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Geochemistry, Geophysics, and Ritual at the Moorehead Circle

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ABSTRACT
The Moorehead Circle is a unique Hopewellian (ca. AD 100 to AD 400) architectural and ritual activity area within the Fort Ancient earthwork (33WA2). Except for the artifacts and features associated with their mortuary program found in and below earthen mounds, most Hopewell ritual areas are virtually devoid of material remains. The data in this article demonstrate that many ritual activities may leave invisible traces. Measuring soil phosphate (PO_4) and magnetic susceptibility (MS) are quick, minimally destructive methods for efficiently studying larger scale ritual landscapes. By mapping PO_4 and MS in two anthropogenic strata within and around the Moorehead Circle, the authors identified previously undetected areas of ritual and domestic activity, both within and beyond the excavated areas. The locus of the most intense activity and the type of activity in the Moorehead Circle changed during the site's history, indicating changes in the structure and organization of ritual practices in and about the Moorehead Circle.

KEYWORDS
Moorehead Circle; Hopewell; anthrosols; soil phosphate analysis; frequency dependent magnetic susceptibility

Introduction

The Moorehead Circle is a 60-meter diameter timber post ring, or woodhenge, that contains unique features not previously observed at other such Middle Woodland Hopewell (ca. AD 90– 400; see Seeman and Nolan 2023) sites. It was fortuitously discovered by Jarrod Burks in 2005 (Burks 2006) during a multi-instrument geophysical survey conducted prior to planned maintenance activities at the Fort Ancient State Memorial park. Following its discovery, the Moorehead Circle has been the focus of a multiyear excavation program directed by Robert V. Riordan (2007, 2008, 2011a, 2011b, 2012, 2013, 2014, 2015a, 2015b, 2016, 2018, 2019). Riordan has shown that a portion of the landform occupied by the Circle was built up to create a roughly level area, around which wooden posts were erected in at least two concentric circles.

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In the central part of the Circle is a unique ceremonial complex (see below) that also contains limestone pavements, postholes, and multiple sand- and gravel-filled trenches. While pottery, stone tools (primarily bladelets; see Riordan et al. 2023), and architectural signatures have been recovered, much about the use of the site remains unknown, and little information has been collected that pertains to activities outside the post ring. With questions remaining about the precise nature of the use of the central ceremonial complex, and its integration with the larger landscape, additional investigative techniques beyond the collection and analysis of the tactile remains of past behavior were conducted by Joshua A. Donaldson. The collection and processing of the phosphate (PO_4) and magnetic susceptibility (MS) data reported herein were part of Donaldson's master's thesis, supervised by Nolan (Donaldson 2016).

Hopewell Rituals

Hopewell is the name given to a distinctive archaeological "culture" defined in part by construction of monumental earthen features such as enclosures, burial and effigy mounds, and earthworks. They also had complex mortuary and ceremonial practices and a penchant for exotic and finely wrought portable goods. The Hopewell societies existed in the Middle Woodland period (AD 90–400; Lynott 2014; Seeman 2004, 2007; Seeman and Nolan 2023). Ohio Hopewell people were ingenious architects who built sophisticated and precise geometric earthworks. The mortuary aspects of their culture, especially those highly visible parts of it that resulted in elaborate burial practices memorialized in deposits in earthen mounds, have been the subject of archaeological excavation and speculation since the nineteenth century. Their nonmortuary ritual life and their domestic life have conversely received relatively little attention, and very few Hopewell domestic sites have been excavated (Dancey and Pacheco 1997; Pacheco 1996, 1997; Pacheco et al. 2009, 2020; Pacheco and Dancey 2006). Similarly, few nonmound contexts within large ceremonial centers have received attention. The application of large-area geophysical survey within Hopewell centers is beginning to change this, while revealing the nonmound spaces were not always empty (see, e.g., Komp et al. 2019). It is well-known that many elements of the large ceremonial centers were constructed with astronomical alignments (e.g., Hively and Horn 1982, 1984, 2013, 2019, 2023; Romain 2004), and nonmound features may also align with significant astronomical events.

In addition to their construction of various ritual landscapes, Ohio Hopewell groups obtained exotic raw materials from across the continent in order to craft numerous unusual and aesthetically appealing portable artworks. Their geographic knowledge of a large part of eastern and central North America, their establishment of extensive social networks "outside the range of Hopewell societies" (Hill et al. 2020:186), and their movement of exotic and other goods and materials are recognized in the definition of a "Hopewell Interaction Sphere" (Caldwell 1964;

Seeman 1979; Struever and Houart 1972). The economic and social exchanges conducted during the Middle Woodland period brought to Ohio obsidian from contexts in Wyoming (Griffin 1965; Griffin et. al 1969; Hatch et al. 1990; Hughes 1992, 2006), copper from the Great Lakes and southern Appalachians (Fraikor et al. 1971; Hill et al. 2018; Nolan et al. 2020; Seeman et al. 2019), mica from North Carolina (Seeman 1979), marine shells from the Gulf of Mexico (Charles 2012), pipestone from Illinois (Emerson et al. 2013; Farnsworth et al. 2004; Hughes et al. 1998), and chert from North Dakota, Illinois, Indiana, Missouri, Kentucky, and Tennessee (e.g., Genheimer 1992; Greber et al. 1981; Hill et al. 2020; Miller 2014; Nolan et al. 2007, 2020; Ruby 1997) and likely included movement of people, information, and beliefs (e.g., Ruby et al. 2005; Ruby and Shiner 2005). This intricate network was intimately linked with the activities that took place at the Hopewell mound and earthwork sites. Excavations of these sites have yielded most of the exotic materials that have been analyzed (see Nolan et al. 2020; Seeman 1979).

The Ohio Hopewell are particularly known for the size and complexity of their earthworks, an architectural effort unmatched in North America until the appearance of the Mississippian culture a thousand years later. The sheer number of earthworks and mounds they constructed in southern Ohio seems to imply a stable, sedentary society fueled by agricultural surpluses. However, nucleated settlements in Ohio were absent until very late in the Middle Woodland or the early Late Woodland period (ca. AD 300–500). The few domestic sites investigated reveal decentralized Hopewell populations in small, dispersed extended-kin residential units (hamlets), practicing a mixed economy based on garden horticulture, foraging, and hunting (Dancey and Pacheco 1997, contra Griffin 1996). This premaize agricultural system may have generated large surpluses (Mueller et al. 2017; Mueller, White, and Szilagyi 2019; Patton and Fahey 2020; Wymer 2020). Coercive leadership structures appear to have been absent from Hopewell cultures.

These earthworks were not hastily built, and there would have been a significant amount of planning and preparation done before any construction occurred. James Marshall (1969, 1978, 1980, 1996) has written about the planning of these earthworks and describes the Hopewell as having been masters of geometry, with their own standard unit of measure, and he suggests the possibility that plans may have been used that could have been duplicated at other sites to produce a similar construction (see also Hively and Horn 2019). In addition to planning the layout of an earthwork's architectural elements, other aspects of site preparation would have included forest clearing and topsoil removal (Lynott 2014). There is also evidence of the laborers having built up a foundation or surface for construction in many places (Connolly 1996a; Riordan 2018, 2019). Even on the small scale, Hopewell floors show planning in that the topsoil was stripped to enable the harder subsoil to serve as a base, while a more formal floor was prepared with gravels, sand, and harder clays (Greber 1996). It is also possible that some soils used in the construction were specifically chosen for their color in order to convey a symbolic effect (Charles 2012; Greber 1996; Lepper 1996). It also appears that as some Hopewell structures concluded their use life, their termination followed prescribed methods. Lynott (2014:224) notes that "most sub-mound structures . . . tend to have been dismantled" before a mound covered them. Riordan (2015a) states that, in addition to the Moorehead Circle's posts having been pulled as part of the deconstruction of the site, a layer of gravel was placed over the Entrance and the central ceremonial core, indicating that its termination was of a ritualized nature.

These earthworks, with their associated social and ritual features, are situated within a larger ceremonial landscape that is often hidden from modern view. The enormous advances in remote sensing and geophysical capabilities have enabled thousands of previously invisible features and constructions within and around Hopewell ceremonial centers to be discerned (Davis and Burks 2019; Komp et al. 2019; Ruby 2019). This study concentrates on some of the ephemeral signatures that are associated with Hopewellian usage of their enclosures, which are just beginning to be more routinely investigated. Few, if any, previously published studies have used geochemical prospecting to explore how the Hopewell used nonmound spaces (cf. Nolan and Hill 2015).

Fort Ancient (33WA2)

The Fort Ancient (33WA2) earthwork is a Hopewell hilltop enclosure located on a peninsular landform 80 m above the Little Miami River in Warren County, Ohio (Figure 1). It is one of a number of hilltop enclosures situated within the Great and Little Miami watersheds, all built by Hopewell societies of southwestern Ohio and southeastern Indiana during the Middle Woodland period (Coon 2008; Riordan 1995, 1996; Ruby 2009). The multiple construction events at Fort Ancient date within the Middle Woodland period at 100 BC–AD 400 (Connolly 1996a; Essenpreis and Moseley 1984). Its enclosure of about 41 ha was accomplished by constructing 5.7 km of earth and stone embankment walls, ranging in height from 1.5 m to 7 m, their segments separated by around 70 openings or gateways (Mills 1920:5; Otto 2004:3).

Fort Ancient is composed of three distinct sections: the North, Middle, and South Forts. The South Fort was likely constructed first (Connolly 1996a, 2004; Moorehead 1890); its embankment walls follow the edges of its irregularly shaped landform. The Middle Fort is a narrow piece of land that connects the North and South Forts, with low embankment walls lining its sides. Earthen crescents in the Middle Fort may have been designed to channel foot traffic through it (Connolly 1996a). The North Fort is the largest section, and its interior contains a crescent-shaped wall, four small mounds that are about 150–160 m apart, forming a nearly perfect square (Romain 2004), another small mound near the western embankments, several wooden structures (Connolly 1996b; Lazazzera 2004), and the Moorehead Circle. Outside the North Fort, where the peninsula is linked to adjoining uplands, the Twin Mounds mark where a set of low parallel walls extended for a distance of 0.7 km northeast, enclosing a small mound at the end.

