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SEDIMENTARY RECORD OF EXTREME EVENTS IN THE LAKE MAUREPAS BASIN, SOUTHERN LOUISIANA

Jonathan Edward Lambert

SEDIMENTARY RECORD OF EXTREME EVENTS IN THE LAKE MAUREPAS BASIN, SOUTHERN LOUISIANA

by

Jonathan Edward Lambert

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Dr. Kam-Biu Liu

Department of Oceanography and Coastal Sciences

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& Agricultural and Mechanical College
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I want to also acknowledge the other members of my thesis panel. Dr. Kanchan Maiti of the Department of Oceanography and Coastal Sciences provided novel insights into analysis of the cores for my thesis, and also ran vital ^{137}Cs and ^{210}Pb tests to determine the age of the upper parts of the cores. Dr. Barry Keim, the final panel member has been a mentor of mine for almost 4 years now, and is one of the reasons that I am fascinated with hurricanes and storm surge research, and I thank him for his time serving on the review panel.

Finally, I want to acknowledge the LSU Honors College and the faculty and staff associated with it for their guidance in the thesis process.

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ABSTRACT

This study characterizes event deposits in sediment cores taken from Carthage Bluff Marsh (CBM) near the mouth of the Amite River at Lake Maurepas in southeastern Louisiana. This research is part of a larger project focusing on the spatial and temporal variability of sediment supply in the context of the coupled natural-human system in South Louisiana. Through analysis of the CBM site, we will gain insight into the sedimentary and flood history of the area, with a goal of detecting changes in deposition rate and sedimentary dynamics due to natural and/or anthropogenic factors. Hurricane Isaac and other recent hurricanes have provided an excellent opportunity to investigate these sedimentary processes. Sedimentary cores were collected and subsequently analyzed via Loss on Ignition (LOI), X-Ray Fluorescence (XRF), and other techniques to determine sediment stratigraphy and chemical composition, from which the environmental history of the area including the occurrence of extreme events and ecological responses can be reconstructed. The Hurricane Isaac event layer is observed, as well as multiple other possible recent, historic, and prehistoric tropical cyclone event layers. Also observed is a possible prehistoric flooding event tentatively attributed to the expansion of Lake Maurepas causing the inundation of the study site.

INTRODUCTION

The motivation to perform this study comes from the impacts of Hurricane Isaac in 2012. This hurricane created extensive flooding throughout southeastern Louisiana, and had enormous economic impacts on the area. Isaac made landfall near the mouth of the Mississippi River as a minimal category 1 storm. Due to its large size and slow movement, it generated a large storm surge and produced extremely heavy rainfall (~50 cm in New Orleans) in southeastern Louisiana, resulting in extensive inland flooding in the fluvial-lacustrine lowlands around Lake Pontchartrain, Lake Maurepas, and the Mississippi deltaic plain (Figure 1) (Berg, 2013). Strong easterly winds across Lake Pontchartrain and Lake Maurepas produced extensive storm surge along the west shore of these lakes, causing unprecedented flooding of the human communities and the forested wetlands between and around the lakes (Keller et al, 2014; Liu et al, 2014a, 2014b, 2014c). Field observations made soon after Hurricane Isaac led to the expectation that this extreme event resulted in significant storm deposition in the wetlands around the lakes. On that basis, it is hypothesized that extreme events like this have occurred in the past, and these recurrent events have contributed significantly to the sedimentary history of the Mississippi River deltaic plain region of coastal Louisiana. The landfall of Isaac offered an excellent opportunity to study the sedimentary impact of a modern hurricane, which can also contribute valuable data for reconstructing the historic changes in sedimentation rates in Louisiana. However, despite the unprecedented flooding and socio-economic impact of Hurricane Isaac, it is likely that it was a relatively minor event compared to those that have occurred in prehistoric times.

To study the history of extreme events in this basin, especially hurricanes, a relatively new field of science called paleotempestology is used. Paleotempestology is the study of

prehistoric tropical cyclones by means of geological proxy techniques, and identifies extreme events such as hurricanes through sedimentary or isotopic evidence (Nott, 2004). Identifying these events can aid in estimation of storm return periods, and can give an estimate of sedimentation in the area (Liu, 2004, Elsner et al, 2008).

The study of cores through paleotempestological methods can also provide evidence of environmental changes in the area such as Lake expansions/formations, drought, and floods (Frappier et al, 2007). The Lake Maurepas basin where this study is conducted is very prone to environmental changes such as these due to its location in the Mississippi River delta, which has shifted positions frequently over recent millennia, and has been subject to changes in sea level (Day et al, 2007). These environmental changes also fall under the hypothesis that other extreme events more catastrophic than Isaac have occurred in the area, greatly affecting the sustainability of the region.

As mentioned, the main objectives of this experiment are three fold: to characterize event deposits of extreme events such as hurricanes or environmental changes in sediment cores taken from the Basin (using paleotempestology), to determine the long-term sedimentation and flood regimes of the area, and to assess the overall sustainability of the region. And, it is hypothesized that events similar to Isaac have happened in the past, and that this was even a minor event compared to those in prehistoric times. It is also hypothesized that these events have significantly contributed to the sedimentary history of the area.

STUDY AREA

This specific study investigates cores taken at Carthage Bluff Marsh (CBM). Carthage Bluff is a small community located 5 km upstream from the mouth of the Amite River west of Lake Maurepas (Figure 1), and was flooded under 2 m of water during Hurricane Isaac, which left behind a 5 cm thick sediment deposit on the ground and presumably also in the forested wetlands adjacent to the river. Evidence of that storm deposit was seen during fieldwork (conducted 29 days post-Isaac by Dr. Liu's research team) in the form of well-developed mud cracks on the ground (Figure 2). This evidence of significant storm surge deposits was intriguing, and catalyzed this study of the sedimentary history of the CBM site. In addition to the presence of evident storm surge deposit, this site was chosen because of its unique position between the Amite River and Lake Maurepas. This close proximity to the river exposes the CBM site to fluvial flooding events, and also presumably sediment deposition from these events. Additionally, the proximity of the site to Lake Maurepas exposes the site to flooding and sediment deposition from storm surge events. Elucidating the effects of this on sedimentation in the area provides good comparison to other studies of sites near only one major body of water in the region (Falcini et al, 2012, Khan et al, 2013).

