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Phosphates, plowzones, and plazas: a minimally invasive approach to settlement structure of plowed village sites

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A B S T R A C T

Inferences about settlement structure play an important role in explanations of social and political change in Late Prehistoric eastern North America, but ethical and logistical challenges posed by extensive horizontal excavations mean that archaeologists must develop low cost, minimally invasive methods for investigating key properties of village structure. There are two important components of most villages in the region: 1) the peripheral distribution of middens; and 2) the size and location of formal communal spaces or plazas, each of which leaves traces in soil chemistry. In shallowly buried, plowed village sites where artifacts have been physically displaced, the chemical signature of middens may be more resistant to disturbance and provide an enduring signature of ancient settlement structure. We conducted a systematic soil phosphorus survey at the Reinhardt Site (33PI880) in central Ohio, the primary occupation of which occurred during the Late Prehistoric Period (ca. AD 1200–1450), to test for the presence and approximate size of a central plaza and the shape and distribution of peripheral midden deposits. Soil samples from the modern plowzone ($N = 131$) were analyzed for Mehlich II extractable phosphorus using molybdate colorimetry. The interpolated phosphorus distributions indicate a clear ring midden approximately 90 m across with an internal plaza that is roughly 30 m × 40 m. Artifact distributions from a shovel test pit survey and interpolations of plowzone magnetic susceptibility measurements identify the location of the village but are ambiguous with regards to village size and do not clearly distinguish the central plaza. Our results suggest that systematic surveys of soil phosphorus are a rapid, minimally invasive, and inexpensive method for generating data on the size and shape of villages and their plazas.

1. Introduction

Settlement structure and village layout feature centrally in archaeological inferences about past social organization. This is especially true for the Late Prehistoric Period (AD 1000–1600) in the Ohio Valley (e.g., Cook, 2008; Means, 2007; Pollack and Henderson, 1992). Reconstructions of these features often rely on extensive horizontal excavations that reveal structures, features, and their spatial relationships. Such investigations are expensive, time-consuming, and may run counter to conservation ethics (Lipe, 1974) and the principle of Stewardship espoused by the Society for American Archaeology (Lynott and Wylie, 1995). Indeed, in a post-NAGPRA world where archaeologists regularly engage with descendant communities (e.g., Mills et al., 2008) and in which further collections only add to the "curation crisis" (Bawaya, 2007), extensive horizontal excavations are increasingly unfeasible and undesirable. It is incumbent upon archaeologists to develop reliable methods for inferring settlement structure that reduce the amount of destructive sampling needed to generate relevant data.

In many parts of the central, midwestern, and eastern United States, the long history of cultivation has destroyed many shallowly buried (<60 cm deep) structures and features. Such post-depositional disturbance can remove unambiguous traces of features within the plowzone and redistribute artifacts vertically and laterally across the site (Dunnell and Simek, 1995; Lewarch and O'Brien, 1981). Although the impact of tillage on lateral artifact movement can be profound (e.g., Navazo and Diéz, 2008), many experimental studies indicate that surface artifacts on plowed sites still provide valuable information (e.g., Dunnell and Dancey, 1983; Roper, 1976), including estimates of village location and size (e.g., Hawkins, 1998). In general, however, the lateral mobility of artifacts, particularly large artifacts (e.g., Dunnell, 1990; Dunnell and Simek, 1995; Lewarch and O'Brien, 1981; cf. Odell and Cowan,

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1987), suggests that in order to identify intrasite patterns, such as the size and shape of internal plazas, plowzone artifact distributions should be complemented with datasets that are strongly linked with human activity and less vulnerable to lateral disturbance.

In this paper, we describe geochemical survey techniques that offer a valuable, minimally invasive approach for inferring settlement structure at shallowly buried, subsequently plowed sites. We begin by briefly describing the importance of settlement structure for inferring social changes in Late Prehistoric eastern North America followed by discussion of anthropogenic soil phosphates and their association with midden deposits. We suggest that because anthropogenic phosphates are associated with fine-grained sediments, the phosphate record is less vulnerable to lateral disturbance by tillage than are artifacts. Through a central Ohio case study (Reinhardt Site, 33PI880) we illustrate the value of systematic sampling of plowzone sediments for reconstructing key settlement features in a Late Prehistoric village (AD 1000–1600). We conclude by discussing the implications of our strategy for improving regional-scale knowledge of Late Prehistoric village size and layout.

2. Background

2.1. Settlement structure and society in the upper midwest

Nucleated villages scattered across the floodplains and terraces of river systems were common during the Late Prehistoric Period in eastern North America. These sites vary in size and details of organization, but throughout the Upper Midwest most are characterized by a generalized doughnut shape with a domestic area surrounding a central open plaza (Cook, 2008; Dunnell, 1983; Dunnell et al., 1971; Graybill, 1981; Hart et al., 2005; Henderson, 1992, 1998; Kennedy, 2000; Means, 2007; Pollack and Henderson, 1992, 2000; Redmond, 1994, 2003). Among the Late Prehistoric trans-egalitarian societies of the Middle Ohio River Valley (i.e., Fort Ancient; Griffin, 1966), villages generally displayed a plaza-centered structure with socially important structures and features in proximity to the village center. This is a pattern that is also exhibited by contemporaneous villages at on the fringes of nearby Middle Mississippian chiefdoms (Fig. 1). At Fort Ancient sites, however, there is no clear evidence that political hierarchies

Fig. 1. Approximate distributions of Middle Mississippian societies with hierarchical socio-political structures and trans-egalitarian Upper Mississippian societies in the eastern United States.

(Henderson, 1998; Schroeder, 2004) accompany variation in settlement size in the region (but see Cook, 2008: 126).

