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THE HOLOCENE DEPOSITIONAL HISTORY OF THOUSAND ACRE MARSH (GEORGETOWN COUNTY, SC, USA) FROM CORRELATION OF GROUND PENETRATING RADAR WITH SUBSURFACE STRATIGRAPHY

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ABSTRACT

Thousand Acre Marsh, near Georgetown, SC has been investigated using ground penetrating radar and auger cores to determine this brackish marsh's recent depositional history. Core lithology, wood samples, vegetation fragments, and geophysical horizons all aided in the construction of a stratigraphic framework and the identification of antecedent environmental changes and the formation of Thousand Acre marsh, North Inlet-Winyah Bay, SC with regard to recent sea-level rise.

INTRODUCTION

Brackish marshes are diverse coastal environments situated at the apex between saltwater and freshwater systems. These marshes can be a key in identifying Holocene sea-level fluctuations. These coastal environments are more susceptible to changes in sea-level than their salt water counterparts. Analyses of brackish marsh subsurface facies and lateral extent can provide indications and timing of Holocene sea-level fluctuations.

Ground Penetrating Radar (GPR) is a non-intrusive, high-resolution method for detecting and mapping subsurface geological features *in situ*. It is widely used in geophysical site characterization studies because it allows for excellent documentation of the lateral extent, continuity, depth, and thickness of the subsurface units in areas where the soil and shallow strata have low conductivity (Neal, 2004).

Brackish marshes are challenging environments for GPR studies due to attenuation of the electromagnetic signal by salt water saturated sediments and clay deposits (Neal, 2004). A previous investigation by Weaver (2006) showed that interpretable GPR data could be obtained from brackish marshes in South Carolina In the Weaver (2006) study, the electro-

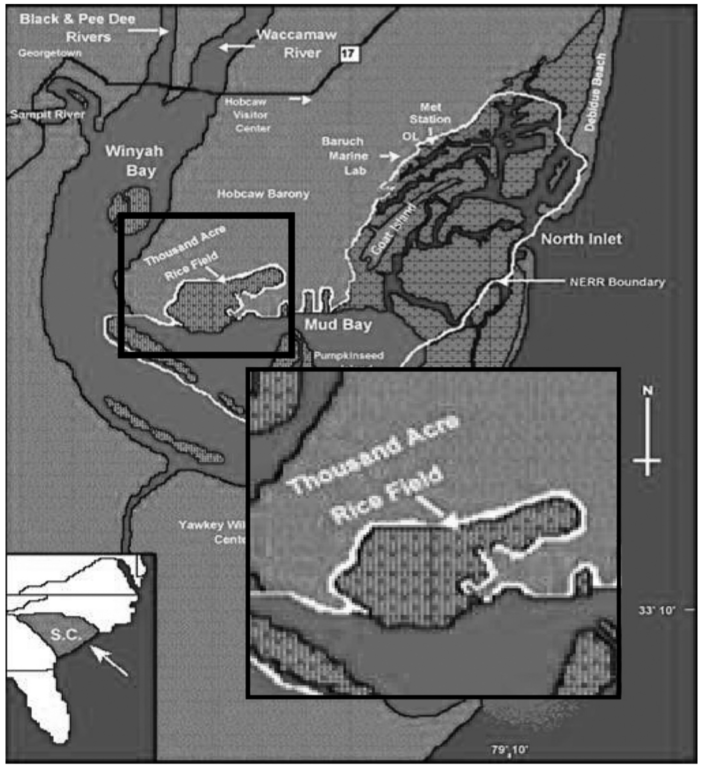

Figure 1. TAM is located east of Georgetown, SC and west of North Island and North Inlet within the NOAA-NERRS and Hobcaw Barony property. Figure has been modified from www.northinlet.sc.edu; the Baruch Marine Field Laboratory is part of NOAA_NERRS.

magnetic signal had significant penetration through shallow clay deposits.

The present investigation utilizes GPR images and sediment cores to aid in facies identification, lateral facies extent, and determination of depositional units for correlation of radar reflectors observed in the GPR data in Thousand Acre Marsh, Georgetown County, SC. The combination of these proxies could aid in the deciphering of Holocene sea-level and the effect on coastal environments.

The documented Holocene sea-level rise of 3 mm/yr on the South Carolina coast (Colquhoun, 1969), is altering the geomorphology of shorelines and coastal environments (DePratter and Howard 1981; Gayes and Scott, 1992; Gardner and Porter, 2001; Baldwin, *et al*.2004). The Holocene stratigraphy of brackish marshes should be investigated to increase our knowledge of antecedent sea-level fluctuations and to forecast the future of our coastal resources in relation to rising sea levels.

