Louisiana's Cajun Prairie: Holocene History of a Southern Grassland.

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LOUISIANA'S CAJUN PRAIRIE:
HOLOCENE HISTORY OF A SOUTHERN GRASSLAND

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Geography and Anthropology

by

Miriam Lee Fearn
B.S. University of South Alabama, 1987
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To Mother: for always being there.

In memory of Daddy: for teaching me that anything worth doing is worth doing well.
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ABSTRACT

Pollen, phytolith, charcoal, and diatom analysis, in conjunction with sediment stratigraphy and radiocarbon dating, of sediment cores from Lake Arthur and Prien Lake, estuaries in southwestern Louisiana, provide 6000 years of data used to reconstruct the late-Holocene vegetation history of Louisiana's natural prairie and to define coastal processes which affected the sites. The Cajun Prairie is a grassland outlier in a climate which normally supports forest. Poorly drained, impermeable soils with poor water yielding capability induce summer drought severe enough to limit the success of trees, resulting in a natural tallgrass prairie.

Pollen, phytololiths, and charcoal suggest that the grassland island has neither expanded nor contracted over the last 6000 years and that fire has contributed to its maintenance. *Pinus*, *Quercus*, and *Taxodium* have been components of southwestern Louisiana's vegetation for the entire period of record with a minor increase in pine from 2000 to 1000 B.P.

High pollen concentrations followed by an *Ambrosia* rise and a drop in *Taxodium* and *Pinus* mark the settlement horizon. Low pollen influx after settlement indicates high rates of erosion and clastic input to the lakes. A crash in the diatom flora of Lake Arthur probably relates to
maximum pollution of the estuary by agricultural chemicals.

The use of phytoliths in sediment to distinguish the source of Gramineae pollen is a promising new technique. Dramatic increases in Gramineae pollen accompanied by high percentages of rondel shaped phytoliths document expanding marsh vegetation around Lake Arthur and Prien Lake as rising sea level initiated drowning of the low gradient rivers by 5000 B.P.

Radiocarbon dates on peat samples indicate relative sea level of -5.5 m by 6000 B.P. followed by slow steady rise at a rate of 9 cm/100 years up to present times. Freshwater diatom assemblages between 4500 and 3000 B.P. coincide with westward progradation of the Mississippi River's Teche Delta Complex, and an abrupt shift to brackish/marine diatom flora at 3000 B.P. signals abandonment of the Teche system.
INTRODUCTION

Displacement of vegetation boundaries over time occurs in response to environmental change. In the historic period, the ecotone between desert and steppe in Africa shifted during the Sahel drought of 1970-1972 (Stanhill, 1989). The Little Ice Age, a colder than normal period culminating in the 1500-1800s, caused abandonment of cultivated fields at high elevations in much of northern Europe as temperatures and growing season became unfavorable for crops (Grove, 1988). Beyond historical time frames, preserved plant and animal remains document similar ecotone movements and furnish proxy evidence of environmental change. Microfossils are especially valuable for detecting such shifts because they are incorporated into sediments and can be analyzed stratigraphically. Some useful microfossils include pollen, phytoliths (silica deposited within plant cells), diatoms (single celled algae), forams, dinoflagellates, and sponge spicules.

Much of our knowledge of past climatic conditions comes from pollen analysis of sediment cores. Vegetation communities with different ecological tolerances leave sedimentary pollen records when environmental boundaries shift. Based on pollen analysis, Davis (1981) documented the northward migration of boreal tree species and, by

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inference, a warming environment in eastern North America following the Wisconsin Glacial Maximum (18,000 B.P.).

Studies in the American Midwest demonstrate that shifts in the ecotone between grassland and forest occurred in response to past climate change (McAndrews, 1966; Bernabo and Webb, 1977). The eastward expansion of prairie into Iowa and Illinois during the mid-Holocene is well documented (King, 1981; Watts, 1983; Baker and Walton, 1985) and is interpreted as the warmest, driest period in the last 10,000 years. However, little paleoecological research exists on tropical or subtropical grasslands because palynological studies in prairie sites beyond the glacial margins are hampered by a lack of suitable coring sites (Chumbly et al., 1990).

This study examines the Holocene vegetation history of Southwestern Louisiana, a subtropical tallgrass prairie which is essentially a southern equivalent of the well-studied "Prairie Peninsula" of the American Midwest. Pollen, phytoliths, charcoal, diatoms, and stratigraphic techniques are used to examine the origin and maintenance of the prairie within a broad framework which considers the equilibrium between vegetation and climate, edaphic (soil) characteristics, fire, anthropogenic disturbance, and the influence of changing sea levels on coastal vegetation.
Southwestern Louisiana's prairie is an anomaly in a region with adequate rainfall to support trees. Under modern climatic regimes, the prairie-forest ecotone is located in Texas, well to the west. In such vegetation outliers, local conditions either enhance or inhibit the effects of climate keeping the outlier on the "wrong" side of the vegetation boundary. Explanations for the grassland in southwestern Louisiana range from burning by Indians to droughty soils caused by underlying claypans.

The major objectives of this research are to determine the age and stability of the vegetation in southwestern Louisiana for the past 6000 years (the period spanned by the sediment cores); to relate vegetation change to possible climatic and/or sea level fluctuation; to ascertain the importance of fire in the establishment and maintenance of the grassland; and to document the effects of human disturbance on the environment. Microfossil analysis of sediment cores from Prien Lake, south of Lake Charles, and from Lake Arthur, south of Jennings, provide most of the data used to decipher southwestern Louisiana's environmental history.
THE SOUTHWESTERN LOUISIANA PRAIRIE

Location

The Southwestern Louisiana Prairie occupies a triangular shaped area west of the Mississippi River in southern Louisiana. As delineated by Post (1962), the grassland covers approximately 9000 square km (3500 square miles). Coastal marshes form its southern boundary; the modern Mississippi floodplain, the eastern boundary; and pine forests, the northwestern boundary (Fig. 1). This extreme southeastern portion of the North American prairie biome is a natural tallgrass prairie and resembles, in its placement, the prairie peninsula which extends into Iowa and Illinois. Because the Southwestern Louisiana Prairie is an outlier of the main body of the biome, it is rarely noted on large area vegetation maps with generalized boundaries (Fig. 2). Prairie conservationists coined the name "Cajun Prairie" for Louisiana's natural grassland (Allen and Vidrine, 1989).

Vegetation

The Southwestern Louisiana Prairie has approximately 500 species of plants with the Compositae and Leguminosae as important forb families (Allen and Vidrine, 1989). Common grasses in the Louisiana Prairie include big bluestem (Andropogon gerardii), Indian grass (Sorghastrum nutans), switchgrass (Panicum virgatum), little bluestem
Figure 1. Vegetation regions of Louisiana (Adapted from Brown, 1945).
Figure 2. Prairie regions of North America (Adapted from Reichman, 1987).
(Schizachyrum scoparius), and Florida paspalum (Paspalum floridanum) (Louisiana Natural Heritage Program, 1988) (Fig. 3). These are C₄, grasses able to photosynthesize efficiently at high light intensities and high temperatures (Waller and Lewis, 1979). These grasses, associated with many prairies of the United States, are virtually cosmopolitan in their distribution and have broad ecological tolerances (Risser et al., 1981).

Forests border the triangular shaped Cajun Prairie on two sides (Fig. 4). The Mississippi alluvial valley, to the east, contains bottomland hardwood species such as oak, hickory, green ash, hackberry, elm, sweetgum, sycamore, red maple, and black willow, as well as cypress-tupelo swamps. Pine, oak, hickory, and sweetgum dominate the forest to the northwest. Marshes to the south of the prairie contain many species of Gramineae and Cyperaceae. Along the streams within the grassland, pine and bottomland hardwood species comprise the gallery forests (Louisiana Natural Heritage Program, 1988).

The natural grassland once covered much of the exposed surface of the youngest of four major Pleistocene coastal terraces known as the Prairie Terrace (Jones et al, 1954). The prairies were described as "natural meadows...interspersed here and there with clumps of trees" (Bruchey, 1967). Rather than one extensive
Figure 3. Dominant grasses of the Cajun Prairie (Hitchcock, 1971).
Figure 4. The Southwestern Louisiana Prairie with study sites (Based on Post, 1962, and Newton, 1972).
grassland, the Louisiana Prairie was made up of many small prairies, called coves by the settlers, which were separated by woodlands along the watercourses (Post, 1940). Today, very little of the original grassland vegetation exists.

**Geologic Background**

The natural tallgrass vegetation of southwestern Louisiana corresponds almost perfectly with the exposed surface of what has been called the Prairie Terrace Formation but which is now designated the coast-parallel Prairie Complex (Autin et al., 1991) (See Fig. 1 and Fig. 5d). Fisk originally named the terrace after the dominant vegetation which existed prior to settlement (Jones et al. 1954). Some of the smaller upland prairies as well as the grasslands east of Baton Rouge (Jennings, 1962) occupy this same exposure, implying that edaphic factors exert considerable influence on the vegetation.

In southwestern Louisiana, the Prairie Complex consists of coarse sand and gravel up to 120 meters (400 feet) thick (Jones et al., 1954) which is overlain by about 30 meters (100 feet) of finer sediments (Varvaro, 1957); interbedded silts and clays are uppermost in the sequence and comprise the soil parent material. The Prairie Terrace has not been firmly dated; however, most authors believe it formed during the last (Sangamon)
Figure 5. Formation of the Prairie Complex (Adapted from Gagliano et al., 1979).

a. Early shoreline of the Prairie deltaic plain.
b. Red River alluvial cone and early Mississippi River meander belt on the Prairie surface.
c. Capture of the Red River by the Mississippi River during Farmdale interstadial.
d. Modern deltaic plain.
interglacial when sea level was perhaps 6-7 meters above present (DuBar, et al., 1991). This high stand occurred about 130,000 to 120,000 years B.P. (Bloom, 1983; Autin et al., 1991). The freshness of features on the Prairie Terrace belies this old age for the entire Complex. Based on stratigraphic relations and correlations with eustatic curves, Autin et al. (1991) conclude that the surface veneer of fluvial sediments on the exposed Prairie Terrace in southwestern Louisiana was deposited later during an interstadial transgression sometime between 60,000 and 27,000 B.P. Earlier, Alford and Holmes (1985) cited the deposition of only one loess sheet on the Prairie Terrace as evidence that it was formed during a Wisconsin interstadial rather than the Sangamon interglacial.

Figure 5 illustrates the formation of the Prairie Terrace according to Gagliano et al. (1979). As the ice melted and sea level rose during the last interglacial, water encroached upon the older land surface. Approximate maximum transgression is marked by a sand ridge paralleling the Houston River north of Lake Charles. The ridge is part of the Ingleside barrier trend recognized along much the Gulf Coastal Plain (DuBar et al., 1991) and considered Sangamon in age (120,000-130,000 B.P.) (Autin, et al., 1991). As sea level stabilized, the Mississippi and Red Rivers deposited sediment across what is now
southwestern Louisiana. Sea level dropped with the subsequent onset of glaciation, and subaerial weathering and slight entrenchment occurred on the exposed surface.

Although 75,000 B.P. marks the beginning of the main phase of the last cycle of glaciation, sea level records suggest that much of the previously formed ice melted between 60,000 and 27,000 B.P. yielding sea levels high enough to affect base level of coastal rivers but still not above present sea level (Crowley and North, 1991). During this interstadial (Farmdale), the Red River deposited an alluvial cone of sediments across much of southwestern Louisiana. At that time the Mississippi River flowed in the eastern part of its alluvial valley separate from the Red River. When the Mississippi moved back to the western side of the valley, it captured the Red River and isolated the old Red River channels from their source. The lower part of the Mississippi River flowed south of Lafayette in a southwestward direction.

The next major avulsion of the Mississippi River shifted its meander belt and delta eastward. The Red River remained a tributary of the Mississippi River throughout falling sea levels associated with the late Wisconsin glaciation (28,000-14,000 B.P.). As sea level dropped and rivers entrenched their valleys, the old Red River channels as well as the Mississippi meanders south of
Lafayette were left high and dry on the exposed Prairie Terrace surface. No major drainage systems developed on the flat terrace surface. In many instances, the topographic lows were the old backswamps, and what stream development took place followed this interleeve drainage rather than the old channels (Varvaro, 1957).

During the last glacial maximum, high winds picked up extensive amounts of silt from the Mississippi River and deposited it as blankets of loess which thin with increasing distance from the river (Otvos, 1975). This loess extends west from the Mississippi escarpment into southwestern Louisiana for approximately 32 km (20 miles) and is 2.5-5 meters (8-16 feet) thick near the alluvial valley (Daniels and Young, 1968). It constitutes the soil parent material in the extreme eastern part of the Cajun Prairie.

With the ameliorating climate of the Holocene, glaciers melted and sea level reached its present height about 5000 B.P. (Kidson, 1982). Recent deltaic and coastal sediments have been deposited on top of the Prairie Complex. These sediments are today's coastal wetlands and chenier plain (Jones et al., 1954).

**Physiography**

The Prairie Terrace surface of southwestern Louisiana is almost level (rise .3-.4 m/km, 1.5-2 feet/mile) with
elevations ranging from sea level near the coast to 30 meters (100 feet) at its northern extremity in Evangeline Parish. Relief on the terrace surface rarely exceeds 30 feet (Jones et al., 1954). On its northern border, it overlaps the next older coastal terrace, the Montgomery, which was tilted gulfward over time as the immense load of Prairie sediments weighed down its southern margin. The greater dissection of the Montgomery and the difference in slope distinguish it from the Prairie Terrace (Doering, 1956). On the east, the Mississippi alluvial valley clearly defines the edge of the Prairie Complex in southwestern Louisiana. Where the river deposited enough sediment to fill the lower reaches of the valley up to the level of the Prairie Terrace surface, recent alluvial deposits overtop the old valley wall and wrap around to merge with Holocene coastal deposits. Farther north, in Avoyelles Parish, the alluvial valley floor lies 10-20 meters below the Prairie Terrace surface and a distinct escarpment marks the boundary (Fisk, 1940).

Topographic relief on the southwestern Louisiana Prairie includes old natural levees, watercourses, salt domes, pimple mounds, and prairie ponds. Some of these reflect the formation processes previously described. Old Red River channel levees are still distinguishable on the Southwestern Louisiana Prairie (Fig. 6), and Mississippi
Figure 6. Physiographic features of southwestern Louisiana (Adapted from Saucier, 1977).
meander scars are clearly visible south of Lafayette on modern aerial photographs. Because they were higher and better drained, the relict levees were preferred building sites for roads, houses, and railroads (Post, 1962).

Streams on the Prairie Terrace either occupy relict channels or old interlevee backswamps. For example: the Vermilion River flows down the ancient Mississippi River course south of Lafayette (Jones et al., 1954); Bayou Nezpique, Bayou des Cannes, and Bayou Queue de Tortue follow topographic lows between old Red River channels. The latter type predominate and have tortuous meanders characteristic of backswamp drainage (Gagliano et al., 1979). These modern streams developed during the last glacial stage when local runoff became entrenched because of lowered sea levels. Some of them (the Mermentau and Bayou Nezpique) do not cut through the dense backswamp clay that forms the land surface and, therefore, have low dry weather flow (Jones et al., 1954).

One of the more unusual features of the Prairie are pimple mounds. These mounds are about 9-15 meters in diameter and 1 meter high (Goodzari, 1978). They are especially numerous in the western part of the Cajun Prairie. Pimple mounds (also called Mima mounds) are associated with grasslands, flat terrain, and shallow or poorly drained soils in localities throughout the western
United States (Cox, 1984, 1986). Major hypotheses concerning their origin include differential erosion, wind deposition, frost sorting, and rodent activity (Goodzari, 1978; Cox, 1986). Significantly, pimple mounds are not found in forests or in deserts.

In contrast to pimple mounds are prairie ponds, called platins or marais by the early settlers (Post, 1962). These circular depressions range from 40-100 meters in diameter, are usually less than 1 meter deep, and have flat bottoms and steep sides. They frequently occur on higher ground and are most abundant in the eastern part of the Louisiana Prairie. Various theories explain prairie pond development. Early settlers attributed them to milling buffalo (Post, 1940); later researchers, to relict channel scour pools (Varvaro, 1957). Modern agricultural practices are slowly obliterating both prairie ponds and pimple mounds.

Climate

Climate is the controlling factor in many grasslands, with prairies usually occupying regions with comparable temperatures but lower precipitation than forests. Periodic drought and low humidity during the summer are especially important in grassland development (Anderson, 1990). The Southwestern Louisiana Prairie exists in a humid subtropical environment dominated by its proximity...
to the Gulf of Mexico. At Jennings, Louisiana, in the heart of the Cajun Prairie, average temperature in summer is 27.6°C (81.7°F); in winter, 11.7°C (53.1°F); mean annual temperature, 20°C (68.1°F). The average annual rainfall is 150 cm (59 in) and is distributed fairly evenly throughout the year. When these values are plotted on a temperature/precipitation classification scheme for natural vegetation, the Louisiana Prairie falls well outside the grassland category (Fig. 7). The Cajun Prairie resembles many tropical savannas that receive high levels of rainfall but support grasslands rather than forests because high temperatures and high potential evapotranspiration rates create excessive moisture demands by plants (Sarmiento and Monasterio, 1975).

Southwestern Louisiana falls outside most climatic prairie classifications (Stephenson, 1990). Using Thorntwaite's water budget variables, Mather and Yoshioka (1968) climatically delineated 20 natural vegetation types based on potential evapotranspiration and the moisture index. Their methods place Jennings, Louisiana (PE 1067 mm, MI 40.5), in the Loblolly Pine Zone, (Fig. 8). Corcoran (1982) examined vapor pressure deficit (the difference between saturation vapor pressure and actual vapor pressure resulting from ambient temperatures higher than dewpoint temperatures). Again, southwestern Louisiana
Figure 7. Relationship of forest, grassland, tundra, and desert to temperature and precipitation (Adapted from Lauenroth, 1979). Star indicates Jennings, Louisiana.
Figure 8. Relation between climatic moisture index, potential evapotranspiration, and natural vegetation at representative stations in the United States, Canada, and the tropics. Star = values for Jennings, Louisiana (Adapted from Mather and Yoshioka, 1968).
ends up in the "forest" category. Sears (1981) eloquently described such vegetation outliers as "islands or archipelagos in a climatic sea."

Precipitation seasonality and soil moisture storage are important in temperate grasslands where the growing season is defined by temperature. Manogaran (1983) successfully defined the modern climatic boundaries of the Prairie Peninsula based on mean annual soil moisture deficit (15-35 mm), water surplus (>0), and moisture index (15-30). Values for the Southwest Climate Division of Louisiana, which corresponds to the prairie region, based on data from 1932-1992, are deficit = 102 mm, surplus = 533 mm, and moisture index = 40.5. Climatically, Southwestern Louisiana's relatively high deficits are offset by even higher surpluses. These values place the southwestern Louisiana Prairie outside his prairie parameters but point to the potential importance of soil moisture deficit and surplus.

Manogaran (1983) emphasizes soil moisture storage as a significant factor in the effective moisture available to plants. Figure 9 shows Thornthwaite water budget surpluses and deficits for the Southwest Louisiana Climate Division during both a dry (1930s) and a wet (1980s) decade. Calculations assume 15.24 cm (6 inch) soil moisture storage capacity and decreasing soil moisture...
Figure 9. Seasonal water budget surpluses (hachured bars) and deficits (solid bars) for a dry versus a wet decade for the Southwestern Louisiana Climate Division.
availability and sum values over three month seasons. If the soil stores and releases less moisture than is specified for Thornthwaite calculations, true moisture deficiency experienced by the vegetation during the summer growing season is greater than calculations indicate. Soil has long been postulated as an important factor in the formation of the Southwestern Louisiana Prairie (Allred and Mitchell, 1955; Stephenson, 1990).

Soil

Grasslands often correlate with Mollisols, deep, dark, fertile soils whose origin seems partially due to the grasses themselves. Dense root systems and abundant annual litter contribute to high humus contents in the soil, while limited rainfall prevents leaching of the accumulated nutrients or accumulation of clays in the B horizon. These rich soils have caused natural grasslands to become the breadbaskets of the world. In contrast, southwestern Louisiana's soils are primarily Alfisols (Harpstead et al., 1988). Typically found under deciduous forests, Alfisols have thin A horizons and clay accumulation in the B horizon. They are most common in humid temperate regions on relatively young land surfaces (Buol et al., 1989). More specifically, the Louisiana Prairie soils are almost all Aqualfs, a suborder of the Alfisols occasionally saturated with water. The water
level may fluctuate seasonally, and reducing rather than oxidizing conditions prevail during the waterlogged period (Birkeland, 1984).

Within this broad classification scheme, the most abundant soil of the Southwestern Louisiana Prairie is Crowley silt loam (Lytle, 1968). Like most Cajun Prairie soils, it formed from parent material deposited by the Red River during the Farmdale interstadial. These deposits are a relatively thin veneer on top of older and more impermeable Mississippi fluvial and deltaic deposits (Jones et al., 1954).

Figure 10 is a generalized profile of the Crowley series with a 0-1% slope. Extensive mottling as well as manganese and iron concretions found in the B horizon confirm reducing and oxidizing conditions associated with alternate drying and waterlogging of the Prairie soils. Moisture stress on trees attempting to establish themselves on the Southwestern Louisiana Prairie is two edged; vegetation must withstand droughty conditions as well as waterlogged conditions. Similar stresses occur in many tropical American savannas (Sarmiento and Monasterio, 1975).

The Crowley series B horizon, with two to four times as much clay as the A horizon, indicates active translocation of clay. Clays result from chemical
<table>
<thead>
<tr>
<th>Horizon depth cm/in</th>
<th>Description</th>
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<tbody>
<tr>
<td>A 38/15</td>
<td>dark grayish brown, silt loam, acid, firm when moist, hard when dry, slightly plastic when wet, many roots in top 3 inches, few roots thereafter</td>
</tr>
<tr>
<td>B 114/45</td>
<td>2-4 times as much clay as &quot;A&quot;, light brownish gray, silty clay loam, acid, mottled, peds coated with gray films, firm when moist, hard when dry, plastic when wet, few roots, some black concretions</td>
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<tr>
<td>C 190/75</td>
<td>large tongues of gray silty clay loam, neutral</td>
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<tr>
<td>D</td>
<td>stratified silt and clay</td>
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</tbody>
</table>

Figure 10. Generalized soil profile of Crowley silt loam 0-1% slope (Soil Conservation Service, 1962).
weathering within the soil or may be present in the parent material. Both origins are likely for Crowley soils. Clays move downward in solution and precipitate in the B horizon or move as particles into the B horizon where they accumulate due to flocculation or due to constricted pore spaces through which they cannot pass. The high concentration of clay in the B horizon forms a claypan almost impervious to water passage.

Crowley soils are defined as imperfectly drained claypan soils of low permeability and low moisture supplying capacity. They are moderately fertile with moderate organic content (Soil Conservation Service, 1962). The high clay content of the entire soil profile is a major factor in the soil's moisture storage capacity and poor drainage. Crowley soil averages 35% clay. Water is tightly held in the fine pore spaces and, despite a high field capacity, no more water is actually available to the plants than would be found in extremely sandy soils. Poorly drained soils limit the volume of soil available for plant use. The A horizon of the Crowley series contains few roots below three inches. Such factors, which tend to make Cajun Prairie soils unfavorable for the establishment of trees, make them well suited to flood irrigation and rice production.
Soils near watercourses historically supported oak/pine on the slopes and oak/cypress/gum on the alluvial bottomland. The main soil associated with the slopes is Acadia silt loam. It is similar to the Crowley series except that surface runoff is faster (Soil Conservation Service, 1962; Lytle, 1968). This suggests that periodic standing water associated with clayey soils, level land, and poorly developed drainage helps prevent establishment of woody taxa on the uplands. However, the proximity of this association to a water source makes it less susceptible to summer moisture deficits as well. The alluvial bottomlands are the flood plains of active streams. High water tables and frequent flooding support vegetation capable of surviving the stress of almost constant waterlogging. The existence of forests on soils that are nearest to water and on soils that are almost continuously waterlogged implies that periodic drought (not waterlogging) is the critical factor inhibiting tree establishment on the prairie uplands.

In the extreme eastern part of the Cajun Prairie, some of the soils which developed on loessal parent material are Udalfs, not quite as wet as Aqualfs (Buol et al., 1989). These soils tend to have less clay, to be slightly more permeable, and to be somewhat better drained than the soils farther west on older parent material (Soil...
Conservation Service, 1977). Some, however, have a well developed fragipan (a dense, brittle subsurface layer due to extreme density or compactness rather than to clay accumulation) which hinders root development and retards drainage the same as claypan (Lytle, 1968; Brady, 1990).

An alternative hypothesis concerning the southwestern Louisiana grassland is that it is due to saline soils (Soil Conservation Service, 1962). High levels of magnesium in the Prairie soils support the theory that the Prairie Terrace had a marine origin or was at least subject to salt water inundation during its formation. In saline soils, water is held tightly by osmotic forces and not available to plants. Trees grow along better drained watercourses where salts are leached out more rapidly. Abundant natural levee and channel scars on the terrace surface point to a long period of terrestrial fluvial formation and invalidate this theory.

Edaphic factors seem to be especially relevant for the southwestern Louisiana Prairie. The fine silts and clays of the Prairie Complex have given rise to an impermeable silty clay soil with poor water yielding capacity. Periodic drought occurs on uplands during summer moisture deficits. At the same time, the low slope of the Prairie Terrace has retarded drainage development. Underlying impermeable deposits of the Mississippi River

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may contribute to waterlogged conditions during rainy periods. Vegetation must be able to deal with both types of stress.