METHODS

Cores for this project were collected on two separate trips. On the first field trip, three sediment cores measuring 196 cm, 47 cm, and 32 cm were collected 4 weeks after Hurricane Isaac with a Russian peat borer from a cypress swamp adjacent to the Amite River. Surface samples were also collected from the Isaac storm deposit on the ground and in the swamp to provide a geological fingerprint for that particular storm. These cores were named CBM-1, CBM-2, and CBM-3. All core samples were placed and kept in a cold room at ~4°C.

The sediment cores were studied stratigraphically by means of loss-on-ignition (LOI) analysis and X-ray fluorescence (XRF) analysis so that the sedimentological and geochemical characteristics of the Isaac deposit as well as previous storm deposits and environmental changes could be identified (Figure 3). LOI is performed by burning sediment samples every centimeter along the core at 100, 550, and 1000°C to determine the amount of water, organics, and carbonates, respectively, in the sample. Sediments from storm surge flooding events typically have lower organics and higher carbonates than natural marsh sediment, which is high in organics and water, and low in carbonates. XRF analysis involves using a handheld XRF spectrometer, and taking readings every 2 centimeters along the core. This device provides a chemical signature based on the secondary x-rays from the sample that has been bombarded with high energy x-rays. This chemical signature provides a higher resolution than the LOI when determining the origin of sediment layers.

Samples for ^{7}Be isotopic analysis from the top 6 cm of each of the three cores were also sent to Dr. Jaye Cable at the University of North Carolina to confirm that the uppermost sediment was indeed deposited by a recent event, i.e., Hurricane Isaac. The ^{7}Be isotope, with a half-life of 53 days, provides an accurate way of determining if sediments have been deposited

recently (within ~1year). Finally, samples from 80 cm and 127 cm in the CBM-1 core were sent to Beta Analytic, Inc., for radiocarbon dating (Figure 4). The ^{14}C isotope has a half-life of 5,730 years.

On the second field trip in late February of 2014, additional cores were collected from the same site to further confirm the event layers seen in the original samples, and to procure more sample material for ^{137}Cs and ^{210}Pb analysis. This particular study looks at a 38 cm slab of sediment taken with a flat shovel, named CBM-201-Slab (Figure 5), which is combined with a 30 cm aluminum core named CBM-201-Alum (Figure 6), taken directly below the slab sample. These cores were then combined in the lab, and are referred to simply as CBM-201. LOI and XRF analyses were run on this core as well to determine its sedimentological and geochemical characteristics, as compared to the previous cores (Figure 7). ^{137}Cs analysis was also conducted for this core (Figure 8). ^{137}Cs has a half-life of approximately 30 years, and the procedure for determining dates is based on the peak of Cs introduction into the atmosphere via nuclear testing, which occurred in 1963. However, Cs was first introduced into the atmosphere in 1952, so this form of dating is only useful until this year. Due to time constraints during this part of the experiment, only three samples were taken and analyzed from 7, 20, and 26 cm for ^{137}Cs.

RESULTS

CBM-1

Visual analysis of the CBM-1 core does not show much obvious change in material, except for a distinctly muddy/clay layer from 80 – 120 cm, contrasted against the rest of the core, which is primarily peaty (Figure 9). There are two other slightly muddy layers near the bottom of the core around 160 cm and 180 to 198 cm as well.

The LOI curve shows a drop in organic matter contents and an increase in carbonate contents in the uppermost 6 cm of the core, a signature indicative of a storm deposit. XRF analysis also detects peaks in the abundance of lithogenic elements such as K, Ti, V, Cr, Fe, Co, Zn, Rb, Mn, and Zr in this uppermost 6 cm of the core. Two more layers with the same geochemical and sedimentological signature are observed at a slightly lower level, at depths of 12-16 cm, and 24-25 cm. Additionally, the thick layer of light-brown colored clay bears a similar geochemical signature, as well as an extreme reduction in organic content, and occurs from 80-122 cm. Finally, beneath this clay layer, three other drops in water and organic contents occur in the lower part of the core, centered at 142, 160, and 185 cm, which are also accompanied by increases in lithogenic elements in the XRF curves, although the correspondence between the LOI and XRF results is more complicated than in the uppermost layers.

^{7}Be isotopic analysis showed highest levels (21.51 dpm/g) in the section samples from 4-6 cm, with detectable levels from 0-2 and 2-4 cm as well. Finally, radiocarbon analysis returned ^{14}C dates of 100 ± 30 yr BP for the 80 cm sample and 770 ± 30 year BP for the 127 cm sample in CBM-1.

CBM-201

Visual inspection of the CBM-201 core (comprised of CBM-201-Brownie and CBM-201-Alum) reveals distinct changes in sediment composition. In the CBM-201-slab core, the sediment from ~0-10 cm appears very clayey in composition, transitioning from 10-20 to a peaty clay, and from 20-40 to more organic/peaty. In the subsequent core, CBM-201-Alum, the sediment composition appears quite organic from ~0-8 cm (corresponding to a depth of 39-45cm), transitioning to more of a peaty clay below, with a distinct clay layer around 15 cm (52 cm below), giving way to another slightly peaty layer from 16-23 cm (53-60 cm below), and finishing the core with another clay layer until 31 cm (68 cm below). LOI analysis generally corresponds to this, with decreases in organic and water contents, with slight spikes in carbonates in the clay layers, and elevated organic and water content in the peat layers (Figure 8). However, the LOI from 0-20 cm shows almost constant low organics, in contradiction to visual evidence, XRF signatures, and relative to the other cores (Figure 10).

XRF analysis detects peaks in the abundance of lithogenic elements generally correlated to dips in organics in the LOI curve for CBM-201, at locations in the core centered at 32, 52, and 63 cm. However, the XRF data do not correspond well to the LOI curve from 0-20 cm, but does correspond well to the XRF curves of the other cores, showing peaks in lithogenic elements from 0-6 cm, 12-16 cm, and ~20 cm.