In South Carolina coastal environments, GPR has been used to investigate Holocene stratigraphy of barrier islands to determine the formation and evolution of these sand systems (Wright et al., 2006). GPR has also been used in the Santee State Park located in Santee, SC, to locate sinkholes within the Santee Limestone that were causing extreme road damage (Addison et al., 2008). In addition, GPR has been utilized often for lithological characterization, such as identification of facies variations and extent within the subsurface (Addison, 2006; Weaver, 2006).

The objectives of this multidisciplinary investigation of the Thousand Acre brackish marsh system include: 1) correlation of the subsurface stratigraphy from analyses of sediment cores with high resolution, non-invasive GPR imaging techniques; 2) determination of the recent depositional history of TAM based only on

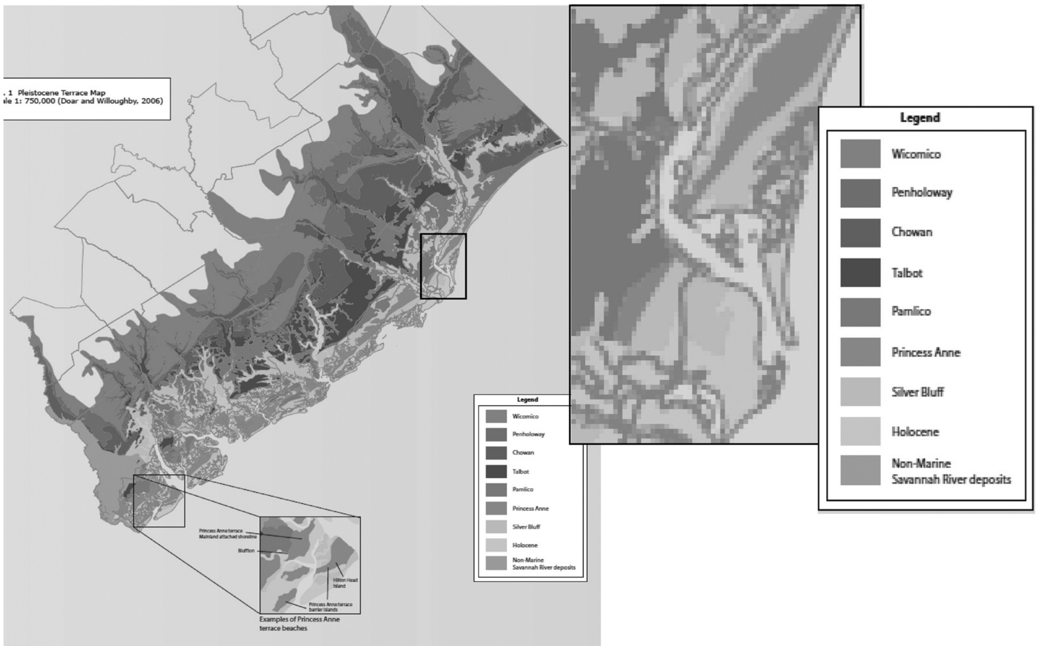

Figure 2. Location of sampling Thousand Acre Marsh GPR transect locations. Transects are represented by black lines. Transects A and A_200 are on the right hand side while transect B runs perpendicular to A and C. C is the western line that runs parallel to A and A_200.

the above mentioned analyses and 3) presentation of these data for future recommendations of sea-level management in these important coastal environments.

STUDY SITE

Thousand Acre Marsh is located northeast of Georgetown, SC, within the National Oceanic and Atmospheric Administration – National Estuarine Research Reserve (NOAA-NERRS) North Inlet-Winyah Bay (NI-WB) site and the Belle W. Baruch Institute for Marine & Coastal Sciences at Hobcaw Barony (Figure 1). This site is a low-lying area with an average elevation 0.5 m above mean sea level (msl), surrounded to the west by relict, 100-80 ka, Pleistocene Princess Anne Formation beach ridges, which average 15 m above msl (Doar and Kendall, 2008). To the north and east of Thousand Acre Marsh, is a younger set of 60-30 ka beach ridges, averaging 3 m above msl, known as the Silver Bluff Formation (Doar and Kendall, 2008) (Figure 2). Thousand Acre Marsh is located in a temperate to subtropical climate with a mean annual temperature of 18°C and an average precipitation of 130 cm/yr. Thousand Acre Marsh is a brackish marsh subject to an average tidal range of 1.5 m. The main vegetation is *Spartina juncus* and *Spartina cynosuroides,* more commonly known as Bullrush and Big Cordgrass, respectively (DeVoe and Vernberg, 1992).