In support of edaphic control of southwestern Louisiana's grassland, a similar prairie vegetation outlier exists in the Mississippi Alluvial valley in Arkansas east and southeast of Little Rock (Fig. 11). The Arkansas "Grand Prairie" occupies a broad nearly level interfluve between the White River and the Arkansas River and, like its counterpart in Louisiana, produces primarily rice (Corbet, 1966). The soils of the Grand Prairie developed on a cone of Arkansas River alluvium and loess deposited on top of impermeable Mississippi River sediments which average 50 feet thick (Soil Conservation Service, 1981; Gonthier and Mahon, 1993). Flat terrain, poorly drained claypan or fragipan soils (including the Crowley series), pimple mounds, and original grassland vegetation in an area with relatively high annual precipitation suggest that the Grand Prairie and the Cajun Prairie have much in common (Irving et al., 1980).

**European Settlement**

European settlement of the Louisiana Prairie began in the 1700s. Early French trading posts named after local Indian tribes were established at Opelousas and Attakapas (present day St. Martinsville) (Gagliano et al., 1979).
Figure 11. Map of lower Mississippi valley showing location of Grand Prairie and Cajun Prairie (Adapted from Saucier, 1981).
The first significant influx of settlers was the French Acadians between 1765 and 1785 (Post, 1962). From the original trading centers, these people spread over the eastern portions of the Prairie. They ran cattle on the grassland, used the better drained land for corn and cotton production, and grew rice in the naturally occurring small shallow ponds (Kniffen and Hilliard, 1988).

In 1882, the Southern Pacific Railroad crossed the prairie and a new wave of settlers, mostly farmers from the U.S. midwestern prairies, established themselves on the largely unoccupied lands of the western part of the Louisiana Prairie. These people developed commercial rice farming in the state (Post, 1940). Water pumps, irrigation canals, terraced fields, and grain elevators replaced the remaining tallgrass vegetation. Rice agriculture has been so successful that only about 200 acres of original Cajun Prairie survive in remnant strips along railroad right of ways (Allen and Vidrine, 1989).

These settlers planted trees near their houses and sometimes along property boundaries. Today, the careful observer will note that many of the oldest and largest trees on the Cajun Prairie are in unnaturally straight rows. In addition to planting trees on the prairie, settlers suppressed fire which enabled the trees they
planted and others which sprung up naturally along fence rows to survive.

Whereas drought contributes to the development of a grassland, frequent fire is important in preventing the establishment of woody species (Anderson, 1990). The fire history of the Southwestern Louisiana Prairie is unknown; however, we may assume that both the prairie and the coastal marshes burned naturally in an area with frequent thunderstorm activity like southern Louisiana. Additionally, Native Americans probably set fires to drive game or to ensure good spring grass to attract game (Sauer, 1975). The gallery forests along the watercourses of the Cajun Prairie may be due not only to the different soil and proximity to water but also to protection from such fires.
The North American Prairie

The North American prairie extends from Montana to Illinois and from central Saskatchewan, Canada, to the Texas coast. Tallgrasses occupy its moister eastern regions; short or bunch grasses, the drier western regions (See Fig. 2). Tallgrass prairie is defined as grassland with the dominant species exceeding 120 cm in height (Risser et al., 1981). Prairies probably originated about 5-7 million years ago during the Miocene-Pliocene transition. Intense speciation of grasses occurred during the Pliocene in response to drier climates in central North America caused by mountain building in the western states (Axelrod, 1985; Reichman, 1987).

Low endemism (species limited to the region) in plants, insects, and birds suggests a short evolutionary history for the North American prairie (Axelrod, 1985). Wells (1970a) states that prairies not only have few endemic species but also have fewer grass species per genus than do grassy openings in the eastern deciduous forests. Grasses reached their current distribution only after the last glacial period making the modern biome relatively young.

Rather than look upon the prairies as representing favorable environments for grasses, it is more appropriate
to consider them as unfavorable environments for trees. The three factors most often cited as important in keeping woody vegetation out of the prairie are drought, fire, and grazing by animals. Grasses developed the herbaceous habit, underground growth buds, and the ability to go dormant during times of stress as evolutionary adaptations to drought; trees did not. These characteristics also make grasses resistant to fire and grazing. Attempts to define a single most important cause of grasslands are unrealistic because separation or ranking of these three factors is virtually impossible (Anderson, 1982).

Sauer (1975) attributed grasslands to frequent fires set by man to assure good spring vegetation growth, to clear land for planting, and to aid in the collection of game. Fire destroys most woody plants easily in the seedling stage with the exception of fire resistant species like longleaf pine (Pinus palustris) in the southeastern United States (Wright and Bailey, 1982). Wells (1970b) presents a convincing argument for the importance of fire in preventing the establishment of trees in grasslands, citing examples such as the wide distribution of scarp protected woodlands in the Great Plains, the success of experimental tree plantations, and the potential for invasion by xerophytic tree species. He states that a major factor contributing to dominance by
fire is the flat, continuous surface of most prairies. Topographic breaks which present barriers to the spread of fire seem to provide a refuge for woody species.

Bragg and Hulbert's (1976) study of burned versus unburned bluestem prairie in Kansas confirms fire as an important agent in preventing the invasion by woody species. They also found that woody plants were unable to establish themselves in droughty silty clay loams even in the absence of fire. Their study demonstrates the futility of trying to separate these factors.

Grasses are admirably adapted to withstand fire because their underground rhizomes are protected by the insulating qualities of the soil. Temperature at the soil surface of a prairie fire is a function of the litter available for fuel; therefore, frequent fires, which allow less litter accumulation, tend to be least destructive to grasses but most effective in killing woody plants while still in the vulnerable seedling stage. Fire helps exclude trees from established prairie but does not create prairies (Transeau, 1981).

Researchers traditionally associate grasslands with moisture stress. Maps in any atlas show an obvious relationship between the North American Prairie and average summer precipitation of less than 50 cm (20 inches). Even closer correlations exist for the prairie
and Thornthwaite's moisture index which estimates how well annual precipitation meets climatic demands for water at a given place. Borchert (1950) related prairie vegetation to climate variables such as average winter precipitation, average summer precipitation, summer rainfall variability, and seasonal air flow. He defined the North American Prairie climate by low winter precipitation, occasional severe summer droughts, and continental air mass dominance. Bryson (1966) related vegetation formations to air mass dominance with the prairie region dominated by air of Pacific origin which becomes warmer and drier after going over the western mountains. Paleoecological studies and paleoclimatic reconstructions assume a direct relationship between moisture stress and grassland. 

**Prairie Paleoecology**

Numerous paleoecological studies document the establishment of the modern North American grassland over the last 18,000 years. These indicate the widespread presence of spruce during the last glacial maximum, the replacement of spruce by deciduous elements as the climate ameliorated, the expansion of grasslands during the maximum warmth of the Holocene, and a slight retraction of grasses since that time. Wright (1970), Delcourt and Delcourt (1981), Watts (1983), Wells (1983), Axelrod (1985), and Baker and Waln (1985) provide summaries of
prairie vegetation which illustrate that the prairie-forest ecotone has been a sensitive indicator of climate changes that took place during the late Quaternary and Holocene. Figure 12 shows the location of all sites referred to in the following discussion.

The Late Quaternary (18,000 to 10,000 B.P.)

Paleoecological studies from Texas to Canada document the presence of trees throughout the modern prairie region during the late Quaternary. Bryant and Holloway (1985) summarize Texas sites and report significant percentages of arboreal pollen including some spruce during this time period. They infer a mixed deciduous hardwood-conifer open woodland for central and north Texas. In northeastern Kansas, Grüger (1973) found high percentages of spruce pollen from 23,000 to 15,000 B.P. suggesting nearby spruce forest. Comprehensive analysis of a core from Pickerel Lake, South Dakota, included pollen, seeds, mollusks, and diatoms (Watts and Bright, 1968; Haworth, 1972). All evidence points to a boreal forest community up to 10,000 B.P. In Canada, Ritchie (1976) notes a spruce-sage (Artemisia) pollen assemblage from 12,000-10,000 B.P. related to the early migration of vegetation onto recently deglaciated terrain. Few of these authors postulate a closed forest canopy but rather suggest a woodland or parkland with both trees and herbaceous ground cover.
Figure 12. Location of selected paleoecological sites, arranged alphabetically from north to south:

a. Southern Saskatchewan (Ritchie, 1976)
b. Itasca Transect (McAndrews, 1966)
c. Pickerel Lake (Watts and Bright, 1968, Haworth, 1972)
d. Lake Mendota (Winkler et al., 1986)
e. Volo Bog (King, 1981)
f. Chatsworth Bog (King, 1981)
g. Muscotah Marsh (Grüger, 1973)
h. Old Field (King and Allen, 1977)
i. Powers Fort Swale (Royall et al., 1991)
j. Ferndale Bog (Albert and Wyckoff, 1981)
k. Boriack Bog (Bryant and Holloway, 1985)
Interesting evidence for continuous tree coverage of the Plains comes from disjunct populations of trees and shrubs (Wells, 1983; Axelrod, 1985). Wells (1983) reviews evidence on eastern and western red cedar (Juniperus virginiana and J. scopulorum) from a study by Van Haverbeke (1968) which showed a regular continuum of morphological characteristics between the two species across the Great Plains. Further work by Flake and others (1978) on chemical characteristics confirms the continuous pattern of variation across space. The disjunct cedars appear to be remnants of relatively uninterrupted late Quaternary populations.

The existence of trees, especially spruce, across what is now a grassland attributed to drought is strong evidence for climate change. The earlier type vegetation is typically associated with a climate that is both cooler and moister than the present prairie. COHMAP (1988) model simulations explain conditions at 18,000 B.P. in terms of a southerly branch of the jet stream which steered midlatitude cyclones across a southern track bringing moisture to the southern plains and by easterly winds immediately south of the ice sheet bringing cool conditions to the northern plains. By 12,000 B.P., the jet stream branches had united, but the plains area was still cooler than present due to influence of the ice sheet.
Because cooler temperatures reduce evapotranspiration rates, they create conditions of higher effective moisture suitable for trees. By 9000 B.P., model simulations indicate warmer and drier than present conditions for the region due to greatly reduced glacial influence and to increased summer insolation related to orbital parameters. This change from cool, moist conditions to warm dry conditions marks the Pleistocene-Holocene boundary.

The Holocene (10,000 B.P. to the Present)

Holocene prairie paleoecology focuses on shifts in the prairie forest ecotone. A classic example is McAndrews' (1966) "Itasca Transect" in Minnesota. Pollen analysis of sites in a line across this transition zone reveals a succession of vegetation through time and across space. Spruce dominates the pollen assemblage at McAndrews' westernmost site prior to 11,000 B.P.; from that time until settlement, grass-sage pollen indicating prairie dominance. His eastern sites went from spruce to pine then to oak savanna which lasted from 8,500-4,500 B.P. Mesic deciduous forest replaced oak savanna after 4,500 B.P. and persisted until European settlement. Climatically, McAndrews' work suggests a period of maximum warmth and aridity between 8,500 and 4,500 B.P. corresponding to the Hypsithermal interval of Deevey and Flint (1957).
Ritchie (1976) compiled information from 30 sites in the western interior of Canada. He detected a definite northward movement of the prairie-forest ecotone from 13,000 to 9,000 B.P. with grass coverage expanding in the wake of northward migrating spruce forest. This gradual expansion continued until 6,500 B.P. by which time the grassland reached a maximum northern limit of 54°N in Alberta and Saskatchewan (Fig. 13). From 6,500 to 2,500 B.P. the spruce forest moved southward into the treeless area, and the prairie-forest ecotone shifted south to 51°N, a retreat of 300 km (187 miles). The major vegetation boundaries have remained stable since 2500 B.P. The climatic implications of such ecotonal movement are (1) warming conditions from 13,000-9,000 B.P., (2) maximum warmth and aridity between 9,000 and 6,500 B.P., (3) cooler conditions from 6,500-2,500 B.P., and (4) modern conditions from 2,500 to the present. Apparently, the warmest part of the Holocene occurred earlier in western Canada than in the central and eastern United States.

The Prairie Peninsula, an eastward extension of tallgrass prairie through Iowa and Missouri into Illinois, is the focus of much paleoecological research. King (1981) analyzed sediments from two bogs in Illinois, Chatsworth Bog in the modern tallgrass zone in the center of the state and Volo Bog in the deciduous forest zone near the
Figure 13. Holocene movement of the prairie-forest ecotone in Canada (Adapted from Ritchie, 1976).
Wisconsin border. At Chatsworth Bog, a change from oak-hickory forest to prairie occurred about 8000 B.P. At Volo Bog a concurrent change from mesic deciduous forest to more xeric oak-hickory forest took place. Both sites maintained their post-8000 B.P. vegetation to modern times.

In southern Wisconsin, Winkler et al. (1986) reconstructed the Holocene paleoenvironment using lake levels and pollen analysis. Their results indicate a period of aridity from 6500 to 3500. Grass pollen percentages increase slightly in this part of the core, but oak dominates the pollen assemblage confirming King's (1981) conclusion that prairie vegetation did not reach into Wisconsin.

At the Old Field Site in southeastern Missouri, King and Allen (1977) reported a decrease in the pollen of bottomland hardwood species and a concomitant rise in grass pollen at 8,700 B.P. The herbaceous assemblage dominated until 5000 B.P. when tree pollen increased. He interprets the data as evidence that the Prairie Peninsula did expand into Missouri in the mid-Holocene. The Old Field site is within the Mississippi Alluvial Valley and King acknowledges that the high percentages of grass pollen could be due to a local source such as cane rather than to prairie taxa. Eighty kilometers (50 miles)
southwest of Old Field at Powers Fort Swale, also within the alluvial valley, Royall et al. (1991) note a similar increase in nonarboreal pollen percentages between 9500-4500 B.P. They likewise infer warm and dry conditions from this evidence.

Iowa is currently located in the transition zone between tallgrass prairie and deciduous forest and is the subject of numerous paleoecological studies (Van Zant, 1979; Nations et al., 1989; Baker et al. 1990; Chumbley et al., 1990; Baker et al., 1992). Like most of the modern prairie, Iowa supported a spruce and pine forest after the ice retreated. By 10,000 B.P., pollen analysis indicates deciduous trees (oak and elm) had replaced northward migrating spruce over much of Iowa (Figs. 14 and 15). The western edge of the state was the transition zone between prairie and deciduous forest. Around 7000 B.P., in palynological studies across the state, tree pollen approaches a minimum and grass a maximum, suggesting that this time marks the greatest warmth of the Holocene and the maximum eastward expansion of the Prairie Peninsula. Baker et al. (1992) place the most arid period between 6,500 and 5,500 B.P. By 5000 B.P., tree pollen begins to increase slowly and reaches modern levels around 3,200 B.P. Prior to European settlement, Iowa was mostly
Figure 14. Generalized composite pollen diagram for Iowa 15,000 B.P. to present (Baker and Waln, 1985).
Figure 15. Inferred vegetation maps of eastern North America 18,000 B.P. to present (Anderson, 1990, adapted from Delcourt and Delcourt, 1981).
tallgrass prairie with an oak savanna in the eastern part of the state marking the prairie-forest transition zone.

The external boundaries of North America's prairie are relatively stable, but internally the grassland is neither homogeneous nor static. In the North Dakota prairie, Redman (1972) describes six major plant communities occupying sites along a soil salinity-moisture gradient. They include wet and saline, poorly drained, and dry. Different grasses dominate each classification. Transeau (1935) described both dry and wet prairies in the Prairie Peninsula noting that some areas were waterlogged for part of the year and desiccated at other times. In fact, many of the so-called "prairie outliers" in Ohio are wet prairies typically found on flat, poorly-drained clayey till plains (Easterly, 1981; Forsyth, 1981; Williams, 1981). Recent research on the distribution of C₃ and C₄ grasses within the prairie biome indicate migration of C₄ grasses toward the north and west (Brown and Gersmehl, 1985; Brown, 1993). This suggests that the North American Prairie is not in equilibrium with modern climate but is a dynamic and continually evolving ecosystem.

Extensive palynological studies of the United States midwestern tallgrass prairie document shifts in the prairie-forest ecotone in response to past climate change. Widespread concurrence between sites confirms the validity
of this method of paleoenvironmental reconstruction. Unfortunately, a lack of suitable coring locations hampers palynological studies in prairie sites beyond the glacial margins (Chumbly et al., 1990). Few paleoecological studies exist for tropical or subtropical grasslands.

Southern Paleoecology

No paleoecological studies exist for southwestern Louisiana. According to inferred vegetation maps compiled by Delcourt and Delcourt (1981) (See Fig. 15) using data from all available North American sites, an oak, hickory, pine forest dominated southwestern Louisiana from 18,000 B.P. until the Hypsithermal (7000 B.P.). Subsequently, the forest became pine-dominated and remained so to the present. Such a coarse resolution network with interpolation between distant sites does not even recognize the existence of Louisiana's tallgrass prairie.

A review of paleoecological studies conducted on sites within 800 km (500 miles) of southwestern Louisiana provides an overview of expected vegetation and inferred climatic changes (Figs. 16 and 17). The presence of spruce pollen and macrofossils in the Florida panhandle (Watts et al., 1992), the Tunica Hills of southeastern Louisiana (Delcourt, 1977; Jackson and Givens, 1994), Rayburn Dome in northwest Louisiana (Kolb and Fredlund, 1981), and in central Texas (Bryant, 1977; Toomey et al., 1993) imply
Figure 16. Map of paleoecological sites within approximately 800 km of southwestern Louisiana (LAP).

BB. Boriack Bog (Bryant Jr., 1977)
BL. Big Lake (Guccione et al., 1988)
BLB. B.L. Bigbee (Whitehead and Sheehan, 1985)
CL. Camel Lake (Watts et al., 1992)
CP. Cahaba Pond (Delcourt et al., 1983)
EP. Edwards Plateau (Toomey et al., 1993)
FB. Ferndale Bog (Albert and Wyckoff, 1981)
FH. Fort Hood (Nordt et al., 1994)
GS. Goshen Springs (Delcourt, 1980)
HB. Hershop Bog (Larson et al., 1972)
LL. Lake Louise (Watts, 1971)
PR. Pearl River Marsh (Li, 1994)
RD. Rayburn Dome (Kolb and Fredlund, 1981)
TH. Tunica Hills (Delcourt and Delcourt, 1977, Jackson and Givens, 1994)
UTC. Upper Texas Coast (Aten, 1983)
WB. Weakly Bog (Holloway et al., 1987)
YR. Yazoo River Basin (Holloway and Velastro, 1983)
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cccc = cool and/or moist  ..... = transitional  xxxx = arid
---- = modern      pppp = high pine %

Figure 17. Inferred conditions at selected paleoecological sites within approximately 800 km of southwestern Louisiana.
cooler and moister conditions within the region from the last glacial maximum (18,000 B.P.) until 13,000 B.P. Delcourt and Delcourt (1985) propose a limited distribution of spruce along the blufflands of the meltwater cooled Mississippi River; however, the presence of small amounts of spruce pollen at widely separated sites suggests the tree was scattered throughout the region in favorable localities. During this period, vegetation responded to reduced temperatures associated with the southward displacement of the polar front by the Laurentide Ice Sheet. Cooler winters with possibly increased frontal precipitation and cooler summers with reduced evapotranspiration rates led to increased effective moisture (Delcourt and Delcourt, 1985; COHMAP, 1988). The spruce involved, however, appears to be an extinct species; so no real relationship between pollen and temperature can be assumed (Jackson and Givens, 1994).

Toomey (1993), in a study on the Edwards Plateau of Texas, detected fluctuations in fauna related to the Younger Dryas, the period from 11,000 to 10,000 B.P. when glacial meltwater abruptly ceased to flow down the Mississippi to the Gulf of Mexico (Broecker, et al., 1988). Dry conditions are associated with a cool Gulf, low evaporation rates, and consequent low inland transport of Gulf moisture. Wetter conditions are inferred at about
10,500 B.P. with less meltwater, warmer Gulf temperatures, higher evaporation rates, and greater inland transport of moisture.

Most researchers postulate transitional temperature and moisture regimes between the cool moist glacial period and the highly seasonal warm dry Hypsithermal. Glacial meltwater from Lake Agassiz shifted toward the North Atlantic after 9500 B.P. (Teller, 1990), the Gulf of Mexico warmed, and summer moisture increased. Vegetation changes indicate this increase was offset by increased evapotranspiration rates associated with higher summer temperatures. Pollen assemblages from this transitional period often reflect changing vegetation communities with no modern equivalents (Delcourt et al., 1983; Watts et al., 1992). Vegetation was not in equilibrium with the climate but was rapidly migrating in response to ameliorating conditions.

Most southern paleoecological studies record drier conditions at 10,000 B.P. marking the onset of the Holocene (Delcourt et al., 1983; Watts et al., 1992; Toomey et al. 1993). During this warm and dry period, seasonality reached a peak at 6000 B.P. (Toomey, et al., 1993). Oak and hickory dominate most pollen assemblages of this period. High summer temperatures probably offset any precipitation increases so that overall conditions were
xeric. However, warm temperatures in the Gulf of Mexico may have led to heavy precipitation in some areas due to an increased frequency of tropical storms (Alford and Holmes, 1985).

Paleoecological studies from Florida to Texas show that the warmest and driest period in the last 20,000 years occurred between 9000 and 3000 B.P. In contrast, COHMAP (1988) suggests warmer and wetter conditions for the southeastern United States due to increased monsoon circulation during that same time span. Delcourt and Delcourt (1985) propose that monsoonal effects did not extend very far inland from the immediate Gulf Coast. Work by Li (1994) on a core from the Pearl River marsh, located near the Louisiana-Mississippi border within the coastal zone, supports this hypothesis. His data show a period of high fluvial discharge about 6000-4500 B.P.

By 3000 B.P. radiation regimes were similar to those of today. Seasonality decreased and effective moisture increased (Delcourt and Delcourt, 1985; Whitehead and Sheehan, 1985; Toomey, et al., 1993). Temperature and sea level reached modern values. Most researchers postulate relatively stable conditions for the last 3000 years with vegetation changes caused by anthropogenic activity rather than climate variation. In Texas, Toomey, et al. (1993) notes more xeric conditions during the last 1000 years.
Several studies in the southern forests document a rise in pine pollen percentages to 60% during the last 5000 years. Watts (1971) at Lake Louise, Georgia, and Delcourt (1980) at Goshen Springs, Alabama, place the pine rise at 5000 B.P. and relate it to an increase in fire caused either by increased thunderstorm activity or to burning by Indians. Whitehead and Sheehan (1985) detect a similar shift (to 30% pine) in eastern Mississippi at 2000 B.P. Kolb and Fredlund (1981) likewise report pine percentages of 50% in the upper portion of the Rayburn Dome, Louisiana, pollen profile following a possible hiatus. Unfortunately, no dates are available for this horizon. In each of these cases, the pine rise follows the apparent period of maximum aridity.

In contrast, Holloway and Velastro (1983a, 1983b) in the Yazoo Basin of Mississippi detected the highest pine percentages (30%) in samples from 16,000-10,000 B.P. Saucier (1983) points out that many of the radiocarbon dates in this study are considerably older than would be expected based on the stratigraphy and fluvial geomorphology of the area. Probably the dates are on reworked older sediments. In that case, the pine rise date in the Yazoo Basin may be closer to 5000 B.P. Pines are noted as early successional species able to withstand the stresses of sandy, low nutrient soils and of fire.
Clearly, no one scenario explains the observed changes at every site.

Ferndale Bog in southeastern Oklahoma is one of the few paleoecological sites near the southern prairie-forest boundary (Albert and Wyckoff, 1981). Although the pollen record is relatively short (5200 years), it suggests oak savannah up to 5000 B.P. followed by an open oak-hickory forest. Pine pollen increases to 20% or more at 1700 B.P. This site supports the hypothesis of somewhat cooler and/or moister conditions after 5000 B.P.

Because southwestern Louisiana occupies the southern prairie-forest transition zone, research on similar areas or on coastal prairies is especially relevant to this dissertation. Holloway et al. (1987) document vegetation change along the prairie-forest ecotone in central Texas; however, their Weakly Bog record only goes back 2400 years. From a pollen diagram with minor changes in pollen percentages, they infer a shift from an oak dominated woodland to an herb dominated xeric community around 2000 B.P. They base their interpretation on abrupt changes in pollen influx which appear more related to a change in sedimentation than to a real shift in the ecotone.

Larson et al. (1972) analyzed cores from Hershop Bog in the post oak savanna of central Texas. They found more tree pollen prior to 10,000 B.P. and infer more mesic
conditions for that time. After 10,000 B.P., grass pollen dominates the assemblage suggesting drier conditions up to the present. At no time does pine contribute significantly to the pollen assemblage.

In central Texas, Nordt, et al. (1994) base their climatic reconstruction on stable carbon isotope analysis of alluvial sediments. Plants utilizing the C_4 photosynthetic pathway take up more $^{13}$CO$_2$ than plants with the more common C_3 pathway; therefore, they have a higher ratio of $^{13}$C to $^{12}$C isotopes in their tissues (Boutton, 1991a, 1991b). Shifts in the ratios of C_3 and C_4 plant biomass production during the last 15,000 years indicate C_4 plant expansion around 6000 B.P. retreating to modern levels around 4000 B.P. C_4 plants are associated with warm, semi-arid environments with high light intensity, so their spread confirms hotter summers around 6000 B.P. likely due to higher seasonality related to orbital changes. They also detect a slight increase in C_4 productivity about 2000 B.P. suggesting a short period of greater warmth corresponding to the widely recognized Little Climatic Optimum (Pielou, 1991).

Aten (1983) summarizes Holocene climatic changes for the upper Texas coast based on pollen, archaeology, faunal remains, and caliche deposits as follows: (1) prior to 10,000 B.P., the region was extremely humid with low
seasonality; (2) from 10,000 to 5000 B.P., the period spanning the Hypsithermal, the coastal plains were drier and warmer; and (3) after 5000 B.P., a subhumid seasonal environment similar to the present prevailed. He cites the absence of bison on the Texas coastal plain between 2000 B.P. and 700 B.P. as evidence for some smaller scale change in the environment which caused changes in the grasslands.

