BEYOND SQUIER AND DAVIS: REDISCOVERING OHIO'S EARTHWORKS USING GEOPHYSICAL REMOTE SENSING

Jarrod Burks and Robert A. Cook

The prehistoric earthworks of Ohio have played a major role in the development of American archaeology and they continue to figure prominently in archaeological research. However, while a select group of larger earthwork sites have been intensively studied and resurveyed with geophysical survey instruments, much of the ongoing earthwork research, and reference to less-well-known sites, still relies on nineteenth- and early twentieth-century maps. In this article, we present the results of magnetic gradient surveys at three earthwork complexes in south central Ohio. Though much degraded by agricultural plowing and other historic impacts, our survey results show that despite near invisibility at the surface, Ohio's earthwork sites are (1) readily detected in geophysical surveys, (2) more complex than most early maps suggest, and (3) more numerous and varied than once thought. Given the major role these sites have taken on in studies that explore topics ranging from community structure and burial ceremonialism to population mobility and the development of socioeconomic complexity, a radical redrafting of the nineteenth-century maps could have far-reaching implications in the study of Woodland period (specifically, ca. 300 B.C.-A.D. 500) cultures in the Midwest U.S.

Las prehistóricas formaciones de tierra de Ohio han tenido un papel muy importante para el desarrollo de arqueología americana y siguen siendo un tema relevante en esta disciplina. Profusa investigación actual y referencia a los sitios pocos conocidos todavía dependen de los mapas de los siglos XIX y XX temprano, sin embargo un grupo selecto de grandes formaciones ha sido estudiado intensivamente y reanalizado con instrumentos de geofísica. En este artículo, presentamos los resultados de las prospecciones de gradiente magnetic en tres sitios con formaciones de tierra, ubicados en el centro sur de Ohio. Sin embargo, dichas formaciones se encuentran bien degradadaspor la agricultura mecanizada y otros impactos históricos. Los resultados de nuestra prospección muestran que no obstante su casi invisibilidad en la superficie, las formaciones de tierra son (1) fácilmente detectadas con las prospecciones geofísicas; (2) más complejas que lo que la mayoría de los antiguos mapas indican; y (3) más numerosas y más variadas de lo que se pensaba. Por su peso, estos sitios han tenido en la historia de la investigación arqueológica una marca colosal sobre muchos temas tales como: estructura comunitaria, ceremonialismo funerario, movilidad de poblaciones y desarrollo de la complejidad socioeconómica. Por lo tanto, un cambio radical de los mapas del siglo XIX pudiera impactar profundamente el estudio de las culturas del periodo Woodland (específicamente, circa 300 a.C. hasta 500 d.C.) del medio oeste de los Estados Unidos Americanos.

Ohio is well known for its many prehistoric earthwork sites. These range from vast earthwork complexes covering well over a hundred acres, like the Newark Works and the less-known Portsmouth Group, to lone small circles, some not more than twenty meters across. Remarkably, nearly all of the region's earthworks were built between about 400 B.C. and A.D. 400 and are associated with what archaeologists have referred to over the last one hundred years as the Adena and Hopewell cultures. Figure 1 shows the locations of nearly 600 earthwork sites recorded in the *Archaeological Atlas of Ohio* (Mills 1914). While the digital elevation model is relatively new, the distributional map of earthworks has changed little over the last 100 years (cf. Dancey 1984).

Many of Ohio's earthworks have figured very prominently in the development of American archaeology, as exemplified in the nineteenth century by Atwater (1820), MacLean (1879), Squier and Davis (1848), Thomas (1894), and Whittlesey (1850). Today, they still play a major role in the research agendas of archaeologists, attracting

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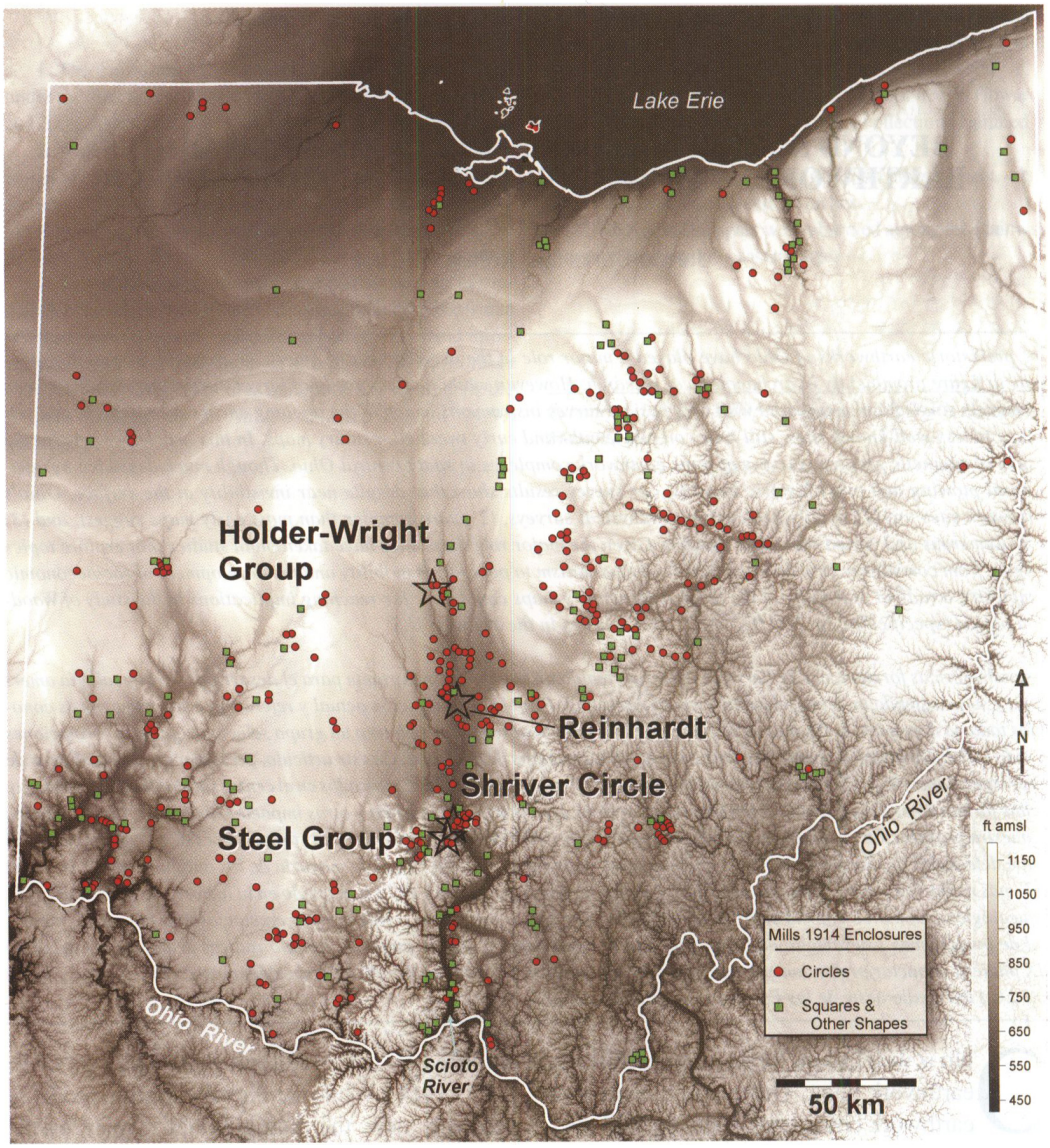


Figure 1. Locations of earthwork sites examined, with a distribution map of earthwork sites in Ohio from Mills (1914).

much attention from scholars who are still, after nearly 200 years of research, trying to understand the Woodland period and the florescence of earthwork construction through studies of archaeoastronomy, community structure, cosmology, burial practice, and connections between sites (e.g., Abrams 2009; Bernardini 2004; Byers 1987, 1996; Carr 2005; Greber 2006; Lepper 2004; Romain 2000; Ruby et al. 2005; Wright 1990). Examples of these earthworks appear in nearly every world prehistory text.

One of the more difficult problems to contend with in today's research on earthworks and their builders is a lack of accurate maps. As early as the late 1800s, archaeologists (e.g., Fowke 1902; Thomas 1889) and civil engineers (Overman 1888) were dissatisfied with the accuracy of the drawings in what was and arguably still is the most important book on Ohio earthworks—*Ancient Monuments of the Mississippi Valley* (Squier and Davis 1848). Many have tried over the years since Squier and Davis's work to remap

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sites showcased in their compendium, and thanks to modern data sources like laser transits and LiDAR (e.g., Romain and Burks 2008a, 2008b) we can now create much less-subjective and very accurate maps of these large and complex sites. However, much has changed over the millennia since these earthworks were built and even since the 1800s when they were first mapped. Natural erosion (e.g., O'Neal et al. 2005) and other forces of degradation, especially agricultural plowing, have so altered many of these sites that they are now barely visible at the surface. Even with very high-density topographic data collected with the latest LiDAR equipment, robotic laser transit, or RTK global positioning system, today's maps are mere sketches of what these earthwork complexes looked like in the past.

In the last decade, archaeologists and others have begun using geophysical survey equipment to remap some of Ohio's many earthwork sites with large-coverage surveys. At some of the larger earthwork complexes like the Hopeton Earthworks (Lynott 2004; Lynott and Weymouth 2002; Weymouth et al. 2009), High Bank Works (Clay 2001; Greber 1999, 2005a; Greber and Shane 2009), Hopewell Mound Group (Greber and Seeman 1993; McKee 2005; Pederson et al. 2001; Pederson Weinberger 2006, 2009), Seip Earthworks (Burks 2005; De Vore 2004, 2005; Greber 1984), and Fort Ancient (Burks 2006a, 2007, 2008), geophysical survey has revealed many new details about these old sites, as well as showing us a more accurate and detailed view of these places than ever before seen. But what of the smaller and/or less well-known earthwork sites? Can geophysical survey data be of use at these sites as well?

