussed in this article was conducted between 1982 and 1985 as part of the Richland Creek Archaeological Project (Bruseth and Martin 1987; Bruseth and Moir 1987; Jurmey and Moir

William A. Martin and James E. Bruseth, Texas Historical Commission, P.O. Box 12276, Austin, TX 78711
Robert J. Huggins, Geometries, Inc., 395 Java, Sunnyvale, CA 94089

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1987; McGregor and Bruseth 1987; Moir and Jamey 1987). This project was a multidisciplinary archaeological study undertaken by the Archaeology Research Program of Southern Methodist University to investigate the processes of human settlement along Richland Creek in Navarro and Freestone counties of north-central Texas. The work was performed within and around the Richland/Chambers Reservoir, an 18,110-ha lake recently constructed by the Tarrant County (Texas) Water Control and Improvement District Number One.

The Richland/Chambers Reservoir is located along the prairie margin of Texas, a natural ecotone separating the deciduous forest of the eastern United States from the grasslands of the southern Plains. The area within and around the reservoir consists of broad uplands dissected by creek valleys and river flood plains with the elevation differential between upland and flood-plain areas typically varying between 15 and 30 m. The entire area is part of the Gulf Coastal Plain, a gently undulating physiographic province bordering the Gulf of Mexico and owing its character to past embayments of the Gulf of Mexico (Sellards et al. 1954). The creeks and rivers of this plain flow southeast toward the Gulf of Mexico. Several geological groups are present within the area in the form of northeast-southwest-trending bands; these include the Navarro, Midway, and Wilcox groups. The differing geological parent materials of each band have resulted in alternating and contrasting soil types located within dose spatial proximity.

Four seasons of fieldwork were conducted during the data-recovery phase of the Richland Creek Project. Referred to as Seasons I-IV, each season was the focus of a slightly different emphasis in research direction as analysis of the previous season's results presented new questions or pointed to new opportunities for data recovery. Intensive fieldwork was conducted at 15 prehistoric sites in the Richland/Chambers Reservoir during Seasons I-IV, but the Bird Point Island site (41FT201) received the greatest concentration of effort. This is particularly true with respect to the development of the geophysical remote-sensing studies, for it was at this site that remote-sensing methods were tested and refined for use at the other sites.

THE BIRD POINT ISLAND SITE

Geological Background

Bird Point Island is a 3.2-ha remnant of an eroded Pleistocene T-1 terrace that extends out into the flood plain of Richland Creek (Figure I). The landform consists of Pleistocene terrace sediments overlying sediments of the Wilcox Group, an Eocene formation that outcrops along the base of the site adjacent to the flood plain (Godfrey et al. 1973). The Holocene alluvium of the Richland Creek flood plain surrounds the knoll on three sides. Along the north side of the landform, a narrow bridge of terrace soil once connected the site to the uplands, providing an avenue of dry ground during all but the most severe of floods; this portion of the terrace has been bisected by a modem farm road (Figure 1). When severe floods cover the flood plain and the farm road cutting through the terrace at the north end of the site, the terrace remnant becomes an island. This fact, along with the abundance of small arrow points found at the site (known locally as "bird points"), accounts for the name given to the site by the avocational archaeologist who first reported it. The terrace soils have been classified as Typic, Udic, and Ultic Haplustalfs by Edward Janak, the regional soil scientist for the USDA Soil Conservation Service, whereas the soils of the Wilcox Group have been classified as Aquic and Udic Paleustalfs. These soils are all freely drained and differ mainly in degree of moisture content and leaching of bases that has occurred.

The terrace deposit is characterized by a well-developed soil profile with a dark brown fine sandy loam A horizon 20-50 cm thick overlying a yellowish-brown to reddish-brown argillic (B) horizon that ranges from 50 to 90 cm thick. Beneath the B horizon, a C horizon consisting of unconsolidated material and bedded sands extends down to the interface with the Wilcox Group. The terrace sediments do not contain any gravel lenses or natural rock inclusions, but the Wilcox sediments contain iron-rich sandstone, siltstone, and ironstone that outcrops in the slough at the south end of the site (Figure I).

Gcomorphological studies indicate that no aggradation has occurred on the terrace since the Pleistocene; therefore, the surface present during the archaeological investigations was roughly the

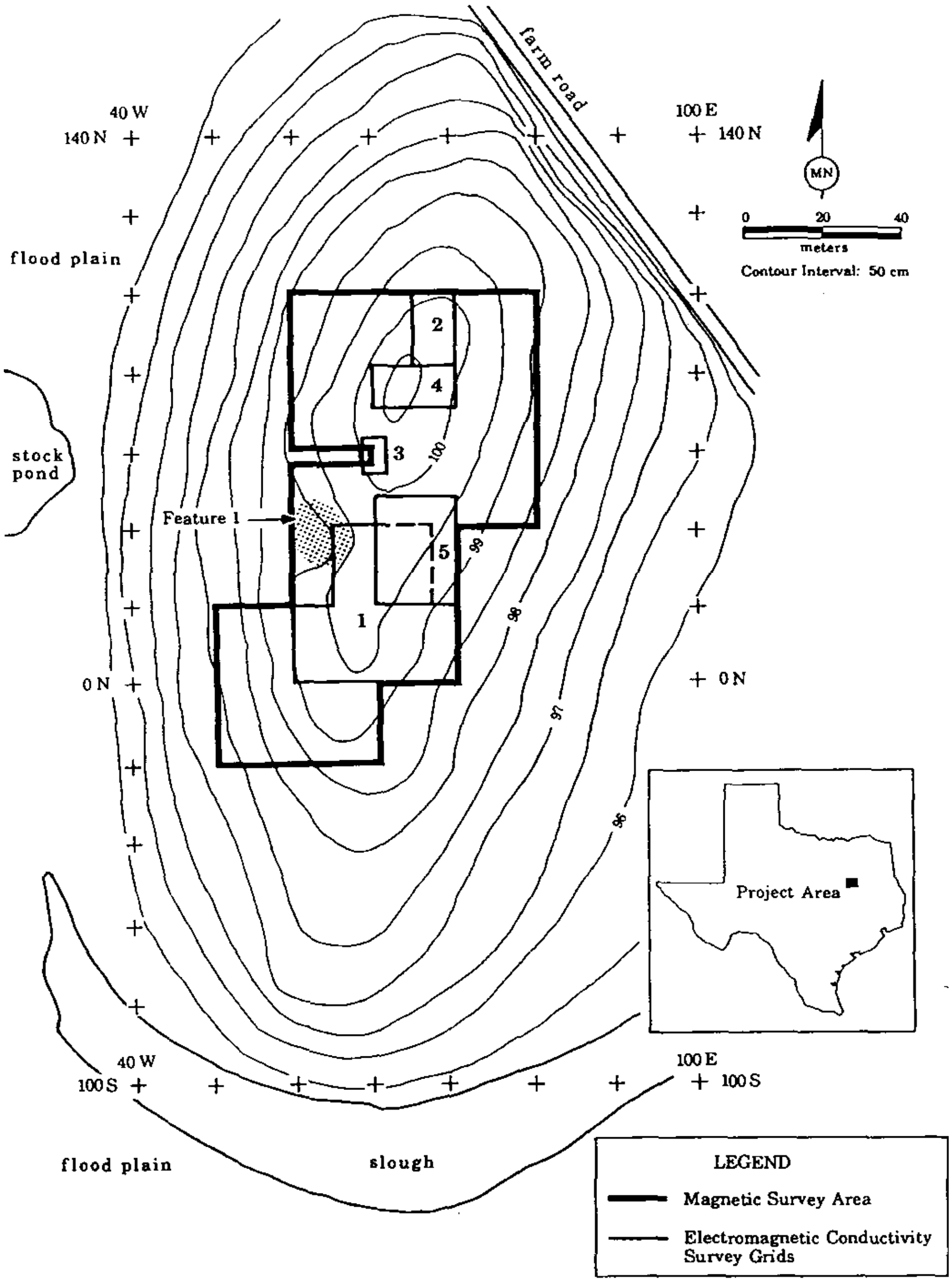


Figure 1. Locations of magnetic and electromagnetic conductivity survey areas across the terrace containing the Bird Point Island site. Richland/Chambers Reservoir area show. in inset.

same as the prehistoric surface. Artifacts originally deposited on the surface were mixed into the A horizon by the actions of plants, burrowing rodents, insects, and plowing. Artifact displacement ceased at the interface with the argillic horizon where the sandy clay resisted the effects of bioturbation. Cultural features were not visible in the A horizon because of the disturbed nature of this layer, but when the A horizon was removed by excavation, features that penetrated the argillic horizon were visible as dark-brown patches of sandy loam against the yellowish to reddish-brown sandy clay.

