Carbon Storage and Late Holocene Chronostratigraphy of a Mississippi River Deltaic Marsh, St. Bernard Parish, Louisiana

First Report: Mississippi Basin Carbon Project Process Studies

Edited by Helaine Walsh Markewich

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INTRODUCTION

Helaine Walsh Markewich

Today, the causes, results, and time scale(s) of climate change, past and potential, are the focus of much research, news coverage, and pundit speculation. Many of the US government scientific agencies have some funds earmarked for research into past and (or) future climate change (National Science and Technology Council, 1997). The Mississippi Basin Carbon Project (MBCP) is part of the U.S. Geological Survey (USGS) effort in global change research . The project is motivated by the need to increase our understanding of the role of terrestrial carbon in the global carbon cycle, particularly in the temperate latitudes of North America. The global land area between 30^{o}and 60^{o}N is thought to be a large sink for atmospheric CO_2 (IPCC, 1996). The identity of this sink is unknown, but is in part the soil and sediment that makes up the upper several meters of the Earth's surface. The MBCP focuses on the Mississippi River basin, the third largest river system in the world (fig. 1), that drains an area of 3.3 x 10^6 km^2 (1.27 x $10^6 mi^2$). The

Mississippi River basin includes more than 40 percent of the land surface, and is the home of more than one-third of the population, of the conterminous United States. Because climate, vegetation, and land use vary greatly within the Mississippi River basin, the primary terrestrial sinks for carbon need to be identified and quantified for representative parts of the basin.

The primary goal of the MBCP is to quantify the interactive effects of land-use, erosion, sedimentation, and soil development on carbon storage and nutrient cycles within the Mississippi River basin. The project includes spatial analysis of a wide variety of geographic data, estimation of whole-basin and sub-basin carbon and sediment budgets, development and implementation of terrestrial carbon-cycle models, and site-specific field studies of relevant processes. Areas can be studied and compared, and estimates can be made for whole-basin carbon storage and flux.

Site specific studies are directed at estimating rates of carbon accumulation, decomposition, erosion, transport, and deposition; and particularly at assessing the sensitivity of these rates to climatic, hydrologic, topographic and land-use gradients. To date, process studies are focused on that part of the Mississippi River basin between 82^{O} and 100^{O}W longitude. Study areas include open- and closed-system lakes, primarily in the northern part of the Mississippi River basin; farmland in Iowa, Ohio, and Mississippi; and marshes and swamps in the Mississippi River deltaic plain (figs. 1 and 2).

One of the most important aspects of the project is *time*, and the ability to determine the rate(s) of carbon accumulation per unit of time. Therefore, attention had to be given to the techniques available for looking at small intervals of time. With this goal in mind, the first field study initiated by the MBCP was an investigation into the rates of carbon accumulation in the Mississippi River deltaic plain. The goal is to determine the accumulation rates on a decadal time scale for the last several hundred years. This ongoing effort is collaborative with the U.S. Army Corps of Engineers (COE), New Orleans District, Louisiana; the Center for Excellence in Palynology (CENEX), Geology Department Louisiana State University, Baton Rouge; and the Great Lakes Environmental Research Laboratory, National Ocean and Atmospheric Administration, Ann Arbor, Michigan.

Field sites were chosen to include most of the major geomorphic and (or) ecological environments characteristic of the Mississippi River deltaic plain. Since the fresh, brackish, and salt marshes comprise the most prominent deltaic environment, approximately 1,500 km^2 (Sasser and others, 1995), the first year's efforts were concentrated in three brackish- to fresh-water marshes located in the western, central, and eastern parts of the deltaic plain (fig. 1). Chronostratigraphic reconstruction of the pre-human development part of the geologic record relied on ^{14}C isotopic, compositional, and palynomorphic analyses. Construction of a chronostratigraphy for the post-European development part of the geologic record involved most of the same analytical techniques. However, ^{137}Cs and ^{14}C bomb spike analyses were used to establish "dated" horizons for the last 30-45 years, and diagnostic microstratigraphic markers were used to identify horizons representing the time period from 1700 to 1900, too recent a time interval for standard ^{14}C isotopic analysis. Carbon accumulation rates and inventory estimates were calculated using data from this study, data from published sources, and data from unpublished sources that were made available to this investigation

FIGURE 1. The Mississippi River drains an area of 3.3 x 10^{6}km^2 and forms a well-defined bird's foot delta as it enters the Gulf of Mexico. Mississippi Basin Carbon Project core

localities in the Mississippi River deltaic plain are indicated by different colored circles: purple, marsh; dark brown, swamp; green, floodplain and (or) back levee. Core locations are named for the parish in which they are located; parish names are shown. The St. Bernard core locality is in the easternmost part of the study area. Triangles indicate localities for which surface and near-surface organic carbon data are available from the National Soil Survey Laboratory in Lincoln, Nebraska (NSSL, 1994).

This report is the first of the Mississippi Basin Carbon Project process studies. It presents findings from the easternmost core locality in the Mississippi River deltaic plain, a marsh on a western border of Lake Borgne in St. Bernard Parish, southeastern Louisiana. It includes: (a) the geologic setting and Holocene geologic history of the easternmost part of the Mississippi River deltaic plain, (b) a brief description of investigative methods used for chronostratigraphic analysis, and (c) results, including the rate(s) of organic carbon accumulation and the amount of organic carbon represented by the organic matter. This report's companion, Markewich (*in press*), contains detailed descriptions of the principal field and laboratory methods used for investigations of the MBCP in the Mississippi River deltaic plain. Data from this study, along with other available data on surface and near-surface organic matter will be used to estimate the carbon inventory and flux, wholly and in part, for the Mississippi River basin.

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GEOLOGIC AND HYDROGEOLOGIC SETTING

L.D. Britsch, D.L. Dillon, and H.W. Markewich

Geomorphology

The St. Bernard core locality is within the St. Bernard subdelta of the Mississippi River deltaic plain. The deltaic plain covers an area of approximately 29,785 km^2 (11,500 $mi.^2$) (fig. 2), encompassing the active and abandoned deltas of the Mississippi River. The deltaic plain is a distinct physiographic unit, bounded on the west by the coastal marshlands of the Chenier Plain, on the east and south by the Gulf of Mexico, and on the north by the Mississippi River Alluvial Valley and older gulfward-dipping Pleistocene deposits (Kolb and Van Lopik, 1958) (fig. 2). The most prominent physiographic feature of the deltaic plain is the vast expanse of fresh, brackish, and salt marshes. Natural levee ridges along active and abandoned distributaries, inland swamp, tidal channels, shallow lakes and bays, and sandy barrier islands and beaches comprise the majority of the remaining surface features.

FIGURE 2. **Physiographic provinces of southern Louisiana. Numerous gulfward-dipping Pleistocene deposits underlie the untitled area north of the Deltaic and Chenier plains.**

The modern alluvial valley and deltaic plain of southern Louisiana have been formed by progradation of the present and former Mississippi River courses and deltas. Each time the Mississippi River has built a major delta lobe seaward, it has subsequently abandoned the lobe in favor of a shorter, more direct route to the sea. These river course (meander belt) changes and accompanying shifts in centers of deposition have resulted in the present distribution of deltaic sediments along the southeast Louisiana coast. Marine transgression, caused in part by compaction and subsidence of deltaic sediments, begins soon after a delta lobe is abandoned. However, for much of the Holocene, the net result between the advancing deltas and the encroaching sea has been an overall increase in the size of the deltaic plain (Kolb and Van Lopik, 1966). During the last 50 years, coastal land loss has accelerated as human activities (particularly sediment trapping by the Mississippi River lock and dam system), combined with relative subsidence and erosion, have resulted in a net rise in sea level and loss of land.

Geologic History of the Mississippi River Deltaic Plain

The geologic history of the Lower Mississippi Valley and the Mississippi River deltaic plain has been determined from more than 30,000 borings and hundreds of radiocarbon age determinations. Some of the important contributions to the understanding of the history of the alluvial valley and the deltaic plain have been made by Fisk (1944, 1952, 1955), Fisk and McFarlan (1955), McFarlan (1961), Kolb and Van Lopik (1966), Frazier (1967), and Saucier (numerous papers, see Saucier (1994) for complete listing). Despite differences in calculations and interpretations of radiocarbon ages, information gained from these data indicates that over the past 8 k yr the Mississippi River has changed its course several times, forming a complex setting in which to observe the various aspects of fluvial and coastal sedimentation. (see Coleman and Roberts (1989) for a description of the Mississippi River alluvial valley and deltaic plain.)

During the last glacial advance, the Late Wisconsinan (about 26 to 12 ka; Martinson and others, 1987), continental ice accumulation caused sea level to be lowered some 90 m (295 ft) below its present level (Dillon and Oldale, 1978). As a result, the Louisiana shoreline was as far as 160 km (100 mi.) south of its present position (Kolb and Van Lopik, 1958). Lowered sea level led to the entrenchment of gulfward-flowing streams and their tributaries into the newly exposed deposits of the last interglacial Pleistocene Prairie Formation (Fisk, 1938). Entrenchment of the ancestral Mississippi River into the late Pleistocene Prairie Formation formed an alluvial valley with branching tributary valleys approximately 16- to 40-km (10- to 25-mi.) wide which trended southeast across the deltaic plain. (The Prairie Formation is not shown on fig. 3, but forms the surface unit updip of the Holocene alluvial/deltaic sediments)

Sea level was at its lowest position about 18 ka (Martinson and others, 1987) and subsequently began to rise as a result of glacial melting and regional subsidence of the coast (Kolb and Van Lopik, 1966; Nummedal, 1983). Streams alluviated the entrenched valley with coarse sediments in order to adjust to the rise in base level. As sea level continued to rise, deposition of coarse sediments was forced farther up the alluvial valley. Closer to the Gulf of Mexico, shallow marine sediments were deposited over coarse basal fluvial sediments as the shoreline transgressed northward. As sea level continued to rise, both the quantity and grain size of detritus supplied to the streams decreased, leaving only fine sands, silts, and clays for deltaic deposition (Kolb and Van Lopik, 1966).