In this article, we present the results of magnetic gradient surveys at three different types of earthwork sites: (1) the Shriver Circle, a large enclosure thought to be destroyed; (2) the Steel Group, two small enclosures in a farm field that are still visible at the surface; and (3) the Reinhardt site, a completely new earthwork complex, invisible at the surface, accidentally found during the geophysical survey of a Late Prehistoric period village site. These results show that the actual configuration of many earthwork sites can be quite different from what has been mapped in the past including differences in such details as enclosure size, shape, and gateway configuration but also substantial differences like the presence of previously undocumented enclosures and entirely new earthwork complexes. The implications of these findings are profound for researchers who study the layout of earthwork sites, for those studying Woodland period community structure, and for the preservation community concerned with protecting these sites. And as our nation considers including a small selection of these earthwork sites on its short list for nomination to the UNESCO World Heritage List, we think it important to remember that what of these sites we can see today is merely a shadow (albeit a very impressive one) of what was once present. Though Charles Whittlesey assured his colleagues in 1850 that "those who choose to speculate upon the objects for which these works were made ... may rest assured that they have reliable facts on which to proceed" (Whittlesey 1850:6), our findings at just three of the many hundreds of earthwork sites in Ohio suggest that those interested in studying earthworks must reassess the reliability of what we have accepted as facts—and not just the details of enclosure size and shape but the configuration of entire earthwork complexes. There is much yet to learn about these earthwork sites.

Earthworks and Their Construction

We use the term "earthwork" to refer to sites with earthen enclosures. Ohio earthwork sites come in a wide variety of sizes, shapes, and arrangements and they contain an array of components including: earthen embankment walls and enclosures, mounds, borrow pits, water-holding features, stone pavements, arrangements of postholes in small and large circles, the remains of wooden buildings and other structures, crematory basins and other burned features, and pit features of various sizes. Of greatest significance to geophysical surveys are the earthen enclosures at an earthwork site because these tend to be easiest to detect and interpret. Of course, many of the other components of Ohio earthwork sites can also be detected and are being recognized more frequently as we learn more about them through ground truthing (e.g., Burks 2010a; Riordan 2010). Enclosures most often consist of earthen embankments, from a few inches to nearly twenty feet high, with adjacent ditches. Most of the earlier,

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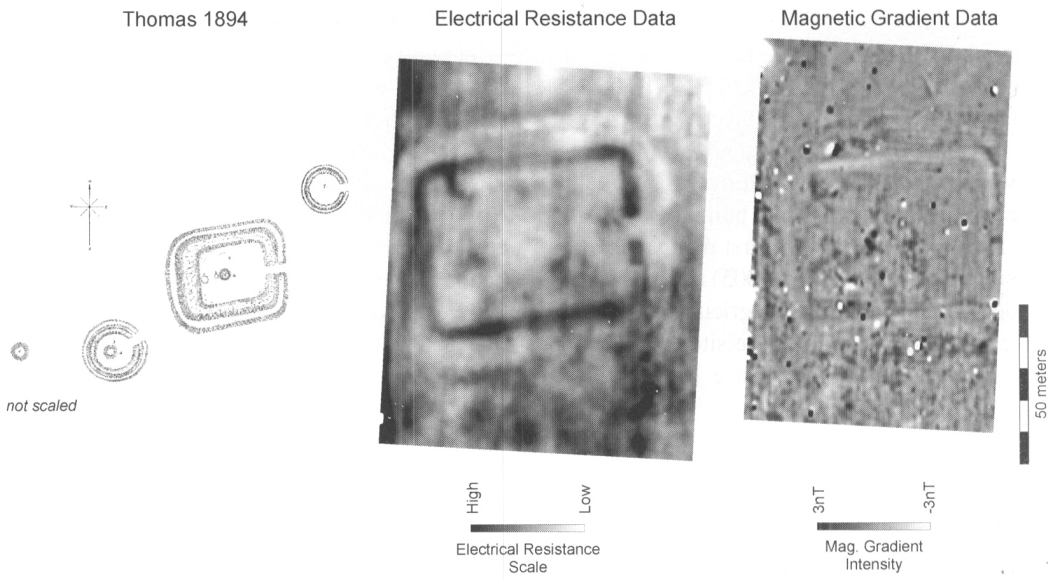


Figure 2. A comparison of magnetic gradient and electrical resistance data collected over the rectangle at the Holder-Wright Group, Franklin County, Ohio.

smaller enclosures, such as the very common small circles (a.k.a., "sacred circles"), have ditches along the inside edge of their embankments, while the larger enclosures have ditches on either the outside or inside edge of the embankment. The largest enclosures of conjoined geometric forms, which come later, most often lack accompanying ditches altogether.[1]

While some of the fill used to construct the embankments was likely derived from the ditches, many earthwork embankments in Ohio were built with soils simply scraped up from their surroundings. In some cases distinctively colored soils were collected and used for construction in specific ways, as at the Anderson Works (Pickard and Weinberger 2009), the Hopeton Works (Lynott and Mandel 2009), and Fort Ancient (Connolly 2004). These contrasting sediments, which differ in particle size, organic content, and mineralogy, are what help make embankments detectable with geophysical instruments, particularly magnetometers. In some cases, there is little to no detectable magnetic contrast between embankments and their surrounding matrix. In these situations, electrical resistance meters are an effective second instrument for detecting flattened embankments. Figure 2 shows the magnetic gradient and electrical resistance data from the central enclosure at the Holder-Wright Group (a.k.a. Wright Group [Shetrone 1925]) in central Ohio (see Figure 1 for location). The only map ever published of Holder-Wright first appeared in Thomas (1894). All three enclosures consist of embankments with an interior ditch, and the ditch with the rectangle was described in 1880 as "some six feet deep" (Williams Brothers 1880:381). Uncharacteristically, as we show below, the magnetometer detected the ditch as a negative area and, not as unexpected, the embankment is barely visible. The electrical resistance data clearly show the embankment, especially the northern edge, and reveal the ditch fill as higher in resistance.[2]

At most sites, the earthwork embankments have been plowed down—many to near invisibility. The fill used in their construction has been spread out, and the ditches have been completely filled in, leaving little at the surface to indicate the presence of an earthwork (see Bernardini 2004: Table 1 for a timeline of embankment flattening at select sites). Since ditches were often dug into the ground as much as .5–1.5 m, they are the best-preserved components of degraded enclosures because plowing has not be able to penetrate to these depths and erase them. But, most ditches have been filled in by years of plowing. When filled with topsoil and other organic-rich sedi-

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Table 1. Comparison of Old and New Data from Surveyed Enclosures.

	#of earthen enclosures	Size	Area Enclosed
Shriver Old[a]	1	1001-1090.5 ft	28 acres
Shriver New[b]	1	1286-1345 ft	~31.2 acres
Steel Group Old	2	Not drawn to scale	--
Steel Group New[c]	10-11	1: 49 m	1831 m^2
		2: 20x25 m	450 m^2
		3: 17x21 m	317 m^2
		4: 19x19 m	408 m^2
		5: 18x18 m	304 m^2
		6: 17x18 m	269 m^2
		7: 14x15 m	214 m^2
		8: 17x17 m	253 m^2
		9: 24x24 m	528 m^2
		10: 22x29 m	508 m^2
		11: 17x19? m	--
Reinhardt Old	0	--	--
Reinhardt New	2-3	Square: 26x32 m	773 m^2
		Circle:27 m	572 m^2

[a]from Squier and Davis 1848; b - area computed by taking average of longest and shortest diameter and then plugging the average into the area formula for a circle.

[b]measurements taken from center of detected and projected embankment as shown in Figure 11.

[c]lengths are all taken from inside edges of the ditches, as are areas. Enclosure numbers from Figure 7.

ments, as most are from millennia of *in situ* A horizon development, ditches are easily detected by magnetometers because of the increased magnetic susceptibility of topsoil relative to the subsoil that surrounds the ditch fill (Clark 2000; Evans and Heller 2003; Le Borgne 1955; Mullins 1977). If a ditch has not been filled in, it might appear as less magnetic than the surrounding soil. Even plowed down, embankment fill can still be detected geophysically. Often, these flattened embankments appear as diffuse, less magnetic areas paralleling a ditch feature. Embankments can be less-magnetic because they are built with clay, which is less magnetic than topsoil, or because the topsoil was stripped away from the surface before the embankment was piled up.

Mounds are the second-most conspicuous component at earthwork sites. They can occur within or outside enclosures, be tall (>7.5 m) or short (< .5 m), and can contain and/or cover the remains of buildings, burials, and thermal features like crematory basins or other burned features. Mounds are surprisingly hard to detect with geophysical survey instruments—even when they are topographically visible. Magnetometers have the most difficult time detecting extant mounds since mounds are often built with sediments that do not contrast magnetically with the surrounding soil. However, mounds containing or covering extensive burned sediments can be very distinctive in magnetic survey data. As with embankments of low magnetic visibility, mounds, even deflated ones, can often be detected with an electrical resistance meter. Detecting features within mounds, however, is a challenge for geophysical survey instruments, though not one that cannot be overcome (e.g., Goodman et al. 2006). In some cases, the mound itself is not detected but the prepared floor on which it is built can be imaged, for example, with electrical resistivity pseudosections and ground-penetrating radar.

