8-5-2010

Late Quaternary Mississippi River Incised Valley Fill: Transgressive Depositional Packages

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A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
In partial fulfillment of the
Requirements for the degree of

Master of Science
In
Geology

by

Scott Wessels

B.S. Geology Kansas State University, 2007

August, 2010

ACKNOWLEDGEMENT

It would not be possible to complete a project like this without a significant amount of guidance, advice, camaraderie, and support. Thank you to everyone who took the time to discuss ideas, ask questions, and generally prepare me for the task of writing a Masters thesis.

I would like to thank my advisor, Dr. Mark Kulp, for directing me throughout this research experience and all the tireless hours he committed to guiding the development of this research. I must also thank Dr. Michael Miner for many valuable geological discussions and comments. Thank you to Dr. Royhan Gani for his participation on my thesis committee and contribution to the sequence stratigraphic content of my thesis.

I also thank the USGS for sponsoring the Northern Gulf of Mexico Cooperative Agreement that funded a portion of my research as well as Jim Flocks for providing access to previously unpublished deep borings. Thank you to the Barrier Island comprehensive Monitoring program for supporting me and providing many opportunities to experience firsthand the environments of coastal Louisiana.

Thank you to the University of New Orleans for supporting my research, and thank you to the Pontchartrain Institute of Environmental Sciences for supplying necessary field equipment along with an adept staff to operate it.

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ABSTRACT

A series of USACE atlas quadrangles and deep borings from the USGS and LGS with radiocarbon dated peats were used to construct several regional cross-sections and paleogeographic reconstructions. Late Pleistocene glaciation and consequent lowered sea level resulted in re-entrenchment of the Mississippi River incised valley. Meltwater floods from proglacial lakes incised into older deposits followed by braided fluvial (substratum) aggradation due to reduced carrying capacity after floods followed by meandering fluvial (topstratum) aggradation as fluvial gradients and discharge decreased. Rapidly rising sea level prevented development of shelf phase deltas prior to ~10 ka. Attenuated rates of sea level rise and periodic avulsions led to development and subsequent abandonment of several shelf phase deltas and barrier island arcs as well as gradual encroachment of the topstratum up the alluvial valley as aggradational depositon filled available accommodation space.

Keywords: Mississippi River, incised valley, topstratum, substratum, Late Quaternary, transgression

INTRODUCTION

Research Problem and Objectives

The modern Mississippi River delta plain and the processes that contribute to its formation have been described extensively by Fisk (1944, 1947, 1951, 1955, 1960, 1961), Fisk et al. (1954), Frazier (1967, 1974), Coleman and Gagliano (1964), Coleman and Prior (1980), Coleman (1976), Kolb and Van Lopik (1958, 1966), Törnqvist et al. (1996), Aslan et al. (1999, 2005), Blum and Törnqvist (2000), Blum (2007), Blum et al. (2008), Penland et al. (1987, 1988), and Kulp et al. (2000, 2002, 2005), focusing on deposition of shelf-phase deltas from 8 thousand calendar years ago (cal kya) to present—the middle to late Holocene. Since Fisk (1944), our awareness and understanding of the influence of sea-level on depositional systems and morphology has grown, and formed the basis for sequence stratigraphic perspectives by Frazier (1974) and later by Boyd et al. (1988, 1989a, 1989b), Kosters and Suter (1993), and Winn et al. (1995). To date there has yet to be a study aimed at revisiting the incised valley filling stratigraphy examined by Fisk (1944).

The presence of a Late Wisconsin incised valley below the modern Mississippi River delta plain (Figure 1.1) was first recognized by Fisk (1944) and provided a conceptual framework for developing modern models of fluvial response to changing base level. Fisk (1944) separated the deposits filling the incised valley into two primary units: substratum and topstratum, coarse-grained braided fluvio-deposits and fine-grained fluvial-deltaic deposits respectively. This study provides a chronostratigraphic framework for transgressive deposits that are within the Late Wisconsin incised valley and provides stratigraphic correlations offshore and updip to the Lower Mississippi River Valley. The substratum-topstratum contact is extended south beyond the latitude of Baton Rouge and a detailed chronostratigraphic analysis of valley filling topstratum deposits is provided.

