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THE LSU CAMPUS MOUNDS, WITH CONSTRUCTION BEGINNING AT ~11,000 BP, ARE THE OLDEST KNOWN EXTANT MAN-MADE STRUCTURES IN THE AMERICAS

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ABSTRACT. Radiocarbon dating of the two LSU Campus Mounds (16EBR6) indicates that the construction of one, Mound B, began at ~11,000 BP, making Mound B the oldest known and intact manmade structure in the Americas. The age analyses presented here are based on thirty one ^{14}C dates. The older (deeper) parts of both of the LSU Campus Mounds contain many thin, burned ash lenses, suggesting that the Mounds may have been used for ceremonial or cremation purposes. These ash layers are composed mainly of phytoliths, bio-silicate (SiO_2) structural compounds in plants that remained after burning of these plants. Analysis of the abundant ash lenses indicates that the plants burned were mainly C4 hydrophilic grasses that are dominated by 90-98% reed and cane plants. The ash layers also contain microscopic fragments of burned, large mammal osteons (bone). The layers of reed and cane phytoliths, containing very small numbers of osteons, are indicative of very hot fires. This finding supports the argument that the fires were used for ceremonials or cremations. No ash beds later than 5,000 BP are known from either LSU Campus Mound A or B, although at ~800 calBP, a wooden post (now charcoal) was planted and burned on the top of Mound B. It appears that construction of Mound B began during the climate amelioration that followed the Younger Dryas climate event, which ended at ~11,700 BP. Construction of Mound A appears to have begun at ~9,500 calBP. Building of the LSU Campus Mounds shows a hiatus when climate deteriorated during the 8200 Climate Event, which defined the end of the Holocene Greenlandian Stage and the beginning of the Northgrippian Stage. Construction began again at ~7,500 BP, when both mounds continued construction until ~6,000 BP, with one apparently anomalous date in Mound A at ~5,100 calBP.

Key words: Indigenous people, ancient mounds, radiocarbon dated ash beds, reed and cane plants, phytoliths, occluded carbon

INTRODUCTION

The LSU Campus Mounds site (16EBR6), located on the Louisiana State University (LSU) campus, consists of two conical earthen structures, each ~5.5 m in height and built by Indigenous People upon the Pleistocene-age loess terrace (Heinrich and McCulloh, 2000; Muhs and others, 2018) (fig. 1A), on which the core of the LSU Campus has been constructed. The crests of LSU Campus Mounds A (northern) and B (southern) are located ~56 m apart. Construction on Mound B appears to have begun as early as *ca.* 11,000 calBP (calibrated 2σ ages; table 1). Sigma refers to standard deviation. At the 1σ level the standard deviation is 68.2%, while at the 2σ level it is 95.4%. This means that if a ^{14}C age has a +/-30 year range, at 1σ,

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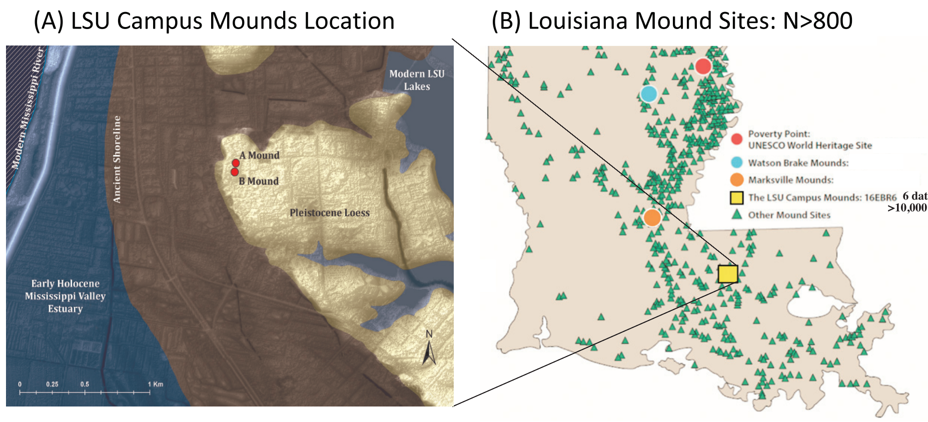

Fig. 1. (A) Geographical setting for the LSU Campus Mounds site at *ca.* ~10,000 BP, after the mounds were built, superimposed on a LIDAR image of the area, showing the Holocene Mississippi Valley Estuary that existed at the time mounds building began (~11,000+/−1000 BP); a modern day analog is Mobile Bay, AL. Blue coloration represents the eastern margin of the Early Holocene Estuary, and brown represents the ancient exposed shelf at that time; the yellow color represents the Pleistocene, loess-mantled river terrace, with lakes (blue); (B) Distribution of the ~800 known Louisiana mound sites, including the Marksville Mounds at *ca.* 2,000-1,500 BP, Poverty Point at *ca.* 3,500 BP, Watson Brake at *ca.* 5,500 BP, and the LSU Campus Mounds at *ca.* ~11,000 BP. Fig. 1B was modified from a diagram that was produced by the Louisiana Division of Archaeology, where many of the sites were identified by Kniffen (1936, 1938).

when 100 samples are analyzed on the same exact carbon, 68.2% of the time the sample would produce similar results, within +/-30 years. However, at 2σ the results would fall within 60 years (2 x 30) 95.4% of the time.

At the time mound building began (~11,000 BP), the Pleistocene Loess Terrace bordered on what was then the Mississippi River Valley Estuary, which has a modern analog in Mobile Bay, Alabama. The LSU Campus Mounds are just two of the >800 mounds known from Louisiana (fig. 1B) and were shown in the initial LSU 1927 campus construction plan as an isolated area intended for preservation. Thus, the LSU Campus Mounds were not destroyed as were many other ancient mounds in Louisiana, including the Monte Sano mounds located ~12 km north of the LSU campus, with dates ranging from 7,575-4,956 calBP 2σ ages (Jones and Brookes, 2017). The LSU Campus Mounds are listed on the National Register of Historic Places as the “LSU Campus Mounds”.

The LSU Campus Mounds were first recognized in the 1800s, with archaeological work starting in the late 1900s. Following the death in 1984 of a sun-bathing student who was run over by a small truck that was driven over the northern Mound A, special efforts were made by LSU to protect these structures and to increase safety around them. This work was accompanied by archaeological excavations (Neuman, 1988; Homburg, ms, 1991, 1993), which included coring and subsurface excavation around the exterior margin of both Mound A and Mound B. However, diagnostic artifacts were scarce. A conclusion from the remediation and research at that time was that the LSU Campus Mounds were built at *ca.* 5,800 BP in one construction phase (Homburg, 1993). At that time, six long cores (~6 m in length) were recovered, three from Mound A and three from Mound B, and Homburg (ms, 1991) in his thesis work showed, through chemical analyses of these cores, that each mound was built from different source materials. However, Homburg (ms, 1991) did not date samples from the mounds. His conclusions concerning the different materials used to build the mounds are supported by the work reported here, where in 2009 we collected two Giddings, ~0.05 m diameter, ~6.4 m long cores, one from the northern Mound A

TABLE 1

Sample #s. Dates, Depths, Material Dated, and presence of Burned Bone/Osteon – yes or no

Mound A1 N=5						Burned
ID	Conventional date BP	Calendric (cal) 2σ age	$\delta^{13}C$ ‰	Depth (m)	Sample	Bone/Osteon
A236P	Beta 538301 - 8,560±40 BP	9,561 - 9,477 calBP	N/A	4.88 m	Phytolith	No
A253	Beta 577887 – 6,050±30 BP	6,981 – 6,797 calBP	17.2	5.20 m	Org. Sed.	yes
A255	Beta 577888 – 6,730±30 BP	7,660 – 7,565 calBP	19.3	5.24 m	Org. Sed.	yes
A257P	Beta 518140 - 7,960±30 BP	8,989 - 8,697 calBP	-26.3	5.28 m	Phytolith	yes
A259	Beta 504775 - 7,560±30 BP	8,412 - 8,343 calBP	-20.6	5.32 m	Ash Bed	yes
Mound A2 N=3						Burned
ID	Conventional date BP	Calendric (cal) 2σ age	$\delta^{13}C$ ‰	Depth (m)	Sample	Bone/Osteon
A-exc.	Beta 259456 - 5,330±40 BP	6,183 - 6,039 calBP	-14.8	1.60 m	Charcoal	no
A 3.48	Beta 495207 - 4,550±30 BP	5,189 - 5,053 calBP	-26.8	3.48 m	Charcoal	no
A178	Beta 504774 - 5,240±30 BP	6,096 - 6,049 calBP	-15.5	3.71 m	Ash Bed	yes
Within Sub – Mound B1 N=8						Burned
ID	Conventional date BP	Calendric (cal) 2σ age	$\delta^{13}C$ ‰	Depth (m)	Sample	Bone/Osteon
B195	Beta 502679 - 7,540±30 BP	8,408 - 8,325 calBP	-17.7	4.00 m	Ash Bed	yes
B205	Beta 503524 - 7,610±30 BP	8,449 - 8,372 calBP	-19.6	4.22 m	Ash Bed	yes
B238	Beta 506319 - 8,770±30 BP	9,775 - 9,647 calBP	-17.8	4.91 m	Ash Bed	yes
B242	Beta 506320 - 7,590±30 BP	8,428 - 8,359 calBP	-19.2	5.01 m	Ash Bed	yes
B246	Beta 504770 - 9,000±30 BP	10,236 - 10,156 calBP	-18.0	5.08 m	Ash Bed	yes
B262P	Beta 536895 - 9,580±40 BP	11,108 - 10,742 calBP	N/A	5.38 m	phytolith	yes
B266	Beta 504771 - 8,130±30 BP	9,134 - 8,999 calBP	-20.8	5.43 m	Ash Bed	yes
B267P	Beta 518141 - 9,860±30 BP	11,316 - 11,228 calBP	-28.6	5.47 m	Phytolith	yes
Mound B1 Cap – weathered and bioturbated N=2						Burned
ID	Conventional date BP	Calendric (cal) 2σ age	$\delta^{13}C$ ‰	Depth (m)	Sample	Bone/Osteon
B2-83	Beta 550606 - 6,490 ±30 BP	7,460 - 7,323 calBP	-19.2	3.03 m	Org. Sed	no
B2-98	Beta 550607 - 6,170 ±30 BP	7,165 - 6,980 calBP	-19.2	3.42 m	Org. Sed	no
Within Sub – Mound B2 N=4						Burned
ID	Conventional date BP	Calendric (cal) 2σ age	$\delta^{13}C$ ‰	Depth (m)	Sample	Bone/Osteon
B-Post	Beta 491213 - 890 ±30 BP	834 - 732 calBP	-26.4	0.6 m	Charcoal	no
B1-12	Beta 550984 - 6,330 ±30 BP	7,318 - 7,173 calBP	-15.0	2.17 m	Ash Bed	no
B2-45	Beta 550983 – 6,900±30 BP	7,795 – 7,669 calBP	-19.4	2.12 m	Ash Bed	?
B136	Beta 504769 - 5,300 ±30 BP	6,185 - 5,991 calBP	-21.1	2.81 m	Ash Bed	yes
Pleistocene loess terrace on which the LSU Campus Mounds sit: N=2						Burned
ID	Conventional date BP	Calendric (cal) 2σ age	$\delta^{13}C$ ‰	Depth (m)	Sample	Bone/Osteon
A288	Beta 522794 - 11,500±40 BP	13,441 - 13,266 calBP	-19.2	5.96 m	Org. Sed.	No
B315	Beta 522795 - 10,980±30 BP	12,954 - 12,725 calBP	-19.0	6.41 m	Org. Sed.	no
Anomalous Dates: N=7						Burned
ID	Conventional date BP	Calendric (cal) 2σ age	$\delta^{13}C$ ‰	Depth (m)	Sample	Bone/Osteon
B269P	Beta 536296 -12,980±50 BP	15,740 - 15,298 calBP	N/A	5.50 m	phytolith	no
B214P	Beta 536294 - 12,460±50 BP	14,983 - 14,250 calBP	N/A	4.39 m	phytolith	no
A221P	Beta 536748 - 9,600±40 BP	10,980 – 10,768 calBP	N/A	4.57 m	phytolith	no
B125	Beta 504768 - 7,910±30 BP	8,785 – 8,598 calBP	-18.9	2.58 m	Ash Bed	yes
B153	Beta 550858 - 9,760±30 BP	11,244 – 11,162 calBP	-21.3	3.13 m	Org. Sed.	no
B168	Beta 550859 - 11,600±40 BP	13,515 – 13,349 calBP	-18.4	3.43 m	Org. Sed.	no
B289	Beta 504772 – 8,570±30 BP	9,555 – 9,485 calBP	-18.7	5.91 m	Ash Bed	yes

^{14}C Dates by Beta Analytic (N=31) for the LSU Campus Mounds (16EBR6) Samples (Fig. 2). NOTE: All dates from within the mounds were collected from archived 8 cc (specially designed and sealed) plastic boxes. If 'yes' in the Burned column, then bone or osteons were found in the ash lens/beds from which the sample was taken. Ash beds are dominated by high concentrations of phytoliths. N/A for phytolith dated samples indicates a Beta sample with low phytolith concentrations, and therefore low carbon. NOTE: Conventional dates listed are not corrected for actual calibrated ages, while Calendric ages listed are calibrated and reflect the actual time (BP) that the sample was created sample was created.

and one from the southern Mound B (fig. 2). The cores showed that Mound A was built from sediment collected from either the local estuarine floodplain (brown shading in fig. 1A), which at that time was ~150 m away from the LSU Campus Mounds, and below the top of the Pleistocene loess terrace, or Mound A may have been constructed from the dark mud that developed in lakes on top of the Pleistocene Loess Terrace. Mound B on the other hand, was built from loess collected from the Pleistocene Loess Terrace on which the LSU Campus Mounds sit (fig. 1A).

