THE HOLOCENE STRATIGRAPHY OF THREE FRESHWATER TO BRACKISH WETLANDS, KENT COUNTY, DELAWARE*

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INTRODUCTION

Objectives

The Holocene history of three tidal, freshwater to oligohaline (brackish) wetlands is examined in cores obtained from modern tidal channels and the adjacent valleys in order to:

1) describe the sediments deposited in modern Riverine, Estuarine, and Palustrine Wetland Systems;

2) describe the sediments deposited in the following wetland subenvironments (wetland classes): channel (Unconsolidated Bottom classes), unvegetated mud-flat (Flat and Emergent classes), and vegetated marsh (Emergent and Forested classes);

3) calculate and compare the sediment accumulation rates of the deposits from the sampled subenvironments: channel, unvegetated mudflat, and vegetated marsh;

4) relate the horizontal distribution and vertical sequence of sedimentary facies to the sea level rise of the Holocene transgression;

5) determine the Holocene history of the three wetland localities sampled by integrating the data from Objectives 1 through 4; and

6) integrate the specific geologic histories of the three localities into a generalized model of transgressive wetlands evolution.

These objectives are met by using modern analogs for past environments. Modern wetland environments are investigated. Then the results are used to interpret the buried wetland environments sampled by cores. The study provides a basis for interpreting the cultural activities, land use, and settlement patterns of prehistoric people whose campsites and villages have been found adjacent to the wetlands.

* This section combines Whallon's 1989 M.S. thesis in Geology at the University of Delaware with a paper published by Pizutto and (Whallon) Rogers (1992) in the Journal of Coastal Research.
The two documents were edited together by Douglas Kellogg.

Location and Geologic Setting of the Study Area

The three places under study are located 8 to 16 km inland (west to southwest) of Delaware Bay in the Atlantic Coastal Plain and Continental Shelf Geological Province (Kraft 1976). The area is underlain by a seaward-thickening wedge of Cenozoic and Mesozoic sediments (up to 2500 m thick near the Delaware shore), and blanketed by Pleistocene sands and gravels of the Columbia Formation (Kraft 1976; Pickett 1976).

Three localities were selected along the corridor of the proposed State Route 1 corridor, all within 1.5 km of the present Delaware State Highway 13 (Figure 2). The localities are in the Smyrna River, the St. Jones River, and the Leipsic River in Kent County, Delaware. These locations were selected because of their proximity to areas of intensive prehistoric settlement (Custer, Bachman, and Grettler 1986, 1987; Bachman, Grettler, and Custer 1988).

Modern Wetland Environments. Today, tidal stream valleys near the coast are occupied by salt-tolerant (halophytic) wetland species (for example, Spartina sp.) which form broad expanses of Estuarine Emergent salt marsh on the substrate of Holocene mud. Upstream, saline Estuarine waters become diluted by fresh water, forming brackish tidal streams and wetlands. Further inland, brackish wetlands are gradually replaced by tidal freshwater Riverine, or Palustrine environments. Beyond the limit of tidal influence are freshwater fluvial streams and wetlands.

The study areas are located in freshwater wetlands of the tidal stream channels and valleys above the influence of salt water. The dynamic transition between salt and fresh water has been characterized by Odum et al. (1984) as having:

1) near freshwater conditions (average annual salinity of 0.5 part per thousand or less);

2) plant and animal communities dominated by freshwater species; and

3) a daily, lunar tidal fluctuation.

The absence of saltwater stress combined with the nutrient fluxes of daily tides create a highly productive and diverse plant community with as many as 50 to 60 species at a single location (Odum et al. 1984).

Because of the difficulties of surveying in these wetland environments the elevations of the coring localities were not determined directly. However, large scale maps (1:600) with a contour interval of 30 cm (1 ft.) and spot elevations accurate to 3 cm (0.1 ft.) cover the coring locations. Wetland surfaces on the maps range from 0.30 to 0.90 m above mean sea level (National Geodetic Vertical Datum of 1929). The mean semidiurnal tidal range is 1.07 m at the closest tide gauge about five miles downstream (east) of the Leipsic River core locality (National Oceanic and Atmospheric Administration 1988).

Wetlands

The term 'wetland' describes a variety of environments characterized by low relief and frequently saturated soil (Cowardin et al. 1979). Marshes, swamps, bogs, and flooded bottomland forests are all wetland environments. Wetlands typically occupy the region between permanently flooded habitats (lakes, rivers, and coastal embayments) and rarely flooded uplands. Wetlands are defined by the Fish and Wildlife Service (Cowardin et al. 1979) as:

"... lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For purposes of this classification wetlands must have one or more of the following three attributes:

1) at least periodically, the land supports predominantly hydrophytes;

2) the substrate is predominantly undrained hydric soil; and

3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year."

This definition recognizes the contributions of hydrology, vegetation, and soil type, and integrates the three aspects of wetlands into one coherent statement.

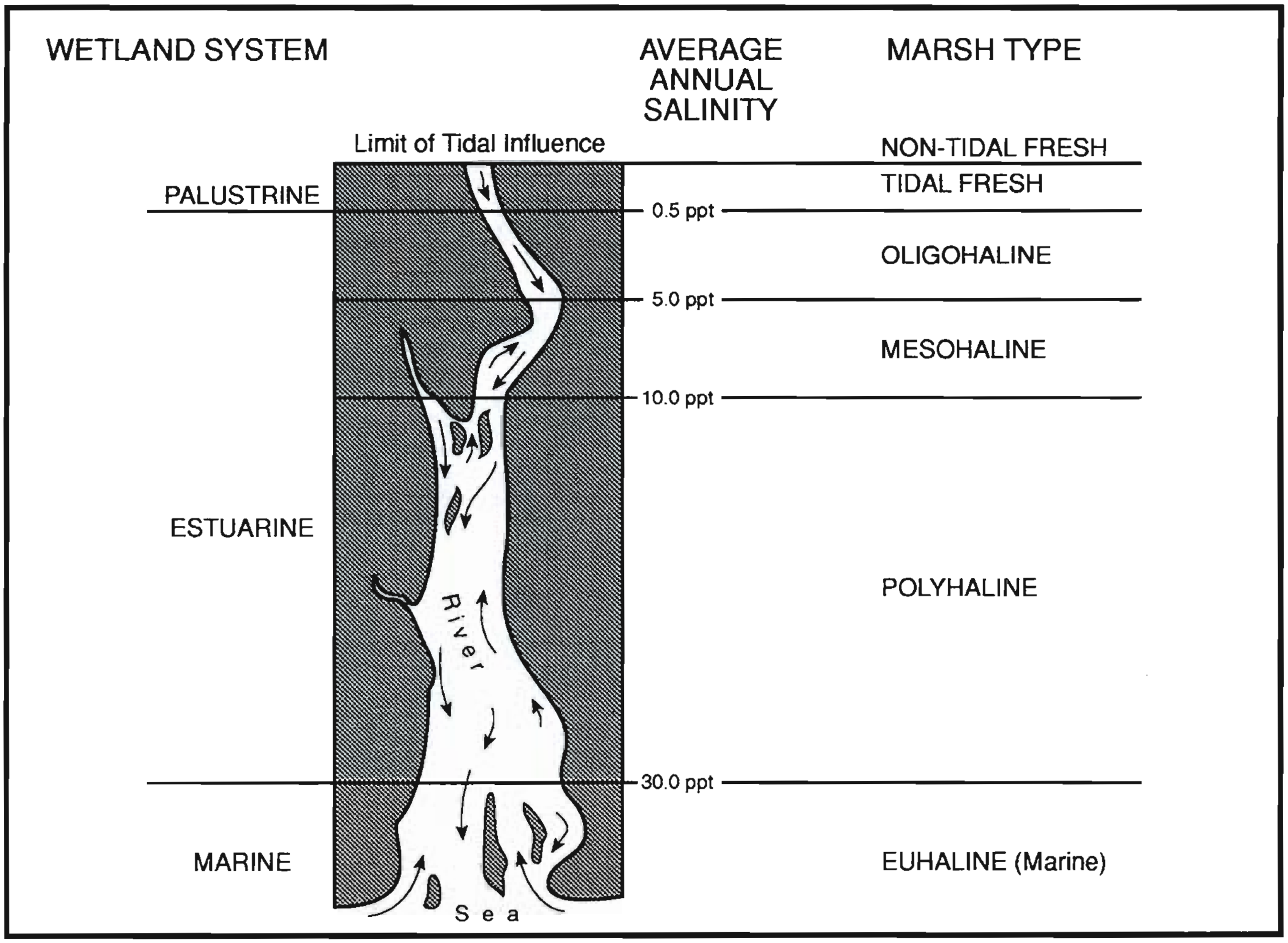
Cowardin et al. (1979) classified wetland environments according to hydrologic, geomorphic, chemical, or biological factors. The structure of the classification system is hierarchal, from general to specific. At the most general level, a wetland is defined as belonging to one of five 'systems': Marine, Estuarine, Lacustrine, Riverine, or Palustrine (Figure 32). Each system except for the Palustrine is further subdivided into 'subsystems' based upon water characteristics (for example, tidal, intermittent, etc.). Subsystems are divided into 'classes' described either by the dominant type of hydrophytic vegetation (for example, emergent, forested, etc.) or, if vegetable cover is less than 30%, by composition of the substrate (for example, rocky shore). Details of the vegetation (for example, broad-leaf deciduous) or the sediment size of the substrate (for example, sand, mud, etc.) are given by the 'subclass' grouping. Conditions of soil saturation or flooding are described by water regime modifiers for both tidal (for example, regularly flooded, irregularly exposed, etc.) and non-tidal (for example, intermittent, seasonally flooded, etc.) wetlands. Water chemistry modifiers describe the hydrogen ion concentration (pH) and salinity of the water.

Most research on wetlands has focused on Estuarine Emergent wetlands known as coastal salt marshes (see references cited in Frey and Basan 1985). More than a century of detailed investigations have produced voluminous literature on the origin and development of salt marshes (Mudge 1862; Shaler 1886; Chapman 1938), including the significance of salt marsh deposits as indications of sea level change caused by Pleistocene glaciations (see Bloom 1964; Redfield 1972; Kraft 1971; Rampino and Sanders 1981).

Freshwater wetlands of the Palustrine, Riverine, and Lacustrine systems have received little attention from geologists. Most investigations describe modern ecosystem processes such as primary production, energy flux, and nutrient exchange (for example, Good, Whigham, and Simpson 1978; Odum et al. 1984). Such descriptions lack a genetic or evolutionary perspective and do not provide a basis for interpreting wetland environments of the past as represented by sedimentary deposits. Wetland ecosystem development by plant succession has been addressed (for example, Mitsch and Gosselink 1986), but again the time scale is too short for geologic purposes. As a result, the evolution of freshwater wetlands as sedimentary environments is poorly understood.

FIGURE 32

Relationship Between Wetlands and Salinity



METHODS

Field Methods

Twenty-seven vibracores, six piston cores, and 16 Eijkelkamp 2.5 cm diameter hand driven cores were obtained during the summers of 1987 and 1988. Vibracores (Plate 4) were collected following the procedures of Hoyt and Demarest (1981). Vibracores were cut into halves lengthwise in the laboratory. One half was cut into 1 m sections, photographed, and then stored. The other half of each core was described and sampled for laboratory analysis.

Methods for Determining Lithologies

The lithology of sedimentary units within the cores was determined primarily by a visual inspection. Sediments were first classified as either mineral (sand or mud) or organic (peat) on the basis of their estimated organic content (U.S. Soil Conservation Service 1975). The size of sand grains (coarse, medium,

PLATE 4

Vibracoring a Wetland Study Locality

A section of aluminum irrigation pipe is vibrated into the mud and peat using a concrete vibrator attached to the pipe by a cable. The weight of the crew helps to force the corer into the mud. The core pipe is removed from the mud using a winch attached to the tripod.

and fine) were estimated by a visual comparison to a grain size diagram (Figure 12-1 in Compton 1962). In cases where the grain sizes or percent organic fraction of the sediment was uncertain, laboratory analyses were performed.

Laboratory Analyses

Grain Size Analysis. Sediments were soaked in a solution of 20% hydrogen peroxide and water for at least one week in order to dissolve the organic constituents. Then the solution was filtered through a 4 phi sieve using standard wet-sieve methods (Lewis 1984). After drying, the sand and mud fractions were weighed. Results are given in Appendix III.

Analysis of the Organic Content of Sediments. The organic content of samples was determined by Loss-On-Ignition (LOI) (Ball 1964). At least one sample was obtained from each lithologic unit in each core at intervals averaging from ten to thirty centimeters. Samples were dried overnight at 100°C, then weighed. Ignition at 375°C for 12 to 16 hours followed. Samples were then weighed again. The difference between the dry and ignited weights represents the amount of organic material in the sediments lost (burnt off) by the ignition process. Nearly 300 samples were analyzed (Appendix IV).