Most of the well known Middle Ohio River Valley villages share a distinctive internal structure. They are composed of concentric rings of features and, although there is some organizational variability within the habitation ring, refuse disposal was either constrained between the habitation ring and the palisades (Carskadden and Morton, 2000; Graybill, 1981), or interspersed with the habitation ring around the plaza (Cook, 2008; Dunnell, 1983; Heilman et al., 1988; Henderson, 1998: 421). Due to the limited number of villages that are well known in terms of their size, structure, and age, it is not yet clear whether: 1) there was a bimodality in Fort Ancient village size (Cook, 2008), thus implicating the presence of some form of settlement hierarchy; or 2) if village size varied along a continuum (Henderson, 1998). Distinguishing between these alternative hypotheses is important for reconstructing Fort Ancient social and political structures but would require a much larger sample of villages across the region than is presently available (see Nolan, 2010: 31–34, 397–399).

In summary, two of the enduring and regular properties of Late Prehistoric villages in the Upper Midwest (and elsewhere in the region) are: 1) a cleared central space or "plaza" that was regularly swept clean (Means, 2007: 20) and that may have had specialized facilities for communal ritual activity (Cook, 2008: 13); and 2) the concentration of secondary refuse areas on the margins of the village, often creating a "ring midden" (Means, 2007: 7). Any minimally invasive archaeological methods that can distinguish both plazas and middens, and their respective sizes, would be appropriate for building the regional samples needed to detect patterns of settlement structure. Indeed, distributions of food remains – including shell and bone – and other indicators of domestic refuse (e.g., Cook and Burks, 2011) from shovel test pit and surface surveys have been used to infer settlement structure in general (e.g., Dancey, 1991), and circular plans in particular (e.g., Hawkins, 1998; Henderson, 1998; Thompson, 2007; Thompson and Turck, 2009). At plowed village sites, a complementary and corroborative method is necessary that is both sensitive to midden and plaza locations and less subject to horizontal disturbance by tillage. A method that can be applied reliably and rapidly across the region will allow archaeologists to significantly increase the sample size with which to address questions about the temporal and spatial variability in plaza and village size that feature prominently in contemporary explanations of Late Prehistoric social formations.

2.2. Soil phosphates, middens, and plowzones

Scholars have long known that human activities leave chemical traces in soils and sediments (e.g., Arrhenius, 1931, 1934; Solecki, 1951), but the resurgent interest in soil chemical studies related to human activity areas among Americanist archaeologists is often traced to the work of Eidt (1973, 1977) on soil phosphorus. The proliferation of methods for measuring anthropogenic phosphorus has led to confusion over the applicability of phosphate analysis for identifying activity areas or anthropogenic deposits, particularly in the Ohio Valley (e.g., Skinner, 1986). The reason for the long interest in phosphorus (P) is the unique role that humans play in P cycling (Wells and Terry, 2007: 285). Most soil P originally comes from the weathering of minerals in the parent material, particularly apatite, which is incorporated into biological phosphorus cycling through root uptake by plants (Holliday and Gartner, 2007: 343). Phosphorus is returned to the soil through the decomposition of organic materials and wastes (Bethell and Máté, 1989; Holliday, 2004: 304–314; Parnell et al., 2001, 2002; Proudfoot, 1976; Terry et al., 2004; Wells et al., 2000). It is through this latter pathway that archaeologists are particularly interested in P. As organic matter decomposes, organic P rapidly becomes "fixed" relative to other ions as it is adsorbed on the surfaces of clay minerals or bound with iron or aluminum (in acidic soils) or calcium (in calcareous soils) to form Fe-, Al- or Ca-phosphate minerals (Bethell and Máté, 1989; Holliday and Gartner, 2007: 344; Proudfoot, 1976). Allogenic phosphates from anthropogenic or natural inputs are most closely linked to the fine fraction of soils (Crowther, 1997: 99, 2002: 405; Wells, 2010: 226). Therefore isolation of fine fraction improves the likelihood of identifying anthropogenic P enrichment.

Middens are secondary refuse aggregates (Wilson, 1994) that include the disposal of large amounts of organic waste, thus creating spatial inhomogeneities in the P cycle. Consequently the chemical signal, and most importantly the anthropogenic P signal, for middens should be exceptionally strong. Although the magnitude of anthropogenic P inputs varies from midden to midden, it is common in many studies to have midden sediments and soils yield extractable P values that are at least 3 or 4 times as large as background P levels in nearby soils (Terry et al., 2004: 1243; Wells et al., 2000: 455). Ethnoarchaeological research suggests that this signal is remarkably robust. Even after midden deposits have been physically relocated by village residents, the chemical signature, including P enrichment, is still measurable in the remnant soil (Beck, 2007: 470). Even in heavily bioturbated areas of Mesoamerica, midden deposits are still readily identified by measuring phosphates extracted from surface (0–20 cm) samples when no other surface indicators suggest the presence of a midden (Wells et al., 2000). Stockade walls may enhance the contrast of middens at the margin of the settlement by constraining the area for deposition. In eastern Hungary, stockaded settlements exhibit sharp contrasts in phosphate concentrations within and without the stockaded area, despite a history of mechanized agriculture (Sarris et al., 2004; Yerkes et al., 2007). The sharp boundary in phosphate distributions between village middens and surrounding soils would be enhanced further if the villages were surrounded by agricultural fields when the middens were accumulating. In that case, cultivated plants would remove P from the surrounding soils that would be consumed, excreted, and deposited in the village middens simultaneously depleting the soils around the village of P while enhancing the P content of midden deposits within the village.

