Facies Reconstruction of a Late Pleistocene Cypress Forest Discovered on the Northern Gulf of Mexico Continental Shelf

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ABSTRACT

A previously buried bald cypress forest (*Taxodium distichum*) was discovered on the continental shelf seafloor, offshore of Orange Beach, Alabama, USA, in ~20 m water depth. The forest was likely buried in the late Pleistocene, possibly exhumed by Hurricane Ivan in 2004, and is now exposed as stumps in life position. In August 2015 and July 2016, submersible vibracores and geophysical data were collected to investigate local stratigraphy and mode of forest preservation. This study focuses on analysis of the longest and most stratigraphically complete vibracore, DF–1 (4.78 m). This core revealed, from top to bottom, a surface of Holocene transgressive sands, underlain by interbedded sand and mud (potentially Holocene or Pleistocene), overlying a swamp or delta plain facies (likely Pleistocene) containing woody debris and mud that has been provisionally dated using radiocarbon to ca. 41–45 ka. One core collected in 2016 revealed a Pleistocene paleosol beneath Holocene sands in a nearby trough.

We hypothesize that floodplain aggradation in the area was a key factor that might have allowed forest preservation. A sea-level rise pulse of 10–15 m occurred ca. 40 ka that could have produced widespread floodplain aggradation, likely burying the swamp and forest sediments. During the subsequent glacial lowstand, sediments that comprise the floodplain were eroded and paleosols were formed in other nearby areas. It is hypothesized that some swamp sediments located in paleo-topographic lows might have

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been preserved and buried due to the deep coverage of the eastern-trending channel infill sediments. Coastal wave erosion during transgression likely eroded high ground but enough sediment remained to keep the cypress forest blanketed and therefore allowed preservation of stumps and woody debris.

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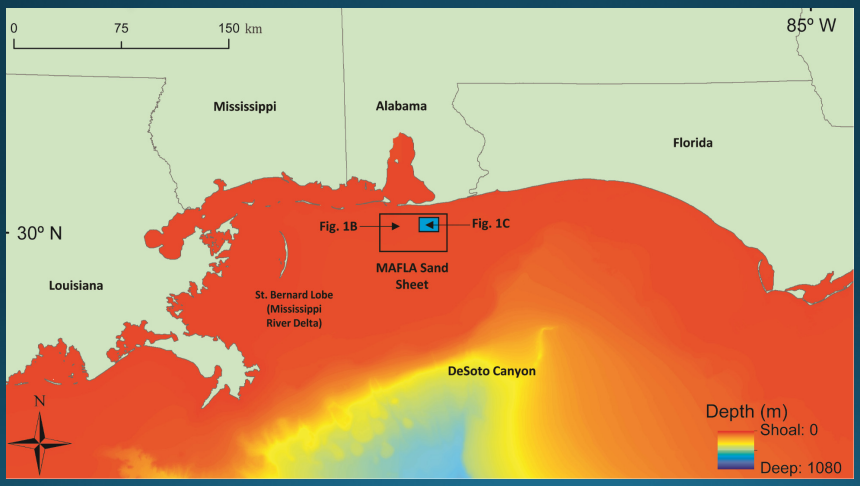
Introduction

- After the landfall of Hurricane Ivan in 2004, a previously buried bald cypress forest (*Taxodium distichum*) was discovered on the northern continental shelf seafloor.
- The cypress trees are very well preserved as stumps in life position with little evidence of decay before recent marine exposure.
- Relatively little is known about the Quaternary geology and stratigraphy of the area.
- Regional stratigraphy based on previous studies (McBride and Byrnes, 1995; McBride et al., 1996; McBride et al., 1999):
  - Facies 1: highly bioturbated, oxidized, clayey quartz sand
  - Facies 2: thin shell bed
  - Facies 3: bioturbated silty quartzose silty to fine sand
  - Facies 4: bioturbated and laminated clay
  - Facies 5: clast supported shell bed
  - Facies 6: laminated fine to coarse quartz sand

- The forest was likely buried in the late Pleistocene and possibly exhumed by Hurricane Ivan in 2004

Study Area



Map of study area showing approximate location of the ancient forest (blue box) within the context of the northern Gulf of Mexico coast.

Study Area:

Northeastern Gulf of Mexico
~15 km south of Gulf Shores, Alabama
18-20 meters below sea level

Seabed: MAFLA (Mississippi-Alabama-Florida) sand sheet

Subdivided into two subprovinces: the Mobile and the Apalachicola

Northwest-southeast trending ridges and troughs

From recent geophysical surveys and seafloor mapping, various locations of drowned cypress trees have been identified (this study).