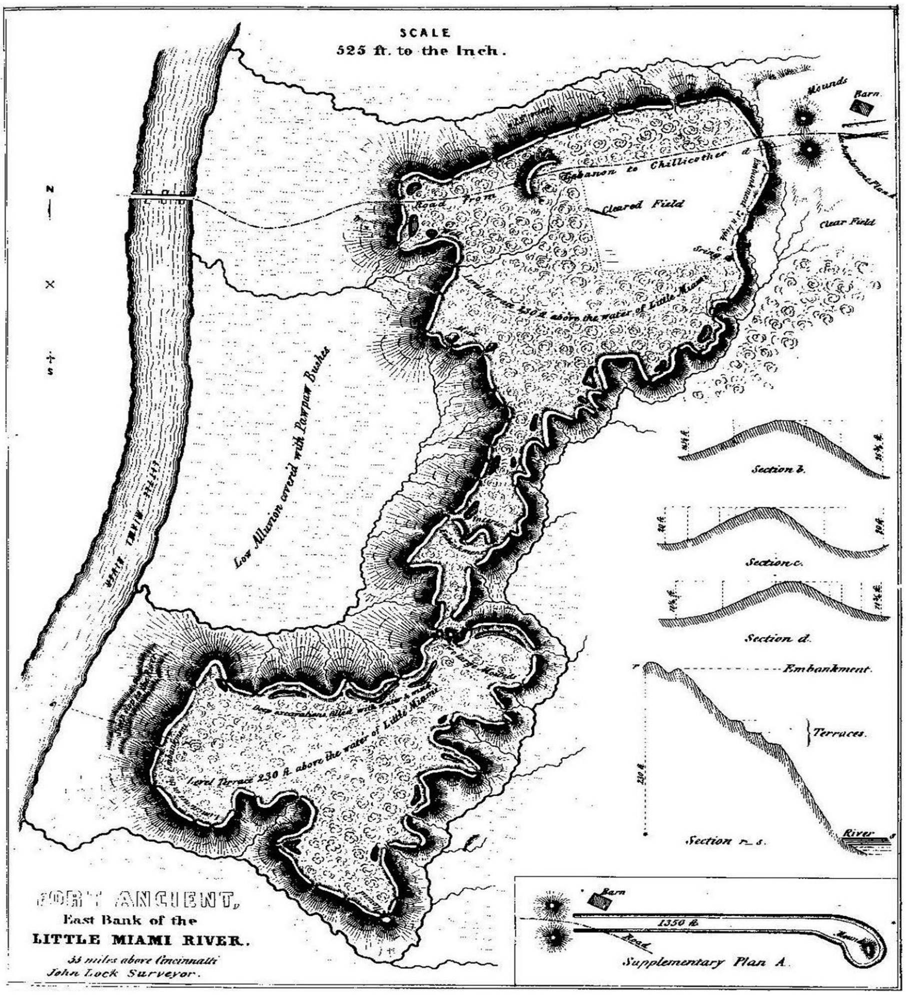

Figure 1. Fort Ancient Earthworks (Squier and Davis 1848).

Fort Ancient also contains earthen mounds, stone circles, and limestone pavements, and numerous burials were found under stone deposits on terraces below the South Fort's embankments. The entire area of Fort Ancient's enclosed space was subjected to remodeling, restructuring, and the construction of additions throughout the approximately four centuries of its active use. While the enclosure and its visible features were of Middle Woodland age, a small late precontact (Fort Ancient culture) village site is located within the South Fort (Harper 2000, 2004).

Fort Ancient stands alone amid all the other examples of Ohio Hopewell enclosures in many ways: It is the largest in terms of the earth, stone, and gravel that was moved to create it; it was almost certainly the most costly Hopewell earthwork ever built in terms of the amount of human labor it required; the earth and stone architecture grew accretively; and there were multiple remodelings of its landscape. Among the hilltop enclosures, it is the only one that is known to have contained internal domestic structures and the only one with a large timber post ring edifice, or woodhenge. It may have been the hilltop enclosure that was in longest use, and the changes that were introduced in its form and features were likely due in at least some instances to developments that occurred in Hopewell religious and ceremonial needs and beliefs over the centuries.

The Moorehead Circle

Remote sensing surveys, both electrical resistivity (ER) and magnetic gradient, were conducted in 2005 by Burks (2006) ahead of maintenance work at Fort Ancient (Figure 2). Burks discovered a circular structure, the Moorehead Circle, in the largest of the six areas he examined. The Moorehead Circle is a 60 m diameter Middle Woodland period timber post ring, or woodhenge, located in the North Fort of the Fort Ancient earthwork. Portions of it were excavated between 2006 and 2016 under the direction of Riordan (Riordan 2019). Similar post-ring features are known at several other Ohio Hopewell sites, including the Hopewell site (Ruby 2019), the Stubbs Earthwork (Cowan and Sunderhaus 2002; Rippl 2009), and possibly the Seip Earthwork (Spielmann and Burks 2011). However, this is the only woodhenge known within a hilltop enclosure. As the most intensively investigated Hopewellian woodhenge, the Moorehead Circle possesses a unique suite of interior features as well as two concentric rings of perimeter postholes. Whether these rings were contemporaneous remains unknown.

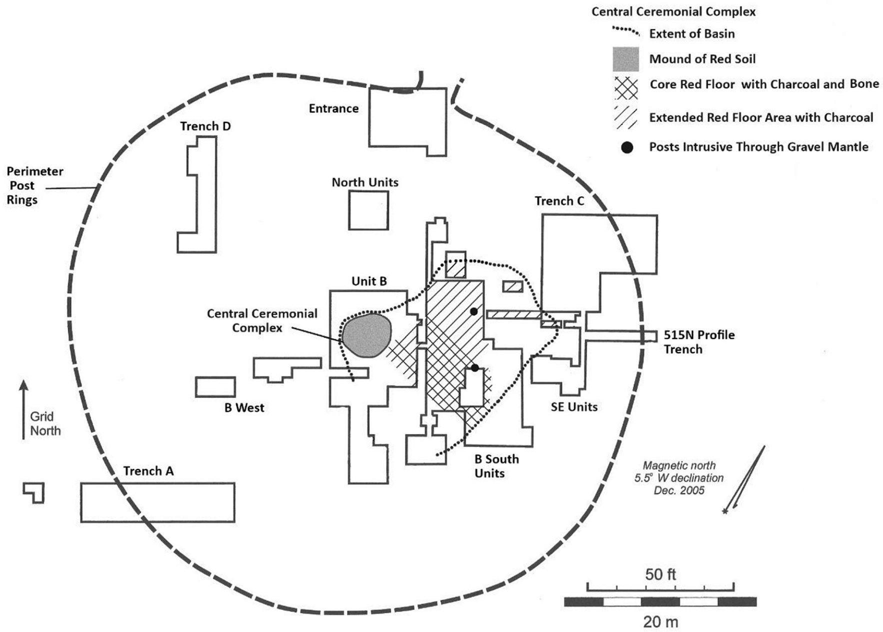

Figure 2. Plan of Moorehead Circle excavations (Riordan, Miller, and Stone 2023). *Note:* Grid north and magnetic north are nearly opposite. Directions used in the text, unless specified otherwise, are relative to UTM grid north with NAD 1983

Before building the Moorehead Circle, about a third of the area was first built up with additions of soil. The artificially leveled landform was the canvas on which the perimeter posts and a formal entranceway into the Circle (with two superimposed stone pavements) were created. A shallow basin (~12 × 18 m) was dug near the center of the complex, with a prepared floor of red sediment, dubbed the "red floor," in which fragments of calcined bone and considerable amounts of wood charcoal were embedded. At the east end of the basin was a low 4 m diameter mounded deposit of orange-red sediment, around which portions of broken ceramic vessels were deposited. The red floor was covered, and the basin was gradually filled with stratified lenses of coarse sediment interleaved with bands of carbon, indicating more burning. A series of approximately 15 closely spaced and generally parallel trenches were then dug across the southern part of the Moorehead Circle, between the Entrance pavement and central ceremonial complex, and partially overlapping the central basin area. The trenches, cumulatively measuring over 400 m in length, were filled mostly with sand and gravel and are thought to have been gravity drainage features (Figure 3; Riordan 2019).

The Hopewell people ended their use of the Moorehead Circle by removing all the perimeter and interior posts. They then covered the Entrance pavement, the central basin complex, and the space in between with a 10–20 cm thick layer of gravel. Riordan (2015a) characterizes this deposition as part of an extended termination rite. It demanded a substantial investment of time and energy of a kind not known elsewhere at Fort Ancient and is believed to connote the degree of ideological importance that was attached to the Moorehead Circle by the Hopewell people who used the site.

Figure 3. Central feature (photo courtesy of Robert Riordan).

A few large postholes were found that had been later dug through the gravel mantle, one of which had an early Late Woodland radiocarbon date. Two others are believed to be later Middle Woodland features that mark a probable post–gravel mantle resumption of summer solstice sunrise observances at the site. Initial construction of the Moorehead Circle may have occurred as early as the late first century or the beginning of the second century AD. It may have been used for 50–100 years or possibly longer, which would mean that several generations of people participated in the events that occurred there (Riordan 2018).

The field to the west of the Circle contains an oval-shaped anomaly, discovered in Burks's 2005 resistivity survey. It measures ~20 × 8 m and lies approximately 100 m from the Moorehead Circle (Riordan 2011a). Known as "The Oval," it has an opening on its south side and a linear post feature (12–15 m long) in its center (Riordan 2011a). A radiocarbon date suggests contemporaneity with the early use of the Moorehead Circle. Roughly halfway between the Oval and the Moorehead Circle, test excavations revealed a burned feature, possible daub, fire-cracked rock (FCR), cordmarked and plain pottery sherds, ~200 pieces of debitage, and 22 bladelets (Riordan 2015b). The relatively high density of artifacts there, compared to within the Moorehead Circle, suggests that this area may have been an extension of the domestic area marked by the structures found by Connolly (1996b) to the south and east of the current museum (Riordan 2015b:105; see also Cowan et al. 2004; Lazazzera 2004).

The Moorehead Circle is part of a unique and complicated ceremonial landscape that underwent alterations throughout its century or more of use. The intricacies of the Circle's archaeology consumed much archaeological labor, with little focus on the larger landscape within which the woodhenge was situated. As reported here, the authors employed a relatively novel approach combining systematic soil phosphate (PO_4) and magnetic susceptibility (MS) sampling to add information about the human use of the Circle as well as in the unexplored wider landscape. Similar approaches hold promise for exploring the nontactile remnants of Hopewell ritual and ceremony "Between the Monuments" (Komp et al. 2019).

Methods

To explore more details on the distribution of activity across the Moorehead Circle and vicinity, the authors conducted a soil sampling survey, a modified version of the field methods previously employed by Nolan (Nolan 2010, 2014; Nolan and Redmond 2015; Roos and Nolan 2012; Swihart and Nolan 2013, 2014). While previous surveys have employed transect and sample spacing of 10 m or 25 m, this survey used transects spaced 7.5 m apart (Figure 4), with samples on a staggered lattice spaced every 7.5 m within transects (Donaldson 2016:28).

Soil phosphate (PO_4) is one of the most useful geochemical indicators of human activity (Arrhenius 1929; Cook et al. 2014:109; Dirix et al. 2013:2969;

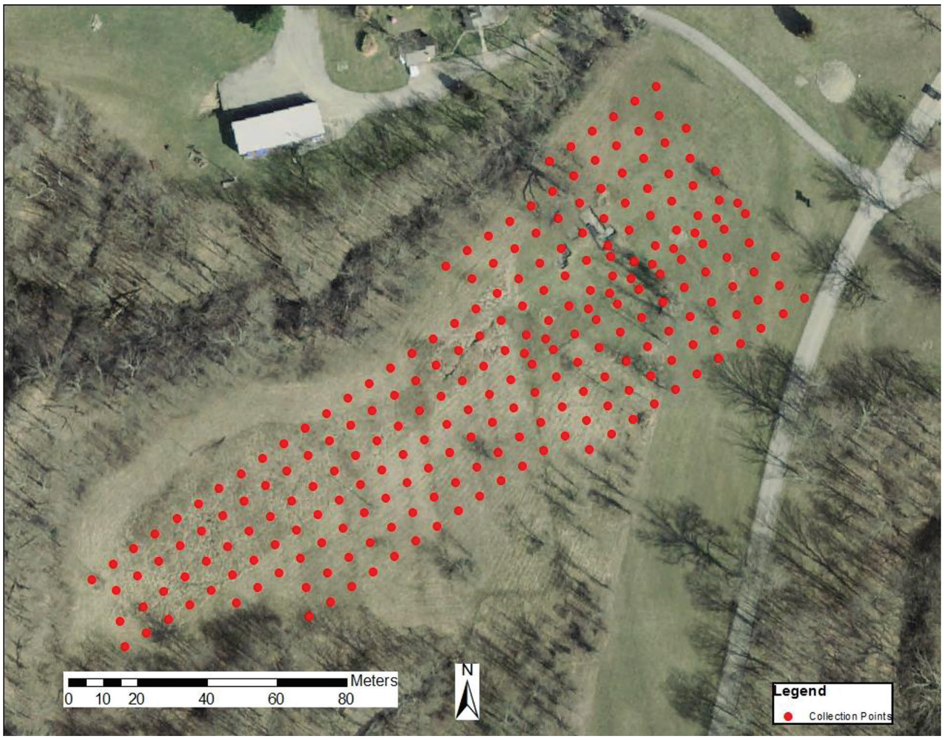

Figure 4. Sample collection locations.