Based on the organic content of the sediment a lithologic could be assigned. Organic soils have been defined by the U.S. Soil Conservation Service (1975) as:

> "... saturated with water for long periods of time and (a) have an organic content of 18% or more if the mineral fraction is 60% or more clay, (b) have an organic content of 12% or more if the mineral fraction has no clay, or (c) have an organic content of between 12% and 18% if the mineral fraction has 0 to 60% clay."

The sediments of the study area consist of mixtures of gravel, sand, mud, and organic matter. The classification scheme in this study combined Folk (1974) for mineral sediments the with the U.S. Soil Conservation Service (1975) classification for organic-rich sediments. Sediments with organic content greater that 18% are termed "peat", a broader definition of peat than for "true peat" (for example, Kosters 1989). Ball (1964) suggested that LOI values inflate the percent organic carbon by as much as 100%; therefore, the cut-off between mineral sediments and peat was placed at 35% LOI in our classification scheme.

'Peat' is the term most frequently used to describe the organic deposits formed in temperate zone marsh environments (Allen 1974), although few such deposits have organic contents high enough to meet the requirements stated in the formal definition of peat. The Glossary of the American Geological Institute (Bates and Jackson 1987) defines peat as:

> "an unconsolidated deposit of semi-carbonized plant remains of a water saturated environment, such as a bog or fen, and of persistently high moisture content (at least 75%). It is considered an early stage or rank in the development of coal; carbon content is about 60% and oxygen content is about 30% (moisture free). Structures of the vegetal matter can be seen. When dried, peat burns freely."

FIGURE 33

Characteristic Loss-on-Ignition Curves for Different Types of Environments

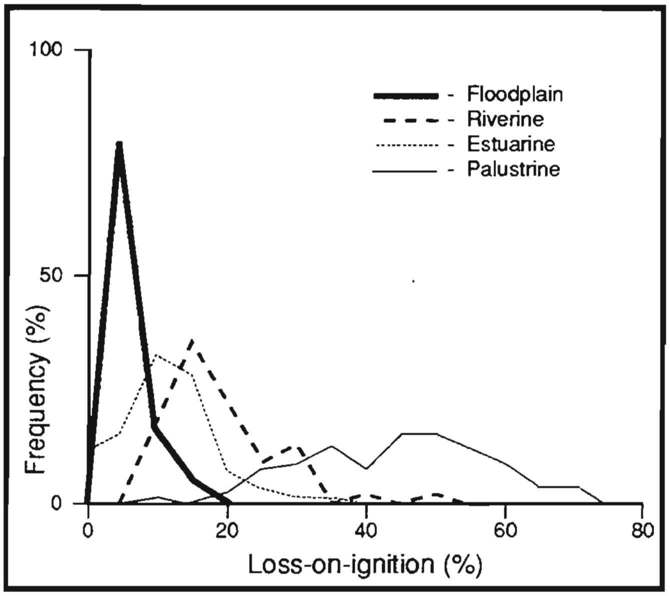


TABLE 6

Radiocarbon Dates for Wetland Cores

Core	Depth	Raw Date	Calibrated Age*
DC-1	205 cm	11,480±150	---
DC-3	120 cm	1370±110	1293 BP
	185 cm	5750±60	6613, 6587, 6550 BP
	205 cm	5620±70	6414 BP
SJ-1	300 cm	1890±220	1837 BP
SJ-3	80 cm	1040±220	951 BP
	160 cm	1360±100	1290 BP
	338 cm	1920±70	
SJ-6	335 cm	3460±80	3800, 3799, 3710 BP
LR-1	175 cm	6230±270	7179 BP
LR-4	154 cm	3515 85	3831 BP
LR-5	216 cm	8020 100	8988 BP

* Using computer program CALIB (Stuiver and Reimer 1986).

Since few marsh deposits contain 60% organic carbon, a more general definition is preferred. Marsh peat, as defined by Redfield (1972), consists of:

> "material formed by mineral sediment deposited among vegetation and containing the roots and other parts of the plants either living or dead."

This qualitative definition is supplemented in this study by the application of the percentage of organic material required to produce an organic soil (U.S. Soil Conservation Service 1975). Peat thus defined includes abundant mud, and is frequently termed "muddy peat".

Supplemental Analyses. One half of one selected core from each of the study locality was sent to Grace Brush at The Johns Hopkins University for pollen analysis (see Brush in this volume). Selected peat samples were also sent to the University of Wisconsin Dating Lab for radiocarbon analysis (Table 6).

Determining Paleoenvironments

Observation alone did not provide a basis for distinguishing wetland environments within the cores because the lithologies are not unique and also because diagnostic sedimentary structures are not present. However, LOI values for sediment samples from modern environments cluster into three distinct groups (Figure 33). Sediments from floodplains have the lowest LOI values, while LOI values increase for riverine, estuarine, and palustrine wetlands. Whigham and Simpson (1976) and Jones and Cameron (1988) have used LOI to discriminate low from high salt marsh. Therefore, LOI was seen as a possible tool for discriminating past wetland environments.

Cross-sections were constructed for each area by correlating the lithologic logs of the cores. The lithologic units comprising each core had been previously identified as either sand (coarse, medium, or fine), peat (generally muddy), mud, or Low-organic mud. Adjacent equivalent lithologic units were correlated from core to core on the basis of lithologic similarity, both of grain size and organic content. The LOI values for each laterally equivalent lithologic unit were then compiled into one population. The subsurface populations were then statistically compared by Analysis of Variance to the LOI populations for modern wetland systems and classes.

RESULTS

The Duck Creek Locality

Six cores were obtained from Duck Creek (Figure 34 and Plate 5). The line of cross-section bisects the stream valley between cores DC-1 and DC-6, then parallels the channel from DC-6 through DC-4.

Description of Lithologies. The core log of DC-1 is representative of the lithologies of the Duck Creek area (Figure 35). Four distinct lithologic units are recognized:

1) a dark yellowish brown mud 71 cm deep containing organic fibers and large wood fragments with a highly organic (peaty) modern root zone (15-20 cm);

2) a grayish black, muddy peat with irregular lenses of fine sand and a large wood fragment;

FIGURE 35

Representative Core from Duck Creek

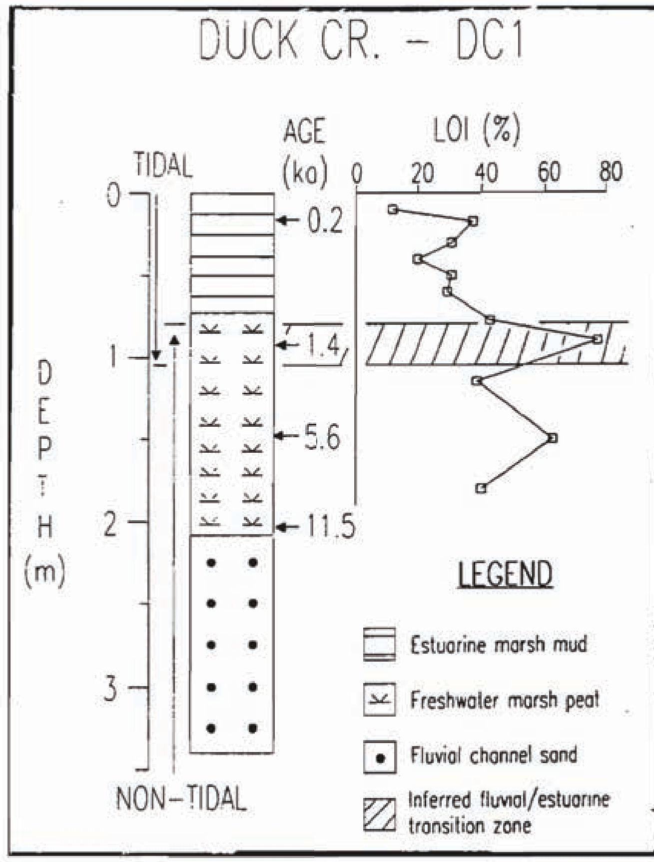
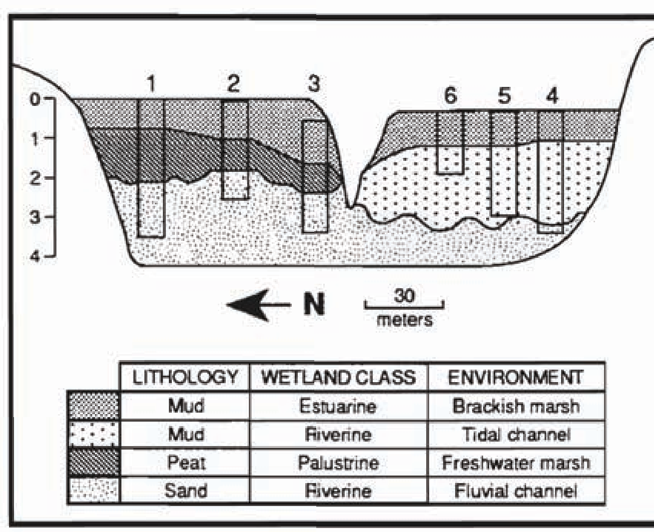


FIGURE 36

Stratigraphic Cross-Section of Duck Creek



3) fine to very fine sand, mostly massive but laminated with coarser sand near its base (306 cm); and

4) medium grained sand with irregular black laminae.

LOI values increase resulting in the gradational transition between units 1 and 2. The color shift to dusky yellowish brown at approximately 170 cm reflects a gradual increase in mud content relative to organic content (decreased LOI value). A radiocarbon age of 11,480 BP was reported for the base of unit 2 (205 cm).

Cross-Section. The cross-section (Figure 36) shows that approximately two meters of mud and peat overlie about one meter of either muddy sand near the center of the valley (cores DC-2 and DC-3), or clean sand along the valley margin (core DC-1). The clean sand is interpreted to be pre-Holocene in age, and is encountered only in this hole.

The Analyses of Variance (Table 7) indicate the following wetland environments for the lithologies, from oldest to youngest, of the Duck Creek study locality:

1) The clean sand at the base of core DC-1 was not analyzed as it is thought to represent the pre-Holocene 'basement' unit;

2) The muddy sand and sandy mud at the base of cores DC-2, DC-3, and DC-4 statistically correspond to a Riverine wetland environment;

3) The peat unit overlying the basal sandy units in cores DC-1, DC-2, and DC-3 corresponds to a Palustrine wetland environment;

4) The mud unit overlying the Palustrine peat unit in cores DC-2 and DC-3 could indicate either a Palustrine Emergent, Estuarine Emergent, Estuarine Flat, or Riverine wetland environment. It does not correspond to a Palustrine Forested environment;

5) The low-organic mud unit overlying the previous mud unit in cores DC-2 and DC-3 is anomalous. The same unit occurs at the base of cores DC-6, DC-5, and DC-4. The very low LOI values and massive nature of this unit have no modern analog in any of the modern environments sampled. This unit is statistically distinct from all modern populations; and

6) A peaty deposit labeled 'modern root zone' on Table 7 overlies the Low-organic mud in cores DC-3 and DC-6, and corresponds to a Palustrine wetland environment. Both the Emergent Peat and Emergent Mud correspond statistically to this unit, while Forested Mud does but Forested Peat does not correspond. The better correlation with the deposits of the Emergent class suggests an Emergent rather than a Forested class environment.

TABLE 7

Analysis of Variance Data for the Duck Creek Study Locality

Core Unit	Modern Environment	ANOVA Table	F (a = 0.05)	Populations distinct?	Environment
Peat	Total Riverine	125.00	4.09	Yes	PALUSTRINE (Emergent or Forested)
	Palustrine Emergent Peat	3.55	4.54	No	
	Palustrine Forested Peat	0.17	4.60	No	
	Total Palustrine Peat	0.74	4.28	No	
	Estuarine Flat	53.20	4.54	Yes	
	Estuarine Emergent	95.28	4.09	Yes	
	Total Estuarine	122.90	4.06	Yes	
Lower Organic Mud	Palustrine Emergent Mud	40.82	4.32	Yes	a ??? (Riverine?)
	Palustrine Forested Mud	266.99	4.35	Yes	
	Riverine Mud	20.36	4.32	Yes	
	Estuarine Flat	76.67	4.26	Yes	
	Estuarine Emergent	23.96	4.06	Yes	
Mud	Palustrine Emergent Mud	1.19	5.59	No	? Palustrine Emergent Riverine or Estuarine ?
	Palustrine Forested Mud	18.47	5.99	Yes	
	Riverine Mud	0.47	5.59	No	
	Estuarine Flat	0.08	4.96	No	
	Estuarine Emergent	0.03	4.16	No	
	Low Organic Mud*	76.43	4.41	Yes	
Muddy Sand	Riverine Sandy Mud	0.01	5.12	No	RIVERINE
	Riverine Sand	15.61	4.49	Yes	
Sandy Mud	Riverine Sandy Mud	0.23	4.84	No	RIVERINE
	Muddy Sand*	0.12	7.71	No	
Modern Root Zone	Palustrine Emergent Peat	1.15	4.84	No	PALUSTRINE (Emergent)
	Palustrine Forested Peat	10.79	4.96	Yes	
	Esturine Emergent	18.23	4.16	Yes	
	Total Estuarine	23.55	4.06	Yes	
	Palustrine Emergent Mud	3.83	5.23	No	
	Palustrine Forested Mud	1.31	5.59	No	
	Riverine Mud	19.98	5.32	Yes	
	Peat*	5.08	4.96	Yes	
	Mud*	9.77	6.61	Yes	

* Indicates comparisons to other subsurface units at this site.

