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RESEARCH ARTICLE

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Evaluating narratives of ecocide with the stratigraphic record at Cahokia Mounds State Historic Site, Illinois, USA

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Abstract

Narratives of ecocide, when a society fails due to self-inflicted ecologic disaster, have been broadly applied to many major archaeological sites based on the expected environmental consequences of known land-use practices of people in the past. Ecocide narratives often become accepted in a discourse, despite a lack of direct evidence that the hypothesized environmental consequences of land-use practices occurred. Cahokia Mounds, located in a floodplain of the central Mississippi River Valley, is one such major archaeological site where untested narratives of ecocide have persisted. The wood-overuse hypothesis suggests that tree clearance in the uplands surrounding Cahokia led to erosion, causing increasingly frequent and unpredictable floods of the local creek drainages in the floodplain where Cahokia Mounds was constructed. Recent archaeological excavations conducted around a Mississippian Period (AD 1050–1400) of earthen mound in the Cahokia Creek floodplain shows that the Ab horizon on which the mound was constructed remained stable until industrial development. The presence of a stable ground surface (Ab horizon) from Mississippian occupation to the mid-1800s does not support the expectations of the wood-overuse hypothesis. Ultimately, this research demonstrates that pre-Colombian ecological change does not inherently cause geomorphic change, and narratives of ecocide related to geomorphic change need to be validated with the stratigraphic record.

KEYWORDS

ecocide, erosion and sedimentation, fluvial geomorphology, mississippian

1 | INTRODUCTION

Environmental explanations for the collapse of complex societies have been popular topics since William Thomas' 1956 volume on “Man's Role in Changing the Face of the Earth” (Thomas, 1956). This seminal work established the philosophical argument that humans are inherently destructive to the environment (Middleton, 2017; Ponting, 1991; Thomas, 1956), a philosophy that is widely applied in anthropology (Oliver-Smith & Hoffman, 1999), geology (Nianfeng et al., 1999; Wilkinson, 2005), biology (Ceballos et al., 2015; Meyer & Turner, 1992; Vitousek et al., 1997), environmental ethics (Attfield, 2008), and general public discourse today (Diamond, 2005; Goudie, 2019; Montine et al., 1990; Ponting, 1991; Ward, 2009). Following this philosophy, environmental explanations for the collapse of complex societies often conform to the ecocide model, ecocide referring to ecological decline resulting from human activities. The ecocide model cites known land-use practices of people in the past and the potential resulting environmental consequences of these activities as contributions to societal collapse (Middleton, 2012; Redman, 1999).

Ecocide narratives of collapse often recognize that the environment is not the only contributing factor to societal collapse; however, these accounts tend to ignore the capacity of people in the past to respond to environmental decline beyond abandonment and migration (Middleton, 2012, 2017). In addition, ecocide narratives rely heavily on evidence of past human activities; however, the resulting environmental consequences are often hypothetical (Kull, 2000; McAnany & Yoffee, 2009; Mt. Pleasant, 2015). Although much of collapse theory has since moved beyond these simplistic correlation narratives to more nuanced understandings of adaptation and resilience, as well as the role of localized environmental change, modern concerns about human influences on the environment perpetuate the popularity of these older narratives in both academic and public discourses (Butzer, 2012; Diamond, 2005; Faulseit, 2016; Middleton, 2017; Tainter, 2008, 2016). Archaeologists who study many of the complex societies used in these older comparative works have since responded to the proposed ecocide scenarios with more nuanced understandings of social response to change and social resilience (Kull, 2000; McAnany & Yoffee, 2009). In some cases, the ecocide scenario can be supported with new data sets; however, there are still many case studies that are mired in old narratives without data to support that these consequences of land-use practices actually occurred. One good example of a major archaeological site where these narratives persist can be found in some environmental explanations for the collapse of the Cahokia polity.

Cahokia Mounds is the largest pre-Columbian settlement north of Mexico (Milner, 1998). Cahokia emerged as a large center around AD 1000 (Milner, 1986, 1998; Pauketat & Lopinot, 1997; White et al., 2018). At its peak around AD 1100, central Cahokia had an estimated population size of 15,000 (Pauketat & Lopinot, 1997), but population began to decline regionally around AD 1200, with ultimate abandonment of the site by AD 1400 (Milner, 1986, 1998; Pauketat & Lopinot, 1997; White et al., 2018). The abandonment of Cahokia fits into the larger depopulation of the central Mississippi and lower Ohio River valleys by AD 1500 (Cobb & Butler, 2002). Many environmental and social explanations have been proposed for Cahokia's abandonment (Benson et al., 2009; Emerson & Hedman, 2016; Kelly, 2008; Samuel E. Munoz et al., 2015; White et al., 2019), but the ecocide scenario, or the "wood-overuse hypothesis," proposed by Lopinot and Woods in 1993 has been one of the most persistent environmental explanations for collapse at Cahokia Mounds (Delcourt & Delcourt, 2004; Emerson & Hedman, 2016; Emerson, 1997; Hayashida, 2005; Hornborg & Crumley, 2006; Kelly, 2008; Lopinot & Woods, 1993; Mann, 2005; Pauketat, 2004; Tainter, 2006; Woods, 2004).

The wood-overuse hypothesis suggests that tree clearance in the uplands surrounding Cahokia led upstream erosion, causing increasingly frequent and unpredictable floods of the local creek drainages in the floodplain where Cahokia Mounds was constructed (Lopinot & Woods, 1993). More frequent and unpredictable flooding in the floodplain would increase the risks involved within bottomland agriculture to "a point where less productive, but more predictable, upland agricultural strategies became the optimal solution to a growing problem" (Lopinot & Woods, 1993: 210). The relocation of agriculture activities from the bottomlands to the uplands would have increased the erosion problem and further exacerbated flooding issues. It is important to note that the wood-overuse hypothesis relies almost exclusively on evidence of land-use practices, in both an evaluation of the amount of deforestation that would have taken place for construction and fuel resources as well as a trend of increased habitation in the uplands toward the end of Cahokia's occupation (Lopinot & Woods, 1993). There is very little evidence that erosion did increase during Cahokia's occupation and no evidence that flooding in the bottomlands became increasingly frequent and unpredictable (Holley & Brown, 1989; Lopinot & Woods, 1993; Woods, 2004). Lopinot and Woods clearly stated that they do not believe they have enough data for their narrative to be used as a probable explanation for the collapse of Cahokia, yet this hypothesis has been cited in academic research and public discourse as a potential cause for collapse at Cahokia (Delcourt & Delcourt, 2004; Emerson, 1997; Emerson & Hedman, 2016; Hayashida, 2005; Hornborg & Crumley, 2006; Kelly, 2008; Mann, 2005; Pauketat, 2004; Tainter, 2006; Woods, 2004). In this article, we specifically address the lack of data to support the hypothesized consequences of the known land-use practices described by Lopinot and Woods. We present new data from geoarchaeological investigations at the North Plaza in the central precinct of Cahokia Mounds, a mound and plaza group built in the flood plains of Cahokia and Canteen creeks, as well as evidence of historic era alluvial deposition and infilling of Canteen Creek. Our results reject the wood-overuse hypothesis' premise that upland deforestation caused increased flooding in the bottomlands at the end of Cahokia's occupation.

2 | SITE SETTING

Cahokia Mounds is located in the American Bottom, a broad expanse of floodplain on the Illinois side of the Mississippi River that was created at the end of the Pleistocene by the scouring action of postglacial meltwaters flooding at the confluence of the Missouri and Mississippi rivers (Hajic, 1993; Iseminger, 1997). The American Bottom floodplain is bounded by sedimentary bluffs on its eastern border, creating a distinct 160 km north–south-oriented floodplain (Hajic, 1993; Figure 1). The headwaters of several local low-order tributaries of the Mississippi River are located in these bluffs, causing high sedimentation and drainage issues when the local tributaries flow into the less than 1% gradient of the American Bottom floodplain (Helm, 1905). Standing water was a major issue for the European settlers of this area; during his visit to the American Bottom in 1842, Charles Dickens remarked that "few people can exist in such a deadly atmosphere … [where] everywhere was stagnant, slimy, rotten, filthy water" (Dickens, 1972:221–222).

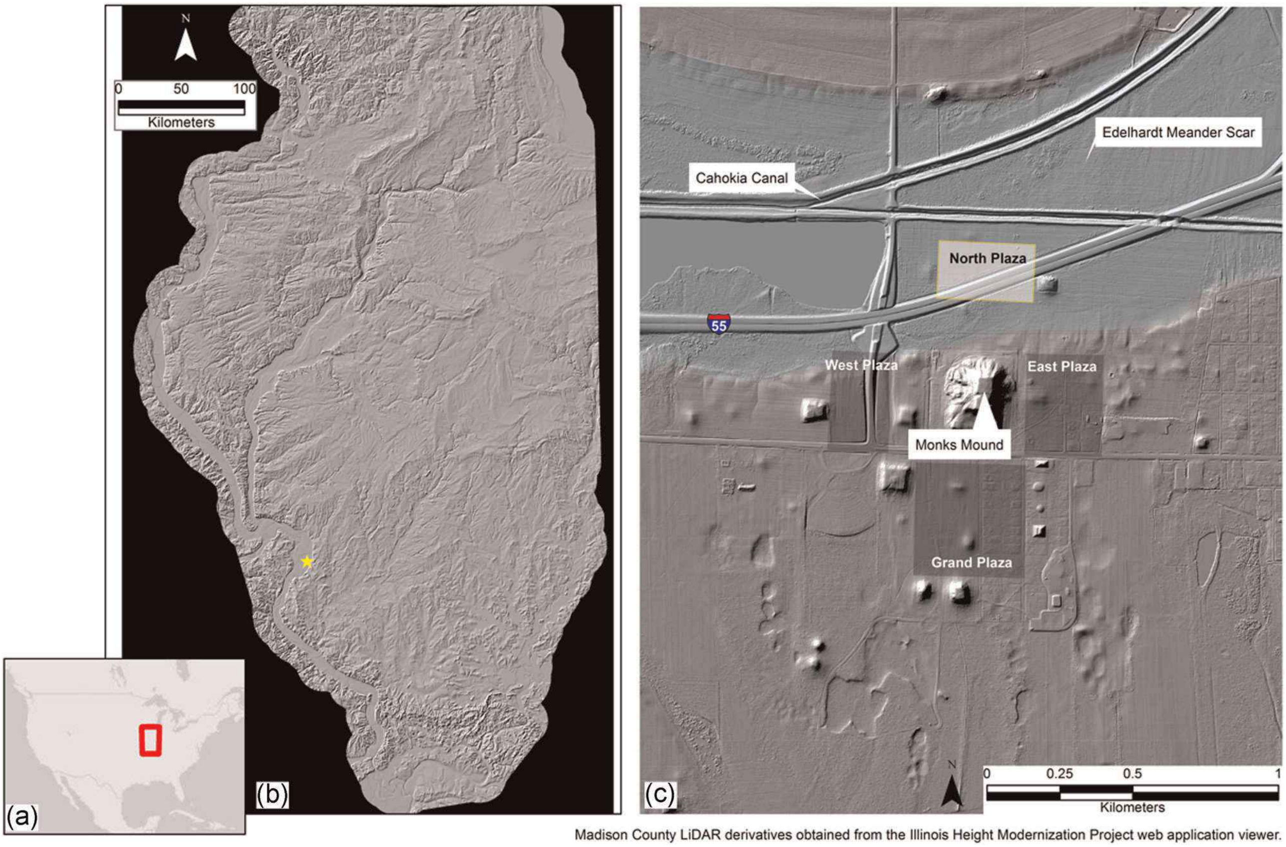

FIGURE 1 Location of Cahokia Mounds within the American Bottom floodplain [Color figure can be viewed at wileyonlinelibrary.com]

In 1905, a local engineer, Edwin Helm, published a demand to improve flood and drainage control by forming one centralized agency to plan and maintain flood infrastructure for the entire American Bottom (Helm, 1905)—a cry that was answered in 1908 with the formation of the East Side Levee and Sanitary District, which was empowered to construct a cohesive and all-encompassing system of canals and levees throughout the entire floodplain (Colten, 1990). The diversion canals of Cahokia and Canteen creeks were completed in 1921 (Colten, 1990; Moorehead, 1929). The system of canals and levees developed in the early 20th century is the primary determinate of the hydrologic system we observe in the American Bottom landscape today.