^{137}Cs analysis of CBM-201 indicates a possible peak in cesium near 15-20 cm, implicating the age of this sediment as ~50 years, going back to the cesium peak in 1963. However, more depth samples need to be analyzed before interpreting these data fully.

Sedimentation

Using a date of 1963 for 20 cm below the surface for the CBM-201 core from cesium dates, the calculated rate of sedimentation assuming constant rate of sedimentation is 0.39 cm per year. A sedimentation rate from 80 cm to the top was not calculated due to the multiple intercepts of this radiocarbon date on the calibration curve, which yield a wide range of possible calendar ages from 15 years BP to almost 300 years BP. However, the reliability of the other radiocarbon date of 770 years at 127 cm is good and provides a sedimentation rate of 0.16 cm per year for the core section above. Given that no compaction correction was performed, the two ages are likely within a factor of two in accuracy.

DISCUSSION

Tropical Cyclone Event Layers

Hurricane Isaac was the catalyst for this study, to elucidate its event layer, but also to investigate event layers of other catastrophic storms. Most results in this study support a Hurricane Isaac event layer from 0-6 cm in most cores. Elevated carbonates and decreased organics indicate a storm surge layer in the LOI, peaks in lithogenic chemicals in the XRF point to an allochthanous depositional event, and the presence of ^{7}Be in the sediment down to 6 centimeters supports that 6 cm of sediment was newly deposited. Since the cores were taken immediately after Isaac, this hurricane was the only possible source of such major and rapid sedimentation.

There are multiple other possible tropical cyclone event layers that are supported by the results. A layer of depressed organics in the LOI and lithogenic sediments in the XRF occurs from 12-16 cm in CBM-1, and this XRF signature is also seen in CBM-201. The cesium data suggest a year of 1963 for sediments approximately 20 cm down, leading to the assumption that this second event layer was likely caused by Hurricane Betsy in 1965. This hurricane took a similar track to Isaac, and therefore would create a similar storm surge (USDOC, 1965). However, this cannot be completely confirmed without further dating and analysis.

Additional possible event layers strongly implicated by CBM-1 are centered at 25, 142, 160, and 185 cm. There is also slight implication of an event layer at 35 cm. CBM-201 implicates an event layer at 35 cm in the LOI as well as slightly in the XRF. CBM-201 also strongly implicates an event layer at 25 cm in the XRF, which is consistent with previous cores. The LOI from 0-20 cm is consistent with the presence of a clastic layer indicative of a flood

event due to its lowered organic content. The Isaac layer is thicker here due to the lack of compaction in the slab dug by the shovel.

Lake Expansion/Formation

One of the most obvious and intriguing aspects of this core was the peculiar clay layer from 80-122 cm that showed up in the CBM-1 core. At first, the possibility that the layer may have indicated the occurrence of another extreme event was exciting, however its true origin needed to be ascertained. If it was primarily a fluvial deposit it would suggest a catastrophic flooding of the Amite River, which may or may not be associated with a hurricane. Alternatively, it may have been a lacustrine deposit laid down on the bottom of Lake Maurepas, either during a storm surge event in which the wind-driven water spilled over the lake's western shore and inundated a vast stretch of the estuarine lowlands along the Amite River. A third hypothesis is that it is a lacustrine deposit laid down during an extended period of time when Lake Maurepas expanded considerably in size to submerge the study site under several meters of water, which would imply that this clay layer is not an event deposit.

To determine an age of this environmental change indicated by visual analysis, LOI, and XRF, radiocarbon dates were taken. It was shown that 80 cm down on the core (the end of the event) was ~100 years old, with 127 cm down being ~770 years old (the beginning of the event). These dates, taken at face value, show that the layer was not created by a single catastrophic event such as a flood or storm surge. With this new evidence, and the fact that the layer is devoid of large roots and organic material indicative of a swamp or marsh, it was determined that the event spanned several hundred years and most likely resulted from lake expansion. This is supported by Flocks et al. (2009) in an article on the geologic history of the area, showing Lake

Maurepas as expanded to encompass the CBM study site as recently as 1000 years ago (Figure 11). At that time, one of the major distributary lobes of the Mississippi River was Bayou Sauvauge, which considerably flooded Pine Island and persisted into the most recent millennium, making it perfectly plausible that Lake Maurepas expanded a few km westward only a few hundred years ago (Figure 12) (Frazier, 1967). Through this analysis, it was determined that this layer was likely an environmental change related to the expansion of Lake Maurepas, thereby supporting the third hypothesis.

Sedimentation

Ascertaining sedimentation rates in the area is important in determining the overall character and sustainability of the region. Based on the resulting dates, sedimentation is highly variable, and given the 6 cm deposited by Isaac alone, is highly event driven. Any sudden environmental changes to alter this rate of sedimentation would have extreme effects on the sustainability of the area. For example, the recent rate of sedimentation is 0.39 cm per year, which is only slightly above the 0.34 cm per year rise in global sea level. This area exists in a delicate balance between sedimentation, subsidence, and sea level rise, and a slight change in either could greatly affect the sustainability of the region.

CONCLUSIONS

A combination of visual, LOI, XRF, ^{7}Be, ^{137}Cs, and ^{14}C analyses allowed for determination of both tropical cyclone event layers and environmental changes in the study area. Other cores concurrently being analyzed around the Lake Maurepas and Amite River basin provide similar results. The Hurricane Isaac event layer occurs at the very top of the core, with historic and prehistoric tropical cyclone event layers such as that of Hurricane Betsy showing up lower in the core, and a significant environmental change related to Lake Maurepas expansion approximately halfway through the last millennium. Sedimentation rates in the core are highly variable and are very comparable to the rate of sea level rise, making the sustainability of the area vulnerable to slight shifts in sedimentation, extreme events, and sea level rise, which are all affected by global climate change.