By contrast, high traffic areas and spaces that are regularly cleaned tend to have lower P concentrations. Ethnoarchaeological studies in Mesoamerica (Wells et al., 2000: 457–458; Wells, 2004) and the Philippines (Beck, 2007) showed that regularly cleaned paths and plazas lacked the P enrichment of other areas. The central plazas of circular villages in the Eastern Woodlands appear to have been cleaned regularly (Means, 2007: 20) and the special use of these spaces, probably for community gatherings and ritual events (Cook, 2008), suggests that central plazas should have much lower P enrichment compared to other contexts. However, some P enrichment might be expected if plazas were used for food preparation and consumption associated with feasts (Wells, 2004).

The association of anthropogenic P with the fine fraction of soils, and thus with mineral grains and aggregates smaller than 2 mm in diameter, suggests that they should be more resistant to lateral disturbance than macroscopic artifacts. In many (but not all) studies of the impact of tillage on artifact distributions, the size of an object significantly influences the magnitude of lateral movement from its original position (Dunnell, 1990; Dunnell and Simek, 1995; Lewarch and O'Brien, 1981). Although anthropogenic phosphates would be vertically mixed in the plowzone, lateral displacement should be minimal because of their association with fine sediments. In limited studies to date, soil chemical patterns persist in plowed sites despite the total destruction of features (e.g., Linderholm, 2007).

Plowed, cultivated fields with a history of artificial fertilization may pose a particular problem for archaeological phosphate studies, however. Artificial fertilizers typically contain a mix of nitrogen, phosphorus, and potassium (i.e., so called NPK fertilizers) since these elements can often be growth-limiting for domesticated plants. Excess fertilizer that is not taken up by plants could be deposited in the Ap horizon and, thus, contribute to the P (and N and K) patterns across a plowed field. For example, artificial enrichment by orthophosphate fertilizers could create false patterns in a phosphate survey if the fertilizers are distributed unevenly across a field. Alternatively, the phosphates from the fertilizer could overwhelm a very weak archaeological signal if the magnitude of ancient anthropogenic phosphorus contributions is less than the magnitude of variation in the elevated background measurements created by recent, artificial enrichment. To identify the possible influence of either of these processes, larger numbers of non-archaeological "control" samples should be analyzed and the magnitude of difference between inferred ancient phosphate enrichment and background levels should be considered conservatively.

2.3. The Reinhardt Site

The Reinhardt Site (33PI880) is on a 31.5 ha plot of land adjacent to the east bank of the Scioto River in central Ohio (Fig. 2). It is owned by the Water Division of the City of Columbus and is presently leased for mechanical cultivation. Examination of a time series of aerial photographs and historic maps indicates the Reinhardt Tract has been in cultivation since at least the 1930s, although it likely has a much longer cultivation history. The Reinhardt Tract was established as Congressional lands after 1798 and may have been purchased for cultivation or pasture prior to 1810 and certainly before 1842 (Wheeler, 1844). The history of fertilizer use is unknown, but likely to have included the use of artificial NPK fertilizers at some point during the 20th century.

Reinhardt is situated on a Wisconsin-age glacial outwash terrace (Pavey et al., 1999) directly adjacent to the floodplain. The Tract is within Ecoregion 55b: Eastern Corn Belt, Loamy, High Lime Till Plains (EPA, 2009; Omernik, 1987) characterized by generally fertile, well-drained soils formed in fine-loamy glacial outwash and alluvium over coarse, calcareous alluvium (Kerr and Christman, 1980: 93–94). Local soils are Typic Argiudolls (i.e., soils with mollic epipedons and argillic horizons in udic – moist – soil moisture regime) on gentle slopes (<2–4%) with dark brown (10YR 2/2 or 3/3) loam or silt loam A horizons between 25 and 36 cm thick overlying loam or clay loam Bt horizons to depths of 100–170 cm. Rock fragments are variable in abundance but may account for up to 20% of the Ap horizon (20–25 cm thick) with about 15–20% clay and neutral to slightly acidic pH reactions (Soil Survey Staff, 2011), which allows for the formation of Al- and Fe-phosphate minerals. The slightly acidic pH means that artificial fertilizers would have been readily available for plant uptake and, therefore, may not have had a significant impact on more stable pools of phosphorus.

Reinhardt village has been well known to local collectors for decades. In the late 1980s, avocational archaeologists conducted limited surface collection and test excavations of the Late Prehistoric component of the site, suggesting that the village was approximately 100 m in diameter (see Nolan et al., 2008). These excavations exposed intact subsurface pit features and resulted in the recovery of several hundred artifacts including grit-tempered