METHODS

Geophysical Data Acquisition

Ground Penetrating Radar (GPR) data were acquired using the Pulse EKKO 100 system manufactured by Sensors and Software, Inc. Five transects, using the common offset method, were acquired across the southern portion of Thousand Acre Marsh. These transects will aid in determining subsurface geometry and underlying depositional sequences. This GPR system operates with a transmitting antenna and receiver which were spaced according to the chosen antenna size.

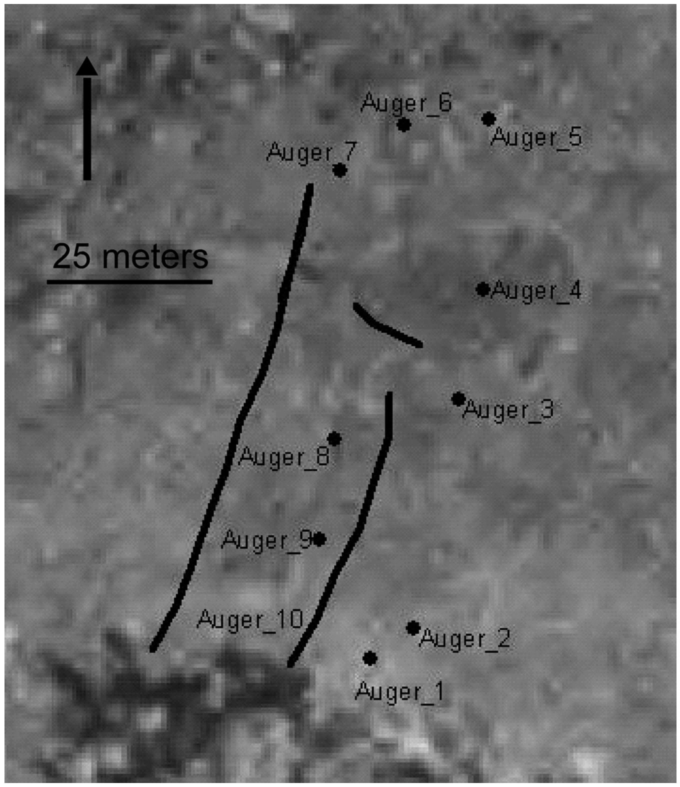

Figure 3. Black lines represent the locations of the GPR transects with respect to the sediment cores, for further information on GPR locations see figure 3. Auger cores are represented with circles, push cores by triangles and squares for vibracores. Figure modified from USDA ADAR image through ArcGIS version 9.

Over 300 meters of GPR transects were acquired. Transect A begins north of the embankment road on the Winyah Bay side and heads north into the marsh. Transect B begins at the end of Transect A and proceeds to the west towards transect C. Transect C begins further into the marsh than Transect A but follows a parallel path back toward the embankment road (Figure 3). Transect A was also examined with a 200 mHz antenna (A_200).

Imaging of approximately 4 m into the subsurface of TAM was possible from the acquired GPR data. This is due to the electrical properties of geologic material (Topp et al., 1980; Davis and Annan, 1989; and Wilson, 1998).

Sediment Core Acquisition

Ten auger cores were acquired for ground truthing and correlation with the GPR data. (Figure 3). Auger cores were extracted at 1 meter length segments with a handheld auger and recorded in the field. Samples of distinction were sealed in containers and frozen for future analyses. Core locations and lengths are recorded in Table 1.

RESULTS

Ground Penetrating Radar

Over 300 meters of Ground Penetrating Radar (GPR) data were acquired along Thousand Acre Marsh transects A-C. Attenuation of a portion of the GPR signal in this environment occurred due to salt water intrusion into the sediments and the presence of clay sediment. Some interference occurred in transects A and C due

Table 1. The table provides the location and depth without compaction of all sediment cores extracted from Thousand Acre Marsh (TAM).

Core ID	Easting	Northing	Depth (cm)
Auger_1	662301	3685896	100
Auger_2	662310	3685902	100
Auger_3	662319	3685948	98
Auger_4	662324	3685970	133
Auger_5	662325	3686004	389
Auger_6	662308	3686003	100
Auger_7	662307	3686003	280
Auger_8	662295	3685994	240
Auger_9	662294	3685940	159
Auger_10	662291	3685920	100

to the surrounding forest. The deeper portions of the radar images of transects A and C which contain the interference have been removed from the figures.

Transect A is 72 meters in length, and was acquired with a 100 mHz antenna (Figure 4). The radargram reveals the majority of the beds are flat-lying but there is visual evidence of radar reflections that are highlighted in Figure 4. The radar reflectors in Transect A are located at depths of: 0.75, 1.5, 3 and 4.5 meters.