The central precinct of Cahokia Mounds is believed to have been arranged as a cosmogram, with Monks Mound (the largest mound north of Mexico) at the center and four mound and plaza groups in each of the four cardinal directions (Kelly & Brown, 2014; Kelly, 1996; Figure 2). The North Plaza was created at the lowest elevation of the central precinct in an abandoned meander scar of the Mississippi River as well as the floodplain of Cahokia and Canteen Creeks (Fowler, 1997; Milner, 1998). This low-elevation wetland is an exception to the normal setting for late pre-contact mound groups throughout Eastern North America, which are typically placed in areas not subject to frequent inundation (Cobb & Butler, 2017; Kassabaum, 2019; Lewis & Stout, 1998; Lewis et al., 1998). Investigations at the Grand Plaza of Cahokia Mounds demonstrated that the plaza was constructed to divert water away from plaza space (Dalan et al., 2003). The North Plaza at Cahokia is bounded by four mounds: three small oval mounds (Mounds 14, 15, and 16) and one large rectangular platform mound (Mound 5; Figure 2). The mounds constraining the North Plaza have also been referred to as the Creek Bottom mound group due to their location in the low-elevation floodplain of Cahokia and Canteen Creeks (Fowler, 1997). At present, the North Plaza and their mounds are still seasonally flooded despite human efforts to drain the American Bottom. Data collected from archaeological excavations at Mounds 5 and 16 as well as sediment coring conducted through Mound 14 and the North Plaza by Caitlin Rankin under the auspices of Washington University in St. Louis will be used to discuss the sedimentological signature of pre-Columbian land-use practices (Figure 2). In addition, geophysical survey in the Edelhardt meander scar and subsequent ground-truthing excavations conducted approximately 240 m east of the North Plaza by Casey Barrier, Timothy Horsley, Robin Beck (University of Michigan), and Timothy Schilling (Midwest Archaeological Center, US National Park Service) confirmed the location of an abandoned channel of Canteen Creek. Data from these geophysical surveys and excavations demonstrate the extent of industrial landscape change, which has dramatically altered the pre-Columbian landscape.

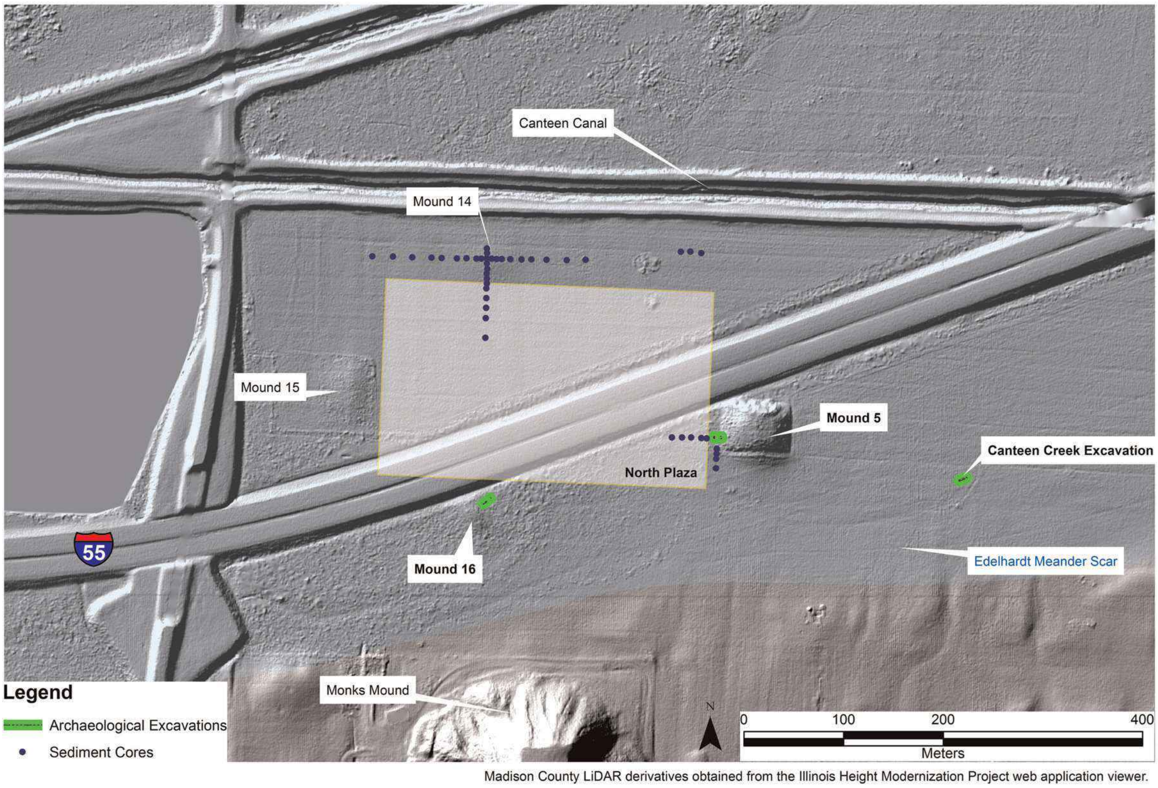

FIGURE 2 Locations of investigations within the central precinct of Cahokia Mounds [Color figure can be viewed at wileyonlinelibrary.com]

3 | METHODS

3.1 | Field methods

Archaeological excavations were conducted on the western side of Mound 5 and the eastern side of Mound 16 (Figure 2). The Mound 5 excavations consisted of a 2 × 5 m trench to a maximum depth of 245 cm below ground surface (cmbs) and a 1 × 2 m trench to a maximum depth of 200 cmbs. The Mound 16 excavations consisted of a 1 × 4 m trench to a maximum depth of 160 cmbs and a 1 × 2 m trench to a maximum depth of 160 cmbs. Soil was extracted with shovel and trowel at 10 and 20 cm intervals. All units were excavated as individual 1 × 1 m quads. Every fourth bucket of soil from the plowzone was screened through 12.7 mm mesh. Outside the plowzone, all the soil was screened through 12.7 mm mesh and soil from features was screened through 6.35 mm mesh. Detailed profile drawings were made for all excavations, and three-dimensional photographic models of the excavation were created in Agisoft Photoscan. Basic stratigraphy data, including Munsell color, soil texture, soil horizonation, redoximorphic features, and bioturbation, were recorded for all stratigraphic features following standard descriptions (Birkeland, 1999; Soil Survey Staff, 1999; Vasilas et al., 2010; Vogel, 2002). Block micromorphology samples were collected from excavation profiles by driving plastic electric conduit boxes continuously up-column. Flotation samples were collected at each 20 cm level and from features for radiocarbon dating.

Excavation of a portion of a relict channel of Canteen Creek was conducted in 2017 after a 2016 magnetometer survey of a portion of the Edelhardt Meander by Horsley and Barrier (Figure 3). An area of 9.4 hectares was surveyed using a Bartington Grad601-2 dual fluxgate gradiometer, with readings recorded at 0.125 m intervals along traverses spaced 0.5 m apart. This survey detected the infilled creek channel as a distinctive positive magnetic anomaly produced by magnetically enhanced topsoil and, potentially, other cultural deposits contained within the fill. The strongest readings within the channel likely reveal the meandering thalweg. Subtler negative magnetic responses were detected on either side of the inferred channel, suggesting constructed levees. On the basis of the geophysical results, the buried channel measures between 7 and 8 m across and the levee responses extend a further 4–6 m from the channel banks.

The magnetometer results also reveal the extent of occupation and anthropogenic modifications along the northern edge of the East Plaza that is outside the Edelhardt Meander. In addition to the distinctive positive anomalies associated with probable house basins, pits, and hearths, several complex, large-scale responses are interpreted as indicating areas of landscape modification; however, further work will be required to verify this. This modification includes the construction of Mound 17 that was formerly visible and recorded in the late 19th century (Fowler, 1997:72). The base of this mound has been detected in a similar manner to other denuded mounds in the region (e.g., the Washausen site [Horsley et al., 2014] and the Pulcher Mound Group), and it corresponds to observations on Native

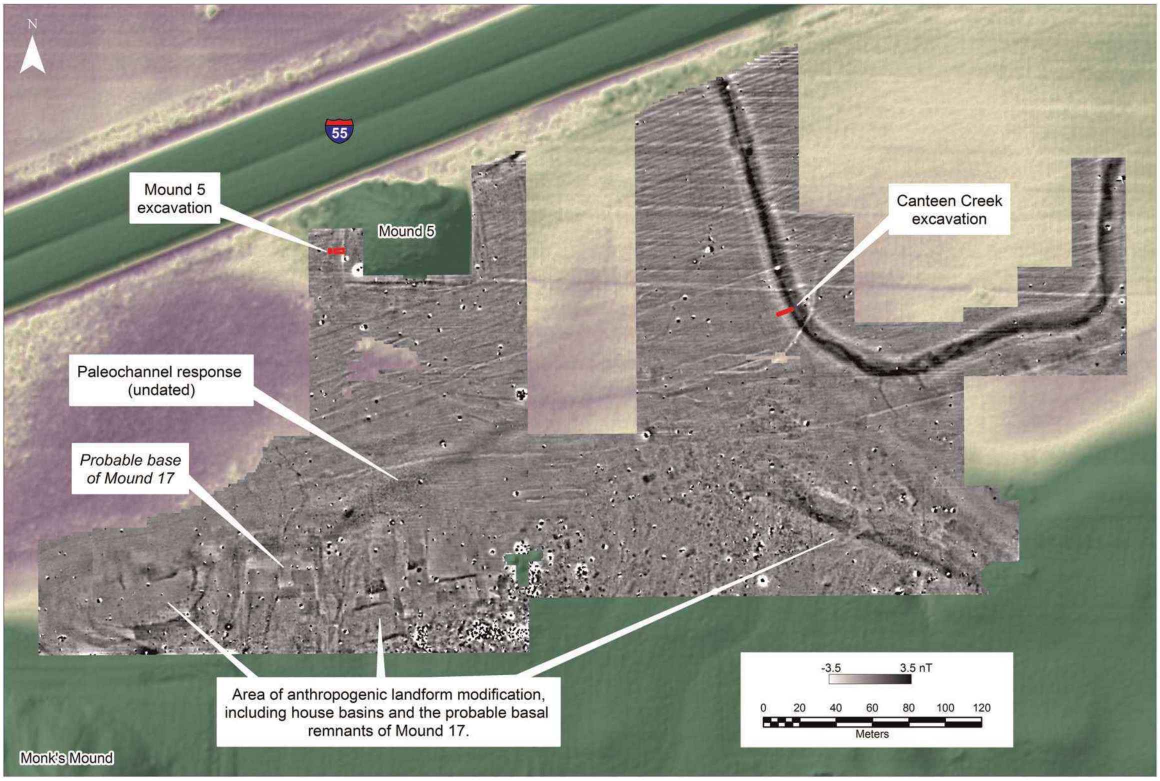

FIGURE 3 Results of the 2016 magnetometer survey conducted by Horsley and Barrier, revealing extensive anthropogenic activity and landform modification along the edge of the Edelhardt Meander Scar and at least one former course of Canteen Creek [Color figure can be viewed at wileyonlinelibrary.com]

American mound construction (Sherwood & Kidder, 2011). With the exception of recent plow scar responses, the magnetometer data reveal no evidence for occupation or other anthropogenic features in the Edelhardt Meander and around Mound 5. From the geophysical data alone, it is impossible to determine whether this is due to a lack of such features or an indication that the earlier pre-Columbian/Mississippian land surface lies beyond the detection limits with this instrument.

