

A geoarchaeological perspective on the challenges and trajectories of Mississippi Delta communities

Elizabeth L. Chamberlain^{a,b,c,*}, Jayur M. Mehta^d, Tony Reimann^c, Jakob Wallinga^c

^a Department of Earth and Environmental Sciences, Vanderbilt University, Nashville, TN, USA

^b Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, USA

^c Netherlands Centre for Luminescence Dating, Soil Geography and Landscape group, Wageningen University, Wageningen, the Netherlands

^d Department of Anthropology, Florida State University, Tallahassee, FL, USA

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ABSTRACT

Recent geochronology of the Mississippi Delta of coastal Louisiana, USA, provides a high-resolution record of land growth that facilitates the study of ancient settlement patterns in relation to delta evolution. We use stratigraphy and optically stimulated luminescence (OSL) dating to show that two Late Holocene earthen mounds were constructed several hundred years after the land emerged from open water. This multi-century pause allowed natural processes of overbank and crevasse splay deposition to elevate the land surface, reduce flood risk, and foster desirable environmental conditions prior to human occupation. These results are applied to obtain new age constraints for a large number of at-risk or lost archaeological sites with little-to-no absolute chronology. We use our findings to comment on prehistoric, contemporary, and future human-landscape interactions in the Mississippi Delta and other deltaic environments.

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1. Introduction

Fluvial systems mobilize and collect an abundance of resources from their source lands, which are delivered by the channel networks to their deltas. The resource richness of deltas has proven timeless in terms of fostering human populations and cultural complexity (e.g., Day et al., 2012; Dillehay et al., 2012). For example, the Mississippi Delta of coastal Louisiana, USA, can be seen as a “cradle of civilization” within the Lower Mississippi River Valley and Gulf Coast. The lower valley has some of the oldest monuments in North America, extending back to 7 ka (Gibson, 1994; Saunders et al., 2005) and showing the early development of collaborative, earthen- and shell-mound-building societies (Rosenswig and Burger, 2012). The region continues to be economically and societally pivotal today, hosting a major petrochemical industry, a global port, and the destination city of New Orleans as well as numerous smaller and unique communities of mixed French Acadian, African, Caribbean, and Native American heritage (Tidwell, 2007; Solnit and Snedeker, 2013). Contemporary Louisiana culture is a commodity in itself, serving as the basis for television programs such as “Swamp People”, “Out da Bayou”, “Cajun Pawn Stars”, and “Duck Dynasty”, giving rise to regionally specific literature ranging from the children’s adaptation of *A Cajun Night Before Christmas* to Anne Rice’s *Interview with a*

Vampire, and fueling trend-setting culinary and music industries (e.g., Gotham, 2007). In other words, resource richness continues to foster cultural growth and diversification in deltaic communities such as the Mississippi Delta today.

In addition to the resource benefits, fluvial landscapes are shaped by and subject to dynamic processes ranging from annual river flooding (e.g., Davis et al., 2018) to multi-centennial channel avulsions (e.g., Fisk, 1944; Saucier, 1994). Deltaic systems are further complicated by coastal phenomena such as ongoing subsidence (e.g., Karegar et al., 2015; Nienhuis et al., 2017), sea-level rise (e.g., González and Törnqvist, 2009), and episodic storm (e.g., tropical cyclone or hurricane) events (e.g., Bregy et al., 2018). Deltas are therefore inherently difficult to lock-in-place in a way that is compatible with the establishment and maintenance of hard infrastructure. In other words, geohazards are also a timeless attribute of deltas.

Such challenges are manifest in the present-day state of the Mississippi Delta, which has lost a reported 45 km²/yr of wetlands over recent decades (Fig. 1, Couvillion et al., 2017). Despite a state-led initiative to mitigate deltaic land loss at a projected cost of \$50 billion (CPRA, 2017), Louisiana has already seen the landward relocation of at least one coastal community. The residents of Isle de Jean Charles have been deemed “the first American climate refugees” (Davenport and Robertson, 2016) for their federally subsidized community relocation (U.S. National Climate Assessment, 2018). It is likely that increasing numbers of people in the US Gulf Coast and in deltas worldwide will be forced inland by the combined threats of subsidence, eustatic sea-

* Corresponding author at: Department of Earth and Environmental Sciences, Vanderbilt University, Nashville, TN, USA.

E-mail address: elizabeth.chamberlain@vanderbilt.edu (E.L. Chamberlain).

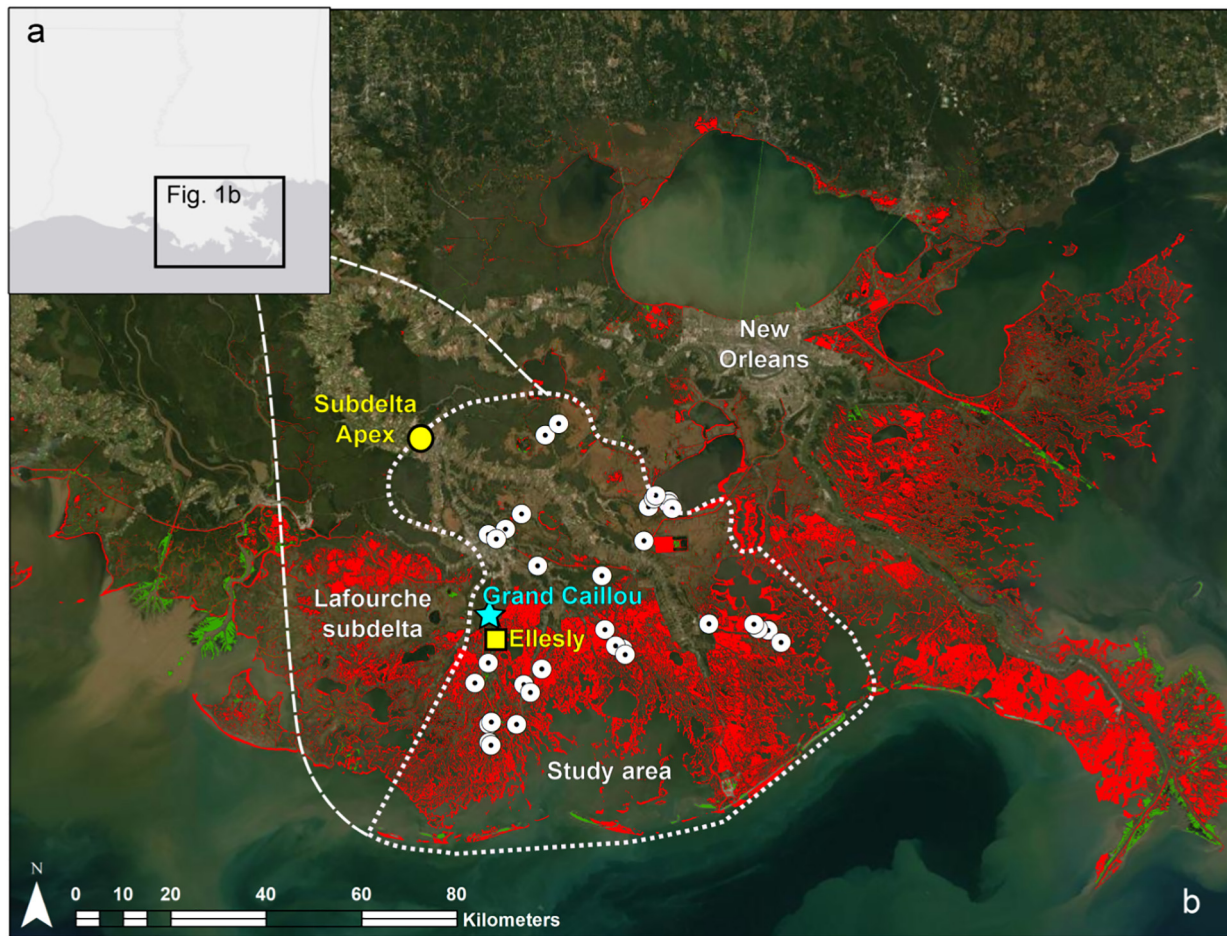


Fig. 1. The Mississippi Delta of southern Louisiana (a) has experienced significant net land loss over the past century. (b) Land loss since 1935 is shown in red, while gain over this same timeframe is shown in green (Couvillion et al., 2017). Within the ~10,000 km² Lafourche subdelta (white dashed and dotted outlines) our study area (white dotted outline) hosts numerous archaeological sites that may provide insights into time-tested strategies for living in vulnerable coastal regions. Of these, we investigate the Grand Caillou and Ellesly earthen mound complexes in detail.

level rise, and increased storm activity (IPCC, 2018). Understanding the human response to such agents is a key component in predicting the trajectories of coastal communities over long timescales. This is particularly important in light of the population density and cultural value of deltas. Geoarchaeological research is also valuable for advancing geomorphic theory because humans are becoming increasingly active and increasingly recognized as primary geomorphic agents (e.g., Hooke, 2000; Church, 2010; Lazarus et al., 2016), and so human activity is not readily decoupled from the other processes that drive the evolution of present-day landscapes (e.g., Brown et al., 2017; Pierik et al., 2018).