Between 8 and 4 ka a stillstand of sea level occurred at approximately its present level (Nummedal, 1983). The Mississippi River began building a series of lobate deltas in a gulfward direction as a result of a stationary sea level, displacing Gulf of Mexico waters that had extended up the Mississippi River alluvial valley to the latitude of Baton Rouge, Louisiana (Kolb and Van Lopik, 1966). The Mississippi River and its associated deltas shifted several times during this gulfward growth of land, resulting in a deltaic plain composed of an active and several inactive deltaic complexes extending some 288 km (180 mi.) across southeast Louisiana. From oldest to youngest, the deltaic complexes are the Maringouin, Teche, St. Bernard, Lafourche, and the Plaquemine-modern (fig. 3). The relative ages of these complexes are well established, but the absolute ages are less accurate. Delta ages have been derived from radiocarbon analysis as well as archeological evidence (McIntire, 1958; McFarlan, 1961; Frazier, 1967; Törnqvist and others, 1996).

FIGURE 3. Major Holocene deltaic lobes of the Mississippi River (modified after Frazier, 1967): Maringouin, 6-8 ka; Teche, 5.8-3.5 ka; St. Bernard, 3.5-2 ka; LaFourche, 2-1 ka; Plaquemine-Modern, 1 ka to the present. Red dot marks St. Bernard Parish core locality SB1.

The earliest delta lobe, the Maringouin, probably prograded sometime between 6 and 8 ka, during a short stillstand when sea level was approximately 12 to 18 m (40 to 60 ft) lower than its present level (Frazier, 1967). Frazier (1967) mapped the Maringouin as the most extensive delta lobe in the Mississippi River deltaic plain. Erosion, subsidence, and burial by subsequent deltaic deposition have made it difficult to reconstruct the exact limits, location, and upvalley extent of the Maringouin delta complex. About 5.8 ka, the initial progradation of the Teche delta began in the western part of the Mississippi River deltaic plain (Frazier, 1967). Gradually, the major locus of Teche deposition shifted eastward depositing sediments in a southeastward direction. The Teche-Mississippi River System was actively depositing sediments in this area until approximately 3.5 ka when the primary flow of the Mississippi River shifted far to the east and continued building the St. Bernard delta. The Mississippi River continued to build the St. Bernard delta until sometime between 2 ka (Frazier, 1967) and 1.4 ka (Törnqvist and others, 1996), when flow was diverted westward and the Lafourche delta began to prograde seaward. Abandonment of the Lafourche course for the Plaquemine-Modern delta lobe occurred around 0.5 ka (Frazier, 1967) or as early as 1.3 ka as suggested by Törnqvist and others (1996).

Geologic History of the St. Bernard Marsh Locality

The St. Bernard core locality (N. Lat. 29°58'53", W. Long. 89°55'27") is in a brackish marsh on the southwestern edge of Lake Borgne. Sediments at this locality are part of the St. Bernard delta complex (fig. 4), which began receiving Mississippi River deltaic sediments in the middle to late Holocene (about 4.7 ka, Frazier (1967); about 3.5 ka, Törnqvist and others (1996)). Based on data from borings, Dunbar, and others (1994) suggest that at this time the area was characterized by open marine water approximately 18 m (60 ft) deep. Homogeneous prodelta clays were the first deltaic deposits to enter the study area. As the Mississippi River and its distributaries prograded, interdistributary bay deposits began to be deposited. Interdistributary bay deposits include those sediments deposited in low areas between active distributary channels, usually under brackish water conditions. Sediment charged water during flood stage overflows the natural levees of the distributray channels, depositing the coarsest sediment (silt) near the channel on the natural levee flank. The finer sediment (silty clay and clay) is transported away from the distributary channel and settles out of suspension as interdistributary deposits. The 15 cm of interdistributary deposits at the base of the St. Bernard long core (designated SB1c) contains numerous fragments of highly degraded plant material. The early Holocene radiocarbon (^{14}C) age of 8,420 ± 60 yr BP (table 1) for charcoal in the sediment supports an interpretation as a fluvial deposit containing organic matter of various ages, but probably does not reflect the actual agee of the deposit. Deposition of interdistributary clay and silt continued until the height of the deposit reached sea level, at which time the sediments were populated by marsh vegetation. Radiocarbon age determinations for the core SB1c confirm that marshes began to form in this part of the deltaic plain about 3,180 ± 50 yr BP (table 1) and have continued to exist relatively undisturbed to the present. Typical depositional environments characteristic of deltaic progradation are found adjacent to the study site. Natural levee, point bar, swamp, and abandoned distributaries located in the vicinity of the study site are shown on fig. 4A.

FIGURE 4A. Deltaic environments in the vicinity of the St. Bernard core locality; these are characteristic of progradation in this part of the Mississippi River deltaic plain. Vegetation associated with the environments of deposition: brackish marsh , predominantly*Spartina patens* (wiregrass) with minor amounts of *Scirpus olneyi* (three-cornered grass); natural levee and point bar, predominantly live oaks and water oaks, with minor amounts of pecan, hackberry, and bald cypress; swamp, predominantly bald cypress trees with minor amounts of tupelo gum, live oaks, water oaks, elms, hackberry, and sweet gum trees.

FIGURE 4B. Map showing St. Bernard core locality in relation to New Orleans, Chalmette, and the Mississippi River Gulf Outlet Canal (MR-GO canal). Fresh-to-brackish water is dark blue; Gulf of Mexico water is light blue. Names of water bodies are blue; parish names are brown.

Active deltaic deposition shifted away from the study site about 2 ka (Frazier, 1967), or about 3 ka as indicated by ^{14}C data for this study (see table 2). However, the area around the St. Bernard core locality continued to receive periodic deposition related to crevassing on the Mississippi River until the early 1900s when levees began to be built along the Mississippi River for flood protection. Marsh accretion due to organic and mineral matter accumulation is the dominant process presently active in the study area

Stratigraphy of the St. Bernard Marsh Locality

The uppermost 4 m of marsh sediment at the St. Bernard core locality was sampled using vibracore techniques (see section on Field Methods). The core SB1c was described in the COE, New Orleans District, soil test laboratory. Both measured and compaction corrected (in parentheses) depths are given in the description. Many of the samples analyzed for this study were from this core and are assumed to be representative of the marsh environment on the western edge of Lake Borgne.

St. Bernard core SB1c

0-55.0 cm (0-77.6 cm) peat; fibrous, plant fragments more identifiable toward surface; less compact toward surface; no apparent wood fragments; few very-small seeds; plant material appears to be reed and grass fragments; 0-7 cm, 10YR 2.5/1-5Y 3/1, 7-26 cm, 2.5Y 2.5/0, 26-55 cm, 2.5YR 2.5/0

55.0-69.0 (77.6-97.3 cm) peat; fibrous, more compact than overlying interval, compaction uniform throughout; no obvious wood fragments, numerous reed and grass; uniform 2.5R 2.5/0

69.0-82.5 cm (97.3-116.3 cm) peat; fibrous, same as above except color change to 5YR 2/1.5

82.5-86.5 cm (116.3-122.0 cm) clay; upper and lower contacts are irregular and abrupt; 5Y 3/1

86.5-121.0 cm (122.0-170.6 cm) peat; compact, fibrous, particularly odorous, peat; finer textured than in 0-82.5 cm, fewer plant fragments than in 0-82.5 cm; 7.5YR 2.5/1; abrupt to clear lower contact

121-140.5 cm (170.6-198.1 cm) peat; 121-124.7 cm very finely disseminated organics, smooth with few to no plant fragments, 7.5YR 2.5/0; 124.7-140.5 cm increasing number of fragments or fibers downward with identifiable changes (abrupt to clear contacts) at 134.5 cm and with the underlying organic clay.

140.5-162.5 cm (198.1-229.1 cm) organic clay; organic matter content appears to decrease downward to 162.5 cm; 140.5-146.0 cm, 7.5YR 2.5/0; 146-158.5 cm 10YR 3-2.5/1; 158.5-162.5 cm, 7.5YR 2.5/0; very finely disseminated organics throughout, very few fibers, clear lower contact

162.5-218.0 cm (229.1-307.4 cm) peat; fibrous, clay content increases upward, 7.5YR 2.5/0; 190.25-191.0 cm clay lens, 7.5YR 3/0; abrupt lower contact.

218.0-233.5 cm (307.4-329.2 cm) organic clay; indistinct layers, more organic and fibrous in basal 3.0 cm with some fibers throughout, bioturbated throughout; 7.5YR 3/0; clear to abrupt lower contact.

233.5-277.0 cm (329.2-390.6 cm) peat; very finely disseminated organics with only few discernible plant fragments, large 4 cm-wide x 6 cm-deep burrows at top; 0.5-0.75-cm thick organic clay at 249.0 cm; bioturbation and clay content increases downward in basal 20.0 cm; abrupt stepped lower contact (irregular); 7.5YR 3/0

277.0-282.0^{+} cm (390.6-397.6+ cm) gray clay; N4; small black organic blobs with plant material throughout.

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FIELD METHODS

L.D. Britsch and D.L. Dillon

Two or more cores were taken at each study site. Sampling technique(s) were determined by conditions at the site from the numerous techniques commonly used for sampling the saturated peats of the Mississippi River deltaic plain. The main considerations at each site were the degree of saturation of the substrate and the depth of sample. In the marshes, all access was by boat, and the water table was at or above the marsh surface.

At the St. Bernard locality, one long core, about 4 m in length, and two short cores, each about 1 meter in length, were extracted. All cores were taken using a vibracore sampler (fig. 5). This technique allows retrieval of continuous, undisturbed samples from unconsolidated saturated sediments. The vibracore works on the principle of liquefaction in fine-grained sediments by displacing sediment to allow passage of the core barrel (Smith, 1984). The effectiveness of the vibracore in relation to penetration and recovery is directly related to the engineering properties of the material being sampled. The vibracore works best in saturated clays, silty clays, silts, and fine sands, but is very inefficient in firm clays and medium to coarse sands. The vibracore system is portable allowing retrieval of relatively long (up to 10 m) undisturbed samples in marsh settings.