There are many kinds of miscellaneous features at earthwork sites that can be detected. Borrow pits, typically filled in, are much like ditches in their detectability. Post circles, like those found beneath many of the Adena mounds excavated in the 1930s and 1940s by William S. Webb in Kentucky (e.g., Webb 1942), also occur with circular enclosures (e.g., Webb 1941). In Ohio, at least one medium-sized circular enclosure, at the Stubbs Works, was found to have begun its existence as a circle of large posts (Cowan 2004). Because posts are small in diameter, they are nearly impossible to detect during most geophysical surveys unless the post fill contains burned earth, as was the case with the post circle detected beneath

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Mound 1 at Hopewell Mound Group (Burks and Pederson 2006). When post circles include large posts set in slip trenches, as was found in 2005/2006 at the Fort Ancient site (Burks 2006a; Riordan 2007), both magnetometers and resistance meters can detect post circles.

Methods

In the three case studies presented here, a Geoscan Research FM 256 fluxgate gradiometer (a magnetometer) was the sole instrument used during the survey. As Kvamme (2006a) has suggested, magnetometry is nature's gift to archaeology; this is especially true with earthwork sites in Ohio. Since our primary goal was to locate large features like enclosures, the magnetic data were collected at a medium-density level of eight readings per meter along transects spaced one meter apart. This data density is not high enough to consistently detect and recognize smaller pit features less than a meter in diameter, though smaller features can be detected at this data density if their fill includes burned earth. We fully appreciate that one-instrument surveys will not detect all possible features at Ohio earthwork sites, as discussed above with the Holder-Wright Group example. But, with a primary objective of finding large enclosures, and the knowledge that magnetometers are perhaps the best tool for detecting enclosures and covering large areas in a relatively small amount of time (usually 2–3 acres per day, with one instrument), we chose to only use a magnetometer for this study. The magnetic data were processed using Geoscan Research's Geoplot v.3(s) software.[3]

Though many are quite large and obtrusive, locating 2,000-year-old earthworks on the ground so as to situate the survey blocks in the proper places required a certain amount of map and aerial photograph sleuthing. Whenever possible, old aerial photographs (United States Department of Agriculture [USDA] aerials available in county engineering as well as soil and water conservation offices) were used to locate portions of the earthwork sites and provide a place to begin the surveys. Once enclosures were found, the surveys were extended outward to cover all known or detected enclosures. An attempt was made to search for additional enclosures beyond the edges of the main complexes, but as our results show, these sites are large and contain many unexpected features, making it difficult to know if their full extents have been detected.

Topographic data are also an important part of the geophysical survey process. Good topographic models of these earthwork sites are a useful tool for locating earthworks to be surveyed and for identifying natural, topographic features that appear in the data, but collecting such large, high-density topographic datasets is very time prohibitive with a ground-based laser transit. For example, in 2001 a complete survey of the Hopeton Works (Squier and Davis 1848:Plate XVII), acquiring a data point every two meters on the embankment walls of the two large enclosures, required about 15 days for two people (Burks and Karen Royce) to complete. Fortunately, in 2006 LiDAR (Light Detection and Ranging) data started to become available online for all of Ohio (by 2009 coverage was statewide).[4] The available LiDAR data in Ohio were collected at a density of approximately one reading every two meters. This density is sufficient to detect many earthworks and larger mounds, but smaller mounds can be invisible (e.g., Tarlton Cross Mound [Squier and Davis 1848: Plate XXXVI, No.1]).

The Sites and Survey Results

We present the results of magnetic gradient explorations at three earthwork sites in southern Ohio: Shriver Circle, Steel Group, and Reinhardt (Figure 1). All three are located in the middle Scioto River valley in floodplain or near floodplain settings, one of the primary loci of Adena and Hopewell and home to the namesake sites for both archaeological complexes. These three sites were chosen because each presents a unique set of survey and preservation challenges.

Shriver Circle (33RO347)

The Shriver Circle is one of the largest ditch-and-embankment circular enclosures in the Middle Ohio valley. It is located on a high floodplain terrace of the Scioto River about 2.6 miles north of downtown Chillicothe.[5] The first map of the site known to the authors is an unpublished drawing in the Daniel and Benjamin Drake section of

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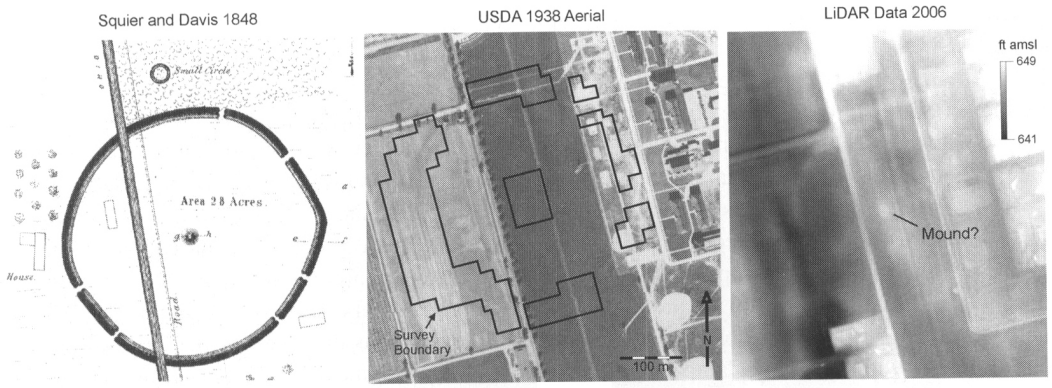


Figure 3. Shriver Circle site nineteenth-century map, historic aerial photograph, and LiDAR topographic map.

the Draper Papers at the Wisconsin Historical Society. While associated with John Poage Campbell, who arrived in Ohio around 1813, the map was likely created a little earlier by Thomas Worthington, the first governor of Ohio (James L. Murphy, personal communication 2010). Though little more than a sketch, this map indicates an embankment with nine gateways enclosing 24 acres (9.7 ha). Text on the map states that the embankment wall and central mound were about ten feet (3 m) tall.

Squier and Davis (1848) made the only well-known map of the site in 1846 (Figure 3), which at that time consisted of an embankment (ca. 1.5 m tall) with an exterior ditch (ca. 1.2 m deep) encircling a mound 1.5 m tall and 12–18 m in diameter. Six gateways are shown in the embankment, which is not perfectly circular. Since the shapes of many of Squier and Davis's enclosure drawings are somewhat different from the actual enclosure shapes on the ground, we were most interested in learning if the unusual shape of the Shriver Circle in their drawing is accurate. If it is, this sets the Shriver Circle apart from other sites with large (>305 m) circles, many of which are near-perfect in their geometry.

Like many earthworks in Ohio, the Shriver Circle has been severely degraded since the first Euro-American pioneers moved into the area, around 1795. If the description from the unpublished map referenced above is accurate, the embankment and mound lost 1.5 m of height from about 1810 to 1846. By 1846, a road and the Ohio and Erie Canal crossed the western third of the enclosure. It is likely that much of the site was being plowed by the 1840s, and perhaps had been for at least two or three decades, as indicated on the Squier and Davis map by the lack of trees within and outside of the enclosure, except to the north (see Figure 3). A number of buildings (apparently not to scale) are also shown within and adjacent to the main enclosure, as is a small circular embankment.

In 1917, a large tract of land including the Shriver Circle was purchased for the construction of Camp Sherman, a World War I army training camp (Peck 1972). About 2,000 structures were built in three months and a strip on either side of the canal, which was filled in, was flattened for use as parade grounds. The construction of the parade grounds on the Shriver Circle is a fortunate coincidence for geophysical survey as it limited other kinds of ground disturbances, such as water pipes, latrines, and iron pipes that were so common in other areas of the camp. After Camp Sherman was largely dismantled, the U.S. Veterans Bureau Training School was built and opened in 1922 on the eastern edge of the Shriver Circle (Cockrell 1999), eventually becoming the Chillicothe Correctional Institute (CCI). Much of the site is now used by CCI as agricultural land. The Ohio and Erie Canal remains buried along the west side of State Route 104, running roughly north to south through the enclosure, and a sliver of the eastern side of the enclosure resides within the prison grounds of CCI.

Our goal in surveying the Shriver Circle was to determine if the enclosure could be followed all the way around in spite of the many disturbances to the site. Though invisible at the surface to the

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casual observer, the faint outline of the enclosure is evident in the 1938 USDA aerial photo shown in Figure 3. While its west side is most apparent in this aerial, the outline of the enclosure is also visible within the walls of the prison along its east side. The recent LiDAR data reveal that the Shriver Circle's embankment is barely detectable topographically (Figure 3). Because of its enormous size, these subtle topographic indications of the enclosure are not visible on the ground unless one knows exactly where to look, and it is easy to confuse them with the many Camp Sherman-era roadbeds that crisscross the area.

The site has only recently been investigated geophysically. In 2001, Pederson and Burks (2002) surveyed a small area at the southern edge of the enclosure with a magnetometer, demonstrating unequivocally that portions of the earthwork were still present beneath the surface. This work precipitated additional geophysical survey in a narrow corridor following the eastern edge of the road in 2002, in advance of a proposed road-widening project (Clay 2002). In 2005, prior to backhoe trenching to examine the subsurface evidence of the earthwork, Burks returned to the site and resurveyed areas along the east side of the road at the north and south edges of the enclosure with a magnetometer and an electrical resistance meter (Picklesimer et al. 2006).