As the past is the key to the present (Lyell, 1830-1833), archaeological sites may contain valuable information regarding human-landscape interactions that transcend timescales. The paleo-record can also provide baselines for understanding geohazards in present-day coupled human-natural systems, including both natural and cultural contributors (James and Marcus, 2006). Here, we aim to gain insight into how prehistoric people coped with intrinsic coastal geohazards by investigating the stratigraphy, geographic context, and timing of establishment of two large monumental archaeological sites known as Grand Caillou and Ellesly (Fig. 1), described in detail later in the manuscript (see Section 2.3. The Grand Caillou and Ellesly archaeological sites).

The two investigated sites are located within in the Lafourche subdelta, a relict lobe of the Mississippi Delta that was active from ~1.6–0.6 ka (Shen et al., 2015; Hijma et al., 2017) and formed 6000–8000 km² of new land through progradation into a shallow bay (Chamberlain et al., 2018a). By placing our findings at Grand Caillou and Ellesly in the context of prior geochronologic records of delta

growth (Shen et al., 2015; Chamberlain et al., 2018a), we assess the location and timing of mound construction relative to the geography of the subdelta and the timing of formation of deltaic substrate. We then use our knowledge of the timing of shoreline progradation (i.e., land formation, Chamberlain et al., 2018a), new calculations of overbank aggradation (i.e., accumulating subaerial deposits of sufficient thickness) (Fig. 2), and the stratigraphic principle of superposition to develop *new terminus post quem* chronologies for numerous at-risk or destroyed archaeological sites in the Lafourche subdelta. This interdisciplinary approach yields insights into how prehistoric people selected optimal locations within a delta and coped with the inherent challenges of living in a delta. Our findings are considered in the context of the contemporary land-loss crisis of southern Louisiana.

2. Context of the study

2.1. Stratigraphy and chronology of the Holocene Mississippi Delta

The Holocene Mississippi Delta is composed of a series of amalgamated sediment packages known as lobes or subdeltas (Fisk, 1944). Subdeltas initiate when the mainstem channel avulses to form a new path to the coast or to occupy an abandoned pathway, thus changing the coastal depocenter and building new land through delta progradation. Chamberlain et al. (2018a) showed that land near distributary channels built through subdelta progradation in the Mississippi Delta manifests in the stratigraphic record as a common succession of lithogenetic units. At the base are shell-rich bay muds, overlain by

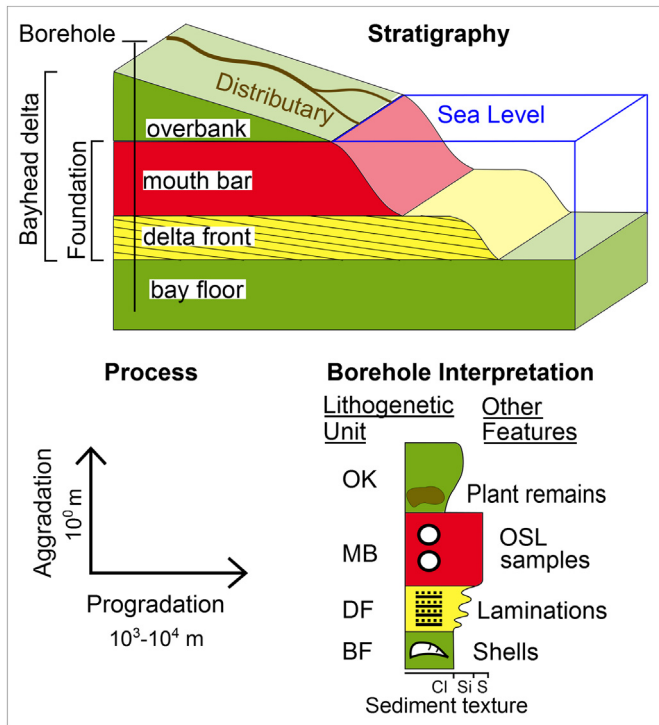


Fig. 2. Cartoon showing the general stratigraphy and characteristics of deposits formed through bayhead delta progradation and aggradation. Red = sand, yellow = silt, green = clay, OK = overbank deposits, MB = mouth bar deposits, DF = delta front deposits, BF = bay floor deposits. Reprinted from Science Advances, Chamberlain et al. (2018a). © The Authors, some rights reserved; exclusive licensee American Association for the Advancement of Science. Distributed under a Creative Commons Attribution NonCommercial License 4.0 (CC BY-NC).

laminated delta front silts, then laterally extensive mouth bar sands (Fig. 2, Chamberlain et al., 2018a). Here, the mouth bars aggrade to near sea level (Roberts et al., 1997; Wellner et al., 2005), meaning that the depositional age of mouth bar deposits is a good indicator of the position of the subdelta shoreline at particular times (Chamberlain et al., 2018a). After land emerges from open water, subaerial land elevation is gained through overbank deposition, which includes episodes of rapid aggradation fed by crevasse splay networks (Shen et al., 2015). Avulsions of the trunk channel, occurring roughly every thousand years (although individual timescales vary greatly, see Hijma et al., 2017) drive the initiation of a new distributary network and thus a new subdelta. Concurrently, discharge decreases down the preexisting distributary network, permitting the intrusion of saline water and ultimately reworking to become a more marine-dominated landform in its coastward regions (Penland et al., 1988). Compared to other deltas (e.g., the Ganges-Brahmaputra Delta, Wilson and Goodbred, 2015), the degree of fluvial reworking of Holocene deposits is fairly low in the Mississippi Delta, so that the abandoned distributaries (regionally known as “bayous”) are often preserved and visible in the planform of the delta. This preservation enables the geologic reconstruction of subdelta histories.

Chamberlain et al. (2018a) tracked the progradation of the Lafourche subdelta shoreline by optically stimulated luminescence (OSL) dating mouth bar sand deposits associated with the relict Lafourche subdelta distributaries using the quartz OSL signal. OSL dating determines the time since last light exposure of quartz or feldspar crystals based on trapped charges that accumulate within the mineral crystal lattice when shielded from sunlight (Huntley et al., 1985). The method therefore has the advantage over radiocarbon of being able to directly quantify the time of deposition of clastic sediments, the primary material that makes up the stratigraphic record of most deltas

(Chamberlain et al., 2020) including the Mississippi Delta. The mouth bar ages showed internal consistency and agreed with prior determinations that the Lafourche subdelta was active from 1.6–0.6 ka, obtained from OSL dating of Lafourche overbank deposits (Shen et al., 2015) and radiocarbon dating of peats directly underlying the Lafourche subdelta (Törnqvist et al., 1996a). The OSL chronology of Chamberlain et al. (2018a) also provided new information on growth rates and patterns within the Lafourche subdelta, showing that the shoreline prograded seaward from the subdelta apex (defined by the position of the paleoshoreline prior to Lafourche subdelta initiation, Fig. 1) at a linear rate characterized by co-activity of all distributaries. This finding now allows for estimating the timing of land emergence at archaeological sites within our study area, which we define as the existing ~6000 km² of land within the Lafourche subdelta formed through subdelta progradation into open water. We referred to this region as “Lower Lafourche” (Fig. 1).

2.2. Archaeological investigations in the Mississippi Delta

Archaeological data can be used to infer landscape evolution (e.g., Törnqvist et al., 1996b; Sarker et al., 2012; Hanebuth et al., 2013). For example, the earliest observations of subdelta activity in the Mississippi Delta were informed by the archaeological record, which showed that material cultures representing different time periods were geographically zoned, or clustered around specific distributary channels (Kniffen, 1936; McIntire, 1958). Such “typology” classifications provide relative chronology for many sites within the Lafourche subdelta that are recorded in State of Louisiana Archaeological Site Record Forms housed at the Division of Archaeology (www.crt.state.la.us/cultural-development/archaeology/). These records are often compiled by state-contracted researchers generally for the purpose of cultural resource management, and are not peer-reviewed reports. Nonetheless, Site Record Forms can provide a comprehensive overview of a region's cultural, archaeological, and historical resources and have been used for scientific research (e.g., see Anderson et al., 2017).

Alternatively, geologic data can be used to infer information about prehistoric people (e.g., Sherwood and Kidder, 2011; Kidder and Sherwood, 2017). For example, relative site chronologies have been drawn from the geochronology of subdeltas on which they were built (e.g., Gagliano and Van Beek, 1975). The geochronologic framework of the Mississippi Delta has evolved significantly since the relative chronologic assessment of archaeological sites in the 1970s, through the addition of new absolute ages obtained from OSL dating of clastic deposits and radiocarbon dating of in situ peats (see Hijma et al., 2017). Many linked archaeological chronologies are therefore now outdated.