FIGURE 5. Photograph of vibracore equipment used to drill the marsh site in St. Bernard Parish, southeastern LA.

The vibracore equipment consists of a 5 horsepower gasoline engine connected to a hydraulic pump and a 15.24 m (50 ft) flexible hydraulic hose attached to a hydraulic vibrator head. For the short core the vibrator head was attached to a 7.62 cm (3 in) inside diameter, 1.27 m (5 ft) length of aluminum irrigation pipe by a quick release clamp. The bottom of the sample tube was cut on a 45 degree angle and sharpened to aid the penetration during sampling. To obtain the sample the pipe was vibrated into the marsh at a low frequency. After the pipe had reached its maximum penetration, the pipe was cut with a hacksaw approximately 0.3 m (1.0 ft) above ground surface. Compaction was then measured as the difference between the marsh surface and the top of the sample inside the pipe. A 7.62 cm (3 in) diameter packer was placed in the end of the pipe and tightened to create a vacuum preventing sample loss. Extracting the core was accomplished by digging a shallow trench adjacent to the sample tube, tilting the sample tube into the trench, and lifting the sample from the substrate. After retrieval, the sample was measured, the sample tube was wrapped in aluminum foil, secured with duct tape on each end, and labeled to indicate top and bottom and location. The same procedure was followed to obtain the longer core except that a 5 m (19.7 ft) section of irrigation pipe was used to obtain a greater depth of penetration. Sample tubes were transported to the laboratory in the horizontal position to minimize movement of material in the tubes.

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^{14}C AGE DETERMINATIONS

J.P. McGeehin

Two cores from the St. Bernard parish core locality were analyzed for ^{14}C resulting in 40 radiocarbon ages. Both cores were taken using vibracore techniques. Dating of the organic carbon sequestered in the cores provides chronostratigraphic constraints that can be used to estimate variations in rates of carbon accumulation for marsh environments of the Mississippi River deltaic plain. The longer of the two cores (SB1c) is approximately 4 m (compaction corrected) and composed of peat to 3.91 m depth. The lowermost 11 cm of core is a blue-gray interdistributary clay. Samples were selected for ^{14}C dating based on visually observed stratigraphic breaks. The shorter core (SB1a) is about 1 m long, composed entirely of peat, and was sampled to analyze the peat for the ^{14}C bomb spike. The "bomb spike" is a measure of elevated ^{14}C activity as a function of the sharp rise in atmospheric ^{14}C levels resulting from above-ground nuclear testing in the 1950s and 60s. The atmospheric ^{14}C bomb peak occurred in the northern hemisphere between 1963 and 1964, although elevated levels of atmospheric ^{14}C can be traced from the early 1950s to the present day (Levin and others, 1985; Burchuladze and others, 1989). A similar peak exists for ^{137}Cs, and it was hoped that the peaks for the two isotopes would match and provide a useful marker with which to measure very recent carbon accumulation rates.

Fifteen ^{14}C analyses were obtained for samples taken from core SB1c. Most of these were run on bulk peat. Two samples were run on grass pieces with corresponding bulk peats at the same depth intervals. One sample was run on degraded peat fragments found in the basal interdistributary silt and clay. All samples were chemically pretreated to remove the inorganic carbon and loosely adsorbed humic acid fractions. The dried samples were then processed to graphite according to the method described in Markewich (*in press*). The graphite was pressed into targets and sent to Lawrence Livermore Laboratory's Center for Mass Spectrometry (CAMS) for ^{14}C analysis. Splits of the chemically-pretreated samples were analyzed for $d^{13}C$ using stable isotope mass spectrometers at the USGS in Reston, Virginia, Denver, Colorado, and Menlo Park, California. The ^{14}C ages were adjusted accordingly to account for naturally occurring fractionation effects.

Data for the SB1c core, including ^{14}C ages, the corresponding fraction modern values, $delta^{13}C$ values, and corrected versus uncorrected depths are shown in table 1. Analytical ages for the bulk peat samples range from approximately 200 to 3,200 yr BP. The sampling errors and the effects of environmental factors on radiocarbon age determinations, and the need to calibrate radiocarbon ages to available tree-ring data, are discussed in the last section of this report *Data Interpretation and Summary*.

TABLE 1. Data for ^{14}C age determinations for peat samples from core SB1c, St. Bernard Parish, LA.

Twenty-five ^{14}C analyses were obtained for core SB1a. The core was sampled at 2.54-cm (1 in) intervals for the entire one meter depth. The bulk of the bomb curve was determined to be above approximately 30 cm, so all the samples collected were not run. Because identifiable grass blades and (or) roots as well as more decomposed peat were found at some depths, for each depth interval, samples of both were selected for analysis. At the 25.9 cm interval, grass seeds were analyzed, in addition to the grass and peat. Possibly, when all the age data (isotope ages and microscopic stratigraphic markers) for the Mississippi River deltaic plain are available, some trend will be identifiable. Then, we may be able to ascertain which peat component is a most reliable age indicator.

TABLE 2. Data for ^{14}C age determinations for peat samples from core SB1a, St. Bernard Parish, LA.

All samples for core SB1a were pretreated and reduced to graphite. Sample results are shown in table 2. Note that the ^{14}C activity is expressed as $D^{14}C$ in addition to the ^{14}C age in years Before

Present (yr BP). This is because the ^{14}C activity in the samples affected by the bomb pulse is higher than the activity of the modern standard, resulting in a >MODERN age. The Delta^{14}C results are expressed as parts per thousand (per mil) values above the activity of the modern standard corrected to the current year from the "zero" year for ^{14}C of 1950. The Delta^{14}C data for core SB1a have been plotted in figure 6. The 1963-64 atmospheric bomb carbon peak can be seen clearly at approximately 15 cm. This results in an accumulation rate of approximately 0.5 cm yr^{-1} from 1963-64 to 1996 when the core was taken.

Note that all ^{14}C ages are reported as standard radiocarbon years, in years before present (yr BP), where BP represents 1950, the zero year for radiocarbon dating. The data have not been calibrated for variations in atmospheric ^{14}C level over time as measured in tree rings. The calibration corrections, which can be made using one of several computer software programs, will be made for the data as efforts proceed to accurately estimate the rates and amounts of organic carbon accumulation in the Mississippi River deltaic plain.

FIGURE 6. ^{14}C bomb curve for core SB1a, St. Bernard Parish, LA. Data corrected for compaction and ^{13}C.

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^{137}Cs ANALYSIS

T.L. Fries and J.H. Robbins

Ritchie and McHenry (1984) give an overview of the extensive use of ^{137}Cs for measuring soil erosion and sediment accumulation in reservoirs and lakes. The time dependence of ^{137}Cs fallout (t1/2=30.2 y) resulting from above-ground testing of nuclear weapons in the 1950s and 60s makes it an excellent tracer for determining rates of sediment accumulation. Commonly a distinct ^{137}Cs peak can be detected by analyzing closely (1-2 cm) spaced core samples. This peak is associated with the maximum rate of ^{137}Cs deposition during 1963 and 64. Rarely, a minor peak can be identified. In the United States this is commonly a secondary peak associated with testing in 1959 (Callendar and Robbins, 1993).

In the Mississippi River deltaic marshes, where there has been only in-situ sediment (peat) production, measurement of ^{137}Cs was carried out to develop an estimate of a mean linear rate of peat accumulation over the last 35 to 40 years. Hand-pushed cores are preferable for ^{137}Cs isotopic analysis, however, at the St. Bernard core locality, we could not get the sample material to stay in the sampling tube when the tube was pushed by hand. Therefore, ^{137}Cs measurements for the St. Bernard core locality are from core SB1b, one of two short (approximately 1m-long) vibracores. The vibracore technique produced intact short cores with less than ten percent compaction. By using a meter long sampling tube to obtain a short vibracore, instead of sampling the top of a longer vibracore, we minimized (or eliminated) the potential problem of contamination of shallow material with water that has been in contact with material from greater depths.

The whole frozen core (SB1b) was cut into 2-cm sections on a band saw. Each saw cut consumed 1 mm of sample length and each 2-cm measurement was made from the edge of the previous cut. As each section was cut the sample and the resulting aluminum ring were transferred to a pre-weighed plastic bag already marked with identification information. Air was removed from the bag, the bag was sealed, and the side of the bag corresponding to the top of the sample was marked. The sample/ring/bag combination was then weighed and the weight recorded.

Upon completion of ^{137}Cs measurements the bags were split open and the entire sample/ring/bag combination was allowed to air dry. When the samples reached constant weight the aluminum rings were removed, cleaned, dried and weighed. A dry sample weight was then calculated for use in ^{137}Cs calculations. Dry sample material was then archived.

Samples from the SB1b core were analyzed by placing the sample/ring/bag assemblage directly on a gamma counter. Each 2-cm section was counted for up to one day and data were recorded for both ^{137}Cs and ^{40}K. ^{137}Cs (661.6 KeV) and ^{40}K (1460.7 KeV) were determined by gamma spectroscopic analyses using a high resolution lithium-drifted planar (GeLi) detector coupled to a multichannel analyzer. Calibration was acheived by doping comparable materials with precisely known amounts of NIST-traceable standard solutions of radiocesium and weights of KCl. Detection limits for ^{137}Cs and ^{40}K were 2x counting error in decays per minute per gram (dpm g^{-1}). These detection levels account for most of the fractional counting errors of 1.5 -5 percent for the peat (table 3).

A plot of ^{137}Cs count rates (decays) versus depth (fig. 7) shows a characteristic shape with a peak normally associated with the years of maximum fallout, 1963-1964. Because a large portion of the shallow material from this core was discarded in the field and another section was lost during preparation it was not possible to accurately model and date deposition throughout the core. A date of 1963.5 can probably be assigned to the maximum ^{137}Cs count rate. Maximum ^{137}Cs activity was found at a compaction corrected center-of-section (midpoint) depth of 16.0 cm. Since the ^{137}Cs peak could be located anywhere in the sample interval, and the compaction corrected length of this interval is 2.2 cm, the uncertainty in the depth estimate is approximately 14 percent (about +/- 1.1 cm).