FUTURE WORK

To completely characterize the cores taken, as well as reconstruct the environmental history of the CBM site, more analysis is needed. First, additional ^{137}Cs and ^{210}Pb dates will be taken on the CBM-201 core to pinpoint the 1963 cesium peak, confirm the date of the 80-120 cm clay layer, and aid in sedimentation rate calculation. Additional radiocarbon dates will be taken, especially near the bottom of the core to determine the age of the entire core. Pollen analysis may also be performed to determine the historic vegetation of the area to further confirm event layers (Reese and Liu, 2001, Liu et al, 1995, Liu, 2013). Finally, personal interviews will be conducted with residents of the CBM area to confirm laboratory results with first-hand accounts of the event impacts.

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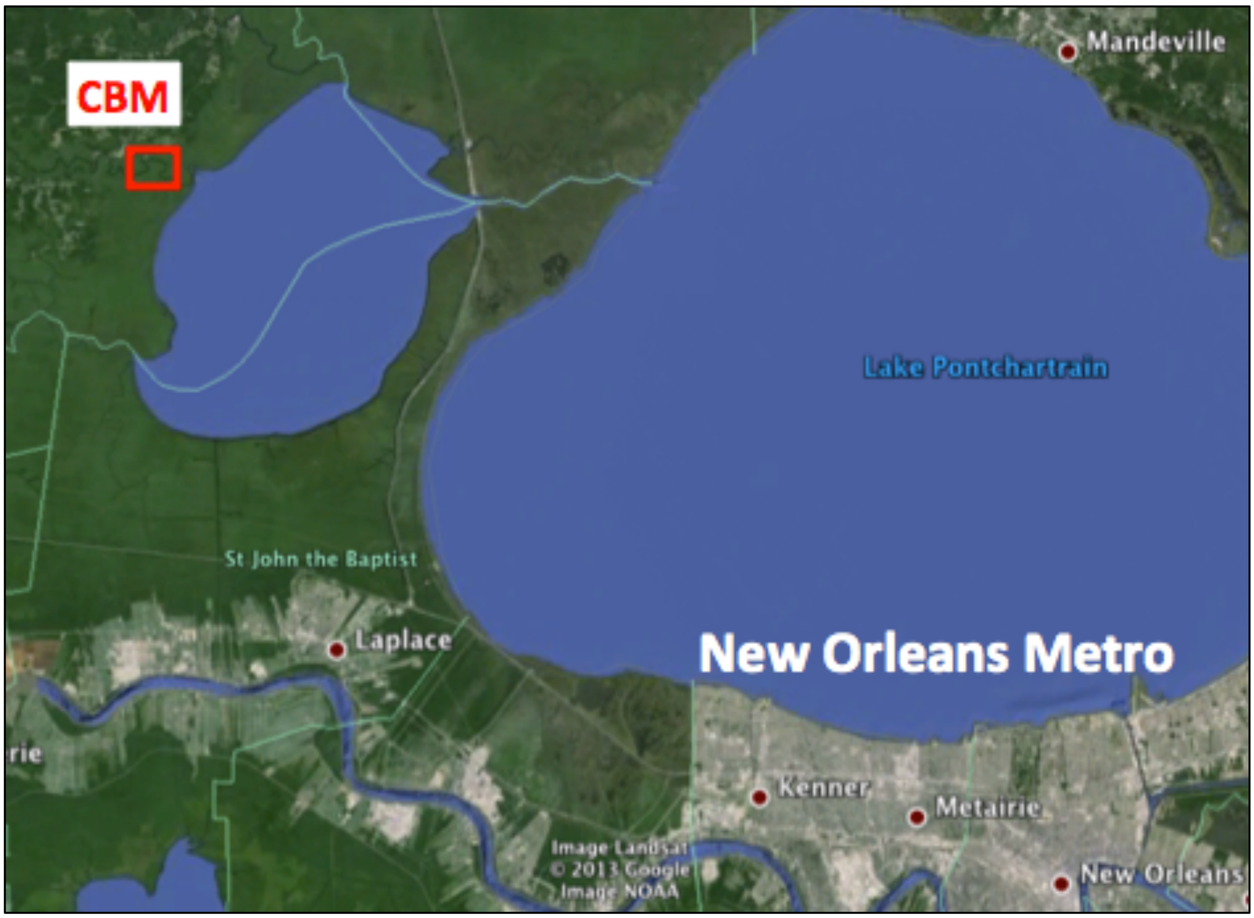

Figure 1: Location of the Carthage Bluff (CBM) study site in southeastern Louisiana, relative to the New Orleans metropolitan area. (Google Earth)

Figure 2: Field picture showing observed mud crack at CBM site 4 weeks after Hurricane Isaac, indicative of a storm surge deposit. (Photo courtesy: Kam-biu Liu, Septmber 2012)