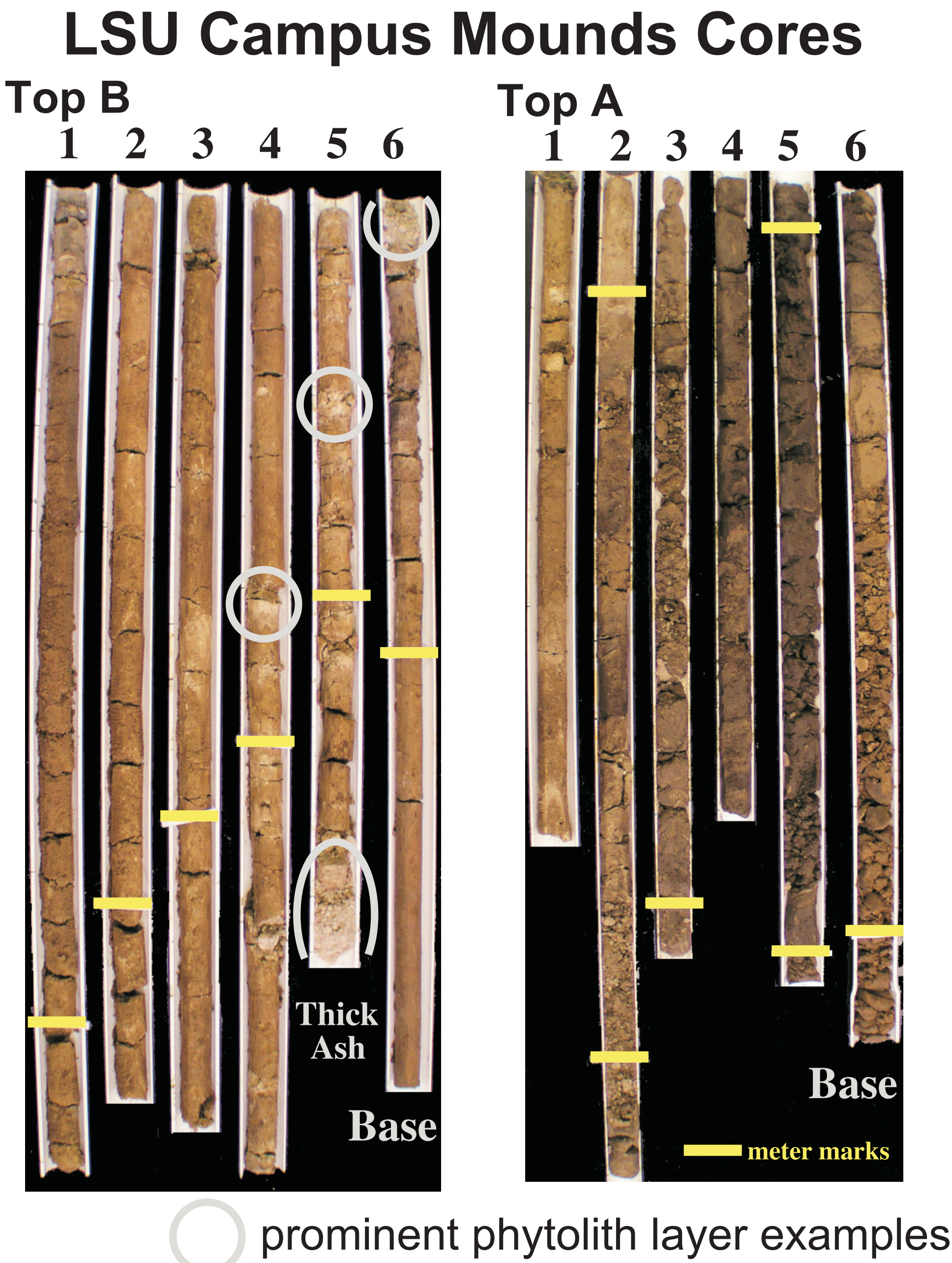

Fig. 2. Cores drilled in 2009 by Joe Saunders (deceased), Thurman Allen, Robb Mann, and Brooks Ellwood, using a Giddings drill system. A few examples of the prominent burned ash lenses in Mound B are identified. Note, Mound A consists mainly of dark-colored floodplain or lake sediment, while Mound B consists primarily of lighter-colored Pleistocene Loess Terrace sediment. Yellow bars represent 1 m depth intervals within each core. The base of each core was estimated based on a change in lithology from the typical mound material to typical Pleistocene Loess Terrace sediment.

Early Known Dates for Mounds in North America

The oldest previously dated and well-documented published dates for mounds built by Indigenous People in North America are from the Monte Sano mounds discussed above, with ages from 7,575-4,956 calBP, and also a *ca.* 5,500 BP date from the Watson Brake mound complex in NE Louisiana (Saunders and others, 1997), a site at which the Indigenous mounds have not been destroyed. Older dates, ranging from *ca.* 900 to 7,300 calBP, have been reported for mounded shell features in Tennessee that were excavated during the Depression in the 1930s, and today these are generally submerged under Kentucky Lake and are not easily accessible (Bissett, ms, 2014 and personal communication).

It is known that humans were present in North America by at least *ca.* 22,000 BP (Wade, 2021), and it is generally accepted by the archaeological community in Louisiana that humans occupied the southern Louisiana region as early as *ca.* 12,000 BP (Haag and Kuttruff, 2017) in the latest Pleistocene, at least 10,000 years after the arrival of humans in North America. It is reasonable to assume that ancient communities living at the beginning of the Holocene, after 10,000 years of human interaction and development in North America, that these communities were capable of community interaction in the form of collaborative action as part of their cultural development.

Current LSU Mounds Research

The research reported here from the LSU Campus Mounds began in 2008 with a number of geophysical studies. This work was followed by collecting two cores (fig. 2), one from the crest of Mound B, and one near the summit area in Mound A, targeted to a magnetic anomaly in the subsurface at that location. The cores were visually studied, including microscopic examination, and subsampled. Analyses of the data collected from the cores were interpreted to indicate that each mound was built in two major steps as platform mounds on the Pleistocene Loess Terrace. Our interpretation of this research indicated that both LSU Campus Mounds were each built in two phases, with Mounds A1 and B1 being built first, and later, after a long hiatus, Mounds A2 and B2 were built on top of the hiatus developed on Mounds A1 and B1, respectively (fig. 3). Both cores were subsampled using specially designed, 8cc nonmagnetic plastic sample boxes, and the magnetic susceptibility of the collected material was measured (fig. 4). These data are discussed in section, *Materials, Methods and Background data*, in this manuscript.

Mounds in North America (1)

There are mainly two types of mounds found in North America, Earthen Mounds, made from local sediment sources, and Shell Mounds. Shell middens are also found, mainly along the Florida Coast (Saunders and Russo, 2011). Earthen and shell mounds are found all over central and eastern North America, from Oklahoma and Iowa, west of the Mississippi River Valley to along the east coast of North America. There are thousands of these mounds, and a number of localities are now National Park areas, including Poverty Point National Monument in Louisiana, containing mainly earthen mounds, Effigy Mounds National Monument in Iowa, containing shell mounds in the shape of animals, and Canaveral National Seashore in Florida, containing large shell mounds (Ellwood, 1996, 2017). At one time there were a large number of shell mounds (21) in Canaveral N.S., but only three remain (Turtle Mound, Castle Windy, and Seminole Rest), with the shells from others having been mined as road-building material. The shells used in building these mounds were harvested by Indigenous People from the Indian River, which flows north along the eastern US

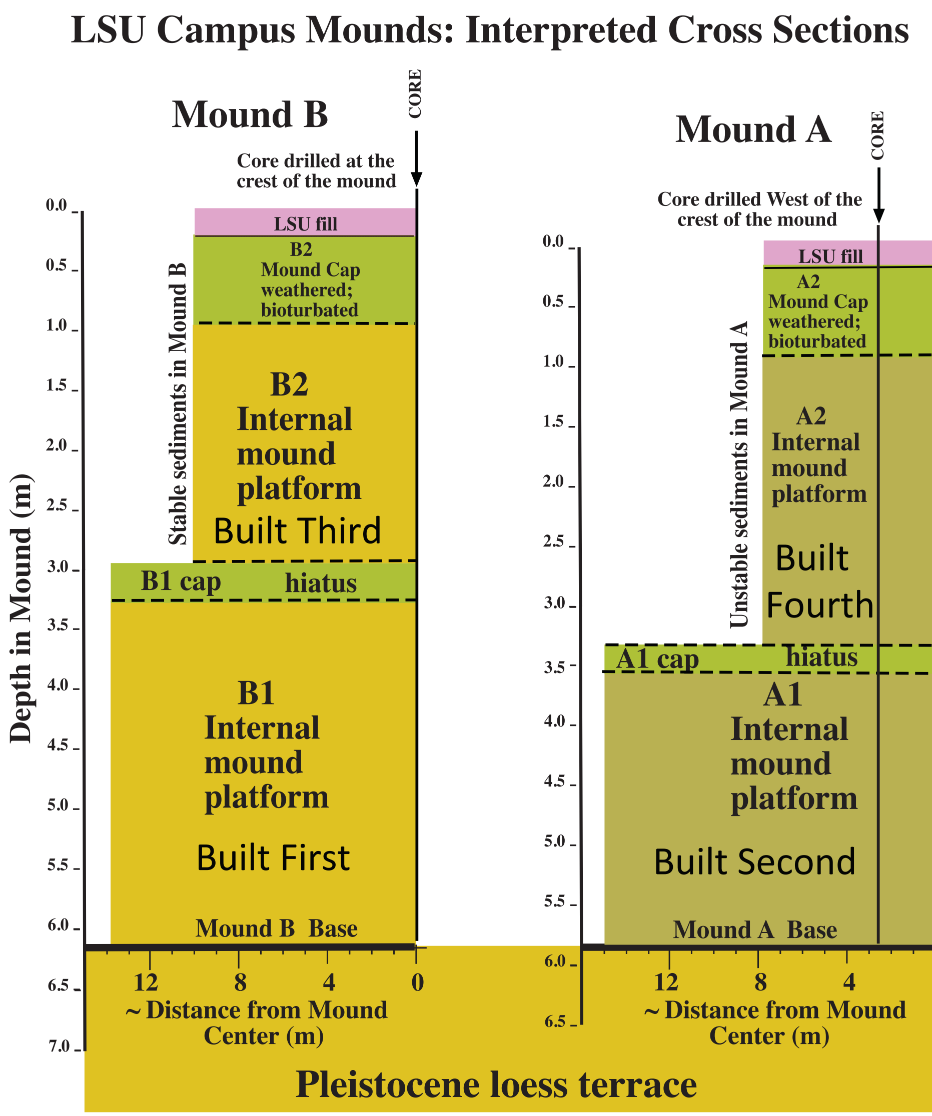

Fig. 3. Interpreted schematic of the internal structure for LSU Campus Mounds A and B as developed from figure 2, and from microscopic examination of the cores. Note that the internal platforms are indicated as A1 and B1 below, and A2 and B2 above, separated by a hiatus that resulted in bioturbation of the tops of A1 and B1. These bioturbated zones are labeled A1 cap and B1 cap, and A2 cap and B2 cap, respectively. Timing of mound element building is based on the dates in table 1.

coastline, behind a barrier island/peninsula, separating the Indian River from the Atlantic Ocean to the east.

There are interesting cases where the Indigenous mounds have been preserved and used by relatively recent human cultures for various purposes. For example, there is a ceremonial earthen mound located ~200 m to the east of the Louisiana State Capitol Building in downtown Baton Rouge, LA. This mound is dated at ~1,000 BP, and it has a flat platform on which sit two Revolutionary War canons. This platform

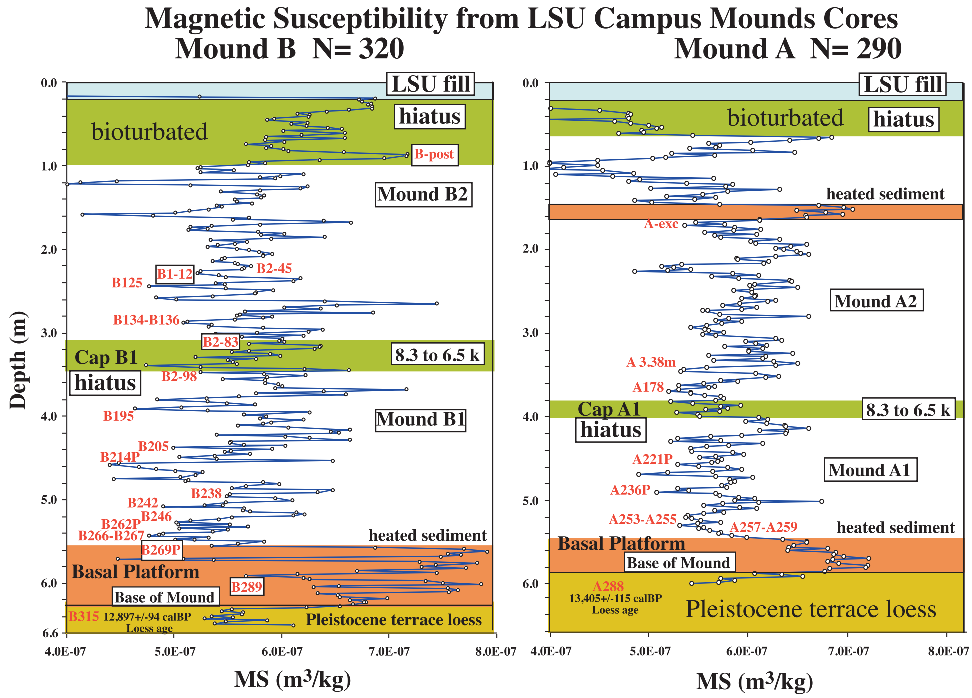

Figure 4. Magnetic susceptibility measured on a continuous set of samples collected from cores drilled through the summit of Mound B, and from a core offset 2.5 m to the west from the summit of Mound A (fig. 3). Samples that were dated are identified in red. Microscopic examination of the cores indicated two hiatuses that are zones of bioturbation within each core (A1 cap and B1 cap in fig. 3). The heated basal platforms at the base of each LSU Campus Mound are identified as heated zones in each mound and are located below a thick ash bed seen at the base of both LSU Campus Mounds. There is one hiatus in each LSU Campus Mound, labeled as the B1 Cap and A1 cap. The age of these is from *ca.* 8,200 calBP to *ca.* 6,500 ca lBP. The yellow band at the base of each core represents the Pleistocene Loess Terrace on which the LSU Campus Mounds and LSU Campus were built.

was probably flattened during the Revolutionary War and used as a gun platform. The Battle of Baton Rouge occurred in 1779 at this site and was the only Revolutionary War battle fought outside of the original thirteen American colonies. The mound was later used as a cemetery for Army officers.

Another example of relatively modern usage of Indigenous mounds, is that of shell mounds and middens found along the eastern coast of Florida, in the town of Ponce Inlet. Here, some of the shell mounds were flattened and in at least one case, a relatively modern personal home was built on one of these mounds, while the shell debris scraped from the mound in preparing the mound for the house, was used in building an access road to the house (Gurler, M., personal communication).

Mounds in North America (2)

Platform mounds are known from Louisiana mound sites, such as Poverty Point in NE Louisiana (Ford and Webb, 1956; Kidder and others, 2004), and the Monte Sano mounds (fig. 5), once located on the east bank of the Mississippi River to the north of the LSU Campus, before they were destroyed (Haag and Kuttruff, 2017). The platform construction interpretation is tested here, and the results are presented below. Dates (table 1) from the LSU Campus Mounds, and the Pleistocene

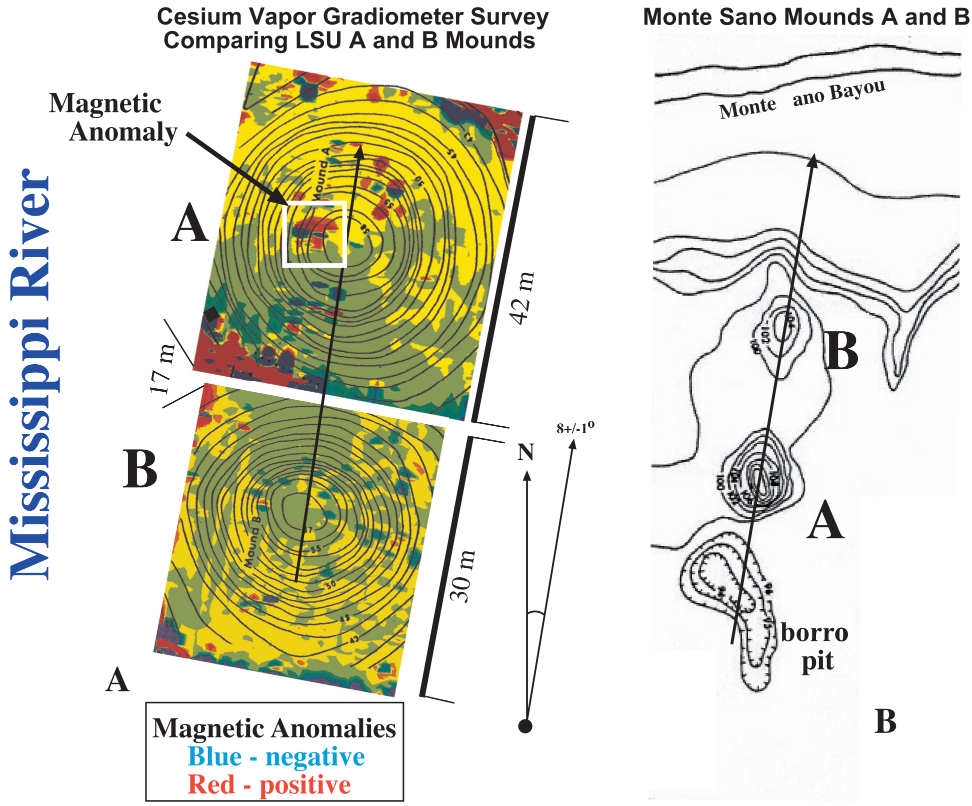

Figure 5. (A) Cesium vapor gradiometer magnetometer surveys of LSU Campus Mounds A, and B. The crests of the two mounds, A and B, are separated by ~56 m. Note the large anomaly present just to the West of the top of Mound A (white square in the figure). A core was drilled, and an excavation was placed at this point to examine this anomaly. Other anomalies around the base of the LSU Campus Mounds are associated with LSU construction and infrastructure, that is, cement re-bar and water pipes. Note that the LSU Campus Mound's crest orientation is shifted ~8° to the East of North; (B) diagram of the *ca.* 7,300 to 5,000 calBP Monte Sano Mounds once located ~10 km north of the LSU Campus Mounds before they were destroyed, also showing an ~8° crest offset that was observed during excavation of the Monte Sano Mounds (Monte Sano Mounds diagram taken from Haag and others, 2017). Both the LSU Campus Mounds and Monte Sano Mounds pairs are/were located near the Mississippi River Valley Estuary on the Pleistocene Loess Terrace along the eastern bank of the river.