The ^{137}Cs curve (fig. 7) for core SB1b is a reasonable match for the ^{14}C bomb spike curve (fig. 6) for core SB1a. Based on the ^{137}Cs data the average linear accumulation rate at the SB1b site since 1963-64 is estimated to be 0.50 +/-0.04 cm yr^{-1}. This is the same rate indicated by the ^{14}C bomb spike data.

FIGURE 7. ^{137}Cs curve for core SB1b, St. Bernard Parish, LA.

TABLE 3. ^{137}Cs data for bomb-curve analysis of core SB1b, St. Bernard Parish, LA.

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BIOCHRONOSTRATIGRAPHY

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Potentially Useful Microscopic Stratigraphic Markers

The biochronostratigraphic portion of the USGS Mississippi River Basin Carbon Project seeks to use stratigraphic markers, in conjunction with the historical record, to provide relative and (or) absolute ages for core samples from marsh, swamp, lake, and floodplain environments. For cores from St. Bernard Parish, Louisiana (figs. 1, 4A-B), the ultimate purpose is to provide chronological control for sediments deposited between calendar year 1750 and 1950 (only the year, not A.D., is used herein). Potentially useful markers include: pollen grains, plant phytoliths, charcoal fragments, carbonaceous spherules, fungal spores, and lithologic storm indicators. The targeted era of the MBCP includes the colonial period (1717-1803) and the Americanization period (1803-1900) of Louisiana. The area around the St. Bernard core locality includes New Orleans, which was settled early and extensively. The historical documents of this era provide a detailed history with which to correlate sedimentary deposits. Historical syntheses, maps, personal journals, memoirs, and census data provide information on past patterns of land use, regional geography, and farming of the region. These records document several events which have produced chronologically significant markers. The events and their potential stratigraphic markers are discussed below and outlined in table 4 in the order of their occurrences.

TABLE 4. St. Bernard Parish, Louisiana cores - events and potential stratigraphic markers.

Heliophyte pollen.--The earliest dated event that would produce strategic stratigraphic markers for the colonial period is the settlement of New Orleans in 1717 by French colonists. As the native forest was felled for building material and to make room for agricultural fields, the thinning and/or removal of the canopy should be reflected in the sediment record as an increase in the pollen of sun-loving plants, heliophytes, especially members of the Compositae family (Whitehead and Sheehan, 1985).

Cultigen pollen and phytoliths .--Commonly in the historical sediment record, the increase in Compositae pollen is followed by the appearance of non-indigenous agricultural crop pollen. In the St. Bernard area, sugarcane *(Saccharum officinarum)*, rice *(Oryza sativa)*, cotton (*Gossypium hirsutum*), potatoes (*Solanum tuberosum*), sweet potatoes *(Ipomoea batatas)*, and peas and beans (Leguminosae family) were introduced and cultivated. Corn *(Zea mays)* is indigenous to the Americas; however, European colonists adopted corn and expanded its cultivation.

Phytoliths, in conjunction with pollen, can be used to achieve higher taxonomic resolution within the Graminea fossils. Sugar cane and corn were the major cash crops cultivated in the St. Bernard area (Menn, 1964). Pollen of sugar cane and corn are not readily distinguishable. They are both members of the Graminea family, a family whose taxa produce similar pollen. However, Piperno (1988) suggests that some taxa of this family may be differentiated based on phytolith morphology.

Sporomiella spores.-- Domesticated livestock came with European settlement and cultivation. Davis (1987) identified the fungus *Sporomiella* as a palynological marker for determining the arrival of these animals. *Sporomiella* is commonly associated with the dung of herbivores.

Although *Sporomiella* spores have been found in some prehistoric sediments, their abundance increases following the introduction of domesticated grazing animals. The first census of New Orleans, taken in November 1721, records 36 cattle, nine horses, and no pigs or sheep (DuFour, 1968), therefore, *Sporomiella* spores may be present or shown an increase in the sediments of that period.

Charcoal layers.-- Charcoal layers can be associated with historical events, and, in association with other stratigraphic markers, may be chronologically significant. In 1788, and again in 1794, when virtually all structures were wood, New Orleans was heavily damaged by fire. The 1788 fire destroyed about 75 percent of the city, (de Rojas, 1937). The fire of 1794, although not as destructive as the 1788 fire (Arthur, 1937), destroyed one third of all residences (Fortier, 1904). As a result of fire, particulate charcoal would have blanketed the surrounding landscape, and runoff would move charcoal from the burned city into small waterways that feed the estuaries, where it would be incorporated into the sediment record.

Carbonaceous spherules.-- Carbonaceous spherules are indicators of urbanization and industrialization. The spherules are produced when resinous wood, oil, or coal are incompletely burnt and the volatile components vaporized, leaving a microscopic spheroidal skeleton of elemental carbon (McCrone and Delly, 1973). Following their release to the atmosphere via chimneys and smokestacks, carbonaceous spherules become incorporated into the sedimentary record.

Decrease in Taxodium distichum *(bald cypress) pollen.*-- The early settlers of Louisiana quickly learned that *Taxodium distichum* (bald cypress) wood resists decay, making it ideal for construction and for use in shipping containers. Although the technological infrastructure required to log Louisiana's extensive cypress swamps developed slowly, by 1890 there was industrial-scale logging operations. By 1925, the cypress swamps were so heavily denuded that commercial logging was no longer cost efficient (Norgress, 1947). The result was also an abrupt decline of *Taxodium distichum* in the sediment record.

Hurricane layers.-- Several hurricane landfalls in Louisiana have been documented in the historic records of the study area. Category 4 or 5 strength hurricanes on the Saffir-Simpson scale leave distinctive sedimentary strata (Liu and Fearn, 1993). Although the Saffir-Simpson scale was not developed until 1977, eyewitness descriptions indicate that some of the early hurricanes approached or achieved these intensities. For example, the hurricane of September 11, 1722, destroyed every home in the fledgling village of New Orleans (DuFour, 1968). In addition to stratigraphic signatures, hurricane surges can deposit open marine microfossils in coastal zones. Both the strata and the microfossils can be diagnostic stratigraphic markers.

Sample Processing

To examine the St. Bernard sediment record for the historic events, each of the potentially diagnostic microscopic stratigraphic markers had to be isolated. The isolation of these markers required four different processing techniques. Details of these processing procedures are given in Markewich (*in press*). The samples processed for each analysis are listed in table 5.

Pollen grains and fungal spores were isolated from twenty-two, 0.9 ml core samples according to the methods of Faegri and Iversen (1964). Sediment samples were processed to recover dispersed phytoliths by oxidizing organic matter and dissolving carbonate using procedures developed in the CENEX laboratory at LSU. Reference phytoliths were prepared from plant samples by heating in a furnace to reduce the organic matter to ash according to standard processing procedures. Charcoal and opaque carbonaceous spherule analyses (OCS) were conducted on the same sample preparations and slides. These were prepared by acid digestion to remove mineral matter and oxidation to remove all organic matter.

TABLE 5. Sample depths and analyses for microscopic markers in core SB1c, St. Bernard Parish, LA.

Pollen

Data.--Absolute pollen counts of selected taxa observed in the SB1c core are presented in figure 8. In the interest of clarity, rare and chronologically/environmentally non-diagnostic taxa were omitted from the diagram. Seven zones were defined in the core and are described in table 6, from zone 1 (oldest) at the base of the core to zone 7 (youngest) at the top of the core.

FIGURE 8. Pollen diagram for core SB1c, St. Bernard Parish, Louisiana.

FIGURE 9. Photographic plate of diagnostic pollen and other microfossils for core SB1c, St. Bernard Parish, LA. A. TCT (Taxodiaceae/Cupressaceae/Thuja); B. Cheno-Am (Chenopodiaceae-Amaranthaceae); C.*Typha latifolia*; D. Graminea; E. Cyperaceae; F. Compositae (high spine); G. *Vigna luteola*; H. foram test lining.

TABLE 6. Discussion of pollen zones depicted in Figure 8.

Discussion of the Pollen-Defined 1700 to 1900 Sediments.-- Based on their pollen assemblages, Zones 5 and 6 are considered to represent the time intervals 1350 to 1890, and 1890 into the mid-twentieth century, respectively (uncalibrated conversion from ^{14}C ages to calendar years). These zones correspond to the radiometrically undatable zone targeted by this research project. Although some of the predicted stratigraphic markers were observed in core SB1c, others were not. In addition, unanticipated markers made substantial contributions to the interpretation of Zones 5 and 6. Four of the strategic markers are discussed in this section.

1. As predicted, a rise in Compositae pollen served to delineate the pre-historic from the historic sediments.

-----1a. The appearance of *Vigna luteola* in this zone, unexpectedly, confirmed this interpretation. *Vigna luteola* is a legume which originated in central Africa and was long cultivated throughout Africa, south Asia, and the Mediterranean. It was introduced into the New World via the Spanish West Indies and diffused from there. As early as 1714, *Vigna luteola* was being cultivated in North Carolina (McKee, 1948, p. 725). Because of its Old World origin, the appearance of *Vigna luteola* provides a maximum age of contact (1492), however it is more probable that the legume was introduced into the study area after settlement began in 1717.

FIGURE 10A. Photograph of 1845 map showing the historical geography of Mississippi River from just east of New Orleans to the bird's foot delta (La Tourrette, 1845). The St. Bernard core locality is indicated by the white circle.

FIGURE 10B. Photograph of 1845 map showing: (1) position of St. Bernard Parish core locality (white circle) on Conseil Plantation lot, and (2) the railroad used for transportation

of agriculture and wood products. This is a close up of part of map in figure 10A (La Tourrette, 1845).