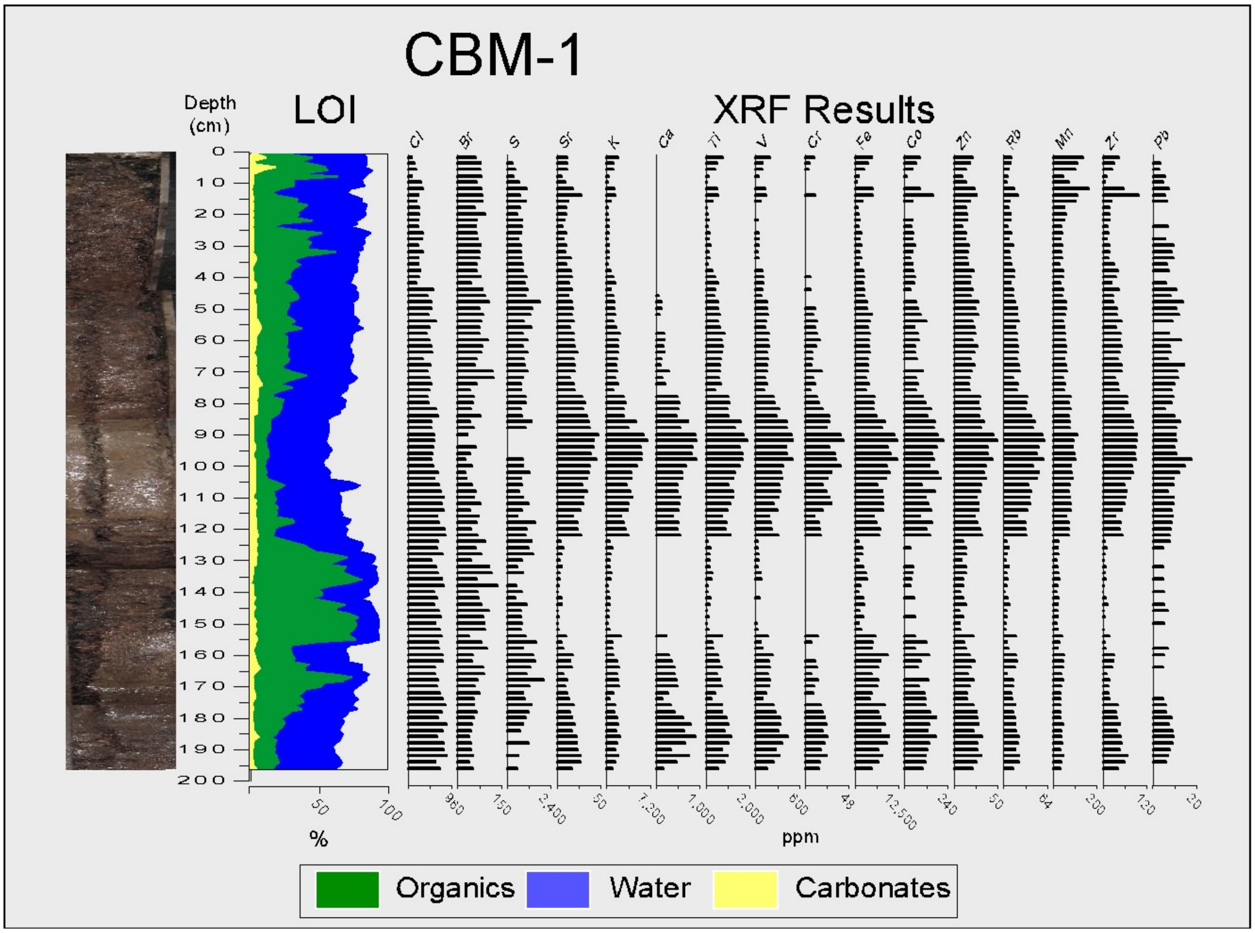

Figure 3: Stratigraphic plot of LOI, and XRF results for the 196 cm CBM-1 core, with core pohoto on the left.

Figure 4: Core photo showing the uppermost 11 cm of the CBM-1 core.

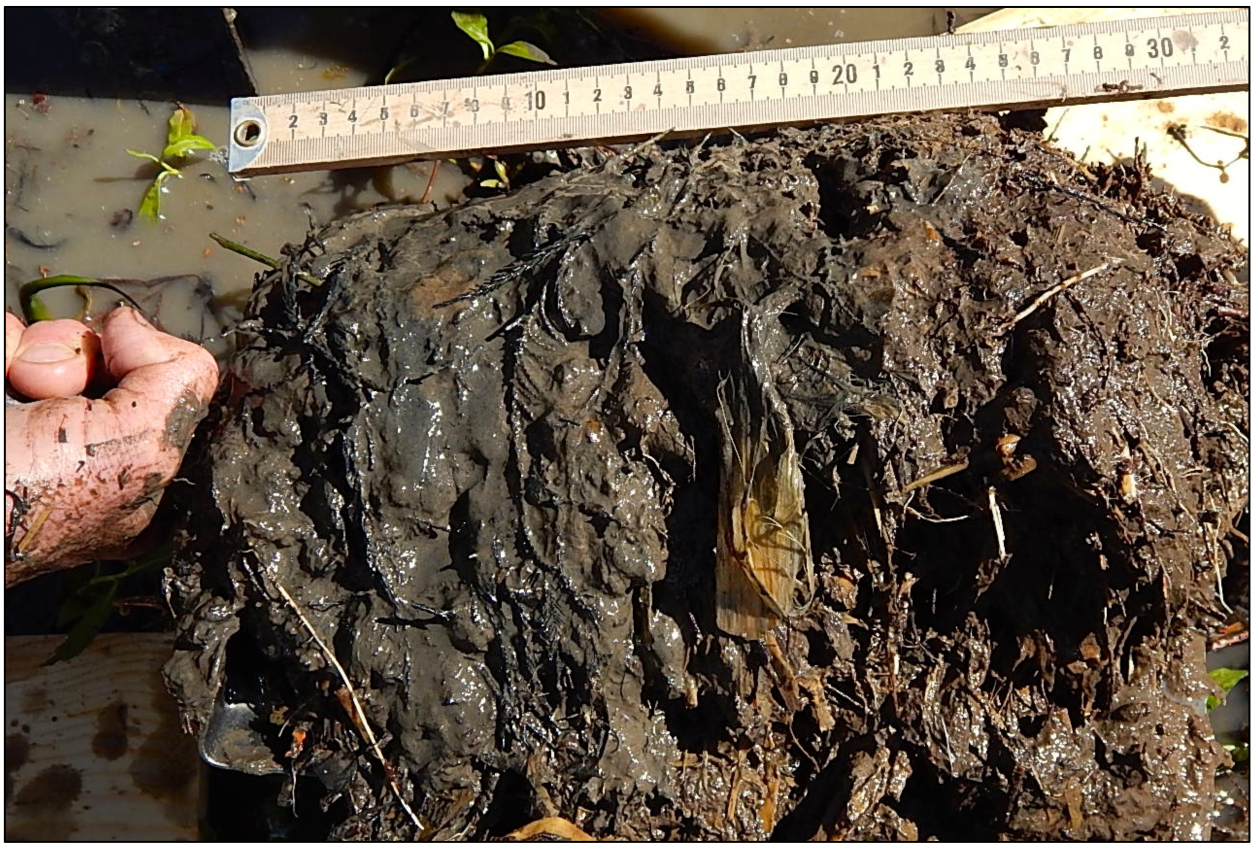

Figure 5: Field photo of CBM-201-Slab, from 0 to 35 cm.