The mud units comprising the tops of the cores are identified as Estuarine Flat (DC-3) and Emergent modern wetland environments (National Wetlands Inventory 1987 map of Smyrna, DE). The Low-organic mud lithology probably forms in a Riverine, Emergent, Non-persistent wetland environment. This modern environment was not sampled by any of the cores, since all of the core localities were mapped as having Persistant vegetation (National Wetlands Inventory 1987). Diagenesis by aerobic decomposition is the likely reason for the low organic content.

The St. Jones River Locality

The locations of the six vibracores obtained at the St. Jones River locality (Plate 6) are shown on Figure 37. Eight Eijkelkamp cores were also taken, but not used in the cross-sections because the small core diameter precludes detail in the recovered sections and because no LOI analyses were performed. The Eijkelkamp cores were collected to provide additional information about the sediment type and the amount of compaction in the vibracores.

Description of Lithologies. Several lithologic units are identified in the representative core log (core SJ-6) for the St. Jones River area (Figure 38):

1) 43 cm of dusky-brown mud that grades into 2)

2) a compact dusky yellowish-brown mud (43-241cm) with low organic content (12%);

3) a sandy mud with pebbles from 241 to 292 cm, interbedded with lenses of medium grained sand;

4) dusky-brown organic mud from 292 to 334 cm radiocarbon dated to 3460 ± 80 BP (330-334 cm); and

5) highly compacted sandy mud (334-351 cm) and fine sand (351-371 cm) speckled with vivianite, a cobalt-blue iron phosphate which forms in reduced environments in the absence of sulfur (P. Leavens, personal communication).

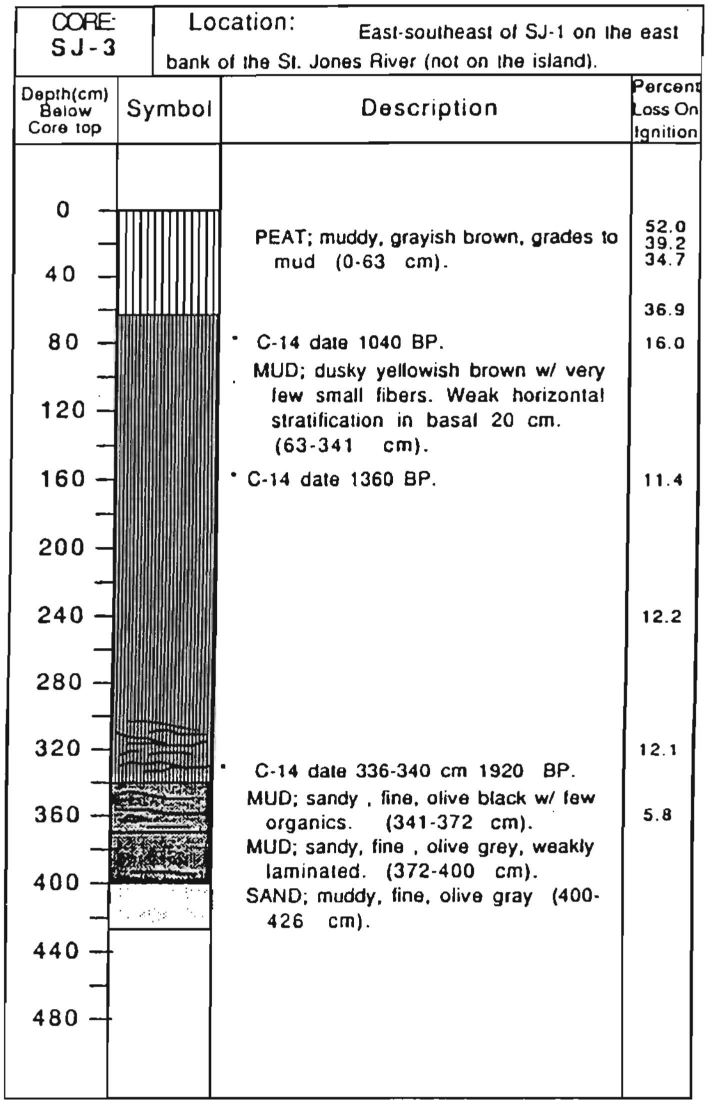
The six vibracores were used to construct two cross-sections (Figure 39). The cross-sections intersect different portions of the modern channel and abut against pre-Holocene outcrops along a valley wall. Deposits of peat and mud ranging from one to about four meters thick overlie more than two meters of sand and gravelly sand in core SJ-1 and overlie 20 cm of compacted fine sand and sandy mud in cores SJ-5 and SJ-6.

The results of the Analyses of Variance for the subsurface populations of the St. Jones River locality are shown in Table 8. The wetland environments determined for the units are listed below from oldest to youngest:

1) The basal sand and sandy mud units cannot distinguished from, and thus are identified as, Riverine wetland environment.

FIGURE 38

Representative Core from St. Jones River



2) A unit consisting of peat mixed with mud is sandwiched between Riverine muddy sand units near the base of SJ-6 ('SJ-6 Deep Mud' in Table 8). It corresponds to deposits of the Palustrine system, but it cannot be resolved at the class level (Emergent versus Forested).

3) A mud unit of low organic content ('Low-Organic mud') is found above the Riverine deposits in all of the cores except SJ-1. This unit is statistically distinct from all of the modern deposits, thus has no modern wetland environmental analog.

4) A peat unit overlies the Riverine deposit in SJ-1, and it corresponds to a Palustrine wetland system but cannot resolved to the class level.

5) Above the peat in SJ-1 and above the Low-organic mud in SJ-3, SJ-5, and SJ-6 is a mud unit of slightly greater organic content ('Mud 2'). This unit is statistically identified with both the Riverine and the Estuarine modern deposits. Since the sea level rise of Holocene

TABLE 8

Analysis of Variance Data for the St. Jones River Study Locality

Core Unit	Modern Environment	ANOVA Table	F (a= 0.05)	Populations distinct?	Enironment
Mud 1	Riverine Mud	16.60	5.12	Yes	PALUSTRINE (Emergent or Forested)
	Estuarine Flat	26.47	4.75	Yes	
	Estuarine Emergent	7.78	4.12	Yes	
	Palustrine Mud	0.12	4.60	No	
	Palustrine Emergent Mud	0.83	5.12	No	
	Palustrine Forested Mud	0.49	5.32	No	
	Mud 2*	37.78	4.75	Yes	
	SJ6 deep Mud*	1.18	5.99	No	
Mud 2	Riverine Mud	0.25	4.67	No	RIVERINE or ESTUARINE
	Estuarine Flat	0.29	4.49	No	
	Estuarine Emergent	0.57	4.09	No	
	Palustrine Mud	13.83	4.41	Yes	
	Palustrine Emergent Mud	15.19	5.59	Yes	
	Palustrine Forested Mud	25.28	4.96	Yes	
	Mud 1*	37.78	4.75	Yes	
	SJ6 deep Mud*	32.62	4.96	Yes	
Peat	Estuarine Emergent	88.29	4.04	Yes	PALUSTRINE (Emergent or Forested)
	Palustrine Emergent Peat	1.00	4.54	No	
	Palustrine Forested Peat	3.45	4.60	No	
Sandy Mud	Riverine Sandy Mud	4.07	4.45	No	RIVERINE
	Riverine Mud	11.63	4.60	Yes	
	Riverine Sand	18.60	4.26	Yes	
	Low Organic Mud*	16.77	4.23	Yes	
Low Organic Mud	Riverine Mud	6.00	4.30	Yes	??? (Riverine ?)
	Estuarine Flat	29.42	4.24	Yes	
	Estuarine Emergent	12.15	4.04	Yes	
	Palustrine Mud	56.66	4.17	Yes	
	Palustrine Emergent Mud	27.52	4.30	Yes	
	Palustrine Forested Mud	187.71	4.32	Yes	
SJ6 Deep Mud	Riverine Mud	15.19	5.59	Yes	PALUSTRINE (Emergent or Forested)
	Estuarine Flat	25.28	4.96	Yes	
	Estuarine Emergent	10.61	4.15	Yes	
	Palustrine Mud	1.51	4.75	No	
	Palustrine Emergent Mud	2.09	5.59	No	
	Palustrine Forested Mud	0.42	5.99	No	
	Peat*	5.20	5.12	Yes	

* Indicates comparisons between subsurface units at the same site.

time has not yet brought salt waters to this locality, the likelihood of Estuarine wetlands lying beneath the modern wetlands is very slight, so a Riverine environment is interpreted for this unit.

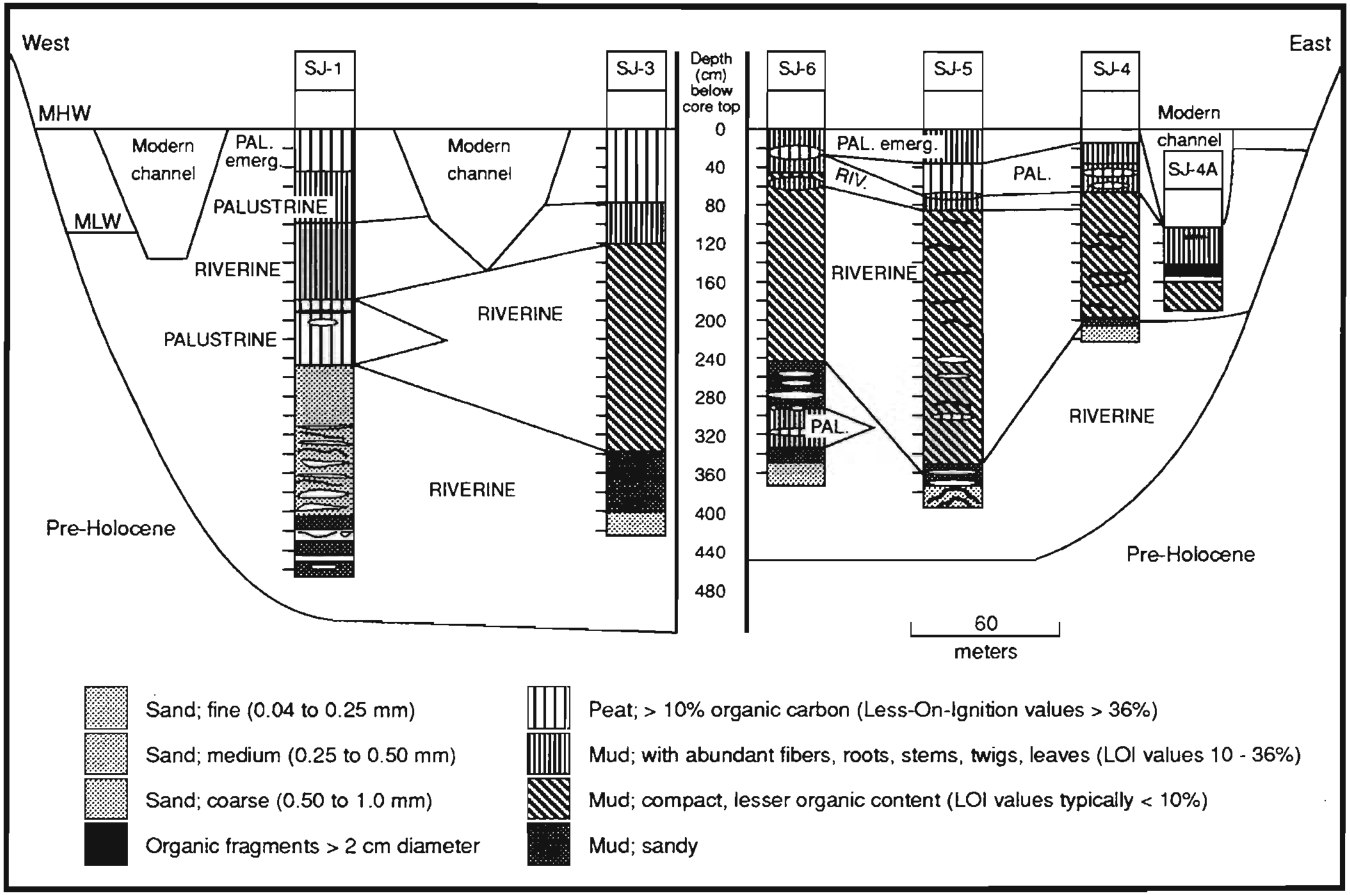
6) Overlying the Riverine mud unit in SJ-1, SJ-4, and SJ-5 is a peaty mud unit ('Mud 1') which cannot be distinguished from the Palustrine wetland system. The class level, Emergent or Forested, cannot be determined.