Although Canteen Creek was diverted to its current location by 1921, the earliest map of central Cahokia, drawn in 1876 by John Patrick (Fowler, 1997:Figure 3.1), shows the creek's course as matching the shape of the magnetic anomaly. It is uncertain whether Patrick witnessed Canteen Creek flowing in this channel in the 1870s or whether he only saw remnants of an abandoned channel by that time. In fact, a map of this same area published 6 years later in 1882 shows Canteen Creek in a different location (Fowler, 1997: Figure 3.2). No subsequent maps of Cahokia display the creek in the area shown on Patrick's map, except ones that copied his original 1876 map. A 1922 aerial photograph taken just after Canteen Creek was moved to its current location (Fowler, 1997:Figure 2.6), however, does show a stretch of dense vegetation oriented linearly in a location and at an angle that appears to match the detected anomaly.

A 1 × 8 m trench was excavated to a maximum depth of 140 cmbs to confirm the presence of an infilled channel and to investigate the features producing the negative magnetic responses. The unit was aligned perpendicular to the creek and placed to expose a portion of its western bank and transect an area of the adjacent negative magnetic anomaly (Figure 3). The plowzone was removed as a single layer, whereas underlying materials were excavated in arbitrary levels. All soil was screened through a 12.7 mm mesh. Profiles were mapped and basic stratigraphy data were recorded. Organic samples were collected at various depths for radiocarbon dating.

In addition to archaeological excavations, 43 continuous sediment cores were collected by Rankin to a maximum depth of 3.6 m with a GeoProbe 54TRs mounted on a tractor with a DT-21 sampling device. The sample tube is 3 cm in diameter. Four sampling transects were created, two placed around Mound 14 and two placed around Mound 5 (Figure 2). At Mound 5, a 35 m transect on the N550 line was established with core locations spaced at 5 and 10 m intervals and a 25 m transect on the E355 line spaced at 5 m and 10 m intervals. At Mound 14, a 215 m transect on the N725 line was spaced at 5 and 10 m intervals and an 85 m transect on the E120 line was spaced at 5 and 10 m intervals. In additiona, a 20 m transect was placed "outside" of the North Plaza on gridline N735 at 10 m intervals.

3.2 | Laboratory methods

Only two sediment cores were cut and described in the field; the rest of the cores were transported to the Paleoclimatology and Sedimentology Laboratory at Indiana University-Purdue University

Indianapolis where there were cut, cleaned, imaged, analyzed for magnetic susceptibility, described, and sampled for future analyses at 10 cm intervals. High-resolution imagery and magnetic susceptibility at 1 cm intervals were collected with a GeoTek Multi-Sensor Core Logger. The N725 transect was archived at the Geoarchaeology Laboratory at Washington University in St. Louis.

Block micromorphology samples were sent to Applied Petrographic Services, Inc. where they were impregnated with epoxy, trimmed to size, and then mounted on 50 × 75 mm glass slides. All samples were ground to a uniform thickness of 30 µm. Thin sections were described and analyzed using standard micromorphological nomenclature (Bullock et al., 1985; FitzPatrick, 1993; Stoops, 2003). Analysis was conducted with a under plane-polarized light and cross-polarized light at ×8–15 magnification with a binocular microscope and ×15–200 magnification with a petrographic microscope.

Descriptions of organic sample context, uncalibrated AMS ages, and laboratories utilized for AMS dating can be found in Table 1. Radiocarbon ages were calibrated and modeled using OxCal v4.3.2 and the IntCal13 atmospheric curve (Ramsey, 2017; Reimer et al., 2013). Calibrated and modeled dates were rounded to the nearest 10 years.

4 | RESULTS

4.1 | Mound 5 excavations

Mound 5 excavations were conducted to a final elevation at 122.99 masl. Four distinct depositional facies were identified in the field; the oldest is a natural soil sequence with buried A and B horizons, the natural soil sequence is overlain with fluvial deposits, Mound 5 construction fill materials are placed directly on top of the fluvial deposits, and finally there is a modern plowzone on top of the Mound 5 construction fill material. A schematic drawing of Mound 5 stratigraphy can be found in Figure 4, with complete soil descriptions in Table 2. The preoccupation natural soil sequence is identified at 123.09 masl and continues until the excavation's maximum depth at 122.99 masl. An Ab horizon occupies the top 20 cm of the buried natural soil sequence. The contact between the Ab horizon and the fluvial deposit is abrupt and smooth. An artifact scatter of ceramic and bone, as well as preserved mudcracks, was found in the top 2 cm of the Ab horizon. Micromorphology of the contact between the Ab and fluvial deposits shows micro-Ab rip-up clasts within the fluvial deposit (Figure 5a).

Micromorphology of the fluvial deposits shows graded beds of fine sand, silt, and clay (Figure 5b). Three different depositional micro-facies can be observed in one slide (Figure 5e), suggesting that this fluvial deposit represents multiple events rather than one single deposition. There is also a 3 mm incipient A horizon within the fluvial deposits (Figure 5c), suggesting a temporary hiatus in fluvial deposition. The contact between the fluvial deposit and mound construction material is abrupt and smooth. This contact between the fluvial deposition and mound fill shows bioturbation between the

TABLE 1 Context of samples used in radiometric dating models

Lab#	Sample number	Provenience	Stratigraphic context	Material notes	Radiocarbon age (BP)	$\delta^{13}C$ (‰)
Beta−474938	14C-1	Canteen creek excavation	base of Stratum 2[a]	Unidentified wood charcoal	140 ± 30	−26.90
Beta−474939	14C-2	Canteen creek excavation	Stratum 6[a]	Unidentified wood charcoal (branch fragment)	120 ± 30	−24.70
Beta−474937	14C-3	Canteen creek excavation	Stratum 20[b]	Unidentified wood charcoal	150 ± 30	−25.50
OS-140346	50-57-4	2017 Mound 5 excavation	Feature 5: wall trench dug into mound fill	*Carya illinoensis*	885 ± 115	Not reported
D-AMS 019338	1960-19 Bag19-3	1960 Mound 5 excavation[c]	Burn layer in inner mound	Lower premolar deer tooth	903 ± 124	Not reported
D-AMS 019339	1960-19 Bag19-12	1960 Mound 5 excavation[c]	Burn layer in inner mound	*Carya cordiformis*	887 ± 26	Not reported
OS-140345	50-58-14	2017 Mound 5 excavation	Fluvial sand deposit underneath mound fill	*Zea mays* kernel	1000 ± 25	Not reported
OS-140221	N550 E110	Sediment core N550 E310	2 mm thick charcoal lens at base of Ab	Unidentified wood charcoal	985 ± 15	Not reported

[a]Sample removed from North profile wall, but its mirror-image location is shown on Figure 9. Dating funded by Casey R. Barrier (Bryn Mawr College).
[b]Sample removed from South profile wall. See Figure 9 for horizontal and vertical context. Dating funded by Robin A. Beck (University of Michigan).
[c]Approval for destructive analysis was obtained through the Illinois State Museum for ISM Accession Number 1960-19.

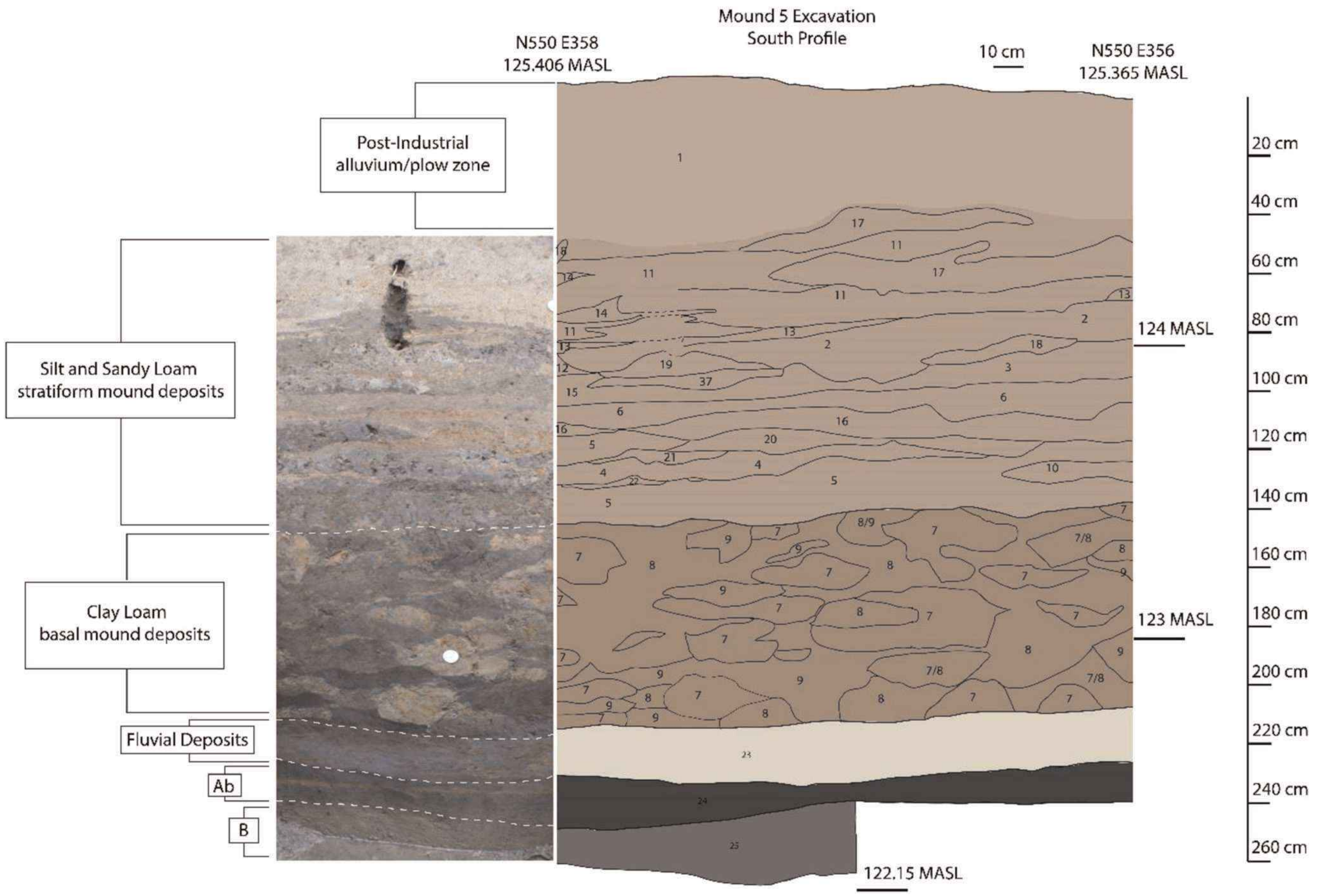

FIGURE 4 A schematic drawing of Mound 5 stratigraphy. Numbers listed on schematic refer to field descriptions in Table 2 [Color figure can be viewed at wileyonlinelibrary.com]

two depositional facies (Figure 5d), but no evidence for incipient soil formation on top of the fluvial deposit (Figure 5d). Mound 5 construction fill materials started at 123.24 masl and continued to 124.84 masl. The lower portion of Mound 5 construction fills is characterized by clay loam basketloads (Figure 4), and at 123.94 masl, the construction fill is characterized by loamy stratiform fills (Figure 4). The upper 70 cm of the excavation is characterized as plowing of rapidly aggrading alluvium, with historic artifacts found to 70 cmbs and plow marks observed at 35 and 60 cmbs.