Transect A_200, 34 meters of Transect A, was acquired with the 200 mHz antenna (Figure 5). The resolution is much improved with the 200 mHz antenna, but depth of penetration is limited. The radar reflectors in Transect A_200 are located at depths of: 0.75 and 1.7 meters.

Transect B, acquired with a 100 mHz antenna, is 30 meters in length and connects Transects A and C from east to west (Figure 6). The radar reflectors of this transect occur at depths of: 0.8, 2 and 3 m.

Transect C is 107 m in length from North to South and was acquired with a 100 mHz antenna. Transect C (Figure 7) correlates well with transect A, which it parallels from North to South. Radar reflectors can be seen at depths of: 0.75, 2, 3.2 and 4.6 meters within Transect C.

All transects and corresponding images that were acquired with the 100 mHz antenna contain distinct radar reflectors. These horizons can be seen in transects A, B and C and Table 2. Radar reflectors in each transect are located at average depths of 0.75, 1.7 and 3 meters depths. The slight disparity of these radar reflector depths in each transect can be attributed to lateral variation due to natural processes such as creeking, erosion and varying sediment distri-

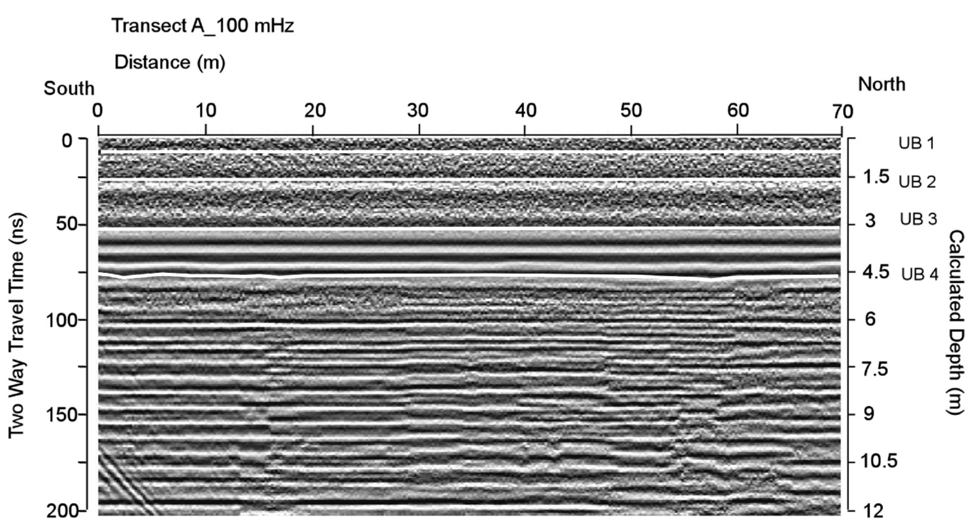

Figure 4. Transect A was acquired with a 100 mHz antenna beginning at the southern portion of the basin headed north into the marsh. The depth scale is based on the assumed velocity of 0.06 m/ns which is considered to be the velocity of the EM wave through wet clays and sands. Unit boundaries are displayed by arrows.

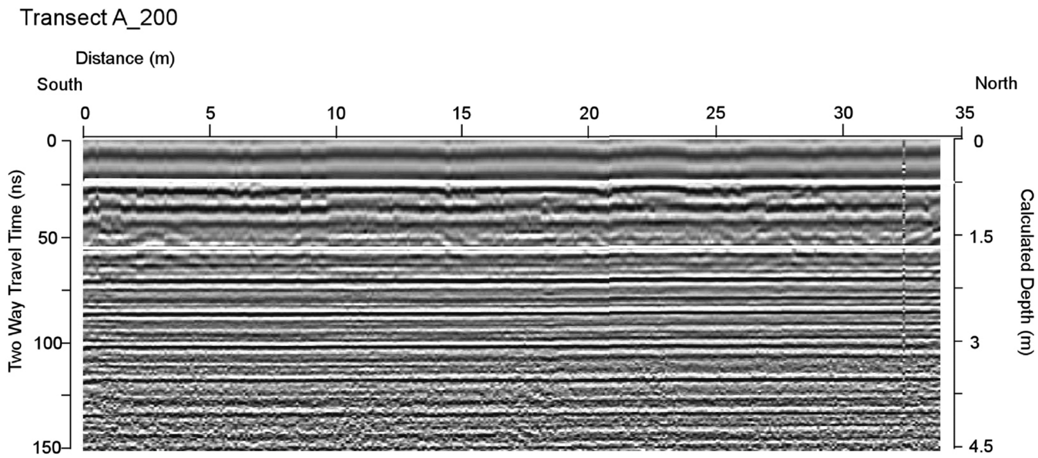

Figure 5. Transect A_200 acquired with the 200 mHz antenna. The depth of penetration is more limited than with the 100 mHz antenna. Unit boundaries are marked by arrows.