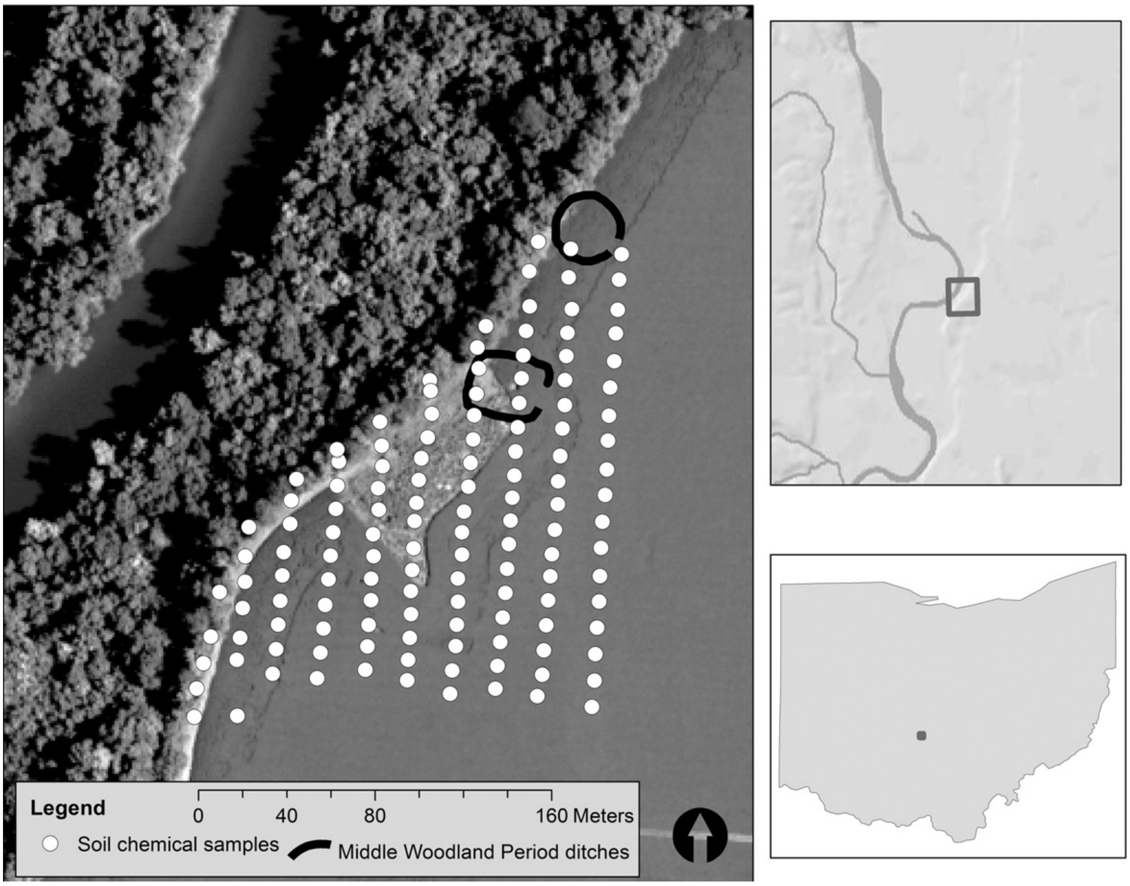

Fig. 2. The location of the Reinhardt Tract in south-central Ohio and the distribution of soil sample locations at the Reinhardt Tract relative to the Middle Woodland Period earthworks identified in a magnetic gradiometry survey (Nolan et al., 2008).

pottery, lithic debitage, several Late Prehistoric bifaces, mussel shell, a sample of well preserved faunal remains, two human burials (Greenlee, 2002), and produced the first chronometric date for the site (see Table 1; Nolan, 2009, 2010). Surface artifacts indicate that the site was occupied episodically over millennia, from the Archaic Period through the Late Prehistoric Period, including previously unknown Middle Woodland earthworks (Nolan et al., 2008) but the vast majority of surface remains are associated with the Late Prehistoric Fort Ancient component (Nolan, 2010).

There were no additional systematic investigations of the property until the winter of 2007, when Nolan et al. (2008) initiated gradiometry and magnetic susceptibility surveys, which were followed in subsequent field seasons with a systematic random shovel test survey, an intensive surface collection of an approximately two acre plowed plot in the village area, a reconnaissance pedestrian survey of the entire Tract, and, finally, feature and trench excavation. Excavations were aimed at recovering subsistence and site structure data in the hopes of evaluating variability along each of these dimensions in Late Prehistoric contexts (Nolan, 2009, 2010, 2011). These excavations have also produced material used to generate chronometric dates for the village and adjacent earthwork complex (Table 1). These dates generally agree with the expected range based on artifacts in extant collections. The Late Prehistoric component dates primarily to the mid-thirteenth to the late fourteenth centuries (Nolan, 2010, in press).

3. Methods and data

In the fall of 2007, the second author and Jarrod Burks collected 132 soil samples for magnetic susceptibility from the plowzone using a 20 m × 10 m systematic grid over a 2.94 ha area within the 35.1 ha Reinhardt Tract (Fig. 2). An east-west base line was established at an arbitrary point south of the village with transect starting points set every 20 m by metric tape. From the base line, north-south transects were traversed and an oakfield soil probe was used to collect a sample approximately every 10 m from the Ap horizon (0–20 cm). The intra-transect spacing was paced and the exact location of each core sample recorded by GPS. Magnetic susceptibility was measured for 132 samples collected from the plowzone across this rectangular lattice by Burks using a Barrington MS2 with MS2B lab sensor. We refer to these data in a comparative context below.

Approximately 99% ($N = 131$) of the 132 samples collected from the plowzone for magnetic susceptibility measurements were reanalyzed for extractable phosphorus. For extracting and measuring phosphates, we employed a modified version of the protocol described by Terry et al. (Parnell et al., 2002; Terry et al., 2000) that is used in the Geoarchaeology Laboratory at Statistical Research, Inc., in Tucson, Arizona. This method extracts soil phosphates using the Mehlich II acid solution (Mehlich, 1978) and measures phosphate concentration using molybdate colorimetry. To enhance the sensitivity of the method to the anthropogenic phosphate signal, we focused exclusively on the very fine sand, silt, and clay sized fractions of sediment (<125 μm on the Wentworth scale) that have a high surface area to volume ratio and, therefore provide a greater number of locations for phosphate adsorption; we refer to this as the "fine fraction."

Soil samples were ground with a porcelain mortar and pestle and passed through 125 μm mesh to collect at least 2 g of fine fraction. We added 25 mL of 1:6 diluted Mehlich II solution to 2 g of the fine fraction and agitated the samples in 50 mL bottles for 10 min. After 10 min, the samples were filtered through quantitative, ashless filter paper and 1 mL of the extraction was diluted to 100 mL with deionized water. One pillow of the PhosVer3 reagent was added to 10 mL of the diluted extraction, shaken for 1 min, and allowed to settle for at least 3 min for color development. Color development was measured using a Hach portable colorimeter with internal calibration for phosphate measurements. One PhosVer3 pillow was added to 10 mL of deionized water and measured as a "blank" along with each batch of 6 or 12 sample measurements. Each sample, including the blank, was measured twice. After subtracting the average of the two measurements of the blank, the average of the two sample measurements (in mg/L) was used to calculate phosphorus concentration (mg/kg) using appropriate dilution factors (Terry et al., 2000: 155).