A Bayesian model of Mound 5 construction was created using five samples collected from within Mound 5 and sub-mound contexts (Table 1). Both the samples from the Ab horizon and the fluvial sediment serve as *terminus post quem* for Mound 5 construction (Figure 6). The latest end boundary for the start of mound construction is estimated to occur after cal AD 1150 (19.2% probability and 18.8% probability), but it likely occurred after cal AD 1050 (76.3% probability and 76.6% probability; Figure 7). The nutshell and deer tooth from the mound construction phase provide a *terminus ante quem* for the deposition of the fluvial sediment (Figure 6). The earliest start boundary for the mound construction phase is cal AD 1030 (95.4% probability; Figure 7). Taken together, it is likely that both the fluvial sediment and the Ab horizon were deposited before Mississippian occupation (circa AD 1050–1400).

4.2 | Mound 16 excavations

Mound 16 excavations were conducted to a final elevation of 123.30 masl. Four distinct depositional facies were identified in the field; the oldest is a natural soil sequence with buried A, B, and C horizons, the natural soil sequence is overlain with Mound 16 construction fill, which is buried by historic fluvial deposits, and finally there is a modern plowzone on top of the historic fluvial deposits. A schematic drawing of Mound 16 stratigraphy can be found in Figure 8, with complete soil descriptions in Table 3. The 1 × 4 m excavation was conducted at the edge of Mound 16, whereas the 1 × 2 m excavation was completely outside of the Mound 16 footprint. In the Mound 16 excavation unit, the natural soil sequence appears at 123.88 masl and continues until the excavation's maximum depth at 123.53 masl. The contact between mound fill and Ab is abrupt. The Ab, B, and C horizons are discontinuous underneath Mound 16, suggesting that there was some degree of soil removal before the construction of Mound 16. Underneath Mound 16, the Ab is 10 cm at its thickest location. In the

TABLE 2 Field descriptions associated with the number labels in the Mound 5 excavation schematic (Figure 4)

Label	Munsell	Texture	Additional notes	Interpretation
1	10YR 5/3	Silt loam	Plow scars observed at 35 cmbs, common bioturbation	Modern topsoil/plowzone
2	10YR 2/1	Silty clay loam	Wall trench dug through this stratigraphic layer, much bioturbation	Mississippian ground surface on top of mound
3	10YR 4/3	Silt loam	Few mottles, less bioturbation	Stratiform mound fill
4	10YR 3/2	Silty clay loam	Many mottles	Stratiform mound fill
5	10YR 3/1	Silty clay loam	Many mottles and clay inclusions (ca. 10 cm)	Stratiform mound fill
6	10YR 4/1	Silt loam	Many mottles, common redox concretions and clay inclusions (ca. 10 cm)	Stratiform mound fill
7	10YR 5/1	Clay loam	Many redox stains and concretions	Basketload mound fill
8	10YR 4/1	Clay loam	Common redox stains and concretions	Basketload mound fill
9	10YR 2/1	Clay	Few redox stains and concretions	Basketload mound fill
10	10YR 5/2	Very fine to fine sand	Few muscovite micas, redox lens	Stratiform mound fill
11	10YR 5/2	Silt loam		Stratiform mound fill
12	10YR 5/2	Sandy loam	Few muscovite micas, few clay mottles, common redox concretions and lens	Stratiform mound fill
13	10YR 5/4	Fine quartz sand		Stratiform mound fill
14	10YR 3/2	Silty clay loam	Mottled with 11, redox lens observed	Stratiform mound fill
15	10YR 5/3	Silty clay	Many clay mottles	Stratiform mound fill
16	10YR 5/3	Sandy loam	Many redox stains, many clay mottles	Stratiform mound fill
17	10YR 5/4	Silty loam	Much bioturbation	Stratiform mound fill
18	10YR 4/6	Sandy loam	Bioturbation from 2	Stratiform mound fill
19	10YR 3/1	Silt loam		Stratiform mound fill
20	10YR 5/2	Sandy clay loam	Few muscovite mica, many redox concretions	Stratiform mound fill
21	10YR 4/1	Sandy clay loam	Few muscovite mica	Stratiform mound fill
22	10YR 5/3	Loam	Common redox	Stratiform mound fill
23	N/A	Clay to medium sand	Fine sequences of graded beds of clay to medium sand	Fluvial deposit
24	10YR 3/1	Silty clay loam	Mudcracks observed in plan-view at 235 cmbd	Ab horizon
25	10YR 5/2	Clay loam	Gradual boundary with Ab	B horizon

Note: All descriptions and interpretations were made in the field by Caitlin Rankin in 2017.

1 × 2 m excavation that is completely outside of the Mound 16 footprint, the Ab is 50 cm thick, with the start at 123.60 masl and the end at 124.08 masl. The upper 10 cm of the Ab in the 1 × 2 m excavation contains coal clinker and slag material from industrial development, indicating that this ground surface was stable from Mississippian occupation until industrial development in the middle 1800s.

In the 1 × 4 m unit, the homogeneous mound fill is buried by historic fluvial deposits in the eastern portion of the unit, but a plowzone is developed on the mound in the western portion of the unit; this difference in stratigraphic relationship is because Mound 16 is sloping to the east (Figure 8). The fluvial deposits that buried the Ab in the 1 × 2 m excavation and the eastern portion of Mound 16 in the 1 × 5 m excavation are horizontally graded beds of fine sand, silt, and clay that begin at 124.08 masl and end at 124.55 masl. The presence of coal clinker and slag material throughout the fluvial deposit suggests that this material was deposited after industrial development.

4.3 | Canteen Creek excavations

Canteen Creek excavations were conducted to a final elevation at of 123.20 masl. At this depth, the water table was reached and excavations were ceased. Nine distinct strata were identified in the field based on color, texture, and abundance of inclusions. A schematic drawing of the Canteen Creek excavation stratigraphy is displayed in Figure 9, with soil descriptions in Table 4.

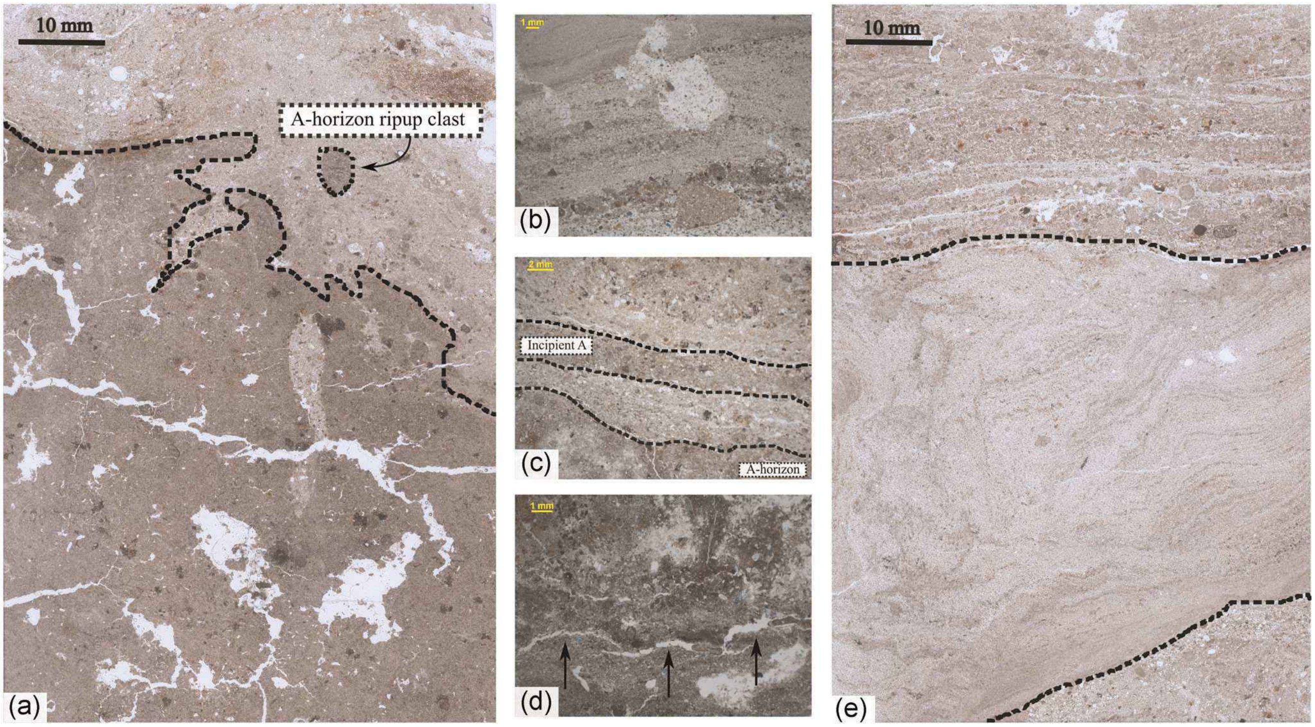

FIGURE 5 Photomicrographs of micromorphology results. (a) Ab rip-up clast in fluvial material. (b) Graded beds of sand, silt, and clay. (c) 3 mm thick incipient A-horizon between fluvial sand deposits. (d) Planar void (indicated by arrows) marks the clear boundary between the fluvial deposit and Mound fill. This contact was observed as abrupt in the field but is clear microscopically. There is microscopic evidence for bioturbation between the contact, but no evidence for incipient soil formation. (e) Three different fluvial sand facies can be observed in one micromorphology thin section [Color figure can be viewed at wileyonlinelibrary.com]

Stratum 2 is interpreted as Canteen Creek channel fill based on morphology (Figure 9), suggesting that all underlying strata were deposited before channel infilling. All strata are generally characterized as alluvial deposition based on texture and sorting, except for Strata 5 and 6. Strata 5 and 6 contain clay inclusions and have a morphology that is consistent with human-constructed embankment for stream channelization. Coal clinker and slag material was found to a maximum depth of 123.85 masl within Stratum 4, suggesting that Stratum 4 and all overlaying strata were deposited after the mid-1800s. To further support the industrial and modern age of alluvial deposition indicated by coal clinker and slag material, three organic samples were removed from the profile and submitted for radiocarbon dating (Figure 9 and Table 1). Sample 14C-1 was removed from a 0.5 cm thick lens of charcoal at the interface of strata 2 and 3. Sample 14C-2 was a small carbonized branch recovered from Stratum 4. Sample 14C-3 was a fragment of wood charcoal removed from the western toe slope of Stratum 5 as it feathers out between strata 4 and 7. As the boundaries between strata 4, 5, and 7 are diffuse, the exact stratigraphic association of Sample 14C-3 is not certain.