Southern paleoecological research generally supports the climatic changes found in the more widely studied regions of North America; however, shifts in arboreal taxa are difficult to detect and to interpret in the South because the dominant oaks and pines are virtually indistinguishable palynologically. Also, few species encounter significant physiological limits in the Deep South like they do farther north. For example, at least 12 tree species reach their northern distribution limits in northern Ontario (Liu, 1990). In the South, climatic inferences based upon movement of the prairie-forest ecotone are potentially more reliable than those based upon changes in forest species because both the pollen and the ecological tolerances of trees and grasses are distinct.
STATEMENT OF RESEARCH PROBLEM

The preceding literature review establishes that shifts in the prairie-forest ecotone over time are related to climate change and that they can be detected by palynological analysis of sediment cores. The Southwestern Louisiana Prairie, like the scattered prairies of Ohio, is an outlier of North America's tallgrass prairie. Figure 18 shows the hypothesized response of vegetation outliers to shifting climatic conditions.

Under modern conditions, the climatic prairie-forest ecotone lies to the west of the Louisiana Prairie. The prairie is an island in a forest climate, also depicted is a forest island in the prairie climate. These outliers are controlled by edaphic factors which have amplified or damped climatic impacts. In the case of the prairie, clay soils with poor water yielding capacity create summer moisture deficits greater than trees can withstand. Under cooler and/or moister climates, the ecotone shifts westward. The forest island expands or may even be incorporated into the main body of the forest. The prairie island is stranded even farther from the prairie climate. Trees invade the prairie from the edges causing a contraction in the grassland; however, some areas remain on the prairie side of the threshold. During warmer and/or drier times, the ecotone shifts toward the east. Now the
Figure 18. Hypothetical changes in vegetation outliers near the prairie-forest ecotone.
tree island shrinks or thins as trees in less favorable sites die off. The tree community dominants may change. On the other hand, the prairie island expands and is perhaps incorporated into the main body of the prairie. Changes such as these should be readily detectable as shifts in arboreal to non-arboreal pollen. Given suitable coring sites, the Southwestern Louisiana Prairie is a potentially sensitive indicator of climate change.

This dissertation is designed to answer the following research questions: (1) How old is southwestern Louisiana's grassland? (2) Has the Southwestern Louisiana Prairie expanded or contracted over time, i.e. has the prairie-forest ecotone shifted? (3) During the Hypsithermal, were coastal sites drier like the reviewed inland sites or were they wetter due to a stronger monsoon effect? (4) Did pine become more important after 5000 B.P.? (5) Has fire played a significant role in the maintenance of Louisiana's grassland? (6) How have human activities affected the vegetation of the Cajun Prairie?
METHODOLOGY

Site Selection

Major sites

Successfully applying palynological methods to unravel the environmental history of southwestern Louisiana depends on the availability of appropriate coring sites. The low slope of the Prairie Terrace and its relative youth support a poorly developed drainage system. No forces have acted upon the relatively flat surface to produce deep lakes as are common in glaciated regions or enclosed basins as might be found in more tectonically active areas.

A comprehensive examination of all of the United States Geological Survey 7.5 minute quadrangles in or adjacent to the Southwestern Louisiana Prairie revealed two lakes with potential for disclosing the environmental history of this southern grassland (See Fig. 4). Lake Arthur and Prien Lake, located on the prairie's southern and western boundaries respectively, are not lakes in the strict sense of the term. Both are drowned river segments close enough to the Gulf of Mexico to be influenced by salt water. Although they are labeled lakes, they are more properly defined as estuaries.

Lake Arthur and Prien Lake have advantages and disadvantages for use as paleoecological sites. Advantages
include size, location of lake and watershed in relation to prairie and forest regions, and accessibility. Disadvantages include relative youth of sites directly tied to current sea level stand, possible influence of sea level fluctuation on sedimentation, proximity to Holocene marshes, tidal or fluvial influence on pollen and sedimentary records, and historical human disturbance of sediments by dredging or boat traffic.

Both lakes are large, over 3 sq. km (1 sq. mile); therefore, regional pollen should be the most significant component of the pollen assemblage. Wind transported pollen falls into three categories (Jacobson and Bradshaw, 1981). Regional pollen, from sources more distant than 200 meters (650 feet), is carried aloft above the vegetation canopy by air currents and deposited as pollen rain on the lake's surface. Extralocal pollen, from sources 200-20 meters (650-65 feet) away, is carried by air currents below the canopy. Local pollen comes from vegetation growing within 20 meters (65 feet) of the lake itself and drops directly into the water. Studies show that the larger the lake the more important the regional component becomes in relation to the other two. Jacobson and Bradshaw (1981) suggest that for lakes over 1 square km in area with no inflowing streams, regional pollen accounts for almost 90% of the pollen influx.
Pollen also enters the lake via surface runoff and streamflow. Research by Peck (1973), Bonny (1978), and Pennington (1979), indicates that streamborne pollen can contribute up to 85% of the total pollen influx to small lakes. These studies show that flood discharges carry high concentrations of pollen which presumably comes from surface runoff. Chmura and Liu (1990) found that Mississippi River water contained significant amounts of pollen from local to regional vegetation, from reworked sediments, and from distant headwater sources. Eyster-Smith et al. (1991) concluded, however, that river influx of pollen grains contributes "substantially but not overwhelmingly" to the pollen assemblage of Lake St. Croix, a large riverine lake on the Minnesota and Wisconsin border. Their study showed that most pollen came from nearby parts of the drainage basin. In areas with relatively high rainfall like Louisiana, pollen influx related to runoff may be significant; however, watershed-vegetation relationships of the selected lakes guarantee that streamborne pollen will enhance rather than detract from the overall pollen reconstruction.

Palynological studies of estuarine sediments imply that pollen is highly correlated with vegetation adjacent to the estuary and that pollen (20-50 μ) behaves like similar sized clastic particles (silt, 2-50 μ) and settles
out with silts and clays. There is little evidence for sorting of pollen in estuarine sediments (Brush and DeFries, 1981; Traverse, 1990). Decreasing pollen concentrations along a riverine-marine transect indicate that tidal action mixes pollen already within the estuary but does not introduce exotic pollen (Traverse, 1990).

Lake Arthur and Prien Lake are ideally situated in respect to the vegetation study region. Lake Arthur is centrally located in the southern part of the Southwestern Louisiana Prairie. Public Land Survey maps from the late 1800's show extensive dry prairie immediately to the north. Lake Arthur is on the Mermentau River whose watershed is confined to and encompasses almost all of the prairie vegetation zone. Streamborne pollen comes either from the gallery forests or from the prairie itself. Prien Lake, on the Calcasieu River, is situated near the western boundary of the Cajun Prairie. Vegetation around Prien Lake in the early 1800's was largely pine forest. Streamborne pollen derived from the Calcasieu's watershed comes primarily from the pine woods immediately northwest of the prairie.

These sites should detect either an expansion or a contraction of the natural grassland vegetation. An expansion of the prairie will lead to increased prairie pollen in Lake Arthur and to higher percentages of prairie
pollen in Prien Lake if the forest boundary retreats northward. A contraction in the prairie will result in higher percentages of tree pollen in Lake Arthur.

Major problems associated with these estuarine sites involve their proximity to the Gulf of Mexico. Lake Arthur and Prien Lake are both drowned river valleys and owe their very formation to the current high sea level stand. Sedimentary records from such sites are unfortunately limited to the last 5000-6000 years. Still, the time span is adequate to detect any post-Hypsithermal changes in vegetation.

Holocene sea level scenarios vary from steady state for the past 5000 years to fluctuations of plus or minus 1-3 meters (Pirazzoli, 1991; Tanner, 1991). Sea level fluctuations affect the location of the freshwater-saltwater interface which in turn affects clay flocculation and sedimentation. Vegetation is also affected by sea level. For example, cypress trees currently surrounding Lake Arthur would be killed if sea level were to rise bringing more salt water into the basically freshwater lake.

The principal complication of estuarine sites is their proximity to wet prairie or marsh vegetation which can expand or contract in response to sea level change. These wetland communities are dominated by the same plant
families as the true prairie, so any increase in grass pollen might be due to marsh expansion rather than to prairie expansion. Preliminary investigations suggest that other microfossils, phytoliths and diatoms, can resolve this dilemma.

Minor Sites

Paleoecological reconstruction is based on modern pollen vegetation relationships (Davis and Webb, 1975). In the case of the Southwestern Louisiana Prairie, modern agriculture has destroyed the natural grassland and obliterated most prairie ponds making it difficult to establish the natural grassland's true pollen "signature." Two small lakes built in the late 1800's near Basile provide a means of determining the pollen rain typical of Louisiana's native prairie before extensive alteration. Soil samples from identified Cajun Prairie remnant strips furnish critical information on southern prairie pollen and phytolith assemblages.

Site Descriptions

Lake Arthur

Lake Arthur (30°3'N, 92°42'W) is located about 19.2 km (12 miles) south of Jennings, Louisiana. The lake is approximately 9.6 km (6 miles) long and 1.6 km (1 mile) wide with a surface area of 14.6 sq. km (5.6 sq. miles). The controlling navigation depth in Lake Arthur is 2.7
meters (9 feet). Currently, the lower end of the lake is about 70 river km (44 river miles) above the Gulf outlet of the Mermentau River. At the time of the public land survey in the late 1800's, Lake Arthur had high prairie along its northern side, wet prairie to the south, swamp woodlands where the Mermentau entered the lake, and a fringe of swamp trees along its shoreline. Presently it is fringed by cypress trees, most out in the water implying that lake water levels have risen during the lifetime of the trees, possibly in response to the Catfish Point control structure 30 km (19 miles) downstream which holds water in Grand Lake and Lake Arthur for rice irrigation. Gibson (1976) reports tidal effects extend up the Mermentau slightly beyond Lake Arthur. Today the Mermentau basin is mostly agricultural land, primarily rice fields. Along the river and its tributaries, gallery forests contain species such as red maple, green ash, elm, sycamore, sugarberry, water oak, willow oak, sweetgum, willow, cypress, and tupelo (Louisiana Natural Heritage Program, 1988).

Historic boat traffic on Lake Arthur includes early steamboats to modern pleasure boats as well as vessels related to logging, rice shipping, fishing, and oil and gas. A major channel dredging project planned by the Corps of Engineers in the 1970's was cancelled prior to bid
opening (Corps of Engineers, 1977). Disturbance of bottom sediments at any particular coring site by human activity cannot be ruled out absolutely; however, extensive alteration of the bottom is unlikely.

Prien Lake

South of Lake Charles, Prien Lake (30°11'N, 93°17'W) is approximately 3.35 km (2 miles) long and 1.2 km (0.75 miles) wide with a surface area of 3.6 sq. km (1.4 sq. miles). It was about 56 river km (35 river miles) above the Gulf of Mexico before modern navigational channel construction. Depths in Prien Lake average 3 meters (10 feet); in the old river channel they reach 8 meters (26 feet) or more. Upstream of Lake Charles, the Calcasieu River exceeds depths of 18 meters (60 feet) on the outside of tight meander bends. The Public Land Survey filed in 1883 notes "low wet prairie" along the western side of Prien Lake but forests along the eastern side and northward. The Census of 1880 estimates 7,960 board feet of merchantable longleaf pine, 30% of Louisiana's total, in the area now comprising Calcasieu, Jeff Davis, Allen, Beauregard, and Vernon parishes. This forest was essentially "pure" with more than 80% pine (Millet, 1966). The Calcasieu drainage basin covers the same parishes. Logging began in earnest after the Civil War and continued until the forests were depleted around 1930 (Croker, 1987;
Walker, 1991). Cypress was also an important timber tree on the Calcasieu and to a lesser extent on the Mermentau River (Millet, 1966).

Historical alteration of bottom sediments in Prien Lake is possible. Logging operations flourished in the late 1800s and early 1900s. Shipping and industrial development followed with a dredged ship channel connecting Lake Charles to the Gulf Intracoastal Waterway and to the Gulf of Mexico. This channel (designated the Rose Bluff Cutoff on a 1939 U.S. Coast and Geodetic Survey map) bypassed Prien Lake. Construction of the Interstate 210 bridge in the 1960s may have affected some parts of the lake bottom. One of the coring sites is in a deep hole not far from the bridge; however, conversations with local fishermen confirmed that the hole existed in the 1950s before the bridge was built. Sedimentary evidence from both Prien Lake and Lake Arthur must be interpreted with potential human disturbance in mind.

Basile Lakes

The two small lakes (30°31'N, 92°33'W) 5 km (3 miles) northeast of Basile occupy an old Red River channel with LeDoux Lake just upstream of Fruge Lake. Late 1800 land survey maps represent them as linear marshy areas in otherwise dry prairie. Fruge Lake and LeDoux Lake were created by early settlers who dammed the intermittent
stream around 1890. Over the last century, the dams have been improved by each successive generation and water from the lakes used for gravity flow irrigation. Currently, LeDoux Lake (about 13 hectares or 33 acres, 1 meter deep) is free of aquatic vegetation, while Fruge Lake (9 hectares or 22 acres, 1 meter deep) is overgrown with water lilies \((Nuphar lutea)\). Jacobson and Bradshaw's (1981) parameters imply these lakes will also be dominated by regional pollen; however, the size of the lakes fluctuates throughout the season with changing water levels.

**Cajun Prairie Remnant Strips**

The native prairie remnant strips identified by Dr. Allen and Dr. Vidrine as part of the Cajun Prairie Preservation Project are narrow pieces of land between the highway and the railroad track. They are railroad right-of-ways and, therefore, have never been farmed. The Fenton Remnant Strip \((30°18'N, 92°57'W)\) is located on U.S. Highway 165 between Interstate 10 and Fenton. The Mermentau Strip \((30°11'N, 92°31'W)\) is located along U.S. Highway 90 between Mermentau and Estherwood.

Each designated "strip" has three sampling sites, each with 10 sampling plots. The Fenton Strip sites, all north of I-10, are Fenton North, Fenton South, and Woodlawn. Elevations along the Fenton strip are around 9
meters (30 feet). The Crowley soils at these sites are
typical of the Cajun Prairie, somewhat poorly drained and
moderate in fertility. Crowley soils are also acid which
aids in pollen preservation (Bryant and Hall, 1993). The
Mermentau Strip sites are Mermentau West, Mermentau East,
and Estherwood, all south of I-10. These sites are lower
in elevation (4.5 meters, 15 feet). Although the
Estherwood site has Crowley soils, Mermentau East and West
have the more poorly drained Midland series (Soil

Dr. Allen and Dr. Vidrine identified all plant
species within 20 meter circular plots randomly placed at
each site. By recording presence/absence data in each plot
throughout 1990, they compiled a comprehensive inventory
of native prairie vegetation. Soil samples from the center
of their sampling plots provide the best available
palynological signature of the Southwestern Louisiana
Prairie.

Palynology
Pollen

Paleoecological studies of the prairie-forest ecotone
establish that pollen analysis is an effective tool in
reconstructing past environments. Wind pollinated
(anemophilous) trees such as pine and oak are known to be
overrepresented in pollen assemblages (Bradshaw and Webb,
1985), but little is known concerning the relationship of grass pollen to actual grass coverage. Pollen assemblages considered typical of prairie vegetation usually contain less than 50% arboreal pollen with the remaining nonarboreal component dominated by Gramineae, Compositae, and Chenopodiaceae-Amaranthaceae. These families have many anemophilous genera known to be prolific producers of pollen (Lewis et al., 1983). Chenopodiaceae is common in saline soils in arid regions and in coastal saltmarshes.

The Cajun Prairie remnant strips are dominated by three plant families: Gramineae (grass), Compositae (daisy), and Leguminosae (bean) (Allen and Vidrine, 1989). Chenopodiaceae and Amaranthaceae are notably absent from Allen's taxa list implying that they were not significant in southwestern Louisiana's grassland. Because Leguminosae generally have enclosed stamens and are animal pollinated, they contribute minimally to the pollen rain (Lewis et al., 1983). Gramineae and Compositae possibly dominated the presettlement pollen of the Southwestern Louisiana Prairie.

A complicating factor associated with the selected sites is their proximity to the coastal marshes or wet prairies. These treeless regions contain the same major plant families as the tallgrass prairie. Dominant species for the two environments differ, but Gramineae,
Compositae, and Chenopodiaceae pollen cannot be readily distinguished at the species level. While fresh and intermediate marshes have indicator species such as Cyperaceae, Sagittaria, Vigna, and Pteridophytes which allow them to be distinguished via pollen analysis, saltmarshes do not. Pollen assemblages of prairie and saltmarsh are almost identical (Fig. 19).

Grasses produce two palynologically useful microfossils, pollen and phytoliths. Since pollen and phytoliths are produced by the same plant, are approximately the same size, and are dispersed by similar mechanisms, Gramineae pollen which is transported to and incorporated into lake sediments should be accompanied by Gramineae phytoliths from the same source. Although grass pollen is similar for all species, phytoliths are not. Preliminary research indicated that phytoliths would be useful in resolving this problem (Piperno, 1988).

Phytoliths

Phytoliths are microscopic silica bodies produced by plants via the deposition of dissolved silica within or between plant cells (Piperno, 1988; Pearsall, 1989; Rapp and Mulholland, 1992). They are found mainly in the above ground parts of plants and are released to the environment when the plant tissue breaks down. Silica deposited in this way by biological organisms is referred to as
PRAIRIE VS. SALTMARSH
Selected Pollen Percentages

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<th>Graminaceae</th>
<th>Total Composite</th>
<th>Cheno-Am</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nebraska</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minn. 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minn. 2</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Iowa 1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Iowa 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iowa 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illinois</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newfound.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louisiana</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 19. Characteristic pollen of the prairie and the saltmarsh. Nebraska (Sears, 1961), Minn. 1 (McAndrews, 1966), Minn. 2 (Almquist-Jacobson et al., 1992), Iowa 1 (Baker et al., 1990), Iowa 2 (Durkee, 1971), Iowa 3 (Baker et al., 1992), Illinois (King, 1981), Newfound. (Clarke and Patterson, 1985), New York (Brookes et al., 1985), Louisiana (Chmura, 1990).
biogenic silica or opal. Many plants incorporate silica into their structure; however, grasses are the best studied and the most prolific producers of identifiable phytoliths.

Phytoliths from grasses take many forms; the most useful are those from deposition of silica within short cells (Bonnet, 1972). These solid silica bodies take on characteristics of the cell itself. Wide variation in size and shape of phytoliths produced by a single species of grass and production of the same shape phytolith by unrelated species make identification of individual taxa from a single phytolith virtually impossible; however, generalizations from phytolith assemblages to subfamilies of grasses are possible. Twiss et al. (1969) examined 17 species of grass. They divided phytoliths into basic types related to three groups of subfamilies of Gramineae. His Festucoid class (grasses of humid regions) contains circular, rectangular, elliptical, and oblong forms; Chloridoid class (shortgrass prairie), saddle shapes; Panicoid class (tallgrass prairie), crosses and dumbbells. Brown (1984) built an extensive phytolith key based on 112 grass species from North America. Brown's classification scheme has eight basic shape categories each with numerous subdivisions. His presence/absence observations on each taxon reveal the variations in size and shape which
complicate paleoecological interpretations based on phytoliths.

More recently, Mulholland and Rapp (1992b) classified grass phytoliths according to the shape of the phytolith base (Fig. 20). Mulholland (1989) also examined shape frequencies in North Dakota grasses. Her shape assemblages confirm Twiss's earlier generalizations, illustrate the redundancy of shapes across classifications, and emphasize the need to examine local vegetation for phytolith production before interpreting phytoliths in soils and sediments.

Phytoliths can be an important component of soils and sediments. Twiss (1983) reported grass phytoliths comprising up to 35 percent of wind transported dust in Nebraska. Andrejko and others (1983, 1984) found high concentrations of biogenic silica in peats of the Okefenokee Swamp with phytoliths contributing significantly. Phytoliths associated with soils are typically most abundant in the A horizon which incorporates the majority of decayed plant matter. There is little evidence indicating significant displacement of phytoliths in soils (Rovner, 1986). While the total amount of plant opal is important in some cases, effective environmental reconstruction based on such microfossils
Figure 20. Phytolith base shapes for morphological classification (Mulholland and Rapp, 1992).
depends on identification of phytoliths to a meaningful ecological level.

Paleoecological studies using phytoliths are frequently based on the abundance of grass phytoliths in soils. High concentrations indicate that the area has been dominated by grassland over a long period of time. Kalisz and Boettcher (1990) analyzed soil samples from Buffalo Beats, an outlier of the Prairie Peninsula in Ohio and found low concentrations of grass phytoliths suggesting that the open area had never been dominated by grasses. Wilding and Drees (1968) found the concentration of plant opal in soils from Ohio at the eastern extremity of the Prairie Peninsula to be an order of magnitude lower than those reported for Illinois. They concluded that the Ohio soils had developed mainly under forested conditions. In Kansas, Kurmann (1985) applied both pollen and phytolith analysis to extant soil samples from the shortgrass and the tallgrass prairie and concluded the two vegetation types could be differentiated using soil phytoliths.

Research on phytoliths indicates that biogenic silica from other plant families has potential in vegetation reconstruction. Work by Ollendorf (1992) on Cyperaceae reveals distinct phytolith shapes associated with different sedges (Ollendorf et al., 1987). Piperno (1988) reports significant phytolith production by several
tropical plant families. Additionally, Pearsall and Piperno (1990) have developed a means of identifying corn phytoliths based on a combination of morphological characteristics. As techniques improve and reference collections expand, phytoliths from other taxa may prove as useful as those from grasses in vegetation reconstruction.

Like pollen, phytoliths are useful paleoecological indicators. In the case of Gramineae, phytoliths have the advantage of being identifiable below the family level thus providing more information about environmental conditions than grass pollen. They resist breakdown under oxidizing conditions hence are well preserved in soils. Because they are approximately the same size as pollen, they are subject to similar sedimentary forces. Wind transport of phytoliths was documented by Twiss (1983); water transport remains largely unstudied (Mulholland and Rapp, 1992a). Since phytoliths are approximately the same size as silt, they are likely carried by surface runoff into streams, transported as suspended load, and deposited in lakes and estuaries. Biogenic silica has a lower specific density than clastic silica; therefore, it can be separated from clastic sediments by heavy liquid flotation and analyzed. Relative percentages of phytolith types in...
sediment provide additional information on the source of grass pollen found in the same sample.

The dominant grasses of the Cajun Prairie and of the Louisiana saltmarshes belong to different subfamilies of Gramineae. The prairie genera (*Andropogon, Sorghastrum, Panicum, Schizachyrum, and Paspalum*) are all Panicoid grasses. *Spartina* and *Distichlis* dominate Louisiana's saltmarshes; they are both in the Festucoid subfamily (Hitchcock, 1971). Based on Twiss et al. (1969), phytoliths from the two subfamilies should be different. The phytolith "signature" of the two communities should reflect that difference even if the pollen "signature" does not.

Diatoms

Because Lake Arthur and Prien Lake are so close to the Gulf of Mexico, sea level is a factor which must be considered. Another microfossil in the palynological arsenal is diatoms. They have potential as sea level indicators (Palmer and Abbott, 1986). Diatom frustules are composed of biogenic silica like phytoliths and are about the same size. If present in the sediments, they are also present in the prepared samples and can readily provide another tool to use in resolving the environmental history of the study region.
Diatoms are microscopic unicellular algae which are important components of the phytoplankton throughout the world. Most are autotrophic (able to synthesize their own food) and require light. Diatoms possess unique silica shells or frustules which are deposited on the bottom of streams, lakes, and oceans when the organisms die. The majority of species float freely in the water column, but some attach to plants or sediment (Raven et al., 1992). If moisture and light conditions are met, they can live in soils (Round, 1981). Some diatoms are cosmopolitan, widespread throughout a range of habitats, while others prefer specific conditions of salinity, acidity, or hardness. Like pollen and phytoliths, diatoms are produced in abundance, are widely dispersed, are resistant to decay (Flower, 1993), and are identifiable. If the ecology of a taxon is known, it becomes a useful paleoecological tool.

Diatoms incorporated into sediments can provide a record of environmental conditions in a water body. Haworth (1972) found changes in the diatom flora of a core from Pickerel Lake, South Dakota, related to changes in pH caused by a shift from spruce dominated woodland to grassland within the watershed. Grönlund (1993) reports eutrophication in the Baltic Sea reflected in the diatom assemblages of a sediment core. Vos and de Wolf (1993a,
1993b) used diatoms to reconstruct sedimentary environments in the Netherlands from an ecological code based on factors such as life form, salinity, pH, nutrients, and temperature. They point out drawbacks involving the lack of reliable ecological data and the problem of autochthonous versus allochthonous (native vs. foreign) species, particularly in estuarine environments. Both freshwater diatoms transported fluvially downstream and marine diatoms transported tidally upstream are found in these locations. Increases in marine diatoms in estuarine sediment samples can be related either to higher relative sea level or to decreased freshwater discharge. Despite complications in interpretation, the sedimentary diatom record is valuable for reconstructing past sea level fluctuations (Palmer and Abbott, 1986).

Diatom preservation is largely a function of water chemistry and sedimentary environment (Flower, 1993). Dissolution is greatest in warm, alkaline, silica poor waters with slow sediment accumulation rates leading to prolonged frustule exposure to the dissolving medium. High sediment accumulation rates, on the other hand, protect the frustule from dissolution by rapidly burying it. Breakage of the diatom valves is significant in high energy environments and in situations where complete drying of sediments or of laboratory samples occurs.
Preservation potential increases with diatom robustness. A diverse diatom assemblage with both robust and fragile taxa in good condition implies good preservation; an impoverished assemblage with primarily robust diatoms and diatom fragments implies poor preservation.