Low microtidal range and a low sediment-supply regime

The Forest

- Bald cypress trees (*Taxodium distichum*) :
  - Have long dominated the forests of wetlands along the Gulf Coast
  - Can be found in a wide range of climatic conditions, but primarily in subtropical lowlands
  - At elevations of up to 30 meters above SL
  - Able to withstand flooding and waters with up to 0.89 ‰ salinity

- They are not found in brackish or saline waters.
- Like any other type of wetlands in the region, bald cypress forests are also subject to the effects of regional sea level rise and increase in flooding and salinity.
- During the past decade or so, numerous examples of tree stumps in life position have been identified exposed on the continental shelf seabed, south of the Alabama shoreline.
- Their depth and location initially suggested their ages to be late Pleistocene to early Holocene
- saline waters of up to 0.89% salinity (Hook reference)

Objectives

1. To document and characterize the sediments that buried and preserved the cypress trees.

2. Establish an absolute geochronology for the site.

3. Gather better insight to paleoenvironmental conditions, such as sea level variations, climate, and position of ancient shoreline in the late Pleistocene and early Holocene time.

The location of these pristine tree stumps, approximately 15 km offshore the Gulf Shores, Alabama, and 20 meters below present day sea level, can give valuable insight to paleoenvironmental conditions, such as sea level variations, climate, and position of ancient shoreline.

1. A detailed description of the different sedimentary facies found in the study site will provide better insight to how, when, and why the tree stumps were preserved.

2. This will contribute greatly to the reconstruction of the geological history of the area.

3. This time frame is not well documented in the region, because many of the sedimentary records have been eroded and in many cases drowned under rising seas.

Photographs of bald cypress stumps at the study site.
Images by: Kristine DeLong

Cypress woods samples recovered from the study site.
Images by: Kristine DeLong

Geologic Setting

- The Gulf of Mexico during the Holocene:
  1. Has been subject to progressive rise in sea level
  2. Late Pleistocene and early-middle Holocene rates were much higher, until near-present sea level was attained in the northern Gulf of Mexico about 6,000 years ago.
  3. The trees which produced stumps preserved in the study area, generally grow between 0-30 m above sea level in flood plain and riparian environments in the humid subtropics (Little, 1971).
  4. Based on this observation, approximate time frames can be identified when the forest may have grown, by studying the sea-level curves.

1. Sea level rise in the area is directly associated with changes in global eustatic sea level. Consequently, this results in changes in shoreline position and therefore regional stratigraphy

4. This slowdown in rate of sea level rise during this time period allowed for the development of coastal landforms in the area. Furthermore, shoreline position has been relatively stable (Donoghue, 2011).

Methods

- Field Work and Data Collection
  - August 2015 & July 2016
  - *R/V Coastal Profiler* of the Louisiana State University's Coastal Studies Institute (CSI)
  - 18 Vibracores
  - Geophysical (swath bathymetry, chirp sub bottom and sidescan sonar)
- Detailed geological analysis of core **DF-1** is the focus of this paper with preliminary geophysical data provided for context.

Submersible vibracorer used for this study to collect cores up to 5 meters in length.
Image by: Kristine DeLong

Data Processing & Analysis

- DF-1
  - Geotek Multi-Sensor Core Logger (MSCL) for whole-core gamma density of sediments.
  - Granolumetry (LS 13-320 Laser-Diffraction Particle Analyzer)
  - Organic-content analysis (LOI)
  - Geochronology (radiocarbon dating)
    - 8 sub-samples
    - Beta Analytic Radiocarbon Dating Laboratory in Miami, Florida

Results

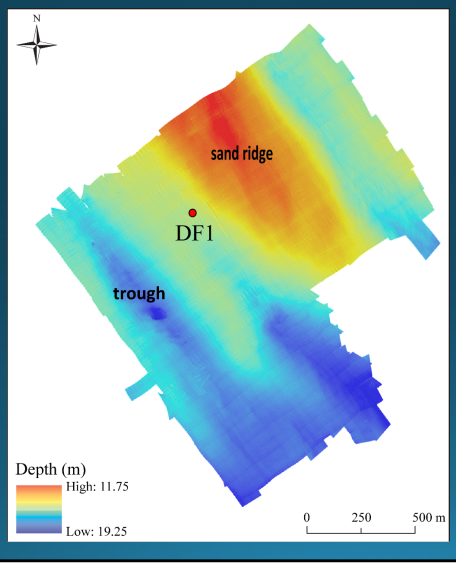
- Radiocarbon Dating
  - Subsamples found in the swamp facies of core DF-1 at 4.05 m and 4.14 m
  - Beta Analytic results revealed a radiocarbon ages of:
    - 37,350 +/- 330 BP or **Cal BP 41,830** (4.05 m)
    - 41,830 +/- 880 BP or **Cal BP 45,210** (4.14 m)