Table 2. Depth of geophysical horizons identified within the acquired GPR transect images.

Transect ID	Horizon 1 Depth (Meters)	Horizon 2 Depth (Meters)	Horizon 3 Depth (Meters)	Horizon 4 Depth (Meters)
Transect A	0.75	1.5	3	4.5
Transect A_200	0.75	1.7		
Transect B	0.8	2	3	
Transect C	0.75	2	3.2	4.6

bution. Transect A_200 which was acquired with the 200 mHz antenna has a higher resolution radar image but lacks the penetration depth of the 100 mHz antenna. Thus, transect A_200 reveals only 2 distinct geophysical horizons at depths of: 0.75 and 1.7 meters, but contains much more detail within these units.

Cores

Ten auger cores were collected, ranging in depth from 98-389 centimeters to ground truth GPR transect data and radar reflector depth and to construct a stratigraphic framework. Figure 8 is a representation of Thousand Acre Marsh stratigraphy based on core analyses. The near surface sediments of the marsh are a thickly vegetated mud typical of a vegetated brackish marsh and will are referred to as Facies 1 (Figure 8). This deposit, termed 'modern marsh' facies, is a brown mud (10YR 2/2) with root mats from the Big Cordgrass, *Juncus cynosuroides.* The 'modern marsh' facies was identified in all cores and ranged in thickness from 20 cm to 45 cm.

Facies 2 is identified by gray clay (5Y 4/1) with interspersed degraded vegetation and is found in all cores. This facies has much less vegetation than the overlying unit and the amount that is present has been highly degraded. The high clay content suggests a quiet environment where the small clay grains settle out of the water column. Thus, Facies 2 could be interpreted as similar to Facies 1 and has either been compacted and vegetation has had a chance to decay due to diagenesis or Facies 2 had a greater freshwater influence and the slight lessening of salinity allowed for different vegetation to flourish.

Facies 3 is a dense gray clay layer and averages 25 cm in thickness. The clay consistency in this facies is much denser, suggesting a deepening of quiet water allowing for the smallest of clay grains to settle from the water column. Fa-

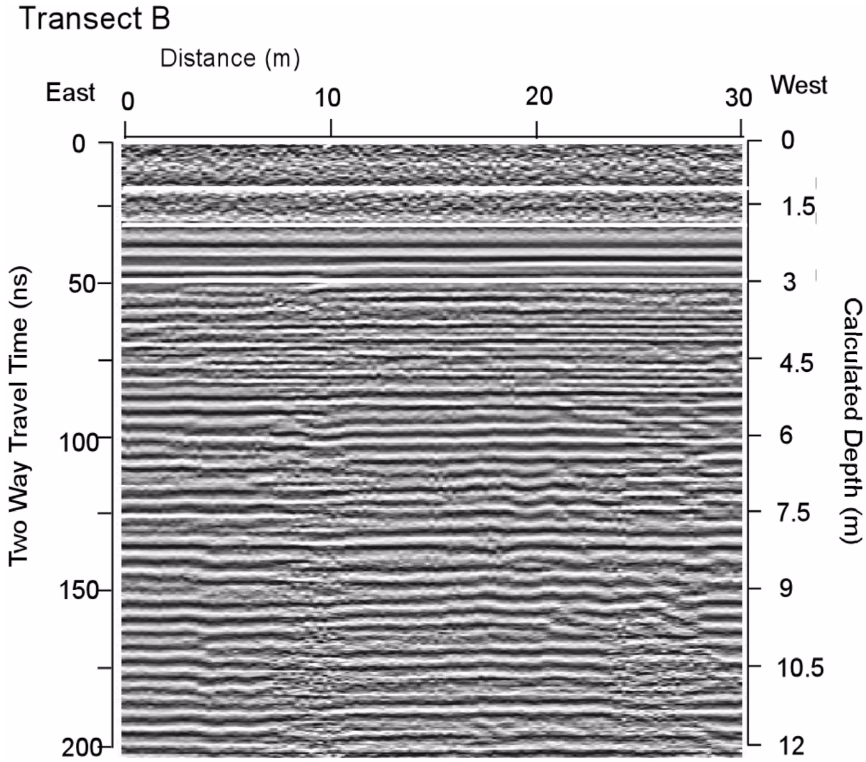

Figure 6. Transect B was acquired from east to west and connects Transect A to Transect C. Depth was determined by D=(v*(TWT/2)) and the average EM wave velocity within saturated clays and soils. Unit boundaries are marked by arrows.

cies 4 is a poorly sorted, orange-brown to tan sand layer which represents a drastic environment change from the overlying clay sediments.