Eidt 1977, 1984; Entwistle and Abrahams 1997: 411; Entwistle, Abrahams, and Dodgshon 2000:299; Entwistle, Dodgshon, and Abrahams 2000:171–172; Holliday and Gartner 2007; Linderholm 2007:418–419; Middleton 2004:47, 53; Nolan 2010; Nolan and Redmond 2015; Oonk et al. 2009:36; Roos and Nolan 2012). Phosphate is deposited in the soil through the decay of organic material and rapidly forms strong bonds with the fine fraction of the sediment or soil column and, thus, is a good indicator of production of food or organic architecture and the deposition of waste (midden, night soil, etc.; Cook et al. 2014:109; Holliday and Gartner 2007; Middleton 2004:52; Oonk et al. 2009:40).

Magnetic susceptibility (MS) is widely used in prospecting for sites and analysis of intra-site patterning (Cook and Burks 2011; Cook et al. 2015; Hodgetts et al. 2017; Nolan 2010; Nolan et al. 2008; Nolan and Redmond 2015; Roos and Nolan 2012). Magnetic susceptibility is enriched through either weathering or thermal alteration (Tite and Mullins 1971). In archaeological applications, it is used as an indicator of midden formation (weathering and organic decay) or places of fire-based activities (heating mechanism). Single frequency measurements are most common (Cook and Burks 2011; Hodgetts et al. 2017; Nolan et al. 2008; Roos and Nolan 2012), but Dearing (1999) notes that dual frequency measurements, when robustly measured through repeat tests, can measure the frequency dependence of the MS (FD MS). Measurements of a high frequency (HF) and a low frequency (LF) MS create generally similar patterns and magnitudes, but the HF measure does not capture magnetism of ultrafine superparamagnetic grains. So, the FD MS measure is a characterization of the percentage of the MS that is contributed by superparamagnetic grains (Dearing 1999:14, 34, 36–38). Dearing (1999:Figure 2.4) shows samples with elevated LF MS and ~6%–9% FD MS are likely created by burning activity. Thus, pairing a measure of organic deposition/decay (PO_4) with a measure of weathering and burning (LF and FD MS) allows analysis of different spatial patterns for different kinds of activities relevant to archaeological interpretation. The combination of PO_4, LF MS, and FD MS provides more information about past human behavior than any in isolation (see Nolan and Redmond 2015) and is, in particular, more useful than single frequency MS measures that are more common in the region.

The surveyed area encompasses roughly 6,400 m^2 overlapping the Moorehead Circle and extending southwest past the Oval. Transects were labeled T0 through T10, with an intermediate transect T4.5 between T4 and T5 across an unexcavated section within the Circle. Following Nolan (Nolan 2010, 2014; Nolan and Redmond 2015; Roos and Nolan 2012), samples were collected with an approximately 1 inch-diameter Oakfield soil probe, and the first ~5 cm of soil was discarded to eliminate modern additions and current organic horizon. Two ~10 cm samples were collected at each sample location in the normal grid. At each sample location, the stratigraphy, soil texture, and Munsell color were recorded. This resulted in 238 total sample locations across the site. The first sample is ~5 cm below surface (cmbs) to ~15 cmbs within the plow zone. The second sample was from ~25 cmbs to 35 cmbs to target the initial Hopewell layer, based on data from prior excavations.

Additionally, four samples were collected in the unexcavated portions of the Central Feature (CF) from two locations 50 cm apart. Sample CF1 was taken under the backfill at 25 cmbs, and CF2 was 30 cmbs at the same location. Samples CF3 and CF4 were taken 50 cm southwest of CF1 from 30 cmbs and 60 cmbs. The samples were bagged, labeled, and taken back to the lab at Wright State University. The sample bags were then allowed to air-dry.

Laboratory Procedures

Following a modified version of the method developed by Terry and colleagues (2000; see also Nolan 2010; Nolan and Redmond 2015; Roos and Nolan 2012), phosphate testing used the molybdate colorimetric method to measure the phosphate that can be extracted by a 10% Mehlich-2 solution. The soil samples were ground in a mortar and pestle and sieved through a 125µ geological sieve, and exactly 2.00 g were collected. The 2 g of soil were placed in 10 mL of a 10% Mehlich-2 solution, shaken for 10 minutes, and filtered through #391 filter paper. The concentration of phosphate was converted to mg/kg, adjusted for dissolution, and recalculated based on its atomic weight. Mehlich-2 extraction and quantitative colorimetric measurements were selected from a variety of other extraction and measurement methods (see Holliday and Gartner 2007:309–316) as it is a simple, robust procedure performable in a variety of contexts (see Terry et al. 2000), and it is time and cost efficient (Roos and Nolan 2012:31).

MS was measured with a Bartington MS2B with MS3 laboratory meter. Both low frequency (LF) and high frequency (HF) mass-specific susceptibilities were measured, and frequency dependent (FD) susceptibility was calculated for each sample. A separate subsample from each sample used in the PO_4 analysis was ground and passed through a 1 mm geological sieve. Three measurements of both HF and LF were taken for each sample and averaged to improve accuracy of calculations of FD.[1] If the three measurements were not internally consistent, then additional measurements were taken of the same sample. The measured LF and HF are presented as 10^{-8} m^3/kg. FD was recalculated from the averages for HF and LF using the formula

$$\%FD = ((LF - HF)/LF) * 100.$$

Due to the uniqueness of the four samples of the Central Feature soil, 18 readings were run to have a reading with increased accuracy of FD estimation.

PO_4 concentration and LF, HF, and FD values were entered into the attribute table of the shapefile for the sample locations in ArcMap 10.x and interpolated using the kriging algorithm in the geostatistical analyst extension. The data were explored in the geostatistical wizard, and the semivariogram model that provided the best curve fit to the binned averages was selected to produce a map for the variable and level.

Statistical and Spatial Analysis

To explore the characteristics of the data, a series of multivariate analyses were conducted. Statistical analysis of variables was conducted in Past 3.26 (Hammer et al. 2001), and the geostatistical interpolation was performed and all maps created in ArcMap 10.x. For each subsample (Composite: all locations and depths; Lower Level [LL]: 25–35 cmbs; Plow zone [PZ]: 5–15 cmbs), the first step was a cluster analysis using neighbor joining (Hammer et al. 2001), with Mahalanobis distances to define the branching. Major branches in the resulting dendrogram were counted as a proxy for the number of coherent groups expected in the sample. The number of major branches was then used to define the number of clusters in a K-means cluster analysis. The resultant cluster ID for each point was added as a new data column for grouping in later analysis. To test the coherence of the clusters, discriminant function analyses (DFA) were conducted on log transformed data (Hammer et al. 2001). The results of classification with raw and log transformed data are generally comparable, with higher success rates for the latter. The clusters' medians were then compared to the relevant median for the whole sample and distributions relative to the standard deviation of the whole sample (a pseudo-Z score). Scores with an absolute value below 0.1 were classified as medium; those between 0.11 and 0.5 as medium–high; those between 0.51 and 1.0 as high; those between 1.01 and 2.0 as very high; and values over 2.01 as very, very high. These relative classes were used to interpret enrichment and depletion of the clusters. Enrichment in PO_4, with or without enrichment in LF MS, is interpreted as evidence of organic deposition and decay. Enrichment of LF MS and FD MS with median values for FD MS in the burning range shown by Dearing (1999:Figure 2.4) are interpreted as evidence of burning. Clusters enriched in LF MS but low or depleted in PO_4 are interpreted as products of weathering and not organic deposition. For all of these analyses, the Central Feature sample was excluded. In the composite measures DFA, it was included as an unknown and had a membership predicted. For the individual layers, this step was excluded as the depth of samples was not the same as the PZ or LL samples. An additional analysis was conducted of the composite sample. The log-transformed variables were input into a principal components analysis (PCA). The PCA did not fully separate clear groups in multidimensional space; however, principal component 1 (PC1) spread the samples into two branches. These two branches were defined as groups and used in another DFA and mapped to explore high-level structure in the samples.

Results

There were 238 locations in the field where soil samples were collected, which resulted in 476 individual samples, 1,428 separate measurements (PO_4, LF MS, and HF MS for each layer in each sample), and calculation of 476 properties (%FD MS). All measurements for each sample location are presented in Donaldson (2016:Table 5.1), and the summary statistics are presented in Table 1. The results are presented below and discussed by subsample. Two approaches to interpreting the distribution of behaviorally meaningful MS and PO_4 values are used. First is a multivariate statistical exploration of the structure of the data by subsample. Second is a more traditional geostatistical interpolation (kriging), which is drawn mostly from Donaldson (2016). Following Nolan and Redman (2015), while the distributional patterns are similar under a variety of semivariogram models, the combination of data transformation and semivariogram models that best fit the data are presented here (Table 1).

Summary Statistics

All measures, except FD of the LL, are right skewed. FD calculations are closest to normally distributed, especially for the LL. The two layers do not exhibit significant differences (Wilcoxon signed rank test) in central tendency in PO_4 (W = 15,586; approximation of $Z = 1.773$; $p = 0.07725$; see Supplementary Table S-1) or LF MS (W = 14,590; approximation of $Z = 0.347$; $p = 0.72787$; see Supplementary

Table 1. Summary Statistics for Phosphate and Magnetic Susceptibility Measurements of the Moorehead Circle.

	PZ PO_4*	Lower PO_4*	PZ LF†	Lower LF†	PZ HF†	Lower HF†	PZ FD%	Lower FD%
Mean	3.669	3.748	27.825	26.446	26.251	24.659	5.509	6.751
Median	3.260	3.100	15.330	18.520	14.565	17.275	5.530	6.815
Mode	1.960	1.790	10.420	12.310	13.430	26.120	4.270	6.720
Std. deviation	1.806	3.167	25.377	19.803	23.937	18.646	1.878	2.232
Skewness	1.333	4.835	1.672	1.685	1.678	1.719	0.520	−0.214
Std. error of skewness	0.158	0.158	0.158	0.158	0.158	0.158	0.158	0.158
Kurtosis	2.959	36.877	1.908	2.538	1.911	2.576	1.050	0.097
Std. error of kurtosis	0.314	0.314	0.314	0.314	0.314	0.314	0.314	0.314
Minimum	0.82	0.16	7.28	6.38	7.0	6.13	0.96	0.58
Maximum	12.71	33.42	130.05	104.68	121.35	96.83	12.26	13.61

Note: Computed with Hammer et al. 2001.