The Lower Lafourche subdelta hosts numerous prehistoric archaeological sites that reflect the presence of a large prehistoric civilization (Fig. 1). Cultures relevant to the 1.6–0.6 ka activity of the Lafourche subdelta include Troyville (1.6–1.3 ka), Coles Creek (1.3–1.0 ka), Plaquemine (1.0–0.3 ka), and Mississippian (0.8–0.3 ka) (Rees, 2010). Indigenous societies of the Mississippi Delta were largely hunter-fisher-gatherer societies until 0.8 ka, after which introduced cultigens, like maize, became minor components of the diets of some delta foragers (Fritz and Kidder, 1993). Insight into the dwelling patterns of prehistoric indigenous people is limited in the Mississippi Delta because few (if any) structures or buildings have been excavated. Archaeologists seem to favor interpretations of itinerant societies that seasonally and/or ritually occupied villages during specific times of the year (Gibson, 2006, 2007). Ceramics motifs show that north-south and east-west cultural exchanges were important (Mehta and Chamberlain, 2019), however, there is little evidence for lithic trade. Local industries of bone-tool manufacture were likely important in the lithic-resource poor delta (Davis et al., 1983). Contact with French explorers in the late seventeenth century and the founding of the French colonies of Mobile and New Orleans in 1702 and 1718, respectively, forced the migration and movement of indigenous groups across coastal deltaic landscape. This

catalyzed the development of modern tribal societies along the Gulf Coast and shaped their current social, political, and cultural needs (Campisi and Starna, 2004; Billiot and Mitchell, 2018; Crepelle, 2018).

To our knowledge, the only peer-reviewed absolute chronology of an archaeological site within our study area is found in Mehta and Chamberlain (2019), although some absolute ages have been reported in Site Record Forms, cultural resource management reports, and other reports to the State of Louisiana (Table A1; Hunter et al., 1988; Mann, 2005). Unfortunately, the physical archives needed to establish new chronology of prehistoric sites have been dramatically reduced as mounds have been destroyed by a variety of means such as dredging/crosscutting by oil and gas canals and leveling for contemporary construction or agriculture. Shell middens, composed of the brackish-water clam *Rangia cuneata*, were often mined to gain the solid, gravel-like substrate for road construction (as little-to-no natural gravel resources are found in the Holocene Mississippi Delta). Of the mounds that have survived, the original cultural context is often lost to invasive practices such as historical burials (Kassabaum et al., 2011). Many mound sites that have persisted to the twenty-first century are further endangered by natural yet human-exacerbated processes such as relative sea-level rise coupled with coastal erosion (e.g., Morton et al., 2006; Couvillion et al., 2017). Altogether, this means that updates to prior chronology and the establishment of new chronologic constraints for Mississippi Delta archaeological sites are needed to better understand these records, yet are difficult to obtain because of the loss of the physical records themselves.

2.3. The Grand Caillou and Ellesly archaeological sites

The Grand Caillou mound complex (16TR38, site numbers assigned by the State of Louisiana are given in parentheses) is located on the natural levee of the west bank of Bayou Grand Caillou (Fig. 3a,b). The site is situated within the ring of the Morganza levee system, which presently protects it from coastal inundation and erosion, and features a remarkably high degree of preservation relative to neighboring sites. The archaeological complex presently hosts at least two earthen mounds, including (i) a ~6 m tall pyramid-shaped flat-topped mound with ~40 m by 40 m footprint and an intact ramp oriented toward a westward plaza, referred to herein as the primary mound (Fig. 4a), and (ii) an elongate 1–3 m tall rise running ~100 m along the bank of the

Grand Caillou crevasse channel that forms the southern boundary of the monumental site (Mehta and Chamberlain, 2019). A third mound was documented to the north of the primary mound, however, the Site Record Form indicates that this was destroyed prior to a 1982 state survey.

In 2016, our team conducted a geoarchaeological survey of the Grand Caillou site, yielding detailed ceramic typology, stratigraphic data describing the primary (pyramid) mound, and information about its position in the delta landscape (Mehta and Chamberlain, 2019). This research showed that the primary mound was intentionally crafted of alternating lithologies (silt and mud), a labor-intensive and specialized building approach that has likely contributed to its endurance. Most interesting, we identified a preserved woody peat layer directly underlying the mound. Composed of horizontal branches and leaf fragments, this layer was interpreted as the relict forest floor. Radiocarbon dating ($n = 6$, Table 1) of wood fragments isolated from the peat plus charcoal fragments sampled within mound strata assigned a construction age of circa 0.8 ka to the mound. No radiocarbon ages were younger than 0.6 ka, hinting that abandonment of the site may have coincided with abandonment of the Lafourche distributary network and changes to the environment and fisheries associated with saltwater intrusion (Mehta and Chamberlain, 2019). The radiocarbon chronology was corroborated with typologic determinations of ceramics, which identified the builders as part of a larger complex of coastal mound-building people known as the “Plaquemines culture”, a group that occupied the U.S. Gulf Coast during the Mississippi Period (Livingood and Rees, 2007; Rees, 2010). We also identified that the mound was constructed up to 400 yr after land emerged near Grand Caillou as determined by Chamberlain et al. (2018a), although no prior studies have presented OSL chronology specific to the natural deposits at Grand Caillou itself.

No peer-reviewed literature presently exists describing the archaeology of the Ellesly site (16TR37, Fig. 3c), although the Site Record Form describes this as a multi-mound complex containing 2–5 earthen mounds. Of these, one mound persists today with a present-day footprint of ~35 by 50 m, yet it appears to have been planed off, pushed and flattened, or otherwise leveled to ~1 m height and is intruded by a historic cemetery (Fig. 4b). Chamberlain et al. (2018a) presented a cross section in their supplementary file showing the deposits that comprise and underlie the Ellesly mound, but did not discuss any archaeological context of the site.

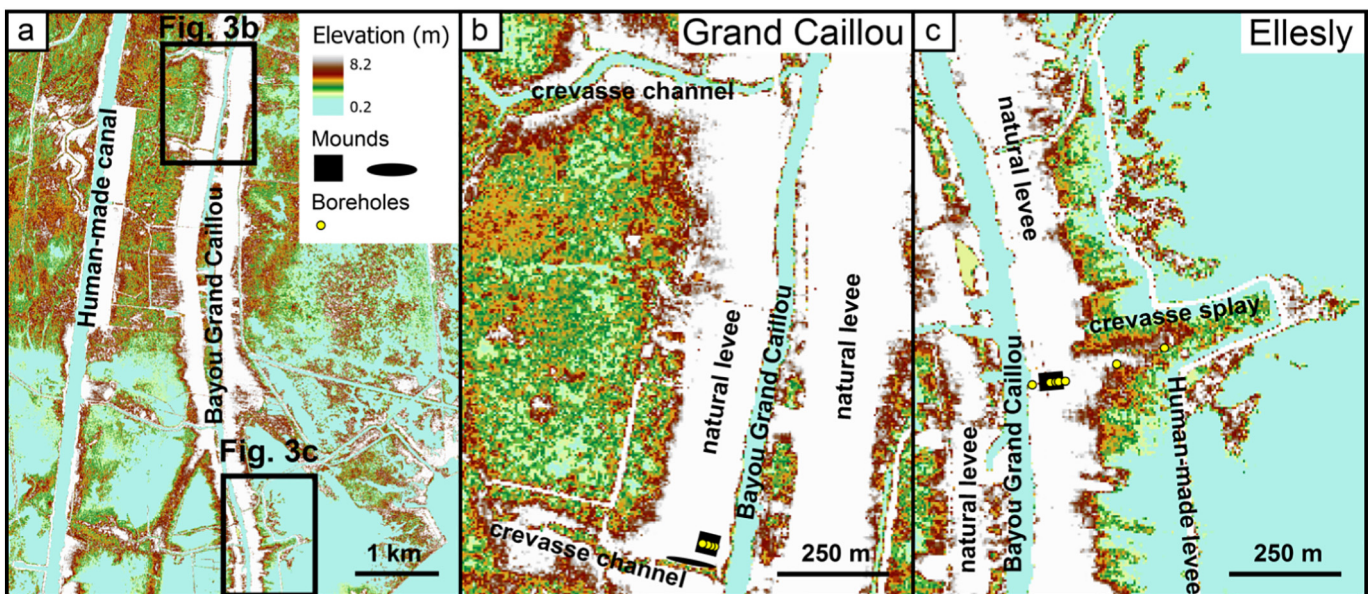


Fig. 3. LiDAR showing the positions of the two archaeological sites investigated in detail relative to the Bayou Grand Caillou distributary (a), and zoomed in LiDAR imagery of Grand Caillou (b) and Ellesly (c) showing the location of boreholes, mounds, geomorphic features and contemporary human-made structures such as levees and canals.