Fieldwork

All fieldwork was completed during 1990 and 1991. Most cores were extruded in the field, wrapped in plastic wrap and aluminum foil, and transported to the L.S.U. Quaternary Paleoecology Lab for processing. Some cores were retained in PVC core barrels and extruded later in the lab. As a general rule, sediment cores were taken from the deeper parts of the lakes to take advantage of sediment focusing (Davis, 1973). Brush and DeFries (1981) established that pollen is similarly concentrated in the deeper channels of estuaries.

A total of fifteen cores were taken from the major sites. Eleven cores come from Lake Arthur (Table 1). They are located in a rough transect oriented down the length of the lake (Fig. 21). Four cores come from Prien Lake (Table 2). One of these was from a 10 meter (33 feet) deep hole (Site D) and one was from a small marshy inlet near the south end of the lake (Site A) (Fig. 22). There is also a temperature and salinity profile of Site D.
Table 1. Lake Arthur core inventory.

<table>
<thead>
<tr>
<th>Core</th>
<th>Date taken</th>
<th>Water Depth m</th>
<th>Total length cm</th>
<th>Segment dated</th>
<th>Radiocarbon years BP</th>
<th>Beta # Sed. rate cm/100 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAA</td>
<td>6/91</td>
<td>2.1</td>
<td>345</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAB</td>
<td>6/91</td>
<td>2.4</td>
<td>474</td>
<td>26-36</td>
<td>1090+/-70</td>
<td>47615 2.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75-85</td>
<td>2350+/-70</td>
<td>47616 3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>90-100</td>
<td>3500+/-70</td>
<td>47617 1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>215-225</td>
<td>4850+/-80</td>
<td>47618 9.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>305-320</td>
<td>5860+/-100</td>
<td>47619 9.2</td>
</tr>
<tr>
<td>LAC</td>
<td>6/90</td>
<td>2.1</td>
<td>210</td>
<td>75-85</td>
<td>3600+/-90</td>
<td>39534 2.2</td>
</tr>
<tr>
<td>LAD1</td>
<td>6/90</td>
<td>2.4</td>
<td>137</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAD2</td>
<td>6/91</td>
<td>2.7</td>
<td>402</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAE</td>
<td>6/91</td>
<td>2.7</td>
<td>538</td>
<td>520-535</td>
<td>3260+/-70</td>
<td>47620 15.7</td>
</tr>
<tr>
<td>LAF1</td>
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<td>3.0</td>
<td>132</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>LAF2</td>
<td>3/90</td>
<td>3.0</td>
<td>108</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAF3</td>
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<td>3.2</td>
<td>185</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>LAF4</td>
<td>6/90</td>
<td>3.2</td>
<td>260</td>
<td>40-50</td>
<td>1100+/-100</td>
<td>43425 4.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60-65</td>
<td>4360+/-80</td>
<td>43426 0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>210-220</td>
<td>5960+/-80</td>
<td>38228 9.4</td>
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<tr>
<td>LAF5</td>
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<td>3.2</td>
<td>158</td>
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</table>
Figure 21. Lake Arthur coring sites.
Table 2. Prien Lake core inventory.

<table>
<thead>
<tr>
<th>Core</th>
<th>Date taken</th>
<th>Water Depth m</th>
<th>Total length cm</th>
<th>Segment dated</th>
<th>Radiocarbon years BP</th>
<th>Beta #</th>
<th>Sed. rate cm/100 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRA</td>
<td>6/91</td>
<td>.3</td>
<td>168</td>
<td>162-167</td>
<td>2540 +/-70</td>
<td>46898</td>
<td>6.5</td>
</tr>
<tr>
<td>PRB</td>
<td>6/91</td>
<td>2.7</td>
<td>300</td>
<td>282-292</td>
<td>3150 +/-70</td>
<td>46897</td>
<td>9.1</td>
</tr>
<tr>
<td>PRC</td>
<td>6/91</td>
<td>2.7</td>
<td>374</td>
<td>310-320</td>
<td>3520 +/-70</td>
<td>46893</td>
<td>8.9</td>
</tr>
<tr>
<td>PRD</td>
<td>6/91</td>
<td>10</td>
<td>410</td>
<td>293-303</td>
<td>2860 +/-90</td>
<td>46894</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>304-314</td>
<td>3020 +/-90</td>
<td>46895</td>
<td>6.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>425-435</td>
<td>4680 +/-130</td>
<td>46896</td>
<td>7.3</td>
</tr>
</tbody>
</table>
PRIEN LAKE CORING SITES

Figure 22. Prien Lake coring sites.
Four cores were taken from the minor sites near Basile, two from the approximate center of Fruge Lake and two from LeDoux Lake. Sixty soil samples for pollen and phytolith analysis come from the center of Cajun Prairie sampling plots established by Dr. Allen and Dr. Vidrine. Fifteen additional soil samples come from a 10 acre piece of land in Eunice that is being restored with native prairie plants (Table 3).

Analysis

I used a combination of stratigraphic and palynological techniques to unravel the environmental history of southwestern Louisiana. Two sediment cores from Lake Arthur (LAB and LAE) and one from Prien Lake (PRD) comprise the bulk of this research. In addition to the main cores, supplementary cores and surface samples contribute information to the overall reconstruction.

Stratigraphy

Visual inspection of the core reveals gross changes in the sediments. I used a standard Munsell soil color chart to define sediment color. Loss on ignition analysis of samples at approximately 10 cm intervals provides information on the relative water and organic content of the sediments. Loss on ignition for the sediment cores was determined by heating the selected samples at 105°C, 550°C, and 1000°C (Dean, 1974).
Table 3. Cajun Prairie sample inventory.

<table>
<thead>
<tr>
<th>Core</th>
<th>Date Taken</th>
<th>Water Depth m</th>
<th>Total length cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>FA</td>
<td>8/90</td>
<td>0.3</td>
<td>32</td>
</tr>
<tr>
<td>FB</td>
<td>8/90</td>
<td>0.3</td>
<td>30</td>
</tr>
<tr>
<td>LDA</td>
<td>3/90</td>
<td>1</td>
<td>62</td>
</tr>
<tr>
<td>LDB</td>
<td>3/90</td>
<td>1</td>
<td>39</td>
</tr>
</tbody>
</table>

**BASILE LAKES: FRUGE AND LEDOUX**

**SOIL SAMPLES**

CAJUN PRAIRIE REMNANT STRIPS

Samples collected 7/90

<table>
<thead>
<tr>
<th>Soil sample location</th>
<th>Sample numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fenton North</td>
<td>1-10</td>
</tr>
<tr>
<td>Fenton South</td>
<td>11-20</td>
</tr>
<tr>
<td>Iowa</td>
<td>21-30</td>
</tr>
<tr>
<td>Mermentau West</td>
<td>31-40</td>
</tr>
<tr>
<td>Mermentau East</td>
<td>41-50</td>
</tr>
<tr>
<td>Estherwood</td>
<td>51-60</td>
</tr>
<tr>
<td>Eunice</td>
<td>61-75</td>
</tr>
</tbody>
</table>
I submitted selected segments from the cores to Beta Analytic, Inc. for radiocarbon dating of strategic horizons (See Tables 1 and 2). Preparation of samples included scraping off several millimeters of outside material to prevent contamination of dated matter by sediment moved up or down along the core barrel when taking or extruding the core. In most cases, a 10 cm segment of core contained adequate organic matter to yield a date with less than 100 year standard deviation. Dates on the organic clay samples are based on accumulated microscopic organic sediment which includes detritus as well as planktonic and benthic organisms. Dates on peat samples are based on visible herbaceous plant remains. Unfortunately, a 10 cm core segment includes material deposited during, at best, 100 years. Radiocarbon dates on bulk sediments necessarily average these all together. Because Lake Arthur and Prien Lake are both estuarine, organic material, just like pollen, could be transported to the site via fluvial or tidal processes. Since estuarine pollen is highly correlated with nearby vegetation, organic matter is probably also dominated by locally produced material rather than by reworked and transported organic matter. All radiocarbon dates assume that the organic matter is contemporaneous with the sediment.
Pollen

I analyzed pollen at approximately 10 cm intervals on cores LAB, LAE, and PRD to determine vegetation changes. Sediment samples were processed using standard pollen extraction techniques (Faegri and Iverson, 1975) with the addition of exotic *Lycopodium* markers for concentration and influx calculations (Stockmarr, 1971). The procedure includes hydrochloric acid to remove carbonates, potassium hydroxide to break organic bonds and remove humic acids, hydrofluoric acid to remove clays, decantation to separate sand from the sample, acetolysis to remove cellulose, tertiary butyl alcohol for dehydration, safranin stain, and silicone oil as a mounting medium. I counted pollen at 400X magnification except on slides where it was sparse. In those cases, I scanned the slide at 200X and identified grains at 400X. I counted a total of 300 pollen grains exclusive of *Lycopodium* in most core samples; 100 grains, in the Cajun Prairie soil samples. A pine pollen fragment equals one half of a whole pine pollen grain if the fragment contains at least one half of a vesicle.

Fragments and whole grains comprise total *Pinus*.

I also estimated charcoal frequency to assess the importance of fire in the prairie's history (Patterson et al, 1987), and I measured the overall length of pine pollen in PRD. Overall length is a significant factor for
discriminating between pollen of different pine species (Hansen and Cushing, 1973; Jacobs, 1985). For most calculations and for generating diagrams, I used Tilia and Tilia-graph software (Eric C. Grimm, Illinois State Museum, Springfield, Illinois). I calculated all percentages based on the total pollen (phytoliths, diatoms) counted at that level, excluding only Lycopodium markers.

Phytoliths

I designed phytolith analysis to meet three objectives: (1) to develop a reference base of phytoliths typical of the Cajun Prairie and of the coastal salt marsh; (2) to examine phytoliths in samples from Lake Arthur and Prien Lake cores; (3) to use the above phytolith information to determine the most probable source of Gramineae pollen in the Lake Arthur and Prien Lake cores.

I processed samples of the dominant grasses of the Cajun Prairie as identified by Allen (personal communication, 1991), samples of the dominant grasses of the Louisiana saltmarsh (Louisiana Natural Heritage Program, 1988), and samples from other potentially significant prairie and marsh taxa by the dry ashing method to develop a phytolith reference collection. I completed this work under the direction of Dr. Dwight...
Brown at the University of Minnesota. I placed small sections (approximately 2 x 5 mm) from the leaf, culm, inflorescence and root on individual microscope slides, covered them with a cover slip, and ashed them at 350°C for 2 hours. Then I scraped the resulting residue loose from the slide with the edge of the coverslip, added 3 drops of Permount, stirred the residue thoroughly into the Permount, and replaced the coverslip. I examined all samples using 400X magnification to determine the phytolith types produced by each taxon. By counting the phytoliths within a few days of preparing the slides, I avoided the problem of Permount's setting hard.

To establish the phytolith "signature" of the Cajun Prairie, I examined phytoliths from 45 soil samples plus one sample from the Fruge Lake core (pollen analysis suggested that this was the only lake and level likely to represent the presettlement prairie). I processed all soil and sediment phytoliths using methods similar to those outlined by Piperno (1988) which I refined at the University of Minnesota with advice from Dr. Susan Mulholland, University of Minnesota, Duluth. A brief description of the procedure follows; for detailed directions, see Appendix A. After destroying organic matter in samples with a strong oxidizing agent, I removed unwanted clays by gravity settling. I then separated the
biogenic silica fraction which contains phytoliths from
the unwanted clastic silica fraction using heavy liquid
flotation. For each sample, I mounted a small amount of
dry biogenic silica in Permount on a microscope slide for
examination. I counted 100 phytoliths for each of the
prairie soil samples and 300 phytoliths for each of the
sediment samples at 400X magnification.

Using the above methods, I processed and counted
phytolith samples from Lake Arthur, Site B, and from Prien
Lake, Site D, at intervals corresponding to every other
pollen sample. This provides adequate phytolith
information for each pollen zone. Wherever possible, I
counted 300 phytoliths. Based on information from the
reference sites, I calculated a ratio of prairie:marsh
indicator phytoliths for each of the core samples to
reflect the most likely source of Gramineae pollen in the
main Lake Arthur and Prien Lake cores.

Diatoms

I analyzed diatoms to provide information on changing
water conditions in Lake Arthur and Prien Lake over the
last 6000 years. The same processing which concentrates
phytoliths concentrates diatoms so both microfossils can
be counted on the same slide. I counted 100 diatoms in
each phytolith sample, enough to identify the major taxa
at each level. Identification and species ecology follows

To estimate the salinity, I originally grouped taxa into the following five salinity classes based on the aforementioned literature: (1) fresh; (2) fresh to brackish; (3) brackish or euryhaline; (4) brackish to marine; and (5) marine. Different authors assign diatoms to different salinity classes or use several modifiers to indicate a range of tolerances, so my groupings are somewhat subjective. Generally accepted salinity values are as follows: fresh, 0-0.5 ppt; oligohaline (fresh-brackish), 0.5-5 ppt; mesohaline (brackish), 5-18 ppt; polyhaline (brackish-marine) 18-30 ppt; and marine, 30-35 ppt (Mitsch and Gosselink, 1986).

I also classified diatoms by habitat. Planktonic or free-floating diatoms either live in the water column above the site or travel to the site via fluvial or tidal currents. Benthic or attached diatoms presumably are more
indicative of conditions at the site itself; however, they
too are subject to redistribution via erosion and water
transport. For diagrams of identified species and their
respective salinity and habitat assignments, see Appendix
B.
POLLEN AND PHYTOLITHS OF THE CAJUN PRAIRIE

Paleoecologists reconstruct past vegetation from fossil pollen assemblages based on observed relationships between modern vegetation and microfossil assemblages from surface sediment samples. This follows the geologists' maxim, "the present is the key to the past." Since the Southwestern Louisiana Prairie no longer exists, presettlement analogues for this study are derived from reference taxa, soil samples, lake cores, and marsh samples.

Reference Phytoliths

Of the 35 plants processed for reference phytoliths, the Gramineae, Cyperaceae, and Arecaceae contain abundant distinct robust silica bodies (See Appendix C for a list of taxa processed and photographs of major shapes). In general, phytoliths are present in the leaf, sheath, and inflorescence, not in the root samples. Since disaggregated phytoliths cannot be accurately assigned to specific plant parts, only presence or absence of the phytolith shape in the species as a whole is noted. The five Cyperaceae produce simple cones, *Scirpus cyperinus* also produces cones with satellites (Ollendorf, 1992). Both *Sabal* species (Arecaceae) contain spherical phytoliths, 10-20 µ in diameter with blunt spines, as noted by Piperno (1988). *Magnolia grandiflora* and
Tillandsia usneoides (Spanish moss) also produce recognizable phytoliths, but they are not present in any of the sediment samples.

Most observed Gramineae shapes fit into Mulholland and Rapp's (1992b) classification. Modifications to the classification scheme for this study include the addition of more specific base shapes to accommodate the diversity of forms encountered in the reference material (Fig. 23). Figure 24 shows the phytolith shapes found in the grasses processed. Cajun Prairie taxa include the top four species in importance as calculated by Allen (personal communication, 1994). These are Panicum virgatum, Schizachyrium scoparium, Schizachyrium tenerum, and Andropogon gerardii. Importance incorporates both frequency of occurrence in sampling plots and percent coverage. Wet Prairie consists of taxa growing on moist soils or in fresh marshes in Louisiana. The Saltmarsh group contains four species which commonly dominate saline soils near the coast. The four grasses associated with the saltmarsh produce exclusively rondel shaped phytoliths; the remaining grasses produce a wide variety of shapes, including some rondels. While the number of taxa surveyed is small, the results suggest that phytolith assemblages of saltmarsh sediments should contain higher percentages of rondels than any other sedimentary environment. Both
PHYTOLITH CLASSIFICATION

I. **Lobate shaped base.**
   A. Length x width approximately equal, four equal lobes at right angles to each other.
      Cross Cross variants
      Partial Elongate "H"

   B. Length x width not equal, lobes not perpendicular. Distinctly narrower shaft between lobes.
      Dumbbell Complex Dumbbell

      Shaft not distinctly narrower.
      Bilobe Linear Polylobe

   Irregular lobes, usually more than four.
      Compact polylobe

II. **Circular, oval, or curved base.** Body a short cylinder or truncated cone. Top flat or "horned."
    Rondel

III. **Saddle shaped** (battle-axe with double edges). Base with two concave and two convex sides. Top has similar outline, but may differ in size.
     Saddle

IV. **Plates.** Long rectangular phytoliths with sinuate edges.

Figure 23. Phytolith shape classification.
**PHYTOLITHS OF SELECTED GRAMINEAE**  
Subfamily in parentheses before taxa name

<table>
<thead>
<tr>
<th>Presence of Phytolith Shape</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cross</td>
<td></td>
</tr>
<tr>
<td>Part.Cross</td>
<td></td>
</tr>
<tr>
<td>&quot;H&quot;</td>
<td></td>
</tr>
<tr>
<td>Dumbbell</td>
<td></td>
</tr>
<tr>
<td>Complex DB</td>
<td></td>
</tr>
<tr>
<td>Bilobe</td>
<td></td>
</tr>
<tr>
<td>Sin.Poly.</td>
<td></td>
</tr>
<tr>
<td>Com.Poly.</td>
<td></td>
</tr>
<tr>
<td>Rondel</td>
<td>Rondel</td>
</tr>
<tr>
<td>Saddle</td>
<td>Saddle</td>
</tr>
</tbody>
</table>

**Figure 24.** Phytoliths of reference Gramineae.
dry and wet prairie taxa produce lobate shapes; however, the "Wet Prairie" group contains more members of the Festucoid subfamily than the "Cajun Prairie" group. Quantitative analysis might reveal greater rondel production in the "Wet Prairie" group which presence/absence data fail to detect.

**Cajun Prairie Soil Samples**

Loss on ignition, pollen, phytolith, and charcoal analysis of the Cajun Prairie soil samples reveals only minor differences between the sampling strips. All of the samples have an organic matter content of less than 10% (Fig. 25). The undisturbed Fenton and Mermentau strips have a higher water content than the Eunice restoration plot probably due to past cultivation on the Eunice land. All samples have moderate amounts of charcoal, most of it is chunky rather than linear in shape. Overall, the Fenton Strip samples contain slightly more charcoal than the Mermentau Strip samples.

Pollen in the soil samples is deteriorated with percentages of indeterminable grains ranging from 10-20 and total concentrations from 20,000 to 80,000 grains per cubic centimeter (Fig. 26). Bryant and Hall (1993) establish a minimum acceptable sample quality of 50% indeterminable and 2,500 grains/cm³. The Cajun Prairie soil samples are well within their acceptable standards;
Figure 25. Cajun Prairie soil samples: loss on ignition and charcoal.
**Figure 26. Cajun Prairie soil samples: pollen.**
however, poor preservation made identification of Compositae below the family level impractical. Gramineae and undifferentiated Compositae dominate the pollen assemblage. *Pinus* is the only tree contributing a substantial percentage of pollen, with values up to 20%. The pollen assemblage accurately reflects the importance of Gramineae and Compositae in the vegetation of the remnant strips and of *Pinus* as a component of the regional vegetation. Chenopodiaceae-Amaranthaceae, common in midwestern pollen assemblages, is notably missing both from the pollen and from the vegetation survey. Non-arboreal pollen of upland herbs averages 65% of the pollen sum, arboreal pollen, 20%.

Samples from the Mermentau strip have slightly higher values for *Quercus*, reflecting their proximity to the Mermentau floodplain forest, and for Cyperaceae, related to the poorer drained soils. Additionally, the Mermentau samples have higher percentages of Compositae and lower percentages of Gramineae than the Fenton Strip samples. Of all the Cajun Prairie Compositae reported by Allen (personal communication, 1994), *Baccharis*, *Ambrosia*, and *Iva* are the only major pollen producers (Lewis et al., 1983). These three taxa are much more frequent in the Mermentau plots than in the Fenton plots, and this
accounts for the high levels of Compositae pollen in those soil samples.

Phytoliths are abundant in the Cajun Prairie soil samples with dumbbells clearly dominating the assemblage (Fig. 27). Dumbbell fragments are also numerous. Some dumbbell fragments closely resemble saddle shapes. Because of the potential for confusing these two, whole dumbbells and dumbbell fragments are considered separately, with greater credibility given to whole dumbbells. Rondels are present in all samples but are generally more important in the poorly drained Mermentau Strip than in the Fenton Strip. Crosses are distinctly more important in the Eunice restoration plot. Many of these are the large tabular type associated with corn which was probably cultivated there in the past. The presence of these phytoliths several years after cultivation demonstrates the potential of soil phytoliths for recording past vegetation.

Dumbbells outnumber rondels by at least two to one in 33 of the 45 samples (95% of the Fenton Strip and 47% of the Mermentau Strip samples). The average whole dumbbell to rondel ratio is highest in the Fenton Strip and lowest in the Mermentau Strip plots. This accurately reflects the difference in grass communities associated with each strip. Table 4 shows the genera identified in the Cajun Prairie Remnant Strips grouped into the two major
Figure 27. Cajun Prairie soil samples: phytoliths.
Table 4. Fenton and Mermentau grass types.

<table>
<thead>
<tr>
<th>Subfamily</th>
<th>Panicoid</th>
<th>Festucoid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genera Represented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Andropogon</td>
<td></td>
<td>Agrostis</td>
</tr>
<tr>
<td>Anthaenantia</td>
<td></td>
<td>Aristida</td>
</tr>
<tr>
<td>Bothriochloa</td>
<td></td>
<td>Briza</td>
</tr>
<tr>
<td>Digitaria</td>
<td></td>
<td>Eragrostis</td>
</tr>
<tr>
<td>Leptoloma</td>
<td></td>
<td>Gymnopogon</td>
</tr>
<tr>
<td>Manisuris</td>
<td></td>
<td>Hordeum</td>
</tr>
<tr>
<td>Panicum</td>
<td></td>
<td>Leersia</td>
</tr>
<tr>
<td>Paspalum</td>
<td></td>
<td>Muhlenbergia</td>
</tr>
<tr>
<td>Schizachyrium</td>
<td></td>
<td>Phalaris</td>
</tr>
<tr>
<td>Setaria</td>
<td></td>
<td>Sphenopholis</td>
</tr>
<tr>
<td>Sorghastrum</td>
<td></td>
<td>Sporobolus</td>
</tr>
<tr>
<td>Sorghum</td>
<td></td>
<td>Tridens</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vulpia</td>
</tr>
<tr>
<td>Total Presence</td>
<td>603</td>
<td>286</td>
</tr>
<tr>
<td>Fenton Strip</td>
<td>280</td>
<td>116</td>
</tr>
<tr>
<td>Mermentau Strip</td>
<td>323</td>
<td>170</td>
</tr>
<tr>
<td>Strip Difference</td>
<td>43</td>
<td>54</td>
</tr>
<tr>
<td>Difference/Total</td>
<td>7.1%</td>
<td>18.9%</td>
</tr>
</tbody>
</table>
subfamilies. Panicoid grasses usually produce dumbbell shaped phytoliths; Festucoid grasses, rondel. The Mermentau Strip has a greater abundance of Festucoid taxa than the Fenton Strip; in fact, *Eragrostis* and *Aristida* rank #1 and #2 in the Mermentau Strip presence data. The phytolith assemblage depicts this difference.

A summary diagram characterizes the Cajun Prairie soil samples (Fig. 28). Nonarboreal pollen typically exceeds arboreal pollen by at least two to one. The ratio of Gramineae to Compositae varies greatly around a median value of one to one. Within the vegetation itself a ratio of one to one is fairly stable. Dumbbell shaped phytoliths are usually at least twice as abundant as rondels, with the average ratio of the Fenton Strip twice that of the Mermentau Strip.

**Basile Lake Cores**

Cores from Fruge Lake and LeDoux Lake basically support the Cajun Prairie microfossil signature derived from soil samples (Figs. 29 and 30). *Pinus* comprises about 20% of the total pollen; however, *Quercus* pollen represents about 10% in the lakes as compared to 5% or less in the soil samples. Both farms have large oak trees planted near the house which probably contributed this pollen type. Grass pollen percentages are 5-10%, much lower than in the soil samples; and Compositae totals are
**Cajun Prairie Remnant Strip Soil Samples**

**Prairie Characterization**

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Pollen: Upland Herbs/Trees</th>
<th>Pollen: Gramineae/Composite</th>
<th>Vegetation: Gramineae/Composite</th>
<th>Phytophils: Dumbell/Rondon</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fenton N</td>
</tr>
<tr>
<td>2</td>
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<td>Fenton S</td>
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<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Woodlawn</td>
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<td>4</td>
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<td></td>
<td>Mermen.W</td>
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<td>5</td>
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<td></td>
<td></td>
<td>Mermen.E</td>
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<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Estherwd.</td>
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<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Eunice</td>
</tr>
</tbody>
</table>

Figure 28. Cajun Prairie soil samples: prairie characterization.
FRUGE LAKE, BASILE, LOUISIANA
Loss on Ignition, Pollen Percentages
Characteristic Ratios
Total Concentration

Figure 29. Fruge Lake: loss on ignition and pollen.
- = pollen sample; o = phytolith sample; a = dark gray stiff silt;
b = dark olive gray clayey silt; c = black soft silty clay, dense roots.
Figure 30. LeDoux Lake: loss on ignition and pollen. • = pollen sample; a = dark gray stiff clayey silt with some fine sand and mottles; b = transitional from a to c; c = very dark gray clayey silt with some small concretions and blocky structure; d = black soft silty clay.
20-30%, much higher than the soil samples. The ratio of upland herbs to trees averages one to one, tree pollen is more important in the lakes than in the Cajun Prairie soil samples. The Gramineae to Compositae ratio resembles that of the Mermentau Remnant Strip. Short spine Ambrosia type dominate the Compositae. Both lakes postdate settlement, therefore, their records cover the period in which agricultural crops replaced natural grasslands. The percentages of Ambrosia type pollen are consistent with those reported for the Ambrosia rise which marks European settlement in the United States (Webb, 1973). The 30 cm of soft upper sediments in each of these cores represents no more than the last 100 years of disturbed prairie. High organic content and significant percentages of aquatic pollen in Fruge Lake accurately reflect the abundance of vegetation in the shallow lake. Low values of aquatics in LeDoux Lake attest to the owner's avowed success with herbicides. A phytolith sample at 17 cm in Fruge Lake has a similar shape assemblage to that of the average Fenton and Mermentau Strip soil samples (Fig. 31).