Archaeological Background

Artifacts dating from the Early Archaic through the Late Prehistoric periods were recovered from Bird Point Island (Bruseth and Martin 1987). More than 500 cultural features were recorded, and 177 of these were excavated during the course of four field seasons. Although the site undoubtedly was visited briefly many times over the centuries, most identifiable features and sizable quantities of artifacts were related to four principal components. Chronological placement of these components was determined on the basis of radiocarbon dates and association with dated ceramic and projectile-point types. Even though artifacts from several periods were present at the site, there was a sufficient degree of horizontal separation of components to formulate conclusions about each of the occupations. In addition, vertical separation of components was observed within Feature 1, a very large stratified pit feature measuring 17 x 13 m in diameter and 2.2 m in depth (Figure 1).

The first substantial occupation occurred sometime between the first and fifth centuries A.D. Radiocarbon assays on bone collagen and bone apatite obtained from a burial at the base of Feature I suggest that initial pit use occurred sometime during the first or second centuries A.D. Two additional uncorrected dates from this period were obtained from other features on the site, indicating the presence of an Archaic occupation.

The second period of substantial occupation occurred during the seventh or eighth century A.D. It is represented by a zone of human cremations and refuse within Feature 1 extending from 70 to 150 cm below surface. The presence of cremations within Feature I indicates that activity took place at the site during this time frame, but none of the other features at the site could be linked positively to this occupation.

A small hamlet consisting of three houses and extensive midden deposits was created during the third, and most substantial, occupation. Seven uncorrected radiocarbon assays from a hearth inside a house and from features associated with work areas outside the house demonstrate that the hamlet was occupied sometime between the eleventh and thirteenth centuries A.D. It is estimated that 75 percent of features found at the site are associated with the hamlet occupation, but an exact number cannot be determined because many did not contain datable materials. Macrobotanical remains recovered from these features indicate that a foraging adaptation to the prairie/forest ecotone maintained the hamlet; there was no evidence of reliance on agriculture during this period (Fritz 1982, 1983).

The final occupation of Bird Point Island occurred during the fourteenth and fifteenth centuries A.D., at which time most occupation was confined to the southern half of the landform. Six uncorrected radiocarbon assays related to this period of occupation were obtained from cultural features. The number of features observed suggests that an intensive occupation took place, but no structures like those present during the third occupation were observed, indicating a shift to a less: sedentary existence. Macrobotanical remains included very small quantities of maize, suggesting that agriculture had been adopted or that trade with agricultural groups had begun.

GEOPHYSICAL REMOTE-SENSING'

Two techniques, magnetic survey and electromagnetic conductivity survey, were tested to assess their effectiveness for finding cultural features. The specific instruments used were EG&G Geometries proton precession magnetometers and a Geonics Limited EM-38 electromagnetic conductivity was conducted by Robert J. Huggins (currently with EG&G Geometrics, Inc., Sunnyvale, California, but at that time with Spectrum Geophysics, Inc., Fort Worth, Texas) with the assistance of Archaeology Research Program staff (Southern Methodist University).

Magnetic Survey

Magnetic survey to locate in situ cultural features was used in Britain and Europe as early as the 1950s, with much of the current knowledge of the field contributed by a few individuals (Aitken 1958; Belshe 1957; Graham and Scollar 1976; Le Borgne 1955; Linington 1964). This technique was introduced into New World archaeology somewhat more recently (Black and Johnston 1962; Ralph 1965) and has been used successfully to locate subsurface archaeological features at several sites across the United States (Gibson 1986; Tile 1972; von Frese 1984; von Frese and Noble 1984; Weymouth 1976; Weymouth and Huggins 1985; Weymouth and Nickel 1977). Its success elsewhere prompted the selection of this technique for use on sites within the Richland/Chambers Reservoir area. For a more extensive discussion of the principles of magnetic surveying, refer to Aitken (1974), Breiner (1973), or Weymouth (1976). In addition, see the March 1986 special issue of the journal Geophysics (Vol. 51, No. 3), which is devoted to the use of remote-sensing techniques in archaeology.

The location of buried archaeological features using magnetic methods depends on the measurement and recognition of anomalies in the earth's magnetic field caused by changes in the concentration, orientation, and type of iron oxides in the soil. In culturally sterile alluvial, or wind blown, sediments, iron oxides commonly are found in the form of weakly magnetic hematite and are distributed in such a way as to produce a distinctive, often uniform magnetic field at the surface. In the presence of cultural activity, various forms of energy are brought to bear on the soil that can create localized changes in the magnetic properties of the oxides. These changes produce measurable variations or "anomalies" in the magnetic field over the area of interest.

The shape, magnitude, and symmetry of magnetic anomalies provide information about the type, size, and depth of buried features (von Frese 1984). Magnetic anomalies can assume a variety of shapes and magnitudes. For the purposes of this discussion, two basic categories are defined, "monopolar" and "dipolar," from which most other more complicated anomalies can be constructed. The monopolar anomaly consists of a group of measurements that has a magnitude greater or less than the background readings in the immediate vicinity. The dipolar anomaly consists of two groups of measurements, one group higher than surrounding background and the other group, lower, but closely associated with the first group.

Survey Procedures. Prior to the magnetic survey, a visual inspection was made of the area around Bird Point Island to search for noncultural sources of magnetism that could affect the results adversely. The road cut through the terrace at the north end of the landform showed that the terrace soil appeared to lack features such as lenses, gravels, or other inhomogeneities that might produce magnetic anomalies. A total of 6,400 m^2 was surveyed during Seasons I and II. Figure 1 shows the total area surveyed during both seasons, with the magnetometer survey area indicated by the bold outline. Measurement of the magnetic field over the site was accomplished using two Geometrics 9-856 proton precession magnetometers. One magnetometer remained stationary to monitor the time fluctuations in the earth's magnetic field (diurnal drift), while the other instrument measured the field over the area of interest at I-m sample intervals. The objective of this broad coverage was to isolate clusters of cultural activity occurring within areas of sparse activity so that excavations could be directed toward potentially more productive areas.

Results. Data collected during the survey were corrected for diurnal drift and run through error-checking routines. Preliminary contour maps were generated to detect the magnetic fields caused by archaeological features. After preliminary processing, color-density contour maps were produced on a computer graphics screen with the magnitude of the readings keyed to a color scale. The computer allowed interactive alteration of color scales to best enhance anomalies of interest and to magnify smaller anomalies that were indistinct.