* In mg/kg.

† In 10^{-8} m^3/kg.

Table S-2). The LL PO_4 is both more left weighted and has a substantially longer right tail (Figure 5a), whereas the Plow zone LF MS is left weighted with a slightly longer right tail (Figure 5b). However, FD MS is significantly different between the two layers, with the LL having significantly more elevated FD MS ($W = 21{,}994$; approximation of $Z = 7.311$; $p = 0.00001$). The LL FD exhibits a bimodal distribution with a taller second peak to the right of the center of the distribution (Figure 5c).

The Central Feature CF-1 and CF-2 had similar phosphate levels (Table 2), which are lower than those associated with the central basin but slightly higher than those immediately south. CF-3 was gathered from ~60 cmbs and exhibits marked enrichment. CF-4 (~30 cmbs) exhibits the lowest PO_4 measurement. The Central Feature exhibits among the highest in LF MS and elevated FD MS. The high LF and FD MS measurements suggest that superparamagnetic grains make up the majority of, if not all, the magnetic grains within the central feature samples (see Dearing 1999).

Plow Zone The PZ PO_4 levels are relatively low, with values of 0.82 mg/kg to 12.71 mg/kg and a mean of 3.67 mg/kg, with a skewness to the right (see Table 1; see Figure 5a; see Donaldson 2016:Figure 5.17). The highest concentration of PO_4 is just within the Moorehead Circle near the Entrance (from 4.7 mg/kg to 5.4 mg/kg). Another spike in phosphate within this range is just southwest[2] of the Central

Table 2. Central Feature Soils Analysis Results.

Sample	Depth	PO4 mg/kg	LFMS X*10-8	FDMS %
CF-1	~25 cmbs	6.85	102.87	10.23
CF-2	~30 cmbs	6.68	93.39	10.3
CF-3	~60 cmbs	11.8	111.16	9.43
CF-4	~30 cmbs	6.19	119.08	11.33

Note: MS are averages of the 18 readings for each sample.

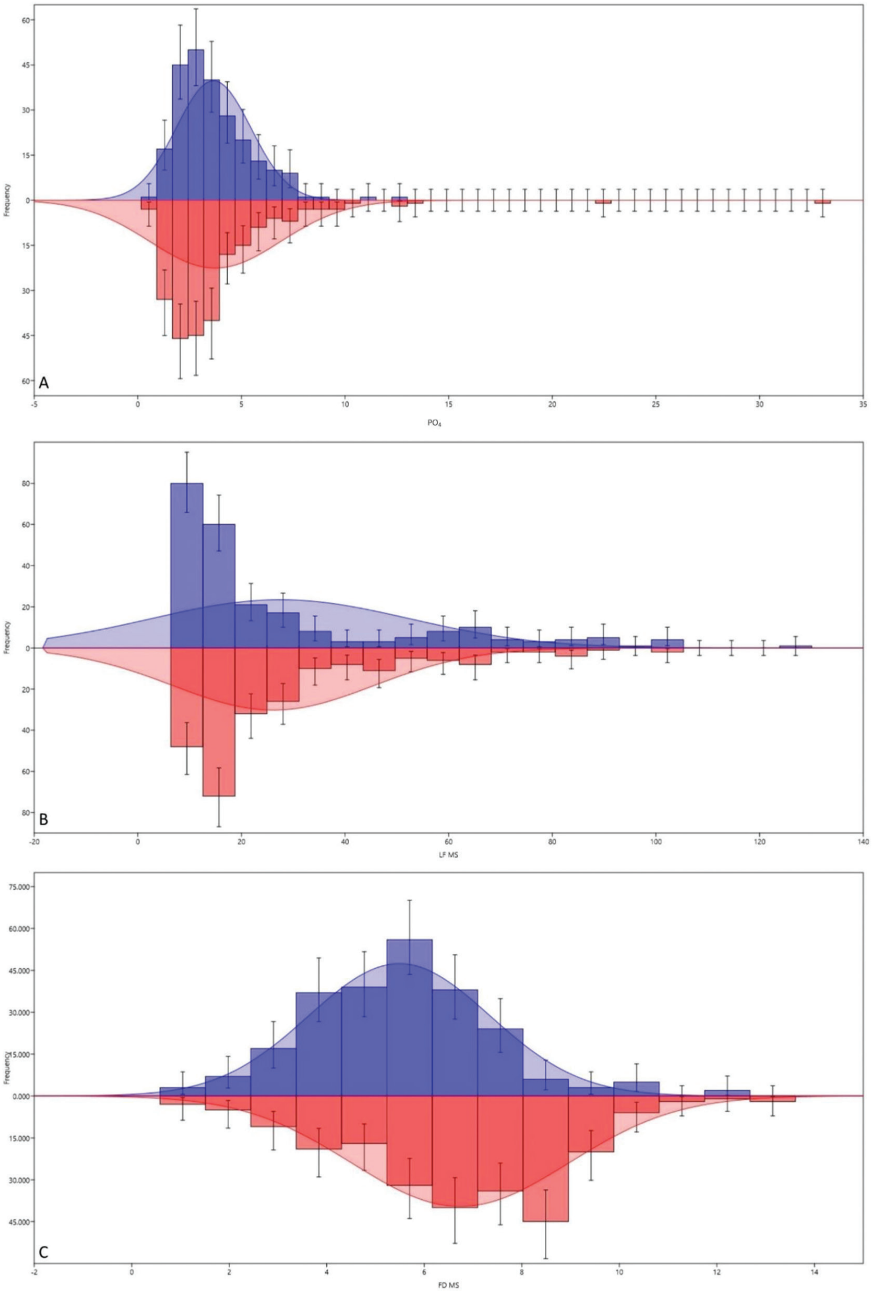

Figure 5. Histograms of PO$_4$ for (A) LF MS; (B) FD MS, and (C) measures for plow zone (*blue*) and Lower Layer (*red*). (Computed with Hammer et al. 2001.)

Feature. Increased phosphate in other areas includes those just outside the Circle to the northeast and an enriched area in the southwest field about 30 m from the Moorehead Circle. The southwestern field is characterized by generally low PO$_4$.

The LF MS for PZ has a mean of 27.83 ± 25.4 $_*$ 10^{-8} m^3/kg and is skewed toward the right (see Table 1; Donaldson 2016:Figures 5.19, 5.20). There is a high spike southwest of the Central Feature (89.5 to $102.4 * 10^{-8}$ m^3/kg), and there is also a slightly elongated concentration from this area to the south side of the Circle near the Entrance. The rest of the samples exhibit a pattern of decreasing LF MS from the center of the Moorehead Circle. The FD MS has a mean of 5.5% ± 1.878% (see Table 1), with a distribution slightly skewed to the right (see Figure 5c; Donaldson 2016:Figure 5.22). There are areas of increased FD MS throughout the entire survey area. Around the Central Feature, FD MS ranges from approximately 7.4% to 11.6%.

Lower Layer The LL phosphate readings are substantially different from those of the PZ. The minimum level is 0.16 mg/kg, but the maximum is slightly more than twice that of the PZ. The mean is about the same as the PZ, at 3.75 mg/kg, but the LL is more highly skewed to the right (see Table 1; Donaldson 2016:Figure 5.24). The highest levels of phosphate are located in the northern portion of the Moorehead Circle, ranging from 4.2 mg/kg to 6.15 mg/kg. The Moorehead Circle has elevated levels of PO_4 in comparison to the areas around it, and the levels decrease into the southwest field.

The LF MS for the LL is largely similar to that of the PZ but slightly less enriched, with a mean of $24.66 * 10^{-8}$ m^3/kg, and right skewed (see Table 1; Donaldson 2016:Figures 5.26, 5.27). The highest levels are centered just southwest of the Central Feature. The highest LF MS values range from $71.46 * 10^{-8}$ m^3/kg to $82.65 * 10^{-8}$ m^3/kg, and nearly the whole Circle is encompassed by the medium to high ranges. There is a sharp drop-off outside the Moorehead Circle, and it lightly picks back up in the southwest field.

The FD MS for the LL ranges from 0.58% to 13.61%, with a mean of 6.75% (see Table 1; see Figure 5c). There are significant spikes in FD MS at the Entrance surrounding the southeastern edge of the Circle and the northern quadrant of the southwest field. The measurements for the Central Feature and the northern area of the Circle are similar to the distribution of FD MS in the PZ.

Interpolation

The data from all samples were interpolated to raster surfaces for each measure (Figure 6). Donaldson (2016) interpreted these surfaces, defining a series of clusters of phosphate enrichment in and around the Moorehead Circle along with magnetic susceptibility distributions throughout the entire site. While the levels of the magnetic susceptibility results are similar to those of other studies, the amount of phosphate within the earthwork was generally lower when compared to that of other sites (Nolan and Redmond 2015; Roos and Nolan 2012; Swihart and Nolan 2014). This may indicate that the Moorehead Circle was not used intensively or on a regular basis.

Plow Zone Concentrated areas of phosphate enrichment in the soil will be used to guide this discussion on specific activities (Figure 7). There are three concentrations

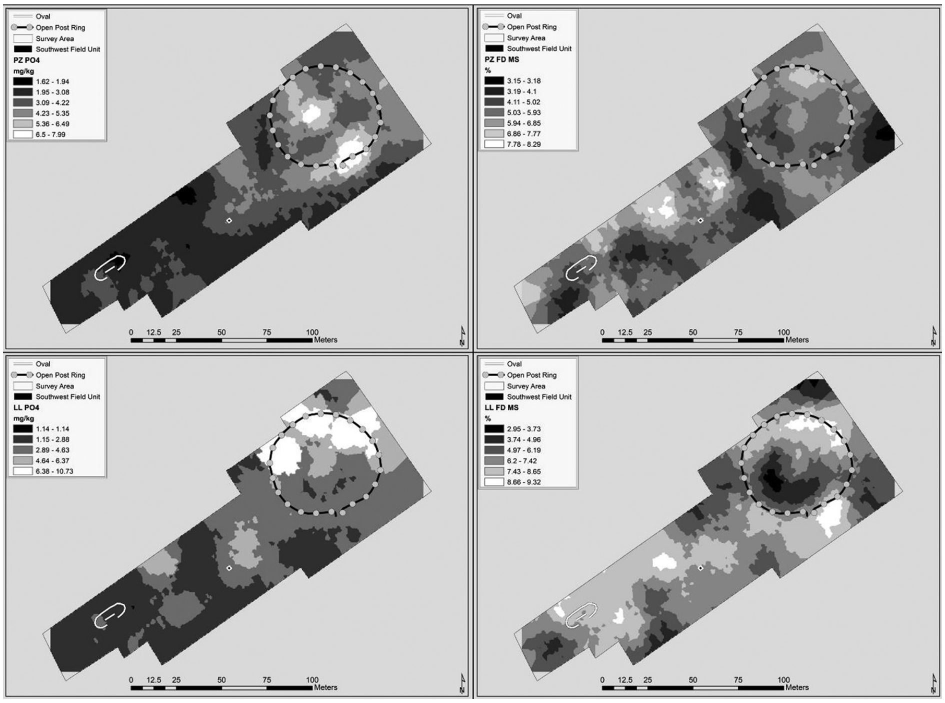

Figure 6. Interpolated surfaces for (*left to right, top to bottom*) plow zone PO_4, PZ FD MS, Lower Level PO_4, and LL FD MS. Note: These maps are oriented to UTM north, not local grid-north, which is approximately south–southwest.