Alternative Environments

Pollen and phytolith assemblages of miscellaneous wetland environments confirm the discriminating power of these microfossils (See Fig 31). The Cajun Prairie is high in Gramineae and Compositae, and in dumbbell shaped
**Figure 31. Cajun Prairie and selected wetlands: pollen and phytoliths.**

<table>
<thead>
<tr>
<th>Site</th>
<th>Total Nuts</th>
<th>Quercus</th>
<th>Gramineae</th>
<th>Compositae</th>
<th>Chenopods</th>
<th>Vigna</th>
<th>Sporobolus</th>
<th>Upland Herbs</th>
<th>Gramineae/Compositae</th>
<th>Cross Type</th>
<th>Whole Dumbell</th>
<th>Rondel</th>
<th>Saddle</th>
<th>Dumbell/Rondel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prairie</td>
<td>Fenton</td>
<td></td>
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<td></td>
<td>Mermentau</td>
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<td></td>
<td>Fruge</td>
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<tr>
<td></td>
<td>Grand Isle</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>LUMCON</td>
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<tr>
<td></td>
<td>Pearl</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Pascagoula</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>Shiloh</td>
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</tbody>
</table>

All Ratios x 100

5 6 0 1 0 0 0
phytoliths. Two saltmarsh samples, Grand Isle and LUMCON, have high Gramineae and Compositae but also have significant levels of Cheno-Ams, saddle shaped phytoliths, and many more rondels than dumbbells. The remaining wetland samples are ambiguous; however, each has some discriminating factor such as an indicator pollen type (Sagittaria or Vigna) or phytolith type (saddle or cross) not associated with either the prairie or the saltmarsh. The Pearl and Pascagoula samples are from intermediate marshes, and the Shiloh sample is from a freshwater, abandoned, mostly infilled oxbow dominated by Zizaniopsis milieaceae. These indicators provide clues for interpreting other microfossil assemblages.
PRIEN LAKE RESULTS

Stratigraphy

Of the four sites cored in Prien Lake, Site D yielded the longest, oldest, and best core for palynological analysis (See Table 2 and Fig. 22). Figure 32 shows the gross stratigraphy and loss on ignition results for all four Prien Lake sites. The first three cores have distinct sediment changes. The Site D core (PRD) is slightly silty clay throughout the core, suggesting that the depositional regime remained similar throughout the time period covered. Microfossil variation in PRD should be related to differences in environment, not to changes in sedimentary regime.

Sediments in the Prien Lake cores relate to water depth. Site A is 0.3m (1 ft.) deep, and core PRA is mostly peat. Sites B and C are 2.7 m (9 ft.) deep, and cores PRB and PRC have sandy segments. PRC also has Rangia shells. These two sites in the center of the lake have higher energy levels associated with shallow water and currents. Site D is in a 10 m (33 ft.) deep hole which has accumulated mostly clay throughout the last 4000 years.

A depth-age curve for each site indicates that the lowest sedimentation rate is at Site A (6.5 cm/100 years) associated with peat accumulation; the highest, at Site D (10.4 cm/100 years for the last 3000 years) (Fig. 33). The
Figure 32. Prien Lake cores: gross stratigraphy and loss on ignition.
Figure 33. Prien Lake cores: depth-age curves.
Site A sedimentation rate is lower than marsh accretion rates noted by Stevenson et al. (1985) but is consistent with rates observed at other coastal locations (Davis, 1992). The low rate could be due to an undetected hiatus in the core most likely associated with the abrupt peat to clay boundary at 15 cm. Sedimentation rates at Sites B, C, and D represent an average rate of 9-10 cm/century for Prien Lake (See Table 2). Accumulation rates of 10 cm/century (1 mm/yr) are common in Gulf of Mexico lagoonal/estuarine sites (Isphording, 1994). All further analysis concerns only the core from Site D.

The overall depth of PRD is 14.4 m (10 m water + 4.4 m sediment) below mean sea level. The sediments could not be penetrated below that point. The bottom 10 cm of PRD is a stiff dark gray clay (slightly lighter than the very dark gray clay above). Nearby soil borings associated with the Calcasieu Ship Channel north and west of the lake encountered a stiff silty clay between 14-17 m (45-55 ft.) (Louisiana Highway Department, 1959; Corps of Engineers, 1961). In most of these borings, the indurated sediments are overlain by sands which are in turn overlain by soft clays or organic muck.

Although PRD has relatively uniform grain size throughout, it has a distinct color change at 303 cm. The entire upper part of the core is black; the lower part,
very dark gray. Surface samples taken with an Eckman dredge smelled strongly of hydrogen sulfide, suggesting that the mud-water interface in this deep hole is anoxic. The black color of the sediments is characteristic of iron sulfide and indicates that these anoxic conditions have prevailed for the last 3000 years. The sediments from before 3000 B.P. are the same dark gray color observed in PRB and PRC in shallower water under oxic conditions. The lack of oxygen at PRD appears due to water depth alone, not to any significant stratification of the water column. Figure 34 shows temperature and salinity changes with water depth in August at Site D. Although the deeper water is cooler and slightly more saline, the observed differences are neither abrupt enough nor large enough to cause stratification.

Pollen

Core PRD contains pollen representing four ecological groups of plants. Woody plants are trees, shrubs, and vines that live for many years; herbaceous plants are annuals or perennials in which the entire plant, or its shoots, lives only one season (Raven et al, 1992). Because of this difference in longevity, woody taxa respond more slowly to environmental change than herbaceous taxa. "Upland Trees and Shrubs" separates the woody taxa characteristically associated with well-drained sites from
PRIEN LAKE, SITE D
Water Conditions
August 26, 1994

Figure 34. Prien Lake, Site D: temperature and salinity profile.
the "Wetland Trees and Shrubs" of waterlogged or riparian habitats. Some of the designated "Upland" taxa also inhabit poorly drained soils; for example, some pines are common in wet pine savannas (Louisiana Natural Heritage Program, 1988). The "Upland" category includes broadly tolerant, cosmopolitan species. Woody plants assigned to the "Wetland" category are obligate or facultative wetland taxa that are relatively unimportant except in poorly drained locations (Tiner, 1993). "Upland Herbs" likewise separates widespread herbaceous plants found primarily in well-drained sites from "Wetland Herbs" characteristic of waterlogged habitats.

The pollen diagrams for PRD contain five pollen zones delineated by examination of all pollen diagrams and supported by a stratigraphically constrained cluster analysis of the data based on percentages of major taxa (Fig. 35). The dendrogram generated by CONISS (constrained incremental sum of squares cluster analysis) within the Tilia program using the square root transformation option (Edwards and Cavalli-Sforza's chord distance) graphically shows the levels that are statistically similar. This option gives some weight to less common pollen types but not to a drastic degree (Grimm, 1987). It is the most effective type dissimilarity coefficient for pollen data (Overpeck et al, 1985). Pollen zone boundaries at 230 cm
Figure 35. Prien Lake, Core PRD: radiocarbon dates, sedimentation rate, pollen sum, dendrogram.

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and at 414 cm correspond to major cluster delineations. Zone boundaries at 95 cm, and 303 cm correspond to minor cluster delineations. Also included for reference in Figure 35 are radiocarbon dates, calculated sedimentation rates, and total pollen counted at each level.

**Pollen Percentages**

Figure 36 illustrates the pollen spectra of the major taxa. Major taxa are those with a maximum pollen percentage of at least 2% at some level and with a combined value of maximum percent plus mean percent across all levels that exceeds 4%. These parameters insure that taxa significant at any one level or present in reasonable amounts at many levels comprise the "major" assemblage. Within groups, the most important taxa, based on mean percent across all levels, come first. Where percentages are similar, taxa are in alphabetical order. Figure 37 contains all minor taxa.

Zone 1 includes the lowermost 4 samples in the core (415-437 cm, 4600-4450 B.P.). Herbaceous pollen dominates the assemblage with maximum zonal averages for Cyperaceae (25%), Gramineae (17%), Tubuliflorae (7%), and Pteridophytes (7%). Obligate wetland herbs such as *Nuphar*, *Nymphaea*, *Myriophyllum*, and *Decodon* are present although percentages are less than 2%. All tree taxa have minimal
Figure 36. Prien Lake, Core PRD: pollen percentage diagram of major taxa.
Figure 37. Prien Lake, Core PRD: pollen percentage diagram of minor taxa.
zonal averages in these samples; however, the whole Pinus low of 4% is the most obvious.

Zone 2 (414-303 cm) encompasses samples in the lower, oxic portion of the core dated from 4450-3000 B.P. Total concentrations average over 100,000 grains/cm³ in this zone. The single low concentration at 370 cm is anomalous. That sample is from an anoxic band in the core and resembles the upper 300 cm in total concentration. Pollen concentration seems directly linked to the environmental change associated with presence or absence of oxygen at the mud-water interface with more pollen deposited when oxygenated conditions prevail. Pinus fragments are important in this zone (8.5%), Cyperaceae is significant (14%) but no longer dominates. Typha and Sagittaria, marsh indicators, together average 5% of the total pollen. The major shift across the Zone 1-Zone 2 boundary is wetland herbs replaced by upland trees. In combination with the oxic regime, this likely represents a strong riverine contribution to the sediment. Grass pollen remains constant at about 15%.

In Zone 3, concentrations drop to a zonal average of 60,000 grains/cm³, typical of all the anoxic sediment samples. Zone 3 spans 303-230 cm (3000-2200 B.P.) Cyperaceae (14%) and Gramineae (16%) remain significant. Pinus fragments decrease. Overall, Zone 3 is a transition
zone characterized by a slow but steady rise in upland tree and shrub pollen offset by an erratic decrease in wetland pollen.

Cyperaceae pollen percentages decrease abruptly from Zone 3 to Zone 4 (230-95 cm, 2200-900 B.P.). Gramineae declines but still averages above 10%. Upland tree pollen percentages for Liquidambar, Carya, Myrica, Ostrya-Carpinus, and Ulmus rise. Total Pinus and Quercus reach their highest zonal average values in Zone 4 (19% and 16% respectively), with whole Pinus accounting for most of the pine pollen increase. Overall Zone 4 has the highest percentage averages for upland trees and shrubs (43%) and the lowest for herbaceous plants (20%), ferns (3%), and marsh plants (8%).

The uppermost pollen zone (95-0 cm, 900 B.P.-present) has significant levels of herbaceous pollen (average of 26%). Wetland herbs remain low, wetland trees and shrubs continue their remarkable stability. The shift in vegetation across the zone boundary is due to a tradeoff between upland trees and upland herbs, mainly an increase in grass pollen. Ambrosia type peaks at 20 cm which likely marks the settlement horizon. Despite extensive logging since that time, no decrease in arboreal pollen is detected.
Pollen Influx

Pollen influx shows the approximate rate at which pollen is deposited on the sediment surface. At Site D, this varies from a high of 11,300 grains/cm²/year to a low of 2,600 grains/cm²/year. Mean influx is 5,700 grains/cm²/year. Total pollen influx from other studies in similar regions ranges from 4,000 to 95,000 grains/cm²/year (Brugam, 1978; Jacobson and Bradshaw, 1981; Mathewes and D'Auria, 1982). Figure 38, the pollen influx diagram for PRD, supports the zonation of the percentage diagram and facilitates identification of the taxa actually responsible for observed percentage shifts.

Zone 1 is characterized by an accumulation rate for Cyperaceae typical of the lower 3 zones. Cyperaceae is no higher in this zone than in Zones 2 and 3, but trees are low. Not only upland trees like Pinus and Quercus but also wetland trees like Taxodium have minimal influx in Zone 1.

On the percentage diagram, Zone 2 has high values for broken pine pollen. The influx diagram confirms higher than usual inputs of Pinus fragments throughout this zone. Influx of Gramineae, Cyperaceae, Compositae, and Pteridophytes is slightly elevated in this oxic zone. These oxic sediments have the highest average zonal influx, 7,500 grains/cm²/year.
Figure 38. Prien Lake, Core PRD: pollen influx diagram.
The three upper zones have relatively stable influx of both upland and wetland trees and shrubs. Changing percentages are due to fluctuations in accumulation of herbaceous components. Zone 3, the lowest anoxic zone, abruptly loses the broken pine component across the oxic-anoxic boundary. Otherwise this zone is transitional in accumulation rates as in percentage shifts, with both herbaceous pollen groups declining throughout Zone 3. Zone 4 exhibits slightly lower influx rates for Gramineae and Cyperaceae and slightly higher rates for unbroken pine and Quercus. The combination of these opposite trends causes the more dramatic observed percentage shifts. In Zone 5, Gramineae and Compositae influx increases but Cyperaceae does not. The highest value in Zone 5 occurs at 20 cm and is likely associated with settlement. Land clearance increases erosion rates and contributes extra pollen grains from terrestrial soil and sediment (Brugam, 1978; Mathewes and D'Auria, 1982).

The most remarkable feature of the pollen influx diagram is the overall stability in arboreal taxa in Zones 2-5. With the exception of the increased Pinus fragments in Zone 2, trees have contributed approximately the same amount of pollen each year to the sediment. Cyperaceae became distinctly less abundant after 2200 B.P. Gramineae
has two peak periods, the highest in Zone 2 and a secondary maximum in Zone 5.

Pine Pollen

Pine is the most abundant tree pollen in core PRD averaging 16% of the total pollen. Figure 39 shows the distribution of measurements of overall pollen length for the 872 fully extended, unbroken, unobstructed, \textit{Pinus} grains encountered during pollen counting. Although the frequency distribution appears somewhat normal, a Kolmogorov-Smirnov Goodness of Fit Test fails to confirm that intuitive conclusion (See Appendix D). The large number of grains measuring 30 ocular units (75 \( \mu \)) is the basis for rejecting the normality of the observed frequency distribution. This suggests that the measured grains are from different but probably overlapping size distributions each associated with a different species of southern pine. Figure 40 presents the minimum, maximum, and mean overall pine measurements for each level in PRD. Great variation exists between levels. A Kruskal-Wallis one-way analysis of variance by ranks leads to rejection of the null hypothesis that all samples are from the same population (\( KW=243, \text{df}=45, \text{at } \alpha=.005 \text{ critical } KW=80 \)). Kruskal-Wallis is a nonparametric statistic appropriate in this case because some levels have extremely small samples (Siegel and Castellan, 1988).
Figure 39. Prien Lake, Core PRD: pine pollen measurement distribution.
Figure 40. Prien Lake, Core PRD: pine pollen summary diagram.
The only recognizable trend in the pine measurement data is that slightly higher than average pine pollen size characterizes Zone 5. Five species of *Pinus* are common in Louisiana: *P. echinata* (shortleaf pine), *P. taeda* (loblolly pine), *P. palustris* (longleaf pine), *P. elliotii* (slash pine), and *P. glabra* (spruce pine). Of these, *P. echinata* has the largest pollen; *P. glabra*, the smallest. A great deal of overlap exists between the species (Whitehead, 1964). Not enough is known about natural variation in size of southern pine pollen between species or under different environmental conditions or about preservation influences to draw any major conclusions from this data. Meaningful differentiation of southern pines awaits a more comprehensive study. The observed variation in pine pollen size in PRD indicates that different pine species possibly prevailed at different times but that the pine forest, as a whole, remained fairly stable throughout the last 4000 years.

Figure 40 includes a ratio of whole pine pollen to fragments which highlights the distinctiveness of Zone 2 and Zone 4. Zone 2 has the lowest ratio which confirms the importance of broken pine in the oxic sediment zone. Zone 4, in contrast, has the highest value indicating the significance of unbroken pine. The high ratio at level 413

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cm is associated with black clay immediately above the organic layer at 415-417 cm.

Charcoal and Opaque Spheres

Charcoal appears at every level sampled in core PRD; however, it is slightly more abundant in the lower part of the core (Fig. 41). The major difference noted in charcoal is in shape. The lower zones all have linear shaped charcoal while Zone 1 is dominated by chunky shaped charcoal (Fig. 42). Chunky charcoal also characterized the Cajun Prairie soil samples.

Opaque spheres are found mainly in Zones 3, 4, and 5, all associated with anoxic sediment. Clark and Patterson (1984) associate these 5-25 μ black spheres with industrial development. In Prien Lake, they are directly related to lack of oxygen at the mud-water interface. Anoxic bottom conditions resulting from eutrophication caused by pollution can perhaps explain the increased number of opaque spheres observed by Clark and Patterson (1984) in recent sediments.

Phytoliths

The phytolith assemblage of core PRD contains approximately equal percentages of dumbbells, rondels, and dumbbell fragments/saddles (Fig. 43). The latter two can be difficult to distinguish and are combined on the diagram. I counted most samples from core PRD before
Figure 41. Prien Lake, Core PRD: charcoal and opaque spheres.
Figure 42. Prien Lake, Core PRD: photograph of linear type charcoal.
Figure 43. Prien Lake, Core PRD: phytolith diagram.
counting the Cajun Prairie soil samples; however, I counted those from 100 to 170 cm afterwards. The abundance of dumbbells in the soil samples, both whole and broken, forced me to reevaluate criterion for identifying saddle shapes. Probably, saddle percentages never exceed 10% throughout the core, and the higher percentages are due to misidentification.

Although the percentages remain relatively stable throughout the period of record, the dumbbell to rondel ratio discloses a distinct difference in the upper meter. Cluster analysis based on the major shapes and exclusive of dumbbell fragments and saddles reveals statistical groupings which partially correspond to the pollen zones established previously.

In Pollen Zone 1, rondel and dumbbell percentages are highest with few broken dumbbells/saddles. Crosses also peak in this bottom segment of the core. Zones 2, 3, and the lower part of Zone 4 have virtually indistinguishable phytolith assemblages. The upper part of Zone 4 exhibits a slight increase in rondels resulting in low dumbbell to rondel ratios. The primary change in the phytolith diagram corresponds to the Zone 4-5 pollen boundary. In the upper meter of PRD, dumbbell percentages rise slightly; rondel percentages fall significantly. The dumbbell to rondel ratio in Zone 5 averages about 150 and comes closest to
the high values typical of the Cajun Prairie soil samples (See Fig. 27). In order to maintain correspondence with the diagrams, all ratios referred to in the text are expressed as the true value \( \times 100; \) for example, a ratio of 1:1 is written as 100.

Figure 44 summarizes information from both pollen and phytolith analysis of PRD using the same ratios previously calculated for the Cajun Prairie (See Fig. 28). With the exception of the upper meter, the dumbbell/rondel ratio averages 100, whereas the Prairie soil samples averaged 400. Gramineae to Compositae pollen ratios range from 84 to 360 with the lowest zonal average (134) associated with Zone 5. These values all fall within the range observed for the Prairie samples. The ratio of upland herbs to trees reaches its highest average (219) in Zone 1. It averages about 100 in Zones 2 and 3, reaches its lowest (50) in Zone 4, and rises to 80 in Zone 5. Only the values in Zone 1 approach the average ratio of 400 established for the soil samples. Also noteworthy is the change in charcoal abundance and type in Zone 5. Overall, the microfossil assemblage for the last 1000 years is clearly different from that of the preceding time period.

**Diatoms**

Diatoms identified in core PRD fall into several salinity classes and occupy different habitats. Salinity
Figure 44. Prien Lake, Core PRD: summary diagram of prairie characteristics.
classes range from fresh to brackish to marine with many identified taxa being euryhaline (tolerant of a wide range of salinities). Identified diatoms include epiphytic taxa living attached to other plants, epipelic, mostly motile, taxa living within or upon the upper sediments, and free floating planktonic species (Round, 1981). Appendix A lists identified diatoms by salinity preferences and habitats.

Cluster analysis of major taxa and subjective evaluation of the diatom assemblage for core PRD reveals four zones which correlate closely with those previously established for pollen and phytoliths (Fig. 45 and 46). As an aid to interpretation, diatom group assignments correspond to zone significance. For example, diatoms in Group AB reach their highest percentages in Zones A and B.

Diatom Zone A encompasses all samples from the lower oxic part of the core (pollen Zones 1 and 2). Diploneis spp. (D. elliptica, ovalis, smithii), Pinnularia spp., and Eunotia spp. together average 50% of the diatoms in this zone. The genera Eunotia and Pinnularia are almost exclusively associated with freshwater (Round and Sims 1980). Both are frequently found in acidic waters of swamps, bogs, and lakes. Eunotia characteristically is epiphytic, and Pinnularia is epipelic. Also reaching a maximum in Zone A are Epithemia, usually a freshwater
Figure 45. Prien Lake, Core PRD: diatom percentage diagram of major taxa.
Figure 46. Prien Lake, Core PRD: diatom percentage diagram of minor taxa.
epiphyte, and *Terpsinoë musica*, an epiphytic or epilithic (attached to rocks) species. *Terpsinoë* is most often found in running water and tolerates a wide range of salinities (Luttenton et al, 1986).

Several of the taxa important in the oxic sediments are also important in Zone B, which corresponds to the transitional pollen Zone 3. There is a marked decrease in *Eunotia* and *Epithemia*, but *Pinnularia* remains important and *Diploneis* spp. reach a maximum zonal average of 25%. This represents a loss of predominantly freshwater epiphytic taxa with continued importance of the brackish epipelic *Diploneis*. Also in Zone B, the first of several *Cyclotella meneghiniana* peaks occurs.

This *Cyclotella* is described as a freshwater planktonic species; paradoxically, it is also listed as halophilous (salt loving). A centric diatom, *C. meneghiniana* reaches its highest densities in water with a low salt content; in fact, an increase in salt concentration appears to induce sexual reproduction (auxospore formation) in this taxon (Schultz and Trainor, 1968). This species is known to contribute to diatom blooms occurring immediately upstream of the turbidity maximum in the tidal freshwater zone of estuaries (De Sève, 1993). *C. meneghiniana* is a superior competitor in silica limited environments and can be heterotrophic,
capable of using organic molecules for "food" during dark periods (Round, 1981). Evidence exists for polymorphism related to salinity with the C. meneghiniana pattern occurring at salinities less than 1.4 ppt and the C. cryptica pattern at salinities greater than 4.3 ppt (Schultz, 1971).

Diatom Zone C (2200-900 B.P.) contains three C. meneghiniana peaks as well as maximum percentages of Coscinodiscus type diatoms. These centric diatoms are primarily marine planktonic types. Also Actinoptychus undulatus is important in this zone. A. undulatus is a non-motile centric diatom which lives on the surface of marine sediments and is frequently suspended by currents into the water column. It is often, somewhat inaccurately, assigned to the plankton (Round, 1981). Both Diploneis spp. and Pinnularia decrease in Zone C. The three taxa that made up 50% of the diatom flora in Zone A, average only 30% in this zone.

The upper 90 cm of PRD has a slight resurgence of Diploneis spp., Eunotia, and Pinnularia. The original "Big Three" average a total of 40% in Zone D. Coscinodiscus type and Actinoptychus maintain significant percentages, and Nitzschia granulata and Navicula peregrina, marine and brackish taxa respectively, reach their highest levels.
Cyclotella is low in Zone D except for a single peak associated with the surface sample.

Figure 47 shows ecological group percentage changes in PRD. I included *C. meneghiniana* in the brackish rather than the freshwater sum. Brackish diatoms dominate the entire core attesting to the presence of estuarine conditions throughout the period of record. Zone A contains the highest proportion of freshwater epiphytic diatoms. Zone B appears transitional from fresh to brackish with the first peak in planktonic taxa. In Zone C, brackish diatom percentages increase slightly, and marine taxa for the first time become almost as important as freshwater taxa. Planktonic forms sporadically dominate the assemblage in this zone. Zone D has an increase in epipelic diatoms. Otherwise, Zone D and Zone C are very similar. The silhouette graph of planktonic diatom percentages, with its extreme peaks related to *Cyclotella* fluctuations, resembles the graph of the ratio of whole pine to broken pine pollen (See Fig. 40). However, a close examination of the samples shows that, of the five peaks in the pine ratio and the five peaks in planktonic diatoms, only two occur at the same level.
PRIEN LAKE, SITE D
Ecological Group Percentages

Figure 47. Prien Lake, Core PRD: diatom ecological group percentage diagram.

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LAKE ARTHUR RESULTS

Stratigraphy

A total of eleven cores from six different sites in Lake Arthur includes several cores deemed adequate for palynological analysis. Sites B and E have the longest cores, and cores LAB and LAF4 have the oldest basal dates (See Table 1 and Fig. 21). Figure 48 shows the gross stratigraphy and loss on ignition results for eight Lake Arthur cores; those not shown (LAD1, LAF2, and LAF5) are replicates. Water depths at the Lake Arthur sites are all relatively shallow, from 2.1 to 3.2 meters. No relation seems to exist between water depth or site location and sediment type.

Most Lake Arthur cores have a peaty section approximately 150-200 cm long which begins gradually sometime after 6000 B.P. but ends abruptly within 20-90 cm of the top of the core. The peat consists of partially decomposed fine plant remains dominated by narrow Gramineae/Cyperaceae type leaf blades and roots. Loss on ignition values between 20 and 60% correspond to those established by Kosters (1989) for salt marsh (5-35%) and freshwater emergent marsh (35-75%). The uppermost peat gives no indication of subaerial weathering. Radiocarbon dates from above this boundary in all cores are younger than 2350 B.P.; dates from below are all older than 3500
Figure 48. Lake Arthur cores: gross stratigraphy and loss on ignition. (fig. con'd.)
B.P. These two dates bracket a significant change in the depositional environment of Lake Arthur.