7) Overlying the Low Organic mud unit in SJ-4A is a sandy mud unit which represents a Riverine channel deposit.

The uppermost unit core SJ-4A is classified as Riverine Tidal Unconsolidated Bottom, and the remainder are Palustrine Emergent containing some randomly occurring Shrub Scrub areas (National Wetlands Inventory 1987 map of Dover, DE).

FIGURE 39

Stratigraphic Cross-Section of St. Jones River



The Leipsic River Locality

Eight vibracores were obtained from the Leipsic River locality (Plate 7 and Figure 40). The line of cross-section bisects the tidal stream valley from core LR-2 to core LR-3.

Description of Lithologies. The representative core LR-90-DC3 (Figure 41) shows a vertical section consisting almost entirely of mud and peat. A darker, sandy mud occurs from 3 cm to 7 cm, but the majority of the core is composed of dusky-brown mud with variable amounts of organics. Some very large wood fragments occupy the entire 3 inch diameter of the core from 115-129 cm and from 131-139 cm. A sample of black organic mud from the base of the unit (217-220 cm) yielded a radiocarbon date of 8020±80 BP.

The cross-section (Figure 42) shows the vertical lithologic record and the relationships between adjacent cores. Between 1.5 and 2.5 m of mud and peat overlie a sandy unit which is encountered in three of the cores.

FIGURE 41

Representative Core from Leipsic River

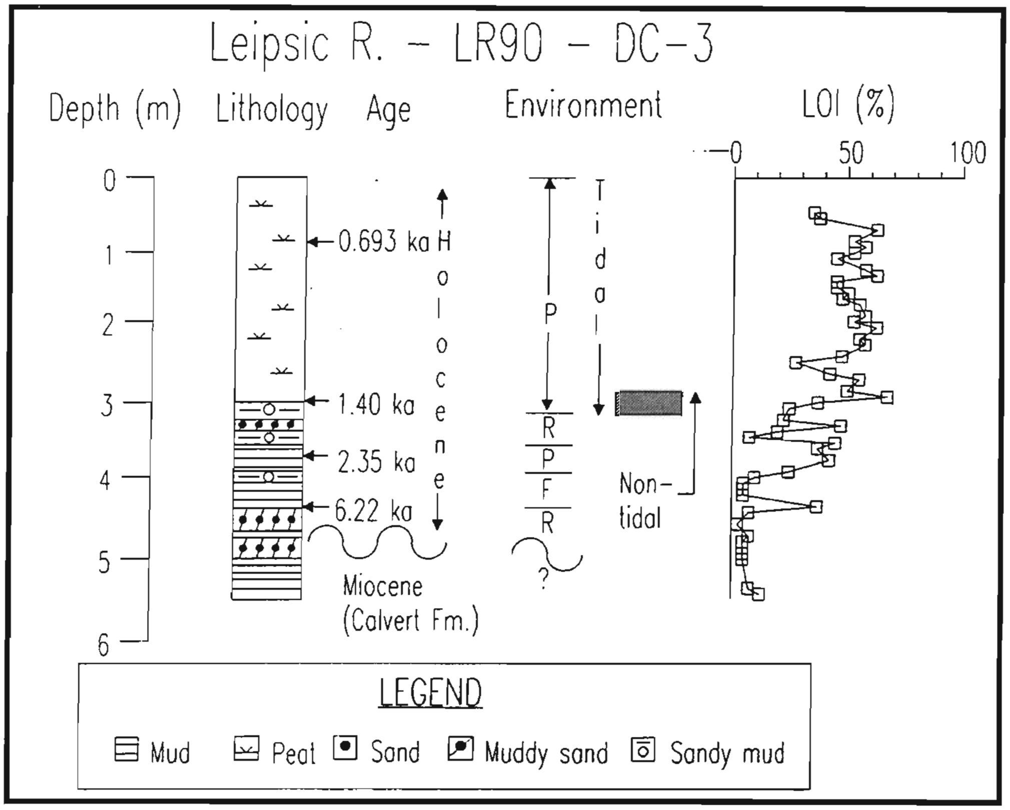


FIGURE 42

Stratigraphic Cross-Section of Leipsic River

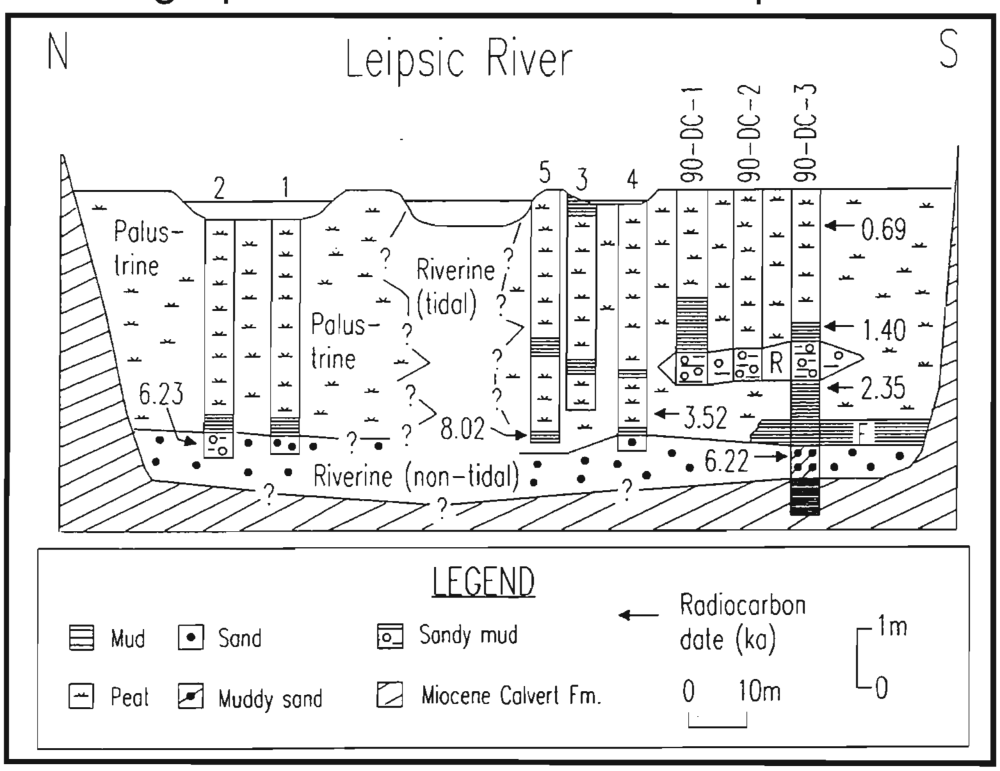


TABLE 9

Analysis of Variance Data for the Leipsic River Study Locality

Core Unit	Modern Environment	ANOVA Table	F (a=0.05)	Populations distinct?	Environment
Peat (high)	Palustrine Emergent Peat	8.81	4.32	Yes	PALUSTRINE Forested
	Palustrine Forested Peat	0.07	4.35	No	
Mud (high)	Palustrine Emergent Mud	0.06	4.84	No	PALUSTRINE (Emergent or Forested)
	Palustrine Forested Mud	2.16	4.96	No	
	Total Palustrine Mud	0.23	4.49	No	
	Total Estuarine	6.18	4.06	Yes	
Peat (low)	Palustrine Emergent Peat	0.69	4.60	No	PALUSTRINE Emergent
	Palustrine Forested Peat	5.40	4.67	Yes	
Mud (low)	Palustrine Emergent Mud	1.05	5.59	No	PALUSTRINE (Emergent or Forested)
	Palustrine Forested Mud	0.02	5.99	No	
	Total Palustrine Mud	0.38	4.75	No	
	Total Estuarine	8.69	4.08	Yes	
Sandy Mud	Riverine Sandy Mud	1.81	4.96	No	RIVERINE
	Riverine Mud	5.60	5.59	Yes(/)	

The results of ANOVA are shown in Table 9. The wetland environments for the populations from subsurface units, from oldest to youngest, are as follows:

1) compacted sand units in the base of LR-2 and LR-4 are probably Pre-Holocene;

2) sandy mud deposits near the base in cores LR-2, LR-1, and LR-5 correspond to a Riverine wetland system;

3) a mud unit overlying the pre-Holocene sand in core LR-4 and above the Riverine sandy mud in core LR-5 ('Mud low' on Table 9) indicates a Palustrine wetland, which cannot be further resolved to the class level;

4) above the mud unit in cores LR-4 and LR-5 and forming the basal deposit in core LR-3 is a peat unit ('Peat low') which corresponds statistically to an Emergent class Palustrine system wetland;

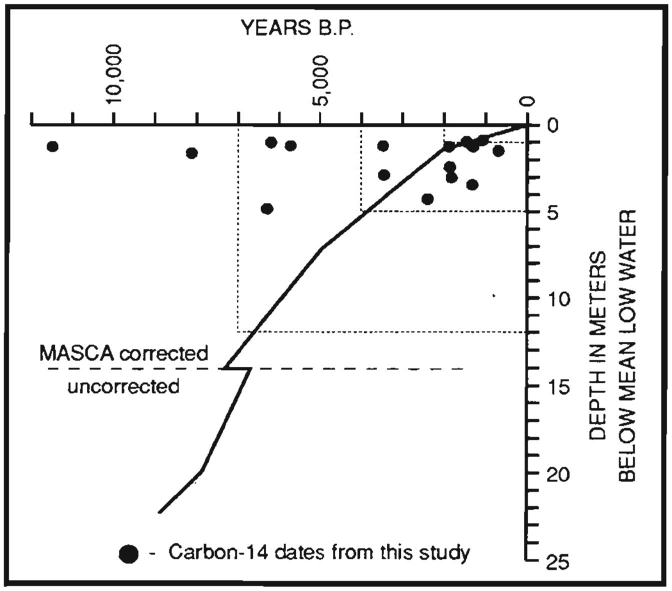
5) a unit of mud overlies the Palustrine peat unit in cores LR-3, LR-4, and LR-5, and overlies the Riverine sandy mud in LR-1 ('Mud high'). This mud corresponds to a Palustrine system of an unresolved class; and

6) above the Riverine sandy mud in core LR-2 and above the Palustrine mud in the other cores is a peat unit ('Peat high') which corresponds statistically to Forested class Palustrine wetland.

The Palustrine Forested wetland environment at the top of the cores was determined by reference to National Wetlands Inventory (1987) map of Smyrna, DE.

FIGURE 43

Delaware Coast
Relative Sea Level Curve



(After Kraft 1976) Radiocarbon dates that plot above the sea level curve are from fresh water environments. Dates that plot below the sea level curve are from brackish or marine environments.

THE HOLOCENE EVOLUTION OF THE WETLANDS OF THE STUDY AREA

Determining the Time of Tidal Incursion

The depths of sedimentary units with respect to the marsh surface were known from their core positions. The time of tidal arrival in years before present for a given depth could be determined from Kraft's (1976) local relative sea-level curve (Figure 43). If the plot of the depth versus age for a given sedimentary deposit coincided with the line of the sea level curve, the unit was interpreted to have originated in a transgressive environment. For example, a marsh peat encountered at a depth of 3 m below mean low sea level with a radiocarbon date of 3000 BP would be considered to be a transgressive unit whose origin was related to the relative rise in sea level, while a peat unit from the same depth but dated at 6000 BP would not. Figure 43 shows that the relative rise in sea level inundated incised stream valleys to depths of approximately -12 m around 7000 BP, -5 m around 4000 BP, and -1 m around 2000 BP (Kraft 1976).