Bayesian modeling treats these radiocarbon data as two uniform phases ordered sequentially. Samples 14C-2 and 14C-3 are treated as a single phase (Phase 1), as the stratigraphic integrity of Sample 14C-3 is suspect. This phase is modeled with an undated start and end boundary. Sample 14C-1 is modeled as a phase (Phase 2) that follows in time. The model fits well with the data ($A_{model} = 95.9$; Figure 10). Sample 14C-1 is considered a suitable *terminus post quem* for Stratum 2 deposition (Figure 11a). This phase is estimated to begin by cal AD 1740–1780 (5.4% probability) or cal AD 1790–1960 (90.0% probability), but probably between cal AD 1830 and 1890 (28.0% probability) or cal AD 1900 and 1950 (40.2% probability). Modeled dates for Strata 4 and 5, which underlie Stratum 2, appear earlier. The undated end boundary for these strata ranges between cal AD 1690 and cal AD 1930 (95% probability), but these strata had probably formed by cal AD 1720–1890 (68% probability; Figure 11b). The undated start boundary for Phase 1 is less informative due to the long probability tails that are likely caused by the presence of only two dates for this phase (Bayliss et al., 2011). Therefore, we rely on the modeled dates themselves (Figure 11c,d) to estimate a period of activity probably in the late 17th through 19th centuries. Thus, using data currently available, it is estimated that strata 4 and 5—with Stratum 5 being of possible anthropogenic origin—accumulated in the AD 1700s or 1800s. A single coal clinker was recovered from Stratum 4, which could signal a post-AD 1853 date for this layer unless the artifact has relocated from overlying strata (see later discussion of historic era coal mining). Subsequent infilling of the Canteen Creek channel began sometime after the formation of Strata 4 and 5, and most likely no earlier than AD 1800. Nine pieces of coal

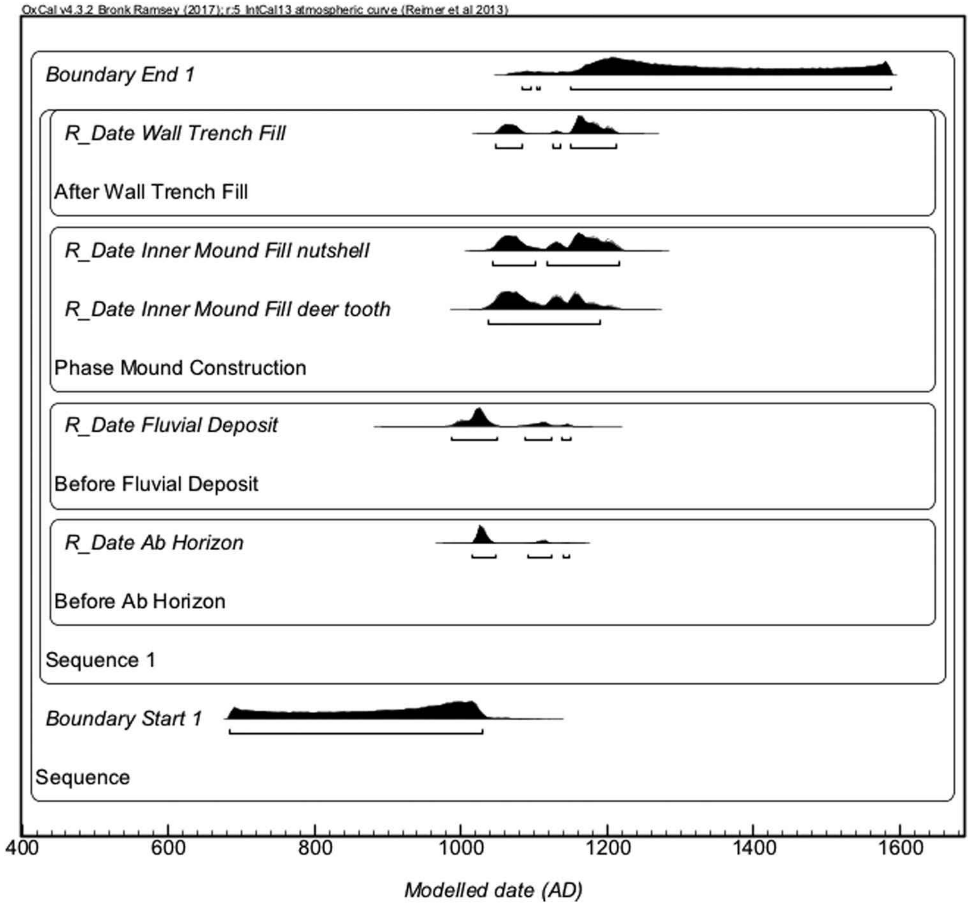

FIGURE 6 Probability distributions and Bayesian model for radiocarbon dates from the Mound 5 excavation

clinker were recovered from Stratum 2, suggesting that the infilling of this channel was ongoing in the mid-1800s or later.

4.4 | Sediment coring

Complete soil descriptions and cross-section drawings for the two analyzed sediment core transects west and south of Mound 5 can be found in Figure 12. The depositional facies relationship of an Ab covered with fluvial sediments around 123.00 masl observed in the Mound 5 excavation is also observed in both the N550 transect to the west of Mound 5 and the E355 transect to the south of Mound 5 (Figure 12). Many of the cores in these transects contain graded beds of sand, silt, and clay (interpreted as fluvial sediment) that continue until the modern Ap. Core N550 E320 contains 2 mm thick coal sand lenses within a fluvial sequence at 123.90 masl, suggesting that these upper fluvial sediments were deposited after industrial development. Figure 13 shows the cross-section drawing and soil descriptions for the Mound 14 transect. In the E120 transect, the base of Mound 14 appears to be around 122.00 masl, as indicated by the presence of an Ab underneath mound construction material. In Core N700 E120, an Ab that formed on top of Mound 14 construction fills is buried by graded beds of fine sand, silt, and clay starting at 123.70 masl and ending around 124.00 masl where the fluvial sediment is buried by the modern Ap. There is no direct evidence within the E120 transect fluvial sediments to suggest that they were deposited after industrial development, but their associated elevations with other fluvial sediments in the N550 transect and the Mound 16 excavations suggest that these sediments were deposited after industrial development. The association of fluvial sediments below the modern Ap is continuous throughout the E120 transect (Figure 13).

5 | DISCUSSION

Lopinot and Woods (1993) proposed the wood-overuse hypothesis based on a decline in the use of nonlocal woods during the Stirling Phase (AD 1050–1150), the most densely occupied phase of Cahokia's history. They hypothesized that the high population demand for local wood resulted in the deforestation of the uplands surrounding the American Bottom floodplain (Lopinot & Woods, 1993). This deforestation led to increased soil erosion in the uplands, which would have caused more "frequent, severe, and unpredictable local floods" (Lopinot & Woods, 1993, p. 230) in the floodplain. Lopinot and Woods correlated the temporal changes in land-use activities to the general trend of population decline starting in the late Stirling Phase and suggested the wood-overuse hypothesis as a potential explanation for the abandonment of Cahokia (Lopinot & Woods, 1993).

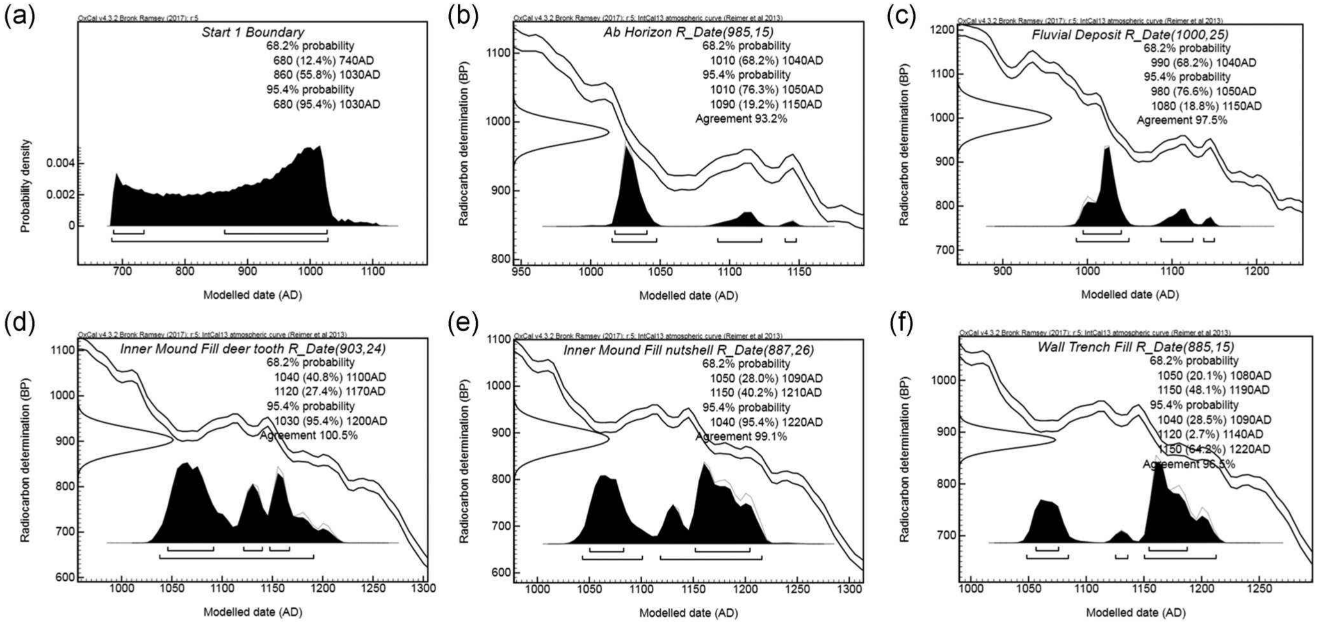

FIGURE 7 Probability distributions from the model presented for dates from the Mound 5 excavation. (a) Calibrated and modeled boundary for the start of the sequence; (b) calibrated and modeled date for Ab horizon, which is considered a *terminus post quem* for the start of Mound 5 construction; (c) calibrated and modeled date for the fluvial sediment, which is considered a *terminus post quem* for the start of Mound 5 construction; (d) calibrated and modeled date for mound construction phase, which is considered a *terminus ante quem* for the deposition of the fluvial sediment and Ab horizon; (e) calibrated and modeled date for mound construction phase, which is considered a terminus *ante quem* for the deposition of the fluvial sediment and Ab horizon; (f) calibrated and modeled date for wall trench dug into mound construction fills, which is considered a *terminus ante quem* for the mound construction phase