Figure 4 shows the results of our 2008 magnetic gradient survey of the Shriver Circle, superimposed on a 1994 aerial photo. The western edge of CCI is visible on the right side of the photo. Most evident in the magnetic data is the enclosure's ditch, which is clearly indicated (dark, arcing linear anomaly) west of State Route 104 and at the south edge of the enclosure, just east of the road. In both areas the inner edge of the embankment, which was built along the inside edge of the ditch, is also visible. We detected a number of gateways in these sections of the enclosure, as indicated by the breaks in the ditch and the small arrows in Figure 4. Though less distinct, the gateways can also be seen cutting through the embankment. One of the gateways, marked Gw1, may not be indicated on the Squier and Davis (1848) map—we think that Gw2 and Gw3 (a possible gateway) are the two gateways indicated west of the canal on the Squier and Davis map (see Figure 3). The many strong anomalies just beyond the western edge of the ditch mark the area where Camp Sherman buildings once existed—note the lack of strong anomalies within the enclosure to the west of the road, once part of the Camp Sherman parade ground. The Ohio and Erie Canal also was detected at the south edge of the circle, to the west of the road, as the approximately 15-m wide, linear anomaly paralleling the road. Apparently the canal was filled in with large iron/steel objects at the southern edge of the survey area, as indicated by the large and highly magnetic anomalies in this location.

At the north edge of the enclosure, east of the road, a linear feature running perpendicular to the road is an active utility line that nearly obscures the magnetic signature of the ditch, which is present just north of the utility line. A gap in the ditch in this section is a cut made by an archaeological trench in 2006 (Picklesimer et al. 2006).

During our day of survey inside the CCI prison, we managed to acquire data in three areas. The northern area covers the infield of the northern baseball diamond; the central linear block crosses through some volleyball courts (with steel poles holding up the nets) and basketball courts (with asphalt and steel poles supporting the backboards); and the southern block covers the infield and a section of the outfield of the southern baseball diamond. An unfortunately positioned iron pipe runs nearly the entire length of our survey blocks inside the prison, but in two or three places the enclosure ditch is clearly visible. At the north edge of the central survey block, just south of the northern baseball diamond, a small section of the ditch is evident trending northwest to southeast. The largest detected section of the ditch was found in the southern baseball diamond and is crossed over by the pipe and another linear utility line. We were unable to image the extreme eastern tip of the enclosure because of its location in an area with intense magnetic clutter. However, when the magnetic data are overlaid on the 1938 aerial the magnetic signature of the enclosure's ditch matches the visible portions of the earthwork. The eastern edge of the enclosure, though not detected in the magnetic survey, is also visible in the aerial photo. Thus, our attempt to follow the path of the enclosure all the way around its perimeter was successful, save for a few gaps where utility lines, roads, and

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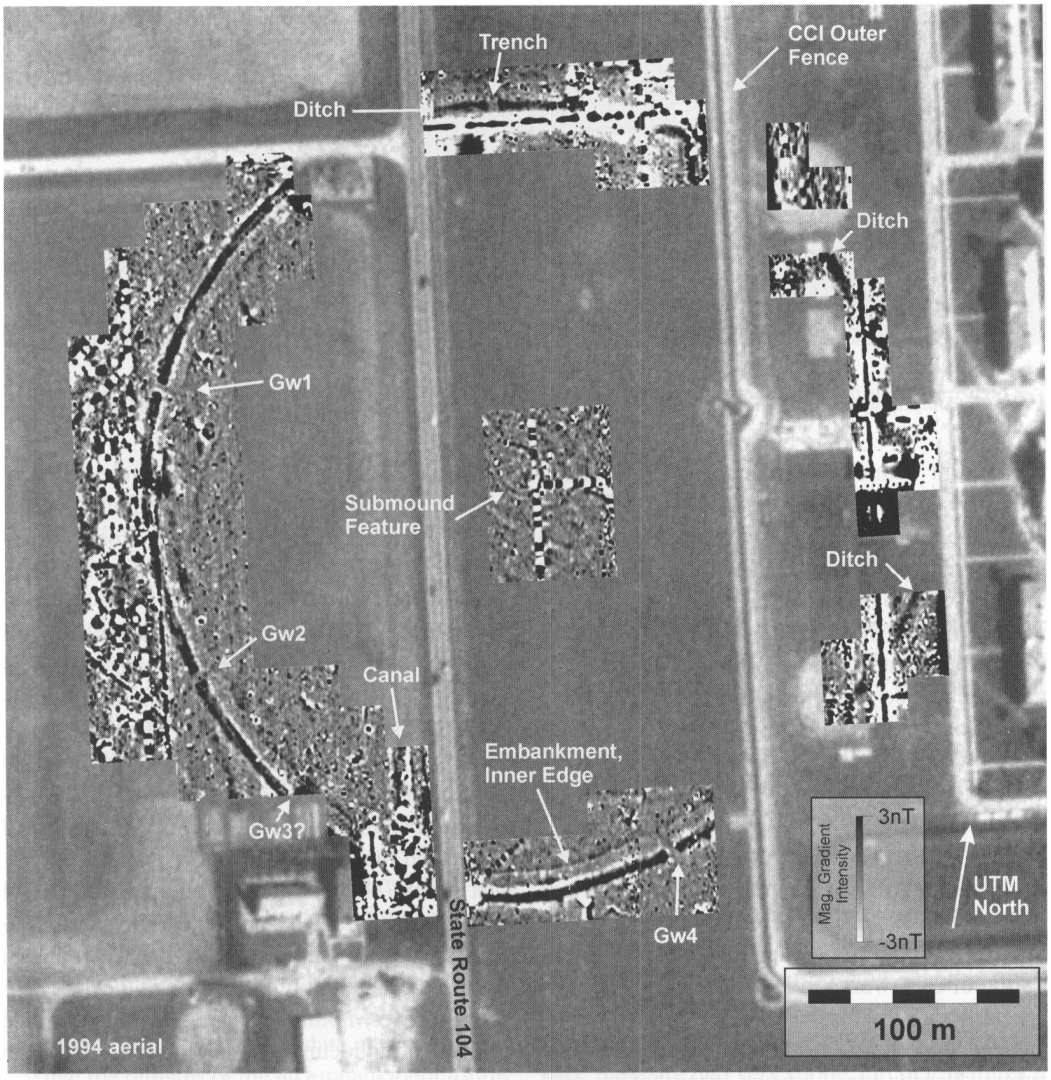


Figure 4. Shriver Circle magnetic gradient data on 1994 U.S. Geological Survey aerial photograph.

the prison fence precluded detection with the magnetometer.

In the middle of the enclosure we positioned 12 20-x-20-m blocks to cover the approximate location of the central mound. In 2001, Pederson and Burks (2002) located what they thought was the central mound during a laser transit-based topographic survey that found a subtle rise, not more than 40–45 cm high and spread across an area at least 40 meters in diameter. This low rise matched the approximate location of the mound as depicted on the Squier and Davis map. Though subtle, the LiDAR-based image in Figure 3 also shows this low rise at the center of the enclosure. In this area the magnetometer detected an arcing anomaly underneath the footprint of the mound. This feature is likely related to the burned feature found within the mound by the Squier and Davis (1848) excavations.

In 2005, two trenches were dug across the ditch at the north side of the enclosure with a track hoe. The profile of Trench 2 (see Figure 4 for its approximate location) is shown in Figure 5 (after Picklesimer et al. 2006:Figure 21). Prehistorically, the ditch was dug down into the underlying, unconsolidated terrace gravels and then lined at

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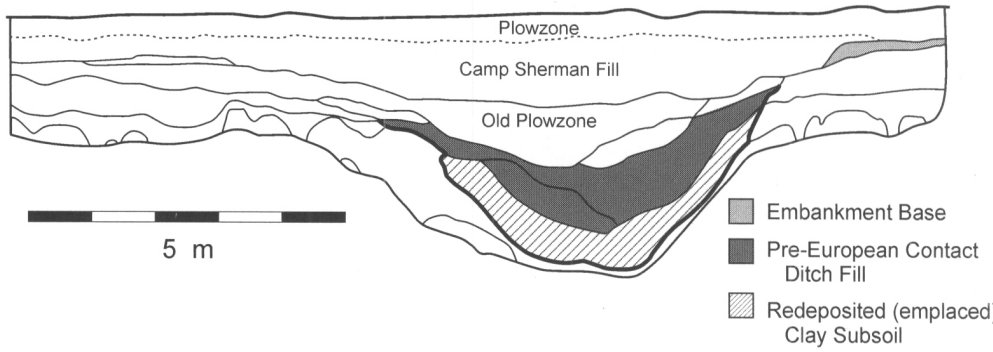


Figure 5. Profile drawing of a trench cut across the Shriver Circle (based on Picklesimer et al. 2006:Figure 21).

the bottom with clayey, redeposited subsoil (Bt horizon sediment). The dark, organic-rich fill above the emplaced clay accumulated in the ditch during the approximate 2,000-year period prior to the site's first plowing in the early 1800s. Plowing had nearly filled in the ditch by the time of Camp Sherman's construction, and it likely had nearly flattened the embankment wall, the very bottom of which is still present beneath the modern plow zone.

Steel Group (33RO62)

In their "Map of Twelve Miles of the Scioto Valley with Its Ancient Monuments," Squier and Davis (1848:Plate II) showed the world, for the first time, a map of perhaps the densest concentration of earthworks in North America. Though the earthworks themselves are not shown to scale, their general locations and shapes are fairly accurate. Nearly every terrace, promontory, and bend in the river seemingly is occupied by an earthwork of one sort or another. On the edge of their map, southwest of the town of Chillicothe, is a small unnamed cluster of two circular enclosures and a small mound (Figure 6). Nowhere else in their book do Squier and Davis describe this site.