Core SB1c was taken from land which was once part of the Conseil Plantation of the Villeré family in a region historically rich in agricultural products (fig. 10). General Jacques Philippe Villeré, the founder of Conseil, was Louisiana's second governor under the American regime and the first native born governor of the state (Villere, 1981). Due to General Villeré's prominent social status, many records exist concerning his public and private life. In 1828, Karl Bernard, the Duke of Saxe-Weimar-Eisenach, visited and described the Villeré property.

> "Back of the elegant mansion-house stand the negro cabins, like a camp, and behind the sugar-cane fields, which extend to the marshy cypress woods about a mile back, called the cypress swamp... The whole [of the living quarters] is surrounded by cane fields, of which some were brought in, and others all cut down. A field of this description must rest fallow for five years and be manured, before being set out again in plants. For manure, a large species of bean is sown which is left to rot in the field, and serves the purpose very well." (Bernard, 1828)

TABLE 7. Selected Entries of the 1860 Census of the Large Slave holders of Louisiana (Menn, 1964).

An 1860 census of the large slave holders of Louisiana records the products of the plantations in the area of St. Bernard core locality (Menn, 1964). The census included the Conseil Plantation, which, in 1860, was under the management of Edmon Villeré, General Villeré's grandson (table 7). The data provide an index of types of pollen to be expected in the core.

No sugar cane pollen was indentified in sediment from the St. Bernard cores. Sugarcane (*Saccharum officinarum*) is a member of the Graminea family. Its pollen is very similar to that of other grasses. If sugar cane pollen grains were present in the core, they were probably grouped in the general Graminea category. The fact that sugar cane rarely flowers in Louisiana (it is replanted from cuttings) suggests that sugar cane pollen would not be common in the marsh sediment

A search of the historical literature of the study area revealed that *Vigna luteola* can probably be considered a "pollen proxy" for sugar cane. In Bernard's journal entry of his visit to the Conseil Plantation, he describes General Villeré's practice of restoring nitrogen to his sugar cane fields with "a large species of bean" which was sown and left to rot in the fields. Literature on southern agriculture of this period indicates that this bean was likely *Vigna luteola*, a cowpea (Gray, 1941, p. 824; Sitterson, 1953, p.126).

As discussed above, *Vigna luteola* makes its appearance in Zone 5, and although never abundant, its presence reflects the cultivation of sugarcane in the area. Because *Vigna luteola* is insect pollinated (Mackie, 1946), and its pollen is not produced in large quantities, it is unlikely that its pollen would have been deposited at the core site without the Villeré's practice of letting the peas rot in place, a practise not common in Louisiana until the 1840s (Sitterson, 1953). The association between *Vigna luteola* and *Saccharum officinarum* provides a new and distinctive marker for the cultivation of sugarcane in Louisiana, the southeastern United States, and possibly the Caribbean Islands.

-----1b. The census of 1860 records Indian Corn *(Zea mays)* as Conseil's second largest crop, yet there is no pollen evidence of this cultigen in the St. Bernard core. Although *Zea mays* produces 2,500 pollen grains per anther, the grains are large and not very buoyant in the air (Lewis and others, 1983). As a result, *Zea mays* pollen typically settles out within 0.5 km from the parent plant (Purseglove, 1972). To increase the probability of finding the rare, and typically large, pollen grain of cultigens in pollen preparations, a sieving and large fraction scanning (LFS) method was developed by Gish (1994). Although we conducted LFS, no *Zea mays* pollen was recovered. The 0.5 km travel distance of *Zea mays* pollen is much less than the 2 -3 km distance between the Villeré corn fields and the core locality and probably explains why no *Zea mays* pollen was found in the St. Bernardcore.

Given the placement of the St. Bernard core on the plantation, it is an enigma why only one cultigen pollen was recovered from the core sediment. We hypothesize that the taphonomy of the expected cultigen pollen (i.e. pollen production, dispersal,deposition, and fossilization) did not allow widespread pollen dispersal.

2. Despite the region's1860 domestic herbivore population (Table 6), *Sporomiella* spores were not positively identified in core SB1c. The absence is probably due to location of the core locality in the deltaic marsh, at the back of the Villeré property, beyond the cypress swamp where the plantation's domestic herbivores were not likely to roam.

3. A decline in *Taxodium distichum* (bald cypress) pollen was predicted based on (1) the intensive logging of this species between 1890 and 1925, and (2) census records and accounts from the Villeré plantation suggesting that clearing for row crop cultivation was common in the early 1800's in the area around the St. Bernard core locality. A decline is seen in the TCT (Taxodiaceae/Cupressaceae/Thuja) category in Zone 6. Although the pollen of the TCT category are difficult to distinguish from one another, the decline of TCT pollen in this area is being attributed to the historically documented decline of *Taxodium distichum* due to logging, most likely in the mid1800's.

4. No hurricane sediment layers were noted in the SB1c core.

Phytoliths

Introduction.--Phytoliths are deposits of opaline silica (SiO_2) or calcium oxalate secreted in or between plant cells, usually as a normal part of growth (Piperno, 1989; Jones and Bryant, 1992). Phytoliths of either composition may exhibit distinctive morphologies (Piperno, 1989). This study is concerned only with siliceous phytoliths (hereafter referred to as "phytoliths").

Phytolith taxonomy is complicated. The leaves, stem and roots of many plants may produce quite different looking phytoliths. In addition, similar looking phytoliths may be produced by different plant species, genera or even families. This contrasts markedly with pollen or spores, a single morphology of which is typically characteristic of a particular plant genus, or even species, and carries the name of that plant (at least with regards to extant plants).

Another complicating factor is that relatively few plants have been processed to determine what types of phytoliths they actually produce. This is especially true of Old World domesticated plants (Piperno, 1988). It is important to have a phytolith reference collection of plants in a study area with which to compare dispersed phytoliths recovered from sediments.

For the above reasons, phytoliths are often designated by descriptive morphologic terms (for example, circles, wagon wheels, bi-spinose rods, and so on) rather than by binomial names of the Linnean classification system. A morphologic designation is used until a correlation between a phytolith morphologic type and a particular plant taxa is made, permitting the name of that plant to be assigned to that phytolith morphologic type. Most forms reported here are referred to by informal morphologic designations.

FIGURE 11. **Phytoliths and other siliceous microfossils diagram for core SB1c, St. Bernard Parish, LA.**

No phytoliths of cultigens (for example, corn, sugar cane, cow peas, and so on) have been identified with certainty in the St. Bernard core sediment. Despite the negative results, the analytical results are discussed because of the potential in using phytoliths as strategic stratigraphic markers.

Results.--Some of the dumbbell or rod shaped phytoliths attributed to grasses may well have been produced by sugar cane. Abundant and diverse phytoliths were recovered from all samples processed. (See " Processing for Strategic Microscopic Stratigraphic Markers " in Markewich [*in press*] for the processing procedures used.) Commonly, a non-terrestrial siliceous component consisting of diatoms, sponge spicules and rare silicoflagellates were present. All elements were included during counting to characterize the entire siliceous residue from each sample. In addition, inertinite (charcoal) was counted along with the siliceous microfossils as a possible indicator of fire. Absolute counts of phytolith types observed in core SB1c are presented in figure 11 and table 8.

Most phytolith types recovered during this study have not been attributed to a specific plant taxa. Specimens of modern marsh plants are being processed to build a comparative phytolith collection with which to make such attributions (See discussion of the "CENEX Phytolith Reference Collection" in (Markewich, 1997). The most abundant phytoliths recovered are the various types of rods and irregular forms, though in some samples sedge (Cyperaceae) and saddle phytoliths are numerous. Dumbbell, biserial and uniserial spinose rods, non-spinose rods and saddle shaped phytoliths have been attributed to grasses based on studies in other areas and environments (Mulholland and Rapp, 1992; Twiss, 1992; Twiss and others, 1969). Marsh grasses probably produced many of the forms recovered from the St. Bernard core samples, though sugar cane, itself a grass, also produces dumbbell phytoliths (fig. 12) similar to those of other grasses. It is not possible at this time to determine if any of the dumbbell phytoliths in the core samples were produced by sugar cane or if all were produced by marsh grasses.

FIGURE12. **Diagnostic phytoliths and other siliceous microfossils present in core SB1c, St. Bernard Parish, LA. A. Dumbbell, produced by various grasses; B. Biserial spinose rod; C. Non-spinose rod; D. In situ dumbbell phytoliths in a modern sugarcane fragment; E. Cyperaceae (type); F. Cyperaceae (type), brownish coloration does not show but is probably due to burning from fire; G. centric and pennate diatoms.**

TABLE 8. **Phytoliths and other siliceous microfossil data for core SB1c, St. Bernard Parish, LA.**

Phytolith morphologies that can be attributed to particular plant groups include:

GRASS: dumbbell, cross, saddle, circle, biserial spinose rod, uniserial spinose rod, non-spinose rod (Mulholland and Rapp, 1992; Twiss, 1992). Non-spinose rods also are produced by some cereals, such as wheat (Kaplan, Smith, and Sneddon, 1992). The core locality is in an area that has been a marsh on the margin of a cypress swamp at least since European settlement; therefore, wheat has probably never been grown in the area.
SEDGE (Cypernaceae): polygonal plates with a verrucate surface and satellite bumps, or rounded and smooth hat-shaped forms. (Some samples contained brown or grey phytoliths that indicate the sedges were burned.)
PALM: spheres (some)
CRYSTOPHYTES: cysts
UNKNOWN: spheres (some), irregular shapes, wagon wheels

Charcoal

The concentration of charcoal in sediments can be used in conjunction with with other microstratigraphic marker data to refine the chronostratigraphy of the cores, particularly in reconstructing the history of natural fires, for example, (Terasmae and Weeks, 1979) or man-made fires (Iversen, 1941; Tolonen, 1978). The latter include those ignited for land clearing, the sacking of cities, industrial activity, and by accident. (See Tolonen (1986) for an overview of charcoal analysis.) Potential contributors of particulate charcoal in the St. Bernard cores include: natural marsh fires; burning of agricultural fields; clearing of the cypress forests; wood burning sugar mills, river boats and trains; major fires in New Orleans; military action during the War of 1812 and the Civil War; and redeposition of old carbon (inertinite). Data for core SB1c are in table 9 and figure 13.