More than 30 anomalies of variable size and magnitude were observed. The attributes used to select anomalies for investigation included: (1) magnitude of anomaly, (2) polarity of anomaly, (3)

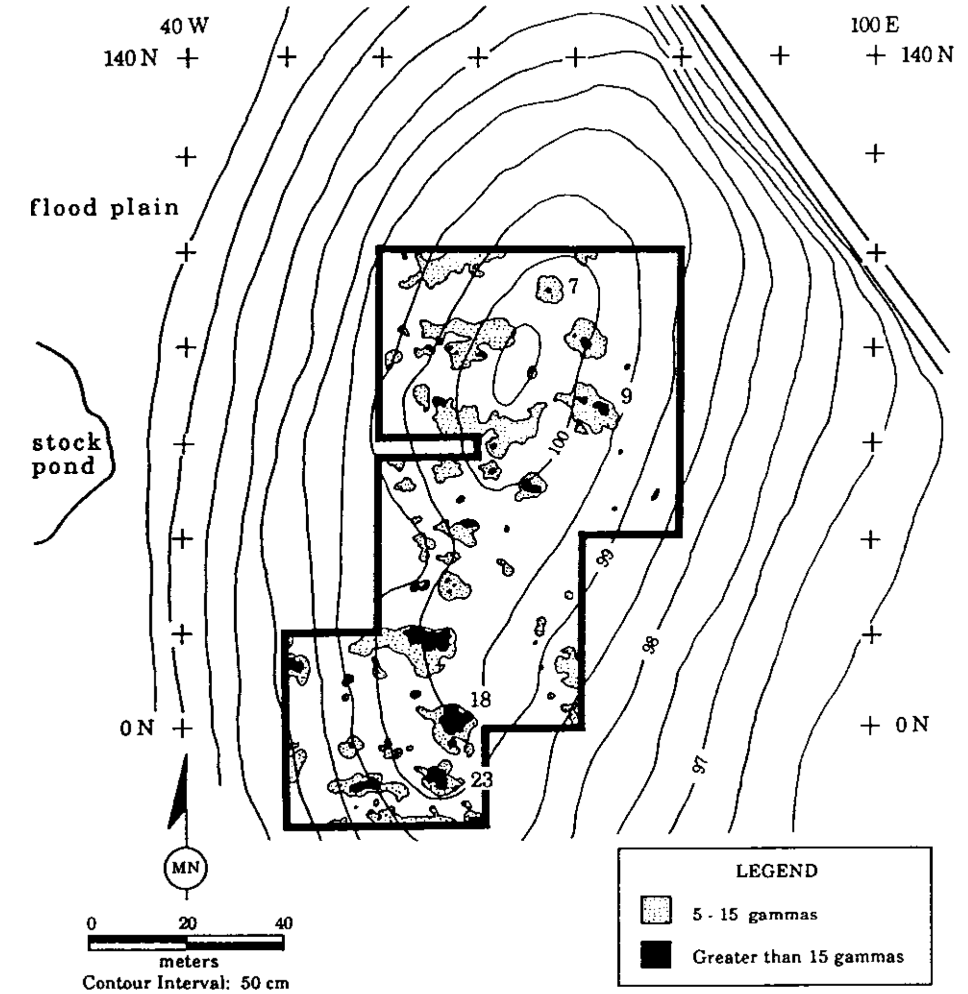


Figure 2. Total magnetic field recorded at Bird Point Island showing major magnetic anomalies superimposed on the topographic map.

direction of polarization, (4) cross-sectional area of anomaly, (5) symmetry of anomaly, (6) similarity to models of idealized archaeological features, and (7) similarity to anomalies created by archaeological features from other areas. Figure 2 is a map of the total magnetic field at Bird Point Island. Virtually all of the anomalies shown on the map were caused by cultural features, but not every feature on the site resulted in the creation of a magnetic anomaly.

Several anomalies exhibited pronounced differences in degrees of symmetry and polarity. Some clearly were caused by cultural features, having polarization toward north and a ratio of high to low components consistent with those found in association with cultural features at other archaeological sites. Many of these anomalies also exhibited pronounced bilateral symmetry, which is a classic indicator of features with uniform composition. Other anomalies were clearly of modern origin, with signatures characteristic of iron objects. However, most anomalies were problematic, exhibiting slightly symmetric to irregular shapes and weak polarity. The Season II excavation program was initiated to investigate the source of these anomalies, and excavation revealed that nearly all anomalies were caused by cultural features.

Electromagnetic Conductivity Survey

Electromagnetic conductivity survey is a technique that measures soil conductivity, the reciprocal of galvanic resistivity. Although resistivity surveys have been used to locate cultural features successfully (Carr 1977, 1982), aside from the work of Beven (1983), there has been relatively little use of conductivity survey for this purpose. However, the EM-38 conductivity sensor provides better resolution and more easily interpretable results than the equipment used to conduct resistivity surveys (McNeill 1980:5). The EM-38 electromagnetic conductivity sensor operates on the principle of electromagnetic induction. A transmitter coil energized with alternating current at an audio frequency induces very small currents in the soil that generate a secondary magnetic field. The meter measures the ratio of the secondary field to the primary field, which is linearly proportional to soil conductivity. This provides a direct reading of soil conductivity in millimhos/m (McNeill 1980:5).

The creation of electromagnetic conductivity anomalies is related to variations in soil moisture, soil porosity, and ionic content. Water, which increases soil conductivity, percolates through the soil matrix at differential rates due to variations in permeability. As a result, poorly drained areas display high-conductivity readings since they retain soil moisture, whereas well-drained areas yield low-conductivity readings due to their low moisture content.

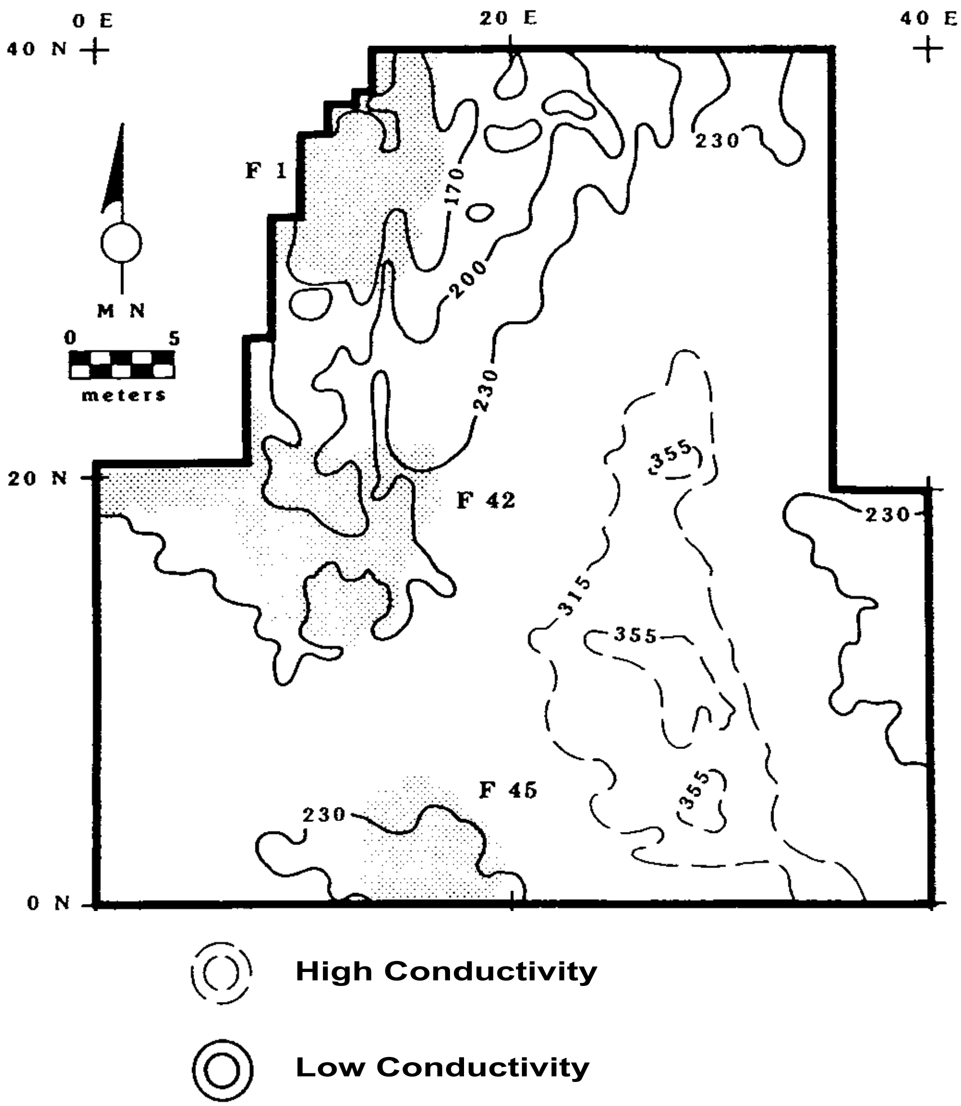
The effects of cultural activity upon the soil can alter soil moisture content to create conductivity anomalies. Excavation of pits into the B horizon is the principal form of cultural activity affecting soil moisture content. The sandy loam A horizon at Bird Point Island is a porous, well-drained soil ranging in depth from 20 to 50 cm, whereas the clay-enriched B horizon is relatively impermeable. Under natural conditions, water perches on top of the B horizon as it percolates down from the A horizon, increasing soil moisture at this depth and registering as highly conductive on the sensor. However, when the B horizon is penetrated completely by the excavation of large pits, drainage is improved within the pits as water drains through the sandy C horizon sediments. As a result, soil moisture decreases within the feature and registers as a low-conductivity anomaly.