Sediments above the boundary consist of dark gray silty clay with some fine sand and occasional *Rangia* shells. *Rangia* is a brackish water clam adapted to high siltation and variable salinity common in estuaries (Day et al., 1989). Two sites, C and E, lack the peaty section completely and are entirely dark gray silty clay with intermittent layers of sand, clay, or organic debris. Core LAC contains a substantial debris layer which appears to represent the same depositional change noted in the peaty cores because the date not far below the debris layer is 3600 B.P. The only core which possibly spans the Lake Arthur environmental change is the core from Site E with its basal date of 3260 B.P.

A depth-age curve of dated core segments indicates a hiatus between 3500 B.P. and 2500 B.P. at sites C, B, and F (Fig. 49). Sedimentation rates prior to that time average about 9 cm per 100 years; after, 3-4 cm/100 years. Core LAE, with only the one basal date, stands out as being completely different from the other cores. Assuming the date is correct, the sedimentation rate at Site E is 15.7 cm per 100 years. Although higher than others in the Lake Arthur cores, this accumulation rate is not unusual in comparison to rates of other Gulf of Mexico
Figure 49. Lake Arthur cores: depth-age curves.
lagoonal/estuarine sites. Rates noted by other researchers range from 2.4 to 38 cm per century (Isphording, 1994).

Peat accumulates when a marsh is at or near sea level; therefore, radiocarbon dating of peat deposits gives an estimate of past relative sea level (Rampino and Sanders, 1981; Reed, 1990). Radiocarbon dates of Lake Arthur peat segments indicate that relative sea level was about 4.6 meters below the present level at 5000 B.P. and about 3.3 meters below by 3500 B.P. (Fig. 50). Since no allowances are made for compaction of sediments or regional subsidence, these represent the maximum difference from current relative sea level. An error of less than 0.5 meter is also possible in the calculations due to the assumption that water level when site water depth was measured equaled mean sea level (MSL). Tidal ranges are less than one foot for most of Louisiana (Chabreck and Condrey, 1979), so the error should be small.

Relative sea levels suggested by Lake Arthur dated peat segments agree with findings by Wanless and Parkinson (1989) in Florida and Penland (1990) in Louisiana that relative sea level stood about -6 meters at 5500 B.P. Wanless and Parkinson postulate a relative sea level rise of 23 cm/100 years from 5000 to 3000 B.P. resulting in a stand of -1 m by 3000 B.P. Penland presents evidence from
Figure 50. Lake Arthur cores: sea level and peat accumulation. Linear regression on these five dates yields the following equation:

\[ \text{Age} = -0.13 - 0.0009 \times \text{depth}. \quad R^2 \text{ is } 0.97. \]
Louisiana for a rapid 5-6 m rise to modern levels between 3000 and 4000 B.P. Also in Louisiana, Coleman and Smith (1964) postulate modern sea level by 4500, and Saucier (1963) and Autin et al. (1991) conclude that sea level was within one meter of its present stand by 5500 B.P. From beach ridge data in the Florida panhandle, Tanner (1991) infers that sea level has fluctuated 1-3 meters during the last 3000 years following a relative high 6000-5000 B.P. and a low around 3500 B.P. Li (1994) in the Pearl River marsh suggests a regression from 3000-2500 B.P. Clearly, there is no consensus concerning recent Holocene sea level history along the northern Gulf of Mexico coast.

The Lake Arthur dated peats indicate a constant accumulation rate of 9 cm/100 years presumably in response to relative sea level rise. This is slightly lower than the slowest marsh accretion rate (14 cm/100 years) noted by Stevenson et al. (1985). The apparently low rate of peat accumulation in Lake Arthur may be due to compaction of the organic matter over time or to low sediment input from the Mermentau River.

Relative sea level rise includes both eustatic changes and subsidence. National Ocean Survey tide gauges located at Grand Isle and at Eugene Island in the Mississippi River Delta Plain in southern Louisiana show historic relative sea level rise rates of 1.03 and 1.19
cm/year, respectively (Penland et al., 1987). In contrast, the Chenier Plain of southwestern Louisiana has rates similar to those of Galveston, TX (0.62 cm/year). Correcting for a Gulf of Mexico calculated sea level rise of 0.23 cm/year (Gornitz et al., 1982) yields a historical subsidence rate for southwestern Louisiana of about 0.4 cm/year or 40 cm of subsidence in the last century!

This modern rate greatly exceeds the postulated southwestern Louisiana relative sea level rise of 9 cm/100 years derived from dated Lake Arthur peats. In fact, if the calculated subsidence rate of 40 cm/100 years had been in effect for the last 6000 years, Lake Arthur would have experienced a relative sea level rise of 14 meters in the last 3500 years due to subsidence alone (Fig. 51). The historic Gulf of Mexico calculated eustatic sea level rise yields a similarly difficult curve to reconcile with the Lake Arthur data, with a projected sea level of 24 meters.

Obviously, modern relative sea level rise as determined from tide gauge data is much greater than rates which have operated over the past 6000 years. The historic data show that rates have more than doubled from 1940-1983 at most of the stations surveyed. The highest rates of subsidence along the northern Gulf Coast are in the Mississippi Deltaic Plain (Penland et al. 1987).
Figure 51. Lake Arthur cores, projected relative sea levels.
The 3500 B.P. peat segment in core LAB is less than 3.5 meters below the water surface clearly indicating that past relative sea level rise was lower than modern rates. A regression line fitted to the four dated peat segments and the sediment immediately below the peat in LAB has a coefficient of determination ($R^2$) of 97% and almost perfectly intersects the origin. If this line represents the relative sea level curve for Lake Arthur, the marsh should have kept pace with the rise of 9 cm/100 years.

The upper limit on relative sea level rise that marshes can cope with may be as high as 140-160 cm/century, and observed marsh accretion rates of 40 cm/century are common (Bricker-Urso et al., 1989). Other studies indicate that marsh accretion can keep up with a 10 cm, but not with an 18 cm/century rise (Rampino and Sanders, 1981). The postulated Lake Arthur relative sea level rise rate is within this more conservative range.

Several possible explanations for the hiatus in the Lake Arthur cores can be put forth. It may represent a sea level drop which exposed the peat to subaerial weathering followed sometime later by a rise, exceeding 9 cm/100 years, which overtopped the peat and eroded the weathered material. This scenario resembles conclusions by DePratter and Howard (1981) of a sea level of -1.5 to -2 meters by 3000 B.P., a drop to -3 to -4 meters sometime between 3000
and 2400 B.P., and a rise to modern levels by 2400 B.P. Li (1994) postulates a similar regression from 3000 to 2500 B.P. in coastal Louisiana/Mississippi, and this corresponds to the low proposed by Tanner around 3500 B.P.

Alternatively, the rapid rise proposed by Penland (1990) and Wanless and Parkinson (1989) might have exceeded the ability of the marsh to keep pace, thereby causing drowning and erosion. These sea level scenarios and the evidence from this study are addressed in the "Discussion and Conclusions" chapter.

Core LAB

The sediment core from Site B displays the typical abrupt change from silty clay to peat at 90 cm (See Fig. 48). The top low-organic 88 cm contains an upper clayey segment and a lower sandy segment. The fine sand is not in layers but is dispersed throughout this lower segment. The contact between the inorganic upper segment and the lower black peat is abrupt. The peat has visible roots and leaf blades which become less distinct downcore. At 200 cm the color of the peat lightens slightly due to the presence of yellowish roots and rhizomes, tentatively identified as Spartina alterniflora based on Niering et al. (1977). At 225 cm (4800 B.P.), the core changes from relatively pure black peat to alternating bands of peaty sediment and very dark gray clay. Below 260 cm, the banding continues but
involves very dark gray clay and dark gray clay. From 325 cm (about 6000 B.P.) to the bottom of the core, sand layers occur. There is a gap of approximately 30 cm in the core because of miscounting rods in the field. The core ends in sand which could not be penetrated farther. The overall depth of LAB is approximately 7.14 meters below mean sea level (2.4 m water + 4.74 m sediment).

A nearby soil boring conducted in relation to a proposed dredging project in Lake Arthur encountered coarse sandy sediment at 7.6 meters; however, the boring was farther from shore than Site B and contained silty clay with no peat above the sand. Of 13 borings taken in the proposed channel, only one near Site D contained a peat segment from 2.3-3.6 m (7.5-12 feet) below MSL. The peat in the boring was both overlain and underlain by silty clay (Corps of Engineers, 1977).

Core LAE

Core LAE is notably lacking any peat segment although it does contain a sandy segment from 60-80 cm which is at the same level as the peat-silty clay transition in other Lake Arthur cores. Layers (1mm-1cm thick) of organic debris or coarser inorganic sediment occur at intervals from 50-100 cm apart throughout the length of Core LAE. At the very bottom of the core, the sediment is distinctly stiffer and somewhat lighter in color. Although it appears
lighter, this basal clay is, in reality, dark gray in contrast to very dark gray or black sediment found in the rest of core LAE. A radiocarbon date on sediment from 520-535 cm in this core has an age of 3260 B.P. and probably represents the inception of Lake Arthur per se.

Pollen

Pollen diagrams for Lake Arthur cores display the same four ecological subdivisions used for Prien Lake Core PRD: upland trees, shrubs and woody vines; wetland trees and shrubs; upland herbs; and wetland herbs. Whereas upland trees dominate the pollen assemblage in Prien Lake, wetland taxa, in general, dominate Lake Arthur. As expected, Pinus is not nearly as important in Lake Arthur as in Prien Lake. Cores containing peat segments exhibit dramatic shifts in pollen percentages due to dominance by local marsh vegetation. Overall, Lake Arthur pollen diagrams have much greater variability than Prien Lake diagrams. Table 5 provides a summary of the individual core zones and facilitates comparison of the independently determined and numbered pollen/phytolith and diatom zones.

LAB Pollen Percentages

The LAB pollen diagrams contain four pollen zones based on visual inspection and supported by a stratigraphically constrained cluster analysis of the data based on percentages of major taxa as specified earlier.
Table 5. Lake Arthur cores: pollen zone comparison.

<table>
<thead>
<tr>
<th>LAKE ARTHUR CORE</th>
<th>LAB</th>
<th>LAF4</th>
<th>LAC</th>
<th>LAE</th>
</tr>
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<tbody>
<tr>
<td>Postsettlement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zone</td>
<td>4 (top)</td>
<td></td>
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<td>4</td>
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<tr>
<td>Total concentration</td>
<td>19,000</td>
<td>38,000</td>
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</tr>
<tr>
<td>Total influx</td>
<td>550</td>
<td>6,200</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Taxodium</td>
<td>30</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Gramineae</td>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Ambrosia/iva peak</td>
<td>16</td>
<td>13</td>
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<td></td>
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<td>3000-1000 B.P.</td>
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<tr>
<td>Zone</td>
<td>4 (bottom)</td>
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<td>2</td>
<td>3/2/1</td>
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<td>Total concentration</td>
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<td>55,000</td>
<td>84,000</td>
<td>78,000</td>
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<td>Total influx</td>
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<td>1,800</td>
<td></td>
<td>12,600</td>
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<td>% Taxodium</td>
<td>37</td>
<td>31</td>
<td>37</td>
<td>38/32/24</td>
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<tr>
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<td>6</td>
<td>8</td>
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</tr>
<tr>
<td>% Cyperaceae</td>
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<td>2</td>
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<td>5000-3000 B.P.</td>
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<tr>
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<td>140,000</td>
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<td>% Gramineae</td>
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<td>% Cyperaceae</td>
<td>50</td>
<td>42</td>
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<td>6000 to 5000 B.P.</td>
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<tr>
<td>Zone</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total concentration</td>
<td>39,000</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total influx</td>
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<tr>
<td>% Taxodium</td>
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<td></td>
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<tr>
<td>% Gramineae</td>
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<tr>
<td>% Cyperaceae</td>
<td>22</td>
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<tr>
<td>Before 6000 B.P.</td>
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<td></td>
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<tr>
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<tr>
<td>% Cyperaceae</td>
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<tr>
<td>% Indeterminable</td>
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<td>87</td>
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for Core PRD in Prien Lake (Fig. 52). Pollen zone boundaries at 88 cm (Zone 3-4) and at 309 cm (Zone 1-2) correspond to major cluster delineations as well as to major sedimentary boundaries (See Fig. 48). The boundary at 281 cm (Zone 2-3) defines a minor cluster. The lowest zone bridges the gap from 380-410 cm. Much of Zone 1 has low pollen counts due to low concentrations and poor preservation. Figure 52 also shows the location of the five radiocarbon dated segments, calculated sedimentation rates, and total pollen counted at each level. The sedimentation rate for the upper zone is about half that of the lower three zones.

Figure 53 shows the pollen percentages of major taxa; Figure 54, minor taxa. Zone 1 encompasses the lowermost relatively inorganic portion of the core mostly deposited before 6000 B.P. Pollen preservation is poor throughout this zone; for most samples, total pollen counted is less than 300 grains (See Fig. 52), and the percentage of indeterminable grains is high. Pollen concentrations are low throughout Zone 1 with an average of 8,660 grains/cm². Overall, upland herbs dominate the zone with Gramineae, Tubuliflorae, and Cheno-Am the main contributors. Tubuliflorae and Cheno-Am are robust pollen grains, easy to recognize in degraded forms, and their importance is likely due to differential preservation and identification.
LAKE ARTHUR, SITE B
Sedimentation Rate, Pollen Sum, Cluster Analysis

Figure 52. Lake Arthur, Core LAB: radiocarbon dates, sedimentation rate, pollen sum, dendrogram.
Figure 53. Lake Arthur, Core LAB: pollen percentage diagram of major taxa.
LAKE ARTHUR, SITE B
Pollen Percentages of Minor Taxa

Figure 54. Lake Arthur, Core LAB: pollen percentage diagram of minor taxa.
rather than to any significant shift in vegetation. Upland trees are almost as important in Zone 1 as they are in Zone 4 with a zonal average of 17%; *Quercus* contributes most toward the high percentage, but *Carya, Liquidambar, Myrica*, and *Vitis* all appear more important in Zone 1 than higher up in the core. *Taxodium* averages 9% making it the most significant wetland tree species. Low concentrations, deterioration, and the presence of sand and debris layers throughout Zone 1 indicate a higher energy environment at Site B in Lake Arthur prior to 6000 B.P.

Gramineae pollen peaks in Zone 2 (309-281 cm, 5800 to 5500 B.P.), with a zonal average of 50%. *Cyperaceae* increases to an average of 21%; *Ambrosia* type, *Tubuliflorae*, and Cheno-Am decrease from Zone 1 values but remain significant in Zone 2. Pollen preservation improves dramatically and concentrations rise to average 39,000 grains/cm³.

*Cyperaceae* is most important in the third pollen zone, averaging 50%. Gramineae remains important but drops to a zonal average of 22%. Zone 3 encompasses the peaty segment of core LAB, and pollen of local marsh taxa dominate the assemblage. Gramineae pollen, assigned to the upland herb group, probably represents mostly wetland grasses like *Spartina* in this zone. Forams (microforaminiferal inner tests) and dinoflagellates peak
in Zone 2 and the lower part of Zone 3. They are both associated with brackish to salt water (Traverse, 1988). In the upper part of Zone 3 at approximately 3500 B.P., Cyperaceae drops abruptly while Gramineae, *Typha* and *Sagittaria* increase. *Typha* and *Sagittaria* are associated with fresh to intermediate marsh (Chabreck and Condrey, 1979; Tiner, 1993). Although highly variable, pollen concentration is high in Zone 3 with an average of 79,000 grains/cm³, consistent with concentrations observed in other marsh studies (Clark and Patterson, 1985; Chmura, 1990; Li, 1994).

*Taxodium* is the most significant taxa in Zone 4, averaging 34%. Other wetland trees, *Fraxinus* and *Nyssa*, also have their highest percentages in this uppermost inorganic part of the core. Indeterminable grains increase indicating either degradation of pollen by transport or introduction of reworked pollen. Pollen percentages throughout Zone 4 characterize the modern, estuarine, sedimentary regime in Lake Arthur and point to its establishment around 3000 B.P.

The top 4 samples in core LAB probably represent postsettlement conditions. *Taxodium* and *Pinus* drop while *Ambrosia* Type, *Tubuliflorae*, and Indeterminable rise. Logging and land clearance increase erosion and surface runoff. This initially causes a spike in pollen concentration.
concentration, but sustained high sedimentation rates eventually result in low pollen concentrations as observed in the upper samples. In Zone 4, concentrations below 30 cm average 65,000 grains/cm³; above, 19,000. The projected date of 1000 B.P. for the start of this phenomenon is too old because it is based on linear interpolation between dates and assumes constant sedimentation rates between them.

**LAB Pollen Influx**

Pollen influx at Lake Arthur Site B varies from 16,400 down to 200 grains/cm²/year (Fig. 55). Zone 1 and the upper portion of Zone 4 have the lowest accumulation rates. The highest rates characterize Zone 3 where local taxa dominate the assemblage. For all zones, the influx diagram supports observations noted for the percentage diagram.

In Zone 3, Typha reaches a maximum at 127 cm (3800 B.P.). Of the total Typha pollen percentage at this level, 2.4% is the tetrad type characteristic of Typha latifolia and 22% is the monad type characteristic of Typha domingensis and T. angustifolia. Typha latifolia and T. domingensis are common species in fresh and intermediate marshes in Louisiana with T. domingensis better able to withstand stress associated with saline and/or deep water (Chabreck and Condrey, 1979; Grace, 1989). The observed
Figure 55. Lake Arthur, Core LAB: pollen influx diagram.
high accumulation rate is probably due to the local presence of this prolific pollen producer.

LAF Pollen Percentages and Influx

The two cores from Site F analyzed for pollen basically support information already noted for core LAB (Figs. 56 and 57). Like LAB, both Site F cores have the abrupt peat-silty clay transition characterized by high Taxodium percentages and low pollen concentrations in the relatively inorganic sediment above the boundary. High Gramineae/Cyperaceae percentages and pollen concentrations typify the peat below the boundary. Typha is highest in both cores in the uppermost peat.

LAF1 and LAF4 contain higher percentages of Pteridophytes (fern spores) than any other Lake Arthur cores. The peak in Pteridophytes at 80 cm (4200 B.P.) in LAF4 is primarily due to a monolete type spore. Although most wetland ferns grow in tidal fresh marshes and swamps, Thelypteris palustris, which has a monolete spore, also inhabits the upper edges of brackish marshes (Tiner, 1993). Chmura (1990) found the highest percentages of fern spores in fresh marsh samples. Site F is farther upstream in Lake Arthur than any other site and is, therefore, closest to freshwater input from the Mermentau River.

LAF4's Zone 1 (older than 6000 B.P.) contains distinctly different sediment from the basal material in
Figure 56. Lake Arthur, Core LAF1: pollen percentage diagram of major taxa.
Figure 57. Lake Arthur, Core LAF4: pollen percentage diagram of major taxa.
other cores. Unfortunately, pollen preservation is
extremely poor in this stiff gray clay and the few grains
counted are almost all indeterminable.

Zone 2 in LAF4 is a peaty clay which spans 6000 to
5500 B.P. and has Taxodium percentages typical of the
upper zones of all Lake Arthur cores. It also has
substantial percentages of Gramineae and Compositae.
Pteridophytes comprise 30% of the pollen in the upper
sample in Zone 2.

Zone 3 in LAF4 is similar to Zone 3 in LAB with
Cyperaceae percentages increasing rapidly after 5500 B.P.
The peak total pollen concentration of 270,000 grains/cm³
corresponds to the Cyperaceae peak of 80% at level 140 cm
(5200 B.P.). Following the Cyperaceae peak, Pteridophytes
and Gramineae assume dominance in the upper part of Zone
3.

The pollen influx diagram for LAF4 (Fig. 58) shows
the high accumulation rates associated with local marsh
pollen deposition in Zone 3. Influx rates for Zone 4
correspond to those noted in the upper portion of LAB. In
Zone 2 the high percentage of Taxodium at 220 cm has an
influx of 8,000 grains/cm²/year which exceeds influx in
the upper part of the core.
Figure 58. Lake Arthur, Core LAR4: Pollen influx diagram.
LAC Pollen Percentages

An early pollen count on the core from Site C provides some supporting evidence for the changes observed in Cores LAB and LAF (Fig. 59). The two delineated pollen zones correspond to Zones 3 and 4 of LAB and LAF4 (See Table 5). Samples in Zone 1, below the 3600 B.P. radiocarbon date, have percentages of Gramineae (19%) close to the Zone 3 average for core LAB. In contrast, percentages of Cyperaceae are low throughout core LAC, and Cheno-Ams are more important than in core LAB. Core LAC, lacking a peat segment, is dominated by fluvially/tidally transported pollen rather than by directly deposited marsh pollen.

Taxodium dominates Zone 2 with values averaging 37%, identical to the average for Zone 4 in core LAB; below the Zone 1-2 boundary Taxodium constitutes 12% of the assemblage confirming the importance of streamborne pollen at Site C. Total pollen concentrations in Zone 1 average about 52,000 grains/cm$^3$; in Zone 2, 84,000 grains/cm$^3$.

Forams are most abundant in the sample below the 3600 B.P. date.

LAE Pollen Percentages

The core from Site E, which lacks a peat section and has only one basal radiocarbon date, has four pollen zones based on relatively minor fluctuations in pollen
Figure 5.9. Lake Arthur, Core LAC: pollen percentage diagram of major taxa.

LAKE ARTHUR, SITE C
Pollen Percentages of Major Taxa

Upland Trees, Shrubs
Wetland Trees, Shrubs
Wetland Herbs
Upland Herbs
Total Pollen
Total Concentration

Zone 1
Zone 2
percentages as opposed to the major fluctuations observed in other cores (Figs. 60, 61, and 62). Taxodium dominates the entire core with values ranging from 19 to 48%. These percentages are only reached in the upper relatively inorganic segments of the other Lake Arthur cores, suggesting that the basal date of 3260 B.P. is indeed an accurate one. The higher sedimentation rate may be due to clay flocculation and settling as freshwater from the Mermentau River mixes with more saline water in the Lake Arthur estuary. Flocculation commonly occurs at salinities of 0 to 5 ppt (Day et al., 1989).

Total pollen concentrations in Core LAE average from 78,000 to 103,000 grains/cm$^3$ in the lower three zones and 38,000 in the uppermost zone. These averages are almost all higher than those of corresponding zones in other Lake Arthur cores (See Table 5). Site E appears to be an area of sediment and pollen focusing. For concentrations to be high, high sedimentation rates must be offset by high pollen accumulation rates. Total pollen influx ranges from 12,600-16,600 grains/cm$^2$/yr in the three lower zones to 6,200 grains/cm$^2$/yr in the upper zone. In comparison, influx is much lower in the inorganic portions of all other Lake Arthur cores.

Zone 1 (3300-2600 B.P.) in LAE has the highest percentages of Cyperaceae for the entire core; however,
Figure 60. Lake Arthur, Core LAE: radiocarbon date, sedimentation rate, pollen sum, dendrogram.
Figure 61. Lake Arthur, Core LAE: pollen percentage diagram of major taxa.
Figure 62. Lake Arthur, Core LAB: pollen percentage diagram of minor taxa.
the zonal average is only 11%. This low value is consistent with zonal averages in other cores. Taxodium (24%) and Gramineae (15%) are the other important taxa in this zone. LAE's Zone 1 appears to be transitional from values found in core LAC for 5000-3000 B.P. to those typical of 3000-1000 B.P. Pinus, Myrica, and Cheno-Am have slightly higher percentages in Zone 1.

In Zone 2 (2600-1200 B.P.), Cyperaceae decreases slightly, Gramineae continues to be important, and Taxodium percentages exhibit a slow upward trend. Total pollen concentrations are highest in Zone 2.

LAE's Zone 3, from 1200 to 400 B.P., has the highest zonal average for Taxodium (38%). This exactly matches the zonal average Taxodium percentage in the lower part of LAB's Zone 4 and probably represents the presettlement Taxodium pollen contribution to Lake Arthur. Gramineae decreases slowly throughout this zone and Indeterminables increase. Total Pinus peaks at the top of Zone 3 in conjunction with a peak in Taxodium. This may signify intensive logging and land clearance with additional pollen grains added to the system by increased surface runoff. Total concentration decreases throughout Zone 3.

The upper pollen zone in core LAE has an Ambrosia Type peak as well as the lowest overall pollen concentrations in the core. Taxodium bottoms out at 19%
then recovers to modern levels of 35% typical of surface samples at most Lake Arthur coring sites. In comparison with other Lake Arthur cores, LAE appears to have greater resolution for the past 3000 years.

**LAE Pollen Influx**

The pollen influx diagram for Site E emphasizes the change in pollen accumulation over time (Fig. 63). Gramineae pollen influx is higher in Zones 1 and 2; Cyperaceae and *Typha* follow that same trend suggesting extensive marsh vegetation on the Mermentau floodplain surrounding an expanding Lake Arthur. *Taxodium* swells to a maximum between 2000 and 1000 B.P. Since 1000 B.P. *Taxodium* has declined except for the spike just below the Zone 3-4 boundary probably associated with settlement. In confirmation, *Ambrosia* Type peaks immediately following the *Taxodium* spike. *Taxodium* plunges to an all time low influx in Zone 4, and all upland trees have minimal accumulation rates.

For the last 3000 years pollen of wetland taxa has dominated in Lake Arthur sediments. The Gramineae influx curve follows the Cyperaceae and *Typha* curves strongly suggesting that Gramineae pollen is coming from the marsh rather than from the prairie.
Figure 63. Lake Arthur, Core LAE: pollen influx diagram.
Charcoal and Opaque Spheres

Charcoal appears in every pollen sample in all Lake Arthur cores. Figures 64 and 65 show the relative abundance and shape of charcoal in LAB and LAE. Chunky shaped charcoal is present throughout both cores. Linear shaped charcoal is present in peat segments and in zones with substantial percentages of Cyperaceae pollen but is absent in the uppermost zones. It appears related to a marsh environment. This same absence of linear shaped charcoal occurs in the top zone of Prien Lake Core PRD (See Fig. 41). Charcoal abundance is lowest in Zone 4, the postsettlement zone, of both Lake Arthur cores. This is likely due to historical fire suppression.