Distinguishing anthropogenic phosphates from phosphates derived from natural organic matter contributions (pedogenic phosphates) or from the weathering of parent material (geogenic phosphates) requires that the background variation be known. In some studies, background levels are based on the measurement of samples from "control" locations of similar geology and soils but lacking archaeological phenomena (e.g., Oonk et al., 2009: 43). These control samples can be problematic in practice because strict comparability cannot always be ensured. In many cases, it is appropriate to identify some proportion of the lowest measurements in systematically collected samples as "background" variation (Wells et al., 2000: 454), particularly when the entire sampling universe is anthropogenic or the sample lattice is defined in a way to include both "on-site" and "off-site" samples. Following Terry et al. (2004: 1242), we define the average concentrations of the lowest 25% ($N = 33$) of P measurements as "background samples" for our purposes.

Phosphorus concentrations were interpolated between sample locations using the kriging function with a linear variogram in Surfer 9 by Golden Software, Inc. To facilitate mathematical comparisons with other datasets, we converted phosphorus concentrations to Z-scores (standard deviation units around the mean value) and compared them to interpolated Z-scores for magnetic susceptibility for mean anomalies from the combined datasets and residual difference (P anomalies minus MS anomalies). Details of the archaeological and magnetic susceptibility procedures can be found in Nolan (2010).

Table 1
Chronometric data from the Reinhardt Site.

AMS samples	Lab sample number	Measured age (BP)	Median calendar age (cal AD)	2σ calendar range (cal AD)	Material
F1/1988	BETA 245378	830 ± 40	1220	1160–1270	Human bone collagen
FS 583	BETA 255920	820 ± 40	1230	1160–1280	Wood charcoal (hickory, *Carya* sp.)
FS 228	BETA 255916	770 ± 40	1270	1220–1290	Wood charcoal (unidentified ring porous)
FS 287	BETA 255917	690 ± 40	1290	1270–1330; 1340–1400	Wood charcoal (hickory, *Carya* sp.)
FS 584	BETA 255921	620 ± 40	1300; 1370; 1380	1280–1400	Nutshell charcoal (pecan, *Carya illinoensis*)
FS 368	BETA 255918	650 ± 40	1310; 1360; 1380	1280–1410	Wood charcoal (red oak, *Quersus* sp.)
FS 436	BETA 255919	490 ± 40	1430	1400–1460	Wood charcoal (willow/cottonwood)
TL sample					
X42-183-1	UW 2000	866.9 ± 46	1142	1050–1234	Grit-tempered body sherd

Table 2
Summary statistics for phosphorus and magnetic susceptibility measurements.

	Phosphorus (mg/kg)	Magnetic susceptibility (χ)
N	131	132
Range	4.2–67.9	21.5–56.5
Mean ± standard deviation	27.6 ± 14.4	40.1 ± 8.5
Background range (lowest 25% of measurements; *N* = 33)	4.2–17.7	21.5–34.1
Background mean ± standard deviation	12.1 ± 3.8	29.1 ± 3.0

4. Results and discussion

Phosphorus concentrations ranged from as little as 4.2 mg/kg to 67.9 mg/kg with average values for all 131 samples at 27.6 mg/kg (Table 2). Background phosphorus concentrations ranged from 4.2 mg/kg to 17.7 mg/kg with an average of 12.1 mg/kg. We expect that as an important, high traffic, and regularly cleaned location, any plaza should be relatively low in remnant P (i.e., at or slightly above background levels). If the plaza is circumscribed by a ring of features, structures, and occupational debris, we expect sediments in the latter areas to be relatively enriched in P. The highest concentrations likely are associated with the Late Prehistoric middens. Interpolated values (Fig. 3) indicate that the highest concentrations (>45 mg/kg; more than 3 times background levels) occur in a roughly U-shaped ring that is open to the south. Phosphorus concentrations more than three times the background level are common for kitchen midden deposits in other archaeological cases (Terry et al., 2004: 1243; Wells et al., 2000: 455). This U-shape of high phosphorus concentrations is most likely the chemical signature of a ring of midden deposits demarcated on the exterior by the edge of the Late Prehistoric village component and surrounding a central plaza space indicated by lower phosphorus concentrations (15–40 mg/kg). Isolated samples with unusually high P concentrations (>45 mg/kg) occur in two places to the southwest of the Fort Ancient village and generally elevated P concentrations (above 30 mg/kg) with several unusually high P concentrations occur to the northeast (see Fig. 3). Without further information, it is difficult to identify the origin of the isolated samples to the southwest of the village, although they could be associated with extra-village activity spaces during the Fort Ancient occupation or be associated with an Archaic or Woodland occupation. The pattern of P enrichment to the northeast of the village is corroborated in the magnetic susceptibility data (Fig. 4) and is spatially associated with buried Middle Woodland earthworks (Nolan, 2010; see Figs. 2–4), suggesting the probable location of Middle Woodland midden deposits.

The U-shaped distribution of elevated, average, and background levels of interpolated phosphorus concentrations allow us to make some general statements about the size of the central plaza and of the Fort Ancient village as a whole. The plaza area may be as wide as 40 m along a north-south axis and around 30 m along the east–west axis. In this interpolation, the reconstructed plaza is an oblong, irregular void in the phosphate distribution, although the particular shape of the plaza could be an artifact of the sampling lattice (Wells, 2010). The larger of these two dimensions would be consistent with Reinhardt as a small village according to Cook's (2008) hypothesis of bimodality in village and plaza size. The thickness of the midden ring (ca. 20 m) is consistent with the width of the ring of occupational zones surrounding the plaza at other Middle period Late Prehistoric sites in Ohio (Brady-Rawlins, 2007; Carskadden and Morton, 2000; Cook, 2008; Essenpreis, 1982) and Kentucky (Henderson, 1998).