Survey Procedures. The EM-38, a portable sensor developed by Geonics Limited, was used to measure electromagnetic conductivity over 1,400 m' at Bird Point Island during Season II. Initially, three 20-x-20-m blocks (Grid I) were surveyed immediately east and south of Feature 1 at a sample interval of 1 m, and one 10-x-20-m block (Grid 2) was surveyed at the north end of the site because magnetometer data indicated that a large magnetic anomaly was present in that area. Later, Grids 3-5 were surveyed in an attempt to identify the locations of structures (Figure 1). Grid 3 was situated over a portion of the undisturbed half of House 1, while Grids 4 and 5 were located in areas thought likely to contain additional structures.

Results. The data were convolution filtered to reveal anomalies caused by discrete features. These anomalies are illustrated in Figure 3. Overlap was observed among high-intensity magnetic anom alies, low-intensity conductivity anomalies, and large cultural features.

The vertical sensitivity of the instrument also affects its ability to record soil conductivity. The vertical sensitivity curve for the EM-38 is a skewed bell shape when the coils are oriented in a vertical position, with maximum sensitivity at a depth of about 40-50 cm and lower sensitivity above and below this depth, particularly near the surface and below 2 m. This implies that water perched in the soil at the 40-50 cm depth will contribute a much stronger reading than water perched at any other depth. At Bird Point Island, the EM-38 successfully distinguished large pits dug through the B horizon because moisture in these pits had moved below the zone of maximum sensitivity.

The results of the survey in Grids 3-5 were not easily interpretable. For Grid 3, readings were taken at 10-cm intervals, and the raw data were convolution filtered to isolate anomalies that might be caused by postholes. Unfortunately, no such anomalies were observed. Grids 4 and 5 were sampled at 50-cm intervals, which provided greater detail than grids surveyed at I -m intervals. In general, however, there was no obvious correlation between the observed conductivity anomalies and the cultural features discovered during subsequent excavation.



Features 1, 42, and 45

Contours expressed as mmhos/m x 10

Figure 3. Map of the electromagnetic-conductivity field over Grid 1 showing areas of high and low conductivity in relation to large cultural features. Contour expressed as mmhos/m × 10.

Assessment of Remote-Sensing Techniques

Both the magnetometer and the EM-38 were able to detect cultural features at Bird Point Island, but each instrument responded to different phenomena. Figure 4 illustrates the responses of both instruments for points sampled at 2-m intervals along the 15E line, along with the depth to the

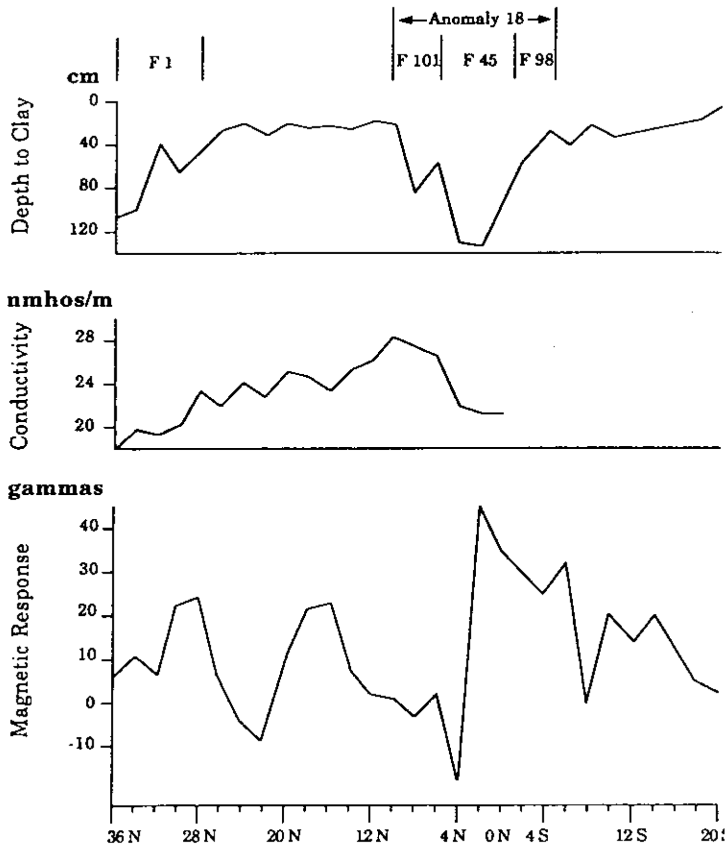


Figure 4. Depth to the argillic horizon (clay), electromagnetic-conductivity response, and magnetic response recorded along the 15 E lice at Bird Point Island.

argillic horizon, as determined by core samples. Soil data and magnetic data were collected along the I5E line between 36N and 20S, but conductivity data were collected only as far south as ON, so the graph of conductivity readings ends at that point. The 15E line was selected to illustrate the readings from both remote-sensing instruments because it encompassed the edge of Feature 1 and cut across all of Anomaly 18, which contained Features 101, 45, and 98.

Depth to the clay B horizon was recorded by Edward Janak of the Soil Conservation Service, using an auger to collect specimens. The upper graph in Figure 4 is a plot of the depth to clay, which shows that the B horizon was encountered between 35 and 40 cm below surface along this portion of the site, except where clay had been removed by the excavation of large pits (i.e., the features associated with Anomaly 18 and Feature 1). The plot of the conductivity response closely parallels the plot of the depth to clay in the area over Anomaly 18. A sharp decrease in conductivity occurs at the same point that depth to clay increases. The relation between depth to clay and soil conductivity is not strictly a one-to-one relation, as demonstrated by the gradual decrease in conductivity toward Feature 1, where depth to clay remains more or less constant. However, it is clear that the EM-38 responded to large pits that had completely penetrated the B horizon, since the lowest conductivity responses were recorded within Feature I and the features associated with Anomaly 18.

The results of the conductivity survey indicate that the EM-38 may be effective only for locating large features that have completely penetrated the B horizon. Although several anomalies were observed on maps of Grids 3-5, excavation revealed that they were not associated with any of the small features present. Since the vast majority of cultural features on archaeological sites are similar in size to these, the inability to record small features appears to be a major limitation of this specific instrument.

The magnetometer response along the I5E line is more complex than the response of the EM-38. The variations in the magnetic readings shown in Figure 4 appear to be only slightly related to the depth of clay, which should be expected since the magnetometer responds to changes in the distribution of iron oxides and magnetically enhanced rock. Even though the plot of the magnetic data fluctuates considerably, it clearly shows the location of Anomaly 18 as a dipole with a group of low readings ranging between 0 and negative 17 gammas to the north followed by a dramatic increase to the south of readings between 30 and 44 gammas. This is the characteristic response of a dipolar anomaly for in situ features.

Excavation revealed that subsurface features, primarily pits of various shapes and sizes, were present beneath nearly all of the magnetic anomalies. Although many features did not exhibit magnetic anomalies, more features were detected by the magnetometer than by the EM-38 relative to the areas surveyed by both instruments. In addition, the magnetometer recorded features as small as I m in diameter in addition to large features, whereas the EM-38 only recorded large features. Also, the magnetometer picked up anomalies over the same large features recorded by the EM-38. For these reasons, the magnetometer appears to be a more effective and efficient instrument for use in locating cultural features, at least within the Richland Creek Project area.