To date there has not been a formal study that describes the lithostratigraphy and chronostratigraphy of the incised valley strata of the Mississippi River that are older than approximately 8 cal kya. Of particular interest to this project are: 1) the identification and documentation of key depositional surfaces and packages, 2) the timing of their formation and

3) their geographic extent. Knowledge regarding the timing and location of deposition provides the framework for better understanding depositional system changes forced by sea-level fluctuations and variation in fluvial sediment loads.

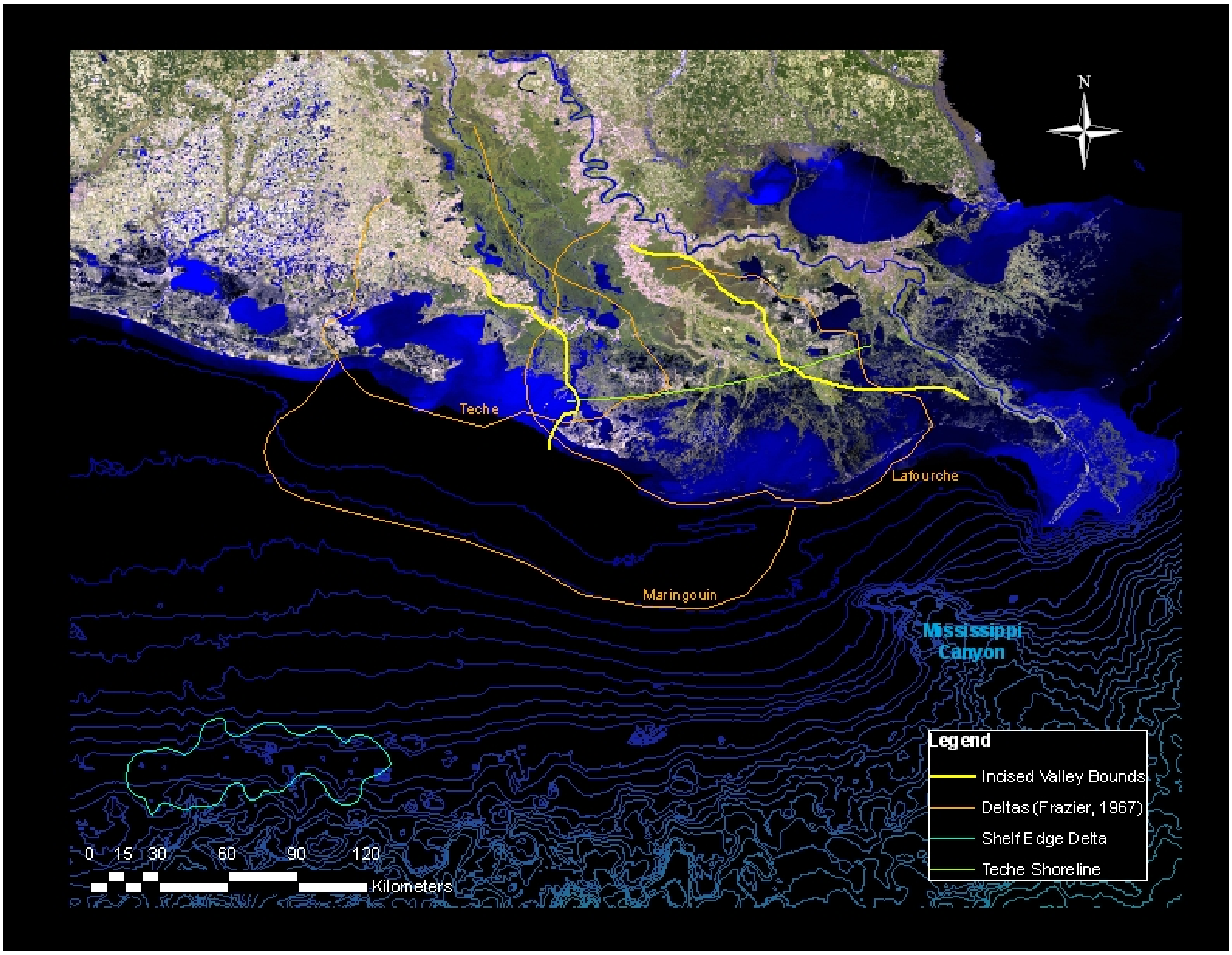

Figure 1.1—Map of study area including incised valley margins from Dunbar et al. (1994, 1995) shown in bold yellow, delta complexes from Frazier (1967) in orange, a shelf-edge delta from Suter and Berryhill (1985) in blue, and the Teche shoreline from Mcbride et al. (1990) in green.

Background Information

Sequence Stratigraphy

Sequence stratigraphy, as defined by Van Wagoner et al. (1988), is the study of rock relationships within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition or their correlative conformities. There are three major topics within sequence stratigraphy that must be understood; they are

depositional systems tracts, sequences, and surfaces. Posamentier et al. (1988) and Posamentier and Vail (1988) developed the sequence stratigraphic model used in this study.

Fisher and McGowan (1967) define a depositional system as a three-dimensional assemblage of lithofacies. Major features within a depositional system are the depositional-shoreline break and the shelf break. The depositional-shoreline break is the point at which the depositional surface passes below base level or sea level. This point for example is coincident with the distal end of distributary mouth bars in a delta (Posamentier et al., 1988; Posamentier and Vail, 1988). The shelf break is located at the point where the gradient increases from very shallow (<1:1000) on the shelf to much steeper (>1:40) on the slope.