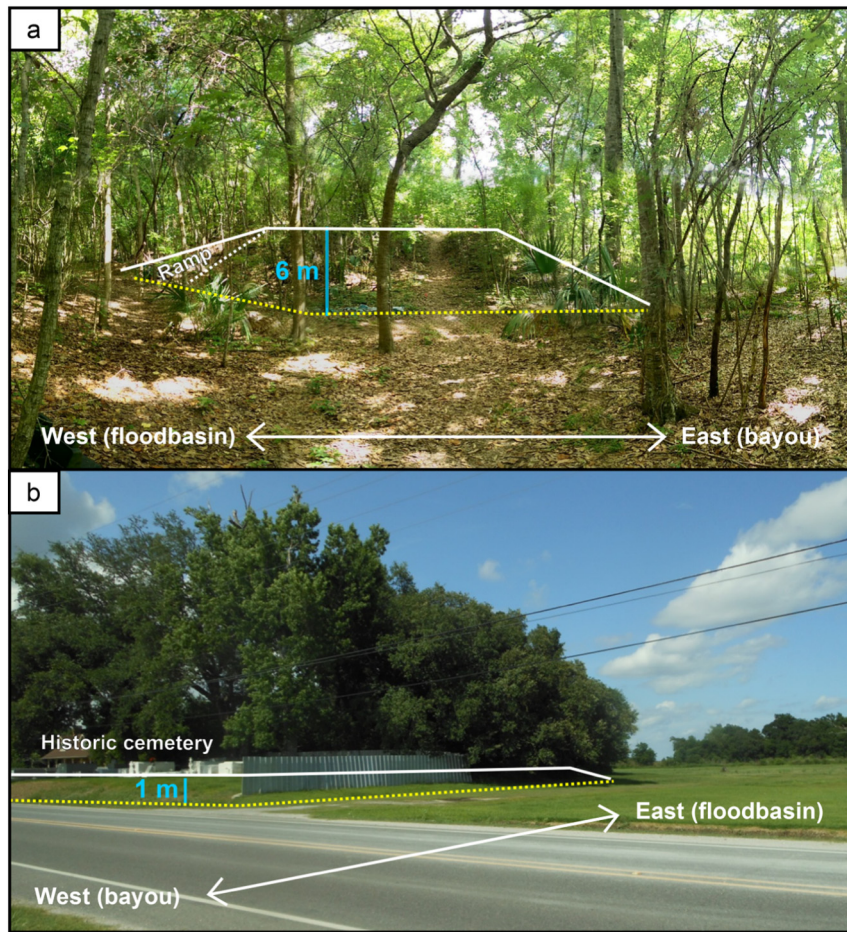


Fig. 4. Photographs showing the primary mounds at the Grand Caillou (a) and Ellesly (b) archaeological sites. The mound at Grand Caillou is a relatively undisturbed ~6 m tall pyramid mound with an intact ramp oriented west toward the plaza of the site (Mehta and Chamberlain, 2019), while the mound at Ellesly appears to have been planed off to ~1 m height and is intruded by a historic cemetery. Mound surfaces are outlined in white, and the present-day footprints of the mounds are delineated with yellow dashed lines.

3. Methods

3.1. Field data collection at mound sites

The stratigraphy of mound and underlying natural deposits at Grand Caillou and Ellesly were determined by previous investigations (Chamberlain et al., 2018a; Mehta and Chamberlain, 2019) through hand coring with an Edelman hand auger and gouge to a maximum depth of 16 m. At each site, the boreholes were positioned both on and off the mound and aligned in a transect perpendicular to the distributary channel (Bayou Grand Caillou). At Grand Caillou, eight boreholes were executed including four that penetrated the earthen mound (Fig. 3b). At Ellesly, seven boreholes were executed including three that penetrated the earthen mound (Fig. 3c).

Recovered sediments were described by sediment texture using the USDA soil classification scheme, features including fossil content (i.e., shells and herbaceous organics), sedimentary structures, and archaeological artifacts. The details of the Grand Caillou and Ellesly boreholes are presented in Mehta and Chamberlain (2019) and Chamberlain et al. (2018a, see "Dulac" cross section), respectively. Of particular interest to this work is the natural-landform-to-mound contact, because identifying this boundary is essential to correctly sampling and dating natural versus anthropogenic deposits. We identified this by a transition in lithology, fossil content, and the presence or absence of artifacts.

3.2. Luminescence dating

3.2.1. Sample preparation and luminescence measurements

We used the OSL signal of quartz sediments to determine the time of deposition and burial of naturally deposited deltaic sediments that directly underlie earthen mounds. New samples were obtained at Grand Caillou ($n = 3$, Table 1) and Ellesly ($n = 3$, Table 1), and placed in the previous Lafourche subdelta luminescence chronology ($n = 19$) presented by Chamberlain et al. (2018a). All samples were captured in a stainless steel Van der Horst sampler that prevented light exposure. Preparation was conducted using standard methods for sand and silt (e.g., see Chamberlain et al., 2017) at Tulane University under amber light conditions.

The OSL equivalent dose (D_e) measurements of samples from the Ellesly site were performed at the University of Liverpool using an automated Risø DA-15 B/C reader providing blue (~470 nm) and infrared (~830 nm) stimulation; those of the Grand Caillou samples were performed at the Netherlands Centre for Luminescence dating (Wageningen University) using an automated Risø DA-20 TL/OSL reader providing blue (~470 nm) and infrared (~875 nm) stimulation (Bøtter-Jensen et al., 2000; Bøtter-Jensen et al., 2003). The heating elements of the Risø readers were used for preheating to 180 °C. The luminescence signals of all samples were detected through 7.5 mm Hoya U-340 filters with UV detection windows.

Both silt-sized and sand-sized quartz grains of the Mississippi Delta have been shown to be sufficiently zeroed prior to deposition to yield

Table 1
OSL and radiocarbon ages for natural and mound deposits at the Grand Caillou and Ellesly archaeological sites. OSL ages are reported with 1-sigma uncertainty while radiocarbon ages are reported with 2-sigma uncertainty.

Optically stimulated luminescence								
Site	Lab code	UTM Coordinates NAD 83, 15N (x,y)	Depth (m)	Grain size	Accepted aliquots (n)	Paleodose (Gy)	Dose rate (Gy/ka)	Age (ka, 2010)
Grand Caillou	NCL-1317139	722687, 3262033	6.45–6.60	4–11	8	2.31 ± 0.02	3.19 ± 0.16	0.72 ± 0.04
Grand Caillou	NCL-1317140	722687, 3262033	7.42–7.58	4–11	8	2.37 ± 0.03	2.91 ± 0.13	0.81 ± 0.04
Grand Caillou	NCL-1317141	722687, 3262033	8.58–8.68	4–11	8	2.40 ± 0.03	2.95 ± 0.14	0.81 ± 0.04
Ellesly	LV804	723225, 3257430	2.53–2.68	75–125	75	2.05 ± 0.06	2.55 ± 0.14	0.79 ± 0.05
Ellesly	LV803	723225, 3257430	3.26–3.38	75–125	69	1.88 ± 0.04	2.38 ± 0.12	0.78 ± 0.05
Ellesly	LV802	723225, 3257430	4.44–4.57	75–125	68	1.95 ± 0.11	2.32 ± 0.12	0.84 ± 0.07
Ellesly	LV801 ^a	723225, 3257430	8.40–8.48	125–180	71	2.37 ± 0.09	2.29 ± 0.12	1.04 ± 0.07
Ellesly	LV800 ^a	723225, 3257430	8.63–8.68	125–180	73	2.34 ± 0.07	2.18 ± 0.10	1.08 ± 0.06
Radiocarbon								
Site	Lab code	UTM coordinates NAD 83, 15N (x,y)	Sediment matrix	Depth (m)	Material	Uncalib. 14C age (ybp, 1950)	Calib. 14C age (ybp, 1950)	Calib. age (ka, 2010)
Grand Caillou	UGAMSA27276 ^b	722692, 3262031	mound clay cap	1.5	charcoal	793 ± 23	676–739	0.74–0.80
Grand Caillou	UGAMSA27277 ^b	722698, 3262029	mound flank midden	4.5	charcoal	685 ± 23	565–679	0.63–0.74
Grand Caillou	UGAMSA27274 ^b	722687, 3262033	relict forest floor	5.6	wood	862 ± 21	726–897	0.79–0.96
Grand Caillou	UGAMSA27275 ^b	722687, 3262033	relict forest floor	5.6	wood	887 ± 22	734–905	0.79–0.96
Grand Caillou	UGAMSA27278 ^{b,c}	722685, 3262024	mound flank (test pit)	0.5	charcoal	660 ± 22	560–670	0.62–0.73
Grand Caillou	UGAMSA27278 ^{b,c}	722685, 3262024	mound flank (test pit)	0.5	charcoal	658 ± 22	560–670	0.62–0.73

^a Age first published in Chamberlain et al. (2018a).

^b Age first published in Mehta and Chamberlain (2019).

^c Not shown in Fig. 5.

reliable OSL ages, if suitable protocols are employed (Chamberlain and Wallinga, 2019). Silt generally requires less machine time than sand to produce an OSL age, because fewer silt aliquots are needed owing to the averaging of signals arising from >1 million silt grains per disk. However, the preparation of sand is much less labor intensive than that of silt. For this study, we elected to use the sand-sized fraction for luminescence measurements, when available, to minimize labor costs. The Ellesly samples were relatively coarse; D_e measurements were performed on 1–2 mm diameter aliquots of 75–125 μm sand (~108 grains per disk). Aliquot preparation and measurement protocol of the Ellesly samples are identical to those described by Chamberlain et al. (2018a).

The Grand Caillou samples were relatively fine, and so for these we measured 10 mm aliquots for D_e s each containing ~2 mg of 4–11 μm quartz silt, purified using the H_2FSi_6 etch procedure of Chamberlain et al. (2017) and a total etch time of 143 h. The success of the etch was verified with the IR/blue OSL depletion test (Duller, 2003). Thermal transfer (Truelsen and Wallinga, 2003, Fig. A1) and dose recovery tests (Fig. A2) were used to tailor and validate a standard single aliquot regenerative (SAR) dose protocol to determine D_e values (Murray and Wintle, 2000, 2003). The results of these tests and the tailored SAR protocol (Table A2) are presented in the supplementary material (Appendix A).