Figure 6: Lab photo of the CBM-201-Alum core, from 0 to 32 cm.

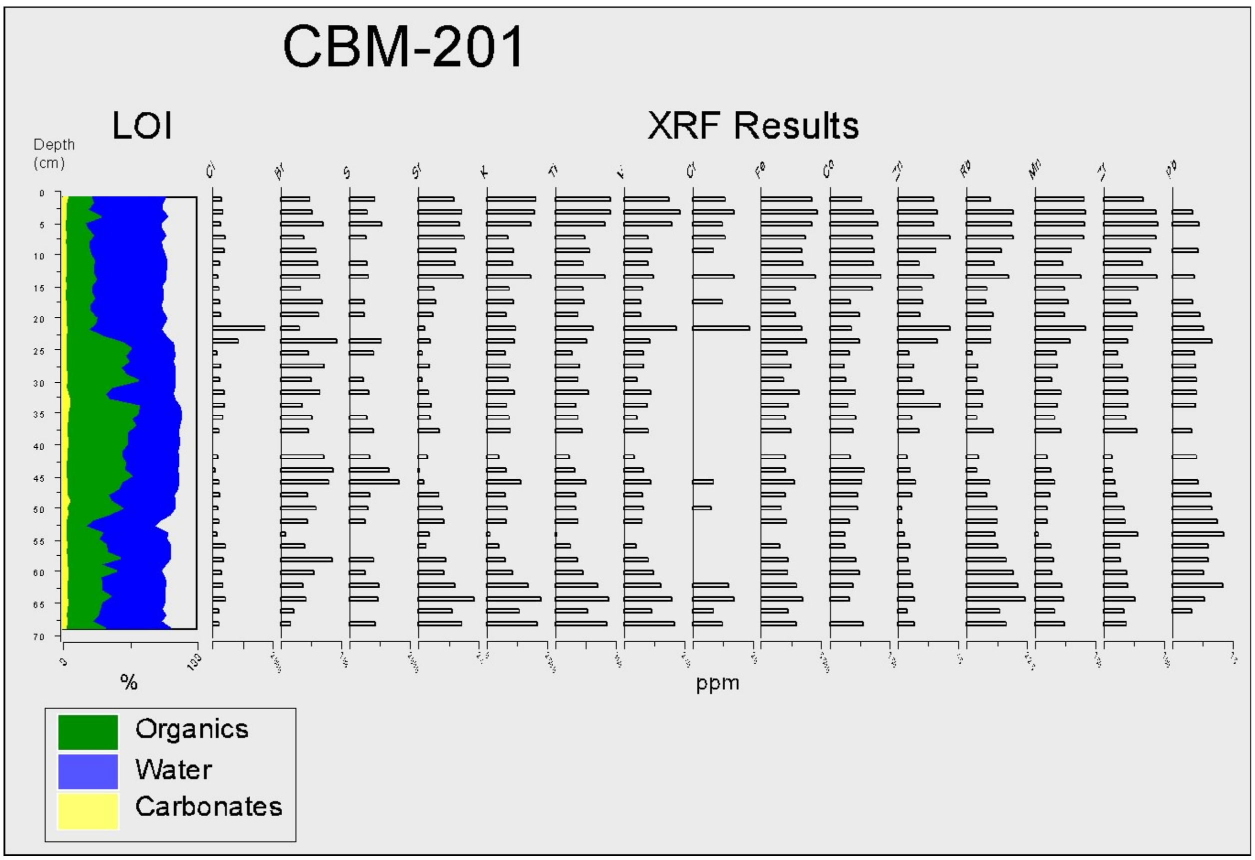

Figure 7: Stratigraphic plot of LOI and XRF results for the 68 cm CBM-201 core.