Loess Terrace on which they sit, indicate that the LSU Campus Mounds are younger than the Pleistocene Loess Terrace, and were built beginning in the earliest Holocene.

An analog to the work reported here comes from the work at the Poverty Point World Heritage Site in Louisiana, where hot cane fires on Poverty Point Mound B there, destroyed most of the bone, leaving only small bone fragments in these fires (Ford and Webb, 1956). However, in one case, a recognizable piece of burned human bone was recovered (Ford and Webb, 1956). It is interesting to note that at the base of Poverty Point Mound B, a thick ash bed containing abundant phytoliths, the microscopic silicate structural elements of plants, was recovered, and this layer appears very similar to the thick ash bed recovered from the base of LSU Campus Mound B, thus the Poverty Point analog. This layer at the base of LSU Campus Mound B has been dated, with two dates in the range of ~11,000 BP (table 1).

Mounds in North America (3)

Studies of mounds built by Indigenous People in Louisiana and throughout the Mississippi River Valley, have a rich history from purely descriptive analyses and useful applications of geoelectric, magnetic, and carbon isotopic dating techniques (Ortmann and Kidder, 2013). Mounds are commonly constructed as either domes or platforms by excavating, transporting, and redepositing local sediment, occasionally through the use of baskets (Henderson and others, 2002). Mounds are generally conical in shape, and range in scale from isolated features occupying several square meters, such as the LSU Campus Mounds, to very large sites containing multiple mounds. Some mounds in the Mississippi River Valley were constructed with flat tops, and are known as platform mounds (Kidder, 1992). In some instances, sediment was built up along many parallel ridges (for example, Poverty Point; Sassaman, 2005). Many mounds were constructed on Pleistocene Loess Terraces within the Mississippi River Valley. The location and duration of mound occupation would have been tightly controlled by shifts in the fluvial system as a consequence of frequent flooding and avulsion (Kidder, 1996), or due to major climate changes, such as the end of Younger Dryas (~11,700 BP) and climate amelioration, or the beginning of the 8,200 BP Event, a time of major climate deterioration. These unpredictable changes have been put forth as a possible explanation for the abandonment of Watson Brake around 4,800 calBP (Saunders and others, 1997). A similar hiatus has also been attributed to river-controlled changes, disrupting earthwork construction (Arco and others, 2006). With increased population densities during the Coles Creek and Mississippi periods (1150–750 calBP), the number and construction of mounds changed, to include the development of architectural complexes with a central plaza and mounds of varying heights (Kidder, 1992). As a direct consequence of these changing communities, mounds from archaeological periods and phases are associated with specific cultures having distinct styles of construction, likely reflecting variable mound functions (Kidder, 1992; Saunders and Allen, 1994). Mounds have been described as serving numerous functions including an observational role, thus allowing hunters to view prey more easily, and as ritual sites, important to the local peoples (Sassaman, 2005). The Mid-Archaic mounds in Louisiana (>3,550 calBP), based on their distribution, scale, and lack of mixed associated objects, suggest a localized tradition (Saunders and others, 2005) that later shifted in the Late Archaic due to increased interactions between large numbers of people, as interpreted for Poverty Point (Sassaman, 2005). Poverty Point is one of the most interesting examples of mound complexes that were likely constructed by a complex hunter-gatherer society, and it is an intriguing example of Late Archaic earthwork architecture in the Mississippi River Valley (Ortmann and Kidder, 2013). Mound use by Tchefuncte (Ford and others, 1945) and Marksville cultures (Ford and Willey, 1940), include earthworks used for burials. Baytown cultures (1550–1150 calBP) include the use of mounds for feasts, with the development of large pits likely used for communal feasting (Lee, 2010). During the transition to the Coles Creek culture (~1150 calBP), mounds continued to serve a social or religious role as tumuli, an ancient burial mound, with interment of individuals at the tops of these features (Kidder, 1992). In addition, Coles Creek flat-top platform earthworks were arranged around level plazas, and mound use may have also included residential as well as mortuary purposes, as observed for previous cultures by Roe and Schilling (2010). Similar mound construction and use was suggested for the Mississippi period as well (Roe and Schilling, 2010). A detailed discussion of mound use, construction, and developments in Louisiana and the Mississippi River Valley has been published by Rees (2010). While many aspects of mounds may never truly be resolved, such as their total height and their exact function, much can be learned from these archaeological sites, including the potential for archaeological remains,

and possibly, the timing or rate of construction and source(s) of sediments (Sherwood and Kidder, 2011).

Most of the Pre-Columbian earthworks recorded in the Mississippi River Valley, particularly in Louisiana, and elsewhere in the Americas (for example, Bevan and Roosevelt, 2003; Rossetti, Goes, and Toledo, 2009), have not been extensively examined to determine their cultural association, methods of construction, or their potential for associated artifacts. In the case of the Mississippi River Valley, this leaves significant gaps in our understanding of mound usage in an area where some of the oldest earthworks in North America are preserved (Ortmann and Kidder, 2013).

Analysis of mounds in Louisiana has evolved from purely physical descriptions and comparisons to detailed examinations of the geoarchaeological context of these features (Sherwood and Kidder, 2011; Ortmann and Kidder, 2013). For example, electrical resistivity (ρ_α) and magnetometer profiling provides noninvasive and cost-effective techniques for the examination of the subsurface without trenching or full excavations. In addition, the development of electrical cross-sections (pseudosections) from measured ρ_α data provides insight into anomalies in the subsurface, which can inform and guide subsequent archaeological excavations. The application of magnetic susceptibility, how susceptible a material is to become magnetized in an inducing magnetic field, has the potential to enable descriptions of the methods of mound construction, and provide some constraints on sediment weathering patterns, with potential implications for assessing the source(s) of sediments utilized in mound construction. Analysis of sediments based on color characteristics alone does not record the subtle transitions observed when magnetic susceptibility measurements are also incorporated. Based on the lack of well-resolved sedimentological or magnetic susceptibility features preserved within mounds, the duration or phases in construction may be unresolved. By using a combined approach of geo-electrical and magnetic susceptibility techniques, both of which are cost-effective and minimally invasive, it is possible to begin to assess the archaeological significance of mounds prior to commencing invasive and destructive excavations. While a complete understanding of the cultural affiliations and archaeological context, such as history of mound construction, mound function(s), source(s) of sediments, may not be afforded by using geo-electric and magnetic susceptibility-based approaches exclusively, but they can provide important first steps toward evaluating a site. Moreover, the combined ρ_a and magnetic susceptibility approach can work in a variety of environments and may prove useful for the study of other ancient earthwork features across the globe (Bevan and Roosevelt, 2003; Rossetti, Goes, and Toledo, 2009). With an estimated >800 mounds in the state of Louisiana alone, applying these techniques to a number of sites should increase our knowledge concerning the earliest inhabitants living along the Mississippi River Valley and elsewhere, as well as other poorly known localities where nonintrusive methods provide a basis for future, in-depth archeological studies.

Materials, Methods and Background Data

Methods Overview

The geophysical studies performed on the LSU Campus Mounds and reported here included sampling for magnetic susceptibility measurements from the 2009 cores recovered from each mound (figs. 2 and 4). Continuous (back-to-back) 8 cc, cubic plastic sample boxes, which were specifically designed for magnetic measurement in the laboratory, were used to collect sediment through the entire length of each core. These boxes were capped and sealed to provide archival samples, some of which were sent to Beta Analytic for Radiocarbon dating (tables 1 and 2), and all of which were measured for magnetic susceptibility (fig. 4). Before sampling, the cores were described and

TABLE 2

Summary of Concentrations in Phytoliths per gram of dried sediment

Sample Name	Phytolith: #counted	Sediment (g)	Lycopodium # counted	Lycopodium # Tablets Used	Total # Lycopodium	Total Calculated Concentration
Loess Control	14	4.2	346	1	9,666	93
KP8-49	15	4.8	9	1	20,848	7,239
B134	336	2.8	10	1	9,666	115,992
B242	358	2.5	3	1	9,666	461,390
B262P	448	11.8	2	1	9,666	183,490
A Exc.	322	8.9	3	1	20,848	251,425
A257P	732	4.8	1	1	20,848	3,179,320

photographed (fig. 2), and that information was used in developing figure 3. Other geophysical studies included cesium vapor gradiometer data from both LSU Campus Mounds (fig. 5A), additional magnetic susceptibility data from a 2x2x1 m excavation on Mound A (fig. 6D), that was placed over a large magnetic anomaly, outlined by a white square on Mound A in figure 5A. In addition, features observed in figure 6A showed the horizontal layering indicative of platform mound construction, where layers of sediment were first deposited and then reed and cane plants were stacked on top of this sediment and burned, thus heating, magnetizing, and discoloring the sediment layers. Electrical resistivity data were also acquired (fig 7), and these data for LSU Campus Mound B (fig. 7B) indicated a possible platform characteristic within the upper part of the mound, while the internal character of Mound A was chaotic (fig. 7A). A 2x1x1 m excavation on the top of Mound B found no artifacts, but a burned post or pole, ~0.1 m in diameter was identified and dated at ~800 calBP (sample B Post in table 1). This indicates that Native American People visited the site at that time.

Description of cores

The sedimentological differences between LSU Campus Mounds A and B cores are obvious upon initial glance at the cores (fig. 2), but even more so with further inspection using Munsell color charts and microscopic examination. Both mound cores have a layer of fill deposited by LSU at the top of each mound (fig. 3; this layer on Mound A is ~0.4 m thick, while on Mound B it is ~0.2 m thick). These layers were added to repair damage done during football games because many students often climbed on the mounds during those games, and this degraded the tops of the mounds. Both mounds sit atop the dull yellowish brown (10YR 5/4) Pleistocene Loess Terrace (fig. 1A) on which the LSU campus was built.

LSU Campus Mound B sediment is primarily built from loess, a dull reddish-brown color (5YR 4/4) with some variations to a bright, reddish-brown (5YR 5/6). In contrast, Mound A sediment is largely moderate to dark brownish-gray (5Y 6/1 and 5Y 4/1). Mound B has eight discernable, light-gray lenses interpreted as ash layers that are a fine-textured, light brownish gray (5YR 7/2) to moderate grayish yellow brown

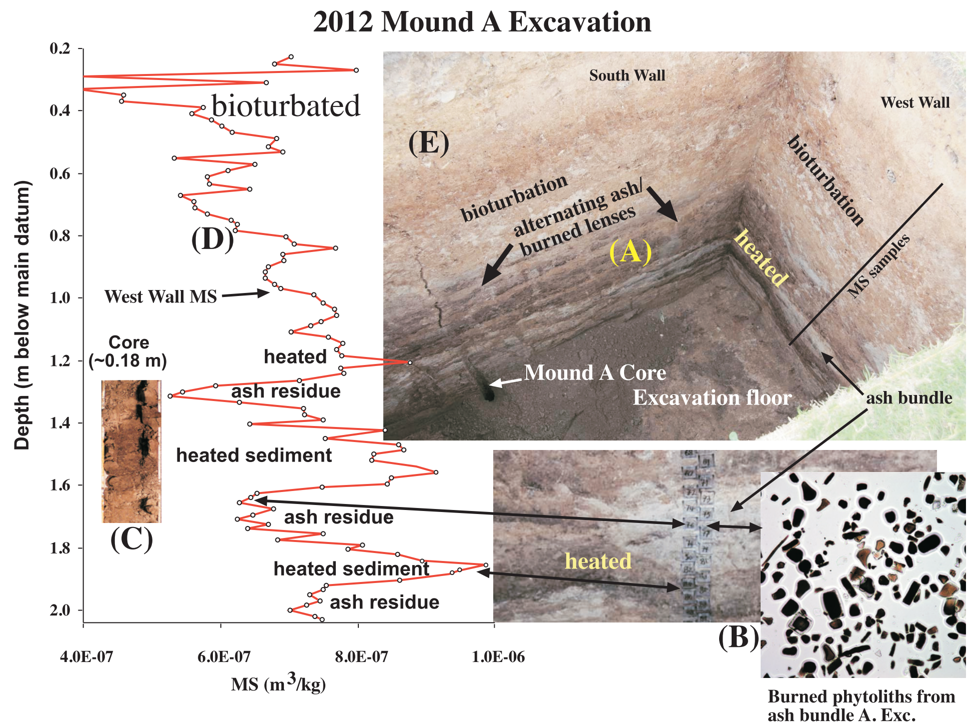

Figure 6. Results from the 2012 Mound A excavation: (A) East Wall of the excavation, illustrating the alternating heated sediment/burned ash beds exposed and showing where the Mound A core was drilled; (B) close-up of the South Wall from which magnetic susceptibility samples and data were collected at ~0.015 m intervals and the magnetic susceptibility measured; burned phytoliths are shown; (C) shown is a reddened (heated) portion of the Giddings core, which penetrated the left margin of the East Wall excavation. It was the ash lens at ~1.65 m in the core (light color) from which the dated charcoal sample A. Exc. (table 1) was recovered; (D) magnetic susceptibility results showing down-section changes in magnetic susceptibility in the excavation where all ash lenses (phytolith residues) show low magnetic susceptibility values due to high concentrations of diamagnetic biosilicate phytoliths, while heated, darkened/reddened sediment shows high magnetic susceptibility values, due to an acquired magnetization during heating of iron-containing sediment, with alteration and annealing of the iron mineralogy in these samples; (E) at the top are values from the bioturbated layer at the top of LSU Campus Mound A, below which the sediment alternates between heated sediment and phytolith layers (East and South Walls), which were the source of the magnetic anomaly noted in figure 5A. Visible in figure 6B are the specially designed 8 cc archival plastic boxes used for collecting samples for magnetic susceptibility measurement, dating, and phytolith extraction.