INTERPRETATION OF MAGNETIC DATA

Feature Function

During Season II, trenches of contiguous 1-x-1-m units were excavated to examine 12 large (8 m^2 or larger) anomalies that exhibited varying degrees of magnitude, symmetry, and polarity. Large pits were uncovered within the areas encompassed by the anomalies, and it was hypothesized that the differences in symmetry and polarity reflected different degrees of redigging and reuse of these pits. Further excavations into many of these pits showed them to have irregular shapes in profile and poorly defined boundaries at their interface with the B horizon. The pit fill was comprised of sandy loam A horizon soil that contained artifacts similar to those found in the A horizon around the pits, however higher frequencies of fire-cracked rock (Wilcox sandstone and ironstone), dart points, scrapers, and cores occurred within the features. Three of these anomalies are discussed in greater detail here as examples of the variations in symmetry and polarity observed and the way in which these variations correspond with different degrees of feature reuse.

Anomaly 7 (Feature 34) had a magnitude of 18 gammas and exhibited the greatest degree of bilateral symmetry observed among all anomalies on the site, with a single peak in magnetic response in the center. It also was oriented closely toward the north (Figure 5). These factors suggested a fairly homogeneous magnetic source and a feature subjected to little reuse. The pit measured approximately 5.0 x 3.4 m in diameter and was .8 m deep. Pit fill was a homogeneous, dark-brown sandy loam containing fire-cracked rock, lithic debris, and baked clay. Macrobotanical remains included charred nut shell and possible prairie turnip (Psoralea). The high content of fire-cracked rock and charred plant remains suggested that the pit may have been used for roasting.

Anomaly 9 (Feature 36) had a magnitude of 45 gammas and an irregular shape in plan view. The most striking aspect of the anomaly was that it exhibited a polarity shifted nearly 30 degrees east of north, suggesting that the feature had been reoriented since the last episode of strong heating (Figure 6). Another unusual characteristic was the fact that two magnetic peaks occurred within the anomaly rather than one. Many other anomalies at the site also exhibited the shift in polarity and multiple magnetic peaks. It was hypothesized that these characteristics reflected episodes of redigging and reuse. Excavation of Anomaly 9 (Feature 36) revealed a roughly basin-shaped pit with an undulating bottom, measuring 9.5 x 5.3 m in diameter and .95 m in depth. The pit fill was a mottled mixture of A and B horizon soil, but the artifact content was identical to that of Anomaly 7 (Feature

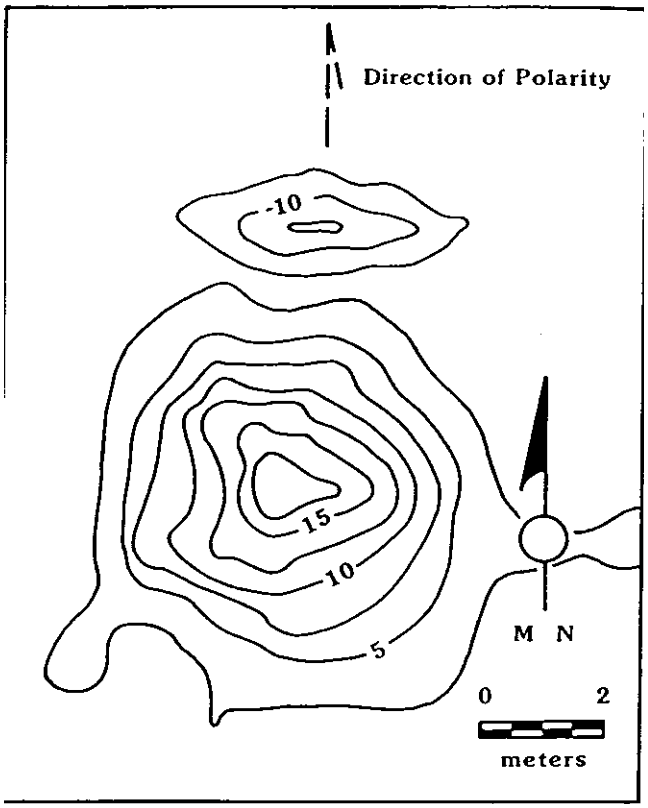


Figure 5. Magnetic field of Anomaly 7 formed by Feature 34 (measured in gammas).

34). The artifact content suggested that both pits had been used for the same purpose; however, Feature 36 appeared to have been reused to a greater extent than Feature 34.

Anomaly 23 (Features 47, 95, 97, and Burial 16) had an overall magnitude of 56 gammas, but exhibited a variety of localized magnetic peaks. The anomaly exhibited very little symmetry and only weak polarity oriented in several directions (Figure 7). These characteristics were thought to represent a complex feature subjected to several episodes of reuse. Excavation supported this hypothesis, revealing several partially overlapping features that were grouped together. A circular pit (Feature 97), measuring 2.5 m in diameter and .76 m in depth, was tangent to two overlapping pits (Features 47 and 95) that encompassed an area of approximately 6 x 3 m. An intrusive burial (Burial 16), measuring approximately 1 m in diameter and .6 m in depth, was found inside Feature 95.

These three examples illustrate the fact that magnetic survey data can be used successfully for assessing the general nature of cultural features prior to excavation. The next step in the use of magnetic data was assisting in the interpretation of feature function by conducting a magnetic survey of experimental features designed to replicate those found at the site.

Replicative Experiments

As previously mentioned, the large pits found to be the source of magnetic anomalies contained concentrations of fire-cracked rock indicating that some kind of heating activity had occurred in the pits. However, little charcoal or oxidized soil was present, unlike hearths found on the site that contained substantial quantities of both. This led to the hypothesis that the sandstone was heated

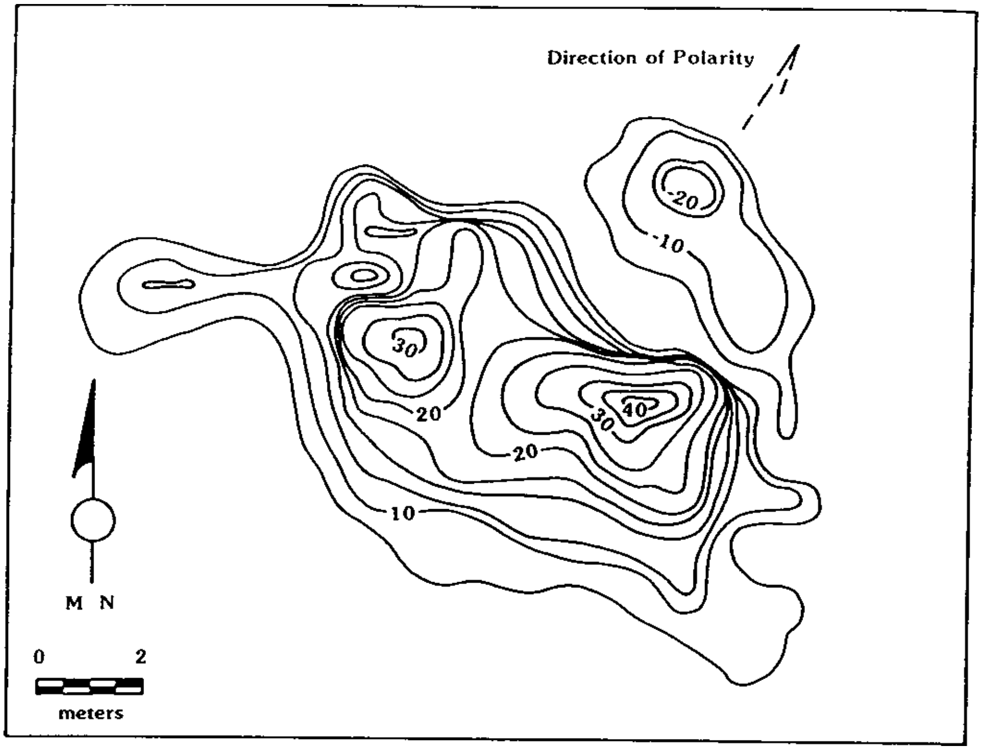


Figure 6. Magnetic field of Anomaly 9 formed by Feature 36 (measured in gammas).

outside of the pits and placed inside while hot. The fact that charred specimens of acorn, hickory, and pecan shell, as well as possible Psoralea tuber, were identified (Fritz 1983) argued for use of the features as either storage pits or roasting pits. The latter possibility seemed most likely because of the presence of fire-cracked rock and because roasting is a historically documented means of nut preparation (Swanton 1946:364), as well as of Psoralea preparation (Reid 1977).