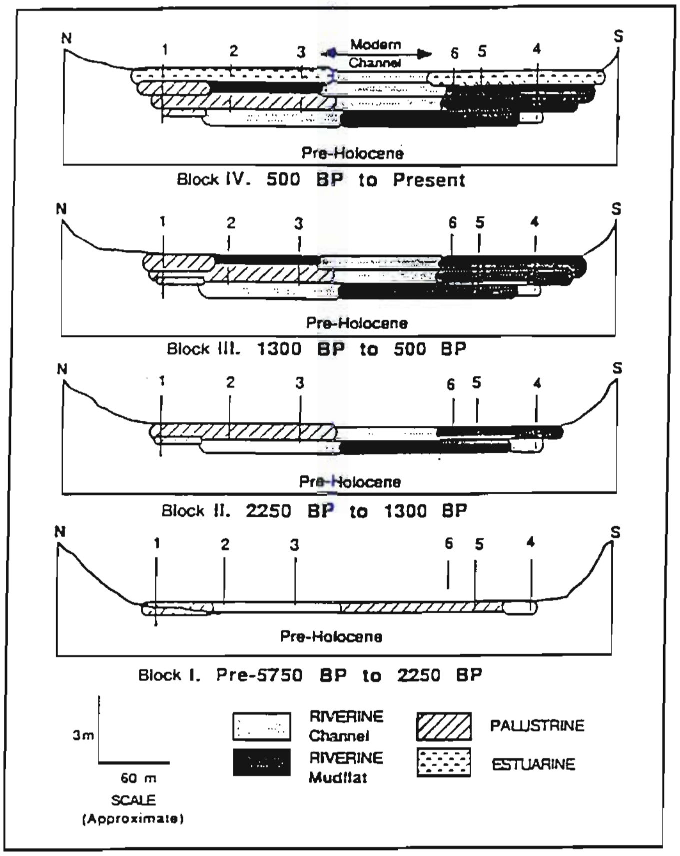
Age versus depth plots of the dated core horizons have been located on the relative sea-level curve (Figure 43). Deposits from cores SJ-1, SJ-3, TS-8, and the top unit from DC-3 are interpreted to be tidal in origin, while the remainder of the dated deposits predate the tidal transgression.

A few potential sources of error exist for this approach (Fletcher 1988). Sediment compaction and changes in tidal range may contribute to some measure of uncertainty in the sea level curve. However, the compaction of core sediments may represent the most significant source of error. Most of the dated deposits are not basal Holocene units and the highly organic nature of most marsh sediments renders them subject to significant compaction over time (Bloom 1964; Kaye and Barghoorn 1964). The apparent depths of the dated sediments in the cores might not be equivalent to the depths at which they were originally deposited.

The probability of this type of error was minimized by taking radiocarbon dates directly above sand deposits or Low-organic mud deposits which probably experienced little compaction relative to that of organic mud or peat. Other indicators of a transgressive environment were also used to supplement the relative sea level curve. An increase in the rate of inorganic sedimentation would indicate the addition of sediment from tidal sources. An increase in the percentage of mud may accompany this increase in sediment accumulation rate. The pollen record may also show an increase in 'wetter' species, both herbaceous and woody, as the local vegetation adjusted to an increase in the base water levels followed by periods of tidal inundation.

FIGURE 44

Development of Wetlands at Duck Creek



Sediment Accumulation Rates

Sediment accumulation rates were calculated for one core from each of the three localities constituting the study area. Average rates of sediment accumulation were calculated for each different lithology by dividing the sediment thickness by the elapsed time interval. Radiocarbon dates were obtained from specific horizons, and the time distribution between these dates was determined using variations in the pollen influxes (Brush 1989). The rates thus obtained allow comparisons of sediment accumulation in different wetland environments, and permit a more detailed chronological sequence of wetlands evolution to be constructed for each analyzed core.

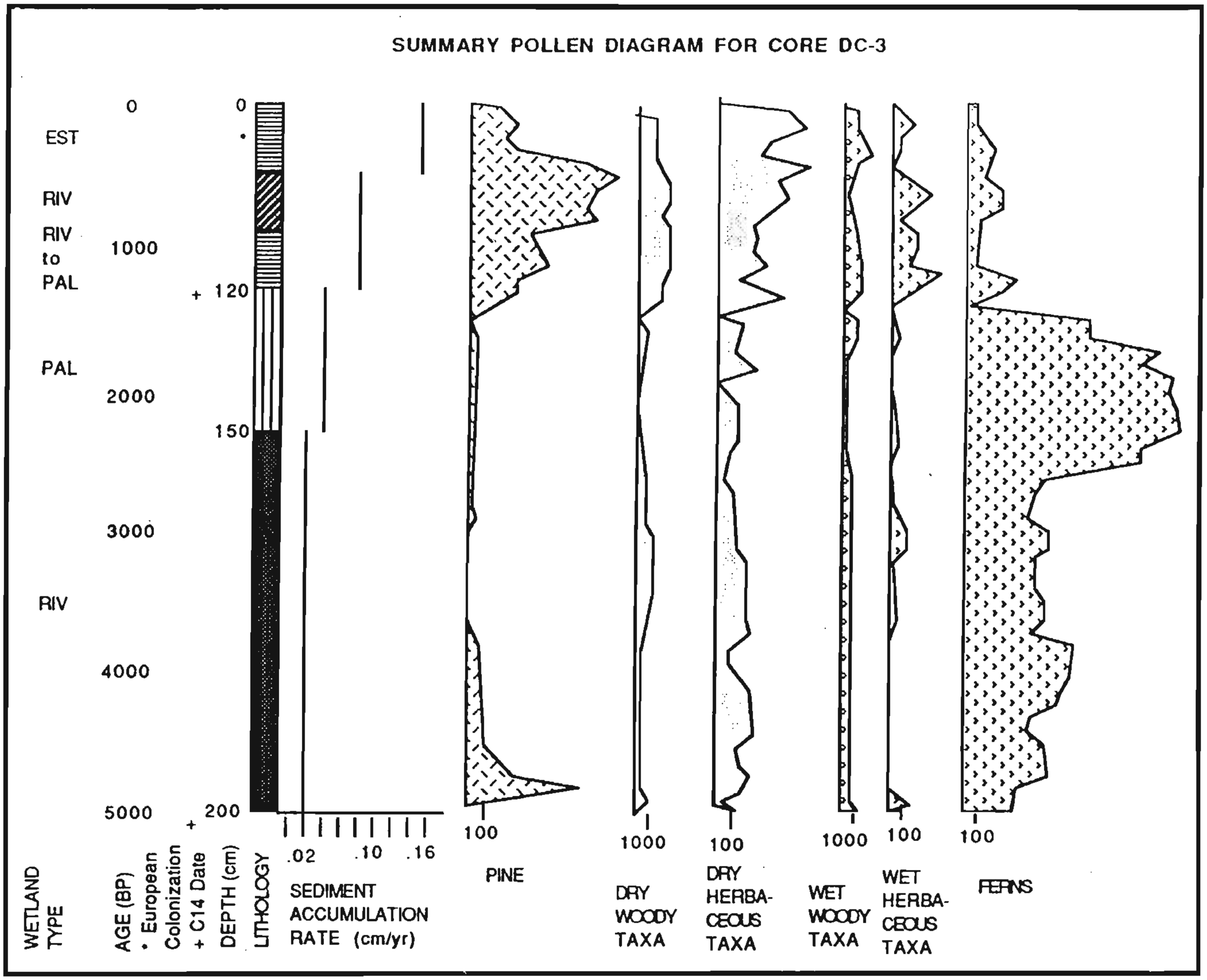
Duck Creek on the Smyrna River

The Holocene sequence of wetlands at the Duck Creek locality is presented below from the oldest known environment to the modern, and is illustrated by a schematic diagram (Figure 44). Refer to the cross-section for scaled lateral and vertical relationships (Figure 36) and Appendix V for lithologic detail from individual core logs. Analyses of core DC-3 provided three radiocarbon dates, sediment accumulation rates, and pollen data (Brush in this volume). An additional radiocarbon date was obtained from core DC-1.

Pre-Holocene Time. Deposits of pre-Holocene age were found in only one core from the Duck Creek area. The lack of data for this period of time prohibits correlation to other cores. A sand unit

FIGURE 45

Summary Pollen Diagram for Duck Creek



interpreted to be pre-Holocene in age is seen in core DC-1 at 205-336 cm, underlying a peat deposit that was dated at 11,480 radiocarbon years BP. The lithology correlates to a dense sand (revealed by a dramatic increase in the number of hammer blows required to penetrate 6 inches) seen at 550 cm in borings for the bridge footings at Smyrna Landing (DelDOT) and in nearby wells (Delaware Geological Survey). The shallow occurrence of the pre-Holocene sand in core DC-1 suggests that the core location is marginal to the axis of the deeply incised (at least 550 cm) antecedent stream valley.

A peat deposit overlies the pre-Holocene sand in core DC-1 from 11,480 BP until approximately 500 BP. The pre-Holocene radiocarbon date is supported by the pollen assemblage, particularly in the abundance of spruce pollen, (Brush, personal communication). The LOI population of this unit, which also occurs later in cores DC-2 and DC-3, identifies a Palustrine wetland, but cannot distinguish whether Emergent or Forested. The abundant pollen of ferns (Figure 45) and the large wood fragments in the core sediments at this depth also suggest a Forested wetland.

Pre-5750 to 2250 BP. Nearly 50 cm of sandy mud lies under the 5750 BP radiocarbon horizon in core DC-3, showing that a wetland environment occupied the locality for an undetermined amount of time between 11,480 BP and 5750 BP. Muddy sand and sandy mud units at the base of cores DC-2, DC-3, and DC-4 correspond statistically to a Riverine channel environment (Block I, Figure 44). The channel was somewhat north of its present location from pre-5750 BP until 2250 BP. Later the channel migrated laterally (south) to its present position. The sediment accumulation rate of the channel unit in core DC-3 is 0.02 cm/yr. The laterally adjacent basal unit in core DC-6 consists of Low-organic mud, interpreted to represent a Riverine Emergent mudflat environment (dark stippled pattern, Figure 44). The absence of time control makes it impossible to be certain of the age of this unit; but since the Low-organic mud lithology is interpreted to be a tidal deposit, it would not be contemporaneous with the adjacent sandy units. It probably formed after some channel bank deposit, or sediments removed by channel erosion. Because the channel was probably 2 to 3 m deep, any lateral migration would have obliterated the Holocene record. Thus, the basal unit of core DC-5 (shown as Palustrine on Block I, Figure 44) was probably eroded away then replaced by a Riverine mudflat Low-organic mud unit (Block II, Figure 44) following tidal inundation.

2250 to 1300 BP. The peat unit occurring from pre-Holocene time at the location of core DC-1 spreads laterally to overlie the channel deposits in the middle of the valley at the locations of cores DC-2 and DC-3 as well. The localities previously occupied by the channel would have become available for colonization by Palustrine wetland species once the channel had migrated slowly to the south. Initially the plant community probably consisted of Emergent class herbaceous macrophytes that later gave way to larger forest vegetation migrating into the valley from the nearby uplands. This pattern of succession is supported by the early date on the peat unit (11,480 BP) at the valley margin near upland forests and the later date on the Palustrine peat at the valley axis (2250 to 1300 BP in core DC-3). The Palustrine wetland is represented by peat and occurs only north of the interpreted channel position.

A rapid twofold increase in the rate of sediment accumulation (0.04 cm/yr) occurs in the peat at 1700 BP (130 cm in core DC-3). The age versus depth plot of this deposit coincides with the line of the local relative sea level curve (Kraft 1976) suggesting the arrival of tidal water at this time. Units found laterally adjacent to the peat on the south of the channel in cores DC-4, DC-5, and DC-6 consist of Low-organic mud, interpreted as a tidal Riverine Emergent mud-flat (Block II, Figure 44).

1300 to 500 BP. The progressive influx of tidal mud led to a gradual, localized transition from peat to mud around 1300 BP (115 cm) in core DC-3 and somewhat later (higher up the core) farther from the valley axis in core DC-2 (Figure 36). Based on the LOI signature, this mud unit could be from any modern mud unit except for a Palustrine Forested environment. It is interpreted to represent a transition from Palustrine to Riverine.

Beginning about 700 BP, the Low-organic mud lithology, seen earlier in cores DC-4 and DC-5, occurs in all but core DC-1. It forms a wedge that is thicker at the valley axis and thinner towards the margins, suggesting a genetic relationship to the stream channel. This unit represents a Riverine wetland system of the Emergent class and Non-persistent subclass. A Palustrine wetland persisted along the elevated valley margin, as shown by the peat found in core DC-1 at this depth (Block III, Figure 44).