(10YR 4/2), ranging from ~0.05 m to ~0.34 m in thickness and composed mainly of phytoliths. At the base of Mound B, there is a phytolith layer that is ~0.34 m thick (fig. 2, core barrels 5 and 6). All of the eight ash layers identified consist almost entirely of phytoliths. In the LSU Campus Mounds, the phytoliths are identified as the internal structural elements of reed and cane plants (fig. 8D). Note that almost all of the phytoliths identified in sample B262P (~183,000 phytoliths per gram of sample) are blackened or dark brown, indicating burned occluded carbon within these phytoliths. A burned bone/osteon sample was also identified within this sample (table 1; fig. 9). See methods Section, *Phytolith Identification and Extraction,* for an explanation of phytolith analysis techniques.

Several of the thin, high-volume phytolith-rich layers, in both Mounds A and B, contain small fragments of charcoal, some of which are burned bone (fig. 9; table 1), but these layers are mainly composed of phytoliths. More of these layers are not evident in the Mound A core because of the chaotic, internal nature of the core identified using electrical resistivity data (fig. 7). This work showed that at least seven samples from Mound A have blackened phytoliths, and sample A275 contains 3.179×10^{-6} phytoliths per gram of sample (fig. 8C), the highest phytolith concentrations measured in this study.

Thixotropic Sediment in Mound A

Mound A sediment has a high water content and the sediment making up the mound is thixotropic in character, which would have slightly deformed when the mound was loaded by large numbers of students climbing, jumping and running on the mounds during football games. The fact that the Mound A sediment is thixotropic was discovered during coring, when a short Mound A core segment liquefied when tapped during sediment extraction from the core barrel. While Mound A is thixotropic, due to its having been built from floodplain sediment, or lake mud collected from the top of the Pleistocene Loess Terrace, Mound B sediment is not thixotropic because it was constructed from the Pleistocene loess that makes up the terrace. As a result, Mound A has deformed over the years, with deformation causing gradual slumping toward the east, while Mound B has not deformed and appears to have maintained its original shape (fig. 5A), although there has been some deformation as a result of root damage from trees growing on the mound. Figure 10A is an example of such a tree that has since been removed to prevent further damage to the mound.

Magnetic Susceptibility Measurements

All materials are "susceptible" to becoming magnetized in the presence of an external magnetic field. Low-field bulk, magnetic susceptibility is an indicator of the strength of this transient magnetism (Mullens, 1977; Ellwood and others, 1995; Ellwood and Gose, 2006). Magnetic susceptibility is very different from remanent magnetism (RM), the intrinsic magnetization that accounts for the magnetostratigraphic polarity variations of materials. Magnetic susceptibility in stratigraphic sequences is generally considered to be an indicator of detrital iron-containing paramagnetic and ferrimagnetic grains, mainly ferromagnesian and clay minerals, and can be quickly and easily measured on small friable samples. Because phytoliths are primarily silicates (SiO_2) with some occluded carbon, like quartz they contribute a negative (diamagnetic) component to the measured magnetic susceptibility. In the very low inducing magnetic fields that are generally applied in the laboratory, magnetic susceptibility is largely a function of the concentration and composition of the magnetizable material in a sample. Generally, when iron is present in sediments and the sample has been heated, sediments acquire a very strong magnetization when they cool in the presence of the Earth's magnetic field and therefore the acquired magnetic susceptibility increases relative to a sample that has

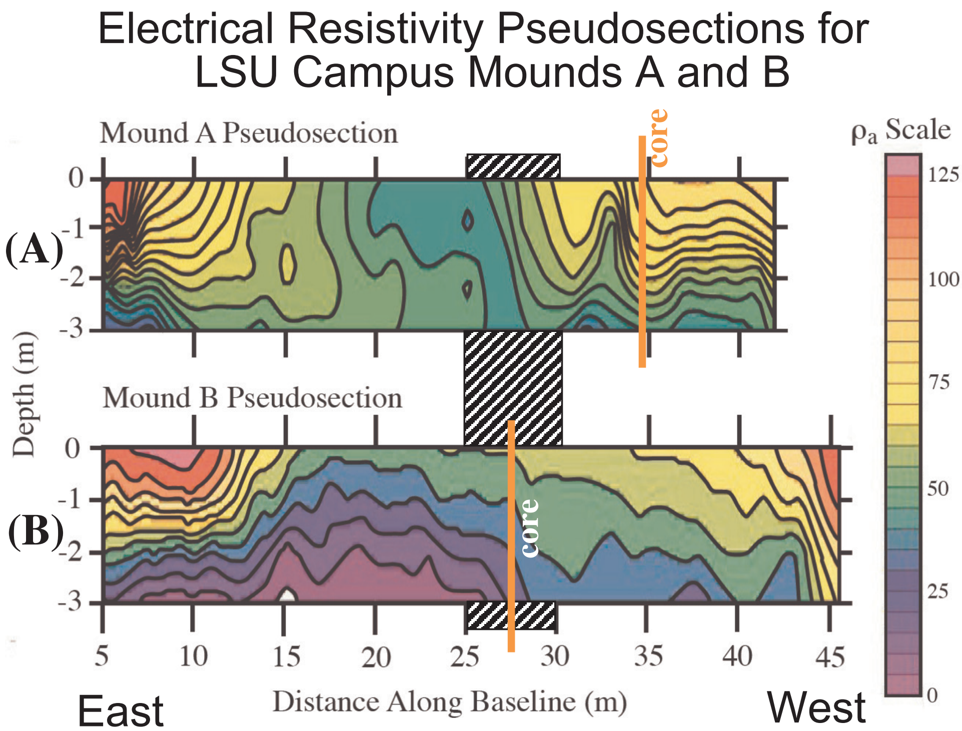

Figure 7. Comparison of electrical resistivity pseudosections for the upper parts of LSU Campus Mounds A2 and B2. Note that the interior of the two LSU Campus Mounds is very different, with Mound A2 exhibiting a disruptive electrical character representing disrupted layering in the mound, while Mound B2 shows an internal, relative uniformity within the B2 internal mound platform. Also note that the modern center of each mound is identified by the black and white filled pattern in figure 7, and the symmetry of the lower part of Mound A2 and Mound B2 is offset to the East. These data are interpreted to indicate that the lower mound constructions (not shown in the diagram) are offset to the East, while the final mound-building event was built upon an earlier platform within each mound. Locations of cores from figure 2 are shown and labeled here, with the Mound A core offset to the west toward the strong magnetic anomaly identified on Mound A in figure 5(A).

not been heated. If only very small amounts of iron are present, such as in an ash formed from burned plant residue, the magnetic susceptibility will be low. Heated sediment containing clay and other iron-containing constituents will show relatively high magnetic susceptibility values when measured. This can produce cyclic variations, as illustrated in the magnetic susceptibility variability observed for samples collected from the LSU Campus Mounds cores (fig. 4). This is true as well for samples collected during the 2x1x2 m excavation of Mound A (fig. 6D), where magnetic susceptibility sample location and sample boxes are illustrated in figure 6B. The light bands in the lower excavation walls in Figure 6 are phytolith-rich lenses that show burned discoloration (fig. 6B), while in contrast the dark brown layers (fig. 6E) are sediment layers that appear to have been added following burning to cover the phytolith layers and the osteons contained in them. The alternating magnetic susceptibility character in the lower part of this section indicates that after the reed and cane plants were burned in large numbers, a sediment layer was placed above the phytolith layer that was produced by burning. Later, more reed and cane plants were added and burned, heating the sediment layer below each new phytolith bed, discoloring the sediment below and producing a strong magnetic susceptibility signature, a process that was repeated many times (fig. 6E). The result was that the phytoliths were blackened and the added sediment layers were

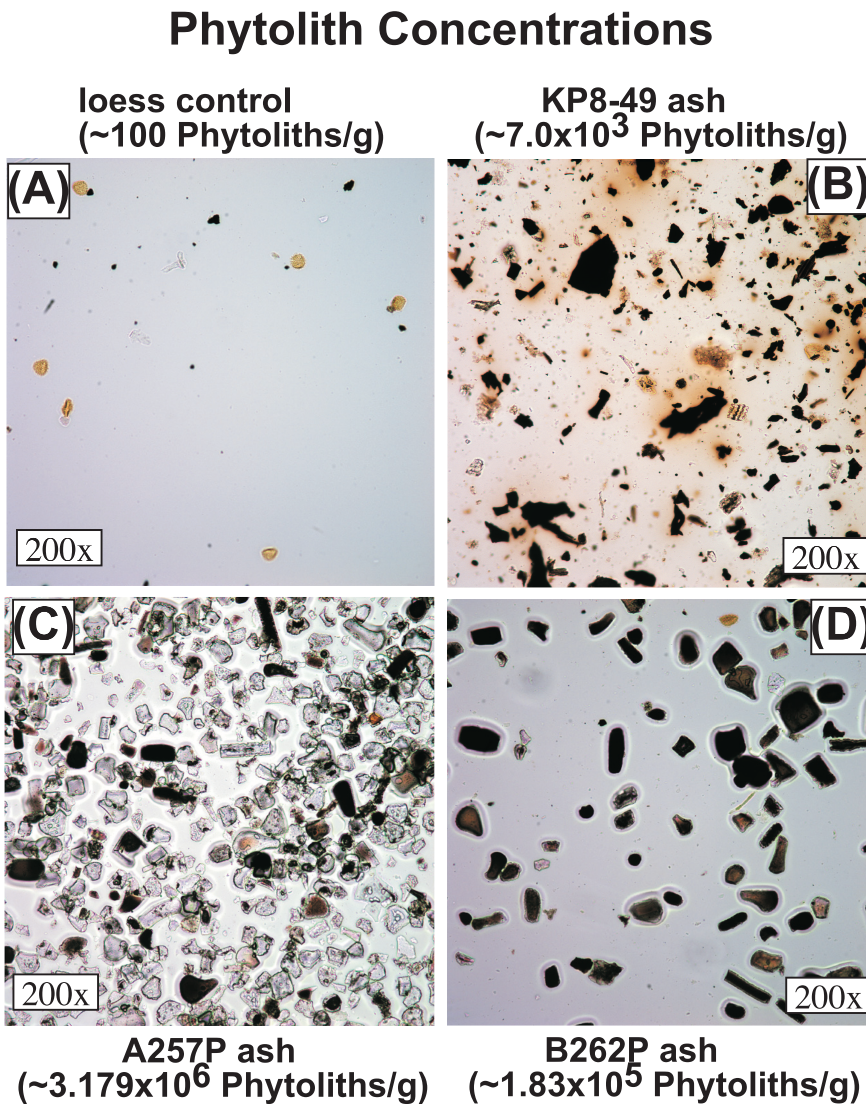

Figure 8. Phytolith (microscopic plant biosilicate (SiO_2) structural elements) concentrations in 2 selected LSU Campus Mound ash lenses (8C–D), a Pleistocene loess terrace control sample (8A), and sample (8B) used for comparing phytolith concentrations from cooking fires at an archaeological site within Konispol Cave in Albania, to the very hot reed and cane fires within the LSU Campus Mounds. Note that the LSU Campus Mounds phytolith concentrations are $>1x10^5$ pytoliths per gram of sediment in all measured mound ash lens samples (C–D; table 1); these represent the residue of the reed and cane plants that were burned. Photographs taken with an Olympus B41 transmitted-light microscope (200x) of a typical phytolith assemblage recovered from all four samples. Note the yellowish particles, easiest to see in (A) – these are the known *Lycopodium* spores added to tabulate the phytolith concentrations. Samples include, (A) a Pleistocene Loess Terrace control sample with ~100 phytoliths per gram of sample; (B) a Konispol Cave cooking fire sample, KP8-49, exhibiting $\sim 7 \times 10^3$/g of phytoliths, and char remaining due to the low-temperature wood cooking fires used there; (C) Mound A sample A257P reed and cane high-temperature fires exhibiting $\sim 3.179 \times 10^6$/g of phytoliths; (D) Mound B sample B262P exhibiting $\sim 1.83 \times 10^5$/g of phytoliths. Dark or black phytoliths indicate burned and discolored phytoliths in the ash lens samples from both LSU Campus Mounds, but the Konispol wood fires (B), were not hot and therefore the abundant char present was not destroyed, while in the extremely hot reed and cane LSU Campus Mound's fires (C and D), all burnable debris is gone except for very small bone or osteon fragments (table 1).

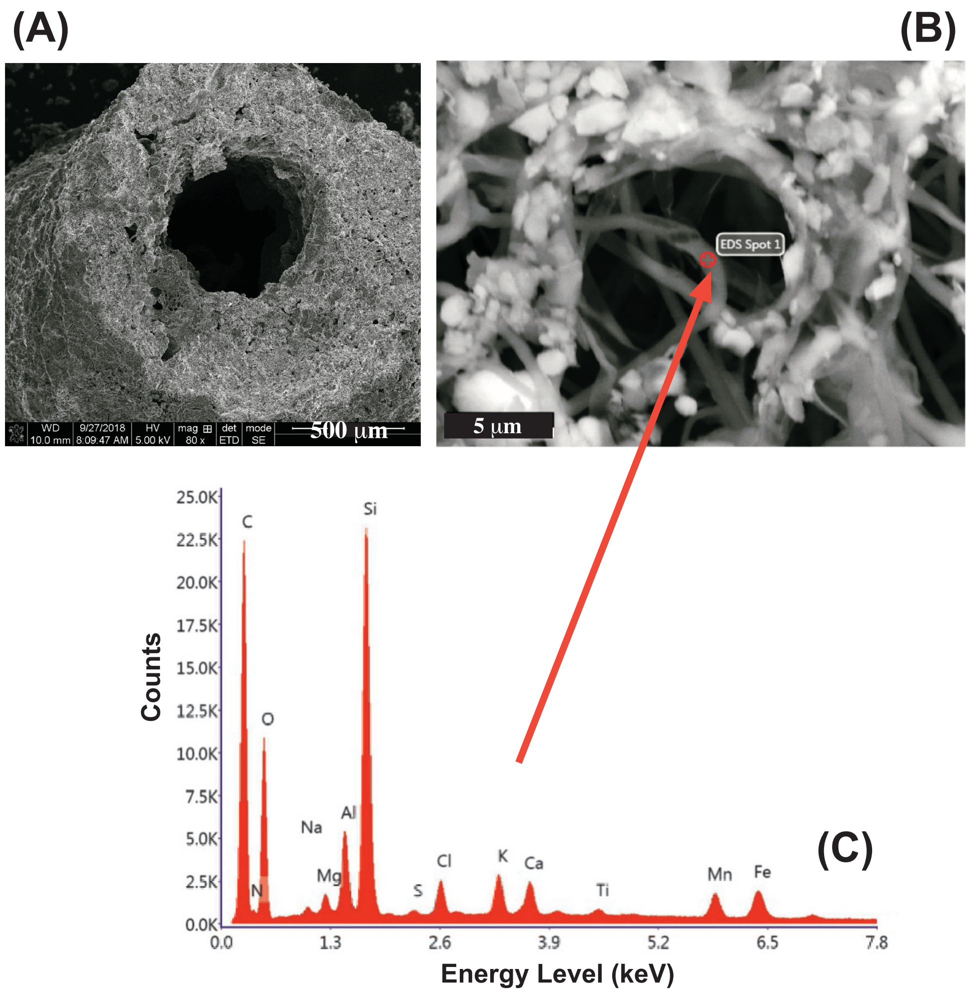

Figure 9. Osteons found within analyzed ash lenses from within both LSU Campus Mounds are burned bone fragments. Here, an SEM image of an osteon (large mammal bone structural element) is given at two different magnifications (A and B) and the chemistry determined. Note in (C) the C, K, and Ca elemental constituents (and others) are important bone elements. The high silica value represents phytolith and loess contamination.

magnetized so strongly within Mound A that these zones could be easily identified using a cesium vapor magnetic gradiometer system.