DF-1 Sediment Samples Radiocarbon Results					
Sample Type	Sample Name	^{14}C age	±	Cal BP age	Cal BP range
Sediment 322 cm	DF1-322	हठटड़ज़			
Sediment 405 cm	DF1-405	41830	880	45210	ठढढ़थज़43625
Sediment 414 cm	DF1-414	37350	330	41830	42235-41350
Sediment 414 cm	DF1-414-2	हठटड़ज़			
Sediment 419 cm	DF1-419	हठटड़ज़			
Sediment 424 cm	DF1-424	हठटड़ज़			
Sediment 456 cm	DF1-456	हठटड़ज़			
Sediment 466 cm	DF1-466	हठटड़ज़			

Plant material that was ^{14}C dated

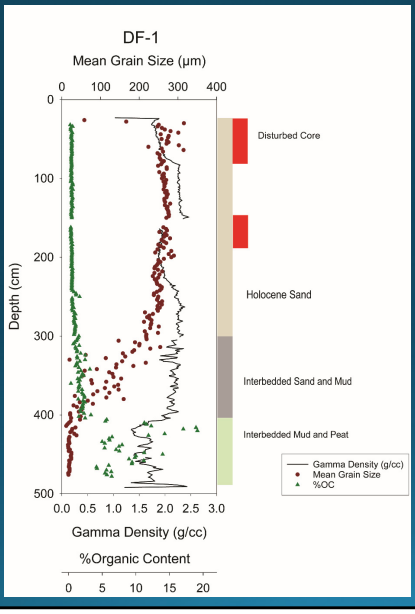
Because these radiocarbon ages are near the upper bounds of reliable detection, ca. 40 ky BP, other absolute dating methods are currently under way, such as optically stimulated luminescence OSL).

Geophysical Data



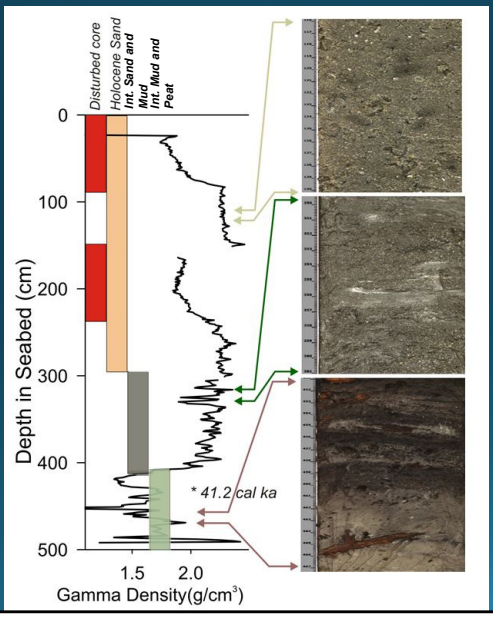
Bathymetric map of study site showing DF-1 core location, collected in August, 2015.

Grain Size & LOI



DF-1 comprehensive graph showing % organic content, mean grain size, and gamma density vs. depth profile.

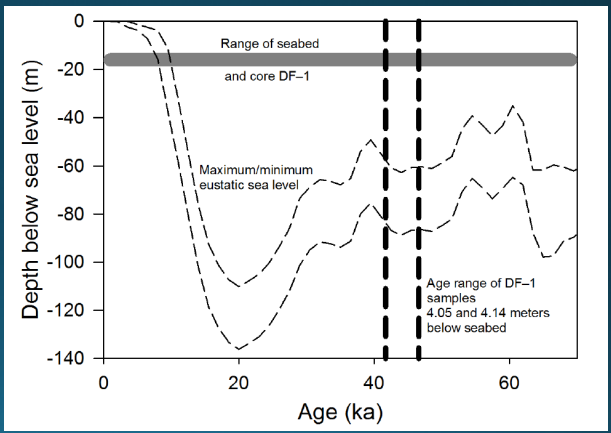
Facies Interpretation



Comprehensive figure of core DF-1 showing gamma density, facies classification and radiocarbon date.

Discussion

- Age and depth relationships can explain how the cypress forest could withstand periods of erosion during the late Pleistocene and Holocene.
- Swamp forest developed at an elevation above and possibly distant from sea level and the shore.