Aliquot acceptance criteria included recycling and OSL infrared (IR) depletion ratios of 10% (Duller, 2003), a maximum test dose error of 20%, and recuperation of 5% relative to the highest regenerative signal. For all samples, the OSL signal was integrated over the first 0.48 s and subtracted background was integrated over 0.48–1.76 s to minimize the contribution of medium and slow components (Cunningham and Wallinga, 2010).

3.2.2. Dose rate determination

The natural radiation of the bulk sediment matrix was assessed from activities of ^{40}K and several radionuclides from the uranium and thorium series (Table A3) measured on a gamma spectrometer at Tulane University. We applied the dose rate conversion factors of Guérin et al. (2011) and beta dose attenuation factors of Mejdahl (1979). The cosmogenic contributions to dose were calculated following Prescott and Hutton (1994). For sands, an internal alpha dose of 0.010 ± 0.005 Gy/ka (Vandenbergh et al., 2008) and no external alpha contribution were assumed. For silts, no internal alpha dose was assumed, and for external alpha dose rate estimation an alpha efficiency of 0.04

± 0.02 (Rees-Jones, 1995) was used. Dose rate attenuation caused by water content (Aitken, 1985) was assessed through the in-situ water content by drying bulk sediment for each sample in a low temperature oven and applying 5% uncertainty to accommodate potential sampling disturbances and/or fluctuation in water content during burial.

3.2.3. Statistical treatments of D_e distributions and age calculation

The sample paleodoses of sand were obtained by applying the bootstrapped (Cunningham and Wallinga, 2012) minimum age model (bootMAM) (Galbraith et al., 1999) to the corresponding D_e distributions, as the bootMAM has been shown to be effective for age modelling of Mississippi Delta sands regardless of the degree of bleaching (Chamberlain et al., 2018b). We input a value of $11 \pm 3\%$ to the overdispersion parameter (σ_b) because this approach was used to date underlying deposits at the same location (Chamberlain et al., 2018a) and the paleodoses of Mississippi Delta sands are generally not sensitive to variations in σ_b on the order of a few percent (Chamberlain et al., 2018b). Paleodoses of silt were determined by calculating the mean and the 1-sigma standard error from the corresponding D_e distributions. OSL ages were calculated as the paleodose divided by the dose rate and are reported in ka relative to 2010 with 1-sigma uncertainty.

3.3. Compilation of archaeological data for the Lafourche subdelta

Information regarding archaeological sites, including mound dimensions and positions, history of academic and private investigations, recovered artifacts, chronology, and historical changes (e.g., contemporary destruction of mounds) are compiled within State of Louisiana Site Record Forms. We mined this archive to identify all prehistoric monumental archaeological sites within the Lower Lafourche subdelta. For each site we identified the architecture (earthen mound complex, single earthen mound, shell mound/midden, combined-material earthen and shell mound, or unknown), culture phase (e.g., Troyville, Coles Creek, Plaquemines, Mississippian), previously estimated site ages and prior chronology approach (relative and/or absolute dating) when available, and the last-reported condition of the site.

As mentioned above (Section 2.2, Archaeological investigations in the Mississippi Delta), Site Record Forms are not peer reviewed literature. Rather, they are an evolving tome of information amalgamated

from state and cultural resource management surveys. After each new survey, the forms may be updated to add a new layer of information. This means that information in the forms can extend well back to the mid nineteenth century, capturing historic changes to the sites such as destruction or submergence. The Site Record Forms also present limitations in that information is often given in different formats following the recorder's preference, some contain illegible hand-written notes and/or maps, and records may be incomplete, lacking citations, and/or not recently updated (many have not been improved in several decades, Table A1). The chronologic assessments are also problematic in that recorders may have used different ceramic typology schemes or cultural phase classifications that are not cited, and the analytical details of absolute ages are rarely given. The site chronology obtained from Site Record Forms is therefore sketchy at best, yet it is presently the best information available to describe the timing of construction of sites in the Lower Lafourche subdelta.

To further improve chronologic constraints for archaeological sites in the Lower Lafourche subdelta, we applied the assumption that sites must be younger than the land on which they were constructed (i.e., superposition). Using the geochronology of Chamberlain et al. (2018a) for land emergence in the Lafourche subdelta, we estimated the *terminus post quem* (i.e., the maximum age) of all sites positioned on this land. To accomplish this, we (i) plotted the location of each site on a map of Lower Lafourche, (ii) measured the site's distance from the subdelta apex in river kilometers along the nearest bayou (Table A1), and (iii) calculated the age of land emergence for the site's location using the linear progradation rate estimated by Chamberlain et al. (2018a) of:

$$t = -0.0084d + 1.6 \quad (1)$$

where d is distance in river kilometers from the subdelta apex (see Table A1), the intercept of 1.6 indicates the initiation of a linearly prograding shoreline at the time 1.6 ka, and t is the age of land emergence and thus the *terminus post quem* of the site. Our approach does not allow for refining the minimum age of sites.

4. Results and discussion

4.1. Detailed investigations at Grand Caillou and Ellesly

Cross sections for the two mounds show the lithologies, fossil and artifact contents, and chronologic constraints obtained for mouth bar, overbank, and/or mound deposits (Fig. 5). We note that no sandy mouth bar deposit was identified at Grand Caillou, and suspect that this is because the site is located in a relatively sheltered region of the delta (e.g., a protected paleo-bay) that did not experience winnowing of fine sediments during delta progradation. Nonetheless, the age of land emergence at this site can be estimated as ~1.2 ka based on the linear growth relationship of Chamberlain et al. (2018a), because shelly, laminated delta front deposits were identified 6–7 m below the silty/sandy sequence of natural deposits underlying the mound (Fig. 5).

The natural-landform-to-mound contact was clearly defined at Grand Caillou by the woody peat "forest floor" at 5.5–5.7 m below the mound surface (Mehta and Chamberlain, 2019) that radiocarbon dated to 0.79–0.96 ka (2-sigma uncertainty, Table 1). Deposits below the peat lacked any cultural artifacts and were deemed sterile, while those above the peat contained abundant shell, ceramic, fish and avian bone, and charcoal (Fig. 5). Furthermore, the sediment texture and structure varied across the natural-landform-to-mound contact at Grand Caillou; more homogenous silts and sands were found below and mottled and/or interbedded silt and clay deposits were identified above the contact (Fig. 5, Mehta and Chamberlain, 2019). As reported by Mehta and Chamberlain (2019) and discussed earlier, radiocarbon dating of charcoal within the mound fill constrained the beginning of mound construction circa 0.8 ka. We report calibrated radiocarbon

ages in ka relative to 2010 because this facilitates comparison with the geochronology of Chamberlain et al. (2018a) (Table 1). For details of the radiocarbon ages, please see Mehta and Chamberlain (2018).

OSL ages for overbank deposits at Grand Caillou, sampled 8.5–8.6, 7.4–7.5, and 6.4–6.5 m below the mound surface ranged from 0.81 ± 0.04 to 0.72 ± 0.04 ka (Table 1). This indicates rapid aggradation of the land surface prior to mound construction, likely through crevasse splay activity as described by Shen et al. (2015). Radiocarbon ages of wood extracted from the forest floor are slightly older than the OSL ages of underlying clastic deposits, however, the ages agree with each other within 2-sigma uncertainty. This suggests that the mound was constructed on a surface that was currently or recently active in terms of river flooding and sedimentation.

The geoarchaeological record of Ellesly is somewhat different in that it features a well-defined mouth bar deposit (Fig. 5), previously OSL dated to 1.06 ± 0.05 ka (obtained as the weighted mean of the two ages, Table 1) and overlain by the typical progradational lithogenic sequence described by Chamberlain et al. (2018a). The overbank unit is also well-developed here, comprising 6.1 ± 0.7 m of clayey, silty, and sandy deposits. Of note, the lowermost overbank deposits contain an organic rich, muddy sequence representing a low-energy floodbasin environment. Above this is a 2 to 4 m thick coarser-grain crevasse splay and natural levee unit, which relates to a large crevasse splay deposit that is clearly visible with LiDAR (Fig. 3c). The crevasse splay deposits sampled at 4.4–4.5, 3.3–3.4, and 2.5–2.6 m depth below the mound surface OSL date to 0.84 ± 0.07 to 0.79 ± 0.05 ka (Table 1), once again suggesting rapid aggradation through crevasse splay activity. The mound is situated on top of the crevasse splay and natural levee deposits (Fig. 5). However, the natural-landform-to-mound contact was less well-defined at Ellesly because of the reworking of mound deposits and a lack of prehistoric artifacts. Here, determinations were made on the basis of sediment structure and topography. Topography and mouth-bar displacement (likely caused by greater sediment loading by the mound) revealed the footprint of the mound, and mottled sediment interpreted as mixed fill was used to classify mound deposits. These showed that the mound is presently 1.9 m thick at the location from which the OSL samples were collected. We did not try to obtain any chronology for the mound itself because of the extensive degree of disturbance.