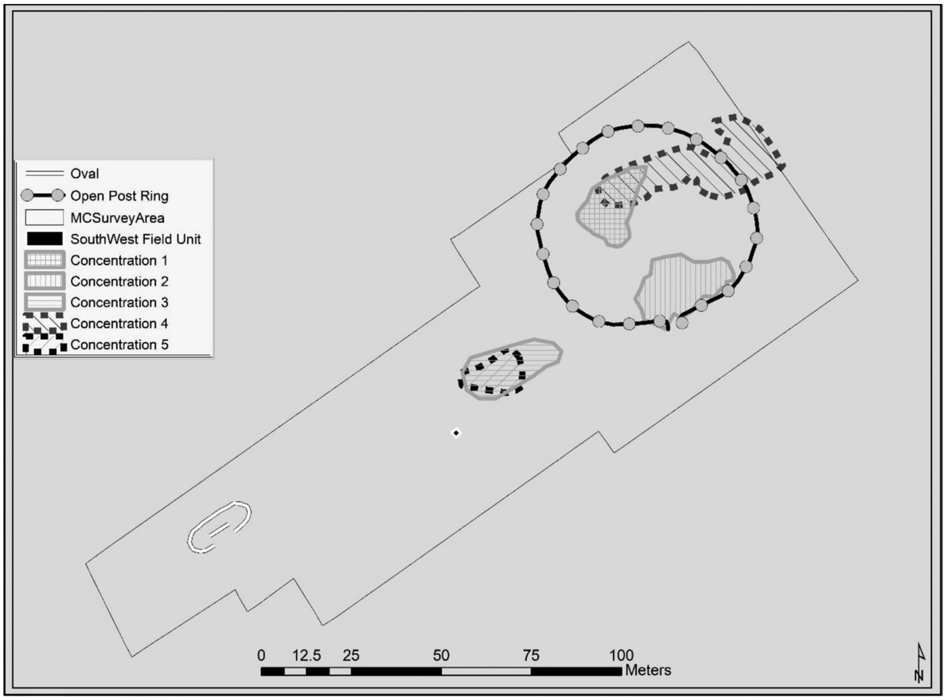

Figure 7. Location of Donaldson's (2016) phosphate concentrations.

of phosphate defined in the PZ layer. Concentration 1 is located in the center of the Circle within the area of the central basin and near the Central Feature. Concentration 2 is at the edge of the southeast side of the Circle near the Entrance. Concentration 3 is centered about 20 m to the southwest of the Moorehead Circle.

Concentration 1 is most likely attributed to the central basin. The phosphate signature being in the shallower level suggests the structure was in use during the later occupation of the area, consistent with Riordan's (2014:74) chronology of the Moorehead Circle. While the nature and function of the basin is unknown, the higher phosphate concentrations on the northern portion indicate that the activity happening in this area may have been related to the red floor.

This concentration is also elevated in LF MS (Donaldson 2016:40), possibly indicating burning within the basin. However, the low FD MS within the structure itself (see Figure 6; see also Donaldson 2016:Figure 6.12) does not indicate burning. This could be caused by the amount of sand and other larger grains within and around the red floor soil. These larger soil grains within the soil samples may be diluting the frequency dependent readings that would suggest burning. However, there is definite evidence of burning from the excavation. There are areas with burned soil, charcoal, and ash within the basin and above the red floor, making it likely the scale of the survey may have missed these burned features that are smaller than the sampling interval.

Concentration 2 is located near the Entrance (see Figure 7). The Entrance is thought to have been where the participants entered the Moorehead Circle by walking over the limestone pavement to reach the other features. As a result of organic deposition and decay in place, it is uncommon for there to be an area of increased PO_4 adjacent to an entry or a pathway. As Middleton (2004:56) notes, "high-traffic areas have very low concentration of all elements, and may even be lower than off-site controls." The PO_4 patterns seem to follow the southern edge of the Moorehead Circle's boundary, and there is an isolated peak just inside the opening in the post rings. The highest levels of phosphate are in the area adjacent to the northeast of the site's suspected entryway, and this lines up approximately with feature 396 (Riordan 2014). Feature 396 is a larger feature that contained a posthole with artifacts, including pottery and many bones, within and surrounding the feature. It is possible that when the posts were deconstructed, the postholes were filled with soil containing organic material.

Concentration 3 has an average phosphate reading for the survey, but it is an irregular, locally elevated cluster outside the Moorehead Circle. There is a coincident spike in FD MS overlapping this concentration (see Figure 6; see Donaldson 2016:Figure 6.19). The southwestern test unit excavated near this concentration revealed a higher density of bladelets and other artifacts than had been found within the Moorehead Circle.

Superposition suggests that these three PZ concentrations are related to the later use (compared to the LL concentrations discussed below) of the Moorehead Circle. There is evidence confirming the existence of a basin for burning within the central basin; however, these were not indicated by the FD MS sample measurements in the PZ.

Lower Layer The PO_4 from the LL follows a different pattern than that of the plow zone. While the boundary of the Circle is not apparent in these surfaces, there is a concentric pattern to both the PO_4 and the FD MS indicating the woodhenge did structure the activity patterns here (see Figure 6). The concentrations of phosphate in the LL are divided into two separate areas: Concentration 4 is located near the northern section of the Moorehead Circle post ring, and Concentration 5 is just to the southwest of the Moorehead Circle, overlapping Concentration 3 (see Figure 7).

Concentration 4 is partially within the central basin. The elevated PO_4 overlaps the northern interior of the structure and extends northeast outside the Circle, suggesting that organic deposition activity here predates the central basin. While it does intersect the central basin, the majority of this concentration stretches through the northern half of the Moorehead Circle and just east of the post ring. Burks's (2006) electrical resistivity also identified this area, and the suspected interpretation is that soil may have been added here to raise up or level a portion of the Moorehead Circle. The FD MS values here are within the burning range (see Dearing 1999:Figure 2.4; discussion in the Statistical and Spatial Analysis section above).

There is a small area of increased PO_4 near Concentration 4 toward a ravine on the northwestern exterior of the post ring, which was also visible in the PZ. This may represent downslope disposal in association with this concentration. The people at the Moorehead Circle may have wanted to keep the disposal away from the center of the woodhenge, tossing organic material downhill toward the ravine to keep the ritual area clean. While the PZ PO_4 indicated the area of the limestone pavement did not serve as a passageway late in the history of the site, the LL absence of enriched PO_4 over and near the pavement is consistent with the area having served as an entryway in the older iteration of the Circle.

Concentration 5 is in the southwest field and overlaps Concentration 3 from the PZ (see Figure 7). Concentration 5 is not only higher in PO_4 but also exhibits elevated FD MS (see Figure 6). Near the southwest test unit is the only PO_4 enriched area that is persistent across levels and not connected to the Moorehead Circle.

Clustering

All DFA classifications and jackknifed classifications for log-transformed data are successful for more than 90% of cases, indicating reasonably good fit between the clusters and the structure of the underlying data.

Composite samples The composite analysis used PO_4, LF MS, and FD MS. HF MS was excluded as it is largely a duplication of LF MS and the difference is captured in the FD MS. The neighbor-joining dendrogram for all six measures for all samples (excluding CF) is shown in Figure 8. The clusters on the seven major branches are

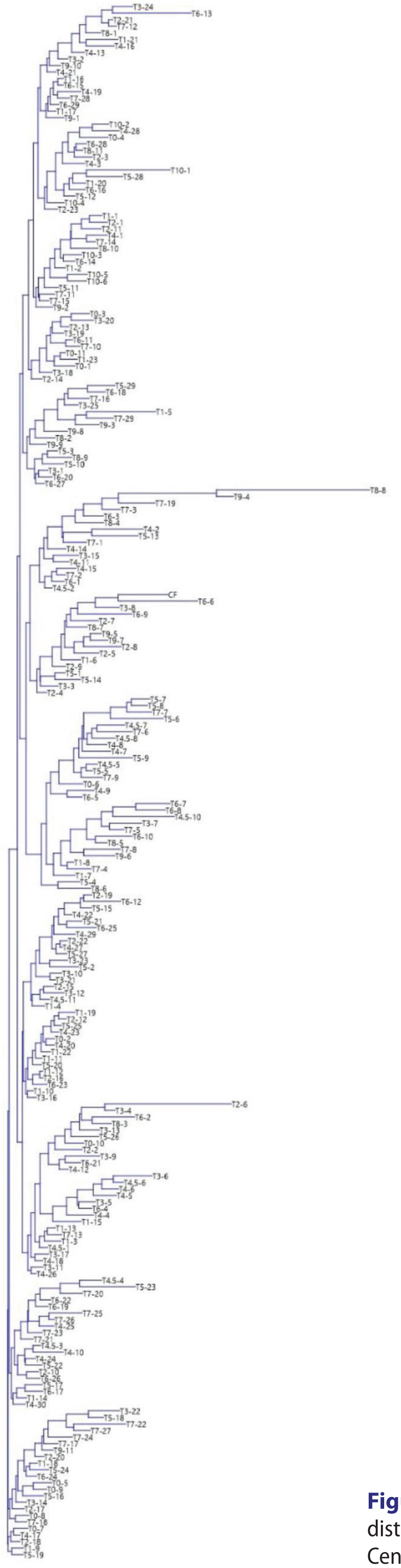

Figure 8. Neighbor-joining clustering by Mahalanobis distances for all measures from all samples except the Central feature. Note seven large collections.

Table 3. Interpretation of Composite K-means Clusters.

Cluster	PZ PO_4	Class	L PO_4	Class	PZ LF	Class	L LF	Class	PZ FD	Class	L FD	Class	Interpretation
1	3.18	Med	3.505	Med-High	21.285	Med-High	28.995	High	6.205	High	8.66	High	Burning-some organic
2	2.69	Low	3.26	Med	29.765	High	19.88	Med	5.72	Med-High	7.34	Med-High	Possible burning
3	4.32	High	3.26	Med	91.12	Very, Very High	75.675	Very, Very High	5.095	Med-Low	4.475	Very Low	Organic deposition
4	5.38	Very High	3.26	Med	46.895	Very High	41.645	Very High	6.18	High	8.285	High	PZ organic-burning
5	2.93	Med-Low	2.45	Med-Low	10.16	Med-Low	11.06	Low	4.8	Low	4.99	Low	Background
6	4.24	High	3.59	Med-High	67.17	Very High	49.29	Very High	5.94	Med-Low	6.77	Med	Organic deposition
7	2.93	Med-Low	1.8	Low	13.93	Med	16.21	Med-Low	4.88	Low	7.39	Med-High	Background-LL burn(?)