500 BP to Present. Around 500 BP a localized deposit of peat formed along the axis of the stream valley above the Low-organic mud, seen in cores DC-3 and DC-6 (Figure 36). Statistically this unit corresponds to a Palustrine wetland system of an undetermined class. It is interpreted to represent a localized riparian Palustrine Emergent wetland, which evolved as emergent vegetation became established

on the underlying mudflat (Riverine Emergent) margins of the channel. The number of pollen from grasses and other herbaceous emergents increased at this depth (25 to 40 cm) in core DC-3 (Figure 45), which corresponds to ages of 500 to 300 BP.

A mud unit is laterally adjacent to the peat along the valley margins, and overlies the peat from 300 BP to the present across the entire valley. This mud forms in a modern environment that is mapped as an Estuarine wetland system of the Flat (core DC-3) or Emergent class (Block IV, Figure 44). There is no lithologic change that signals the arrival of slightly saline tidal waters. Increasing relative sea level continues to supply tidal mud at present. The mud supports herbaceous emergents (grasses and sedges) which contribute organic detritus and trap tidal mud. The rate of sediment accumulation for transgressive deposits averaged 0.08 cm/yr, a 400% increase over the rate from the pre-transgressive Riverine sand.

<u>Summary</u>. Sedimentary deposits at the Duck Creek locality represent three different wetland systems. Riverine wetlands have occupied the area from before 5750 BP to the present, Palustrine wetlands existed north of the channel from 11,480 to 500 BP along the valley wall and from 2250 BP to 1300 BP in the center of the valley, and Estuarine wetlands have occupied the area for at least 500 years. Tidal influence began in the region around 1700 BP. The arrival of brackish water is estimated to coincide with the base of the Estuarine wetland deposit at around 500 BP. The modern Estuarine Emergent wetland (National Wetlands Inventory 1987 map of Smyrna, DE) is dominated by freshwater grasses and sedges, including common reed, big cordgrass, and bulrushes.

The St. Jones River Locality

The Holocene sequence of wetlands at the St. Jones River locality is presented below from the oldest known environment to the modern and illustrated by a schematic diagram (Figure 46). As on the cross-section, two different lines of section are shown on the diagrams. Refer to the cross-section for scaled lateral and vertical relationships (Figure 39) and Appendix V for lithologic detail from individual core logs. Analyses of core SJ-3 provided pollen data, three radiocarbon dates, and the time scale for calculations of sediment accumulation rates (Brush in this volume). Two additional radiocarbon dates are also available: one from core SJ-1 and one from core SJ-6.

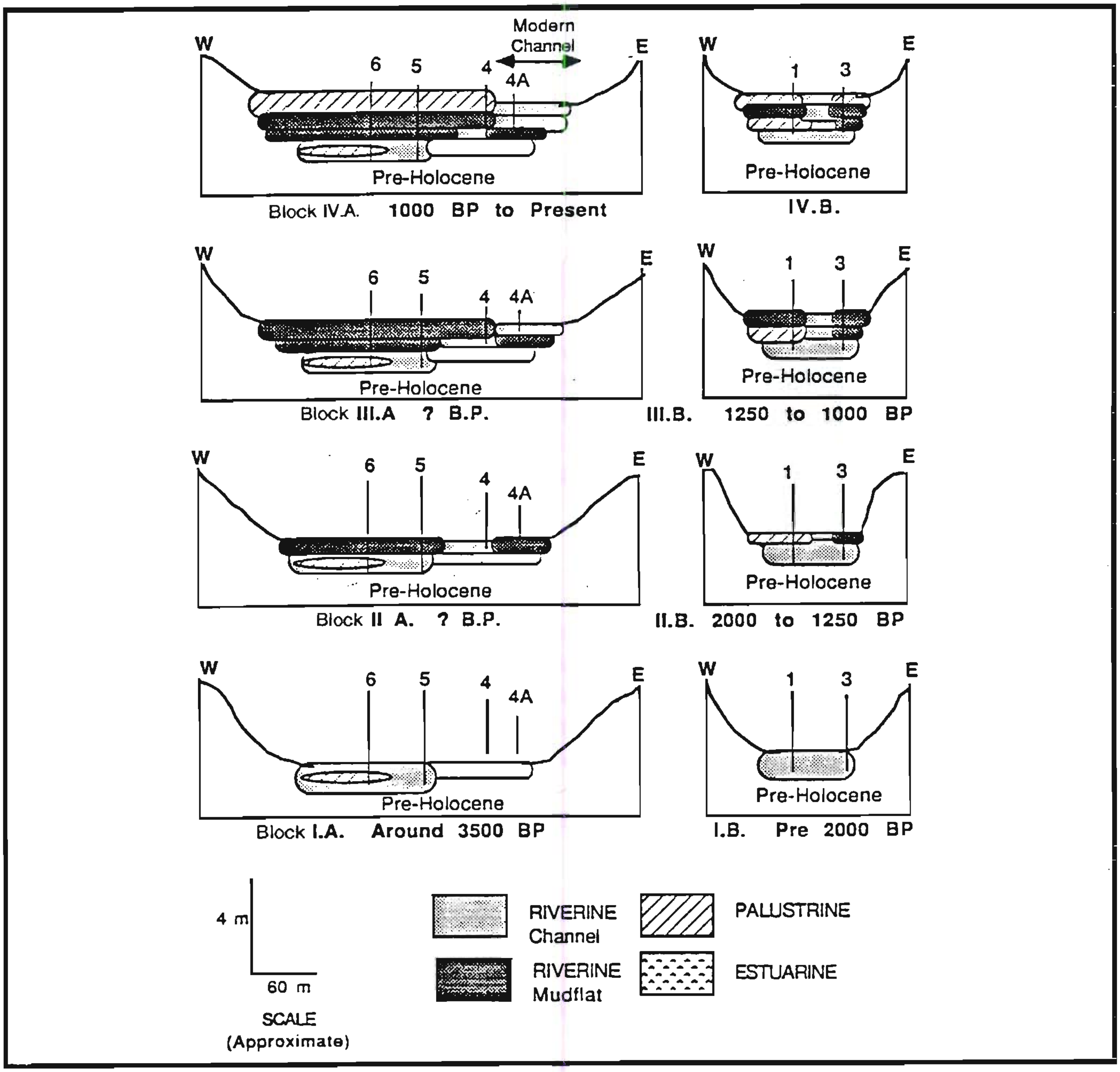
<u>Pre-Holocene</u>. Radiocarbon dates do not support a pre-Holocene age for any of the units found here. However, data on the lithology of pre-Holocene units were collected from field inspection of a Columbia Formation outcrop, from nearby well records (Delaware Geological Survey), and from boring records for the Route 10 bridge (DelDOT). The occurrence of channel sediments identical to the pre-Holocene deposits, but of a much younger radiocarbon age, strongly supports the erosion and reworking of pre-Holocene age sands into Riverine wetland channel deposits during the Holocene.

<u>Mid-Holocene</u>. Sand and sandy mud constitute the oldest deposits sampled at this location. Although the LOI values from these units are somewhat lower than those of the modern analog, they statistically identify a Riverine wetland channel environment (Block I, Figure 46). The difference in LOI values may be related to differences in the water regime. The modern Riverine regime is tidal, while the oldest Riverine units formed in a pre-transgressive (non-tidal), fluvial regime.

Radiocarbon dates from cores obtained along the large meander bend (cross-section A) show that the oldest Riverine deposits predate 3460 BP (334 cm in core SJ-6), while those from the meander cutoff (cross-section B) were formed sometime before 1890 BP (300 cm in core SJ-1) and 1920 BP (330 cm in core SJ-2). The time equivalence of the Riverine units in cross-sections A and B can not be determined on

FIGURE 46

Development of Wetlands at St. Jones River



the basis of the available age data, although the dense, compact nature of the basal units in cores SJ-5 and SJ-6 suggests that cross-section A may be somewhat older than cross-section B. In addition, the age versus depth plots for the dated deposits indicate that the oldest pre-3500 units formed in a pre-transgressive, fluvial water regime. Local relative sea level was 4 m below Mean low sea level at 3500 BP (Kraft 1976), while the sand deposits are less that 2.5 m deep. Age versus depth plots for the younger channel deposits from core SJ-3, as well as, other lithologic evidence support a transgressive tidal origin. This also suggests a younger age for the Riverine units of cross-section B than those of cross-section A. The meander channel may have been abandoned coincident with the transgression of tidal water into the area in approximately 2000 BP.

Cross-Section A

Beginning in 3500 BP, a small Palustrine wetland occupied the location of core SJ-6, succeeding the Riverine channel environment. Riverine deposition continued in the adjacent channel, sampled by core SJ-5. Sometime after 3500 BP, channel deposits of the Riverine system once again reoccupied the location of core SJ-6, demonstrating some lateral channel migration (Block I, Figure 46).

Overlying the Riverine channel deposits in cores SJ-5 and SJ-6 is a wedge of compact mud with very low LOI values. This Low-organic mud is interpreted to represent a Riverine, Emergent class wetland (mudflat). The composition, geometry, and vertical position of the unit between two units of a statistical Riverine signature support that interpretation. Laterally adjacent channel sands of the Riverine system occur in core SJ-4 at this depth (Block II A, Figure 46).

The Low-organic mud wedge is overlain by a mud unit whose LOI values correspond to those of modern Riverine mud deposits. Riverine channel sands are present in core SJ-4A at this depth (Block III A, Figure 46). The Riverine mud is overlain by peat and mud deposits of the modern Palustrine system and Emergent class (National Wetlands Inventory 1987 map of Dover, DE). The wetland succession to Palustrine represents the colonization of the Riverine mudflats by Emergent herbaceous vegetation (Block IV A, Figure 46).

Cross-Section B

Pre-2000 BP. The lithology and LOI values of the sand and sandy mud units at the base of cross-section B correspond statistically to a Riverine channel environment (Block I B, Figure 46). A Riverine channel environment persisted at the location of core SJ-1, but the location of core SJ-3 became occupied by the Low-organic mud representing a Riverine Emergent mudflat around 2000 years BP. These units are considered to have originated in a tidal transgressive environment because:

1) the coincidence of the age versus depth plots with the local relative sea level curve (Kraft 1976);

2) the occurrence of sand and mud interbeds, indicative of a tidal regime (Frey and Howard 1986); and

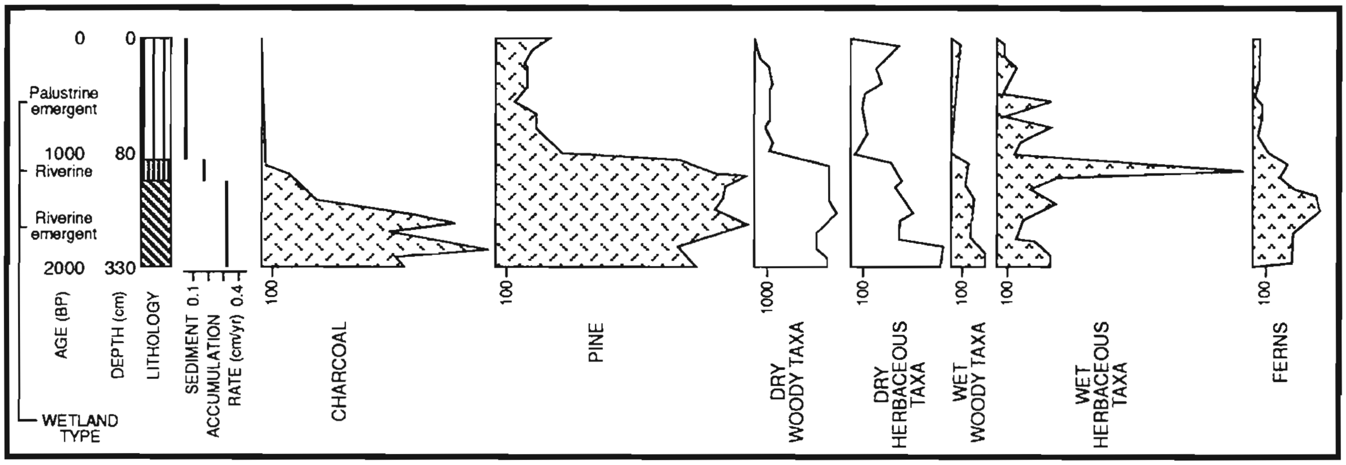
3) a very high (0.32 cm/yr) sediment accumulation rate (based on Brush in this volume).

2000 to 1250 BP. A Riverine Emergent wetland continued to occupy the channel margin at the location of core SJ-3 depositing Low-organic mud. Meanwhile, a Palustrine wetland became established and created the peat seen at the location of core SJ-1 (Block II B, Figure 46). The peat was gradually replaced by mud that reflects the upward growth rate of the Palustrine marsh was lower than that rate of deposition of tidal mud supplied in response to the continued rise in relative sea level.