FIGURE 13. Concentration diagram of charcoal and carbon spherules from SB1c, St. Bernard Parish, LA.

Organic Carbonaceous Spherules

Introduction.--One of the particulate emissions produced by the high temperature combustion of oil, coal or resinous woods is organic carbonaceous spherules (OCS), commonly composed of elemental carbon (Rose, 1990). OCS can be transported considerable distances, depending on their aerodynamic characteristics and local weather conditions at the time of burning. Because they are inert, they are preserved and accumulate in sediments (Renberg and Wik, 1985). Although OCS appear similar when viewed with a transmitted light microscope (fig. 14A), OCS produced by by oil (fig. 14B), and those produced by wood or coal (fig. 14C), generally can be distinguished from one another using scanning electron microscope (Griffin and Goldberg, 1979).

OCS have been used to document the geographic and stratigraphic distribution in sediments of atmospheric pollutants generated by burning fossil fuels (Griffin and Goldberg, 1981; Renberg and Wik, 1985; Rose, Harlock, and others, 1995). They also have been used stratigraphically, in conjunction with palynology and ^{210}Pb radiometric dating, to provide relative ages of sediments, such as intertidal sediments in eastern Long Island Sound (Clark and Patterson III, 1984). OCS and historic records are used in this study to mark the advent of coal and oil burning, and to refine age estimates of the deposits.

The numerous sugar cane plantations in the St. Bernard area in the 1800's used railroad lines as well as wagons for transportation of goods. The core locality is within 7 km of both the old line of the Mexican Gulf Railroad (built in 1853) and the Mississippi River (figs. 10A, 10B), both were sources of OCS. Si,ilarly, the steam powered sugar-processing mills on the plantations, and the various river and ocean-going steamboats that plied the Mississippi River were all generating OCS. The type of OCS produced depended on the fuel being used - wood, coal, and (or) oil; the type produced changed through time.

Coal OCS.-- The first coal powered steamboat to arrive in New Orleans, the *New Orleans*, docked in 1814 (Hunter, 1949), however, before the 1850's steamboats on the Lower Mississippi rarely burned coal, and then it only on the down river leg. Wood was burned on the return, up river voyage because it was cheaper and readily available (Hunter, 1949). Wood was the major steamboat fuel until well after the Civil War.

The first coal barges reached the New Orleans area in 1829; their contents consigned to the Labranch Plantation (Fossier, 1957, p. 25) to power the plantation sugarmill. This event provides the maximum age for coal-generated OCS in the area.

Coal became widely used in the lower valley by the 1880's for sugar mills, steamboats and steam locomotives. It was the dominant fuel used in all ocean going steamships, and merchant or naval vessels, that visited New Orleans until the beginning of the 20th century (Milton, 1953). Even by the beginning of the Second World War, 60 percent of all oceangoing steamships were still coal powered (Milton, 1953).

Oil OCS (also called liquid fuel, crude petroleum, or petroleum residue).--Oil was little used, alone or mixed with crushed coal, on merchant or warships before 1900 (Beig, 1906). It was well into the first decade of the 20th century before navies and merchant marines began switching to oil. Laminated OCS (fig. 9B), produced by the incomplete combustion of fuel oil (Griffin and Goldberg, 1979) provide a horizon marker for the first decade of the 20th century.

TABLE 9. Carbonaceous spherule data for core SB1c, St. Bernard Parish, LA.

Discussion of OCS data.--The lowest verified occurrence of OCS is at 85 cm. These are wood or coal OCS that probably mark the advent of high temperature wood or coal burning in the area. The maximum age for OCS at 85 cm, if produced by burning coal, could be 1814 when the first steamboat arrived in New Orleans; it was coal burning (Hunter, 1949). However, significant steamboat traffic did not develop in the Lower Mississippi Valley until the 1820's, and these were wood burners until the 1850's. If the OCS at 85 cm were produced by the burning of coal, the maximum age would more likely coincide with the arrival of the first coal shipment to New Orleans in 1829 (see *Coal OCS* above). The appearance of oil OCS at 56 cm suggests a maximum age of 1900-1910 (Milton, 1953; Gardiner and Lambert, 1992).

If the first appearance of coal OCS was around 1830, and a linear rate of accumulation is assumed, then the rate of organic matter accumulation in the marsh from 1830 to 1900 was about 0.4 cm yr^{-1}. If a linear rate is assumed, then from 1900 to 1996 OCS data suggest a rate of about 0.6 cm yr^{-1}. These rates bracket the 0.5 cm yr^{-1} rate suggested by ^{14}C (core SB1a) and ^{137}Cs (core SB1b) data (tables 2 and 3) for the period from 1964 to 1996.

FIGURE 14. Carbonaceous spherules present in core SB1c, St. Bernard Parish, LA.

Summary/Conclusions for Microscopic Stratigraphic Markers

Microscopic stratigraphic markers were used to subdivide the segment of core SB1c that covers a time interval no older than 1717 to about 1900, from 85 to 55 cm depth (fig. 13). Diagnostic stratigraphic markers were also used to achieve chronological resolution within this sediment segment.

FIGURE 15. Composite diagram of diagnostic microfossils from core SB1c, St. Bernard Parish, LA.

1. Carbon isotope ages and the presence of diagnostic microscopic stratigraphic markers suggest that the founding of New Orleans in 1717 occurred sometime during deposition of sediments between 106 and 85 cm depth. A ^{14}C age of 550 ± 50 yr BP at 106 cm (about 1350-1450 in uncalibrated conversion from ^{14}C ages) (table 1) provides a lower age limit. The age estimate at 85 cm is interpreted from the pollen and OCS data which indicate that this level dates to about 1830 (tables 5 and 8).

The relative age of about 1830 at 85 cm was determined by three stratigraphic markers. First, the appearance of *Vigna luteola* at 85 cm provides a maximum age equal to that of settlement, 1717. The probable age of sediment at 85 cm is about 1830. This is based on records of the Conseil Plantation which describe the use of *Vigna luteola* for fertilizing the plantation fields date from the mid 1820s. Second, the estimated number of OCS cm^{-3} at 85 cm is too few to plot on figure 13, however the first appearance of coal OCS at 85 cm suggests an 1829 maximum age for this level, coincident with coal being burned in area sugar mills. And, third, the beginning of the increase in Compositae pollen at 85 cm reflects land clearing activity and is consistent with the *Vigna* and coal spherule record.

2. The peak of wood/coal OCS at 71 cm provides the second chronological horizon within the targeted sediments and is attributed to wood and coal combustion in mills, steamboats, and steam locomotives during the mid1800's, probably between 1860 and 1880. The drop in TCT, probably *Taxodium distichum* (bald cypress), at this level could indicate a later date of 1890, the period of large-scale regional cypress logging. The charred Cyperaceae phytoliths and abundant charcoal at this level suggest that this is a fire horizon, probably associated with cypress logging . Since land clearing in the area of the St. Bernard core began in the late 1700's and continued through the 1800's, the drop in TCT pollen probably documents accelerated local cypress logging in the mid 1800's rather than the 1890 regional increase in logging activity.

3. The uppermost identified horizon within the targeted sediments is at 56 cm. It is identified by the appearance of oil produced OCS, which came into common use around 1900. This is the transition period from steam to internal combustion engines.

4. The rise in aquatic taxa above 56 cm indicate a greater water to land ratio in the upper sediments of the core. This aquatic characteristic is in contrast to sediments below 56 cm which have more terrestrial components. This shift is likely due to the removal of the cypress trees, the roots of which acted as sediment traps, and to the construction of the MR-GO and other canals through the marshes.

5. Finally, an important diagnostic marker in the St. Bernard SB1c core is *Vigna luteola* It is important not only as a stratigraphic marker, but also as a proxy for sugar cane cultivation. This is particularly relevant given the low flowering frequency of sugarcane in Louisiana. Using

Vigna luteola as a proxy for sugar cane may prove to be an important new palynological tool for dating historical deposits in Louisiana, the southeastern United States, and perhaps the Caribbean area.

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COMPOSITIONAL ANALYSIS

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Chemical and Isotopic Analysis and Carbon Fractionation

We analyzed the chemical composition of the peat in order to determine (1) the relative content of organic carbon (OC) and inorganic constituents, and (2) track the relations between relative percents of organic and inorganic constiuents to climate and (or) human activity. *Chemical and Isotopic analysis.*-- Samples from each of the three St. Bernard cores were analyzed for bulk density (BD) (tables 3, 10, and 11). Cores SB1a and SB1c were analyzed for (a) total carbon and inorganic carbon by a UIC CO_2 coulometer, equipped with a furnace for the determination of total carbon and an acidification module for the determination of carbonate carbon; (b) OC by difference; (c) total N, ^{15}N, total C, and ^{13}C by a VG Optima elemental analyzer/isotope ratio mass spectrometer system; and (d) inorganic elemental analysis (tables 10B and 11B) by extracting approximately 100 mg of air dried sample with concentrated nitric acid. This procedure provides a near total extraction for many elements including Cu, Pb, Zn, Mn and Fe (Luoma and Bryan, 1981; Graney and others, 1995). Elemental concentrations were determined using a Perkin-Elmer 6000 inductively coupled plasma mass spectrometer(ICP-MS).

Carbon fractionation.-- The total OC did not exceed 40 percent for any sample; values were commonly between 25 and 35 percent (tables 10A, 11A). Carbon fractionation procedures were designed to provide data that might allow differences in organic matter composition, and associated inorganic components, to be detected and related to transport or in-situ production. As previously mentioned, detailed procedures are described in Markewich (*in press*).