When this hypothesis was originally published, the only evidence for soil erosion during the Mississippian occupation was from the Goshen site buried in an alluvial fan in the intermediate zone between the upland and bottomland (Holley & Brown, 1989; Lopinot & Woods, 1993). The original report for the Goshen site was written before the publication of the wood-overuse hypothesis (Holley & Brown, 1989), and no investigations to evaluate depositional processes at the Goshen site were conducted after the hypothesis was proposed (Woods, 2004). Additionally, there is no direct evidence suggesting that regular increased flooding of Cahokia and Canteen Creeks did occur in the American Bottom floodplain at the end of Cahokia's occupation (Lopinot & Woods, 1993; Woods, 2004). Increased habitation in the uplands near the end of Cahokia's occupation is the only line of evidence used to support increased frequency of flooding (Lopinot & Woods, 1993; Woods, 2004). Munoz et al. (2015) found evidence of a large flood from the Mississippi River occurring around AD 1200 (2015). Flooding of the American Bottom from the Mississippi River is typically driven by

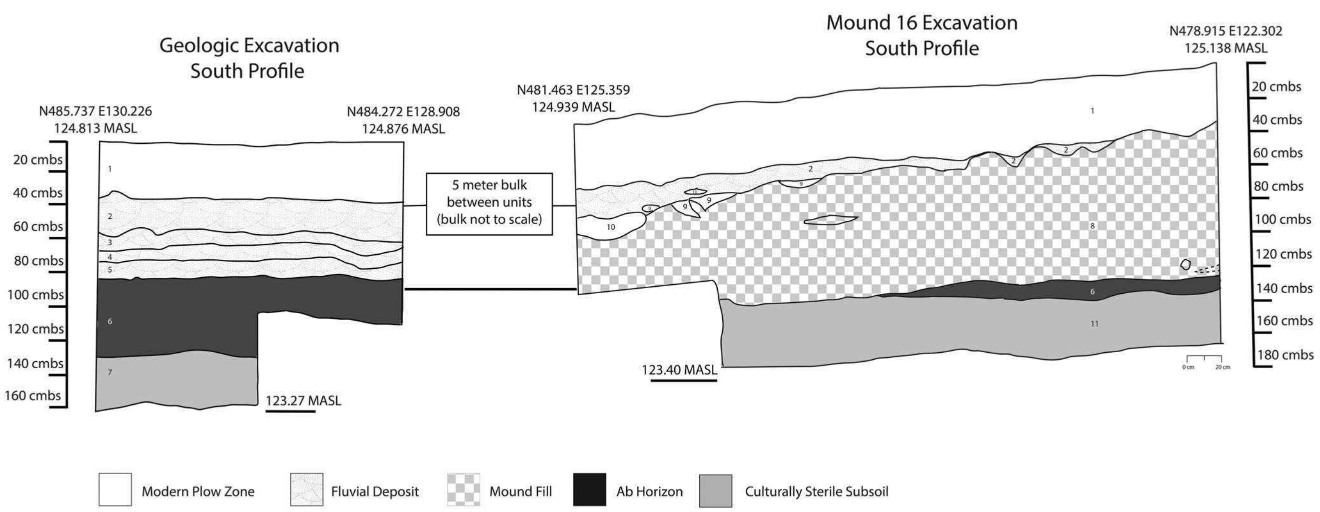

FIGURE 8 A schematic drawing of Mound 16 stratigraphy. Numbers listed on schematic refer to field descriptions in Table 3

TABLE 3 Field descriptions associated with the number labels in the Mound 16 excavation schematic (Figure 8)

Label	Munsell	Texture	Additional notes	Interpretation
1	10YR 4/2	Silt loam	Many roots in upper 25 cm, angular blocky structure	Modern Ap
2	N/A	Clay to fine sand	Finely bedded clay to fine sand (1–2 mm thick), Common Fe concretions and stains in biopores, contains coal clinker	Postindustrial fluvial deposit
3	N/A	Clay to silt	Finely bedded clay and silt, rootlets present, bioturbated fine sand, contains coal clinker	Postindustrial fluvial deposit
4	N/A	Clay to fine sand	Same as 2, but with thicker beds (~10 mm), contains coal clinker	Postindustrial fluvial deposit
5	10YR 2/1	Clay to silt	Very dark, thin clay lens contains coal clinker	Postindustrial fluvial, lower energy than 3 and 4
6	10YR 3/1	Clay loam	Many redox concretions, angular blocky structure, few roots and biopores	Ab horizon
7	10YR 5/2	Clay loam	Many Fe stains and Mn concretions, gradual boundary with 6, Few rootlets, angular blocky structure, slickensides	B horizon
8	10YR 3/1	Sandy loam	Homogenous	Mound fill
9	10YR 4/1	Clay loam	Many Mottles of 2, plow scars observed	Plow Scar
10	10YR 4/1	Sandy loam	Much Bioturbation, broken boundary with 2	Plowzone
11	10YR 5/2	Clay loam	Many Fe and Mn concretions, many Fe redox stains, slickensides, few rootlets	C horizon

Note: All descriptions and interpretations were made in the field by Caitlin Rankin in 2018.

external weather events occurring in the upper Mississippi River Valley or the Missouri River. Our paper is a discussion of how localized human activities impacted the local hydrology of the American Bottom; as flood events from the Mississippi River are not primarily driven by the local hydrology of the American Bottom, the Munoz et al. (2015) dataset is outside the scope of our discussion.

Results from investigations in the North Plaza, a mound group constructed at the lowest elevation in the central precinct of Cahokia and in the floodplain of Cahokia and Canteen creeks, indicate that the floodplain was stable after the construction of the mounds that define the North Plaza. At Mound 5, the presence of fluvial deposits between an Ab horizon and mound construction sediments indicates that the human response to flooding was to invest labor into landscape modification. The radiometric dating model of Mound 5 construction suggests that this human response to flooding happened early in Cahokia's developed as opposed to the end of Cahokia's occupation (Figure 6). Associated stratigraphy in terrestrial sediment cores outside of the Mound 5 footprint indicates that the landscape remained stable after the construction of Mound 5 until the industrial era. The presence of an Ab horizon underneath Mound 16 that remained stable until industrial development indicates landscape stability before the construction of Mound 16 until the establishment of coalmines during the middle 1800s. The upper 10 cm of the Ab horizon contains coal clinker and slag, suggesting that this stable ground surface was exposed when the Mall & Williams Mine opened in 1853, the first coal mine established within the Cahokia Creek watershed (Stehman, 1992). The Ab horizon is buried under 50 cm of fluvial deposit, all which contains coal clinker and slag material. In addition, associated fluvial deposits in core samples near Mound 5 contain lenses of coal sands, suggesting that

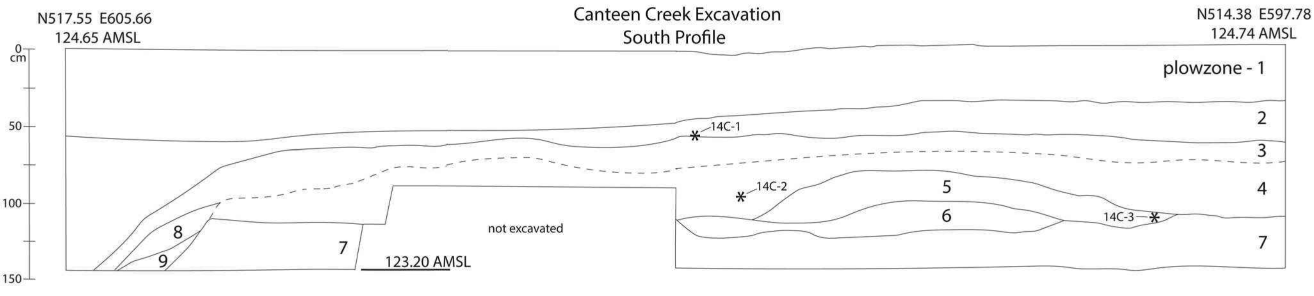

FIGURE 9 A schematic drawing of the South profile stratigraphy from the Canteen Creek excavations. Numbers listed on schematic refer to field descriptions found in Table 4. The locations of recovered organic samples used for 14 C AMS dating are also displayed (note: samples 14C-1 and 14C-2 were removed from the North profile wall, but their mirror-image location is shown here)

TABLE 4 Field descriptions for the Canteen Creek excavation schematic (Figure 9)

Label	Munsell	Texture	Additional notes	Interpretation
1	10YR 4/3	Silt loam	Redox concretions common; massive structure; roots common; lower boundary is abrupt	Modern Plowzone
2	10YR 3/2	Clay loam	Angular blocky structure; few roots; well-sorted silt and clay laminations ranging from .5 to 2 cm in thickness; lower boundary is abrupt	Channel fill alluvium
3	10YR 4/2	Silty clay loam	Redox concretions common; blocky angular structure; less bioturbation; lower boundary is diffuse	Overbank alluvium
4	10YR 5/2	Silty clay loam	Redox concretions common; blocky angular structure; few roots	Overbank alluvium
5	10YR 3/1	Clay	Granular structure	Possible fill for embankment construction
6	10YR 3/1	Silty clay loam	Common 10 YR 5/3 silt mottles; few 10 YR 4/1 silty clay loam mottles	Possible fill for embankment construction
7	10YR 3/1	Clay	Granular structure	Overbank alluvium
8	10YR 2/1		~2 cm thick laminations of 10YR 6/3	Overbank alluvium
9	2.5Y 6/4	Silty clay loam	Massive structure	Overbank alluvium

Note: All descriptions and interpretations were made in the field by Timothy Schilling in 2017.

the high sedimentation related to increased flooding rates in the Cahokia Creek floodplain is a result of upstream historic coal mining activities, which occurred after European settlement of the American Bottom. As early miners used creek drainages to find coal seams, increased sediment influx into the Canteen and Cahokia creeks was likely a result of both mining and deforestation related to land clearance in the industrial era (James, 2019; Munoz et al., 2014; Stehman, 1992).

The results of the North Plaza investigation at Mound 16 show a sedimentological signal of landscape stability after Mississippian mound construction until industrial development of the region. Floods along Cahokia and Canteen creeks do become more frequent after industrial development. Whereas no evidence for the pre-contact record was recovered during the Canteen Creek excavation, evidence from the Canteen Creek excavation suggests at least 0.65 m of observed flood deposits postdate the mid-19th century. If Stratum 4 dates to no earlier than the mid-1800s, then at least 1.1 m of alluvium is deposited across the site that is temporally related to historic era industrialization.