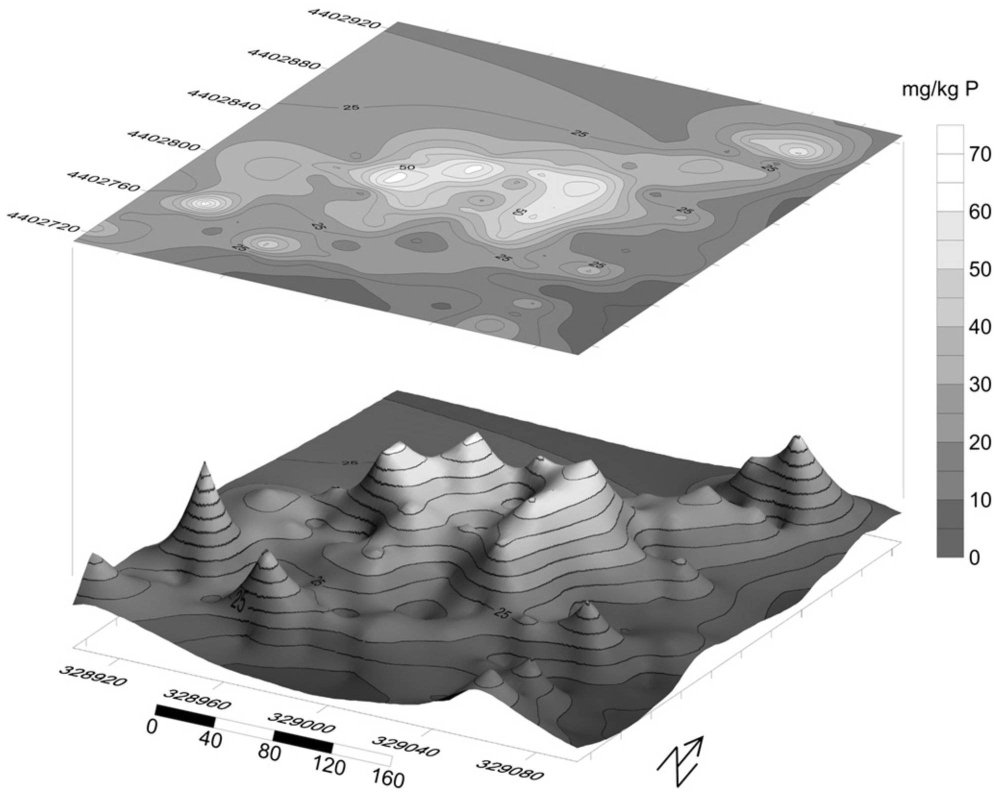

Fig. 3. Plots of interpolated phosphorus concentrations across the Reinhardt Site. Note the central, U-shaped ring of high values with steep declines around the margins of the ring and toward a central area. High phosphorus concentrations outside the U-shaped ring may indicate extra-village occupation areas or be associated with the Middle Woodland occupation to the north of the Fort Ancient village. The very high values in the north are located between the two Middle Woodland ditch features.