The limited amount of sample material available, and the high percentage of the total sample in the low density fraction, made it impossible to carry the procedure beyond the initial density fractionation for most samples. For the available sample size only those samples with less that 10 percent total carbon, dry weight basis, contained sufficient high density material for further fractionation. With the exception of the sample of interdistributary clay from the base of the SB1c core, the high density material from these low carbon samples contained less than 10 percent of the total carbon in the sample. The low-carbon samples were from sections of the core that had been visually described as clay. The low carbon content and small sample size made further fractionation impossible.

Summary and Interpretation of Compositional Data

Data for the SB1a core show shifts in organic C (OC), total N (N), ^{15}N, bulk density (BD) and carbon storage (CS) at two depth ranges (table 10A). OC and N decrease; BD increases. These shifts are also accompanied by shifts in a number of inorganic constituents including increases in aluminum (Al), iron (Fe), lithium (Li), lanthanum (La), cerium (Ce), thorium (Th) (table 10B), and calculated percent mineral matter (table 10A).

Some samples from the uppermost meter of core SB1c were analyzed for OC, N, and BD (fig. 16). Although values for the two cores are similar at comparable depths, the fine-scale variability present in the uppermost meter of peat is not adequately defined by the limited data from SB1c.

FIGURE 16 . Organic carbon, nitrogen, and bulk density profiles for cores SB1a and SB1c, St. Bernard Parish, LA.

FIGURE 17. Elemental chemistry profiles for cores SB1a and SB1c, St. Bernard Parish, LA: (A) aluminum, (B) iron, (C) manganese; (D) lithium, (E) sodium, (F) potassiuim; (G) calcium, (H) magnesium, (I) strontium; (J) arsenic, (K) cadmium, (L) lead; (M) copper, (N) nickel, (O) zinc; (P) vanadium, (Q) chromium, (R) cobalt, (S) lanthanum, (T) cerium, and (U) thorium.

Chemistry.--The first shift in constituents occurs from 18-12 cm. Many elements show peak concentrations at about 15 cm. ^{137}Cs data indicate that sediment at 16 cm in core SB1b (fig. 6, table 3) was the surface in 1963-64. Assuming an accumulation rate of about 0.5 cm yr^{-1}, the 18-12 cm interval in core SB1a is assigned an age range of 8 to 10 years, representing most the 1960s. This interval corresponds in time to the construction of the Mississippi River-Gulf Outlet (MR-GO) Canal (fig. 1), 1958-1968 (US Army COE, 1975). Higher concentrations of metals, such as nickel (Ni), copper (Cu), chronium (Cr), vanadium (V), and cobalt (Co) (figs. 17E, F) are coincident with the ^{137}Cs and ^{14}C peaks (figs. 6, 7). However, they are probably not related. The higher (albeit still low) trace metal concentrations are more likely related to a decrease in OC accumulation due to dry climatic conditions (Cook and others, 1997) or possibly to local emissions from idustrial sources and (or) to construction of the MR-GO Canal. The higher concentrations of crustal elements such as Al, Fe, manganese (Mn), Ce, La, and Th in this 18-12 cm depth interval support a natural rather than an anthropogenic source, suggesting that the increase in inorganic components is due to a decrease in peat production during a dry climatic interval. It is also possibe that the increase in inorganics is due to a large-scale Mississippi River flood or to a local disturbance, such as dredging for the MR-GO canal. Disurbance due to hurricane activity could also result in an increase in crustal and trace elements. We propose that the increase in inorganics (major and trace elements) is relative and that the increase in inorganics results in an increase in BD and corresponds to an area drought in the early 1960's (Cooke and others, 1997).

Below 18 cm, the Ni andCu levels drop off rapidly; similarly high levels are not seen in any other part of the core.

The second shift in core SB1a occurs between 42-29 cm with increases in the concentrations of almost all the inorganic constituents, including Al, and a 1.7X increase in BD (fig. 17). Although we ran whole-peat ^{14}C ages,which suggest that this section of core is 200-400 years old, we cannot calibrate the ages, so are not using them for age assignments to this part of the Sb1a core material. OCS data for core SB1c indicate that peat in the depth interval of 50-56 cm was deposited around the turn of the century, probably between 1900 and 1910 (table 9). If we assume a linear rate of organic matter accumulation (table 12) between 1905 and 1952, then the peak in concentrations of inorganic constituents and BD values occured in 1936-37. As with the shift in values from 18-12 cm, there is no identifiable clay and (or) silt lens associated with the shift between 42 and 29 cm. We speculate that the increase in BD values results from the increase in inorganic constituents. We suggest that the increases are climatically related and correspond to (1) the 1925 drought (Cooke and others, 1997), or (2) 1930's regional drying in the south-central U.S. The absence of an increase in Ca supports number 1, but neither hypothesis is proved by the available data.

Trends in the inorganic constituents show that the two intervals with noticeable shifts in data trends, 18-12 and 42-29 cm in core SB1a, occur during a period of generally increasing concentrations of metals such as Cr, Co, V, lead (Pb), and Cu beginning at a depth of about 60 cm. This gradual increase in metal concentrations is probably associated with the continued increase in the urbanization and industrilization of the New Orleans area. Zinc has a slightly different pattern that other inorganic constituents. Zinc (Zn) concentrations increase sharply at about 80 cm depth. If the age estimates are correct, then Zn concentrations increase during the 1800's, remain relatively high through the early 1900's, and then decline markedly until 1960 when they again increase. We hypothesize that the increase in Zn concentrations in the 1800's may be associated with the presence of a U.S. mint in New Orleans at that time (Collins, 1971), but when more data become available we may see that Zn is a proxy for human activity.

At corrected depths greater than 80 cm there appears to be an increasing trend in the concentrations of Al, Fe, Li, potassium (K), Co, La, Ce, Th, Pb, Zn, as well as in calculated percent mineral matter and BD. This trend continues to the bottom of the core SB1a at 100 cm. If looked at stratigraphically, then inorganics and BD *increase* upward toward an overlying clay layers and *decrease* upward from the clay layer The description of SB1c core in the *Geologic and Hydrogeologic Setting* section of this report support the analytical data.

TABLE 10A. Physical and chemical data for samples from core SB1a, St. Bernard Parish, LA

TABLE 10B. Major-element and trace-element data for samples from core SB1a, St. Bernard Parish, LA

TABLE 10C. Trace-element data for samples from core SB1a, St. Bernard Parish, LA

TABLE 11A. Physical and chemical data for samples from core SB1c, St. Bernard Parish, LA.

TABLE 11B. Major-element and trace-element data for samples from core SB1c, St. Bernard Parish, LA.

TABLE 11C. Trace-element data for samples from core SB1c, St. Bernard Parish, LA.

Mercury (Hg) was run for five samples from core SB1c (table 13) by methods described in Elrick and Horowitz (1986). There is an apparent increase in concentration toward the surface, similar to trends documented as early as the 1970s, from Canada (Thomas, 1972) and England (Aston and others, 1973). However, because all Hg values were at or below background values for most terrestrial sediment (commonly from 0.1-2 ppm; Förstner and Wittman, 1979), no other samples were analyzed.

TABLE 12. Mercury values for selected samples from core SB1c, St. Bernard Parish, LA.

Bulk density (BD).-- In general, BD data for SB1a (table 10a) and SB1b (table 3) are highly correlated, r^2=0.9. SB1a BD values range from 0.07-0.16 g cm^{-3}; SB1b BD values range from 0.07-0.18 g cm^{-3}. BD values for 10 and 64 cm depths in core SB1a are 0.11 and 0.09 g cm^{-3}, respectively. Values for the same depths, 10 and 65 cm, in core SB1c are equivalent, 0.10 and 0.09 g cm^{-3}.

There are clear shifts upward in BD values at the same depth increments, 12-18 and 36-42 cm, as seen in the inorganic constituents, suggesting that the increase inBD may result from the increase in percent inroganics (fig. 16).

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DATA INTERPRETATION AND SUMMARY

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Data for cores taken in a brackish marsh in St. Bernard Parish, near Chalmette, Louisiana can be use to indicate the rate of organic carbon (OC)accumulation for about the last 3 k yr. Compositional data allow estimates of the rate of decay as well as the rate of accumulation. Trends in the elemental chemistry of the peat deposits and in the microstratigraphic markers allow age/depth relations to be determined on a decadal time scale for the last 200 years. The combination of age and chemical data allows estimates of carbon storage for the cores. This section summarizes the data and shows how the data were used to determine sedimentation rates and carbon storage.

The successful application of various analytical techniques for determination of sediment age fulfilled a major goal of our investigation in the Mississippi River deltaic plain. The techniques and the results of their application are also summarized in this section.

Age Data

One of the problems inherent with using different methods of sample collection, particularly in peat, is accounting for the degree of compaction. Even when using one method in uniform parent material, just one change, such as the diameter of the sample tube, results in a major change in the degree of compaction. Using the same method with exactly the same equipment in what appears to be exactly the same type of parent material does not necessarily ensure the same degree of compaction. For instance, at the St. Bernard core locality, the 1-m cores SB1a and SB1b were less than 7 m apart and taken using the same vibracore techniques and identical 3-in (7.62 cm) diameter sample tubes (aluminum irrigation pipe). The measured compaction for SB1a was 7.3 percent; for SB1b it was 9.7 percent. Core length also affects compaction, as demonstrated by the measured compaction of 29 percent in 4-m long core SB1c located in close proximity to cores SB1a and SB1b. Thus, even with correcting for compaction, assigning an age to a given depth in one core to the same depth in another core is problematic without verifying data. In the case of the St. Bernard cores, C and Cs isotopic analyses were used for age determinations for the uppermost 25 cm of sediment. The comparison of first-appearance and peak-occurrence of microscopic stratigraphic markers with historical records was used for age determinations for the 85-50 cm depth interval (from about 1830 to 1910). The age of sediment below 1 m depth was determined by radiocarbon (^{14}C) analysis.

Several summary statements can be made concerning the ages of specific depth intervals in the surface 4 m of sediment at the St. Bernard core locality.

-Cs and C isotopic data for cores SB1b and SB1a, respectively, indicate that the sediment at 15-16 cm was land surface in 1963-64; the sediment from 25 -28 cm was land surface in the early 1950s, and is here considered to be background for above testing and is assigned to the year 1952.