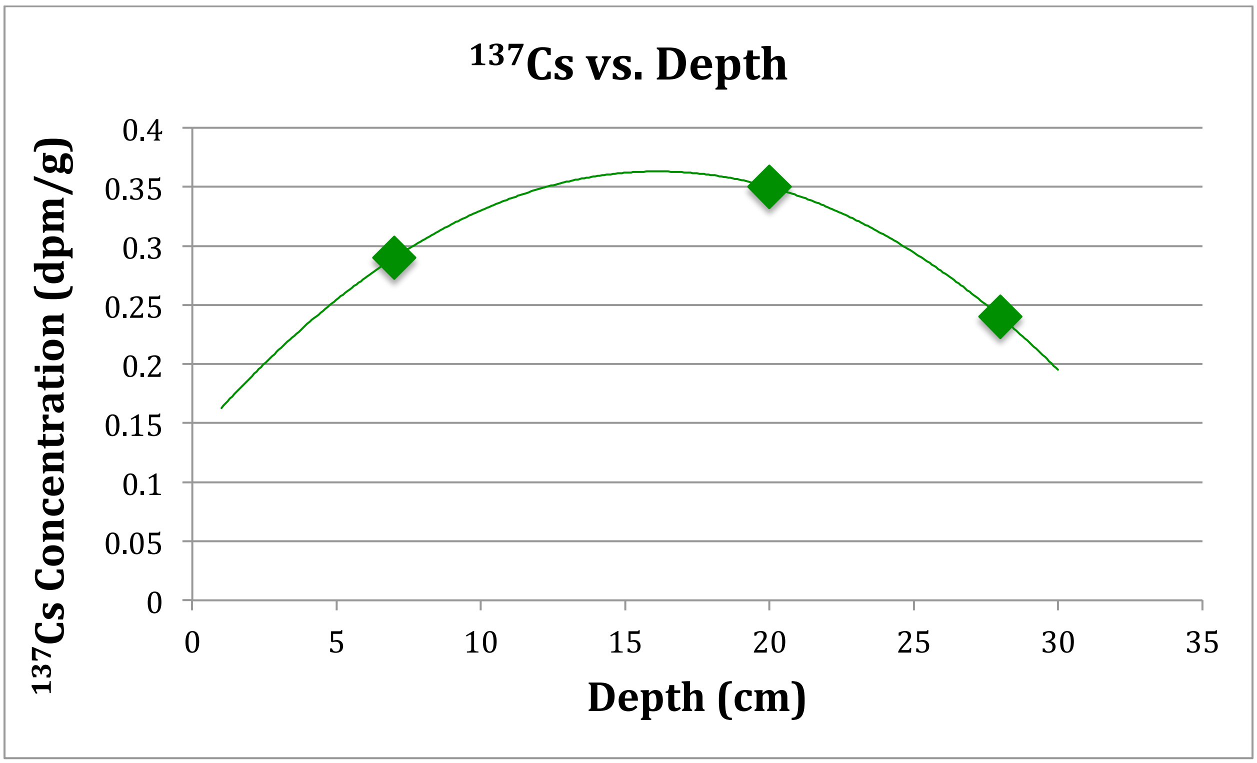

Figure 8: ^{137}Cs radiochemistry results (in dmp/g) plotted against depth via a polynomial regression to estimate the 1963 cesium peak.

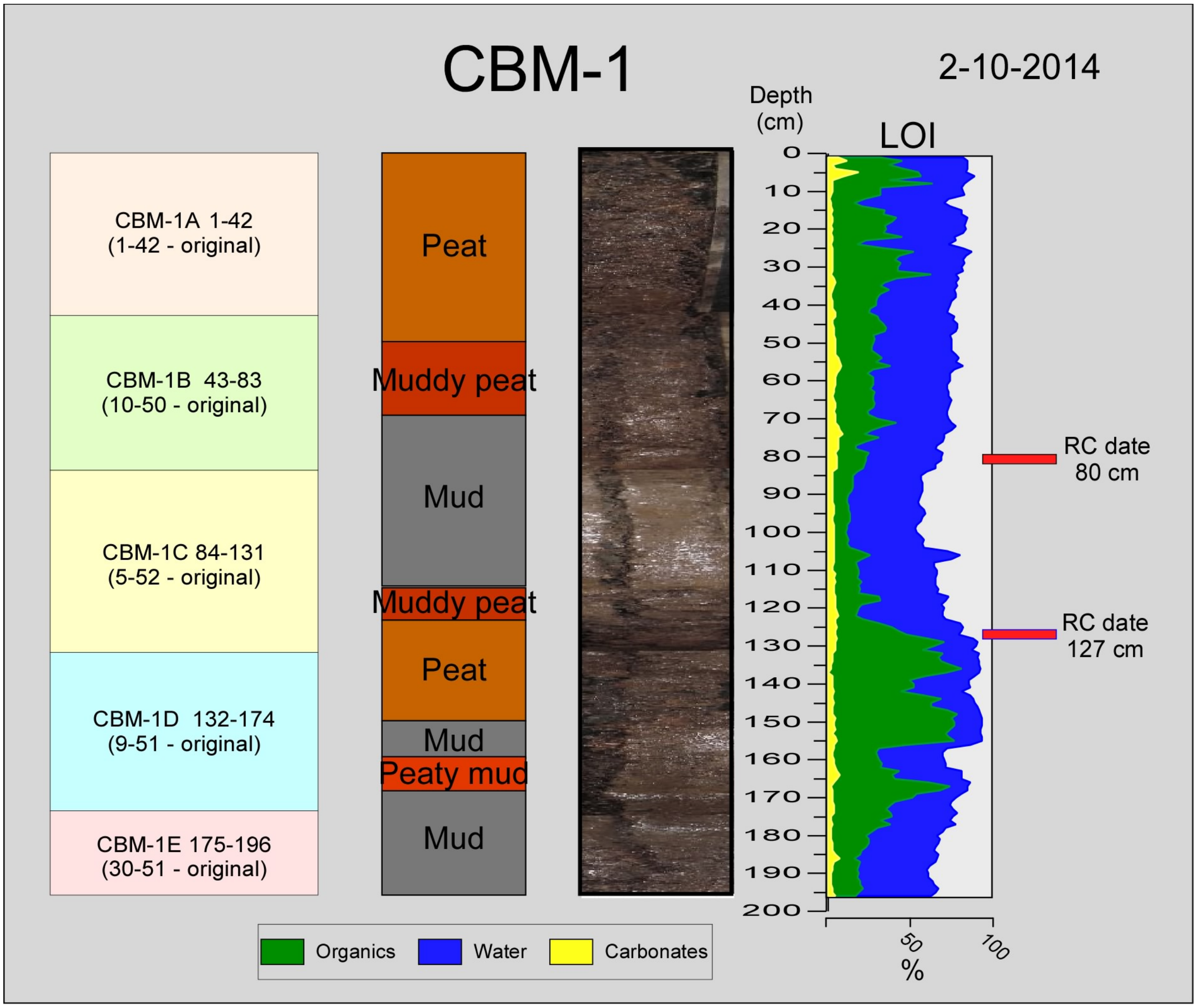

Figure 9: From left to right, the original Russian Peat Borer core names (5) with delineations of how they were combined into one core, the observed characteristics of the material in the core, the lab core photo, the LOI curve, and the locations of radiocarbon dating samples for CBM-1