Many years later, Seeman (1986:Figure 22.7) published an oblique aerial photo of this site that he took in 1980, and referred to it as part of the Junction Group, which is a logical conclusion given the relatively close proximity of the two sites. Junction Group, a collection of circles, squares, and small mounds is located about one mile to the southeast (Squier and Davis 1848:61). We suggest that the Steel Group (a.k.a., the Robert Steel Earthworks) is a spatially discrete cluster of enclosures and at least one small mound located on a stream terrace overlooking the North Fork of Paint Creek,[5] about 7.2 km downstream from Hopewell Mound Group.

Steel Group differs in many ways from its neighbor, Junction Group. For starters, Steel Group is consistently visible on aerial photographs, as in the 1964 aerial photo shown in Figure 6. In 2007, after being contacted by one of the landowners about surveying the site, Burks captured some new aerial photos of the site that suggested the presence of more enclosures than just the two shown by Squier and Davis. A few of these undocumented enclosures appear in Seeman's photo (Seeman 1986:Figure 22.7) and in the 1964 image in Figure 6, though they are subtle. However, nothing could prepare us for the number of undocumented enclosures detected in the magnetic survey.

Figure 7 shows the results of the magnetic gradient survey at Steel Group. The small inset in the upper right provides a key to the enclosure numbering we use here. Enclosures 1 and 2 are the original two included on the Squier and Davis map and Enclosure 1 is visible in most every aerial photo taken of the site. The other nine enclosures are previously undocumented. Once their locations are revealed in the magnetic data, all enclosures but 6, 7, and 8 can be vaguely discerned in the 1964 USDA image, Seeman's image from 1980, or in Burks's most recent image from 2007, which was coincidentally taken under ideal conditions in early June when the wheat crop was maturing (turning golden brown) and moist areas still supported green plants. Importantly, only En-

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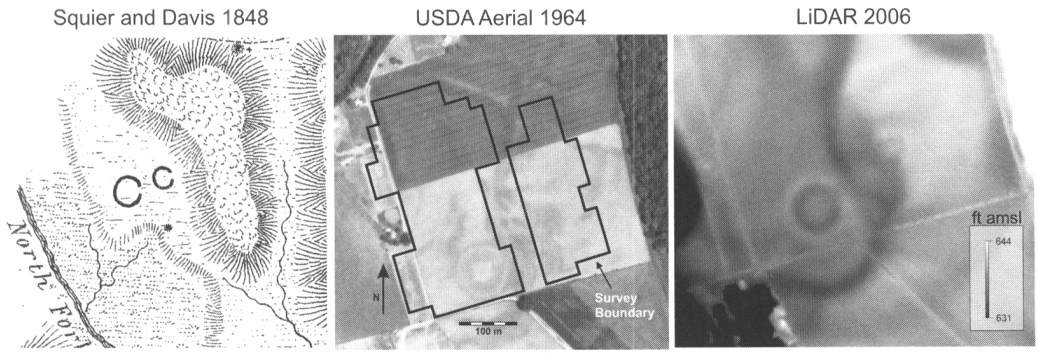


Figure 6. Steel Group site nineteenth-century map, historic aerial photograph, and LiDAR topographic map.

closures 1 and 2 are visible in the LiDAR data (see Figure 6). Apparently, these ditch-and-embankment enclosures can become so degraded and eroded that they are not detectable topographically (i.e., in LiDAR data) and do not appear in aerial photography, even in photographs taken under ideal conditions.

Aside from the presence of so many new enclosures, the magnetic survey results from Steel Group are also remarkable because they reveal an enclosure shape that has yet to be documented in southern Ohio. Enclosure 4, or at least its ditch (the darker part of the magnetic signature), is a near equal-sided square that has had two adjacent sides angled outward to create a gateway at a corner, making it somewhat diamond shaped. The corner opposite the gateway is a 90-degree angle. While subtle in the magnetic data, it is possible to see that the remains of the #4 embankment follow the outline of its associated ditch, though the sharper angles of the ditch appear more rounded in the embankment footprint. No such enclosure shape is present in the nineteenth-century literature (e.g., MacLean 1879; Squier and Davis 1848; Thomas 1894; Whittlesey 1850).

In addition to earthworks, there are many other anomalies in the magnetic data at Steel Group. Most of these are the striping caused by plowing and the sand and gravel terrace structure that underlies the earthworks (e.g., the arcing linear features between Enclosures 4 and 9). The linear features between Enclosures 1 and 2 are portions of an old stream channel cutting across the site. At least five of the enclosures have gateways that open onto this old channel scar, which we know was present when the earthworks were built since part of the Enclosure 2 embankment extended out on top of it. This suggests that this naturally occurring channel may have been worked into the planned site layout. The channel extends to the north and west where it intersects, part way up the creek bank, the active channel of the North Fork of Paint Creek. This old channel scar could have served as a natural causeway, bringing site visitors up from the creek and into the site. Causeways linking streams to earthwork clusters are present at several Ohio Hopewell sites.

Of course, it is likely that some of the other linear features are prehistoric in origin but are just not as obvious in the magnetic data as the geometric enclosures. Other possible features might be more obvious in a different type of geophysical data, such as electrical resistance. Nevertheless, there are two very subtle, circular features in the magnetic data that are not earthen enclosures. One is located about 60 meters east of Enclosure 3 and is about seven meters in diameter. The other, about 10 meters in diameter, intersects the east side of Enclosure 9 and likely underlies it—the portion of the Enclosure 9 ditch that is missing was stripped out during data processing. These smaller, subtle circles are likely post circles, which are a common occurrence at Adena and Hopewell mound and earthwork sites in the Middle Ohio valley. Postholes rarely are detectable in magnetic data because of their small size and low magnetic contrast, but they have been detected at Hopewell Mound Group in the area of Mound 1, for example, where the posthole fill contained burned earth (Burks and Pederson 2006; Pederson

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Figure 7. Steel Group magnetic gradient data on 1964 USDA aerial photograph.

and Burks 2001), and at the Moorehead Circle (the Fort Ancient site) where the posts were placed in slip trenches (Burks 2006a; Riordan 2007).

Reinhardt (33PI880)

The Reinhardt site[6] is a little-known, Middle (A.D.1200–1400) Fort Ancient village site located on the east bluff of the Scioto River at the northern edge of Pickaway County, Ohio (see Figure 1). The site has been known to artifact collectors for decades and was brought to the attention of archaeologists in the late 1980s. In a recent effort to examine the structure of the Fort Ancient village, magnetic gradient and magnetic susceptibility surveys were conducted in an area originally centered on the greatest density of Fort ancient artifacts on the surface (Nolan et al. 2008). At the end of the first day of magnetic gradient survey a linear feature at the north edge of the village proved to be too provocative to ignore. An additional day of survey revealed a rectangular ditch-and-embankment enclosure that was previously unknown to archaeologists. An examination of the available aerial photographs of the site found a very faint feature at the location of the rectangular enclosure and another possible enclosure to the north (Figure 8). The survey was expanded northward, locating a circular ditch-and-embankment enclosure comparable in size to the rectangle (Figure 9).

As at Shriver Circle and Steel Group, the ditches of the Reinhardt enclosures are positive

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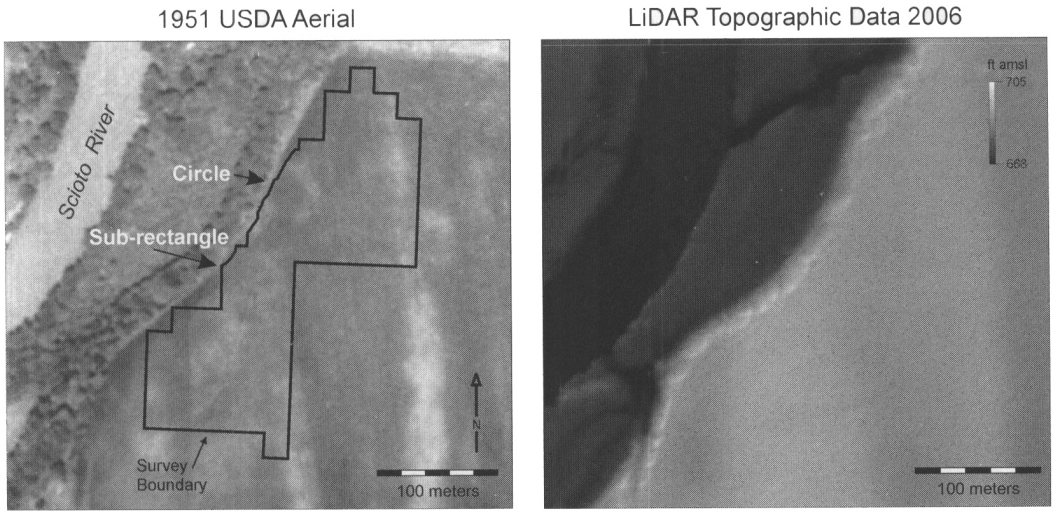


Figure 8. Reinhardt site historic aerial photograph (1951, USDA) and LiDAR topographic map.

magnetic anomalies while the remains of the embankments are just barely visible and are predominantly less magnetic than their surrounding matrix. The linear anomalies south of the rectangular enclosure are marks from plowing done to improve visibility for surface artifact collection (see Nolan 2011). At least four star-shaped, or tentacled, anomalies (two south of the rectangle and two north and east of the circle, all about 10 m across) may be the magnetic signatures of lightning strikes (see Jones and Maki 2005). Numerous pit features also were detected; most south of the rectangle are related to the Fort Ancient village (Nolan et al. 2008).