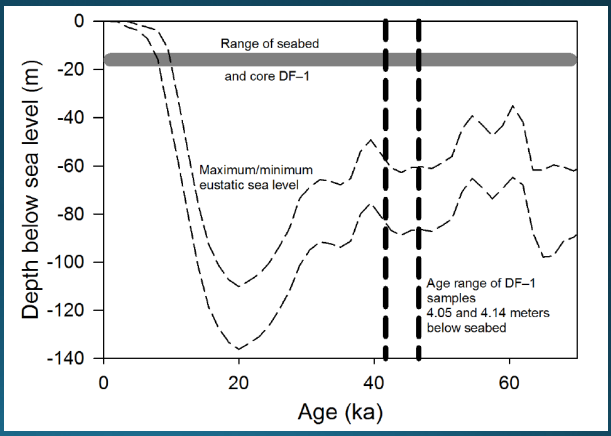


Global sea level variations since 60,000 years ago. Modified from Waelbroeck et al., (2002).

- Sea level near that time was in the range of -50 to -90 m below present sea level and regional topographic relief was relatively low.
- However, this relationship indicates that the forest grew at an elevation above and possibly distant from sea level and the shoreline, respectively.
- Based on this assumption, we can identify approximate time frames when the forest may have grown, by studying sea-level curves in Figure above.
-
- Age constraints on the mud and peat unit in core DF-1, and the likelihood that this unit immediately overlies the buried stumps, suggests that the forest was buried by aggrading swamp and floodplain in deposits before 42-45 ka.
- These deposits were buried and protected from erosion during a period of perhaps 30,000 years of regression, transgression, and likely extensive subaerial exposure. For this to happen, it is likely that these deposits were originally buried by a substantial thickness of sediments, which were mostly, but not entirely eroded during Pleistocene exposure and Holocene transgression. One potential process that could have produced such sediment burial is floodplain aggradation.

Discussion

- Hypothesis for Forest Burial & Preservation
  - Most likely these swamp deposits were buried by a substantial thickness of sediments, which were mostly, but not entirely eroded during Pleistocene exposure and Holocene transgression.
- Temporary sea-level rise of 10-15 m occurred ca. 40 ka may have produced local floodplain aggradation, burying the forest and inland floodplain.

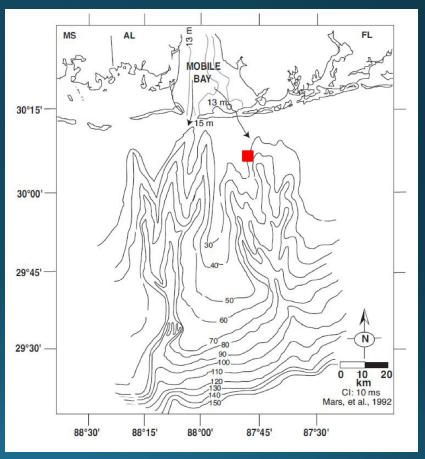


Global sea level variations since 60,000 years ago. Modified from Waelbroeck et al., (2002).

- We hypothesize that floodplain aggradation in the area is a key factor that might have allowed for forest preservation
- A temporary sea-level rise of 10-15 m occurred ca. 40 ka, which may have produced local floodplain aggradation that might have buried the swamp and forest sediments. Such rapid aggradation has been observed many km inland in other coastal-plain alluvial valleys (other studies)
- During lowstands, sea level falls and the sediments that comprise the floodplain are eroded. Subsequently, paleosols were formed in other nearby areas.

Discussion

- Bartek et al., (2004) study
  - Bifurcation of the Mobile-Tensaw River system during the MIS 2 (Marine Isotope Stage) formed two incised valleys south of Mobile Bay.
- Hypothesis:
  - Some swamp sediments located in topographic lows might have been preserved and buried due to the deep coverage of channel infill sediments.



Time structure map of MIS (Marine Isotope Stage) 2 sequence boundary. Redbox shows approximate location of study site. Modified from Bartek et al., (2004).

- With bifurcation of the Mobile-Tensaw River system during the MIS 2, two incised valleys were reoccupied south of Mobile Bay. One eastern trending incised valley and one western trending incised valley were identified by Bartek et al., (2004).
- Sea-level-rise patterns in the area during the Holocene are interpreted to have led to transgression of the depositional environments associated with the incised valleys, therefore changing the position of the coastline.
- We propose that swamp sediments such as in DF-1, located in topographic lows, might have been preserved and buried by fluvial/floodplain sediment accumulation.
- Finally, as sea level rose and transgression occurred, sediments within the incised valleys were first eroded by transgression of the coastline and associated wave energy, and later covered by Holocene shelf sands as sea level rose, thus causing the coastline position to retreat.
- Coastal wave erosion during transgression likely eroded high ground but enough sediment remained to keep the cypress forest blanketed, therefore fortuitously favoring preservation.