Note: Computed with Hammer et al. 2001.

well separated on the dendrogram. There are several subclusters in the dendrogram that also exhibit reasonably good separation. There are also a few extreme outliers on the dendrogram: T8–8, T9–4, and T2–6. The major branches (*n* = 7) were used to group the sample locations and composite measures (Table 3). The DFA of the log-transformed composite measures K-means clusters achieved a classification success rate of 93.28% (90.76% jackknifed; see Supplementary Table S-4). Clusters 5 and 7 are relatively frequently confused with each other (jackknifed *n* = 6 total). Cluster 6 has the highest percentage of misclassified cases (*n* = 3); though only 23 samples originally, all misclassified as Cluster 3. Cluster 3 has the next highest confusion frequency (2/16). Interestingly, one is classified as the Central Feature, and in the jackknifed DFA, the CF was classified as Cluster 3. The other misclassified Cluster 3 samples were classified as Cluster 6. The confusion results are with similar functional interpretive categories (see Supplementary Table S-4).

Cluster 5 is below median on all measures and is interpreted as background. Cluster 7 is at or below median on all but lower FD MS and may also be a background association. Three clusters are associated with organic deposition (3, 4, 6), with one possibly associated (1). Two clusters are associated with burning (1, 4), with two additional possibly associated (2, 7). The organic clusters are concentrated within the Moorehead Circle, with a concentration of lesser organic deposition between the southwestern test unit (SWTU) and the Oval (Figure 9). Burning is limited to the northeast side of the interior of the Circle and outside

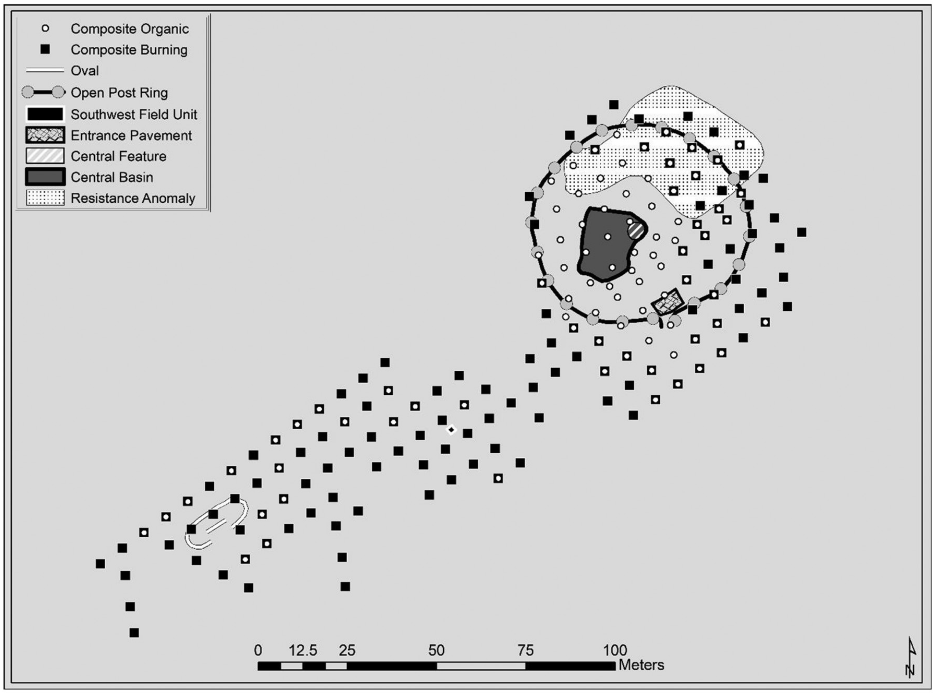

Figure 9. Distribution of burning and organic deposition related clusters from the composite measures of all transect samples.

the entrance. A second burning cluster follows the second organic cluster near the Oval.

The PCA conducted on the log-transformed composite data reveals a dense cluster low on PC1 and a wide diffuse scatter of samples high on PC1 (Figure 10). There are no breaks on the other components. The low PC1 cluster has two branches of outliers: high and low on PC2. Using a cutoff of −0.07 on PC1, all samples were separated into two groups (Low PC1 and High PC1). A DFA for the PC1 groups has a jackknifed success rate of 92.86% (94.12% original; see Supplementary Table S-4). The High PC1 group is misclassified 14.66% (jackknifed). The CF samples are classified as a member of the High PC1 group, and only one Low PC1 case is misclassified as High PC1. The High PC1 group is concentrated on the Moorehead Circle, with a secondary concentration between the SWTU and the Oval (Figure 11). The High PC1 group largely matches the difference between background and anthropogenic points in the composite measures K-means cluster analysis, reinforcing overall interpretation of the structure of the data. The presence of multiple functional interpretive types also likely explains the unpredictability of the High PC 1 group.

Cluster Central Tendency Comparisons To explore the structure of variability and the validity of the K-means clusters, a series of multisample central-tendency comparisons were conducted (Hammer et al. 2001). The full details of the multisample comparisons are contained in Supplementary Table S-6 and summarized in Table 4. As noted above, all variables except LL FD MS deviate from a normal distribution, and as can be seen in Table 4, they exhibit significantly different variances. Due to the unequal variances for all measures except LL FD MS, the Welch F-test was used for comparisons among groups, and the Mann-Whitney post hoc

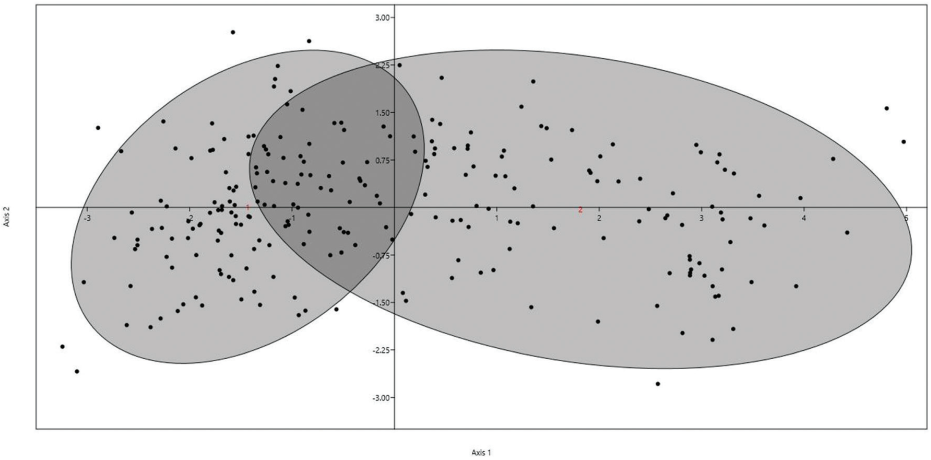

Figure 10. Plot of Axis 1 and Axis 2 for discriminant function analysis of groups defined by values on principle Component 1 for all measures on all transect samples.

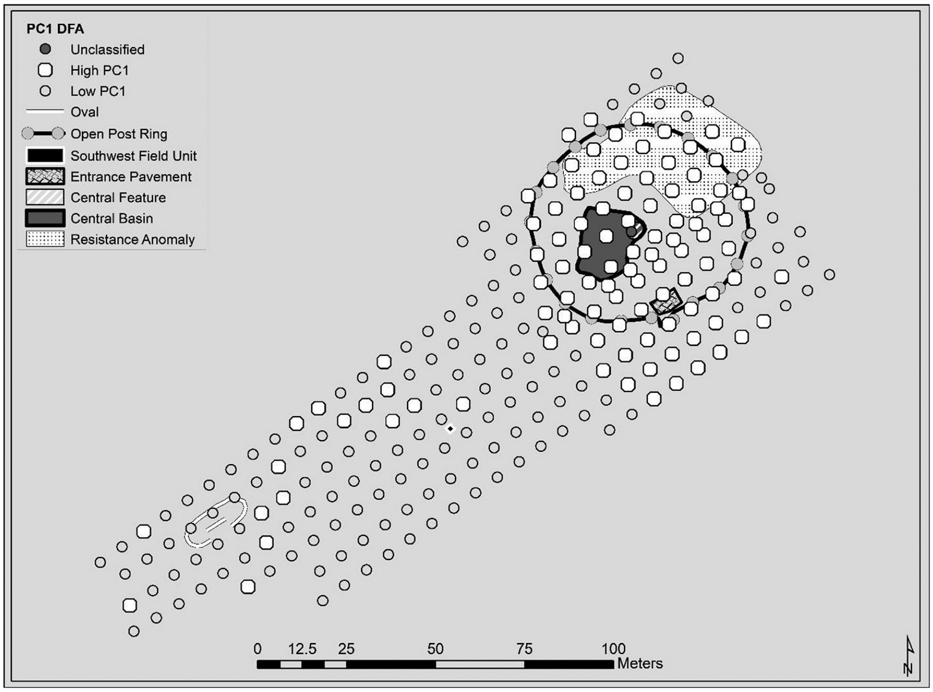

Figure 11. Distribution of groups defined by PC1 for composite measures of all transect samples.

test with Bonferroni corrected *p*-values for multiple comparisons was used to explore the distribution of difference between groups. For FD MS of the LL, an ANOVA with a Tukey-Kramer pairwise post hoc test was conducted.

The background clusters (5 and 7) are significantly different from organic deposition (3 and 6) in plow zone PO_4, plow zone LF MS, LL LF MS, and LL FD MS. Additionally, Cluster 5 (background) and Cluster 6 (organic) are substantially different in LL PO_4. The possible burning cluster (2) is significantly different from the background clusters (5 and 7) in plow zone LF MS, and LL FD MS. Cluster 2

Table 4. Summary of Several Sample Central Tendency Comparisons for Composite Measures K-means Clusters and Paired Cluster Significant Differences.

Variable	Equal Variance[a]	Test[b]	F	*p*	Post hoc[c]	Pair 1	Pair 2	Pair 3	Remainder
PZ PO_4	**0.004835**	W	4.675	**0.0005929**	MW-B	7, 3	5, 3	7, 6	5, 6; 1, 3
LL PO_4	**0.0001107**	W	2.172	0.05788[d]	MW-B	5, 6	-	-	-
PZ LF	**1.57E-15**	W	333.1	**4.87E-42**	MW-B	5, 1	7, 6	5, 6	All[e]
LL LF	**2.09E-23**	W	202.9	**4.59E-36**	MW-B	5, 7	7, 1	5, 1	All except 7, 2 and 4, 6
PZ FD	**0.0002358**	W	4.65	**0.0005046**	MW-B	7, 1	5, 1	N/A	N/A
LL FD	0.2135	A	14.6	**1.00E-05**	Tukey	5, 1	5, 7	1, 3	7, 3; 5, 4; 4, 3; 5, 2; 2 ,3; 5, 6

Note: Computed with Hammer et al. 2001. Bold indicates statistically significant difference.

[a] Levene´s test for homogeneity of variance, from means; [b] W = Welch F test in the case of unequal variances; A = ANOVA; [c] MW-B = Mann-Whitney, Bonferroni corrected *p* values; Tukey = Tukey-Kramer pairwise after Copenhaver and Holland 1988 as cited in Hammer et al. 2001; [d] Kruskal-Wallis registers a significant difference, $p = 0.0218$; [e] All pair-wise comparisons are significantly different at $\alpha = 0.001$.

is significantly different from Cluster 5 in LL LF MS but not from Cluster 7 (p = 0.08755). The burning related clusters (1 and 4) are significantly different from the background in plow zone and LL LF MS and various combinations of FD MS in either layer (PZ: 7/1, 5/1; LL: 5/1, 5/4). This structure of significant differences in central tendency reinforces the robustness of the K-means clusters as representing functionally different groups of samples.