Despite the differences in geology, architecture, and preservation, the two sites have commonalities regarding the relationships of the mounds to the landscape. Both sites are underlain by a rapidly aggraded crevasse splay and natural levee deposit that is ~200 to 400 yr younger than the timing of land emergence (Fig. 5). This suggests that ancient people were not immediately occupying and modifying newly-emerged coastal land. Rather, there was a multi-century pause that allowed for natural processes of overbank deposition to aggrade the land prior to mound construction. Overbank deposition has been shown to occur over short timescales (i.e., individual crevasse splay episodes) at rates up to 1–4 cm/yr in the Lafourche subdelta (Shen et al., 2015). Here, we also estimate the elevation that could be gained at any site in Lower Lafourche during this ~200–400 yr lag as a function of centennial-timescale overbank aggradation (Fig. 7). We approach this by plotting overbank thickness as a function of sedimentation time, using the stratigraphic and chronologic data of Chamberlain et al. (2018a). Sedimentation time is calculated as the time between land emergence (i.e., the mouth bar sand OSL age) and the end of sedimentation corresponding with the abandonment of the Lafourche subdelta at 0.6 ka (Shen et al., 2015; Hijma et al., 2017; Chamberlain et al., 2018a). This test indicates the centennial-timescale rate of overbank aggradation in Lower Lafourche was ~0.7 mm/yr. In the ~200 to 400 yr between land emergence and site construction, land could have therefore aggraded to ~1.4–2.8 m above sea level (Fig. 7), making sites less flood-prone and more desirable for habitation.

As elevation at these locations increased with time, the locations also became more relatively inland because the Lafourche subdelta continued to prograde coastward at a rate of 100 to 150 m/yr (Chamberlain

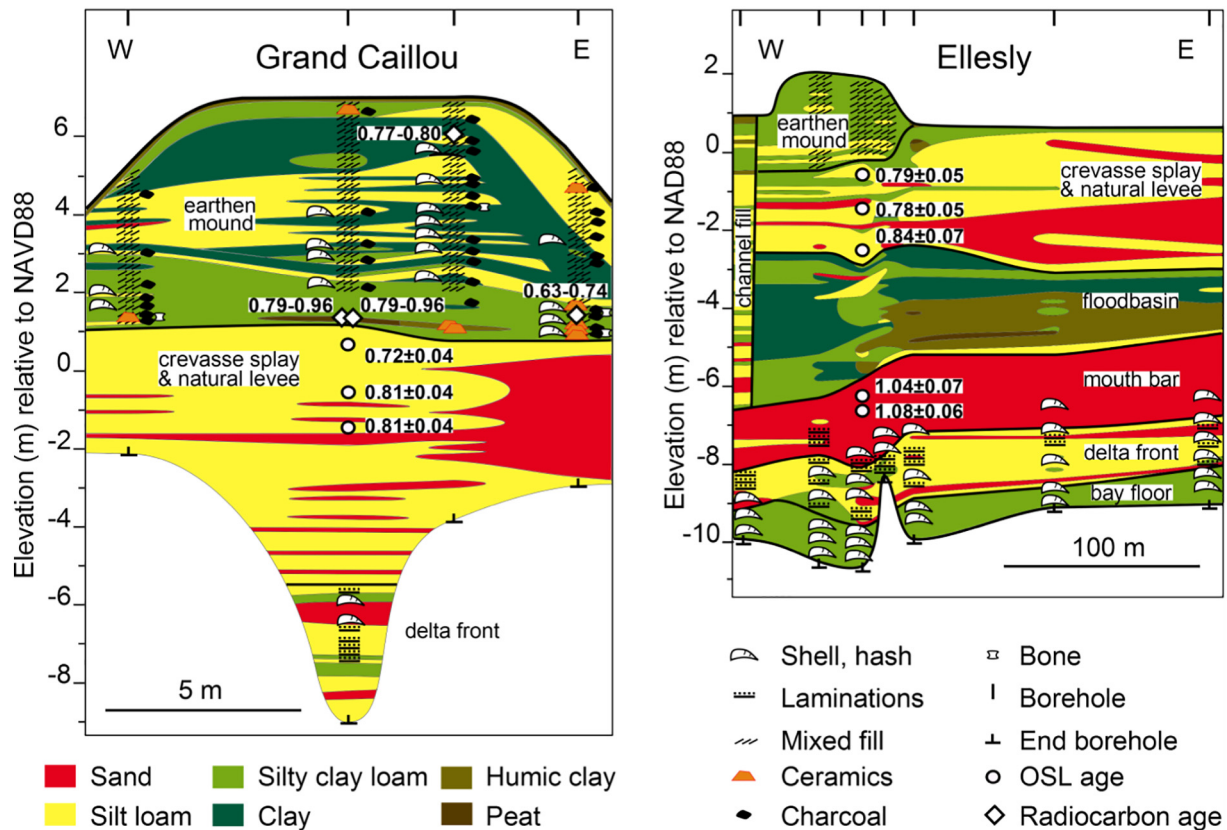


Fig. 5. Cross sections showing sediment texture, OSL and radiocarbon chronology, natural features, artifacts, and interpreted depositional units for the Grand Caillou and Ellesly mounds and underlying natural deposits. The Grand Caillou cross section is modified and its radiocarbon ages are from Mehta and Chamberlain (2019); the Ellesly cross section is modified from Chamberlain et al. (2018a), Supplementary File. OSL ages for the mouth bar deposits at Ellesly are from Chamberlain et al. (2018a); all other OSL ages are presented here for the first time.

et al., 2018a). This would have afforded occupants additional protection from hurricane flooding because of the seaward natural buffer of newly-emerged land and wetlands. In addition to elevation gain at the mound sites, the environment of the broader area near the mound would have changed from wet and exposed to drier and sheltered in the several hundred years after land emergence. We expect this change to correspond to improved opportunities for gathering food (e.g., hunting, fishing, berries) necessary to support the populations of mound-building communities.

4.2. Chronology and conditions of Lower Lafourche archaeological sites

Our investigation of Site Record Forms and previous literature identified 36 prehistoric, monumental archaeological sites within the delineated study area (Figs. 1 and 6). Of these, 22 were characterized by relative chronology obtained from ceramics typology, and five also had absolute chronology obtained by radiocarbon dating (Table A1). The radiocarbon ages ($n = 6$) for the Grand Caillou site were obtained from charcoal and wood materials (Mehta and Chamberlain, 2019; see Table 1), while the previously reported ages ($n = 6$) for the other sites ($n = 4$) were primarily obtained from *Rangia cuneata* shells (Table A1). No chronologic constraints were identified for 14 sites (Table A1).

We estimated new constraints for the *terminus post quem* of the previously-dated sites, including those with prior relative chronology obtained from ceramics (Fig. 8, orange open triangles) and prior absolute chronology obtained from radiocarbon dating (Fig. 8, gray and red bars). The *terminus post quem* ages we estimated (Fig. 8, blue open diamonds), constrained by the time of land emergence (Fig. 8, black filled circles and linear regression), are up to 600 yr younger than those determined by previous work (Table A1). Maximum ages obtained from ceramics typology tended to scatter above and below our *terminus post*

quem ages; we show the ceramics ages as maximums because the range of this relative dating approach is quite large and our method only allows for refining the upper limit. Ages obtained by prior radiocarbon dating documented in the Site Record Forms were generally older than the *terminus post quem* and best-estimate ages we determined (Fig. 8) with the exception of the Dulac site (Table A1) where prior radiocarbon dating of charcoal produced one near-modern age indicating disturbance of the mound. The inaccuracy of the radiocarbon ages is not surprising as estuarine shells were the most common dated material (Table A1) and this is prone to poorly constrained reservoir effects (Törnqvist et al., 2015). No reservoir correction for these ages was recorded in the Site Record Forms. The radiocarbon ages of Mehta and Chamberlain (2019), obtained from in situ charcoal and wood and not requiring a reservoir correction, are in agreement with our new age constraints. In all, our work was able to refine the upper age of 16 previously dated sites. We also provide new chronologic constraints for the 14 previously undated sites (Fig. 8, Table A1).

Our findings at Grand Caillou and Ellesly showed that the two tested mounds were constructed ~200 to 400 yr after land emergence (see Section 4.1. Detailed investigations at Grand Caillou and Ellesly). We propose that site ages may be 200 to 400 yr younger than the *terminus post quem*, indicated in Fig. 8 by blue arrows, and we provide a best estimate of the earliest timing of site construction as a function of distance to the subdelta apex based on this observation. Nonetheless, we note that this observation is based on detailed investigations of only two sites, and so the *terminus post quem* ages may be better relied on as conservative estimates.