1250 to 1000 BP. Mud indicating a Riverine channel environment overlies the Palustrine and Riverine Emergent wetlands dating until approximately 1000 BP (Block III B, Figure 46). The rate of sediment accumulation decreased to 0.20 cm/yr for this interval. Abundant charcoal and pollen of dry species appear in core SJ-3 from 2000 BP to 1000 BP (Figure 47) suggesting a 'dry' plant community that was populated by pitch pine - a fire-adapted, colonizing species (Brush in this volume). A progressive

FIGURE 47

Summary Pollen Diagram for St. Jones River



decrease in pollen abundances towards the top of the section may represent the demise of the dry community in response to the wetter conditions associated with, but lagging behind, tidal inundation.

<u>1000 BP to Present</u>. Beginning about 1000 BP (80 cm in core SJ-3), a Palustrine Emergent wetland became established and persisted to the present time forming the peat seen at the top of both cores in cross-section A (Block IV B, Figure 46). The change in wetland environment is accompanied by a rapid increase in the pollen abundances of 'wet herbaceous taxa' (for example, wild rice) for core SJ-3 (Figure 47). The modern Palustrine wetland environment has also formed the mud and peat units at the tops of the cores in cross-section B, except for core SJ-4A which is in the modern channel (National Wetlands Inventory 1987 map of Dover, DE).

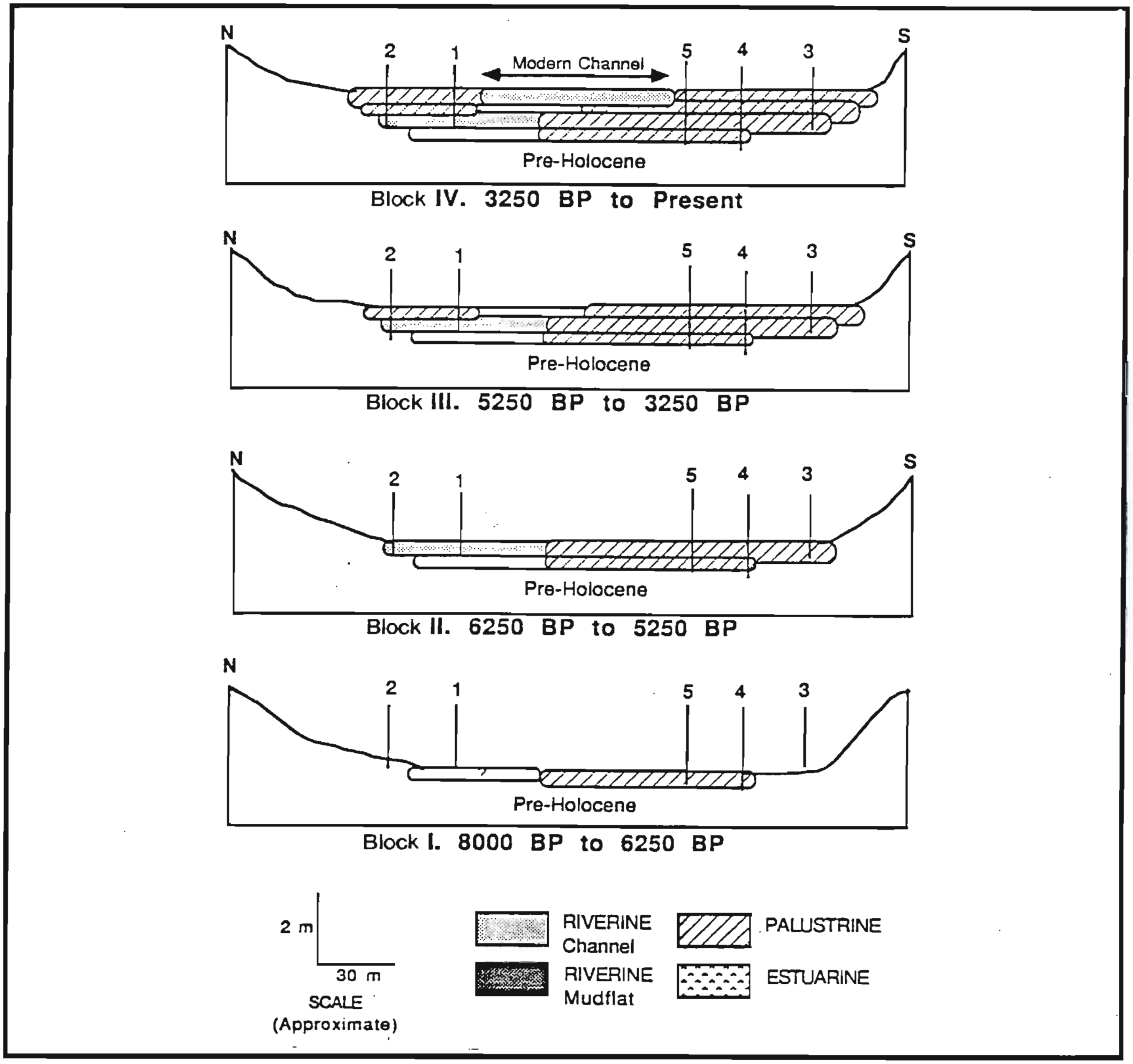
<u>Summary</u>. Although the cores obtained at the St. Jones locality were approximately the same length as those obtained at the other study localities, the rapid rate of sediment accumulation (0.07 to 0.32 cm/yr as compared to 0.02 to 0.08 cm/yr for the Duck Creek locality) resulted in a shorter sampled time interval. Units which correspond to Riverine wetland environments dominate the section, with localized episodes of vegetative colonization producing Palustrine wetlands at 3500 BP along the outside of the meander cutoff. The incursion of tidal freshwater into the area occurred around 2000 BP. A Palustrine Emergent wetland became widespread after 1500 BP, and is represented at the surface today (National Wetlands Inventory 1987 map of Dover, DE). The modern environment is a freshwater wetland dominated by erect, herbaceous hydrophytes (water-tolerant plants), producing a mixed plant community of narrow-leaved cattails, poison ivy, and other common emergent plants. Scattered shrubs and small trees of species such as willow, red maple, and wax myrtle are also present (Tiner 1985).

The Leipsic River Locality

The Holocene sequence of wetlands at the Leipsic River locality is presented below from the oldest known environment to the modern, illustrated by a schematic diagram (Figure 48). Refer to the cross-section for scaled lateral and vertical relationships (Figure 42) and Appendix V for lithologic detail from individual core logs. Analyses of core LR-1 provided pollen data, a basal radiocarbon date, and dates used to calculate sediment accumulation rates (Brush in this volume). An additional radiocarbon date was obtained from core LR-5.

FIGURE 48

Development of Wetlands at Leipsic River

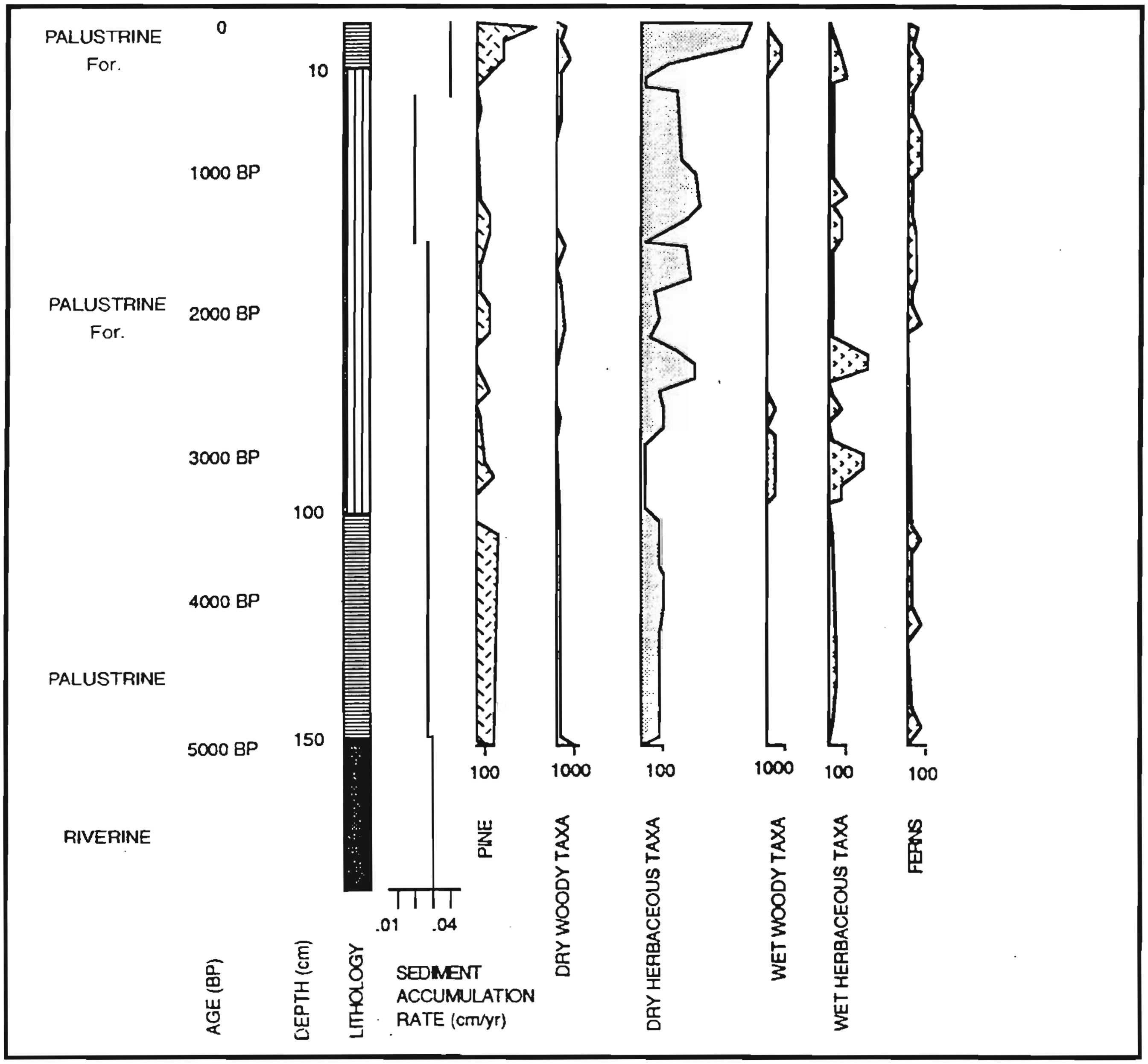


Pre-Holocene. No age is available for the compacted basal sand deposits in cores LR-2 and LR-4. Thus, they may represent either in-situ pre-Holocene units or erosion and redeposition by fluvial action in Holocene time. The units correlate with deposits interpreted to be pre-Holocene on the basis of their lithology and density (number of hammer blows required to penetrate one foot) encountered in bridge borings drilled a few kilometers up the stream valley at Garrison's Lake (DelDOT).

8000 to 6250 BP. A basal mud dated to 8000 BP occurs in core LR-5 and above the 'pre-Holocene' sand in core LR-4. LOI values for the unit correlate to an unknown class Palustrine wetland

FIGURE 49

Summary Pollen Diagram for Leipsic River



(Block I, Figure 48). The mud-forming environment was replaced by a peat-forming environment at a time which has no age control, but is somewhat older than a 6230 BP channel deposit in a laterally adjacent core.

6250 to 5250 BP. Basal sandy mud deposits in core LR-1, overlie the 'pre-Holocene' sand in core LR-2 represent deposition in a Riverine system wetland on the basis of their sand content and LOI value (Block II, Figure 48). The base of both units contain sand lenses probably derived from the reworking of underlying sands. The basal radiocarbon date of 6230 BP in core LR-1 shows that the channel was slightly north of its present position for a portion of mid-Holocene time (6230 to 5250 BP). The lack of pollen from this unit suggests a period of fluvial flooding (Figure 49; Brush in this volume). The sediment accumulation rate for the sandy mud in core LR-1 is 0.03 cm/yr.

The other cores record peat deposition at a depth adjacent to the Riverine sands. The statistical analysis of the LOI values for these peat units indicates a Palustrine Emergent environment (Block II, Figure 48) such as the modern wetland at the Saint Jones River locality.