A trench excavated across the southern side of the rectangular enclosure by William S. Dancey in 2009 revealed a ditch about 2.25 m wide that extends down to 90 cm below surface. The inside edge of the ditch is nearly vertical while the outside edge, which was adjacent to the embankment, was more gradual in its descent.

Close examination of the magnetic data within the circle reveals a faint ring of small, positive magnetic anomalies that are probably postholes. This probable post circle inside the Reinhardt circle is about 16 m in diameter. Excavation of one of these small anomalies near the circle's gateway uncovered a probable post trench (slip trench for a large post) that would have held a post as much as 45 cm in diameter.

Discussion

In this article we have presented the magnetic gradient survey results from three earthwork sites in southern Ohio that exemplify the on-the-ground condition of many earthwork sites. Most earthworks are so degraded they are almost invisible at the surface but nearly all can be detected in some way by geophysical surveys. While scholars have known for some time that the nineteenth-century earthwork maps are inaccurate at many levels, the sometimes subtle and often drastic differences we found in our small sample of sites have obvious and far-reaching implications in the study of earthworks in the Middle Ohio valley and beyond. Some of the more important implications fall under issues of site preservation, site detection, and caution when utilizing old, or any, maps of these complex sites.

The rapid disappearance of earthworks from the landscape is a preservation issue that was recognized long ago. In 1847, little more than 50 years after the Treaty of Greenville had officially opened the Northwest Territory for settlement and the clearing of the vast forests had begun, Squier and Davis (1848:xxxix) were already lamenting the fact that "thousands [of earthen works] have already disappeared, or retain but slight and doubtful traces of their former proportions." The average circular earthwork, such as the

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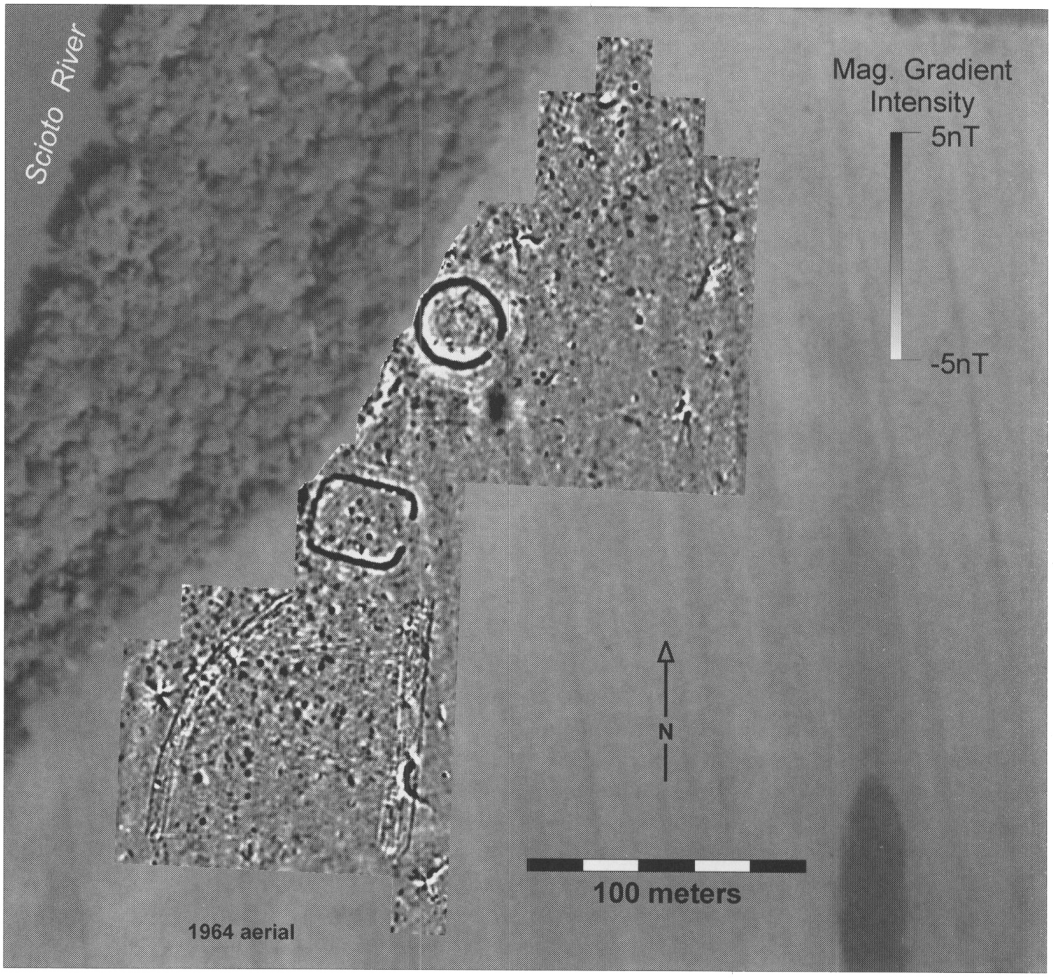


Figure 9. Reinhardt site magnetic gradient data on 1964 USDA aerial photograph.

Eagle Township Works (33BR10) in southwestern Ohio with an embankment once ten feet in height, was reduced to just two feet by 1885 (MacLean 1886)—a reality observed at many sites in the nineteenth century. Today, sites like this are invisible at the surface and can be quite difficult to relocate if their locations were not accurately recorded.

In their 1848 volume, Squier and Davis provided maps and locations for approximately 88 earthwork sites in Ohio. A recent attempt by Burks to locate these sites and determine their current status produced some disheartening results. Happily, 16 sites (18 percent) are now preserved whole or in part within parks (e.g., Hopewell Culture National Historical Park in Chillicothe, Ohio). Less encouraging are the 18 (20 percent) that are mostly or completely destroyed, with urban development and gravel mining being two of the primary destructive processes. The status of the remaining 54 (62 percent) is hard to determine because most are now invisible at the surface, their locations have been improperly recorded, and/or they are not evident in historic aerial photography.

At the Shriver Circle we found that what seemed like a near-destroyed earthwork was quite intact and could be detected even in areas of intensive historic building construction and demolition. Importantly, this shows that while the aboveground portions of earthwork complexes have been heavily degraded by agriculture, the

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subsurface remains are intact, giving us hope that some of the missing 54 Squier and Davis sites might be found. It takes a great deal of erosion and soil loss to erase an enclosure's ditch. At the Steel Group we went into the survey expecting two enclosures and came away with 10 or 11, as well as two possible post circles. Finding additional enclosures at earthwork sites in geophysical data is not a new discovery. Previous surveys at Hopewell Mound Group (Pederson et al. 2001; Pederson Weinberger 2009) and Fort Ancient (Burks 2006a) have also encountered new enclosures at well-known sites.

Like the results of many surveyors and scholars that have come before us (e.g., Fowke 1902; Overman 1888; Thomas 1889), our mapping efforts at three earthwork sites show that the actual layout of these sites can differ quite substantially from the nineteenth-century maps. This is not a result that has yet been observed in geophysical surveys at larger earthwork sites, for example, the Hopeton Works (Lynott 2004, 2007; Weymouth et al. 2009) or the High Bank Works (Greber 2005a). In Table 1 we provide comparative data on basic enclosure measurements derived from Squier and Davis (1848) and from our geophysical survey results. Interestingly, while Squier and Davis produced a very accurate map of the Shriver Circle, their estimates of the size of the enclosure are significantly different than our measurements. We suggest that in part the difference in size, for example, is a function of the scale provided with their map. Since their scale is descriptive, "500 ft to the inch," rather than a scale bar, it relies on the accurate reproduction of their original map, which likely was not perfectly reproduced in the first edition and now in reprinted editions it is even more altered.

Differences between the geophysical survey results and the nineteenth-century maps are especially apparent in enclosure shape, size, and orientation (i.e., the geographic alignment of walls and gateways). This should give great pause to those using the older maps for studying alignments, especially at smaller earthwork complexes. Earlier maps also often lack entire enclosures that are detected by the geophysical instruments. While it would be easy to attribute these differences to poor mapping skills or inadequate mapping equipment, it is also likely that erosion and agricultural plowing had already altered these sites to such a degree that it was not possible in the nineteenth century to create accurate maps with surface mapping techniques. Even high-density topographic maps, as collected today with LiDAR and laser transits, would not be able to portray the actual shapes of degraded mounds and enclosures. Furthermore, it is possible that some of these enclosures were erased in prehistory as the configurations and functions of the earthwork complexes changed (cf. Byers 1987; Riordan 2006).