Opaque spheres are low in both Lake Arthur cores. They are slightly more abundant in Zone 1 of Core LAB, but never reach the sustained levels observed in the anoxic segment of PRD.

Phytoliths

Like the pollen diagram for LAB, the phytolith diagram exhibits great variability directly related to changes in sediment type (Fig. 66 and see Fig. 48a). Whereas almost equal percentages of dumbbells, rondels, saddles, and dumbbell fragments typify the inorganic sediments; rondel shaped phytoliths alone dominate the peat segment (pollen Zone 3) resulting in an extremely low
LAKE ARTHUR, SITE B
Charcoal Data

Figure 64. Lake Arthur, Core LAB: charcoal and opaque spheres.
LAKE ARTHUR, SITE E
Charcoal Data

Figure 65. Lake Arthur, Core LAE: charcoal and opaque spheres.
LAKE ARTHUR, SITE B
Phytolith Percentages

Figure 66. Lake Arthur, Core LAB: phytolith diagram.
dumbbell to rondel ratio. Ratios are expressed as the true value \times 100 (1:1 or 1 is written as 100). Cluster analysis based on the major shapes and excluding the easily confused dumbbell fragments and saddles reveals statistical groupings which closely match the previously established pollen zones.

In Pollen Zone 1, dumbbell percentages are highest with a zonal average of 33%. Rondel percentages are low leading to a relatively high dumbbell/rondel ratio averaging 184 throughout Zone 1. In Zone 2, the sediment changes to peat, and the phytolith assemblage shifts abruptly to rondel dominated and remains so in Zone 3. Such overwhelmingly high rondel percentages characterize the salt-intermediate marsh samples depicted in Figure 31. Rondel type phytoliths have a zonal average of 74% in Zone 3 and the dumbbell:rondel ratio averages only 20.

In Zone 4, rondel percentages decline, and the overall phytolith assemblage resembles that of Zone 1 but has slightly higher percentages of cross types and saddles. The dumbbell/rondel ratio averages 119. Samples from Zone 4 had low phytolith concentrations and sums counted ranged from 42 to 145. This suggests a high input of clastic sediment essentially diluting the biogenic silica contribution.
Figure 67 summarizes information from both pollen and phytolith analysis of Core LAB using the same ratios previously calculated for Core PRD in Prien Lake (See Fig. 44) and for the Cajun Prairie (See Fig. 28). Gramineae pollen constitutes a substantial part of the pollen assemblage with the highest percentages and the highest influx values associated with pollen Zones 2 and 3. In these zones, Gramineae values match those established for the Cajun Prairie soil samples.

Although the pollen percentages in Zones 2 and 3 resemble prairie values, phytolith assemblages and other ratios do not. Zones 2 and 3 have lower dumbbell/rondel ratios than observed in any Cajun Prairie samples implying that the source of grass pollen is not prairie taxa. In Zone 1 the dumbbell/rondel ratio averages 170; in Zone 4, 119. Although higher than in Zones 2 and 3, these values are still far from the Prairie soil sample average ratio of 400; however, they do resemble the values for Zone 5 in Core PRD.

In core LAB, pollen Zones 2 and 3 have average Gramineae:Compositae values of 1000 and 600 respectively indicating that grasses dominate the vegetation to a greater extent than observed in the Cajun prairie. Overall, Gramineae to Compositae pollen ratios range from a low of 28 in Zone 4 to a spurious high of infinity at
Figure 67. Lake Arthur, Core LAB: summary diagram of prairie characteristics.
level 372 cm in Zone 1. At this level, less than 20 grains of pollen were counted due to extremely poor pollen preservation in the sandy sample, and total Compositae equals zero. The ratio of Gramineae to Compositae for Prairie soil samples also varies widely but rarely exceeds 300.

The ratio of upland herbs to trees reaches its highest averages in Zones 2 and 3. Although the observed values of 840 and 380 in those zones equal or exceed the average ratio of 400 established for the soil samples, the grass pollen included in the "Upland Herb" category is likely a wetland species. The Upland Herb:Upland Tree average ratio for Zones 1 and 4 (182 and 90) corresponds to the ratios established for the uppermost zone of the Prien Lake core.

Charcoal abundance is lower in the uppermost zone of Core LAB than it is in the uppermost zone of PRD. However, the same absence of linear shaped charcoal in the upper zone occurs at both sites.

The pollen, phytolith, and charcoal assemblage for the last 3000 years in Lake Arthur is clearly different from that of the time period from 6000 to 3000 B.P. Unfortunately, local marsh vegetation dominates the Lake Arthur record between 6000 and 3000 B.P., and the
microfossil record prior to 6000 B.P. is poorly preserved and unreliable.

Diatoms

Diatoms identified in Lake Arthur cores fall into the same salinity and habitat classes as delineated for Core PRD. As in Prien Lake, many diatoms are broadly tolerant species. Cluster analysis of major taxa and subjective evaluation of the diatom assemblage for core LAB reveals four diatom zones, which partially correspond to previously established pollen and phytolith zones (Figs. 68 and 69). On these diagrams, diatom group assignments correspond to zone significance. Figure 70 shows percentages for salinity and ecological groups. See Appendix B for individual diatom salinity and habitat classifications.

Diatom Zone A encompasses the lower inorganic part of the core and overlaps pollen Zones 1 and 2. Cyclotella meneghiniana, Coscinodiscus type, Actinoptychus undulatus, and Diploneis spp. (D. elliptica, ovalis, smithii) dominate the diatom assemblage. These are primarily brackish to marine types, and all but Diploneis are planktonic. The Zone A-B boundary at 292 cm corresponds to the change from inorganic sediments to banded organic sediments which are transitional between the lower clay and the pure peat segments of LAB.
Figure 68. Lake Arthur, Core LAB: diatom percentage diagram of major taxa.
Figure 69. Lake Arthur, Core LAB: diatom percentage diagram of minor taxa.
LAKE ARTHUR, SITE B
Ecological Group Percentages

Figure 70. Lake Arthur, Core LAB: diatom ecological group percentage diagram.
In Zone B, 292-226 cm, Diploneis species increase in importance and Achnanthes, Actinocyclus, and Campylodiscus echeneis join the major diatom flora. Achnanthes temperei, the predominant species identified, lives in the extreme upper to middle tidal portions of coastal rivers (Patrick and Reimer, 1966). Campylodiscus echeneis is a fresh to brackish epipelic species (Van Heurck, 1896). In general, planktonic forms decrease and epiphytic forms increase in this zone.

With the sedimentary change to pure peat in Zone C, marine and planktonic diatoms decrease abruptly and fresh-brackish water diatoms, Pinnularia and Nitzschia scalaris become significant in the assemblage. Pinnularia is an epipelic freshwater genus (Round et al., 1990). Vos and de Wolf (1993a) describe N. scalaris as a marine-brackish, epipelic, eutrophic species. In this zone, diatoms living in and on the sediments (epipelic) are more common than species living in the water column (planktonic). This change is consistent with a marsh environment. At the top of Zone C, Eunotia replaces Nitzschia scalaris leading to a peak in freshwater taxa percentages.

Zone D encompasses the uppermost silty clay sediments and contains a diatom flora composed primarily of fresh-brackish and epiphytic diatoms. Terpsinoë musica (35%) and Campylodiscus echeneis (16%) dominate the assemblage, with
Eunotia and Pinnularia also important. In the uppermost sample, Group A diatoms, marine and planktonic, make a reappearance suggesting current conditions in Lake Arthur are favorable for these taxa. A similar resurgence of planktonic taxa occurs in the Prien Lake core. These "marine" incursions are probably related to high modern relative sea level rise as well as to the construction of navigation channels which facilitate penetration of Gulf waters.

The sample at level 40 cm contains very few diatoms. As noted in the phytolith results, samples at levels 20, 40, and 60 cm have low biogenic silica concentrations. At 40 cm phytoliths are present, but diatoms are not. This crash in the diatom flora of Lake Arthur may relate to maximum pollution of the lake with agricultural chemicals.

Overall, brackish diatoms dominate Core LAB indicating estuarine conditions in Lake Arthur for at least the past 6000 years. Zones A and B contain the most marine taxa, and Zone C contains the most freshwater taxa. Despite the high freshwater diatom component in Zone C (peat segment), brackish taxa still dominate the diatom flora. This implies that the peat formed in an upper tidal marsh. Epiphytic species are most common in Zone D.
DISCUSSION AND CONCLUSIONS

Cajun Prairie

Combined pollen and phytolith data from Lake Arthur and Prien Lake cores suggest that the Southwestern Louisiana Prairie has remained relatively stable over the last 6000 years (Table 6). Although significant fluctuations in Gramineae pollen percentages occur in the Lake Arthur cores, the phytolith dumbbell/rondel ratio shows that local marsh grasses rather than prairie grasses are the pollen source in the Gramineae dominated zones (See Fig. 67). Surprisingly, in the upper zones representing the last 1000 years, Gramineae pollen percentages in Core PRD are higher than those in the Lake Arthur cores (See Fig. 36); however, this is primarily the result of high levels of Taxodium in Lake Arthur which depress the Gramineae percentages (See Figs. 53 and 61). Gramineae influx in these upper zones ranges from 500-1000 grains/cm²/year in Core PRD (See Fig. 38), from 33-192 in LAB (See Fig. 55) and from 372-15,450 in LAE (See Fig. 63). Lake Arthur receives as much grass pollen as Prien Lake. Low postsettlement pollen influx for Lake Arthur is the result of high sedimentation rates associated with intensive rice agriculture.

Zone 1 in Core LAB precedes marsh dominance (See Fig. 53). In this zone, pollen percentages resemble those

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<td>95/96</td>
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<tr>
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<td>3/3</td>
<td>1</td>
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<tr>
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<td>5</td>
<td>4</td>
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<td>% Upland trees</td>
<td>43/27</td>
<td>19</td>
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<td>% Taxodium</td>
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<td>37</td>
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<tr>
<td>% Fresh diatoms</td>
<td>19/23</td>
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<td>14</td>
<td>4</td>
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<td><strong>5000-3000 B.P.</strong></td>
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<td>2 - A</td>
<td>3-C</td>
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<tr>
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<tr>
<td>Total influx</td>
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<td>6800</td>
<td>12,000</td>
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<tr>
<td>% Gramineae</td>
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<td>20</td>
<td>11</td>
<td>19</td>
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<td>42</td>
<td>3</td>
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<tr>
<td>% Upland trees</td>
<td>29</td>
<td>8</td>
<td>5</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>% Taxodium</td>
<td>8</td>
<td>2</td>
<td>3</td>
<td>12</td>
<td></td>
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<tr>
<td>% Fresh diatoms</td>
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<td></td>
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<tr>
<td>% Marine diatoms</td>
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(table con'd.)
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<th>LAB</th>
<th>LAF4</th>
<th>LAC</th>
<th>LAE</th>
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<td>% Cyperaceae</td>
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<td>22</td>
<td>3</td>
<td></td>
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<tr>
<td>% Upland trees</td>
<td>15</td>
<td>7</td>
<td>9</td>
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<tr>
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<td><strong>Before 6000 B.P.</strong></td>
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<tr>
<td>% Upland trees</td>
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<td>% Fresh diatoms</td>
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<td>% Marine diatoms</td>
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<tr>
<td>% Indeterminable</td>
<td>20</td>
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<td>87</td>
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observed in the upper Zone 4 with the exception of significantly lower percentages for Wetland Trees (primarily the relatively fragile *Taxodium*) and higher percentages for robust Cheno-Ams and for Indeterminables. This pollen assemblage predates 6000 B.P. Low pollen concentrations, low pollen influx, poor preservation, and multiple sand layers suggest an environment where either river currents or wave base provided energy to winnow the sediments and to degrade pollen. Pollen sums in most of Zone 1 are less than 100; therefore, the pollen assemblage is not as reliable as in the upper zones. Despite low pollen sums and preferential preservation/identification of robust grains, the Zone 1 pollen assemblage does not suggest drastically different vegetation from that of Zone 4. This implies that the Southwestern Louisiana Prairie was present 6000 years ago and covered roughly the same area.

Has the prairie expanded into the Prien Lake watershed? Overall Gramineae statistics for Core PRD are as follows: mean, 13.6%; minimum, 6.7%; maximum, 22.1%; standard deviation, 3.4%. Not enough variation exists to infer significant encroachment by grasses into the pine-oak dominated woodlands; however, minor increases in Gramineae and Compositae and a decrease in Upland Trees occur in Zone 5 (900 B.P. to present) (See Fig. 36). The
dumbbell/rondel ratio also peaks in Zone 5 suggesting a "prairie" pollen source (See Fig. 43). Although the change is minor, it lends some support to slightly more xeric conditions proposed by Toomey et al. (1993) for the last 1000 years in Texas.

Have trees expanded into southwestern Louisiana's grassland? Has the grassland island contracted? Pollen Zone 4 in Core PRD has somewhat lower Gramineae values and higher percentages of upland tree species, mainly pine and oak, implying that the grassland retreated slightly between 2000 and 1000 B.P. (See Fig. 36). The timing corresponds to the absence of bison on the Texas coastal plain noted by Aten (1983).

This slight expansion of arboreal taxa occurs during the same period that paleoecological sites in Texas and Oklahoma seem to have experienced higher effective moisture (Hall, 1982; Hall and Lintz, 1984; Toomey et al., 1993). However, Nordt et al. (1994) infer drier/warmer conditions at 2000 B.P. based on an expansion of C₄ grasses. Both Whitehead and Sheehan (1985) in eastern Mississippi and Albert and Wyckoff (1981) in Oklahoma detect a slight rise in Pinus pollen around 2000 B.P. suggesting that the observed increase in Pinus is regional and that it occurred on both sides of the prairie-forest ecotone. In humid areas, pines are noted for their
occupation of sandy droughty soils; in arid areas, pines are indicative of greater effective moisture. This mixed signal probably represents a non-moisture factor, such as fire, which gave pines a competitive advantage.

Charcoal data indicate that fire has always been a factor in both the Prien Lake and the Lake Arthur watersheds (See Figs. 41, 64, and 65). There is no increase in charcoal associated with the observed increase in Pinus pollen; therefore, pine expansion due to increased fire frequency cannot be substantiated. Chunky type charcoal typical of the Cajun Prairie is present throughout all cores. Linear type charcoal is strikingly absent in the uppermost zones implying that fire suppression or perhaps simply loss of local wetland habitats occurred in the last 1000 years.

Was upland tree expansion in the Prien Lake watershed from 2000 to 1000 B.P. accompanied by a similar expansion in the Lake Arthur watershed during that time? Core LAE provides the best resolution during this period and shows a concurrent decrease rather than an increase in Upland Tree pollen percentages (See Fig. 61). Core LAE Upland Tree pollen influx for Zones 1, 2, 3, and 4 is 12,450; 15,450; 14,820; and 7000, respectively. Influx does show some increase in upland tree taxa in pollen Zone 2; however, similar values for all the lower zones imply that
any expansion of trees in the Lake Arthur watershed was minimal. The apparent drop in Upland Tree pollen percentages in Zone 2 is caused by high levels of Gramineae and Cyperaceae related to nearby marsh vegetation. Exclusion of all wetland taxa from the pollen sum yields a pollen diagram which still fails to show any increase in Upland Tree pollen in Core LAE between 2000-1000 B.P. Although the increase in Upland Trees noted in Core PRD hints at the possibility of wetter conditions from 2000-1000 B.P., total lack of support from the Lake Arthur cores suggests that the change is minor.

Unfortunately, the cores do not go back far enough in time to address some of the posed research questions. Insufficient data exist to draw any conclusions concerning Hypsithermal conditions. Pinus pollen maintains a relatively steady percentage throughout the time period spanned by these cores; therefore, no evidence exists for a clearcut rise in pine during the last 6000 years. Pinus has been an important component of the vegetation of Southwestern Louisiana for the entire period of record.

The overall stability of the Cajun Prairie vegetation for the past 6000 years is consistent with paleoecological data for the southeastern U.S. (See Fig. 17) as well as for the midwestern prairie-forest ecotone (Baker and Waln, 1985). Is an edaphically controlled grassland responsive
to climate change? No major climate change is suggested by any southeastern paleoecological site for the past 6000 years; therefore, the lack of detectable vegetation change in the Cajun Prairie cannot be taken as a lack of sensitivity.

Human impact on the Cajun Prairie follows expected patterns with the settlement horizon samples exhibiting the highest percentages of Ambrosia type pollen. Despite known heavy logging in both watersheds, the drop in tree pollen is slight. Rapid regeneration of cypress and pine along the watercourses, relatively coarse resolution from the pollen samples, and mixing of sediments effectively mask much of this dramatic but short-lived change in vegetation. There is a plunge in Taxodium pollen and a drop in Pinus pollen in Zone 4 of Core LAB (See Fig. 61). This follows a sharp peak in Pinus and Taxodium in the top sample of Zone 3 which likely marks major logging and the peak influx of pollen via surface runoff from the watershed to the lake. This human disturbance signal is not nearly as obvious in Core LAB with its coarser resolution, although the rapid total concentration drop following the Taxodium peak at about 50 cm probably represents the same event (See Fig. 53). Pinus and Taxodium both have lower percentages above 50 cm.
In Prien Lake, the Ambrosia peak occurs at about 20 cm, concurrent with a peak in total concentration (See Fig. 36). Changes in tree pollen percentages are negligible. Although humans cut trees and turned native prairie into rice fields, they did not actually replace arboreal vegetation with non-arboreal vegetation over a broad region. Areas that were woodland mostly still are woodland albeit second-growth forest. A cultivated grass replaced native grasses of the original Cajun Prairie.

Rice (*Oryza sativa*) is in the Festucoid grass subfamily (Hitchcock, 1971); however, it produces primarily dumbbell shaped phytoliths (See Fig. 24) and may have contributed to the relatively high dumbbell/rondel ratio observed in the uppermost phytolith zones. Although characterized by their orientation across the leaf blade, rice phytoliths are not distinguishable in their disarticulated state.

Core LAE might provide information to refine the above environmental interpretation. The pollen assemblage implies that the basal date of 3260 B.P. is correct, but at least one additional date is needed to confirm the stratigraphy. Also, phytolith data on Core LAE would serve to identify any difference in the grass pollen source during the last 3000 years with better resolution than is available from Core LAB. This would help to tie down any
change related to the slight increase in tree pollen noted in Core PRD from 2000 to 1000 B.P.

Sea Level

Radiocarbon dates, sediment stratigraphy, and microfossils of the Prien Lake and Lake Arthur cores provide insight into relative sea level rise in southwestern Louisiana over the last 6000 years. Figure 71 shows the depth below mean sea level (MSL) of all radiocarbon dated samples in this study as well as the modern water depth at each site. Assuming that peat accumulates at or near sea level, a line connecting the peat samples should represent approximate sea level through time. Linear regression on the four peat and the two peaty clay segments yields the estimated relative sea level rise plotted as a thick hachured line. With the y intercept set to zero, R² equals 0.97. All non-peat dated segments, with the exception of the sample from LAC, fall below the line. This is to be expected since they all represent sediment deposited below the water surface. Interestingly, depth below MSL versus age plots for Cores PRB, PRC, and PRD have virtually the same slope as the regression line. Nichols (1989) established that for most estuary/lagoon systems sediment accumulation rates equal relative sea level rise. The sedimentation rates for Prien
Figure 71. Lake Arthur and Prien Lake radiocarbon dates with proposed relative sea level curve and Prien Lake sedimentation rates.
Lake support the relative sea level rise of 9 cm/century suggested by the dated peat segments.

Why do so many of the Lake Arthur cores have an abrupt transition from organic to inorganic sediment when a relative sea level rise of 9 cm/century should not exceed the ability of the marsh to keep pace? The stratigraphy of Core PRA provides a clue to understanding the abrupt stratigraphic changes observed in many of the Lake Arthur cores. Site A in Prien Lake is located in a small marshy inlet (See Fig. 22). Core stratigraphy shows peat accumulation beginning shortly after 2500 B.P. and continuing up to within 15 cm of the core top (See Fig. 32). Water in this inlet is only 0.3 meter (1 foot) deep, and it is surrounded by healthy marsh. Apparently, local destruction of the marsh by erosion probably related to human activity caused the demise of marsh vegetation in this area. The abrupt peat-clay transition in Core PRA resembles that observed in the Lake Arthur cores, which may also be due to an erosional process.

The most parsimonious interpretation of these data is a slow steady relative sea level rise throughout the period of record which agrees with several sea level curves for the Gulf Coast published by Pirazzoli (1991). Other researchers along the Gulf Coast, however, postulate a punctuated sea level rise or fluctuations of several
meters during the late-Holocene (Penland, 1990; Tanner, 1991). Four scenarios need consideration: (1) slow steady rise; (2) punctuated rise with long stillstands and rapid rises; (3) punctuated rise with shorter stillstands or periods of slow rise and longer periods of moderate rise; (4) fluctuations of several meters above and below modern levels.

Diatom analysis on Cores PRD and LAB help to resolve this issue (See Figs. 47 and 70). From 4500 to 3000 B.P. diatoms at PRD are primarily fresh and/or brackish indicating an estuarine environment with significant riverine/freshwater influence. After 2200 B.P. freshwater diatoms are less important and marine taxa increase somewhat, indicating greater tidal influence and higher salinities. Broadly tolerant estuarine taxa dominate throughout the period of record. There is nothing in the PRD diatom data to suggest anything other than a fairly steady relative sea level rise over the last 4500 years.

The Lake Arthur record extends further back in time. Sediments laid down prior to 5000 B.P. contain significant percentages of marine planktonic diatoms. The subsequent peat contains high levels of freshwater diatom taxa and a freshening pollen assemblage with plentiful Typha and Sagittaria by 3500 B.P. implying riverine/freshwater dominance (See Fig. 53). Above the hiatus associated with
the change from peat to clay, freshwater diatom taxa decrease and euryhaline, estuarine taxa dominate the assemblage. The freshwater episode in Lake Arthur corresponds to the freshwater episode in Prien Lake, but it is preceded by a marine phase.

Prien Lake core stratigraphy provides supporting evidence for an estuarine-fresh-estuarine environment. Sediments deposited in Prien Lake at Site D prior to 4500 B.P. are black and anoxic (See Fig. 32). Between 4500 and 3000 B.P. sediments are dark gray (oxic); after 3000 B.P., anoxic. Assuming that the black color is related to the accumulation of iron sulfide (pyrite) under reducing conditions, the color may be related to the salinity. Pyrite is less likely to form under freshwater conditions which are much more sulfate limited (Berner, 1984). The oxic (dark gray) segment of PRD was probably deposited under freshwater conditions; the anoxic (black) segments, under more saline conditions.

Forams and dinoflagellates in Lake Arthur Cores LAB and LAF4 peak between 5000 and 6000 B.P. (See Figs. 54 and 57). They are associated with marine environments, which adds to the evidence that higher salinity conditions existed in Lake Arthur during that period. Forams/Dinos in Core PRD are present throughout the core but in extremely low concentrations (See Fig 37). This may be due to
overall higher freshwater discharge by the Calcasieu River which has a larger watershed than the Mermentau or to the distance of Prien Lake and Lake Arthur from the contemporaneous Gulf of Mexico.

Figure 72 summarizes evidence from both freshwater and marine indicators in Cores PRD and LAB. Keeping in mind the information in Figure 71, the following sea level scenario seems likely. By 6000 B.P. rising sea level influenced deeper parts of both the Mermentau and Calcasieu River valleys with tidal influence and saline water extending upstream into river channels that would eventually enlarge into Lake Arthur and Prien Lake. Marine planktonic diatoms carried upstream by tidal currents settled out in the quiet water of the new estuaries. Marshes developed on the floodplain of the Mermentau River in response to slightly higher relative sea level. Site D in Prien Lake, which apparently originated as a deep meander pool in the Calcasieu River channel, became brackish as sea level rose to approximately 4 meters below current levels by 4500 B.P.

Between 4500 and 3000 B.P. both sites show freshwater conditions, yet peat continued to build at LAB and LAF at a rate of 9 cm/century, presumably in response to continued relative sea level rise. At PRD the sedimentation rate also equalled 9 cm/century, tending to
Figure 72. Summary of evidence from fresh and marine indicators for Cores PRD and LAB.
confirm a continuation of the relative rise. Two possible explanations exist. Higher effective precipitation leading to increased runoff and higher freshwater discharge for both the Mermentau and Calcasieu Rivers could keep conditions fresh in spite of marine transgression. Alternatively, depressed salinities along the Gulf of Mexico Coast south of the lakes might mask the marine characteristics associated with transgression.

Increased effective moisture from 4500 to 3000 B.P. should lead to some detectable change in the vegetation, such as an expansion of trees and a contraction of the prairie. In Zone 2 of Core PRD Upland Tree percentages do increase slightly, but the change is primarily due to an increase in Pinus fragments (See Fig. 36). Broken pollen grains suggest erosion and the addition of reworked grains to the pollen assemblage or higher energy transport (either riverine or tidal). Erosion accompanying the expansion of Prien Lake under gradually rising relative sea level seems the most likely pollen source and can also account for the high pollen concentrations in Zone 2. The real expansion of Pinus and Quercus comes later in Zone 4 from 2200-1000 B.P. Whole Pinus increases, indicating a proximal source. No substantive changes are noted in the Lake Arthur cores from 4500 to 3000 B.P. except the
buildup of *Typha* and *Sagittaria* already noted as fresh marsh indicators (see Fig. 53).

If increased effective moisture is responsible for the freshwater conditions, the effect should be noted in the Pearl River Marsh core in Mississippi. Li (1994) does report a freshwater diatom assemblage, but it is dated 3500 to 2000 B.P.. This lags behind the Southwestern Louisiana freshwater phase by almost 2000 years, an unlikely scenario if climate change is the forcing mechanism at both locations.