The post-European settlement sedimentological signal for flooding is so strong that it has concealed the North Plaza landscape beneath ca. 1.5 m of fluvial sediment. Given that the first coal mine was established in 1853 and Cahokia and Canteen Creeks were canalized by 1921, sedimentation rates from industrial era flooding are calculated at 2.2 cm/yr. Using elevations from sediment cores and excavations of the Mississippian occupation Ab horizons, we constructed a 3D model of what the North Plaza landscape would have looked like during Mississippian occupation (Figure 14). Our results clearly show strong evidence of increased fluvial sedimentation postcontact, whereas the pre-Columbian stratigraphy indicates low sediment accumulation and landscape stability. Although our study is limited by a small area of investigation, previous geoarchaeological studies conducted within the modern Cahokia and Canteen Creek canals corroborate our observations of a buried stable ground surface underneath historic fluvial sediments throughout a much larger area of the floodplain (Conner & Hajic, 1997). A recent study on the impacts of pre- versus postcolonial land use on floodplain sediment in temperate North America has called this phenomenon the "paradox of precolonial geomorphic stability" in which archaeological, ecological, and historical studies indicate a pre-Colombian humanized landscape, whereas floodplain stratigraphic studies indicate stable landscapes (James, 2019). This paradox can be resolved in accepting that ecological change does not inherently equal geomorphic change (James, 2011, 2019). By studying pollen and sedimentation rates from lacustrine cores from the Black Bottom floodplain in southern Illinois, Bird et al. (2019) demonstrated that sedimentation rates changed independently of pre-Columbian periods of land clearance, whereas increased sedimentation post-1820 is linked to industrial land clearance activities. A palynology study of lacustrine cores from the American Bottom floodplain, adjacent to

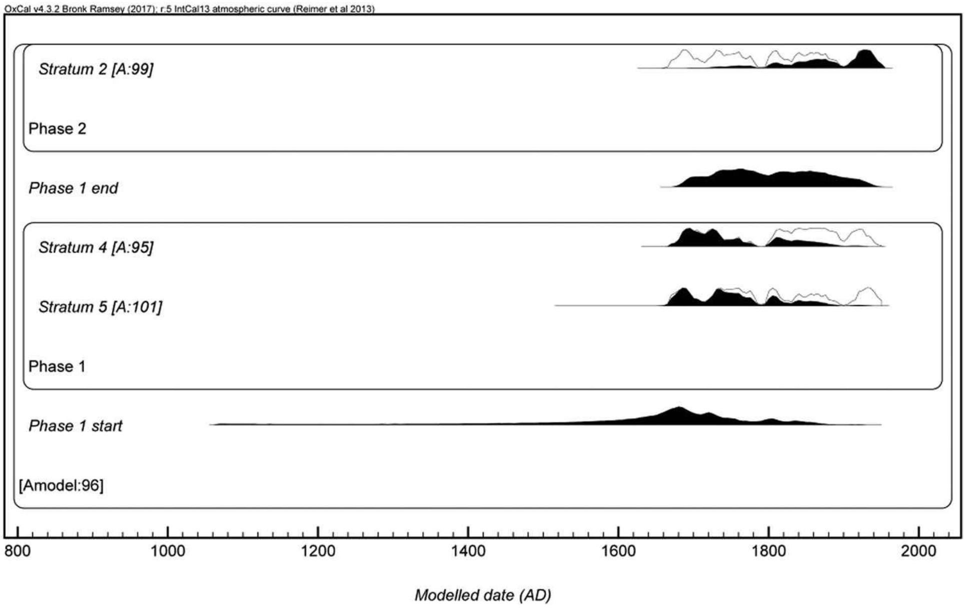

FIGURE 10 Probability distributions and Bayesian model for radiocarbon dates from the Canteen Creek excavation

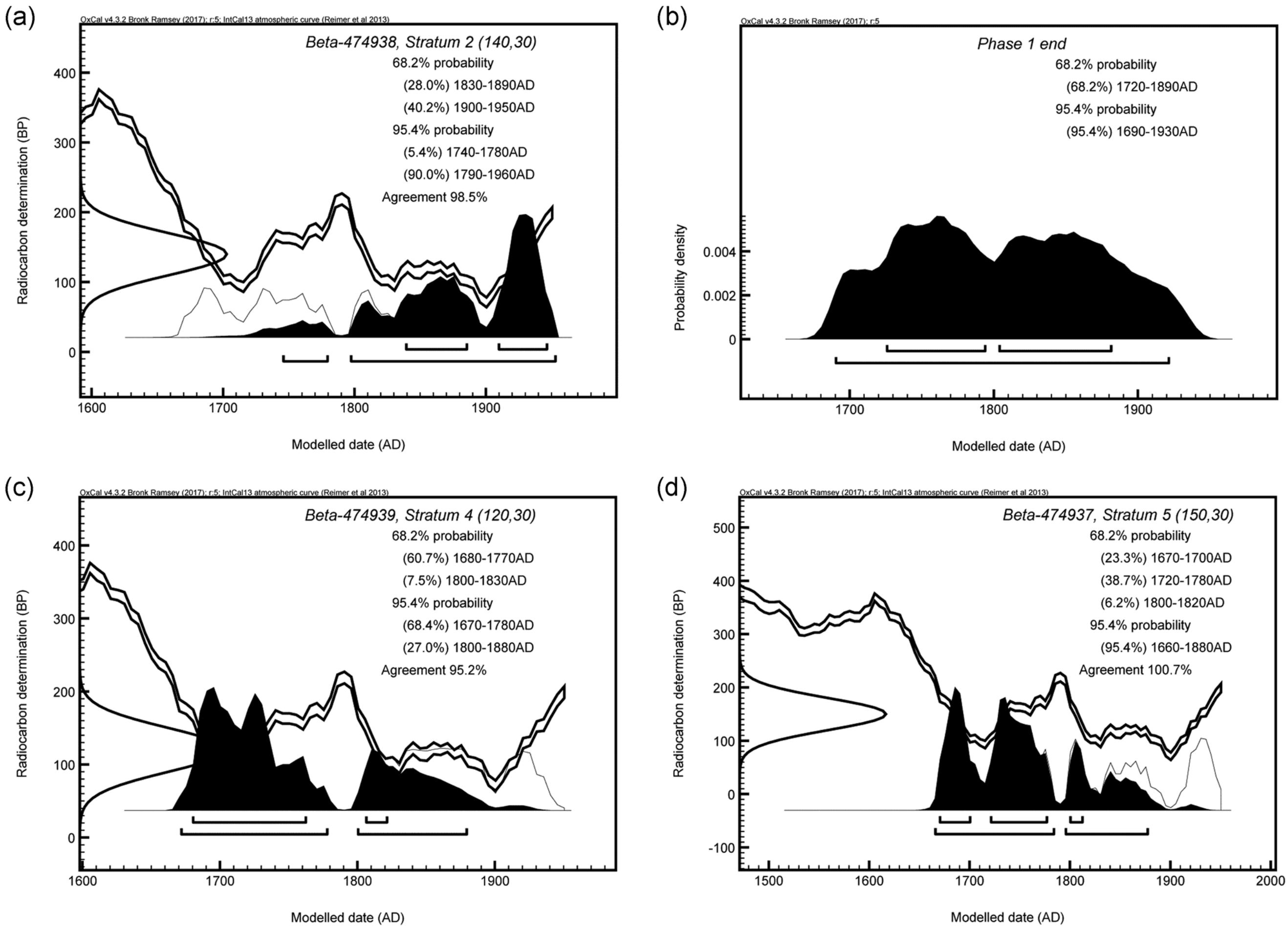

FIGURE 11 Probability distributions from model presented for dates from the Canteen Creek excavations. (a) calibrated and modeled date for sample 14C-1, which is considered a close proxy for the start of infilling of the channel and the formation of Stratum 2 alluvium; (b) undated end boundary for Phase 1; (c) calibrated and modeled date for sample 14C-2; (d) calibrated and modeled date for sample 14C-3

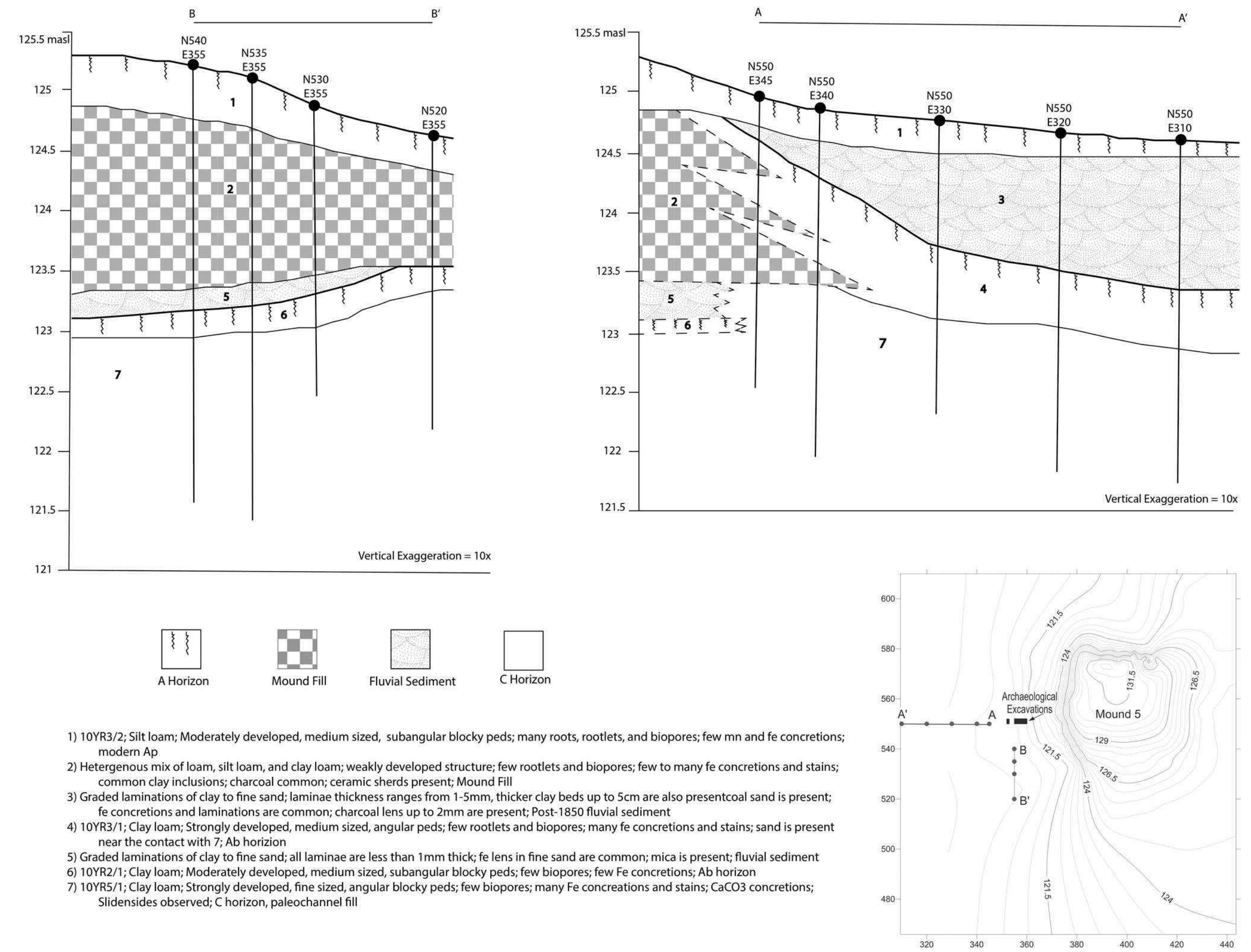

FIGURE 12 Cross-section drawings for the soil transects west and south of Mound 5