Auger cores 1-3 all terminate in a gray sandy clay at 100cm depth, Facies 5, which could represent a fluvial channel bend, crevasse splay or floodplain, as evidenced by a mix of clay and sand at 80-100 cm. Auger cores 5, 7 and 8 all recovered an average 100 cm of dark black/gray to black clay that contains numerous large black wood fragments, (Facies 6). These same auger cores terminate in dark gray/ black clay with red cedar wood fragments (Facies 7) appearing at depths of 220-390, with an average thickness of 130 cm. Facies 7 may represent a period of time when a freshwater swamp influenced TAM, as evidenced by the presence of the cypress tree fragments. Cypress trees are commonly found in southeastern freshwater wetlands such as freshwater swamps and floodplains (Montane, 2007).

DISCUSSION

The main objectives of this investigation of Thousand Acre Marsh were to utilize sediment core lithology to ground truth GPR transects and to provide knowledge of Thousand Acre Marsh's recent depositional history. The impedance character of different substrates reflect and scatter the GPR signal in order to provide an average depth for GPR unit boundaries and correlation of sediment cores. Four radar reflectors were identified from the GPR images within in the TAM study area at average depths of 0.7, 1.7, 3 and 4.5 meters (Figures 4-7).

The first radar reflector at an average depth of 0.7 meters does not directly correlate with any of the lithologic changes in the stratigraphic framework from sediment core analyses, but could represent the water table. The second radar reflector located at an average depth of 1.7 meters correlates with a lithological boundary

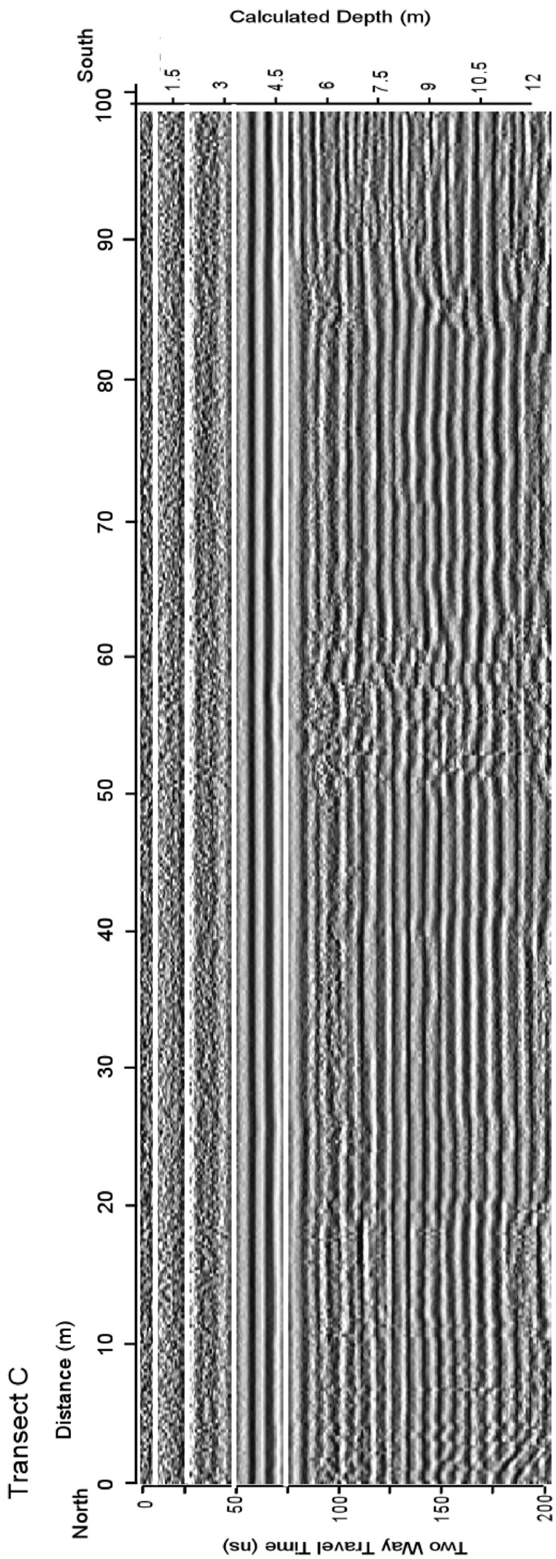

Figure 7. Transect C was acquired from North to South within the TAM basin. Depth was determined by D=(v*(TWT/2)) and the average EM wave velocity within saturated clays and soils. Unit boundaries are marked by arrows.