Cesium Vapor Gradiometer Surveys

The magnetometer surveys (fig. 5A) were performed using a cesium vapor gradiometer magnetometer, where two sensors were used, Sensor 1 at ~0.3 m above the ground, and Sensor 2 fixed at 2.0 m above sensor 1. Both sensors were fixed to a single, non-magnetic wooden shaft. Cesium vapor magnetometers are continuous reading systems that can be used to rapidly measure Earth's magnetic field variations over large areas. In this case, magnetic data from Sensor 1, close to each mound's surface and dominated by magnetic effects within the subsurface of the mounds, were automatically subtracted from Sensor 2 data, to eliminate magnetizations dominated by

(A)

(B)

Figure 10. (A) LSU Campus Mounds B and A photo (looking ~north) before removal of the Bois d' arc (Osage Orange) tree that was located on the eastern flank of Mound B, where it caused some damage to Mound B. (B) The Lavonia Mound in Lavonia, La. Note the tree growth and deformation (bioturbation) after the upper part of the mound was abandoned. Also note that the lower flanks of the Lavonia Mound are maintained by mowing, and thus inhibiting further deformation.

Earth's main-field and diurnal magnetic effects. Magnetic anomaly maps for both mounds were developed (fig. 5A) and a magnetic anomaly in Mound A was chosen for core placement and for the excavation performed on Mound A (fig. 6). The cesium vapor magnetic anomaly identified by the white square placed over Mound A (fig. 5A), was produced by burning, and the source of the anomaly was identified in the excavation performed on Mound A (fig. 6A). Magnetic anomalies of lesser magnitude are present throughout Mounds A and B (fig. 5A) and are possible targets for further excavation.

Electrical Resistivity Pseudosections

Electrical resistivity data collection from both mounds (fig. 7), used the four-probe Wenner configuration method, where probe spacing during data collection remained constant, and the array was moved along a profile line and data collected at 0.5, 1.0, 1.5, 2, 2.5 and 3.0 m spacings. These probes were connected through electrical cables to the measuring instrument. After measurement the resistivity data were calculated using the equation,

$$\rho_a = 2\pi \, DR, \tag{1}$$

where 2π is a geometric factor, D is the distance between the electrodes, and R is the measured resistance for each data acquisition point. These data for each measured line were used in calculating the pseudosections (cross-section contour maps) from the measured data, depth versus distance along each line (fig. 7). Interpretation of these datasets indicates that the internal part of Mound A is somewhat disturbed due to the thixotropic nature of the sediment from which Mound A was built. One result of the water saturation levels within Mound A was that the resistivity values showed somewhat higher conductivities than were expected. During coring and the ground penetrating radar work, it was determined that Mound A has a perched water table lying within the mound, and an analysis of the sediment recovered from the Mound A core indicated a thixotropic character, possibly explaining why the electrical dataset from Mound A does not exhibit a well-defined mounded pattern. The Mound A chaotic pseudosection (fig. 7A) contrasts strikingly with Mound B, which exhibits a relatively uniform character (fig. 7B), and which mirrors the internal, platform shape of the mound, showing resistivity values decreasing with depth within Mound B. These lower resistivity values at depth are interpreted to indicate higher clay concentrations within the Mound B redeposited loess, from which Mound B was built.

Phytolith Dominated Ash Layers

In LSU Campus Mounds A and B, the light colored layers are observed to be huge concentrations of burned reed and cane plant phytolith residues that accumulated in vast numbers, containing $>10^6$ phytoliths per gram in most of these layers. These well-defined burned ash layers observed within the cores, are shown here to contain high concentrations of discolored and nearly opaque phytoliths, the biosilicate (SiO_2) structural elements formed in most plants. As discussed above, there are at least 8 of these phytolith-rich layers in the Mound B core and 7 in the Mound A core. However, these layers have been previously interpreted as natural E (eluviation) soil horizons (Homburg, ms, 1991). To test this interpretation, phytoliths were extracted from several of the gray layers observed in the Mound B core (fig. 2, Mound B). Distinct phytolith morphologies can be used to distinguish plants by family, subfamily, genus and occasionally species. They are particularly useful in differentiating grass subfamilies, namely Pooideae, Panicoideae, Arundinoideae, Bambusoideae, *etc.* (Twiss and others, 1969; Piperno and Pearsall, 1998; Chen and others, 2020). In the case of the LSU Campus Mounds, 90 to 98% of the extracted phytoliths are from reed and cane plants. To get such high concentrations of reed and cane plant phytoliths, it would have been necessary to burn huge amounts of these plants. Only 2 to 10% of phytoliths in these layers represent plants other than reed and cane. The fires must have been very hot, due to the fact that the occluded carbon within the phytoliths, in many instances, have been burned black, requiring fire temperatures greater than 300°C (Epstein and others, 1977). This black discoloration was first identified in occluded carbon contained within conodonts, microscopic silicate animal teeth found

within ancient marine limestone samples, but the mechanism discoloring the mound's phytoliths was burning, and not geologic time as was the case for conodonts.

The concentrations of phytoliths in Mound A and B ash samples is very high, thus producing the light lenses observed in figure 2. For comparison to natural soil horizons, phytoliths were extracted from a loess control sample located ~3 km north of the LSU Campus (table 2; fig. 8A). Concentrations were 100 phytoliths per gram of sediment in the natural control sample, but >1x10^5 phytoliths per gram in all the light-layer samples examined for phytoliths from Mounds A and B, with one sample from Mound A containing >3 x10^6 phytoliths per gram of sample (fig. 8C).

Natural soil formation processes associated with soil horizons O, A, E, and B, could not have produced the phytolith concentrations observed within these mounds, especially when 8 such layers are identified in Mound B over a depth interval of just 6.5 m. If these were natural E horizons, which are not often found because of the long time periods necessary to isolate the silicates in an E horizon, then the question needs to be asked, where in the cores are the associated O, A, and B soil horizons that would be evident if these light layers are dominated by reed and cane phytoliths and are simply E soil horizons? Given that these concentrations are dominated by reed and cane plants, and that these plants grow in shallow, near-shore lake marshes, then these mounds, which are located on the high, Pleistocene Loess Terrace, would have had to have been submerged in fresh water for long periods of time, in order for the reed and cane plants to die and recover through their natural annual growth cycles. In addition, the phytoliths observed in an E horizon, would not have been burned. Clearly, there is no evidence for flooding of these mounds, indicating that the phytolith layers reported here are not natural E soil horizons.

Phytolith Identification and Extraction

Phytoliths are microscopic biosilicate (SiO_2) structures that precipitate in microcavities in a plant's stems, roots, leaves, etc., mostly between the various cells. The precipitated silica takes the shape of the microcavities. Unlike pollen and spores, phytoliths can withstand oxidation and fire at temperatures below 1,700°C, so they are typically studied at archeological sites when evidence of fire is found and most other microorganisms and particles are oxidized and destroyed by fire (Piperno, 1988; Albert, and others, 2000; Boyd, 2002; Parr, 2006). As the result of this burning, the phytoliths are concentrated. The samples presented here come from 5 burned layers, from core samples B133P, B246P, A257P, B262P, and one loess control sample.

Archaeological work within Konispol Cave in Albania provides a useful example of the phytolith record associated with cooking fires (Petruso and others, 1994; Ellwood and others, 1997). To contrast cooking fires, where the meat is cooked to be eaten and not destroyed, versus cremation-level heat generated by burning reed and cane plants, phytoliths from ancient, stacked known cooking fires excavated in Konispol Cave, are shown in table 2 and in fig. 8B, sample KP8-49. For comparison, we use here the stacked ash lenses in Konispol Cave, Albania, as an analog for ash lenses found in cooking fires. Because the Konispol phytoliths are from wood cooking fires, the number of phytoliths from the Konispol sample was only 7,239 per gram. These fires were significantly cooler than reed and cane fires, and as a result a large charcoal residue remains in the Albanian heaths (fig. 8B). In contrast, the LSU Campus Mound's ash lenses are very clean and much richer in phytolith residues (figs. 6B and 8C, D; table 2).

Phytoliths were separated and extracted via the following processes. Approximately 10 g of sediment was broken into pea-size pieces. The samples were then placed in bleach for 12 hours. Hydrogen peroxide was added, and the solution was heated on a hot plate for 2 hours and rinsed with distilled water until neutrality

was achieved. A 10% HCl acid solution was then added to the residue to remove carbonates and rinsed four times with distilled water after the reaction ceased. Clays were removed from the residue by first sieving through a 150-micron sieve, and then by adding Calgon to the fraction smaller than 150-micron. The solution was then decanted every two hours as many times as needed to remove the clays. The final step focused on separating the geological silicates from the biosilicates, each with a different specific gravity. To do this, the residue was placed in a 12 ml centrifuge tube and lithium metatungstate was added to the residue. The new solution remains essentially neutral and has a low viscosity. The centrifuge tubes were then centrifuged at 1000 rpm for 10 minutes. The float, that contains the bioclasts, was decanted and rinsed with distilled water. The bioclastic fraction that was destined for dating was later sent to the geochemical laboratory. The fraction destined for microscopic analyses was pipetted off and mixed within one drop of polyvinyl alcohol with a glass-stirring rod. When the polyvinyl alcohol residue dried, one drop of clear casting resin was added, and the cover slip was turned and sealed. Permanent curing occurred in about one hour. A known quantity of *Lycopodium* spores was added to the samples processed for taxonomy to compute concentrations. Then the residues were scanned for phytolith remains using a 20x objective.

Phytolith concentration in each sample was calculated using the Benninghoff equation,

$$C = (Pc \times Lt \times T)/(Lc \times W) \quad (2)$$

where, C = concentration (per gram of dried sediment), Pc = the number of phytoliths counted, Lt = the number of added *Lycopodium* spores per tablet, T = the total number of *Lycopodium* tablets added per sample, Lc = the number of *Lycopodium* spores counted, and W = the weight of the dried sediment processed (Benninghoff, 1962). The Lycopodium batches used were *Batch 3,862 and 1,031*, with the amount of spores per tablet equal to 9,666 and 20,848, respectively. One tablet was used per sample. The summary of the results can be found in table 2.

The phytolith samples analyzed have a much higher concentration than do control samples, with $\sim 4.61 \times 10^5$ phytoliths per gram of dried sediment for mound sample B246, $\sim 3.179 \times 10^6$ phytoliths per gram for mound sample A257P, and $\sim 1.83 \times 10^5$ phytoliths per gram for mound sample B262P (fig. 8B–D). Phytolith concentrations were extremely low in the loess control sample, at $\sim 1.0 \text{x} 10^2$ per gram (fig. 8A), while all other phytolith lenses analyzed produced $>1.0 \text{x} 10^5$ phytoliths per gram of sample. Sample B262P is further differentiated from the other two phytolith layers given in figure 8B and 8C, because of the difference in oxidation. In phytolith lenses B246 and A257P, the phytoliths are mainly colorless and almost transparent, with only a few that are dark brown to black in color, indicative of some burning. In sample B262P, all phytoliths have an unusually dark brown to black coloration, which is typically the result of prolonged exposure to intense fire. This sample was from the unusually thick phytolith layer (0.34 m thick) identified at the base of the Mound B core (fig. 2).

Mound excavation yielded a significant amount of phytoliths ($>1.0 \text{x} 10^5$ per gram), with bulliform ('fan-shaped' and blocky), smooth, echinate and dendritic long-cells, and trichomes constituting 90 to 98% of the assemblage in samples B133, B246, B262P, A257P and A.EXC (figs. 6 and 8; table 2). Sample A257P differed slightly from the other ash samples, with 85% of the assemblage dominated by bulliforms ('fan-shaped' and blocky), smooth and echinate long-cells, and trichomes. Both bulliforms and long-cells are formed in the leaves and husks of grasses and are not generally diagnostic. However, high proportions of fan-shaped bulliforms have been linked to water-tolerant grasses, particularly those in the Arundinoideae (for example,

Phragmites spp. (reeds)) and Bambusoideae/Oryzoideae subfamilies (for example, *Arundinaria gigantea* (giant cane), *Zizania aquatica* (wild rice)) (Bremond and others, 2005; Weisskopf and others, 2014; Chen and others, 2020). Squat and flared edge 'fan-shaped' bulliforms in the samples further suggest the presence of common Gulf Coast reeds and wild rice, respectively (morphology based on Lu and others, 2006; Piperno, 2006).

In contrast, grass short cells were very rare (1–2%) in Mound B samples, with plateau saddles and rondel (flat tower) morphotypes noted (Mercader and others, 2010). Grass short cells are less robust than bulliforms and are more susceptible to post-depositional processes and preservation (Cabanes and Shahack-Gross, 2015). The Mound A sample A257P, had a higher diversity and percentage of grass short cells (10–15%), including tall saddles and plateau saddles, rondels, and bilobates (<1%). The plateau and tall saddle and rondel morphotypes, support the presence of hydrophilic grasses (Piperno and Pearsall, 1998; Lu and Liu, 2003; Tedford, ms, 2009). Sample A EXC (fig. 6B; table 2) differed from other samples due to the presence of sinuous trapeziform (3%) morphotypes in addition to rondels and squat saddles. This morphotype is formed in wetland grasses (that is, *Phalaris caroliniana* – Carolina canary grass, *Avena sativa* – wild oats) in the Pooideae subfamily (Lu and Liu, 2003; Tedford, ms, 2009) and further supports the dominance of hydrophilic grass-types in Mound A sediments.

SEM-EDS analyses

Particles of burned bone (mainly osteons) were picked from the LSU Campus Mounds samples and mounted onto SEM stubs for further analyses. First, the particles were photographed using LSU's Shared Instrumentation Facility's Quanta™ 3D Dual Beam™ FEG FIB-SEM that combines a Focused Ion Beam (FIB) with a high-resolution Field Emission Gun Scanning Electron Microscope (FEG-SEM). As a second step, particles were analyzed using the integrated EDAX Pegasus EDS & EBSD system in order to obtain the chemical composition of the selected bone fragments. These results are given (fig. 9) and discussed in the section *Interpretation of Phytolith Data*.