-An increase in microforam linings in the uppermost 11 cm of sediment in core SB1c suggests that this interval of sediment post-dates cutting of the Mississippi River - Gulf Outlet canal (MR-GO canal) , 1958-1968.

-The appearance of oil-produced OCS at 56 cm indicates that sediment at this depth was the land surface no earlier than 1900, and marks the transition from steam to internal combustion engines.

-The peak of wood/coal OCS at 71 cm is attributed to the combustion of wood and coal in mills, steamboats and steam locomotives during the mid-1800's, probably between 1860 and 1880. The drop in TCT, probably *Taxodium distichum* (bald cypress), at this level could indicate a later date of 1890, the period of regional cypress logging. However, large-scale logging of cypress in and around New Orleans, including this part of St. Bernard Parish, occurred earlier than the region-wide clearing. So the decrease in TCT in the St. Bernard core samples reflects clearing activities in the mid 1800's.

-Assigned ages for the 56-200 cm depth interval are probably the most uncertain. First, there is the sampling error inherent with any compressed core material (discussed in the first paragraph of this section). Within the uppermost 1 m of core the sampling error probably puts a +/- of at least a decade on all assigned ages. Pollen, specifically *Vigna luteola*, and OCS data indicate that the probable age for peat at 85 cm is about 1830. However, if the increase in charcoal concentration at 71 cm is related to the 1788 New Orleans fire, and not to the logging of *Taxodium* (bald cypress), then the assigned age of 1830, based on microscopic stratigraphic markers, could be too young by 40 to 60 years. This is possible since it is known that*Vigna luteola* was introduced into the New World by the late 1700's. One argument against this older age assignment is the fact that the Conseil Plantation, which includes the St. Bernard core locality, was not established until 1790, and *Vigna luteola* was just not reported in the New Orleans area until 1828. If the 85 cm depth is assumed to represent the 1830 surface horizon, and a 0.5 cm yr^{-1} rate of peat accumulation is applied backwards in time, then the peat at 106 cm was the land surface in 1790. The reported ^{14}C age for sediment at 106 cm is 550+/- 50 yr BP (table 1). We suggest that neither the 1790 nor the ^{14}C age are definite. Even if a 40 to 60 year correction is applied to account for sampling error, the ages determined by matching

diagnostic stratigraphic markers with the historical record are at least 300 years younger than the 550 ± 50 radiocarbon age. As with the other ^{14}C ages the 550 ± 50 yr BP age need to be tree-ring calibrated and corrected for reservoir effects.
One source of error for all the radiocarbon ages is the use of just one standard deviation for an error bar. A more realistic error should probably be two standard deviations (table 1) . This would make the 1140 yr BP age at 166.4 cm and the 1000 yr BP age at 194.6 cm indistinguishable. The same would be true for the 1920 yr BP age at 235.5 cm and the 1980 yr BP age at 265.1 cm.
Also, all ^{14}C ages should be, but have not yet been, tree-ring calibrated. For example, the 550 yr BP age, including all error bars, when calibrated would most probably be equivalent to 1421-1327.
Another problem in the ^{14}C age determinations may be related to allochthonous material transported with the interdistributary silt and clay deposits and incorporated into the adjacent peat. There are two lenses of interdistributary silt and clay in the surface 2 m, at 82 and 158 cm. The material in these lenses could be the same age, but probably is older than the surrounding autochthonous peat.
The effects of environmental factors on ^{14}C ages also need to be considered. One example is the effect of marine water (Stuiver and Braziunas, 1993). Peats in the St. Bernard cores are saturated with brackish water. The reservoir effect of the water on the age of the peat needs to be determined.
Another source of error may be the effect of old carbon on plants growing in a substrate of similar but decomposed material such as discussed by Kilian and others (1995). We are presently involved in specific sampling and analyses of peat in the region to see if the problems with age determinations in this part of the sediment record can be resolved.

-Pollen and ^{14}C data indicate that by 1 ka marsh vegetation was fully dominant in this part of the St. Bernard delta; the Mississippi River had by this time migrated westward to form the LaFourche delta (fig. 3).

-^{14}C ages and palynomorphic data from this study, and^{14} ages from previous studies (Frazier, 1967; Törnqvist and others, 1996), indicate that floodplain and marsh vegetation began forming about 3 ka in this part of the St. Bernard delta.

-The 8420 ± 60 yr BP age on organic material in the interdistributary clay (at 396 cm in core SB1c) suggest a 5 k yr hiatus between the clay and the overlying peat. We hypothesize that the 8420 ± 60 yr BP age does not represent the real age of the clay, but only the age of the allochthonous (transported) material included in the clay. More data are needed to determine the true age of the clay.

Carbon Inventory - Accumulation and Storage

Data for incremental carbon storage for core SB1a shows a decreasing trend from 100 to 50 cm (fig. 18). The trend may possibly be related to the apparent increase in mineral matter content (table 10A) over the same period. Carbon storage in this depth interval also shows dramatic short-term shifts at those depths where shifts in bulk density are observed, 42-29 and 18-12 cm. The change in the pattern of incremental storage above and below 85 cm may be an artifact of not having good age control for the sediment record from 200-85 cm. Cumulative carbon storage is relatively unaffected by any of the perturbations in incremental carbon storage (fig. 18).

TABLE 13. Organic carbon cumulative mass and age-interval accumulation rates for cores Sb1a and SB1c.

FIGURE 18. Carbon storage: (A) incremental; (B) cumulative for cores SB1a and SB1c, St. Bernard Parish, LA.

An evaluation of carbon storage as a function of time (table 13, fig. 9), based on ^{14}C ages for core SB1c and ^{14}C bomb spike determinations for core SB1a and ^{137}Cs analysis of core SB1b, suggest that (1) the OC accumulation rate is reasonably constant through time; or, if the near surface data (0-85 cm) is viewed separately, then (2) the OC accumulation rates for about the last 200 years may be an order of magnitude greater than long term rates. Neither possibility can be proven or excluded using the data from this study. The higher rates in the upper 85 cm of core may be an artifact of our ability to differentiate time intervals. The 170 years, represented by the uppermost 85 cm of sediment, has an average OC accumulation rate of 0.20 kg m^{-2} yr^{-1}. While this seems high when compared to the long-term OC accumulation rate of 0.04 kg m^{-2} yr^{-1}, the 170 year interval represents only 1/8 to 1/4 the time represented by the sediment intervals between ^{14}C "dated' samples below 85 cm. It is entirely possible that periods of low or no deposition included in these longer time intervals are just not present in the shorter recent record. It may also be possible, that the ^{14}C ages, which have not been corrected for environmental variables, are significantly older than the actual ages. This possibility is reflected by the difference in grass and peat ^{14}C activities shown in figure 6. The most probable explanation is that there is an inherited OC fraction in the whole peat sample. As mentioned above, we are investigating the various sources of error in the analytical age dterminations.

FIGURE 19. Plots of carbon mass/area versus time (years before present) for the SB1c core, St. Bernard Parish, LA. (A) arithmetic plot showing apparent difference in recent (first four data points) and long term rates, (B) semi-log plot showing an exponential relation, and (C) log/log plot showing, that once the corrected age data become available, a decay constant can be calculated for the decomposition rates of marsh organic matter.

The wide variation in apparent OC accumulation rates for the last 200 years and for the period from 1,000-3,000 yr BP may also be explained by decomposition of organic matter over time, shown for the marsh environment as the difference in ^{14}C values for grass and peat in figure 6. Studies of organic matter breakdown in peat bogs have shown an order of magnitude difference in rates of loss of organic matter observed for young peats compared with the rates for older peats. Changes in decomposition processes with depth (aerobic to anaerobic) have been proposed as the major cause of this difference (Clymo, 1965, 1984). By fitting an exponential decay function to the time versus OC accumulation data, turnover times for organic matter can be estimated (fig. 19A, B, C). If OC accumulation is thought of as production, then the amount OC at a given time (t^1) is equal to the amount at t^0 plus the amount accumulating yr^{-1} minus the amount decomposed yr^{-1}. This method assumes a constant rate of loss as well as a constant rate of production and is limited by the accuracy of the dating methods. At present, the age data are not definitive enough for us to determine if the change in accumulation rates above and below 85 cm depth is real. The probability of material at a given depth being a certain age will be calculated as data from other marsh cores become available. Decay (decomposition) functions will be determined at that time. We anticipate that for cores SB1a and SB1c the long-term turnover (decay or decomposition) time will be between 2,200 and 5,000 years and that short-term turnover time will be between 80 and 250 years, similar to those described in Clymo

(1984).

A few summary statements can be made about OC accumulation rates and OC storage from analysis of the St. Bernard Parish, Louisiana, core SB1a and SB1c.

- Incremental OC accumulation values range from 0.15-0.37 kg m^{-2} cm^{-1} for core SB1a and 0.05-0.44 kg m^{-2} cm^{-1} for core SB1c.
- Cumulative storage for core SB1a is 27.8 kg m^{-2}. Cumulative storage for core SB1c is 132 kg m^{-2}.
- Variations in incremental storage do not seem to effect the near linear trend of cumulative storage.
- There appears to be a relatively constant primary production of organic material, despite annual variability. The OC accumulation rate decreases exponentially with age and is governed by a constant decay rate from the time of burial when all decomposition is anaerobic.

- OC inventory for the surface 1 m compares with values shown by Bliss and Waltman (1995) for this area. Their map, based on the STATSGO data base (USDA, 1991), places this part of the Mississippi River deltaic plain in two categories, from 24-41 kg $m^{-2}$and from 41-69 kg m^{-2}. An average depth of 1 m is assumed.
- The values shown on soil carbon map (Bliss and Waltman, 1995) are comparable to the 41.5 kg m^{-2} cumulative storage value for 127 cm depth in core SB1c. The rate of OC accumulation shown for core SB1a in table 13 corresponds well to rates determined by Smith and others (1983) for brackish and freshwater marshes in southeastern Louisiana.

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