within Auger Core_5 which changes from dense peaty clay to olive black clay with large wood fragments (facies 3 to facies 5). The inclusion of wood fragments suggests either a freshwater environment where trees could survive or a location that trapped wood fragments such as a riverbank, delta or riverbend. All of these environments suggest freshwater influence much greater than the present. Thus, this second radar reflector could represent an older freshwater environment, possibly a floodplain. The presence of a previous freshwater environment is evidenced by several other studies, including the presence of tree stumps near Bly Creek located northeast of the current investigation (Gardner and Porter, 2001). Montane (2007) located three freshwater peat samples at 1.11, 2.16 and 2.41 meters depth within cores from a North Inlet salt marsh island Baldwin (2002) using a sub-bottom profiler, located a paleochannel offshore of North Inlet, which led the investigation to contemplate if that channel was the ancestral PeeDee River channel justifying the presence of these freshwater environments at a much lower sea level.

The third GPR radar reflector is located at an average depth of 3 meters. Analyses of the auger cores identified a lithological boundary at 3.2 meters that separates black clay with wood from black clay with fragments of wood that are red. The red wood fragments suggest a freshwater Cypress-Tupelo swamp, which are common along the southeastern coastal states and portray a much lower sea level then present. A present day example would be Congaree Swamp, a floodplain swamp of the Congaree River outside of Columbia, SC. Core lithology associated with the fourth radar

reflector cannot be used for ground truthing because sediment from that depth could not be retained with the auger core. However, previous investigations have discovered evidence of relict sand dunes from the ancient barrier island systems of Princess Anne and Silver Bluff highstand formations (Doar and Kendall, 2008; Gardner and Porter, 2001).

The combination of core lithology, sediment stratigraphy and geophysical images and horizons have aided in the interpretation of the depositional history of Thousand Acre Marsh. The facies reveal gradual changes from a possible relict dune swale-forest-river floodplain-freshwater swamp-freshwater marsh-brackish marsh due to the recent inundation of saltwater into this low lying marsh. Doar and Kendall (2008) suggest that TAM could be the result of a low-lying area located between to relict barrier islands which represent highstand shorelines. During the Pleistocene, this area was a swale between the former Princess Anne barrier island system, deposited ~100-80 kya and the later Silver Bluff barrier island system, deposited ~ 60-30 kya. The relict dune systems then slowly transitioned into forests and the swale became vegetated. The Pee Dee River migrated southward toward its present location during the Holocene due to the uplift of the Cape Fear Arch (Montane, 2007). The Pee Dee River could have flooded TAM creating a floodplain, then maybe a floodplain swamp as the North Island prograded southward and with it the PeeDee river, which was part of the most recent Myrtle Beach highstand barrier island system between ~135 – 120 kyrs (Dubar et al., 1974, Baldwin, 2002). There is also evidence that the Waccamaw could have flooded through North Inlet as well. Further analyses will be conducted to determine which or if both events affected Thousand Acre Marsh.

The continuation of saltwater inundation, increasing each year at an average rate of 3mm/yr (Colquhoun, 1969) is changing the dominant macrophyte from the black needlerush *Juncus roemarianus* to the grass *Spartina alterniflora*. If inundation of Thousand Acre Marsh by saltwater continues at the current rate of sea-level rise, the surrounding forest will begin to retreat up the relict dunes. As sea level continues to rise Thousand Acre Marsh could easily become flooded. The surrounding higher elevated forest area could disrupt the lateral migration of this environment and TAM would be come flooded instead of migrating. Thus, TAM could become similar to modern day mudflat environment of Mud Bay.

CONCLUSIONS

Here we present a description of the depositional history of Thousand Acre Marsh based on auger sediment cores and GPR data. The depositional history of this brackish marsh system includes the maturing of this environment 1) from a swale between relict beach ridge systems, 2) to a fluvially influenced environment by the migrating Pee Dee River and morphing from a floodplain to a floodplain swamp, and lastly 3) transitioning to the present day brackish marsh dominated by *Juncus roemarianus* related to the recent sea-level rise. Based on current trends, Thousand Acre Marsh will become inundated by saltwater as sea level continues to rise, thus, drowning and morphing Thousand Acre Marsh into a modern day Mud Bay.