Early in the course of the research at Bird Point Island, the archaeologists (Martin and Bruseth) and the magnetic specialist (Huggins) met informally on several occasions to discuss possible causes of anomalies and excavation strategies. At this point, additional meetings were convened to devise a means of testing the hypothesized functions of the features. A series of experiments was designed to examine the two hypotheses related to storage and roasting, and to determine the precise source of magnetism within the features.

It was reasoned that magnetic enhancement of the iron-rich Wilcox sandstone probably occurred when it was heated for use in cooking or roasting. This idea could be tested by examining the magnetic response of Wilcox sandstone before and after heating in an experimental hearth. On the other hand, the disturbance of iron oxides in the soil caused by digging a storage pit and backfilling after use may have accounted for the observed increase in magnetism. This hypothesis could be tested by measuring the magnetic response of a pit dug and refilled as part of the experiment. If a magnetic increase was observed over the heated rock, but little increase was observed over the pit, this would lend support to the roasting hypothesis. If the reverse was observed, then the storage hypothesis would make more sense.

The test required an area free from excessive background noise and devoid of cultural anomalies. A nearby terrace was selected that had geological and soil properties identical to Bird Point Island,

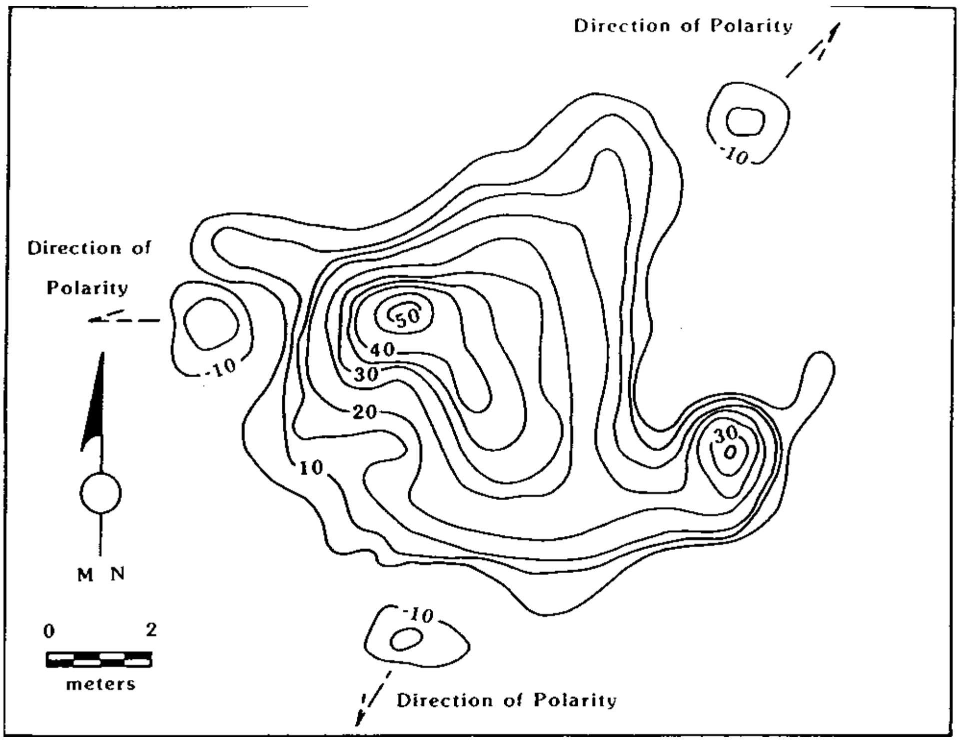


Figure 7. Magnetic field of Anomaly 23 formed by Features 47, 95, 97, and Burial 16 (measured in gammas).

but which lacked cultural material. Two contiguous areas of 440 m' each (designated Areas I and 2) were surveyed with readings taken at 50-cm intervals. The results showed that little variation existed in the natural magnetic field of the terrace. No anomalies were recorded in Area 1, and only a small anomaly due to an iron object was recorded in Area 2. In retrospect, the data from the control areas would have been useful for the initial interpretations of the magnetic field at Bird Point Island. The data demonstrate that virtually all of the anomalies observed at the site are the result of cultural activity, including small anomalies of lesser intensity that were omitted initially from investigation.

The magnetic properties of the Wilcox sandstone were examined during the first part of the experiment. Approximately 22.7 kg of Wilcox sandstone were gathered from the outcrop in the slough south of Bird Point Island and spread evenly over a I-m' pit dug to a depth of 10 cm within Area 1. A magnetic survey conducted over this pit and the surrounding area revealed that the rock was very weakly magnetic, with a low component of -12 gammas to the north (Figure 8). A fire then was built over the pit to heat the rock, and another survey was conducted after allowing several days for the rock to cool. This time a magnetic anomaly exceeding 400 gammas with a strong north–south polarity was recorded, demonstrating beyond a doubt that Wilcox sandstone becomes magnetically enhanced when heated (Figure 9).

It was clear from these results that any hearths containing Wilcox sandstone would be clearly visible on the map of the magnetic field of the site. Reexamination of this map revealed an anomaly within the midden, Anomaly 32 (Feature 104), that was virtually identical in size, shape, and polarity to the anomaly produced by the experimental hearth. Prior to the experiment, it had been assumed that this anomaly was caused by an iron object that had been missed by the metal-detector ex-

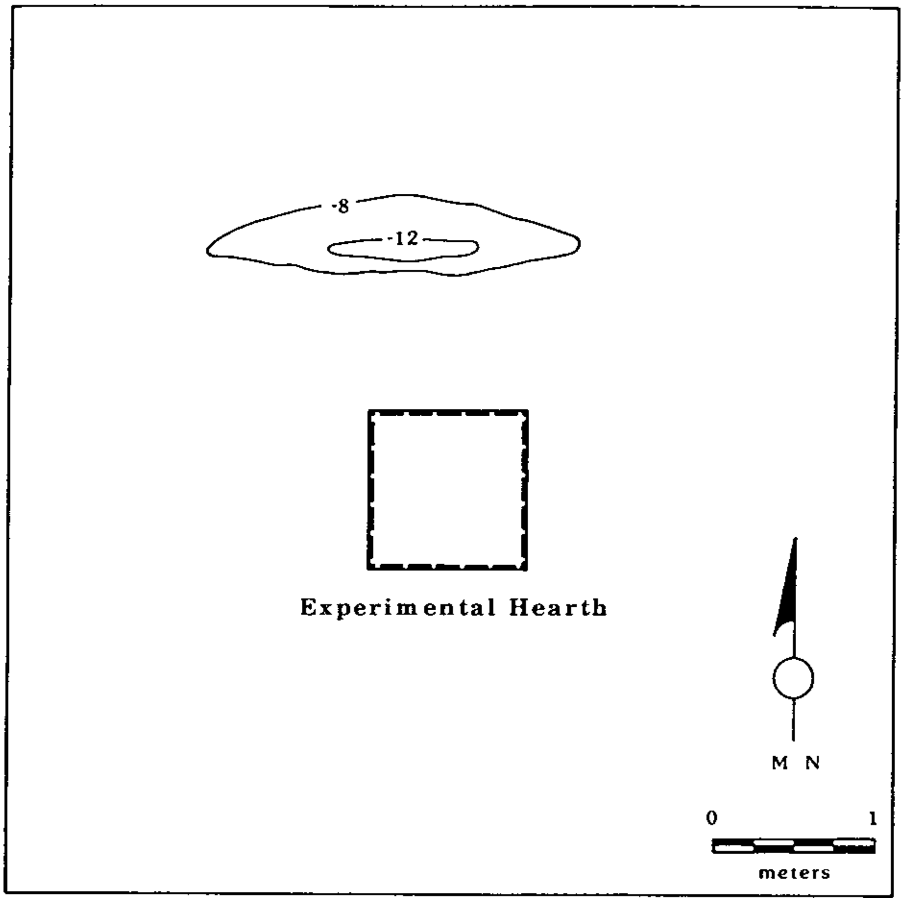


Figure 8. Magnetic field over the experimental hearth prior to burning (measured in gammas).

amination because its magnitude was far greater than that of most anomalies produced by cultural features. However, subsequent excavation revealed a rock-and-charcoal-filled hearth (Feature 104) measuring I m in diameter, which looked nearly identical to the experimental hearth. The archaeological hearth had a magnitude of 140 gammas, approximately 35 percent of the magnitude of the experimental hearth, but it contained only 6.8 kg of rock, approximately 30 percent of the quantity used in the experimental hearth. As might be expected, this indicates that the magnitude of the anomalies observed at the site is related directly to the quantity of burned rock contained within the features.