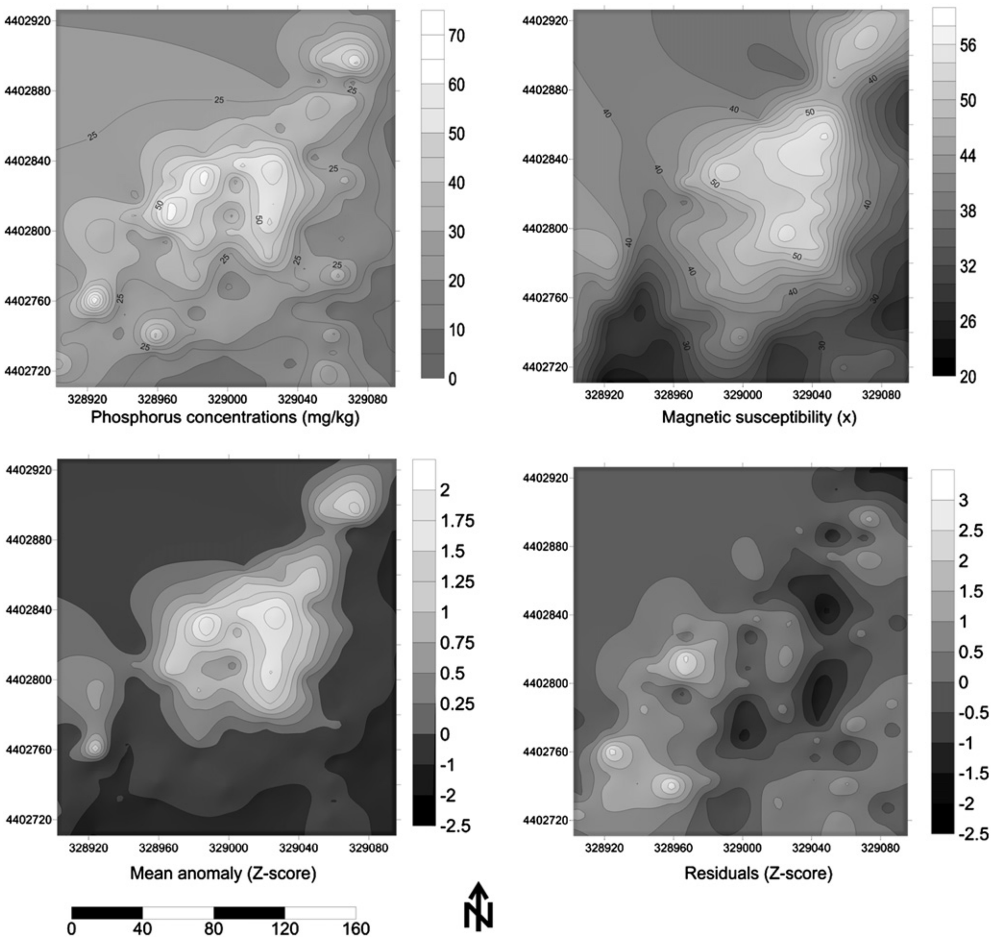

Fig. 4. Plots of phosphorus (top left), magnetic susceptibility (top right), average of *Z*-score values for phosphorus and magnetic susceptibility (lower left), and the residuals of phosphorus less magnetic susceptibility anomalies (lower right). Note that the elevated magnetic susceptibility measurements correspond with the northern and eastern part of the U-shaped ring identified in the phosphorus data and that the difference between the occupation ring and the plaza is visible in the mean anomaly data, as well.

The systematic collection of soil samples along a staggered lattice allows us to interpolate the P concentrations with some confidence but we can only cautiously infer aspects of the shape of the plaza and the village as a whole. Rectangular lattices in particular can introduce artificial patterns into the interpolated results that require some caution in interpretation (Wells, 2010: 227). Cook's (2008) model of Fort Ancient settlement structure presupposes that both the central plaza and the overall plan of contemporary villages should be circular. At first glance, the interpolated data from Reinhardt would seem to reject that hypothesis. However, given the coarseness of the sample lattice used for this study, we cannot yet rule out the possibility that the irregularity of the plaza shape and village ring are artifacts of the lattice distribution and subsequent interpolations. Closer sampling intervals within the village area and the use of a staggered lattice may improve the accuracy of the interpolated reconstruction (Wells, 2010).

The phosphorus anomaly overlaps with the distribution of anomalously high magnetic susceptibility measurements in the north and east portions of the P-inferred ring midden (Fig. 4). This suggests that refuse deposition in this zone is more enriched in ferromagnetic material (Tite and Mullins, 1971), perhaps from hearth cleaning, than the western margin of the village. When the anomalies for both phosphorus and magnetic susceptibility are combined, the U-shaped ring midden and oblong plaza space are still quite visible, although the plaza is slightly less distinct. Residuals indicate a strong east-west trend in the divergence of the phosphorus and magnetic susceptibility indicators of anthropogenic sediments. This pattern suggests that magnetic susceptibility and phosphorus are not documenting the same patterns of human activity and chemical deposition (see also Marwick, 2005). Phosphates are strongly linked with midden deposits in the archaeological and ethnoarchaeological literature (Beck, 2007; Wells et al., 2007), therefore we suspect that the magnetic susceptibility data may be more sensitive to other anthropogenic or natural alterations (e.g., pyrogenic activities) and not just midden deposits (cf. Cook and Burks, 2011).

Artifact densities from the shovel test pit survey are ambiguous but appear to be capable of distinguishing the location and general size of the Late Prehistoric village, as inferred from the phosphorus survey (Fig. 5). However, there is some variability in the patterns indicated by different material classes. For example, fire-cracked-rock appears to be an exceptionally poor predictor of the village area and plaza space, whereas the density of faunal remains corresponds quite well with the P-indicated occupation ring. As another indicator of midden deposits, it is not surprising that the density of faunal remains is the best indicator among the artifacts recovered from the plowzone. The low-phosphorus plaza space, however, includes test pits with both high and low densities of faunal remains. In the absence of the P data, we could not securely infer the size or shape of the plaza on the basis of faunal density alone. The artifact distributional data and the magnetic