RESULTS

Ages Overview

Phytoliths incorporate occluded carbon within their structure, which remains after plant decay or burning. Therefore, phytoliths can be used for radiocarbon dating (Piperno and Pearsall, 1998; Parr and Sullivan, 2005; Piperno, 2016). Reed and cane plants dominate the phytoliths observed in the LSU Campus Mounds, and their source to Indigenous People would have been the marshes of nearby freshwater lakes where these plants grow and die annually. The ages of mound building for the LSU Campus Mounds may indicate timing of either ceremonial or possibly cremation activity. Thirty samples from the mounds and two samples from the Pleistocene loess terrace on which the mounds sit, were sent to Beta Analytic for AMS ^{14}C dating (fig. 11; table 1). All dates reported here are calendar ages relative to present (1950 CE), with 2σ uncertainties. The mean age for the two Pleistocene loess samples is *ca.* 13,000 BP. All but two sample dates below 3.7 m in both mounds (A1, B1 in fig. 11), are greater than *ca.* 8,200 BP. These ages alone are older than any other known standing man-made structure in the Americas. Ten samples were collected from the Mound A core and from an excavation on Mound A and dated (fig. 11). Three of these samples lie in the upper part (A2) of Mound A, above 3.7 m in Core A (fig. 11). Note that Core A was offset from the center of Mound A (fig. 7A) by ~2.5 m. This location was chosen to test the magnetic anomaly at that location, which had been identified during the

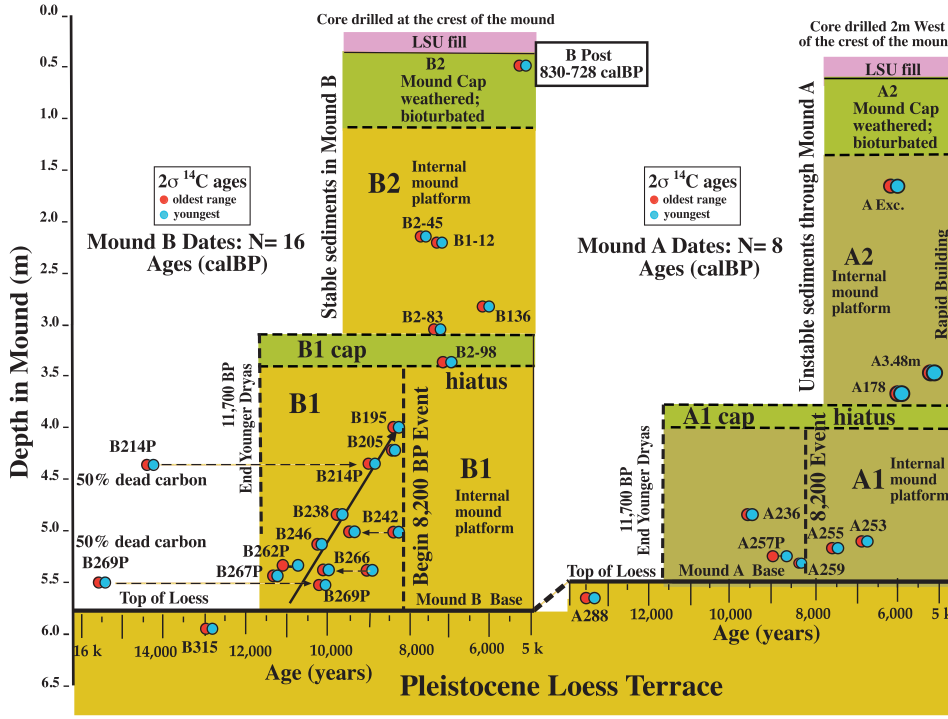

Figure 11. Age (calBP) relative to depth for the Pleistocene Loess Terrace, and North to South locations of LSU Campus Mound's, levels B1, B2, A1, and A2. ^{14}C 2σ ages from Beta Analytic for the LSU Campus Mound ash lenses and other sampled material (table 1), collected from cores extracted from Mound A and Mound B (fig. 2). Timing for the end of Younger Dryas (YD) at 11,700 BP and the 8,200 BP Climate Event are also indicated (black vertical dashed lines). Note that all dates in B1 are older than 8,200 BP, and there is a general linear age/depth trend in the B1 dates. Also indicated is the top of the Pleistocene Loess Terrace relative to the LSU Campus Mound's bases. Red (oldest) and Blue (youngest) dots indicate ^{14}C 2σ age ranges for each sample presented here (table 1). Anomalous dates are attributed to bioturbation or caused during mound building in Mounds A and B, or these may be due to modern carbon from burrowing trees or organisms and are found in the anomalous samples section in table 1. Samples B1-12, B2-45, B2-83 were collected ~2 m to the south of the crest of Mound B. Five anomalous samples in table 1 are not included in figure 11 but are discussed in the text. Note that samples B214P and B269P are corrected for dead carbon contamination, and samples B242 and B266 are corrected for modern carbon contamination.

cesium vapor gradiometer magnetometer survey (fig. 5A). Mound A2, the upper part of Mound A (figs. 3 and 11), is interpreted to have been built beginning at *ca.* 6,096 BP and ending at *ca.* 5,053 BP (table 1), and it covers an earlier structure, Mound A1, buried beneath it (figs. 3 and 11). Six samples were dated from within Mound A1, with dates ranging in age from 9,591-6,797 BP, at depths from 4.57 m to 5.32 m (figs. 3 and 11), with one anomalous sample, A221P exhibiting an age of 11,140–10,761 calBP (table 1). Sample A221P is discussed in the section *Age Anomalies,* due to its anomalous stratigrphic position within Mound A1. Below the base of the core, a single sample was collected and dated from the Pleistocene loess terrace on which the mounds were built, with a mean age of *ca.* 13,354 calBP (sample A288; fig. 11).

Samples from Mound B were collected from Core B, which was centered on LSU Campus Mound B (fig. 3), and from two smaller diameter (~0.02 m) cores, one from the crest of Mound B, and one from ~3 m to the south along Mound B's sloping side

(fig. 11). Twenty-two samples from Mound B were dated (table 1). Five of these were collected from the upper Mound B2, above ~3.1 m in the main Core B (fig. 11).

Most of the ages from Mound B1, below 3.9 m depth, show an age-stratigraphic linear trend (fig. 11), beginning near the base of Mound B in Mound B1 at *ca.* 11,300 BP, and extending upward through the Mound B1 cap and into Mound B2 at ~3.0 m, a systematic age-stratigraphic trend that includes 11 samples (fig. 11; table 1). Of these samples, two (B269P and B214P) were initially excluded from figure 11, but were given in table 1, due to their extremely anomalous dates that are older than the Pleistocene Loess Terrace. Excluding samples B269P and B214P, Mound B1 has a reasonable, linear distribution of dates ranging from sample B267P at 11,316–11,228 calBP to sample B195 at 8,408–8,325 calBP. Above that in Mound B2, there are 4 dates shown (fig. 11) ranging in age, for B2–45, from 7,795–7,669 calBP, to B136 from 6,185–5,991 BP (fig. 11; table 1). Sample B2–98, from 7,165–6,980 calBP lies within the B1 Cap and falls along the date trend within Mound B1.

Also anomalous are two dates from the B1 cap, samples (B168 and B153, table 1). Given that these samples are from within the transitional and disturbed B1 cap, those dates were susceptible to bioturbation and acquisition of older carbon contamination. The third date in the B1 cap, B2-98 (fig. 11) appears not to be disturbed. This sample is transitional between Mound B1 and B2.

Because reed and cane plants produce a new crop annually in isolated shallow lakes, like those that exist today on the Pleistocene Loess Plateau on which the LSU Campus is built, after the plants die, their decay produces young carbon that is captured by each new reed and cane annual crop. This then constrains the phytolith dates given here, to primarily young carbon phytolith dates, reflecting the age of the reed and cane phytoliths recovered from the LSU Campus Mounds. These phytolith dates are represented by sample numbers having a ‘P’ after the number in figure 11 and in tables 1 and 2. Here we report a total of 7 phytolith dates out of the 31 dates given in table 1. These phytolith dates include three out of 9 samples from Mound A (table 1) and four out of 22 samples from Mound B (table 2). Most, but not all of the dates in Mound B are consistent with the age-stratigraphic trends shown here (fig. 11).

Interpretation of the ^{14}C ages requires consideration of the source of dated carbon. The source of water into these lakes is rainfall and groundwater from the Pleistocene Loess Terrace. Therefore, the major source of carbon found in the mud in which these plants are growing today, is contributed to by the reed and cane plants that die annually and decay, with these annual plants providing a small source of carbon that flows through the plant’s root systems. Most of the carbon found in reed and cane plants comes through photosynthesis. However, Olson and Broecker (1958, their fig. 2) have shown that contamination of the samples with “dead” carbon can produce a significant increase in the measured ^{14}C age. Thus, carbon contamination by dead carbon seems to be a highly likely explanation for the antiquity of the anomalous old measured ^{14}C ages shown in table 1. Therefore, an expected 10,000 year old date, if contaminated by old dead carbon, would need to have had 5% dead carbon to produce an age of 10,400 BP, 10% dead carbon to produce an age of 10,800 BP, and if ~50.0% of all the carbon in the sample is dead carbon, this would produce an age of 15,500 calBP, the age given by sample B269P (table 1). Table 3, used and provided by Beta Analytic, illustrates the progression of age discussed above, when samples are contaminated by dead carbon. This ‘dead carbon’ problem is illustrated in figure 11 by two samples, B269P (initial age at 15,740–15298 calBP) and B214P (initial age at 14,983–14,250). Using table 3, these outlier samples were projected (horizontal dashed arrows toward the right in fig. 11) to ~10,000 BP for sample B269P and ~9,000 BP for sample B214P (fig. 11). These results are consistent with the data in Olson and

Table 3

Approximate age after contamination with Modern (1950 AD) carbon on the sample age

True Sample Age	1% Modern	5% Modern	20% Modern	50% Modern
900 BP	890	850	700	400
5,000 BP	4,950	4,650	3,700	2,100
10,000 BP	9,600	9,000	6.800	3,600
20,000 BP	19,100	10,600	10,600	5,000
30,000 BP	27,200	12,200	12,200	5,400
100,000 BP	37,000			

Approximate age after contamination with OLD (Radiocarbon Dead) carbon on the sample age

True Sample Age	5% OLD	10% OLD	20% OLD	50% OLD
500 BP	900	1,300	2,200	6,000
900 BP	960	1,770	3,200	6,630
5,000 BP	5,400	5,800	6,700	10,500
10,000 BP	10,400	10,800	11,700	15,500
20,000 BP	20,400	20,800	21,700	25,500

Source: Beta Analytic (Ron Hatfield, personal communication).

Broecker (1958, their fig. 2). Given the source of carbon discussed above for reed and cane plants growing in freshwater swamps on the Pleistocene Loess Terrace, it is clear that any contamination by dead carbon would have come from dead carbon within the Pleistocene Loess Terrace sediment. This sediment was derived from the Canadian Ice sheets that generated, by grinding the rock surface, melting, and producing the loess out-flow that was picked up and deposited along the Mississippi River valley as Pleistocene Loess Terrace sediments, some of which contained dead carbon.

Table 3 also illustrates age problems when there is contamination by modern carbon. Two samples, B242 (8,428–8,359 calBP in table 1) and B266 (9,134–8,999 calBP in table 1) show relatively young ages, given their stratigraphic height in the core. When a correction from table 3, due to modern carbon contamination is applied, then both samples move to the left, closer to the line of correlation (solid arrow) in figure 11, with B242 exhibiting a corrected age of ~9,600 BP, due to 1% modern carbon contamination, and with B266 exhibiting a corrected age of ~10,000 BP, due to 5% modern carbon contamination (table 3). These results are also consistent with the data presented by Olson and Broecker (1958, their fig. 2).

Age Anomalies

Six samples were collected and dated from Mound A1, below 4.3 m depth in Core A (fig. 11), but one sample A221P (^{14}C conventional date; table 1) appears to be anomalous because it is too old (10,980–10,768 calBP) for its stratigraphic position, with a height of 4.57 m in Mound A1 (table 1). Sample A221P in Mound A may have been contaminated during construction of the mound or be the result of the thixotropic nature and internal disturbance within that mound. In fact, the thixotropic character of the sediment within the mound may be the main cause of a broad, internal redistribution of samples collected and dated from Mound A. However, there is another cause, and this is addressed below.

Samples collected and dated from Mound B, included nine samples from Mound B1, below ~4.0 m depth in Core B (fig. 11). Two samples, B168 and B153 (^{14}C conventional dates) (fig. 12; tables 1 and 2), appear to be anomalous because they are too old for their stratigraphic position. Samples B168 and B153 are conventional dates that lie within the B1 Cap that was abandoned for a long period of time and was susceptible to bioturbation and burrowing while the cap of Mound B was exposed. These sample's older dates are attributed to burrowing roots and animals bringing older sediment to the surface within the Mound B1 cap, and this older carbon skewed these samples toward older ages. Other causes may have been contamination during coring, or post-construction disturbances that occurred after the phytolith layers were produced by burning.

Phytolith Date Problems

Seven phytolith-rich samples were chosen for ^{14}C dating. Of these, two, A257P and B267P had a reliable amount of carbon to allow for a $\delta^{13}C$ evaluation of the sample. Five of the other samples (A221P, B214P, A236P, B262P and B269P) were low in carbon extracted from the phytoliths and therefore the $\delta^{13}C$ evaluation was not possible (N/A in table 1). However, one of the N/A labeled phytolith dated samples did have additional carbon from identified bone/osteon fragments within that sample (B262P, table 1), and the ^{14}C date was consistent with the overall ^{14}C sample trend in Mound B1.

Age Summary

The ^{14}C ages for carbonaceous materials in the phytoliths give consistently old ages, that are much older, by at least 4,000 years than existing ages for the oldest standing mound structures elsewhere in the region, which are widely considered to be 7,400–7,325 2σ calBP (Jones and Brookes, 2017). When testing this hypothesis, it was necessary to consider the analytical uncertainties for the measured ages. In general, given the age trends in Mound B (fig. 11), there is a systematic increase in age with depth in core, with slight variations in samples as is normally expected.

Overall, most of the sample's dates are consistent with the general trends that are clear in Mound B (fig. 11). Some of the variations within the data are interpreted to represent contamination from either a burrowing animal or tree root penetration into the Pleistocene Loess Terrace during the time when Mound B was built. Trees growing on the mounds in Louisiana are a common sight (fig. 10B), and the last one growing on LSU Campus Mound B, was removed by LSU in 2010 (fig. 10A).

T-Test on the Radiocarbon Ages

To compare the ages of the material above and below the ash layers in LSU Campus Mounds A and B, an independent one-tailed T-test was performed on the radiocarbon ages. In Mound A, the 6 dates ($M = 7,743$ conventional years BP, $SD = 1,272$ years) below the ash layer but above the loess in Mound A1, were significantly older than the 3 dates ($M = 5,040$ conventional years BP, $SD = 427$ years) in the undisturbed zone above the ash layer in Mound A2, where $t\ (7) = 3.48$, with $p = .0055$. In Mound B, the 10 dates ($M = 9,352$ conventional years BP, $SD = 1,958$ years) below the ash layer but above the Mound B1 loess were significantly older than the 6 dates ($M = 6,786$ conventional years BP, $SD = 2,834$ years) in the undisturbed zone above the ash layer in Mound B2, where $t\ (14) = 2.85$, with $p = 0.0064$. In summary, for both Mound A and B we find that deeper layers are significantly older than the shallower layers. This is consistent with our model in which there are two episodes of LSU Campus

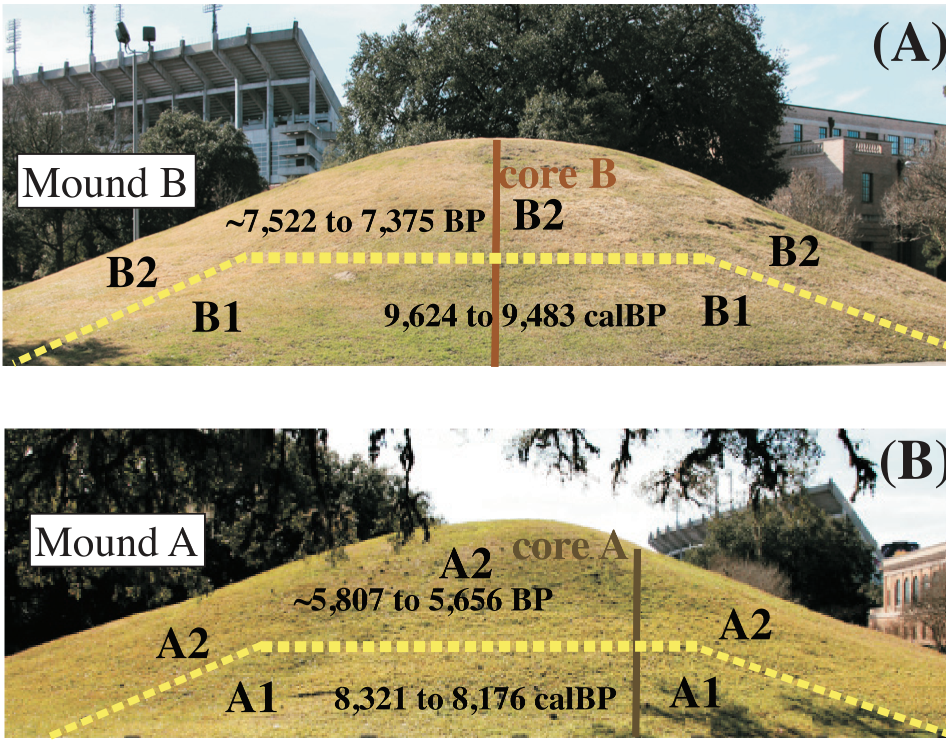

Figure 12. Overview, looking southwest, over the two LSU Campus Mounds that are Paleoindian in age, 11,500 to 9,000 BP (Walter M. Beecher, Louisiana Heritage Museum, LSU). Given are the estimated boundaries for internal Mounds B1 and B2 (table 1), with the core centered on the mound; and a similar summary of ages for internal Mounds A1 and A2 (table 1), with the core offset to the west and centered over the magnetic anomaly in Mound A (fig. 5).