PZ Layer There are five major branches in the neighbor-joining dendrogram, less distinctly separated on the y-axis than the composite, but the branching structure is still present. A K-means cluster analysis of the three measures of the plow zone from each sample location (Table 5) produces very robust groupings separated along axis 1 of the DFA (Figure 12; see Supplementary Figure S-4). Most of the confusion is Cluster 4 classified as Cluster 2 (9/98 jackknifed), indicating that Cluster 4 may not be entirely composed of background samples. Three cases are confused between the two clusters interpreted as organic and burning (1, 5; see Table 5; see Supplementary Table S-8). The organic samples occupy the entire area within and around the Circle and a linear arrangement heading toward the Oval (Figure 13).

Lower Layer The neighbor-joining cluster analysis for the LL yields six major branches in the dendrogram (see Supplementary Figure S-5). A K-means cluster analysis of the LL data produces robust groupings separated along axis 1 of a DFA (Figures 14 and 15; Supplementary Figures S-6 and S-7). The DFA achieves 96.2% successful classification with a 94.51% success rate on jackknifed classification (see Supplementary Table S-8). Most of the confusion is between Clusters 4 and 5 (n = 6 jackknifed), both interpreted as background (Table 6). The next most frequent confusions are Cluster 4 (n = 2 jackknifed, background) being identified as Cluster 1 (burning) and Cluster 1 being classified as Cluster 6 (n = 2, organic/burning). The nonbackground points follow a pattern similar to the composite and plow zone samples (Figure 16).

Table 5. Interpretation of Plow Zone K-means Clusters.

Cluster	PO_4	~Z	Class	LF	~Z	Class	FD	~Z	Class	Interpretation
1	6.345	1.708	Very High	28.965	0.5373	High	6.345	0.434	High	Organic/burning
2	5.71	1.356	Very High	16.52	0.0469	Med	5.71	0.096	Med	Organic/poss. burning
3	4.7	0.797	High	91.14	2.987	Very, Very High	4.7	−0.442	Low	Organic/no burning
4	4.855	0.883	High	10.915	−0.174	Med-Low	4.855	−0.359	Med-Low	Mod. organic/no burning
5	6.07	1.556	Very High	62.48	1.858	Very High	6.07	0.288	Med-High	Organic/lt. burning

Note: Computed with Hammer et al. 2001.

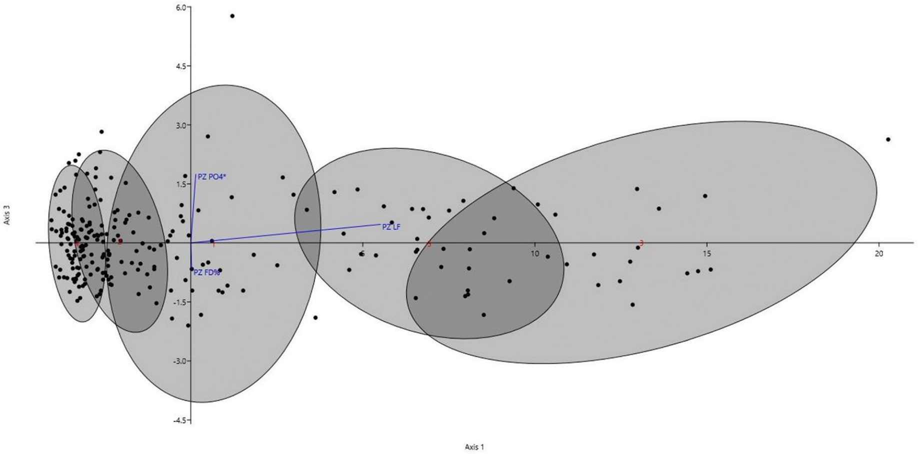

Figure 12. Plot of Axes 1 and 3 of a DFA performed on the five K-means clusters for plow zone measures of all transect samples.

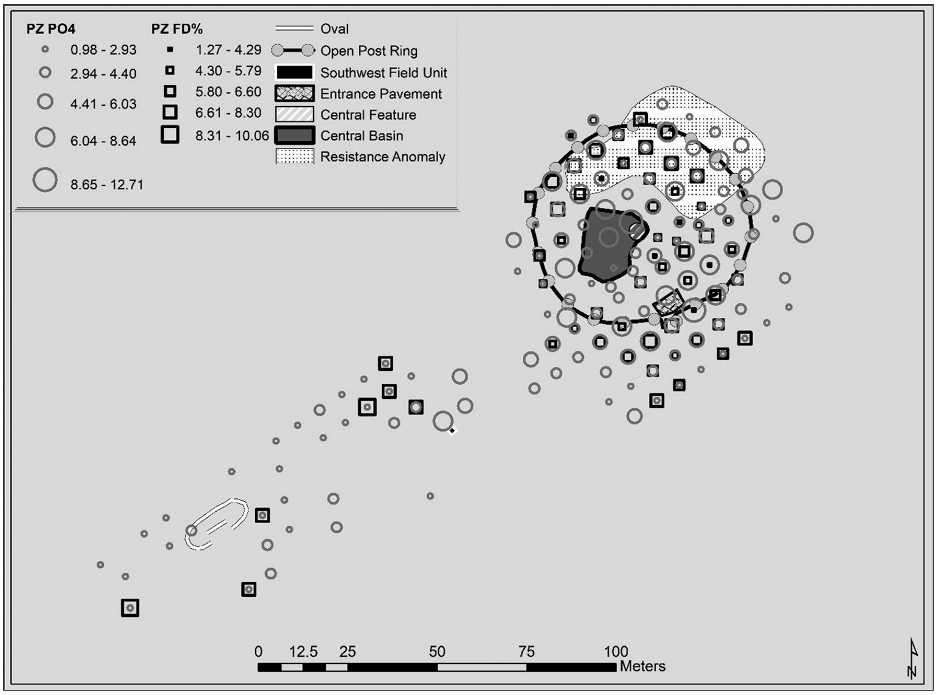

Figure 13. Conservative distribution of burning and organic deposition related clusters from the plow-zone measures of all transect samples.

Using a buffer distance of half the sample spacing, activity areas are defined based on the cluster interpretations (Figure 17). The burning indicators are largely coincidentally distributed across layers (see Figure 17). The composite measures show a wider distribution of burning-related activity, but generally burning is indicated as concentrated in the northern half of the Circle and around the Circle,

Table 6. Interpretation of Lower Layer K-means Clusters.

Cluster	PO_4	~Z	Class	LF	~Z	Class	FD	~Z	Class	Interpretation
1	3.1	0.000	Med	22.32	0.192	Med-High	8.48	0.746	High	Burning
2	3.59	0.155	Med-High	46.68	1.422	Very High	7.23	0.186	Med-High	Organic/burning
3	3.1	0.000	Med	72.48	2.725	Very, Very High	4.45	−1.060	Very Low	Weathering
4	2.45	−0.205	Med-High	14.865	−0.185	Med-Low	6.82	0.002	Med	Background
5	2.77	−0.104	Med-Low	10.21	−0.420	Low	4.54	−1.019	Very Low	Background
6	3.42	0.101	Med-High	29.74	0.567	High	8.4	0.710	High	Organic/burning

Note: Computed with Hammer et al. 2001.

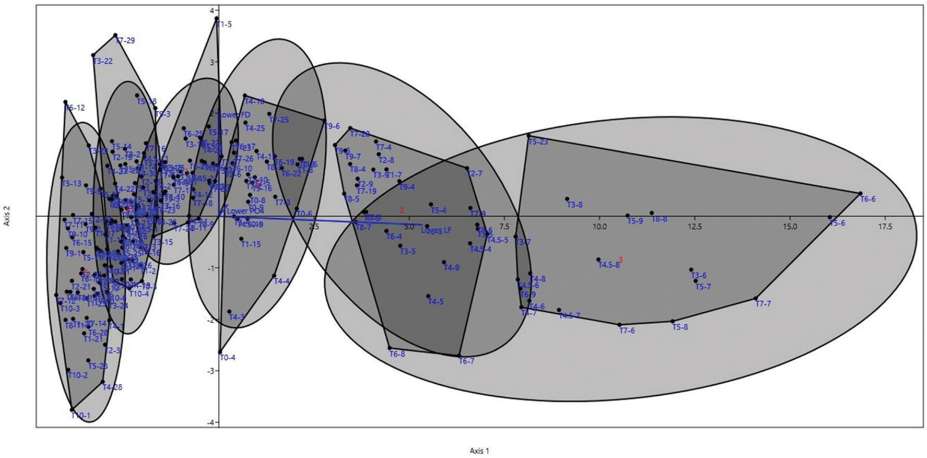

Figure 14. Plot of Axes 1 and 2 of a DFA performed on the six K-means clusters for Lower Layer measures of all transect samples including 95% confidence ellipses and convex hulls for each cluster.

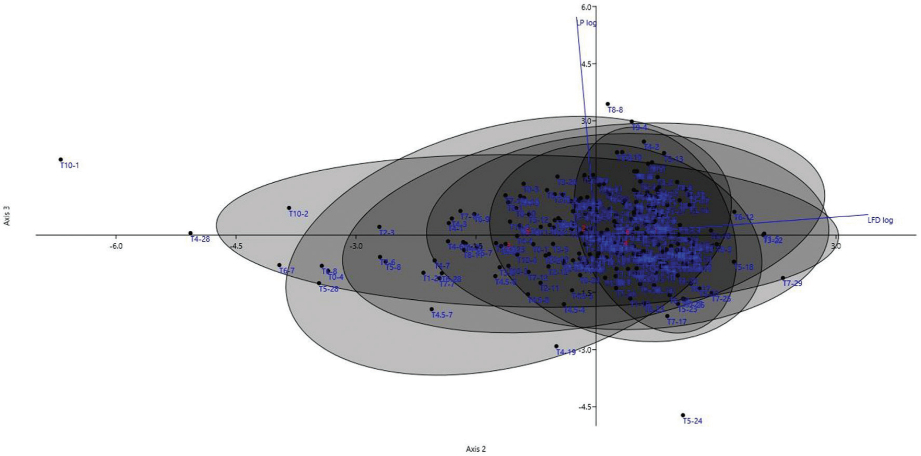

Figure 15. Plot of Axes 2 and 3 of a DFA performed on the six K-means clusters for Lower Layer log transformed measures of all transect samples including 95% confidence ellipses for each cluster. Note that the DFA for each layer produces a nearly identical Axis 2/Axis 3 plot.