Conclusions

- This unique scenario where cypress trees have been preserved for over 45,000 years represents a puzzling geologic setting.
- Relatively rapid burial and floodplain aggradation prevented erosion by coastal processes during the Holocene transgression thus preserving the tree stumps and wood debris.
- If this hypothesis is ultimately proven correct by further study, this could help identify the locations of other similar drowned forests of similar age around the Gulf of Mexico.

- If hypothesis is CORRECT: because the depth range of such forest preservation would be caused by the regional impact of sea-level rise and associated flood plain transgression, similar to our study area, forming a sort of “bathtub ring” around the Gulf of Mexico at common age and depth
- Also, these sites should be concentrated offshore of modern river systems that would have incised the shelf at lower sea levels, and deposited sediments during the phase of floodplain aggradation around 40 ky ago that likely preserved our drowned forest.

Ongoing & Future Work

- Establish a more complete and descriptive geochronology that integrates both ^{14}C dates and OSL (Optical Stimulated Luminescence) dates.
- Broader stratigraphic context that includes all 18 cores
- As micropaleontology work continues, we hope to determine the unconformities and further characterize the depositional environments based on the microfossil assemblage.

- microfossil assemblage will help characterize changes in depositional environment and ravinement surfaces between facies.

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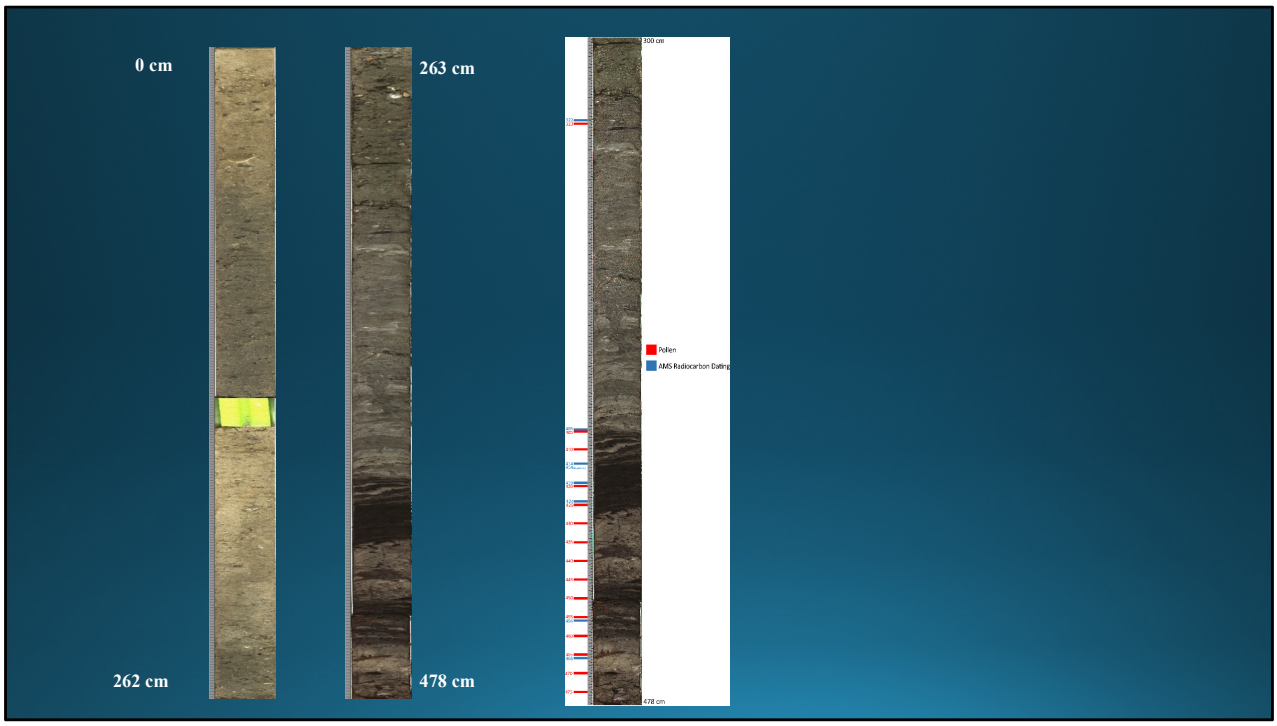
0 cm
262 cm
263 cm
478 cm
300 cm
Pollen
AMS Radiocarbon Dating
478 cm