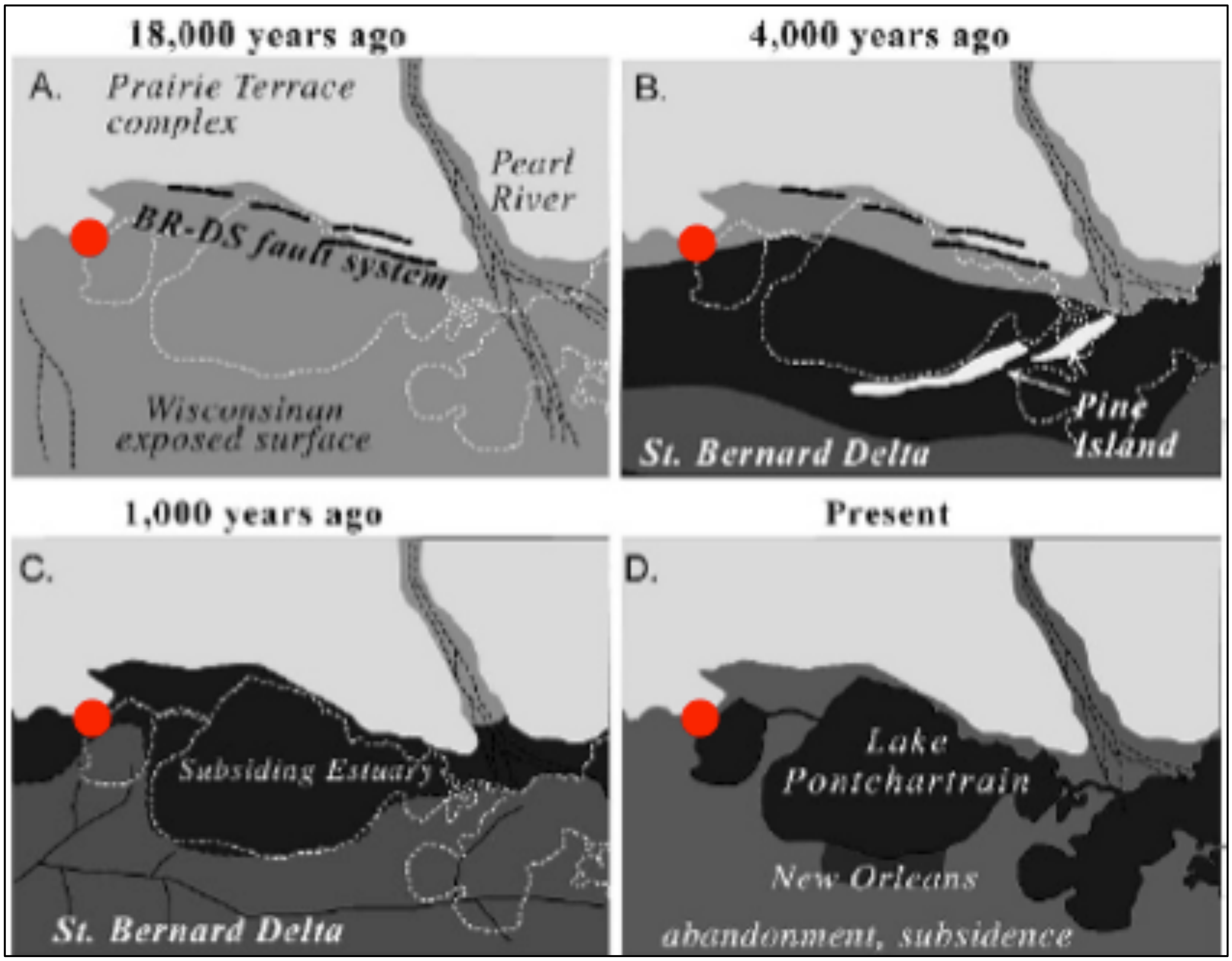

Figure 11: Geological history of Lake Pontchartrain basin, with red dot indicating the location of the CBM site, being under water at 1,000 years BP. (Modified from Flocks et al. 2009).

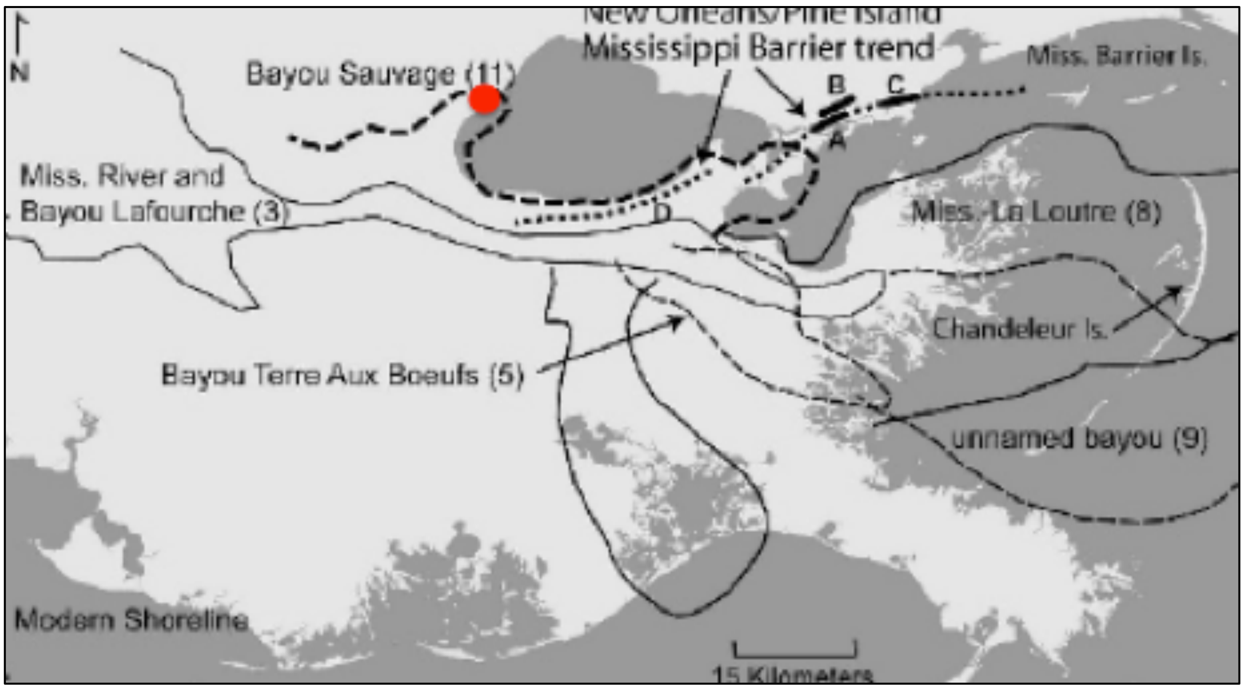

Figure 12: Historical delta lobes of the Mississippi River, with a red dot indicating the CBM site, which is within the range of the most recent deltaic lobe, Bayou Sauvage. (Modified from Flocks et al, 2009).