Cahokia, shows that the abundance of upland and floodplain arboreal species decreased before the emergence of Cahokia as a large center, whereas the abundance of arboreal species remained stable throughout Cahokia's occupation (Munoz et al., 2014). This palynology study suggests that there were no significant land clearance events during Cahokia's occupation (1050–1400 AD; Munoz et al., 2014). Abundances of upland and floodplain arboreal species increased after Cahokia's abandonment, ca. AD 1400, and decreased post-1800s (Munoz et al., 2014). The decrease in upland Oak and Hickory trees is consistent with deforestation activities related to industrial development post-1800 (James, 2019; Munoz et al., 2014; Stehman, 1992). The lack of consistency between palynological and archaeological studies of wood consumption at Cahokia is puzzling; however, a recent reevaluation of the wood required to construct the palisade fortification around Cahokia suggests that previous estimates of wood exploitation are too high (Krus, 2011). We reject the wood-overuse hypothesis as a potential contributor to the collapse of the Cahokia polity on the basis that human-caused ecological change did not lead to geomorphic change in the context of our investigations. We recognize that our area of investigation does not encompass the entire floodplain; however, previous work by Hajic demonstrated that the pre-Columbian buried soil observed in our area of investigation is present in other parts of the floodplain and is also buried by historic alluvium (Conner & Hajic, 1997). Although increased flooding at the end of Cahokia's occupation could still have occurred in some unexplored parts of the floodplain, we have demonstrated that increased flooding did not occur ubiquitously. We find it unlikely that people would leave Cahokia due to the effects of flooding if these flooding events were constrained to limited areas. In addition, new palynological data and new evaluations of wood needed for construction suggest that previous estimates of wood use by the people who built Cahokia were overestimated. Mt. Pleasant, an indigenous agronomist and soil scientist, argued that archaeologists tend to underestimate and/or ignore conservation strategies employed by North American pre-Colombian people in agricultural and arboricultural activities (Mt. Pleasant, 2015). Perhaps, in attempt to push away from the pristine myth of the pre-Colombian landscape, we have ignored the capabilities of

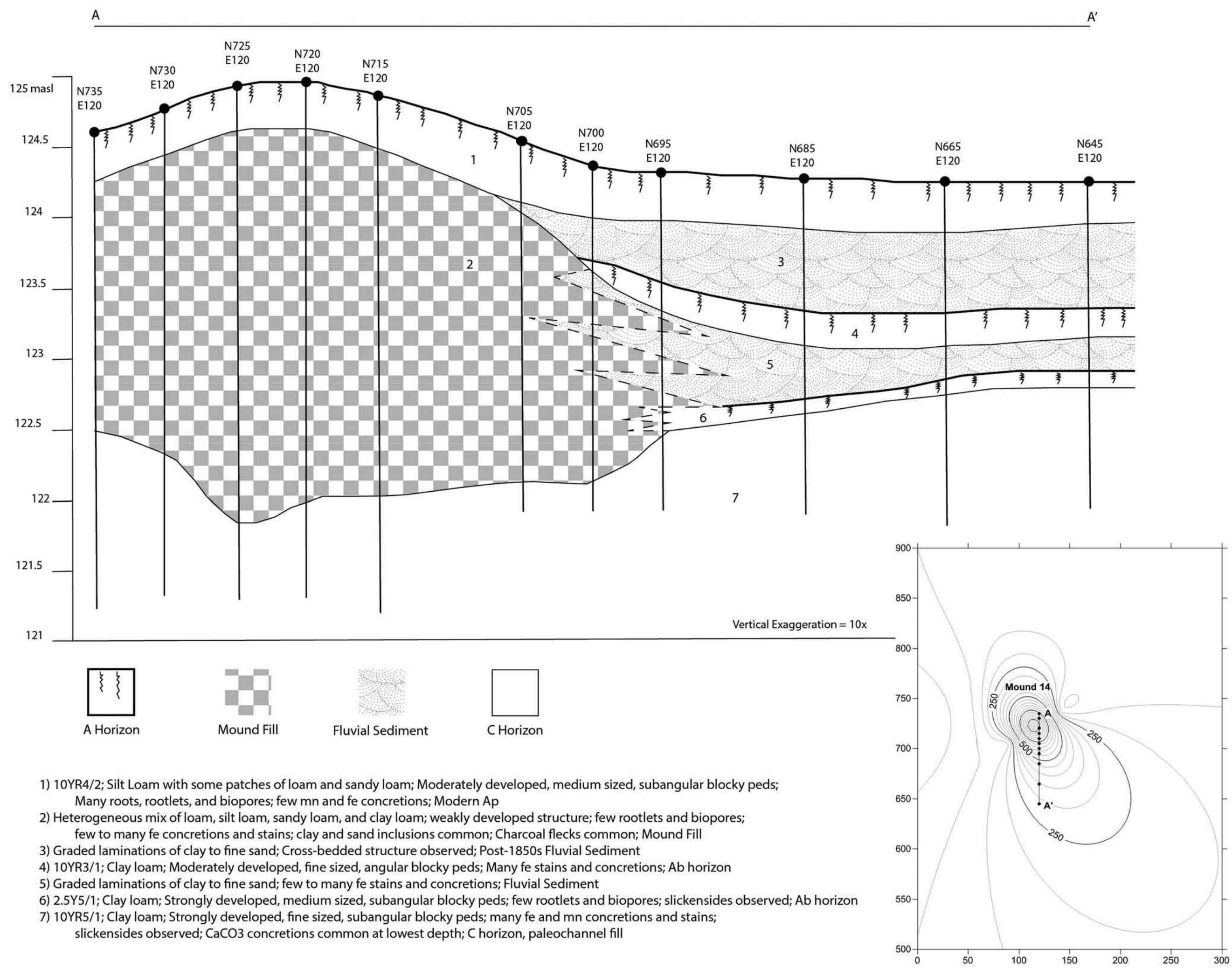

FIGURE 13 A cross-section drawing for the soil transect through Mound 14

these people as purposeful conservationists of their landscape and resources.

6 | FINAL THOUGHTS: WHY OLD THEORIES OF COLLAPSE PERSIST THROUGH TIME

Although many archaeologists have moved beyond classic narratives of ecocide made popular in the 1990s and early 2000s (Kull, 2000; McAnany & Yoffee, 2009), there are still major archaeological sites where the methods for understanding past environmental change have advanced, but the theory used to interpret these data has remained static (d'Alpoim Guedes et al., 2016). Using Cahokia as a case study, we suggest the following causes for the persistence of hypotheses through time:

(1) Lack of Data. Lopinot and Woods (1993) made it clear in their chapter on the wood-overuse hypothesis that there were insufficient data to move their narrative from hypothesis to a probable cause for collapse at Cahokia. The only evidence that the erosional effects of deforestation occurred came from a buried Mississippian site in the intermediate zone between upland and bottomland (Holley & Brown, 1989) that was never evaluated for site-formation processes. Despite the lack of data to support this hypothesis, the ecocide narrative has been maintained in the literature as a potential contributor to Cahokia's abandonment (Kelly, 2008; Mann, 2005; Woods, 2004). Since the publication of the wood-overuse hypothesis, no attempts have been made to evaluate if erosion in the uplands and/or increased flooding in the floodplain did indeed occur during Cahokia's occupation.

(2) Lack of environmental data taken from the archaeological record. Many studies of environmental change rely on proxies taken from the general region of the society in question. These regional datasets are unable to account for localized variability of change and also lack the direct link between environmental change and human activity.

(3) Lack of interdisciplinary training. There is a shortage of archaeologists who are trained in interdisciplinary work,

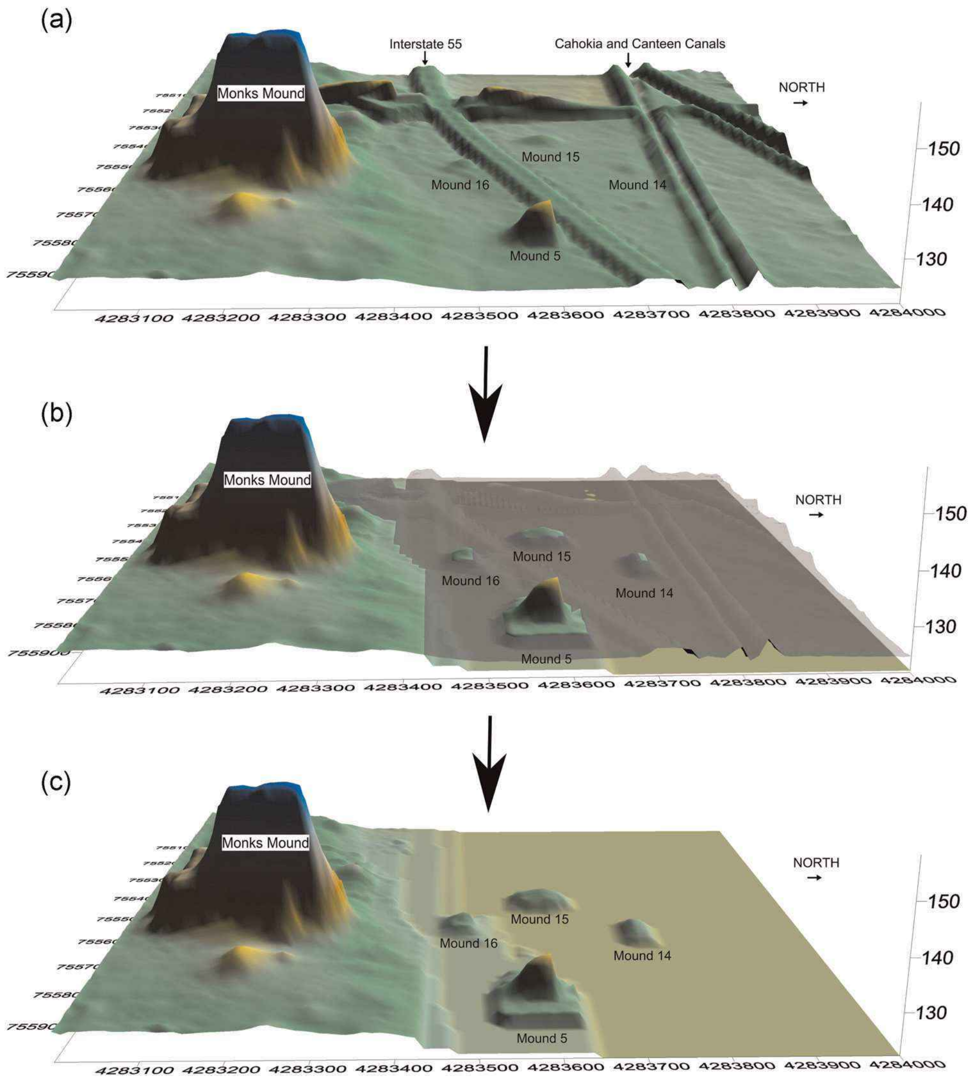

FIGURE 14 A 3D model of North Plaza landscape during Mississippian occupation, based on Ab elevations from excavations and sediment cores. (a) A 3D model of modern ground surface created in Golden Software's Surfer 13 from Madison County LiDAR derivatives obtained from the Illinois Height Modernization Project web application viewer; (b) modeled Mississippian ground surface with an overlay of the modern ground surface in gray; (c) modeled Mississippian ground surface, based on Ab elevations from excavations and sediment cores [Color figure can be viewed at wileyonlinelibrary.com]

making it necessary for archaeologists to rely on collaborators for evaluations of site formation and proxies of environmental change. These collaborators might not be accustomed to working at the hyperlocal scale of archaeology sufficiently versed in current anthropological theory. Insights concerning the relationship between humans and the environment can improved by ensuring that the proposed dataset is at a scale capable of obtaining information that can address the more localized scale of interactions between humans and their environment.

Moving forward, we propose that to move past these older narratives of ecocide, there needs to be increased engagement with obtaining both archaeological and environmental data to address these older theories, a need for researchers who are trained in interdisciplinary research, as well as increased support for long-term, interdisciplinary collaborations. The interdisciplinary field of geoarchaeology is especially equipped to help us move forward, as long as the members of the field remain engaged with developing anthropological theory.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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