Earthwork researchers are understandably fascinated by the geometry of Woodland period earthworks in Ohio, which has led to many interesting observations concerning the size, alignment, and spacing of these sites and their components (e.g., DeBoer 2010; Hively and Horn 1982, 1984, 2006, 2010; Marshall 1996; Romain 1996, 2000). Most serious studies of archaeoastronomy and geometry are based on new measurements, taken from on-the-ground data, aerial photographs, or, more recently, LiDAR data. However, a number of researchers have taken on the challenge of using nineteenth-century measurement data in one form or another (e.g., DeBoer 1997, 2010). For example, Bernardini (2004:338) cleverly uses estimated embankment width measurements taken from multiple nineteenth-century sources in the calculation of embankment wall volume as a means to estimate construction labor expenditures. Since the nineteenth-century embankment morphometric data for his study sites are incomplete, he had to create expected estimates based on similar sites in the region. Because he was working with the tripartite earthworks of Ross County, Ohio, which are quite large, even small errors in his estimates could result in large errors in estimates of the overall amount of dirt used to construct these sites. Geophysical surveys at large earthwork sites like High Bank Works and Hopeton have detected the original widths of the embankments, which in the future could be used to create more accurate estimates of labor investment. Of course, we may never know exactly how tall earthwork embankment walls once were. We caution others against extending such labor-estimation exercises to other earthwork sites using nineteenth-century maps, especially those of smaller sites. The nineteenth-

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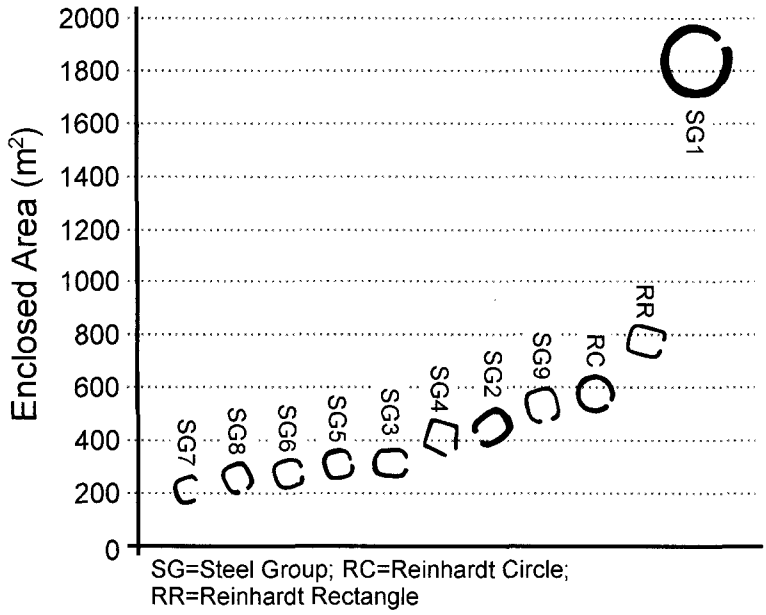


Figure 10. Distribution of enclosed space within Steel Group and Reinhardt site enclosures.

century maps of small earthwork complexes, such as the Steel Group, are less accurate than maps of the larger sites, as we and others have demonstrated through geophysical survey.

Many researchers today still rely on the nineteenth-century maps for basic types of data, such as estimates of overall enclosure size. For example, most nineteenth-century surveyors provide estimates of the area enclosed by the earthworks but many of these numbers are incorrect. As just one example, Squier and Davis (1848:Plate 5) report the area enclosed by the Fort Hill works as 48 acres but a 2005 survey with a global positioning system (with submeter accuracy) found that it was only 35.3 acres (Romain and Burks 2005). Since geophysical survey data are spatially precise, very accurate measurements of enclosed space can be generated. The areas provided in Table 1 are graphed in Figure 10. None of the enclosures are exactly the same, though many differ little in basic dimensions. Enclosure size appears to increase gradually except for Enclosure 1 at Steel Group, which is much larger than the other enclosures. Interestingly, the four smallest enclosures at Steel Group all seem to open out onto the natural causeway (an old stream channel) that traverses the site, suggesting that perhaps they were built to a common plan. Obviously, accurate measurements of enclosure size and alignment are necessary clues for studying the use of space and growth of earthwork complexes.

Based on geophysical survey results to date, we anticipate that future surveys will significantly alter our understanding of the region's earthworks. In fact, we can already begin to see this happening. Table 2 is a summary of "sacred enclosures" that William S. Webb presented in 1941, which includes a selection of sites from all across the Middle Ohio valley, though most are from Ohio. Circles clearly dominate Webb's sample, with crescents and squares being the next largest classes. As more of these sites are geophysically surveyed, one of the biggest changes that we are finding is the greater number of rectangular enclosures than previously thought. The "With New Surveys" column in Table 2 includes new results from Steel Group and Reinhardt (not in Webb's 1941 list), Hopewell Mound Group, and Junction Group, the latter a site located just a mile southeast of Steel Group. The number of rectangles has more than doubled thanks to new geophysical survey data. By "rectangle" we are referring to rectangular and square enclosures with rounded corners, which differ from the larger squares that

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Table 2. Webb's 1941 List of "Sacred Enclosures" and an Updated List Based on Geophysical Survey Results.

	Webb 1941		With New Surveys[a]	
Shapes	n	%	n	%
Circles	76	75	79	69
Crescents	9	9	10	8
Panduriforms	3	3	3	3
Ovals	2	2	2	2
Rectangles	6	6	13	11
Complete Circles	4	4	4	4
Hexagon	1	1	1	1
Diamond			1	1
Quatrefoil			1	1
total	101		114	

[a]includes geophysical survey results from Steel Group, Reinhardt, Hopewell Mound Group (Pederson et al. 2001; Pederson Weinberger 2006), and Junction Group (Burks 2006b, 2010b).

appear during the latter part of the Middle Woodland period (Greber 2006). Though Mills (1914) reported many rectangles in Ohio, most of these were never mapped and published, leading Webb to ignore them in his summary of sacred enclosures in 1941. Perhaps rectilinear enclosures are not as "foreign" to the region as some have suggested (see DeBoer 1997), but the appearance of large squares at Hopewell earthwork complexes could still signal a disruption in the social fabric of the communities building these earthworks.

In addition to more squares with rounded corners, continued geophysical survey is likely to identify more unique shapes. The new diamond-shaped enclosure at Steel Group (Enclosure 4) appears to be an unusual variant of a square with at least one corner forming a right angle. Ongoing geophysical survey at the Junction Group, by Burks, N'omi Greber, and Wesley Bernardini, discovered that one of the Squier and Davis (1848:Plate XXII, No.1) squares at Junction Group, the smaller one, is actually a quatrefoil—a four-lobed enclosure consisting of four intersecting circles (Burks 2010b). Assuming the complexes of small enclosures (e.g., Junction Group, Steel Group, and Black Water Group) date to a time before the large Hopewell complexes (e.g., Seip, Liberty, and High Bank), perhaps the presence of unique enclosure shapes indicate a time of uncertain or rapid change in the function of these earthwork complexes—a trend that eventually led to the abandonment of the smaller complexes and the construction of the immense Hopewell complexes. More surprises are surely in store as more of these sites are geophysically surveyed.

Conclusions

> The work of investigation has been just commenced; its future progress may, and no doubt will, result in new and perhaps more important disclosures than any hitherto made [Squier and Davis 1848:xxxix].

Obtaining the bigger picture of complex sites through remote sensing is not a problem unique to Hopewell archaeology. In other regions archaeologists are now relying on a variety of different kinds of remote sensing data to do the same: in England magnetic gradient surveys are laying bare entire Roman cities (Gaffney et al. 2000), in the rainforests of Belize LiDAR data are revealing the shrouded secrets of the Maya city of Caracol (Chase et al. 2011), and in many parts of the world new aerial imagery accessible via the Internet, Google Earth, and other sources is resulting in a rapid pace of site discovery on a landscape scale (e.g., Pärssinen et al. 2009; Thomas et al. 2008).

The maps made of Ohio earthworks in the nineteenth century with chain and compass are still today used by archaeologists as a primary data resource. Without these maps, many of these sites would never have been known to exist. However, hundreds of earthwork sites were never mapped. Early aerial photography beginning in

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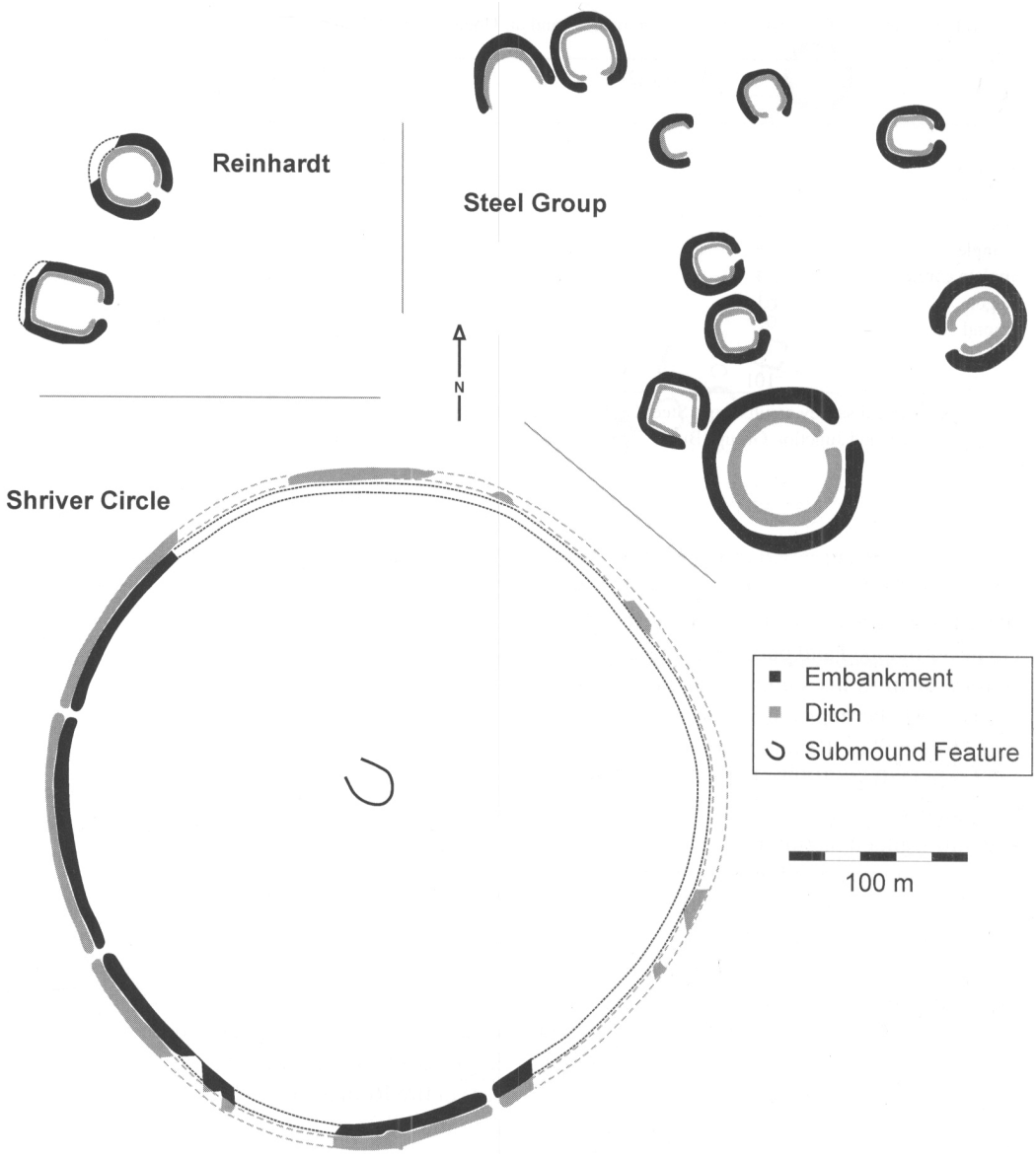