To examine the effect of excavation and mixing of soils on the magnetic field, a pit 1 m in diameter and .75 m deep was excavated in Area 2. This depth was selected to ensure that A and B horizon soils would be disturbed and mixed to a similar degree as that found in the the prehistoric features at Bird Point Island. The pit was refilled and surveyed with the results showing no detectable anomaly. The conclusion derived from these experiments is that the pits at Bird Point Island were detectable largely due to the presence of magnetically enhanced fire-cracked rock.

The next question that was addressed concerned the site-formation processes responsible for the deposition of fire-cracked rock in the pits. Although it was clear that the magnetism in the pits was

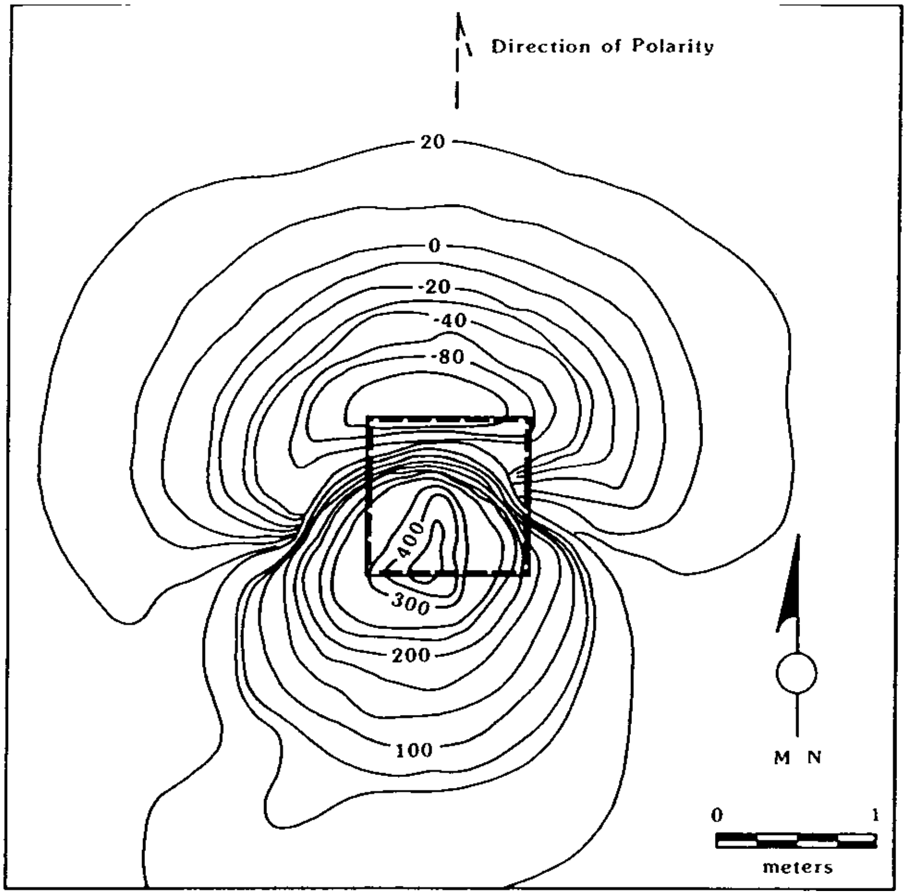


Figure 9. Magnetic field over the experimental hearth after burning (measured in gammas).

due to the presence of fire-cracked rock, it was not clear whether this rock had entered the pits as the result of a primary, heat-related activity or was introduced as discard from activity elsewhere on the site. Since trash disposal in pits was common prehistorically, disposal of the fire-cracked rock was considered a likely possibility unless otherwise ruled out.

Once again, magnetic properties were used to provide the answer to this problem. One of the properties of magnetically enhanced rock is that as it cools in situ, the iron oxides become oriented toward magnetic north, giving the rock the same magnetic declination and inclination as the earth's magnetic field at the time of cooling. This realignment of iron oxides during heating is the same property utilized by the archaeomagnetic dating technique. If the rocks had been placed in the pit while hot and had cooled in situ, they should all exhibit the same, or allowing for the effects of bioturbation, very similar orientations. On the other hand, if the rocks had been discarded into the pit, then their orientations should vary and no central tendency should be apparent. Because disturbance of the rock from reuse of these features would also create varied orientations, relatively undisturbed portions of these features had to be identified in order to find suitable rocks for sampling.

Five samples of Wilcox sandstone were obtained from a cluster of three rocks uncovered in one of the large pits believed to have been used for roasting. Feature 38 (Anomaly 13) measured approximately 6.3 x 5.0 m and was 1.0 m deep. The matrix was characterized by a zone of light-brown mottled fill to a depth of about 70 cm, with a gradual transition to a yellowish-brown fill in the lower 30 cm. Small fragments of Wilcox sandstone were scattered throughout the fill, with occasional larger fragments present, such as those from which the samples were obtained. Anomaly 13 exhibited a single large magnetic peak covering a broad area over the middle of Feature 38, which was associated with a magnetic low shifted toward the northeast. The shifted polarity was similar to that observed for Anomaly 9 (Feature 36) described earlier, but Anomaly 13 did not exhibit the multiple magnetic peaks present in Anomaly 9.

Feature 38 was excavated as a test case to examine the nature of pit use and hypothesized episodes of reuse. Small units (I x .5 m) were dug across the center of the pit for finer spatial control, and the vertical and horizontal distribution of Wilcox sandstone was examined. In some units, similar densities of Wilcox sandstone were present in nearly all levels throughout the profile, suggesting that little disturbance from redigging had occurred in that portion of the feature. On the other hand, in one group of three adjacent units, evidence suggesting reuse was observed. The middle unit contained moderate frequencies (100—149 pieces per level) of sandstone in levels 1—3 followed by higher frequencies (150—199 pieces per level) in levels 4—6, whereas both surrounding units had high densities (150—199 pieces per level) in upper levels and moderate densities at lower levels (100—149 pieces per level). This pattern suggests that a pit may have been dug into the middle unit at some time after the sandstone was originally deposited, thereby redistributing some of it in the upper levels of the surrounding units. The results of this analysis suggest that some portions of the pit were subjected to reuse, whereas other portions remained intact. Samples for magnetic analysis were taken from a cluster of three larger rocks in an area thought to have remained intact.

The rock samples were collected by Holly Hathaway of the Colorado State University Archaeo-magnetic Laboratory. Horizontal strikes were made on each rock while in situ and the rock's compass orientation was recorded. One-inch cylindrical cores were taken from the rocks in the laboratory, which then were cut to appropriate lengths and sanded to remove impurities from the coring process. Three samples were taken from the largest rock (samples 1—3) and one sample each was obtained for the other two rocks (samples 4 and 5). The cores were measured for their natural remanent magnetism on a Schonstedt Spinner Magnetometer (Holly Hathaway, personal communication 1983). The results indicate that all of the rocks had magnetic fields oriented towards north. Hathaway reports:

> Each of the cores is generally oriented in a northerly direction. Sample 4 is the possible exception to this, but this is probably due to the incomplete field orientation. Although there appears to have been slight shifting of the fragments prior to field collection due to their small size, the natural remanent magnetism directions indicate a strong possibility that these fragments have generally retained their original in situ position from past heating of the material (Holly Hathaway, personal communication 1983).

These results support the hypothesis that some of the fire-cracked rocks found in the pits cooled in situ and indicate that the Wilcox sandstone was not deposited as a result of trash disposal, lending additional support to the roasting-pit hypothesis.