Mound building, A1 and B1, separated by an hiatus in each mound, identified as A1 cap and B1 cap (fig. 11).

In summary, the LSU Campus Mounds were built by Indigenous People. They did this in part by carrying large quantities of dry reed and cane plants onto a flat-prepared (platform) sediment surface, on the growing LSU Campus Mounds. The plants were piled there and ignited, thus producing extremely hot reed and cane fires that left only refractory materials behind, and darkened phytoliths (fig. 8C and 8D); those refractory materials include high concentrations of phytoliths. These fire events were intermittent as indicated by the alternating darker sediment layers below and on top of the burned reed and cane ash layers, producing alternating high/low/high magnetic susceptibility values in the alternating phytolith/sediment layers (fig. 6 A through D).

DISCUSSION

Physiographic Location of the LSU Campus Mounds and Relation to Climatic Events

Reconstruction of the lower Mississippi River Valley paleogeography at the beginning of the Holocene (Kesel, 2008; Bentley and others, 2016) shows that the LSU Campus Mounds were located on a Pleistocene-age terrace, covered with a thin layer (5–10 m) of late Pleistocene loess. This terrace overlooked a narrow shoreline and

estuary (fig. 1A) that filled the Mississippi River valley at the time construction of the LSU Campus Mounds began, *ca.* ~11,000 BP, a time when climate moderated after the Younger Dryas cold event ended at *ca.* 11,700 BP (Walker and others, 2018). Dates indicate that burning reed and cane plants on the LSU Campus Mounds continued for ~3,500 years (fig. 11), at which time there was a hiatus in mound building activities on both Mounds A1 and B1 (figs. 3 and 11). This time is essentially coincident with onset of the 8,200 Climate Event, a time when global climate radically changed (Rohling and Pälike, 2005; Alley and Ágústsdóttir, 2005). The impact of this change appears to have been the impetus for the departure of the LSU Campus Mound builders from the region at ~8,200 BP. Because this event was so severe, it is now used to define the end of the Greenlandian Stage of the Holocene and the beginning of the Northgrippian Stage (Walker and others, 2018). This climate change may explain why construction of both LSU Campus Mounds ceased for *ca.* 500 to 1,000 years after the 8200 Event, especially if rapid filling and changing salinities in the Mississippi Valley Estuary (fig. 1A), in conjunction with climate deterioration, would have dramatically impacted the ecology near the LSU Campus Mound's site, and thus food resources. For instance, a study of a similar site on nearby Baffin Bay along the Texas Gulf of Mexico coastal area saw the coast flooded and its oyster beds migrating 15 km inland as a consequence of the 8200 Event (Ferguson and others, 2018). The event is also identified elsewhere in Texas (Ellwood and Gose, 2006). In addition, at ~8,000 BP there was a significant shift to the west of the Mississippi River (Roberts, 1997; Kesel, 2008), that would have had a major impact on resources available at the LSU Campus Mounds site, which could have led to the abandonment of the region. It is interesting to note that in Tennessee, there is also a *ca.* 8,200 BP age offset (hiatus) reported for ^{14}C dates from shell middens there (Bissett, ms, 2014). Later, in Louisiana at ~6,000 BP, sea level stabilized at essentially modern levels (Donoghue, 2011), possibly explaining why the second mound-building phase, A2 and B2 (figs. 3 and 11), occurred. Overall, these regional observations suggest that the first phase of mound construction occurred while the valley was an open estuary, and the second phase occurred after the valley was largely filled by the late Holocene delta of the Mississippi River.

As recorded in Gulf of Mexico sediments, the last major melt-water flood, orders of magnitude greater than modern floods on the Mississippi River (Bentley and others, 2016), occurred at *ca.* 9,200 BP (Aharon, 2003). The lower parts of the LSU Campus Mounds, Mound B1 and possibly Mound A1 (figs. 3 and 11), appear to have been built before this time. From Late Pleistocene to Early Holocene time, the valley was first uplifted due to glacial loading from the North American ice sheet and then eroded by deglacial floods. Then the valley subsided due to deltaic sediment loading as the young Holocene Mississippi River Delta began to form at *ca.* 8,000 BP (Blum and others, 2008). The combined effect of these interacting processes allowed the emergent Mississippi River Valley to flood, creating a low-salinity estuary much like today's Mobile Bay, between *ca.* 12,000 BP and *ca.* 8,000 BP. During this time the shoreline may have been within several hundred meters of the Pleistocene Loess Terrace on which the LSU Campus Mounds were built (Saucier, 1994). After *ca.* 8,000 BP, the estuary was gradually filled with estuarine and deltaic sediment (Kesel, 2008). The lack of catastrophic floods after *ca.* 9,160 BP (Aharon, 2003) suggests that after this time, the estuary would have been more quiescent and potentially more ecologically productive. Overall, these regional observations suggest that the first phases of LSU Campus Mound construction (B1 and then A1) occurred while the valley was an open estuary, and the second phases (B2 and then A2) occurred after the valley was largely filled by the late Holocene delta of the Mississippi River.

Mound A Excavation

The Mound A excavation was initially offset to the west of the center of the mound to coincide with a large magnetic anomaly identified in the 2008 magnetic survey (fig. 5A). Modeling of this anomaly at that time suggested that it represented a heavily burned horizon at ~1.6 m within Mound A, and the excavation provided an opportunity to examine sediments responsible for the anomaly (fig. 6E). This work confirmed the source of the magnetic anomaly during the excavation. The South and East walls in the lower part of the excavation have a number of alternating burned/ash lenses (fig. 6A, E). The gray oval-shaped ash lens (ash bundle in fig. 6A, B) sampled in the South Wall, contains huge numbers of burned phytoliths ($\sim 2.51 \times 10^{-5}$ phytoliths/g; fig. 6B), and the alternating layers seen in the South and East walls exhibit typical alternating ash lenses above (low MS), with heated sediment below (high MS). This variation results in the typical burned cycles observed in the magnetic susceptibility data sets (figs. 4 and 6C–D). A *ca.* 6,100 calBP date was obtained from a charcoal fragment collected from one of the ash lenses (A-exc.) exposed in this LSU Campus Mound A2 excavation (table 1).

Interpretation of Phytolith Data

Very hot reed and cane fires can darken and even destroy almost everything in the fire, even the phytoliths, and often no char remains. It is this difference, between lower temperature cooking fires, and the very high-temperature reed and cane LSU Campus Mound ash residues, that are distinctive in the LSU Campus Mounds. These high temperature fires only contain a few microscopic fragments of burned bone that are interpreted to be osteons, the building blocks of large-mammal long bones, such as from horses, dogs, deer, and humans. Osteons were extracted from several of the dated ash lenses reported here (table 1; fig. 9). It is concluded that the burned bone in these ash lenses may be responsible for some of the dates in table 1. The presence of the osteons suggests that the ash beds in the LSU Campus Mounds were ceremonial or possibly cremation fires.

It might be argued that the Indigenous People responsible for building the LSU Campus Mounds, set fire to the accumulated underbrush in an area and then moved the ash that was produced up and onto the mounds. This hypothesis seems unlikely, because the reed and cane plant pytoliths found in the LSU Campus Mound's cores, grow in marshes, and burning them in place would not produce thick ash lenses. The relatively pure phytolith concentrations observed here could only be produced after stacking and burning large quantities of these plants, thus producing burned remnants as ash. The sediment layers, underlying the burned ash lenses, were clearly heated during the burning process, as identified in the Mound A excavation (fig. 6) and in the cyclic magnetic susceptibility data sets presented in figures 4 and 6D. During the microscopic search of the ash lenses found in the Mound B core, only a few osteons were found, because the fires were very hot, further indicating that the ash lenses were not cooking fires. It was not possible to determine if the osteons in the ash lenses are of a human or animal origin. We did request permission to perform DNA tests on the microscopic bone material found, but permission was denied by the Native American tribal communities that were contacted.

Timing of Mound Building

Figure 12 gives the mean ages for dates collected from each of the mound elements, B1, B2, A1, and A2. The mean age for dates from Mound B1 shows a range from 9,624 to 9,483 BP. This mean is ~1,000 years older than the mean age range for Mound A1, at 8,321 to 8,176 BP, which in Mound A1 is centered around the

beginning of the 8,200 event (figs. 11 and 12). We interpret these data to indicate that Mound B1 was built first, while Mound A1 was built after Mound B1 was complete. It is interesting to note that following building of Mound A1, Mound B2 was built, with an age range of 7,500 to 7,375 BP. Then, after ~1,500 years, Mound A2 was built, in age from 5,807 to 5,656 BP. These data appear to indicate that each mound segment was built at a different time from each of the others. Also note that Mound A2 was built more or less during the time that the Monte Sano mounds were built, with both the LSU Campus Mounds and the Monte Sano mounds pairs having an alignment of ~8° east of North, indicating some coordination between the Indigenous people who were building the two mound pairs.

ASTRONOMICAL ALIGNMENT

The uppermost A2 and B2 crests built during the final stages of mound building for both LSU Campus Mounds, shows a crest-to-crest alignment of ~8° east of north (fig. 5A). The final building is dated at ~7,600 to ~5,300 BP, during which time the final crest alignment was produced. During this time, the point where the bright red star Arcturus rose above the horizon would have been ~8° east of north. Arcturus is, and has been, one of the brightest stars in the sky. It is a reasonable hypothesis that the alignment seen for the crests of the LSU Campus Mounds A and B was a purposeful act on the part of the LSU Campus Mound builders. We believe that it is no accident that the crest alignment of the Monte Sano mounds pair, dated at 7,575 to 4,956 (Haag and Kuttruff, 2017), and located ~10 km north of the LSU mounds, but destroyed in 1967, appears to have had a similar ~8° east of north alignment (fig. 5B), and the timing is coincident with the building that was also taking place on the LSU Campus Mounds at that time.

CONCLUSIONS

The LSU Campus Mounds (16EBR6) (fig. 1A) appear to have been constructed in four stages (fig. 11), with Stage One (B1 in fig. 11) beginning at *ca.* ~11,000 BP on the Pleistocene Loess Terrace along the then Mississippi River Estuary (fig. 1A). The LSU Campus Mounds system has five stratigraphic phases, each capped by unconformities. First, Phase One, represents deposition of the Pleistocene Loess Terrace, followed by a hiatus in the latest Pleistocene. Then during the earliest Holocene, Phase Two, building of internal Mound B1, followed by a hiatus in deposition (B1 cap, fig. 11), and an interval of weathering and bioturbation at the top of internal Mound B1. Phase Three is represented by building of internal Mound A1 (fig. 11), which was also followed by a hiatus in deposition (A1 cap, fig. 11), and an interval of weathering and bioturbation. Phase Four is represented by the building of internal mound B2 (fig. 11), and Phase Five is represented by the building of internal mound A2 (fig. 11). After building of internal mound A2 was completed, the LSU Campus Mounds were no longer undergoing construction by Indigenous People. Given the ages for internal Mound B1 (figs. 11 and 12), the LSU Campus Mounds may represent the oldest known and still intact, man-made structures on Earth. At *ca.* 8,200 BP, LSU Campus Mound construction paused, possibly because of a major climatic event, beginning at *ca.* 8,200 BP, which destabilized the global ecological system that supported the Indigenous People living here, similar to what happened in nearby Coastal Texas at the same time. Then ~2,500 years thereafter, following the Phase Five final mound's building event, the LSU Campus Mounds were abandoned by the Indigenous people for good.

Dates from the LSU Campus Mounds were obtained from archived samples of ash lenses that have clearly been burned. Evidence of burning was: (1) extremely high concentrations of reed and cane phytoliths that are the main residue of the very hot

fires produced by burning large amounts of reed and cane plants; (2) blackened and discolored phytoliths in the ash lenses; (3) microscopic fragments of burned bone/ osteons found in the dated ash lenses (fig. 9); (4) alternating darkened sediment and phytolith layers in the Mound A excavation (fig. 6); (5) magnetic susceptibility data giving high values in burned sediment and low values in ash lenses (figs. 4 and 6); and (6) the large magnetic anomaly centered over an area in Mound A that was clearly burned multiple times (fig. 5A). Given that these were not cooking fires, our interpretation is that these were very hot ceremonial or possibly cremation fires containing a few, very small osteons, that may have been human bone. While material was available for DNA analysis, requests to tribal groups to do this work were rejected. Therefore, in consideration of these objections, we were not able to test the hypothesis that the microscopic burned bone fragments are human bone osteons.

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REFERENCES

Aharon, P., 2003, Meltwater flooding events in the Gulf of Mexico revisited: implications for rapid climate changes during the last deglaciation: Paleoceanography, v. 18, n. 4, https://doi.org/10.1029/2002PA000840

Albert, R. M., Weiner, S., Bar-Yosef, O., and Meigan, L., 2000, Phytoliths in the Middle Palaeolithic Deposits of Kebara Cave, Mt Carmel, Israel: Study of the Plant Materials used for Fuel and Other Pursposes: Journal of Archaeological Science, v. 27, n. 10, p. 931–947, https://doi.org/10.1006/jasc.2000.0507

Alley, R. B., and Ágústsdóttir, A. M., 2005, The 8k event: cause and consequences of a major Holocene abrupt climate change: Quaternary Science Reviews, v. 24, n. 10–11, p. 1123–1149, https://doi.org/10.1016/j.quascirev.2004.12.004

Arco, L. J., Adelsberger, K. A., Hung, L. Y., and Kidder, T. R., 2006. Alluvial Geoarchaeology of a Middle Archaic Mound Complex in the Lower Mississippi Valley, U.S.A.: Geoarchaeology, v. 21, n. 6, p. 591–614., https://doi.org/10.1002/gea.20125

Benninghoff, W. S., 1962, Calculation of pollen and spore density in sediments by addition of exotic pollen in known quantities (Abstract): Pollen et Spores, v. 4, p. 332–333.

Bentley, S. J., Blum, M. D., Maloney, J., Pond, L., and Paulsell, R., 2016, The Mississippi River source-to-sink system: Perspectives on tectonic, climatic, and anthropogenic influences, Miocene to Anthropocene: Earth-Science Reviews, v. 153, p. 139–174, https://doi.org/10.1016/j.earscirev.2015.11.001

Bevan, B. W., and Roosevelt, A. C., 2003, Geophysical exploration of Guajará, a prehistorical earth mound in Brazil: Geoarchaeology, v. 18, n. 3, p. 287–331, https://doi.org/10.1002/gea.10064

Bissett, T., ms, 2014, The Western Tennessee Shell Mound Archaic: Prehistoric Occupation in the Lower Tennessee River Valley between 9000 and 2500 Calendar Year BP: Ph. D. dissertation, University of Tennessee, Knoxville, 597 p.