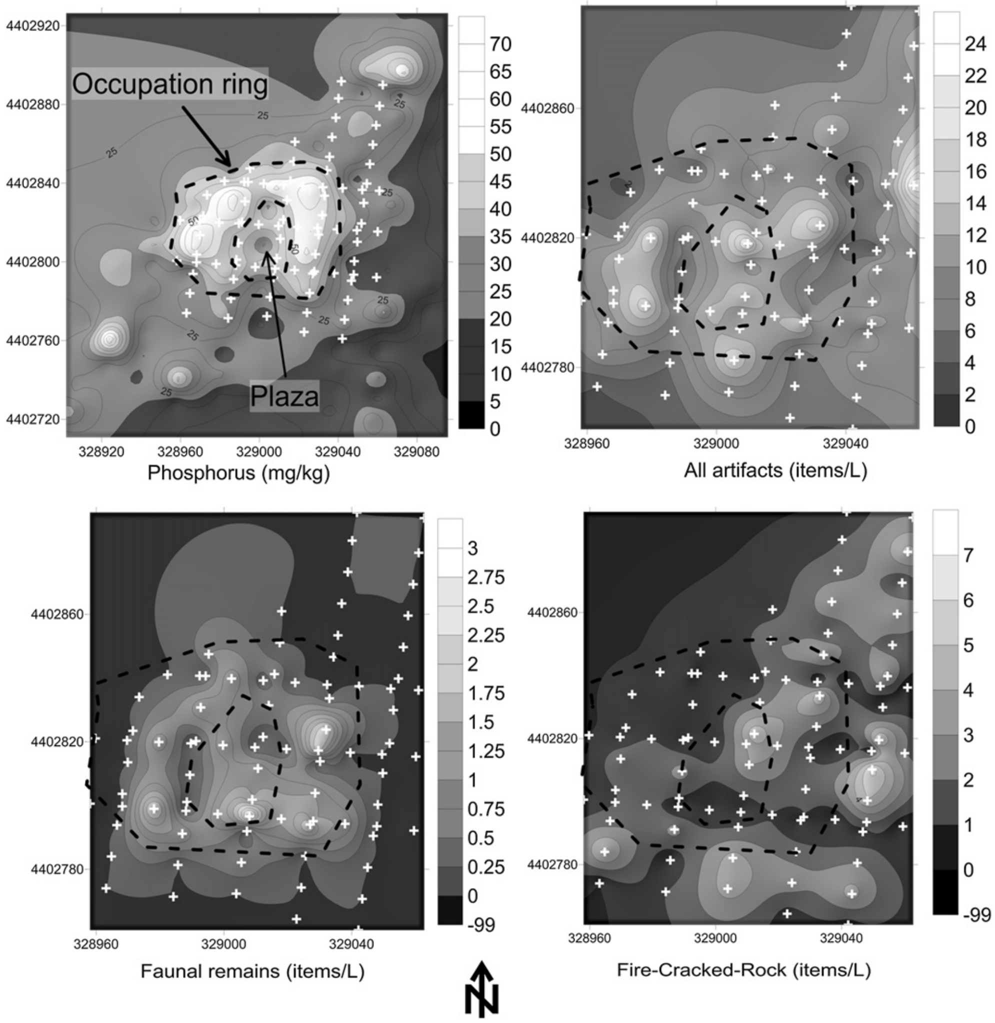

Fig. 5. Comparisons of the phosphorus data with interpolations of the shovel test data. The locations of shovel test units are marked with small crosses (Note the difference in scale for the phosphorus plot and the shovel test plots). Although the density of all artifacts from shovel tests (top right) and the density of faunal remains (lower left) generally corroborate the phosphorus-inferred village ring as an artifact rich location, neither artifact-based data set identifies the phosphorus-inferred plaza. Other artifact-based reconstructions, including fire-cracked-rock distributions (lower right), do not appear to corroborate any of the patterns observed in other datasets.

susceptibility data corroborate aspects of the phosphorus pattern but are incapable of distinguishing both the occupation ring and the plaza as recorded in the remnant soil phosphates. This is what we would expect based on our knowledge of the tillage effects on artifact distributions (Dunnell and Simek, 1995; Lewarch and O'Brien, 1981; Navazo and Diéz, 2008; Roper, 1976) and our knowledge of midden impacts on soil chemistry (Beck, 2007; Parnell et al., 2002; Terry et al., 2000; Wells et al., 2000).

It is worth noting here that the clarity of the pattern at Reinhardt may have been obscured if the multiple components at the site were superimposed rather than horizontally separated. Cultural soilscapes (*sensu* Wells, 2006) are palimpsests of chemical traces, therefore superposition of subsequent activities can overprint and obscure the traces of previous activities. It is remarkable that, although Reinhardt was the locus of human activities over more than a millennium from the Middle Woodland to the Late Prehistoric Periods and has been mechanically cultivated for more than a century, the pattern of middens surrounding the plaza space at the Late Prehistoric village occupation is still discernible in the phosphorus concentrations. However, given the intensity and duration of activity that included interruptions of P cycling associated with the Late Prehistoric agricultural village relative to earlier periods, this should not be unexpected (Dunnell, 1983).

5. Conclusions

Variation in village structure and size is important for understanding demographic, sociocultural, and political processes in the Late Prehistoric Eastern Woodlands (e.g., Cook, 2008; Henderson, 1998). Our knowledge of the spatial patterns of this variability is significantly hampered by the expense, ethical, and logistical challenges that extensive, horizontal excavation strategies pose. Geophysical methods may not be appropriate for all contexts, particularly shallowly buried sites that have been plowed. Shovel test surveys are time-consuming, costly, and, due to the taphonomic impacts of tillage, of variable quality for identifying plaza size. At Reinhardt, artifact abundance generally corroborated the size of the Fort Ancient village area but was generally incapable of distinguishing a central plaza space. Similarly, although magnetic susceptibility can be a valuable tool for identifying anthropogenically enriched sediment (e.g., Cook and Burks, 2011; Marwick, 2005; Tite and Mullins, 1971), variable cultural formation processes produced a palimpsest magnetic susceptibility record at Reinhardt that was not suitable for distinguishing a circumscribed plaza space in the absence of other data.

By contrast the measurement of extractable phosphorus from plowzone deposits may provide a relatively inexpensive (less than

$1000 capital outlay for the colorimeter, glassware, and plasticware, and less than $1 per sample for consumables), minimally invasive method for identifying the presence and size of central plazas at these villages as well as overall village size. Unlike artifacts, the association of anthropogenic phosphates with the fine fraction of soils and sediments suggests that phosphate enrichment should be less susceptible to lateral disturbance than larger artifacts. Because magnetic susceptibility can be enhanced by a wide variety of human activities that may or may not be associated with middens, it may be a less reliable indicator of midden accumulation than phosphorus (cf., Cook and Burks, 2011). An additional benefit of our phosphate survey approach will be in its ability to rapidly generate data for a large number of Late Prehistoric village sites throughout eastern North America, particularly in the areas adjacent to the florescence of Mississippian chiefdoms, thus significantly increasing the sample size with which to evaluate prevailing hypotheses of social change in the centuries prior to Euro-American contact. Do these villages emerge as "periphery peers" (Cook, 2008) with limited variability in the size and structure of these plazas and villages? Do they change systematically over time as population increase in size or aggregation becomes more pronounced (Pollack and Henderson, 1992)? These questions will be more amenable to investigation with regional datasets on settlement size and the presence, size, and shape of plazas. For shallowly buried, plowed village sites, we suggest that systematic soil phosphate surveys offer a valuable, minimally invasive tool for generating such data across the region. Such an approach allows us to generate data to evaluate our research questions while acting within the ethical and logistical constraints of 21st century archaeological practice.

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