Spatial Distribution of Fire-Cracked Rock

Aside from providing information about feature function that could have been obtained by no other means, magnetic data also aided the interpretation of spatial distribution of fire-cracked rock. In recent years, increasing emphasis has been placed on the study of spatial patterning of artifacts as a means of delineating discrete activity areas on archaeological sites. The generation of maps from large data sets has been simplified by computer programs such as SYMAP (Jermann and Dunnell 1976). Defining the spatial distribution of features and activity areas was a major research goal at Bird Point Island, so SYMAPs were generated for each artifact category. Use of magnetic-survey data, in conjunction with the expertise of the magnetic specialist, helped to explain puzzling patterns observed with respect to the distribution of fire-cracked rock across the site.

When the SYMAP for large fire-cracked rock (2.5 cm in diameter or greater) was compared with the SYMAP for small fire-cracked rock (1-2.5 cm in diameter), major differences were observed. A cluster of large fire-cracked rock was observed in an arc measuring 20 x 7 m that curved around the wall of House I, but the distribution of small fire-cracked rock exhibited a low density in the same location. This phenomenon was rather confusing, so the map of the magnetic field was examined to search for some interpretive clue.

Although two small magnetic highs were observed within the area encompassed by the large cluster, the vast majority of the duster exhibited an overall decrease in magnetism. Since the magnetometer experiment had demonstrated that Wilcox sandstone is weakly magnetic in an unfired state and becomes strongly magnetic when heated, it was clear that the majority of rock in this cluster had never been fired. Because of the natural reddish-to-black color of the unmodified sandstone, it was often impossible to visually distinguish burned from unburned sandstone in the laboratory. As a result, the rock in the cluster had been misidentified as fire-cracked and included on the map. Without the aid of the magnetic survey, this fact would not have been recognized.

The presence of a concentration of unburned rock makes sense if Wilcox sandstone was stored on site for use in hearths and roasting pits. The fact that the rock outcrop in the slough is under water during a significant portion of the year strongly implies that collection and storage must have occurred during the dry season. A likely location for storage would be an area in close proximity to hearths and roasting pits. The location of the cluster next to House I would have placed rock within easy access for household cooking and for roasting in a nearby pit associated with House 1. The unburned large fragments recovered from excavation probably represent pieces that broke off as rocks were tossed in piles.

SUMMARY AND CONCLUSIONS

Magnetic surveys and electromagnetic conductivity surveys were conducted at Bird Point Island during three of the four seasons of field work conducted during the Richland Creek Project. A large area was surveyed with a proton precession magnetometer, an instrument proven effective for locating cultural features on other archaeological sites. The results of the magnetic survey were positive, with most anomalies marking the locations of subsurface pits. In addition, the shapes and sizes of many of the anomalies closely resembled the shapes and sizes of the corresponding archaeological features. A small area was surveyed with an EM-38 electromagnetic conductivity sensor to assess its utility for locating features. The initial results were good, with the sensor recording the same large features recorded by the magnetometer, so additional areas were surveyed. However, the EM-38 did not pick up small features, and therefore, recorded far fewer features than did the magnetometer. As a result, magnetic survey appears to be a more appropriate remote-sensing technique for sites found in the Richland Creek area. The conductivity contrast appears to be insufficient to allow the EM-38 to locate anything other than the largest archaeological features.

Some important points were noted over the course of the work conducted at Richland/Chambers Reservoir with regard to the best manner in which to conduct a survey and examine the resulting data. First of all, for a magnetic survey to successfully locate cultural features, a broad area should be covered and the survey of a control area away from the archaeological site under study is recommended highly. Only under rare circumstances is it possible to survey an entire site, but it is usually feasible to include some marginal site areas where little activity is believed to have occurred. This information is useful for delineating site boundaries and isolating areas of concentrated activity. The survey of a control area having geological and pedological properties similar to those of the site also provides useful data for comparison and should be an essential part of any overall program. The magnetic field over the control area can allow cultural anomalies to be separated from any natural anomalies that may be present by providing a picture of the natural level of background noise and the extent of natural anomalies.

Second, once features have been located and excavated, magnetic data often can aid in their interpretation. The experiments conducted with the magnetometer to test hypotheses about feature function provided important information that could not have been obtained in any other manner.

Long-term projects can benefit by budgeting for experimentation designed to identify sources of magnetism. Such identification is a major step toward defining feature function.

Finally, communication between the archaeologist and the magnetic specialist is essential for eliciting the most from the data. The ability of a proton precession magnetometer to detect cultural anomalies depends on the geological and pedological properties of the site as well as the kinds of cultural features present. Data collection requires corrections for diurnal drift and a knowledge of the natural factors that can adversely affect survey results. Once data have been collected, valid interpretation of the results requires a firm foundation in the physical properties that cause magnetic anomalies, as well as a knowledge of filtering techniques necessary to remove extraneous responses. Magnetic survey is a scientific tool readily available to the archaeological community, but it is important for archaeologists and physicists to work together closely to arrive at reasonable and justifiable interpretations. Archaeologists who believe that a magnetometer can be used with the ease of a metal detector probably will be disappointed with the results of their surveys and may miss out on information essential to the interpretation of the sites they are examining.

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NOTE

[1] The equivalence of terms for geophysical units of measurement are as follows: 1 gamma = 1 nanotesla (nT}, 1 millimho/m = 1 millisiemens/m (mS/m).

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March 1:	Greater Southwest, Mesoamerica, Central America.
June 1:	Caribbean, The Amazon, astern Brazil, and the Orinoco, Andean South America, Southern Cone.
September 1:	Siberia, Far North, Northwest, California and the Great Basin.
December 1:	Plains, Great Lakes, Northeast, Southeast.

GREATER SOUTHWEST

ARIZONA. Paul F. Reed and Anthony L. Kiesert (Navajo Nation Archaeology Department [NNAD]) directed surface collection and test excavation at 20 sites ranging from Middle Archaic to Anasazi Pueblo III located along the Antelope Point Road (Navajo Route 22B), south of Page. All of the sites (temporary camps) consist predominantly of lithic artifacts with few ceramics and surface features.

Larry Benallie (NNAD) surveyed an Indian Health Service water line from Klagetoh to Wide Ruins (Kindel). This survey revealed considerable prehistoric and historic occupation of the area with sites from Basketmaker III through Pueblo III and early Navajo occupation (Kin Nazhin Pueblito, A.D. 1760). Three Chacoan Great houses and a Basketmaker III village with an associated Great Kiva have been located and recorded.

Dennis Gilpin (NNAD) has been coordinating analysis of a Basketmaker II site at Lukachukai where water-line construction exposed an ash lens, two pit structures, five hearths, one bell-shaped pit, and one ash stain. Carol Brandt (Zuni Archaeology Program [ZAP]) analyzed flotation samples in which maize and Cheno-Am seeds were most common, respectively. Radiocarbon dates for the site are 3110 t 90 B.P. (Beta-43317) and 3040 ± 90 B.P. (Beta-43318).

The Museum of Northern Arizona/Northem An zona University/Oberlin Field School (under direction of David R. Wilcox and Linda Grimm investigated sites in three areas of the Kaibab and Pres colt National Forests. On the Mogollon Rim, two Co honina ball courts and associated sites dating to ca. A D. 1000 were identified and mapped. On a site nea Sitgreeves Mountain, excavations continued in two al cove houses, a linear room block, and a deep, 13-n pithouse with central hearth. A large walled plaza sit, with several large rooms and outside cremation area was also mapped and surface collected. South of Grand Canyon, Linda Grimm surface collected am tested a shallow Archaic site.

The University of Arizona [UA] Archaeological School completed its twenty-eighth season at Grass hopper in 1990 under the direction of J. Jefferson Reio Survey activities focused on ceramic variability an. population movement during the late A.D. 1200s. Ex cavations at Grasshopper Spring Pueblo (ca. A.D. 1275 1300) provided information on an earlier room bloc occupied by an Anasazi group during the Pueblo I period. Research continued on the rapid social an economic changes that occurred ca. A.D. 1300 involv

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