The best explanation for the observed freshwater episodes both in Lake Arthur and Prien Lake and in Pearl River Marsh is changing salinity of coastal water related to Mississippi River discharge. Although absolute dates on individual Mississippi River delta lobes differ among researchers, general agreement exists on relative delta complex chronology. The freshwater phase in the southwestern Louisiana cores occurs during Teche (western discharge) dominance, and the Pearl River Marsh freshwater phase occurs during St. Bernard (eastern discharge) dominance (Figures 73 and 74).

The oldest delta complex, the Maringouin, experienced abandonment and transgression around 6000 B.P. At that time Saucier (1995) states that sea level was no more than 5 meters below present levels, which is close to the
Figure 73. Comparison of freshwater phases in southwestern Louisiana cores and Pearl River Marsh core (Li, 1994) with Mississippi River delta chronology (Saucier, 1995). Black filled portion of bar represents freshwater phase or active delta.
Figure 74. Mississippi River delta complex chronology and location in relation to southwestern Louisiana study sites and to Pearl River Marsh (Adapted from Bloom, 1991; based on Coleman, 1988).
postulated southwestern Louisiana relative sea level of minus 5.5 m at 6000 B.P. Evidence of this transgression extends up the Mississippi valley as far as Baton Rouge (Frazier, 1967). Frazier (1967) suggests that Maringouin transgression was due to resumption of sea level rise after a stillstand. This coincides with the earliest record from southwestern Louisiana and supports the presence of brackish conditions at 6000 B.P. Both the Mermentau and the Calcasieu Rivers at the study sites flow through low gradient low elevation terrain. If brackish water extended as far as Baton Rouge, it probably also extended upriver to proto Lake Arthur and Prien Lake.

Frazier (1967) places initial Teche delta complex progradation at 5700-5000 B.P. near Point Au Fer Island south of Morgan City, an extreme eastern lobe in the complex. He also reports a subsequent temporary diversion eastward into the Mississippi and Bayou Lafourche. This early Teche complex eastward delta lobe progradation apparently had little effect on southwestern Louisiana and the sedimentary record remained brackish.

The next delta lobes to dominate were Bayou Sale and Bayou Cypremort in the extreme western portion of the Teche delta complex. Frazier (1967) and Gould and McFarland (1959) credit the Sale/Cypremort system with providing the sediment which became the foundation for the
southwestern Louisiana's chenier plain. Coleman and Smith (1964) date the Sale/Cypremort at 4700 to 4200 B.P. Partly concurrent with the Sale/Cypremort, a delta lobe near Bayou Black south of Morgan City formed from 4500-3500 B.P. (Saucier, 1995). Coleman (1988) states that the typical delta lobe has a life span of 1,200 to 1,700 years. This timing and duration correspond closely to the freshwater phase in the Lake Arthur and Prien Lake cores. Even though the Calcasieu River is located farther west and therefore farther from the freshwater source, both sites responded similarly. Lower forams and dinoflagellates throughout Core PRD suggest that freshwater influence from the Calcasieu River is stronger than from the Mermentau.

Teche complex abandonment occurred about 3000 B.P. (Saucier, 1995). This event precipitated the formation of southwestern Louisiana's chenier plain as progradation ceased and landward reworking and winnowing of sediments created the well known ridges. Interestingly, the oldest, most landward, of the cheniers (Little Chenier) is dated to 3000 B.P. (Penland, 1990). This indicates maximum proximity of the Gulf to the coring sites and coincides with the abrupt change from fresh to more saline (estuarine) conditions in both Lake Arthur and Prien Lake. A sudden change from low to high salinity tidal influence
could quickly cause dieback, erosion, and overtopping of the freshwater marsh in Lake Arthur resulting in the observed truncated freshwater peat stratigraphy.

The freshwater phases from 3400 to 2200 B.P. and from 1400 to 1100 B.P. at Li's (1994) Pearl River Marsh site on the eastern side of the Mississippi River closely correspond to progradation of the Mississippi-La Loutre (3000-1800 B.P.) and the Bayou Sauvage (1900-600 B.P.) lobes of the St. Bernard delta complex (Frazier, 1967) (See Fig. 73). Discharge through the St. Bernard delta complex was toward the Pearl River to the east (See Fig. 74). The Mississippi also utilized the Lafourche outlet from 3500 to the present, and it became dominant around 2000 B.P. (Autin et al., 1991). Despite the fact that three deltas were operational during the same time period, the Teche delta complex dominated first, then the St. Bernard, and thirdly the Lafourche (Autin et al., 1991).

Radiocarbon dates on peat cores from the Pearl River and Pascagoula River marshes in coastal Mississippi plot close to the proposed relative sea level curve (black rectangles on Figure 75). The only exception to the match of the nine available dates is the basal date on peaty clay from Pearl River Marsh which lies almost two meters below the proposed level for 6000 B.P. Given this many dates on coastal marsh deposits far enough from the
Figure 75. Radiocarbon dated peats versus the southwestern Louisiana proposed relative sea level curve. • = Lake Arthur and Prien Lake; ■ = Pearl River (Li, 1994) and Pascagoula River (Liu, 1995); ▲ = Cote Blanche Bay (Coleman and Smith, 1964); X = Chenier Plain (Gould and McFarland, 1959).
Mississippi River depocenter to eliminate the worst subsidence, a relative sea level rise of 9 cm/century for the last 6000 years seems reasonably secure.

Coleman and Smith (1964) derived a similar curve based on radiocarbon dated marsh peats from the Mississippi Deltaic Plain approximately 65 miles east-southeast of Lake Arthur. Their dates (plotted as triangles on Figure 75) fall close to the curve proposed for southwestern Louisiana for the past 4500 years, then rapidly diverge to four meters below the proposed curve by 6000 B.P. They interpret the data to indicate that eustatic sea level rise ended 4000 years ago and that relative sea level rise since that time is due to subsidence alone.

Radiocarbon dates from this study and from the Pearl and Pascagoula River marshes suggest that subsidence affected some of their sites in the Mississippi deltaic plain more than others. The dates which deviate most from the southwestern Louisiana proposed curve are those designated Bayou Sale and Mound Point, they are farthest east and therefore most vulnerable to subsidence related to the Mississippi River sediment loading.

Historic rates of relative sea level rise for the Teche Basin exceed those of the Chenier Plain. Ramsey and Penland (1989) determined Louisiana subsidence rates based
on 40 years of tide gauge records. The Chenier Plain averages 0.33 cm/year; the Teche Basin, 1.11 cm/year, a difference of 0.78 cm/year. Coleman and Smith's sites are close to Calumet, the station with the most extreme historic relative sea level rise. A subsidence difference of only .07 cm/year between the southwestern Louisiana sites and Coleman and Smith's sites (an order of magnitude smaller than the historic difference between the two regions) is adequate to account for the deviation of their dated peat segments from the proposed southwestern Louisiana sea level curve.

Two of Gould and McFarland's (1959) dates on peat samples north of Little Chenier plot about one meter above the proposed southwestern Louisiana sea level curve. Their data support a scenario in which sea level rose more rapidly than 9 cm/century until 3000 B.P. and then leveled off. Slower sedimentation rates associated with the upper portions of Lake Arthur cores LAB and LAF4 tend to confirm this interpretation (See Table 1). However, the cluster of dates between 3500 and 5000 B.P. along the proposed sea level curve outweighs the few dates above the hachured line.

The data from this dissertation do not extend far enough back in time to address the issue of sea level prior to 6000 B.P. The constant rate of relative sea level
rise noted is probably due to a combination of both subsidence and eustatic sea level rise. The proposed sea level curve agrees well with the scenario proposed by Colquhoun and Brooks (1986) for South Carolina for the last 6000 years. From archaeological data, Colquhoun and Brooks infer possible small fluctuations of less than one meter superimposed on a slow overall rise of approximately 7.5 cm/century; however, age and elevation data from their numerous peat samples do not confirm the proposed fluctuations.

In short, the evidence from this research points to a slow steady relative sea level rise over the last 6000 years with coastal salinities affected by delta switching of the Mississippi River. The slowing down of relative sea level rise proposed by Coleman and Smith (1964) at 4000 B.P. or by Gould and McFarland (1959) at 3000 B.P. is not apparent in the combined data from Lake Arthur, Prien Lake, Pearl River Marsh, and Pascagoula River Marsh. There is no evidence to support the rapid sea level rise from 4000 to 3000 B.P. proposed by Penland (1990), the regression from 3400 to 2200 B.P. proposed by Li (1994), nor the fluctuations proposed by Tanner (1991).

Significance

This dissertation establishes that the Southwestern Louisiana Prairie is at least 6000 years old and that it
has remained relatively stable throughout that time. The grassland seems entirely due to edaphic factors and to fire rather than to climate or to human disturbance.

The use of phytoliths to discriminate the source of grass pollen is a new technique, and it has broad applications in the field of palynology. Increases in Gramineae pollen are invariably linked to low effective moisture, which may not always be true. In this study, the presence of marsh peat is a clear indicator of wetland grasses; however, if no such stratigraphic signal exists, this dissertation shows that phytolith analysis can be an invaluable tool in deciphering the source of grass pollen.

Clearly, the use of multiple lines of evidence enhances any palynological work. This research demonstrates the effectiveness, and the necessity, of a multivariate approach in marginal sites.

**Future Research**

An obvious gap in this study, specifically, is the lack of phytolith and diatom data on Core LAE from Lake Arthur. Its unique high resolution record for the last 3000 years in Lake Arthur might provide information concerning changes in grass pollen source or changes in diatom flora to refine the environmental history of southwestern Louisiana.
Phytolith analysis proves to be an effective discriminator of Gramineae pollen; however, little empirical research exists on phytolith dispersal, transport, and deposition by water. Also, more work needs to be done on the relationship of phytolith assemblages to grassland types. Fredlund and Tieszen (1994) recently demonstrated the potential of phytolith assemblages to delineate major grassland categories in North America. Since most palynological work uses sediment cores from lakes and wetlands, attention must be focused on wetland grasses and the relative importance of this local phytolith component in sediment.

Phytolith taxonomy often utilizes small tissue samples, assuming them to be representative of the species as a whole. More accurate paleoecological interpretation requires knowledge of the disarticulated phytolith assemblage produced by each taxa. Digestion of the entire plant for a reference sample would give a better idea of phytolith variation within and between species.

Although there is general agreement among researchers about phytolith types produced by Gramineae subfamilies, no work exists concerning variation of phytolith production within a taxon in response to different environmental conditions. For example: rondel types are common in Festucoid grasses associated with arid lands or
saline environments where plants must deal with physiological drought. Do these taxa produce primarily rondels regardless of conditions, or is rondel production a response to stress? Do other grasses make higher percentages of rondels when subject to stress? Answering these questions requires examining phytolith assemblages from the same taxon under different controlled growing conditions.

There is a clear need for better ecological data on diatoms. Current diatom research centers on refining taxonomy rather than on determining physiological limits of species. If diatoms are to be useful paleoecological indicators, we need accurate information on many taxa. Additionally, little research exists on diatom dispersal or on the relationship between diatoms in sediment samples and actual conditions at the site.

A definitive answer to late-Holocene sea level fluctuation along the northern Gulf of Mexico awaits an integrated study of multiple sites in relatively stable portions of the Coastal Plain. The Mississippi River dominates much of the area and influences salinity over a broad region. Dinnel and Wiseman (1986) postulate that freshwater from the Mississippi system follows the continental shelf as far south as the Texas-Mexico border. Sea level reconstructions based on changing salinities
must be synchronous both east and west of the Mississippi to be accepted.
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Geology and Groundwater Resources of Southwestern 


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APPENDIX A

**Extraction Procedure for Biogenic Silica in Soil and Sediment**

Regular tap water is used except as noted.

1. Place 5 cc (1 teaspoon) of material in a 1000 ml beaker (one quart wide mouth mason jar will do).

2. Add 50 ml (1/4 cup) of Chlorox to digest organic matter. I originally used 30 % hydrogen peroxide for this step, but I later substituted household Chlorox because it is effective and cheap. Cummings (1993) also reports using Chlorox successfully.

3. Let stand until organic matter is digested. Gentle heating enhances this process (cover with black plastic and set in the summer sun). Usually this step takes 48 hours.

4. Add water up to 1000 ml to dilute any remaining reagent, stir thoroughly, allow to settle overnight, siphon off the supernatant down to about 2 cm from the bottom of the beaker being careful not to disturb the sediments. Always hold the end of the siphon near the top of the supernatant not down near the sediment.

5. Add about 2cc (1/2 teaspoon) sodium pyrophosphate or other deflocculating agent (Calgon). Stir thoroughly several times during the day to completely break up any clay lumps. Let stand overnight. Siphon off and
discard the supernatant down to about 2 cm from the bottom of the beaker.

6. Wash sample through #70 sieve (200 micron opening) into small container to filter out any remaining coarse material. Return sample to 1000 ml beaker.

7. Add water up to 1000 ml, stir thoroughly, let settle 1 hour, siphon or carefully pour off and discard top 500 ml which contains clay sized particles held in suspension. Larger particles including phytoliths will settle below the 500 ml mark in one hour.

8. Repeat step #7 until supernatant is clear after the hour of settling. Typically step #7 must be repeated 10 times to remove all clay sized particles.

9. Let settle overnight and siphon off and discard supernatant down to within 2 cm of bottom of beaker being careful not to disturb sediments. Transfer sample into 50 ml test tubes, centrifuge, decant and discard supernatant.

10. Add 5-7 ml heavy liquid (specific gravity 2.3), mix thoroughly using vortex mixer. At this specific gravity, biogenic silica floats, clastic silica sinks. Centrifuge 5 minutes, decant supernatant containing biogenic fraction carefully into clean 50 ml test tube. Do not contaminate with residue in bottom of test tube.
11. Repeat #10 decanting biogenic fraction into same new test tube. Discard contents of original test tube containing the clastic silt sand fraction.

12. Add distilled water to the biogenic silica fraction up to 1 cm from top of test tube mixing well. This reduces the specific gravity and allows the biogenic silica to sink. Centrifuge and decant diluted zinc bromide solution into the recycling beaker.

13. Transfer biogenic silica with water into 15 ml test tube, centrifuge and decant.

14. Add 5-7 ml of ethanol, stir on vortex mixer, centrifuge, and decant.

15. Transfer biogenic silica to small vial with ethanol. Centrifuge vial, decant, leave open to dry.

**Preparation of Zinc Bromide Heavy Liquid**

Zinc bromide is toxic, all work should be done in a fume hood. Add approximately 144 grams of zinc bromide to 50 ml of distilled water in a medium sized beaker. Heat and stir until dissolved. Adjust specific gravity using a sink-float indicator. (I used a 2.3 sink-float standard made by Cargille Laboratories, Inc., Cedar Grove, NJ 07009.)
Recycling Zinc Bromide Heavy Liquid

Zinc bromide is expensive. If only distilled water is used to mix the heavy liquid, it can be recycled easily by boiling the diluted filtered liquid from step #12 until enough water is driven out to restore the specific gravity to 2.3. Filter diluted solution from step #12 above through a #635 or higher sieve (20 micron or smaller opening) to remove contaminants, heat to boiling in a large beaker on a hot plate. Do not force the specific gravity much above 2.3 or the zinc bromide will precipitate out of solution.

Preparation of Microscope Slides Using Permount

Permount with a refractive index of 1.5 is a better mounting media for biogenic silica than silicone oil, refractive index 1.4, in common use for pollen analysis (Piperno, 1988). Permount, however, has the disadvantage of drying hard, so slides must be counted within a week of preparation or material cannot be turned during examination. Permount slides are best prepared one day ahead of counting. Transfer a small amount of dry biogenic silica to a microscope slide, add three drops of Permount, stir the dry material into the mounting medium, add a cover slip, press down on the cover slip to drive out any air bubbles and to distribute the material. For the longest lasting slides, force some Permount out from under
the cover slip and spread it around the edges as a sealant.
APPENDIX B

Diatoms Identified in Lake Arthur and Prien Lake Cores

Salinity Categories

Fresh Water Taxa

Cyclotella meneghiniana
Epithemia
Eunotia
Fragilaria
Gomphonema
Melosira (Aulacoseira)
Pinnularia
Stauroneis phoenicenteron

Fresh to Brackish Water Taxa

Achnanthes
Caloneis lewisii
Campylodiscus echeneis
Cosmioneis (Navicula) pusilla
Cymbella
Diploneis elliptica
D. smithii
D. oblongella (ovalis)
Rhopalodia gibberula
Terpsinoë musica
Unknown Pennales
Brackish Water Taxa

*Diploneis bombas*

*Gyrosigma/Pleurosigma*

*Navicula delawarensis*

*N. maculata*

*N. peregrina*

*Nitzschia scalaris*

*Nitzschia unknowns*

*Pleurosira (Biddulphia laevis)*

*Surirella*

Brackish to Marine Water Taxa

*Caloneis permagna* (or *C. oregonica*)

*Entomoneis alata*

*Tryblionella* (*Nitzschia circumsuta)*

Unknown Centrales

Marine Taxa

*Actinocyclus type*

*Actinoptychus undulatus*

*Biddulphia*

*Coscinodiscus type*

*Eupodiscus*

*Nitzschia granulata*

*Paralia sulcata*
Lifestyle Categories

Epiphytic Taxa

Achnanthes
Eunotia
Fragilaria
Gomphonema
Rhopalodia gibberula
Terpsinoë musica

Epipelic Taxa

Caloneis lewisii
Caloneis permagna (or C. oregonica)
Campylodiscus echeneis
Cosmioneis (Navicula) pusilla
Cymbella
Diploneis bombas
D. elliptica
D. smithii
D. oblongella (ovalis)
Entomoneis alata
Epithemia
Gyrosigma/Pleurosigma
Navicula delawarensis
N. maculata
N. peregrina
Nitzschia granulata
N. scalaris
Nitzschia unknowns
Pinnularia
Stauroneis phoenicenteron
Surirella
Tryblionella (Nitzschia circumsuta)

Planktonic Taxa
Actinocyclus type
Actinoptychus undulatus
Biddulphia
Coscinodiscus type
Cyclotella meneghiniana
Melosira (Aulacoseira)
Paralia sulcata
Pleurosira (Biddulphia laevis)

Unknown Lifestyle
Eupodiscus
Unknown Centrales
Unknown Pennales
Illustrations of Identified Taxa

Illustrations are arranged by salinity groups. Unless noted below, drawings are from Patrick and Reimer (1966 and 1975). Names in parentheses are synonyms.

Illustrations from Van Heurck (1896)

Actinoptychus undulatus
Actinocyclus type
Aulacoseira (Melosira) granulata
Campylodiscus echeneis
Coscinodiscus type
Nitzschia scalaris
Pleurosira (Biddulphia laevis)
Terpsinoë musica
Tryblionella (Nitzschia circumsuta)

Illustrations from Foged (1984)

Cyclotella meneghiniana
Nitzschia granulata

Illustration from Crawford (1979)

Paralia sulcata
Epithemia turgida
60-150 μ

Stauroneis phoenicenteron
70-380 μ

E. pectinalis
17-140 μ

Eunotia maior
35-220 μ

Aulacoseira granulata
(Melosira) 5-17.5 μ

Cyclotella meneghiniana
10-20 μ

Gomphonema gracile
24-90 μ

FRESH WATER DIATOMS
P. dactylus
160-320 µ

P. viridis
50-170 µ

P. nobilis
45-400 µ

P. lata
70-160 µ

P. maior
140-200 µ

Pinnularia species

FRESH WATER DIATOMS
Achnanthes temperei 38-75 µ

Achnanthes inflata 30-65 µ

Diploneis elliptica 20-130 µ

D. smithii 25-200 µ

D. oblongella (ovalis) 10-100 µ

Rhopalodia gibberula 40-70 µ

Caloneis lewisii 27-42 µ

FRESH TO BRACKISH WATER DIATOMS

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FRESH TO BRACKISH WATER DIATOMS

Terpsinoë musica
125 μ

Cymbella aspera
70-200 μ

Navicula pusilla
25-50 μ

Campylodiscus echeneis
80-140 μ
Navicula peregrina
36-150 μ

N. delawarensis
60-100 μ

N. maculata
90-120 μ

Diploneis bombas
30-150 μ

Gyrosigma wormleyi
75-115 μ

Nitzschia scalaris
up to 480 μ

Pleurosira
(Biddulphia laevis)
50-120 μ

BRACKISH WATER DIATOMS
Entomoneis alata
55-160 μ

Tryblionella
(Nitzschia circumsuta)
up to 210 μ

Caloneis permagna
(or C. oregonica)
85-220 μ

BRACKISH TO MARINE DIATOMS
APPENDIX C

Reference Taxa Processed for Phytoliths

Gramineae subfamilies according to Hitchcock (1971)

Gramineae, Panicoideae

Andropogon gerardii
Panicum hemitomon
Panicum sphaerocarpon
Panicum virgatum
Paspalum floridanum
Schizachyrum scoparium
Schizachyrum tenerum
Setaria magna
Sorghastrum nutans
Tripsacum dactyloides
Zea mays

Gramineae, Festucoideae

Distichlis spicata
Eragrostis spectabilis
Leersia oryzoides
Oryza sativa
Phragmites australis
Spartina alterniflora
Spartina cynosuroides
Spartina patens
Zizaniopsis miliaceae
Cyperaceae

Cladium jamaicense
Eleocharis sp.
Scirpus olneyi
Scirpus cyperinus
Scirpus robustus

Miscellaneous

Borrichia frutescens
Juncus sp.
Kosteletzkya virginica
Magnolia grandiflora
Sabal minor
Sabal palmetto
Sagittaria lancifolia
Thelypteris palustris
Tillandsia usneoides
Typha latifolia

Phytolith Photographs

The following photographs of representative phytolith shapes are cut from color laser print 11x17 enlargements made from 35 mm slides taken on a light transmission microscope at 600X magnification.
CROSS SHAPED PHYTOLITHS

Zizaniopsis miliaceae

Zizaniopsis miliaceae

20 μ
DUMBBELL SHAPED PHYTOLITHS
SADDLE SHAPED PHYTOLITHS

20 µ

RONDEL SHAPED PHYTOLITHS

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APPENDIX D

Kolmogorov-Smirnov Goodness of Fit Test

Pine pollen size distribution against normal distribution

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<th>Score</th>
<th>Cumulative Probability</th>
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D critical at alpha of .01 = .055
D maximum = .067; therefore, reject null hypothesis and conclude pine size not normally distributed.
APPENDIX E

Letters of Permission

A copy of the letter requesting permission to use Dr. Charles Allen's unpublished vegetation data from the Cajun Prairie and of his letter granting permission follow this page.
Dr. Charles Allen  
Department of Biology  
Northeast Louisiana University  
700 University Avenue  
Monroe, Louisiana 71209  

Dear Dr. Allen,

I see from the date of the last letter I wrote to you that three years have gone by. I hope you still remember who I am!!! I am actually planning to finish my dissertation this school year. I have counted the pollen, phytoliths, and diatoms for my cores, and I am now in the throes of writing. Included are the preliminary diagrams from the soil samples I collected from your sampling plots in the Cajun Prairie remnant strips. If you want, I'll send you a copy of the dissertation when it is finally complete.

The reason I'm writing is to ask if you have published your vegetation study yet? If so, could you send me the reference or maybe a reprint? If not, LSU requires me to get written permission from you to use any of your data. What I want to include is a summary of identified grass genus in the Panicoid and Festucoid subfamilies and a ratio of total Gramineae/Compositae identified in each sample. Enclosed is the preliminary chart which I compiled from the presence data you sent me for 1990. The Fenton group of sites are the three north of I-10 on Highway 165, the Mermentau group are the three sites south of I-10 on Highway 90. Interesting how the pollen and phytoliths reflect the difference in the two. I know that the elevations are around 30 feet for the Fenton group and 15 feet for the Mermentau group. The soils are also different with the Mermentau sites not as well drained. I actually had some diatoms in the Mermentau biogenic silica samples.

Thanks lots for your help.

Sincerely,

Mimi Fearn

Mimi Fearn
Sept 22, 1994

Mimi Fearn
2307 North Riviera Drive
Mobile, Ala. 36605-2550

Dear Mimi,

Good to hear from you. I have been busy and haven’t published the prairie data yet. You have my permission to use the data in your dissertation. I still hope to publish it this Winter.

Your data look interesting. Yes, I would appreciate a copy of the dissertation. I am enclosing a table that I will use in the Prairie paper. It is a ranking of the species in descending importance value (sum of relative frequency and relative cover). I may have already sent you this.

Good luck with the wrapping up of your dissertation.

Sincerely,

Charles Allen

Monroe, Louisiana 71209-0520
VITA

Miriam Lee Fearn was born in Mobile, Alabama on June 23, 1944. She attended Birmingham-Southern College for three years in the 1960s then embarked on a career as a wife and mother. In 1985, she enrolled at the University of South Alabama in Mobile and graduated magna cum laude in 1987 with a Bachelor of Science in Geography. That same year she entered the Ph.D. program in the Department of Geography and Anthropology at Louisiana State University on an Alumni Federation Fellowship. After completing her coursework at L.S.U., Ms. Fearn studied at the University of Minnesota for several months on a Global Paleorecords Research Training Group Traveling Fellowship. She worked as a research associate in 1992-1993 for Dr. Kam-biu Liu, Department of Geography and Anthropology, L.S.U., on a National Science Foundation funded project, "Reconstructing the late-Holocene hurricane climate along the northern Gulf of Mexico coast." Since 1993, Ms. Fearn has taught evening and weekend classes in Physical Geography at the University of South Alabama and at the University of Mobile.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Miriam Lee Fearn

Major Field: Geography

Title of Dissertation:

Louisiana's Cajun Prairie: Holocene History of a Southern Grassland

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

May 16, 1995