Figure 11. Interpretive drawings of magnetic gradient survey results.

the 1930s produced amazing new images of earthworks and even detected sites previously unknown (e.g., Reeves 1936a, 1936b). In fact, the Anderson Works, a fairly large square enclosure, was found independently by two researchers in aerial photographs as recently as just a few decades ago (Anderson 1980; Pickard and Weinberger 2009). New topographic data collected for the entire state using LiDAR is an exciting new resource that, while perhaps unlikely to lead to the discovery of many new earthwork sites, is making it easier to locate sites that have become lost or have been mislocated. The biggest benefit of the new LiDAR data is that it allows us to visualize these often complex earthwork sites on the landscape and take fairly accurate measurements of their dimensions without having to collect new field data. Trying to find these earthwork sites among the many gigabytes of data is a further challenge, one we hope to one day solve with a

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publically accessible database of terrain models for many of the sites. Most exciting for earthwork studies is the growing body of geophysical surveys, nearly all of which have revealed important new aspects of these sites not observable in any of the other available maps, images, and datasets (Figure 11). From new enclosure shapes and gateways to entirely new earthwork complexes, geophysical survey is considerably refining our view of the earthworks of Ohio, rediscovering them in ways never imagined by early pioneers such as Squier and Davis.

Acknowledgments. The surveys reported here were largely conducted on weekends during the autumn and winter of 2007 and 2008. Funding for the Steel Group survey was provided in part by donations from the South Central Ohio Preservation Society, based in Chillicothe, Ohio. The Shriver Circle survey was funded by a grant from The Ohio State University College of Social and Behavioral Sciences.

Geophysical survey is a long, tedious process that often requires the assistance of a few dedicated volunteers to help set in grid stakes and move survey ropes. Two individuals in particular, Karen Leone and Harry Campbell, spent many weekends helping with the surveys. Harry also made a trip to Circleville, Ohio to collect images of the old aerial photos of the Reinhardt site. A number of others kindly volunteered their time to help with the surveys, including Amy Kuhner, Ben Nelson, Kevin Nolan, and Kyle Spurgen. We owe a debt of gratitude to a number of landowners and others who helped facilitate our survey work. Amy Kuhner made it possible for the Steel Group survey; Rick Perkins of the National Park Service helped arrange our access to the Shriver Circle, while the Warden and Deputy Warden of CCI graciously facilitated our access to the Shriver Circle, both within and outside the Chillicothe Correctional Institute prison. The City of Columbus allowed us access to the Reinhardt site and Kevin Nolan took care of arrangements with the Peters family, who farm the site. Joan Harless and Kaye Myers, whose family has owned the farm containing the Holder-Wright Group for generations, are big supporters of our continued work at this now-urban prehistoric earthwork. Bill Kennedy compiled the data we used to construct the DEM in Figure 1; James Murphy tracked down and kindly provided us a copy of the Worthington map of the Shriver Circle; William Romain put together the LiDAR data and provided us with XYZ files so that we could generate our own LiDAR-based maps; and John Picklesimer and Cinder Miller of Gray & Pape, Inc. provided a copy of the Shriver Circle report detailing the results of the 2005 trenching. We thank Lane Fargher for preparing our Spanish abstract and the reviewers for their kind and useful remarks.

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Notes

1. Dating earthwork construction is a tough job as the sites are often large and lack good contexts from which to acquire dateable material. Decades of work in the Middle Ohio Valley have produced a basic sequence. Webb and Snow (1945) and Clay (1987), among many others, attribute small circles, or "sacred circles," to the Adena. However, very few of these smaller earthworks have been excavated, published, and radiocarbon dated. And, since the Adena cultural complex is known to extend into the second and third centuries A.D. (see e.g., Greber 1991, 2005b; Murphy 1987), the "Adena persistence" (Carr and Hass 1996:28) makes it difficult to attribute the smaller circles solely to a pre-Hopewell time. In fact, many small circles were often incorporated into large Hopewell earthwork complexes. Extensive work by McCord and Cochran (2008) in southwestern Indiana has yielded several radiocarbon dates that support the general origins of small circles first (with select, larger circular enclosures [Carr and Hass 1996; Clay 1987; Cramer 2008]) in the second to third centuries B.C., followed later by subrectangular forms during the first to second centuries A.D. Most large geometric earthwork complexes were built between the second and fifth centuries A.D. (Greber 2003). It is likely that at least some earthworks continued to be used in some fashion after Hopewell abandonment (e.g., Lynott and Mandel 2009).

2. The Holder-Wright Group is located on and constructed with Glynwood (fine, illitic, mesic Aquic Hapludalf) and Blount (fine, illitic, mesic Aeric Epiaqualf) series soils, which are deep, moderately well to poorly drained soils formed in Wisconsinan glacial till (USDA 2007, 2008). Both have A and Bt horizons, Glynwood soils also have an E horizon, and Blount soils, being less well drained, have gleying in the B horizon. Clasts are 10 percent or less by volume in any horizon and pebble-gravel size. Gleying in soils indicates that the soils are wet a significant portion of the year and this likely is hindering the magnetic susceptibility of the ditch fill (Evans and Heller 2003).

The electrical resistance data at the Holder-Wright Group in Franklin County, Ohio were collected with a Geoscan Research RM15 electrical resistance meter arranged as a twin electrode array (see Clark 2000 for a description of this array). Mobile probe spacing was 50 cm and readings were collected at 50 cm intervals along transects spaced one meter apart. Data were processed with Geoscan Research's Geoplot v.3(s) software and included the following processing steps: despike, edge match, deslope, interpolate, and low pass filter (see Somers 2006 for more on processing electrical resistance data).

3. All magnetic gradient datasets were processed with Geoscan Research's Geoplot v3(s) software using three processes: zero mean traverse, interpolate, and low pass filter. The functioning of these processes is discussed by Ciminale and Lodo (2001), Kvamme (2006b), and Aspinall et al. (2008). In some portions of the survey areas the zero mean traverse function had to be used sparingly so as not to strip out the magnetic signatures of the earthworks. Thus it was important to keep the instrument well balanced and aligned during survey so that less data processing was needed.

4. Ohio's LiDAR data can be found on the OGRIP (Ohio Geographically Referenced Information Program) website: (http://ogrip.oit.ohio.gov/Home.aspx; accessed January 16, 2011).

5. Shriver Circle and Steel Group were built on and with Fox series soils (fine-loamy over sand or sandy-skeletal, mixed, superactive, mesic Typic Hapludalfs), which are developed in calcareous sandy glacial outwash (USDA 2009a). Fox soils have clay-rich Bt horizons that often are red in color (on the 7.5YR Munsell page), extend down to about 50–100 cm below surface, and are underlain by unconsolidated, stratified sand and gravel outwash deposits. Both sites have been plowed since the early 1800s. Such soils are ideal settings for magnetic gradient surveys due to a relatively high contrast in magnetic susceptibility between the A and Bt horizons. Sediments in earthwork ditches may also have become magnetically enhanced from repeated fires within the enclosures.

6. The Reinhardt site earthworks are built on and within Warsaw series soils (fine-loamy over sandy or sandy-skeletal, mixed, superactive, mesic Typic Argiudolls). At Reinhardt, this well-drained soil likely developed in an outwash plain/terrace that now very rarely floods. Warsaw soils have a thickened A horizon and a mollic epipedon underlain by dark Bt horizons down to as much as about 100 cm below surface (USDA 2009b). Gravel is common in the B horizons as the soil has developed into stratified gravel and sand. Because of the darkness of both the A and B horizons, the identification of features extending down into the subsoil can be difficult, though the magnetic data make this chore somewhat easier in that they indicate the locations of many probable features, including some probable postholes. This site has very magnetic surface sediments, which is quite evident when collecting data over open plow furrows (these make very distinctive anomalies in the magnetic gradient data).

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