<u>5250 to 3250 BP.</u> Lateral channel migration resulted in the end of Riverine channel deposition and the beginning of mud deposition from 5250 BP to 3250 BP in core LR-1. Equivalent mud units are seen in the other Leipsic River cores at slightly shallower depths. Statistical analysis of the LOI values identify this unit as Palustrine wetland environment, but cannot distinguish between the Emergent and Forested classes (Block III, Figure 48). The lithologic transition from Palustrine peat to Palustrine mud seen in the three cores obtained south of the channel (cores LR-3, 4, and 5) could reflect two possible environmental changes, either a relative increase in fluvially supplied mud, suggesting perhaps increased stream discharge and a wetter climatic regime, or a relative decrease in the in-situ organic productivity, suggesting a drier climate. The decreased rate of sediment accumulation (0.0275 cm/yr) and palynologic evidence support the latter. Although some pollen of ferns, mosses, and grasses is present (Figure 49), the predominate pollen signature is of 'dry woody' (oak, hickory, and pine) and 'dry herbaceous' taxa. This indicates the environmental transition from an Emergent to a Forested environment.

<u>3250 to 1500 BP.</u> By 3250 BP in core LR-1, a Palustrine Forested wetland had been established, depositing a highly organic peat above the Palustrine mud in all of the Leipsic River cores (Block IV, Figure 48). The peat occurs at somewhat lower depths, and therefore may be slightly older, along the valley margins (LR-2 and 3) where trees succeeded from the wooded uplands. Following an interval of no pollen, representing fluvial flooding (Brush in this volume), the pollen abundances for this unit are greatly increased over those of older deposits (Figure 49). The occurrence of wild rice, water lily, alder, birch, and ash pollen indicates a wetter interval, accompanied by a slight increase in the sediment accumulation rate (0.028 cm/yr). The presence of 'dry' species such as grasses, ragweed, goldenrod, oak, and hickory suggests, however, that the Palustrine Forested environment increased the productivity of both wet and dry species. Increased numbers of trees and shrubs supplied abundant organic detritus to the peat. The time of increased pollen deposition, resulting perhaps from wetter conditions, is not due to the incursion of transgressive water due to the rise in relative sea level, as the plots of the sediment age versus depth do not coincide with the relative sea level curve (Kraft 1976).

<u>1500 to 500 BP.</u> Around 1500 BP (40 cm in core LR-1) the pollen concentration sharply increases, corresponding to a decrease in the rate of sediment accumulation (0.020 cm/yr). Wet species such as cattail, wild rice, birch, and willow disappear from the pollen assemblage (Figure 49), which along with the reduced sediment accumulation, suggesting a reduction in the available moisture. No lithologic change is seen at this time, interpreted to mean that the productivity of the 'dry woody' species (for example, oak, hickory, maple) was adequate to maintain the supply of organic detritus so that peat deposition persisted. The LOI values show a progressive decrease towards the top of the peat unit in all of the Leipsic River cores, representing a reduction in the organic contribution within a Palustrine Forested wetland (Block IV, Figure 48).

<u>500 BP to Present.</u> An abrupt twofold increase in the rate of sediment accumulation (to 0.04 cm/yr) is seen at 500 BP (20 cm in core LR-1), corresponding to a renewed 'wet' pollen assemblage (Figure 49). This is interpreted to represent the arrival of tidal waters in to the area, and coincides with ages and depths on the local relative sea level curve (Kraft 1976). The increase in water level and the deposition of tidally supplied mud gradually overwhelmed the in-situ production of organic detritus, creating the lithologic unit of mud found at the top of cores LR-1, LR-2, and LR-3. Localized areas of restricted circulation permitted the continued deposition of peat at cores LR-4 and LR-5. A 5 cm bed of muddy sand

near the top of core LR-5 represents a Riverine subtidal channel deposit probably formed at elevated water levels as the channel continues its slow southern migration. The modern environment is mapped as a Palustrine Forested wetland flooded seasonally by fluvial action and less often than daily by tidal action (National Wetlands Inventory 1987 map of Smyrna, DE). Vegetation consists of green ash, red maple, and black gum, with some black willow, American holly, various oaks, Atlantic white cedar, and Loblolly pine. Emergent grasses and sedges may be established where the forest canopies opens (Tiner 1985).

Summary. Palustrine wetlands have existed on the south side of the present Leipsic River channel since at least 8000 BP according to radiocarbon dates, and around 5250 using ages determined from pollen influxes. (The lack of correspondence between the dates and depths to the local relative sea level curve (Kraft 1976) supports a riparian, non-transgressive environment of formation for these wetlands.) Riverine channel deposits have been present from at least 6250 BP to modern time. Tidal water reaches this locality only 500 BP.

SUMMARY COMPARISONS OF THE THREE WETLAND LOCALITIES

Channel Migration Rates

The lateral migration rate of the channels was approximated by dividing the map distance between subsurface Riverine deposits and the modern channels by the elapsed time in radiocarbon years. The rates obtained are roughly equivalent for the three study areas, ranging from a minimum of 0.006 m/yr to a maximum of 0.03 m/yr. All of the rates are at least one order of magnitude smaller than average rates of 0.32 m/yr from freshwater tidal wetland channels cited by Garofalo (1980).

The Pollen Record

A comparison of the pollen records of the three localities shows little temporal equivalence in the major shifts in vegetation. This suggests that the pollen signature records local conditions, rather than regional patterns of climate change. Vegetation changes were related to the local tidal transgression controlled by distance from the Delaware Bay and antecedent topography and local patterns of wetland succession.

Rates of Sediment Accumulation

Differences between the study areas are also evident in the rates of sediment accumulation for each lithologic interval (Table 10). The absence of any obvious pattern in the rates of sediment accumulation supports the localized nature of deposition in wetland environments.

CONCLUSIONS

The Loss-On-Ignition Method

The organic content of wetland sediments as indicated by their LOI values provided a method whereby sedimentary deposits formed in different modern depositional subenvironments could be statistically identified and distinguished from one another. Statistical methods used to compare LOI populations included the Analysis of Variance and the Mann-Whitney ranked median test, which resolved populations at the 0.05 significance level and yielded 95% Confidence Intervals for the population means or medians, respectively.

TABLE 10

Sediment Accumulation Rates for Radiocarbon Dated Wetland Cores

Site	Core	Lithology	Water Regime	Wetland System	Wetland class	Environment of Deposition	Sediment Accumulation Rate cm/yr
Duck Creek	DC-3	Sandy Mud	fluvial	RIVERINE	Unconsolidated bottom	channel	0.020
		Peat	fluvial	PALUSTRINE	Forested	marsh	0.040
		Mud	tidal	PALUSTRINE/ RIVERINE	Emergent?	transitional	0.080
		Low-organic Mud	tidal	RIVERINE*	Emergent*	mudflat	0.086
		Peaty Mud	tidal	PALUSTRINE	Emergent	marsh	0.150
		Mud	tidal	ESTUARINE	Flat	mudflat	0.067
St. Jones River	SJ-3	Low-organic Mud	tidal	RIVERINE*	Emergent*	mudflat	0.320
		Mud	tidal	RIVERINE	Unconsolidated Bottom	channel	0.200
		Peat	tidal	PALUSTRINE	Emergent	marsh	0.070
Leipsic River	LR-1	Sandy Mud	fluvial	RIVERINE	Unconsolidated Bottom	channel	0.030
		Mud	fluvial	PALUSTRINE	?	marsh	0.028
		Peat	fluvial	PALUSTRINE	Forested	marsh	0.028
		Peat	fluvial	PALUSTRINE	Forested	marsh	0.020
		Peat-to-Mud	tidal	PALUSTRINE	Forested	marsh	0.040

* = inferred

Lithologically heterogeneous LOI populations from three modern wetland systems (Riverine, Estuarine, and Palustrine) were distinguished from each other at the 0.05 significance level. The large wetland group systems were then subdivided according to lithology to provide a means for identifying the paleo-wetland environment of deposition for a given lithologic unit. Populations of such lithologically heterogeneous LOI values could then be recognized at both the class level and the subclass level of wetlands classification. This allowed for the correlation of LOI value, wetland classification, and depositional subenvironment (channel, mudflat, or marsh). These correlations were used to determine the sequence of wetland environments represented by subsurface sediments at the core localities. Paleoenvironmental interpretations made using the LOI method were supported and enhanced by pollen data.

One lithologic unit could not be classified using the LOI method because it was not represented in the surface environments sampled. However, knowledge of wetland plant communities and classification models permitted the depositional subenvironment of the Low-organic mud to be hypothesized even though it was not represented in the sampled modern record.

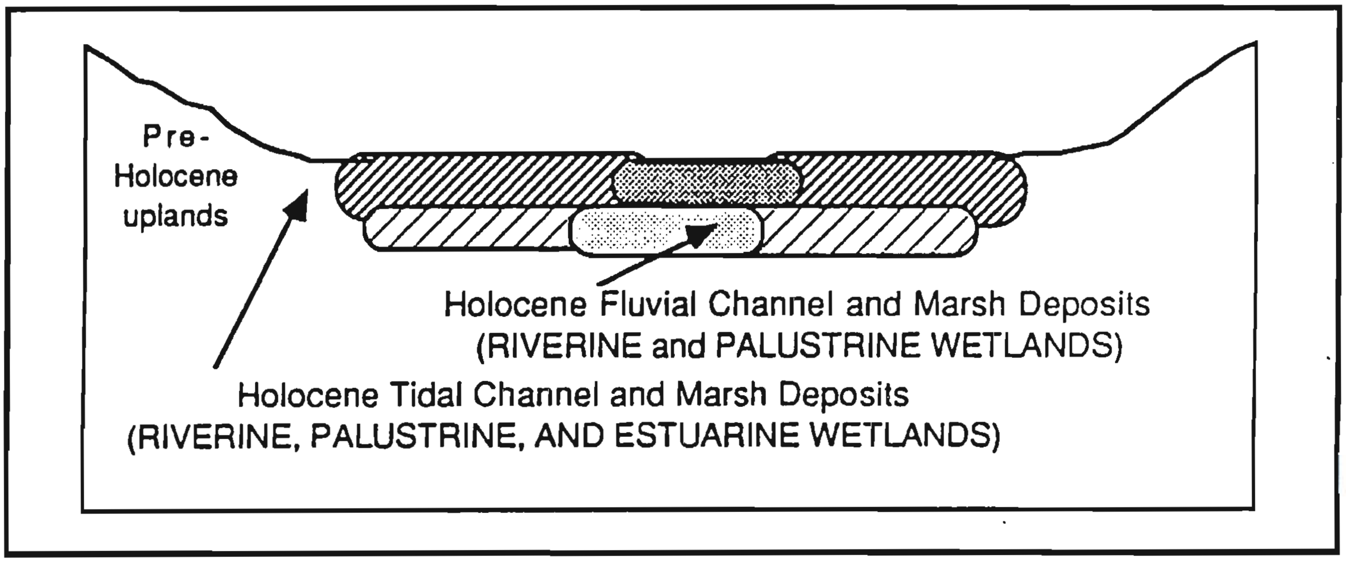
Pollen data supported LOI wetland identifications and allowed for two conclusions to be reached. First, the synchronous shifts in the pollen assemblages and in lithology suggested that they were both recording the same genetic processes. Second, the differences in the ages of shifts in the pollen assemblages from the three localities indicated that the pollen signature is a local rather than regional. Variations in the rate of sediment accumulation for any given lithology emphasizes the localized nature of sediment deposition in wetland environments.

Holocene History

Cores from three different wetlands reveal a Holocene history that is conceptually logical and supported by evidence. Holocene freshwater fluvial channel and marsh deposits of the Riverine and Palustrine wetland systems, respectively, overlie pre-Holocene sand units encountered at depths of

FIGURE 50

Generalized Development of Wetlands in Delaware



approximately 150 cm in the Leipsic River area, and 205 cm in the Duck Creek area (not encountered in cores from the St. Jones River area). The date of the tidal transgression into each of the three localities was approximated by considering the local relative sea level curve published by Kraft (1976), increases in the rates of sediment accumulation (which increase the ratio of mud to organic matter), and pollen analyses. The ages are estimated to be 2000 BP, 1700 BP, and 500 BP for the St. Jones River, the Duck Creek, and the Leipsic River localities, respectively. Note that the St. Jones locality has the longest tidal history and the thickest Holocene section, while the Leipsic River locality has the shortest tidal history and the shallowest Holocene deposits.

The marine transgression brought tidal units landward and upward in space and time, and deposited them over older fluvial units on the pre-Holocene basement. Between 0.4 and 2.0 m of freshwater Holocene, fluvial deposits of the Riverine and Palustrine wetland systems are overlain by between 0.2 and 4.7 m of tidal channel and marsh deposits of the Riverine, Palustrine, and Estuarine wetland systems. The schematic relationship between the pre-Holocene transgression surface and the Holocene fluvial and tidal deposits is depicted in Figure 50.

Finally, in light of the continued relative sea level rise along the Delaware coast, the modern occurrence of Estuarine wetlands at the Duck Creek locality provides a model with which to predict the future occurrence of Estuarine wetland deposits at the St. Jones and Leipsic River localities.