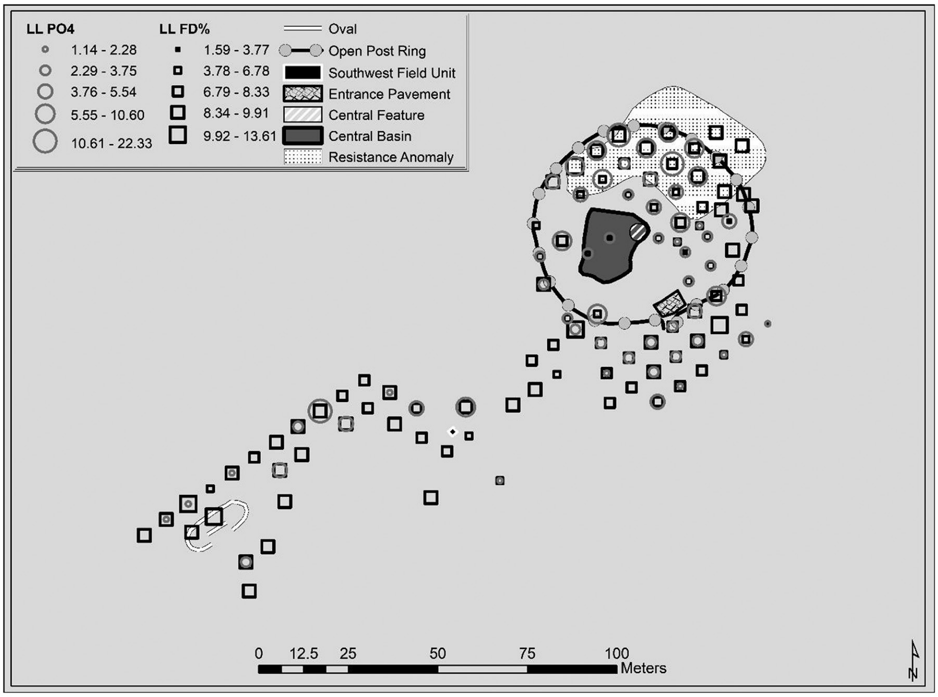

Figure 16. Distribution of burning and organic deposition related clusters from the plow zone measures of all transect samples.

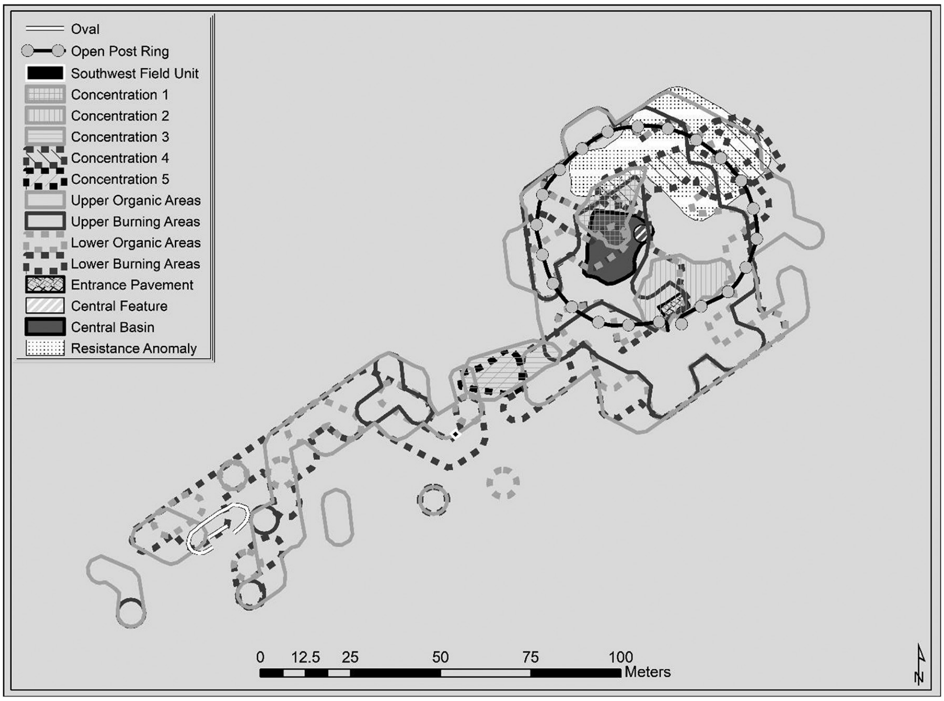

Figure 17. Areas of organic deposition and burning activity from the K-means clusters for plow zone and Lower Layer measures of all transect samples.

then as a line southwest to the Oval. The organic deposition cluster points are distributed largely the same as those of the burning (see Figure 17); however, they occur throughout the Circle and are less dense in the line heading toward the Oval. Unlike the burning, the composite organic clusters entirely overlap with at least one of the layers. The distribution of organic deposition narrows with depth, whereas the burning areas expand with depth.

Central Feature The CF is not classified as a burning area according to the composite DFA, and when it was included within the composite DF analyses, it was classified as a member of Cluster 3, interpreted as organic deposition and no burning, but is clearly associated with the nonbackground in the PCA group DFA. However, the CF1 and CF2 measures have the second highest plow zone LF MS, the third highest LL LF MS, the sixth highest plow zone FD MS, and ninth highest LL FD MS. Samples CF3 and CF4 exhibit high FD MS as well (9.43% and 11.33%, respectively). All of these LF and FD MS combinations indicate very high proportions of superparamagnetic grains within the magnetic minerals of the CF samples. These levels are consistent with burning. The PO_4 levels for the CF samples are well above the medians for all LL and composite clusters and more similar to Clusters 1 and 5 (though still above the medians) for the plow zone clusters. The very high PO_4 values, especially CF 3 (~60 cmbs; 11.08 mg/kg), may account for why the CF1 and CF2 were classified with the organic deposition Cluster 3 in the composite K-means cluster DFA. Revisiting the neighbor-joining dendrogram (see Figure 8), it is evident that T6–6 and CF1/2 are outliers on a middle branch that, with their next closest cluster to the right, are near perfect matches for the contents of K-means Clusters 3 and 6. The defining characteristic seems to be high PO_4 with middle to high FD MS in either or both layers. It is possible that some burning locations are masked by high to very high PO_4 in the composite DFA analysis.

Conclusions

The Moorehead Circle and vicinity are areas of sustained, but possibly intermittent, activity. While the general extent and distribution of activity are relatively consistent through the two layers, the nature of activity changes through time (see Figure 17). The earliest activity structure observed (lower layer) is dominated by fire-related activities (see Figure16). Within the Moorehead Circle, the LL burning and organic deposition activities are nearly coextensive. Notably, neither area encompasses the Central Feature, nor do they extend to the southwestern half of the Circle or the Pavement and Entrance. The Central Feature is classified as an area of organic deposition (Cluster 3) within the composite measures analysis, but it also has evidence of fire-generated superparamagnetic grains indicating both organic decomposition and fire-altered sediment incorporated into this feature. Both organic deposition and burning clusters extend outside the Circle, but the burning clusters are more extensive. There is no area in the entire LL that exhibits evidence of only organic deposition. The entirety of the central basin area is within both functional areas, but samples within the structure are either at the low end of enrichment or classified with the background.

This distribution has interesting implications not only for interpretation of the overall activities associated with the area but also for potential targets for future excavation or other sampling tactics. The relatively discrete areas of organic deposition outside the Circle may represent relatively distinct or short-term activities, whereas those within the larger concentrations are more likely to represent a palimpsest of repeated activities for generations associated with maintenance of the Circle as a persistent ritual focus. Drilling farther into the burning-related clusters, the most intense LL FD MS values are distributed around the northern edge inside the Circle, just outside the entryway, and sporadically toward the Oval (see Figure 16). With a single sample exception (T7–4), the interior of the central basin exhibits low or very low FD MS values. The low FD MS samples included within the burning clusters may not actually represent burning-related activity. Nearly all of these dubious burning samples are within the Circle.

The highest LL PO_4 values are concentrated in the northwest of the Circle, partially overlapping the central basin (see Figure 16). There are no other coherent clusters of elevated PO_4. The relatively high values for PO_4 are low for general PO_4 enrichment associated with settlement locations, occupying only the low end of the distribution for habitation sites (Nolan and Redmond 2015:Figures 2, 3, 4; Nolan et al. 2014:Table 2; Roos and Nolan 2012:Table 2, Figure 3; Swihart and Nolan 2014:Figure 19; Swihart et al. 2017:Figure 8). The different geological settings notwithstanding, the relatively small enrichment of PO_4 in the vicinity of the Moorehead Circle and the Oval indicates a probable lack of intensive and/or prolonged domestic activity in the survey area.

The more recent layer(s) of activity (plow zone) shows a reduction in the distribution of burned areas, especially the distribution of high-intensity burning (see Figure 13). The relationship between burning activity and organic deposition is reversed, with organic deposition more extensive and completely encompassing the burning areas. The two largest concentrations of burning are in the northwest of the Circle and around the exterior of the entryway. A third smaller concentration is adjacent to the SWTU. There are isolated high FD MS points around the Oval indicating possibly discrete burning within the organic deposition areas. The predominance of PO_4 in the highest quartile and the relatively limited frequency of burning within the Circle during the most recent period analyzed (plow zone) reveal a very stark change in the nature, but not the location, of activity in the Circle over time.

The change in the organization of the activities associated with the Circle is best illustrated when looking at the intensity of PO_4 in the organic deposition clusters (see Figure 13). Nearly the entirety of the Circle is enriched in PO_4, which extends to the southeast around the entryway. There is also a cluster of relatively enriched PO_4 around the SWTU. It is interesting to note the distributional differences between the interpretation of interpolated surfaces and the clustering analysis of discrete sample locations. While the clustering shows a spike in both functional categories similar to Concentrations 3 and 5 (see Figure 7), the clustering emphasizes the area just northwest of the SWTU (see Figure 13), where the interpolated surfaces extend this spike to the north and northeast. While in general agreement with each other, these two ways of analyzing the distributional patterns of past activity may differ in significant ways. Both are useful, but this analysis highlights a reason to exercise restraint in the interpretation of interpolated surfaces, especially when the distributions of measured properties do not represent clinal trends. The scale of usefulness here may also be different.

The Moorehead Circle and vicinity were an area of persistent nondomestic activity that involved (minimally) burning and processing/deposition of organic material. While the overall activity areas were largely the same over time, the activity that was predominate changed. The earlier period activity was dominated by burning around the edge of the Circle and in a line to the Oval. The later period activity was dominated by organic processing/deposition very strongly focused on the Circle. Over time, the distribution and abundance of fire-related activity decreased, and the deposition of organic processing and deposition increased and refocused on the Moorehead Circle and its immediate vicinity. This is in line with Riordan and colleagues' (2023) proposal that the Circle may have continued to be a locus of craft production involving animal body parts (i.e., bear jaws), which could have caused the recurrent introduction of significant organic material into the area even in post-circle Middle Woodland times.

In closing, systematic sampling of sediment across archaeological sites of all types—ritual, ephemeral production, and domestic—provides ample opportunity for adding resolution and detail to researchers' attempts at understanding events in the past. The current analysis shows that even subtle signatures independent of, but complementary to, tactile artifact recovery and feature recording are detectable. These subtle signatures, especially at low intensity/duration ritual sites, reveal details about activities that researchers would otherwise never detect. The two tests performed, while adding details, leave many questions unanswered. Additional excavation in some of the discrete areas of burning and/or organic deposition or geochemical analyses that supplement the current analyses will fill in more details about discrete activities or even reveal new signatures not yet indicated.

Notes

1. While Dearing (1999) recommends 10 readings for accurate estimates, Nolan (Nolan and Redmond 2015; Swihart and Nolan 2014) has found that three consistent readings are sufficient for useful estimates of FD.
2. Note that cardinal directions in this discussion are actual directions from a UTM NAD1983 coordinate system, not the local grid-north, which is oriented south–southwest.

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Supplementary Material

Supplementary material for this article can be found at https://www.midwestarchaeology.org/mcja/supplemental-materials.

Tables S-1 through S-9
Figures S-1 through S-7

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