Though this investigation has not been able to document specific Holocene sea-level cycles it has shown the present inundation of Thousand Acre Marsh and perhaps a forecast of future geomorphic changes to the South Carolina coast.

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REFERENCES

Addison A. 2006. Determining the Thickness of an Alluvial Sand Using the Ground- Penetrating Radar. African American Professors Program Monograph.

Addison A., N. Badger, B.M. Battista, C. Amos, I. Gupta, H. Park, D.M. Encui, R. Trenkamp, C. C. Knapp and J.H. Knapp, 2008. Ground Penetrating Radar (GPR): Seeking for Sinkholes at Santee State Park, Santee, SC. GSA- southeastern Section – 57th Annual Metting (10-11 April, 2008). Abstracts with Programs. 40(4), 1-10.

Baldwin W. E., 2002. Effects of Local and Regional Antecedent Geology of the Middle Inner Continental Shelf: Southern Long Bay, South Carolina. Geological Sciences. Columbia, University of South Carolina**:** 138.

Baldwin W.E., R.A. Morton, J.F. Denny, S. V. Dadisman, W.C. Schwab, P.T. Gayes and N.W. Driscoll, 2004. Maps Showing the Stratigraphic Framework of South Carolina's Long Bay from Little River to Winyah Bay, 2004-1013, USGS.

Baldwin, Wayne E; Morton, Robert A; Schwab, William C; *Gayes*, Paul T; Driscoll, Neal W., 2004. Modern availability and historic supply of sediment along the inner-continental shelf offshore northeast South Carolina. Abstracts with Programs - Geological Society of America, vol.36, no.2, pp.132,

Brockington L., 2006. Plantation Between the Waters, A Brief History of Hobcaw Barony. Charleston, The History Press.

Colquhoun D.J., 1969. Geomorphology of the Lower Coastal Plain of South Carolina: Division of Geology, South Carolina State Development Board, Publication MS-5, 1-36.

Davis J.L. and A.P. Annan, 1989. Ground-Penetrating Radar for High-Resolution Mapping of Soil and Rock Stratigraphy. Geophysical Prospecting. 37(5), 531-551.

Doar W. R., III and Kendall, C. G., 2008. Late Pleistocene to Holocene Sea Level Curve Derived from South Carolina Coastal Terraces: A Correlatable Datum for both 18O and Coral Reef Terrace Sea Level Curves, American Association of Petroleum Geologists/SEPM Joint Annual Meeting, San Antonio, Texas, Abstracts with Programs.

DePratter C. B. and J. D. Howard, 1981. Evidence for a Sea Level Lowstand Between 4500 and 2400 Hundred Years B.P. on the Southeast Coast of the United States. Journal of Sedimentary Petrology 51(4): 1287-1295.

DeVoe M. R. and F. J. Vernberg, 1992. Characterization of the Physical, Chemical and Biological Conditions and Trends in Three South Carolina Estuaries: 1970-1985 Winyah Bay and North Inlet Estuaries, v. 2. Charleston, S.C. Sea Grant Consortium**:** 1-115.

Gardner L. R. and D. E. Porter 2001. Stratigraphy and geologic history of a southeastern salt marsh basin, North Inlet, South Carolina, USA. Wetlands Ecology and Management 9: 371-385.

Gayes P.T., D.B. Scott, E.S. Collins and D.D. Nelson, 1992. A Late Holocene Sea Level Fluctuation in South Carolina. Quaternary Coasts of the United States: Marine and Lacustrine Systems, SEPM Special Publication 48: 155-160.

Montane, J.M. 2007. Geophysical and Stratigraphic Analysis of a southeastern Salt Marsh, North Inlet, SC. Dissertation Geological Sciences. Columbia, University of South Carolina**:** 124.

Neal A., 2004**.** Ground-Penetrating Radar and its use in Sedimentology; Principles, Problems and Progress. Earth Science Reviews 66 (3-4):261-330.

Topp G.C., J.L. Davis and A.P. Annan, 1980. Electromagnetic Determination of Soil Water Content: Measurements in Coaxial Transmission Lines. Water Resources Research, 16(3): 574-582.

Weaver Wendy, 2006. Ground Penetrating Radar Mapping in Clay: Success from South Carolina, USA. Archaeological Prospection 13: 147–150.

Wright E., A.C. Hine, S. L. Goodbred, and S.D. Locker, 2005. The Effect of Sea-level and Climate Change on the Development of a Mixed Siliciclastic-Carbonate, Deltaic 17 Coastline: Suwannee River, Florida, U.S.A. Journal of Sedimentary Research, 75: 621- 635.