Our investigation also returned data about the last-reported condition of the monumental sites (Table A1). We found that 11 sites were reported to have been completely destroyed. We classified an additional 11 sites as disturbed, typically by historic intrusive cemeteries, erosion, canal dredging, leveling, and/or submergence in water. The Site Record

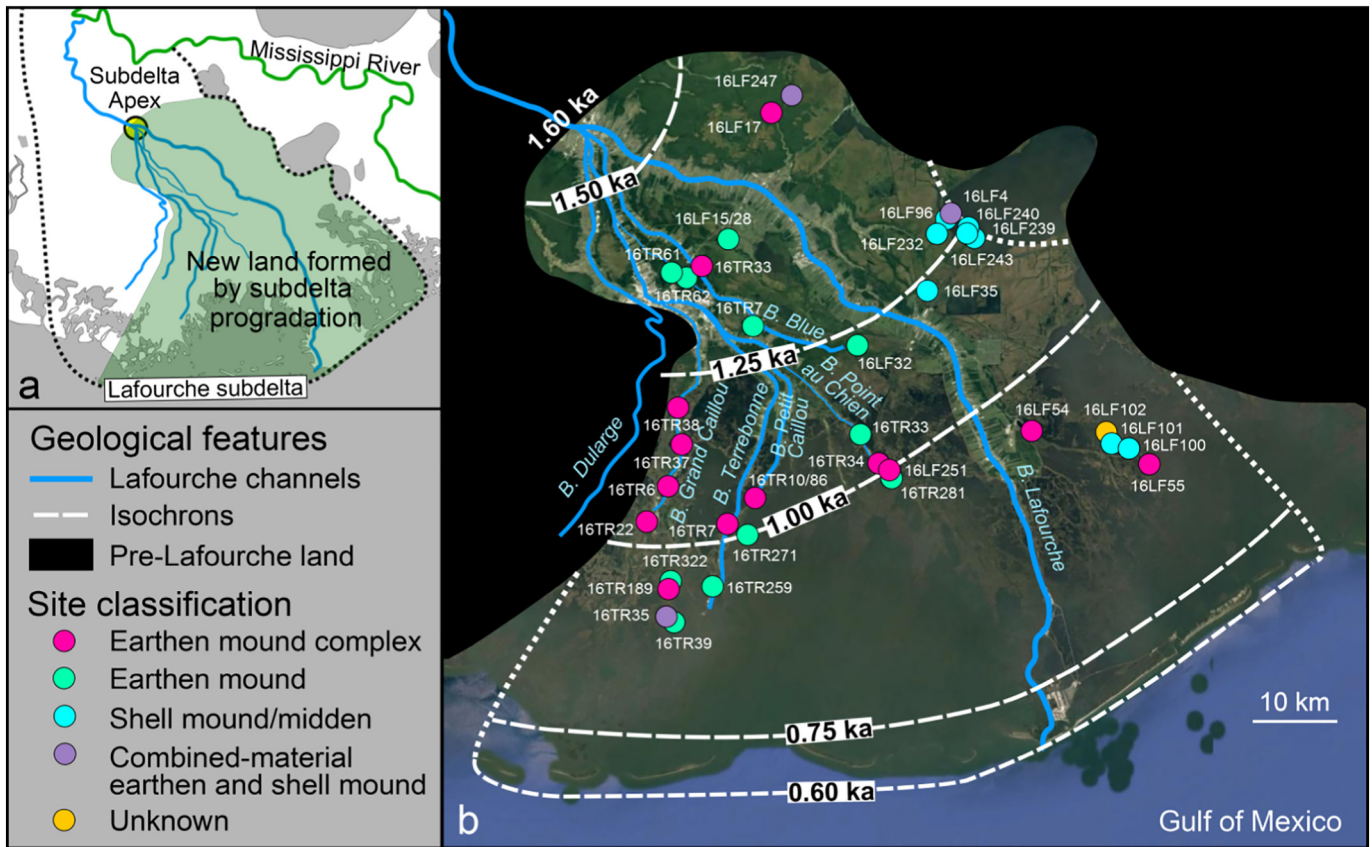


Fig. 6. The location and architectural classification of monumental archaeological sites are shown in the context of the growth history of the Lafourche subdelta. The Lafourche subdelta initiated at ~1.6 ka and grew seaward in a radial fashion from the subdelta apex, forming 6000–8000 km² of new area (shaded region, (a) (Chamberlain et al., 2018a). The *terminus post quem* of the archaeological sites were estimated based on the timing of land emergence (Chamberlain et al., 2018a) indicated by the white dashed isochrons (b).

Forms contained no information regarding the condition of seven sites. We only identified seven sites as including at least one intact mound at the time of last reporting, which ranged from 1955 to 2018. Of these “intact” sites, only two were assessed within the twenty-first century, meaning that the true number of intact sites may presently be much

smaller. This observation underscores the importance of our approach and its results; although we are not able to directly obtain high-resolution chronologies of many of the sites, we do provide valuable chronologic constraints for a large number of at-risk or lost archaeological sites for which ages may not be otherwise obtained.

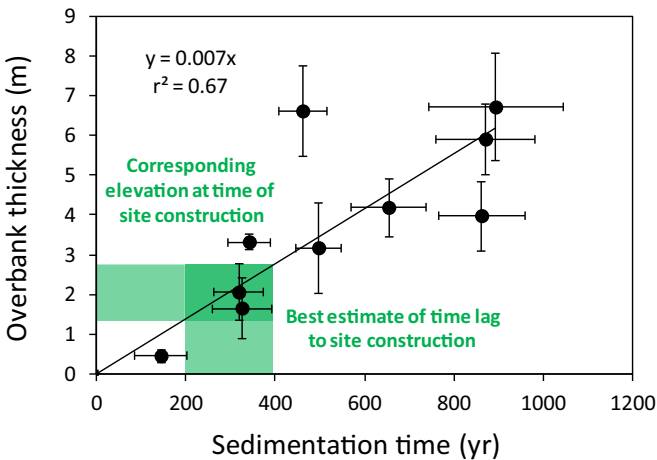


Fig. 7. We identified a 200–400 yr lag between land emergence and site construction at Ellesly and Grand Caillou. Using the chronology and overbank thickness data of Chamberlain et al. (2018a), we estimate this corresponds to an elevation gain of ~1.4–2.8 m at a centennial-timescale average overbank aggradation rate of 0.7 mm/yr. Sedimentation time is calculated as the time between land emergence (i.e., the mouth bar sand OSL age) and the end of sedimentation corresponding with the abandonment of the Lafourche subdelta at 0.6 ka.

4.3. Distribution of archaeological sites

High-elevation land is relatively scarce in the coastward regions of the Mississippi Delta; prehistoric and present-day communities tend to cluster along the banks of the distributary channels or bayous. As such, these rare strips of land have complex and lengthy human histories. It is not uncommon for a site to contain a succession of material culture, serving first as a prehistoric monumental complex, then as an antebellum plantation, subsequently a farm, and ultimately a present-day community (Morris, 2000). For example, the location that hosts the contemporary community of Berwick was once the site of the Berwick plantation, and also featured a large collection of earth and shell middens (Prichard et al., 1945) that coincide with the present-day eponymous city center (Ryan et al., 2005).

We observe that the majority of the earthen mounds and earthen mound complexes in the Lower Lafourche subdelta, including Grand Caillou and Ellesly, are situated on natural levees of distributary channels consistent with previous findings in the region (Törnqvist et al., 1996b; Kidder and Balee, 1998; Rodning and Mehta, 2015) and similar to human settlement patterns in other deltas (e.g., Holz, 1969; Louwe Kooijmans and Knip, 1974; Donoghue and White, 1995; Stanley and Chen, 1996; Politis et al., 2011; Pierik and van Lanen, 2017). This strategic location places them in a naturally high-elevation setting with access to major waterways that served as important modes of transportation

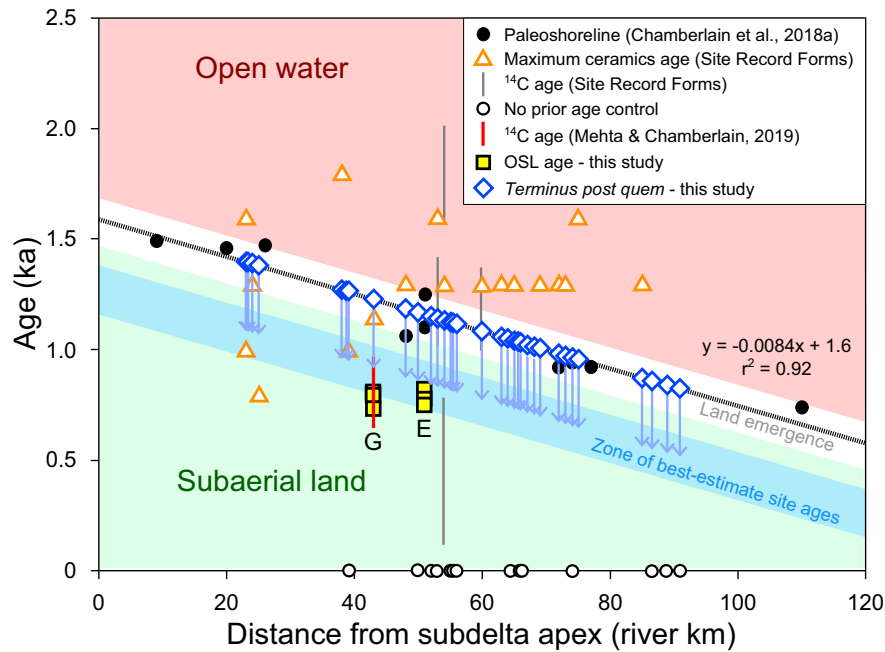


Fig. 8. Prior work showed that the shoreline of the Lower Lafourche subdelta prograded from the subdelta apex (Fig. 5a) at a linear rate determined from OSL dating of emergent-land deposits (filled black circles). We use this information to identify the *terminus post quem* (open blue diamonds, x-axis) of archaeological sites of unknown ages (open circles), with relative ages from ceramics typology (orange triangles), and with absolute ages from radiocarbon dating (gray and red bars). For relative ages, we show only the maximum age. The black line indicates the time of land emergence as a function of distance from the subdelta apex; site-age datapoints within the red shaded region above this line indicate incorrect site ages, while site-age datapoints within the green and blue shaded region below may be accurate. The Ellesly and Grand Caillou sites are identified as “E” and “G”, respectively. By applying our finding that mounds were constructed ~200–400 yr after land emergence, we also make a best estimate of the time of site construction (shaded blue region) as a function of distance from the subdelta apex. Blue arrows indicate uncertainty on our age estimates.