Blum, M. D., Tomkin, J. H., Purcell, A., and Lancaster, R. R., 2008, Ups and downs of the Mississippi Delta: Geology, v. 36, n. 9, p. 675–678, https://doi.org/10.1130/G24728A.1

Boyd, M., 2002, Identification of anthropogenic burining in the paleoecological record of the northern prairies: a new approach: Annals of the Association of American Geographers, v.92, n. 3, p. 471–487, https://doi.org/10.1111/1467-8306.00300

Bremond, L., Alexandre, A., Peyron, O., and Guiot, J., 2005, Grass water stress estimated from phytoliths in West Africa: Journal of Biogeography, v. 32, n. 2, p. 311–327, https://doi.org/10.1111/j.1365-2699.2004.01162.x

Cabanes, D., and Shahack-Gross, R., 2015, Understanding fossil phytolith preservation: The role of partial dissolution in paleoecology and archaeology: PLoS ONE, v. 10, n. 5, p. 1–16, https://doi.org/10.1371/journal.pone.0125532

Chen, I., Li, K. T., and Tsang, C. H., 2020, Silicified bulliform cells of Poaceae: morphological characteristics that distinguish subfamilies: Botanical Studies, v. 61, n. 5, p. 1–25, https://doi.org/10.1186/s40529-020-0282-x

Donoghue, J. F., 2011, Sea level history of the northern Gulf of Mexico coast and sea level rise scenarios for the near future: Climate Change, v. 107, 17, https://doi.org/10.1007/s10584-011-0077-x

Ellwood, B. B., 1996, Geology and America's National Park Areas: Prentice Hall, 372 p.

Ellwood, B. B., 2017, Physical Geology with emphasis on America's National Park Areas: Kendal Hunt, 451 p.

Ellwood, B. B., and Gose, W. A., 2006, Heinrich H1 and 8,200 Year B.P. Climate Events Recorded in Hall's Cave, Texas: Geology, v. 34, n. 9, p. 753–756, https://doi.org/10.1130/G22549.1

Ellwood, B. B., Peter, D. E., Balsam, W., and Schieber, J., 1995, Magnetic and Geochemical Variations as Indicators of Paleoclimate and Archaeological Site Evolution: Examples from 41TR68, Fort Worth, Texas: Journal of Archaeological Science, v. 22, n. 3, p. 409–415, https://doi.org/10.1006/jasc.1995.0040

Ellwood, B. B., Petruso, K. M., and Harrold, F. B., 1997, High-resolution paleoclimatic trends for the Holocene identified using magnetic susceptibility data from archaeological excavations in caves: Journal of Archaeological Science, v. 24, n. 6, p. 569–573, https://doi.org/10.1006/jasc.1996.0140

Epstein, A. G., Epstein, J. B., and Harris, L. D., 1977, Conodont color alteration – an index to organic metamorphism: U.S. Geological Survey Professional Paper, 995, 27 p., https://doi.org/10.3133/pp995

Ferguson, S., Warny, S., Anderson, J. B., Simms, A. R., and White, C., 2018, Breaching of Mustang Island in response to the 8.2 ka sea-level event and impact on Corpus Christi Bay, Gulf of Mexico: Implications for future coastal change: The Holocene, v. 28, n. 1, p. 166–172, https://doi.org/10.1177/0959683617715697

Ford, J. A., and Webb, C. H., 1956, Poverty Point, a late Archaic site in Louisiana: Anthropological Papers of the American Museum of Natural History, New York, v. 46, pt. 1, 136 p.

Ford, J. A., and Willey, G. R., 1940, Crooks Site, a Marksville Period burial mound in La Salle, Parish, Louisiana: Anthropology Study No. 3: New Orleans, LA, Department of Conservation Louisiana Geological Survey.

Ford, J. A., Quimby, G. I. Jr., and Snow, C. E., 1945, The Tchefuncte culture, an early occupation of the Lower Mississippi Valley: Memoirs of the Society for American Archaeology: The society for American Archaeology, v. 2, iii–142.

Haag, W. G., and Kuttruff, C., 2017, The Monte Sano mounds site (16EBR17): Salvage investigations of a Middle Archaic mound site in East Baton Rouge Parish, Louisiana: Louisiana Archaeology, v. 44, p. 9–54.

Heinrich, P. V., and McCulloh, R. P., 2000, Baton Rouge West, LA 7.5 minute geologic quadrangle: Open-File Map 2000–02: Louisiana Geological Survey, Baton Rouge, scale 1:24,000.

Henderson, W. G., Anderson, L. C., and McGimsey, C. R., 2002, Distinguishing natural and archaeological deposits: Stratigraphy, taxonomy, and taphonomy of Holocene shell-rich accumulations from the Louisiana chenier plain: Palaios, v. 17, n. 2, p. 192–205, https://doi.org/10.1669/0883-1351(2002)017<0192:DNAADS>2.0.CO;2

Homburg, J. A., ms, 1991, An Archaeological Investigation at the LSU Campus Mounds: Ph. D. thesis, Louisiana State University, Baton Rouge, 218 p.

Homburg, J. A., 1993, Comments on the age of the LSU Campus Mounds: reply to Jones: Louisiana Archaeology, v. 20, p. 183–196.

Jones, D, and Brookes, S. O., 2017, Gone but surely not forgotten: Implications of the Monte Sano site (16EBR17): Louisiana Archaeology, v. 44, p. 105–120.

Kesel, R. H., 2008, A revised Holocene geochronology for the lower Mississippi valley: Geomorphology, v. 101, n. 1–2, p. 78–89, https://doi.org/10.1016/j.geomorph.2008.06.006

Kidder, T. R., 1992, Coles Creek period social organization and evolution in northeast Louisiana: Archaeological Papers of the American Anthropological Association, v. 3, n. 1, p. 145–162, https://doi.org/10.1525/ap3a.1992.3.1.145

Kidder, T. R., 1996, Perspectives on the geoarchaeology of the Lower Mississippi Valley: Engineering Geology, v. 45, n. 1–4, 305–323, https://doi.org/10.1016/S0013-7952(96)00019-1

Kidder, T. R., Ortmann, A., and Allen, T., 2004, Testing Mounds B and E at Poverty Point: Southeastern Archaeology, v. 23, n. 1, p. 98–113.

Kniffen, F. B., 1936, A preliminary report on the Indian mounds and middens of Plaquemines and St. Bernard Parishes. Lower Mississippi River Delta: State of Louisiana Department of Conservation: Geological Bulletin, v. 8, p. 407–422.

Kniffen, F. B., 1938, The Indian mounds of Iberville Parish: Department of Conservation, Louisiana Geological Survey, Bulletin, v. 13, p. 189–207.

Lee, A. L., 2010, Troyville and the Baytown period, *in* Rees, M. A., editor, Archaeology of Louisiana: Baton Rouge, LA: Louisiana State University Press, p. 135–156.

Lu, H. Y., and Liu, K. B., 2003, Phytoliths of common grasses in the coastal environments of southeastern USA: Estuarine, Coastal and Shelf Science, v. 58, n. 3, p. 587–600, https://doi.org/10.1016/S0272-7714(03)00137-9

Lu, H. Y., Wu, N. Q., Yang, X. D., Jiang, H., Liu, K. B., and Liu, T. S., 2006, Phytoliths as quantitative indicators for the reconstruction of past environmental conditions in China I: phytolith-based transfer function: Quaternary Science Reviews, v. 25, n. 9–10, p. 945–959, https://doi.org/10.1016/j.quascirev.2005.07.014

Mercader, J., Astudillo, F., Barkworth, M., Bennett, T. A., Esselmont, C., Kinyanjui, R., Grossman, D. L., Simpson, S., and Walde, D., 2010, Poaceae phytoliths from the Niassa Rift, Mozambique: Journal of Archaeological Science, v. 37 n. 8, p. 1953–1967, https://doi.org/10.1016/j.jas.2010.03.001
Muhs, D. R., Bettis, E. A. III., and Skipp, G. L., 2018, Geochemistry and mineralogy of Late Quaternary loess in the upper Mississippi River valley, USA: Provenance and correlation with Laurentide Ice Sheet history: Quaternary Science Reviews, v. 187, p. 235–269, https://doi.org/10.1016/j.quascirev.2018.03.024
Mullens, C. E., 1977, Magnetic susceptibility of the soil and its significance in soil science - a review: Journal of Soil Science, v. 28, n. 2, p. 223–246, https://doi.org/10.1111/j.1365-2389.1977.tb02232.x
Neuman, R. W., 1988, Report on the soil core borings conducted at the campus mounds site (16EBR6) East Baton Rouge parish, Louisiana: Louisiana Archaeology, v. 15, p. 1–27.
Olson, E. A., and Broecker, W. S., 1958, Section of geology and mineralogy: Sample contamination and reliability of radiocarbon dates: Transactions of the New York Academy of Sciences, v. 20, n. 7, p. 593–604, https://doi.org/10.1111/j.2164-0947.1958.tb00623.x
Ortmann, A. L., and Kidder, T. R., 2013, Building mound A at Poverty Point, Louisiana: Monumental public architecture, ritual practice, and implications for hunter-gatherer complexity: Geoarchaeology, v. 28, n. 1, p. 66–86, https://doi.org/10.1002/gea.21430
Parr, J. F., 2006, Effect of fire on phytolith coloration: Geoarchaeology, v. 21, n. 2, p. 171–185, https://doi.org/10.1002/gea.20102
Parr, J. F., and Sullivan, L. A., 2005, Soil carbon sequestration in phytoliths: Soil Biology and Biochemistry, v. 37, n. 1, p. 117–124, https://doi.org/10.1016/j.soilbio.2004.06.013
Petruso, K. M., Ellwood, B. B., Harrold, F. B., and Korkuit, M., 1994, Radiocarbon and archaeomagnetic dates from Konispol Cave, Albania: Antiquity, v. 68, n. 259, p. 335–339, https://doi.org/10.1017/S0003598X00046640
Piperno, D. R., 1988, Phytolith analysis: An Archaeological and Geological Perspective: San Diego, Academic Press, Inc., 280 p.
Piperno, D. R., 2006, Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists: Lanham, MD, Alta Mira Press, 304 p.
Piperno, D. R., 2016, Standard evaluations of bomb curves and age calibrations along with consideration of environmental and biological variability show the rigor of phytolith dates on modern neotropical plants: Review of comment by Santos, Alexandre, and Prior: Journal of Archaeological Science, v. 71, p. 59–67, https://doi.org/10.1016/j.jas.2016.01.013
Piperno, D. R., and Pearsall, D. M., 1998, The silica bodies of tropical American grasses: Morphology, Taxonomy, and Implications for Grass Syastematics and Fossil Phytolith Identification: Smithsonian Contributions to Botany, n. 85, p. 1–40, https://doi.org/10.5479/si.0081024X.85
Rees, M. A., 2010, Archaeology of Louisiana: Baton Rouge, LA: Louisiana State University Press, 488 p.
Roberts, H. H., 1997, Dynamic changes of the Holocene Mississippi River Delta Plain: the Delta Cycles: Journal of Coastal Research, v. 13, n. 3, p. 605–627.
Roe, L. M., and Schilling, T. M., 2010, Coles creek, *in* Rees, M. A., editor, Archaeology of Louisiana: Baton Rouge, LA: Louisiana State University Press, p. 157–172.
Rohling, E. J., and Pälike, H., 2005, Centennial-scale climate cooling with a sudden cold event around 8,200 years ago: Nature, v. 434, p. 975–979, https://doi.org/10.1038/nature03421
Rossetti, D. F., Goes, A. M., and Toledo, P. M., 2009, Archaeological mounds in Marajó Island in Northern Brazil: A geological perspective integrating remote sensing and sedimentology: Geoarchaeology, v. 24, n. 1, p. 22–41, https://doi.org/10.1002/gea.20250
Sassaman, K. E., 2005. Poverty point as structure, event, process: Journal of Archaeological Method and Theory, v. 12, n. 4, p. 335–364, https://doi.org/10.1007/s10816-005-8460-4
Saucier, R. T., 1994, Geomorphology and Quaternary geologic history of the lower Mississippi Valley: Vicksburg, Mississippi, Mississippi River Commission, v. 1, 205 p.
Saunders, J. W., and Allen, T., 1994, Hedgepeth mounds, an archaic mound complex in North-Central Louisiana: American Antiquity, v. 59, n. 3, p. 471–489, https://doi.org/10.2307/282460
Saunders, R., and Russo, M., 2011, Coastal shell middens in Florida: A view from the Archaic period: Quaternary International, v. 239, n. 1–2, p. 38–50, https://doi.org/10.1016/j.quaint.2010.08.008
Saunders, J. W., Mandel, R. D., Saucier, R. T., Allen, E. T., Hallmark, C. T., Johnson, J. K., Jackson, E. H., Allen, C. M., Stringer, G. L., Frink, D. S., Feathers, J. K., Williams, S., Gremillion, K. J., Vidrine, M.F ., and Jones, R., 1997, A Mound Complex in Louisiana at 5400–5000 years before present: Science, v. 277, n. 5333, p. 1796–1799, https://doi.org/10.1126/science.277.5333.1796
Saunders, J. W., Mandel, R. D., Sampson, C. G., Allen, C. M., Allen, E. T., Bush, D. A., Feathers, J. K., Gremillion, K. J., Hallmark, C. T., Jackson, E. H., Johnson, J. K., Jones, R., Saucier, R. T., Stringer, G. L., and Vidrine, M. F., 2005, Watson Brake, a Middle Archaic mound complex in northeast Louisiana: American Antiquity, v. 70, n. 4, p. 631–668, https://doi.org/10.2307/40035868
Sherwood, S. C., and Kidder, T. R., 2011, The DaVincis of dirt: Geoarchaeological perspectives on Native American mound building in the Mississippi River basin: Journal of Anthropological Archaeology, v. 30, n. 1, p. 69–87, https://doi.org/10.1016/j.jaa.2010.11.001
Tedford, R. A., ms, 2009, A multi-proxy approach to investigating the latest Holocene (~4,500 yrs. BP) vegetational history of Catahoula Lake: Louisiana: Ph. D. dissertation, Baton Rouge: Louisiana State University, 391 p.
Twiss, P. C., Suess, E., and Smith, R. M., 1969, Morphological Classification of Grass Phytoliths: Soil Science Society of America Journal, v. 33, n. 1, p. 109–115, https://doi.org/10.2136/sssaj1969.03615995003300010030x
Wade, L., 2021, Footprints support claim of early arrival in the Americas: Science, v. 373, n. 6562, p. 1426, https://doi.org/10.1126/science.acx9159

Walker, M., Head, M. J., Berkelhammer, M., Björck, S., Cheng, H., Cwynar, L., Fisher, D., Gkinis, V., Long, A., Lowe, J., Newnham, R., Rasmussen, S. O., and Weiss, H., 2018, Formal ratification of the subdivision of the Holocene Series/Epoch (Quaternary System/Period): two new Global Boundary Stratotype Sections and Points (GSSPs) and three new stages/subseries: Episodes, v. 41, n. 4, p. 213–223, https://doi.org/10.18814/epiiugs/2018/018016

Weisskopf, A., Harvey, E., Kingwall-Banham, E., Kajale, M., Mohanty, R., and Fuller, D. Q., 2014, Archaeobotanical implications of phytolith assemblages from cultivated rice systems, wild rice stands and macro-regional patterns: Journal of Archaeological Science, v. 51, p. 43–53, https://doi.org/10.1016/j.jas.2013.04.026