(Rodning, 2003). Alternatively, the lack of interdistributary earthen mounds and complexes in our analyses may represent a survey or preservation bias, as these sites would be the most difficult to document and also the most vulnerable to submergence.

By contrast, we note that shell mounds/middens tend to be localized near brackish lakes occurring in the drainages in between subdeltas (Fig. 6). This shows that indigenous peoples were likely exploiting mollusks and other aquatic resources that were abundant in these interdistributary environments. This observation also enables paleoenvironmental reconstructions because it suggests that such regions within our study area hosting present-day brackish-water lakes with numerous adjacent shell mounds/middens have likely been open water for more than a millennium. Additional analyses in the future could look to isotopic analyses of shellfish and aquatic animal resources found in archaeological middens to identify aquatic regimes and environmental conditions. The absence of shell middens in other environments might indicate that shell was not transported over long distances or that cultural rules mandated that shell remain close to its source.

Many monumental sites are located in a chronologic band where land emergence and thus the *terminus post quem* of sites has been constrained to 1.25–0.9 ka suggesting that coastal indigenous communities may have been particularly active in mound building during this time or the several hundred years afterward. The high density of sites within the 1.25–0.9 ka chronologic band may reflect resource richness within the Lafourche subdelta; during that time interval the subdelta likely hosted the most dominant waterway and depocenter in the Mississippi Delta (Hijma et al., 2017; Chamberlain et al., 2018a). The Lafourche distributary network had been active for >400 yr, meaning inland locations were relatively stable and had developed high-elevation natural levees through overbank aggradation (Chamberlain et al., 2018a). The band of sites may also be culturally significant; previous work has shown that the territorial limits of political boundaries on land is roughly a day’s travel (Hally, 1993). Political boundaries may explain the spacing of earthen mound complexes along Bayou Grand

Caillou and also the connectivity of sites within the Lafourche subdelta. However, in this aquatic landscape, canoe travel would have greatly enhanced travel capabilities and distances, and consequently the travel distances of terrestrial models are not directly applicable to our study area. Instead, we must consider how canoe travel would have expanded the boundaries of political units along the Gulf Coast, which would require additional research and resources to document the relationships between archaeological mound sites spread across the Lafourche subdelta. The chronologic banding of sites may also relate to broader cultural trends within mound building peoples outside the delta; previous studies have identified rapid cultural growth of coeval Gulf Coast societies during this window (Sears, 1954; Schilling, 2004; Kidder, 2007; Shuman, 2007; Weinstein and Dumas, 2008). Alternatively, the high occurrence of monumental sites from 1.25–0.9 ka may be caused by sample/preservation bias because significant coastal erosion and/or subsidence has driven land-loss of more seaward (younger) locations (Fig. 1).

4.4. Implications for present-day coastal communities

In present-day Louisiana, the implementation of engineered diversions aiming to siphon sediment from the modern Mississippi River to feed shrinking wetlands (CPRA, 2017; Xu et al., 2019) hints at a paradigm shift, beginning with the end of the “Levees-only” policy (which aimed to strictly control the river exclusively through artificial levees while cutting off many natural outlets, Rivera and Miller, 2006; Barry, 2007), to embrace river and coastal engineering solutions that incorporate rather than fight natural processes. These “nature-based approaches” are of growing interest for delta management because they may be more cost effective, sustainable, and ecologically friendly than traditional hard infrastructure (e.g., Saeijs et al., 2004; Stive et al., 2013).

The geoarchaeological record is a valuable archive for identifying coupled human-landscape interactions (e.g., Goodbred et al., accepted) including human-exacerbated geohazards and time-tested

nature-based solutions to landscape management that may inspire present-day sustainable solutions. For example, Pierik et al. (2018) used a geoarchaeological record of the Netherlands spanning >3 ka to show that early agriculture and wetland reclamation drove channel avulsion in the Rhine-Meuse Delta. Similarly, Nieuwhof et al. (2019) found that wetland reclamation in combination with dike construction beginning circa 0.9 ka exacerbated land-surface subsidence and thus flood-vulnerability of coastal Dutch communities. They showed that prior to dike construction, people lived in community-scale elevated earthen platforms and allowed for periodic inundation of surrounding plains, and proposed this could be considered as an alternative delta management strategy (Nieuwhof et al., 2019). In fact, such strategies have recently been implemented along a branch of the river Rhine in the Netherlands, where a dike has been displaced to reduce flood levels through increasing floodplain area, and farms in the area were relocated to newly constructed mounds (Roth and Winnubst, 2014).

Here, we show that early occupation of the Mississippi Delta occurred only on favorable sites such as high-elevation natural levees at relatively inland locations. It has also been suggested that prehistoric people in the Mississippi Delta moved with the river, abandoning sites as the depocenter (and fresh water source) shifted (McIntire, 1958; Mehta and Chamberlain, 2019). Although prehistoric people have been shown to have regional impacts on ecology and land change (for example, discarding shells in piles that generated new topography and ecological islands, Kidder, 2000), the habitation strategies we identify would have had little impact on delta-scale land-building processes.

Subsequent historic advances in water management including the construction of artificial levees and later river control structures aimed to prevent flooding and stabilize the path of the Mississippi River, both upstream and within the delta (Alexander et al., 2012). Locking the river in-place and reclaiming wetlands allowed land-use opportunities to expand to less ideal locations such as near-river floodplains and floodbasin swamps, accommodating a twentieth century burgeoning urban population in southern Louisiana and industrial interests (Campanella, 2017). Similar engineering strategies have also been employed in other deltas worldwide (e.g., Van de Ven, 1996).

However, this approach has not withstood the test of time. Rather, the historic infrastructure that stabilized the Mississippi Delta and other deltas and allowed rapid expansion into distal floodplains and former wetlands has had the longer-term damaging effect of inhibiting natural delta building processes by cutting off sediment resources (e.g., Day et al., 2007; Auerbach et al., 2015) and lowering the water table to inhibit peat preservation and development (e.g., Hooijer et al., 2012; Higgins et al., 2013). Moreover, land-use driven changes in the hydrological system may accelerate subsidence rates (e.g., Erkens et al., 2016; Minderhoud et al., 2018). As a result of recent human activity, many modern coastal communities and infrastructure in Louisiana and elsewhere are extremely vulnerable to inundation from high-energy storms and meteoric water (Syvitski et al., 2009; Tessler et al., 2015), a situation that is expected to worsen as deltaic land shrinks and eustatic sea level rises (IPCC, 2018).

We recognize that abandoning or allowing for controlled river flooding of vulnerable, yet inhabited, regions would be quite disruptive for modern communities in the Mississippi Delta. However, serious consideration should be given to whether these regions will be sustainable and how they may be best maintained. Ultimately, the strategic relocation of endangered present-day coastal communities and careful planning of new developments to minimize flood and storm risk for the future may be less expensive and damaging, enhance cultural preservation, and result in less loss-of-life than unplanned abandonment of vulnerable communities in response to immediate crises such as hurricane flooding.

5. Conclusions

Our study used stratigraphy and new OSL chronology in the context of recently published records of deltaic land growth to refine the knowledge and understanding of archaeological sites in a large region of the

Mississippi Delta. We first discussed two archaeological sites in detail to understand their architecture and relationship to the landscape. Through novel methods, we then estimated new chronologic constraints for 30 prehistoric archaeological sites including 14 sites that have been destroyed and may not be dated by any other means. From this effort, we arrive at the following conclusions:

- Despite differences in their geoarchaeological records, both sites investigated in detail are underlain by rapidly aggraded crevasse splay and natural levee deposits. Geochronologic constraints at Ellesley and Grand Caillou sites and rates of overbank deposition elsewhere suggests that it took several hundred years after land emerged before the environment was suitable for the communities that constructed earthen mounds.
- The upper age limits for site construction based on the OSL age of underlying natural deposits are generally several hundred years younger than those obtained by prior radiocarbon dating of estuarine shells, while ages obtained by ceramics typology tend to scatter above and below those obtained by OSL dating of associated natural deposits. Our approach provides valuable chronologic constraints for archaeological sites that may no longer be directly dated and thus helps to build knowledge of indigenous people of the Mississippi Delta.
- The majority of earthen monuments in the Lafourche subdelta were constructed on high-elevation natural levees, consistent with prehistoric settlement patterns worldwide. Monument construction appears to be enhanced during the peak of Lafourche subdelta activity, consistent with optimal living conditions within the Lafourche subdelta but also consistent with active mound-building in the broader region of the Gulf Coast.

Finally, we considered our findings in the context of contemporary land loss in coastal Louisiana. We conclude that early inhabitants of the delta chose favorable community sites with little impact to delta-scale land-building processes. By contrast, historic developments rely heavily on river engineering that has perturbed natural processes of land growth and maintenance within the delta, making present-day communities extremely vulnerable to inundation. The sustainability and management of these regions merit serious scrutiny.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.geomorph.2020.107132>.

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