A sequence is the basic unit within sequence stratigraphy and is represented as an interval of genetically related strata composed of systems tracts and bounded by unconformities and their correlative conformities (Posamentier et al., 1988; figure 1.2). The bounding unconformities and systems tracts within a depositional sequence develop as a result of successive cycles of high and low relative sea level. There are two types of sequence boundaries (SB); type 1 and type 2 (Posamentier et al., 1988). A type 1 SB forms in conjunction with a relative sea-level fall, subaerial exposure, stream incision, basinward shift of facies, and downdip movement of coastal onlap (Posamentier et al., 1988). A type 2 SB is not associated with a relative sea level fall. There is not necessarily any stream incision, subaerial exposure, or a basinward shift of facies (Posamentier et al., 1988). A type 2 sequence boundary forms when basin subsidence is greater than the overall eustatic sea level fall. There is no basinward facies shift or stream incision.

Systems tracts—highstand, lowstand and transgressive—are genetically related time synchronous depositional systems and are subdivided into parasequences (Brown and Fisher, 1977; figure 1.2). A parasequence is a succession of genetically related beds or bedsets that are relatively conformable and are bounded by marine flooding surfaces and correlative surfaces (Posamentier et al., 1988). Parasequence sets are groups of genetically related parasequences often bounded by major marine flooding surfaces and their correlative conformities (Van Wagoner, 1985). The division between parasequence sets may be based on: 1) stacking

patterns, 2) coincidence with sequence boundaries, or 3) downlap surfaces or systems tract boundaries (Van Wagoner et al., 1988).

Key surfaces used within sequence stratigraphy include marine flooding surfaces, the maximum flooding surface (MFS), transgressive surfaces (TS), downlap surfaces (DS), onlap surfaces (OS), condensed sections (CS), unconformities, and correlative conformities (Van Wagoner et al., 1988). Marine flooding surfaces lie between older and younger depositional units and show signs of a rapid relative sea level rise. This surface may appear in the sedimentary record as a wave ravinement surface (WRS), lagoonal sediments, or a hiatal surface, and usually lies within the TST (Van Wagoner et al., 1988). A WRS is an erosional surface formed by wave erosion during transgression (Van Wagoner et al., 1988). Overlying strata may onlap this surface if it is coincident with a sequence boundary. The MFS is a flooding surface that forms when sea level is at its highest point and is representative of maximum transgression (Posamentier et al., 1988). A transgressive surface is the first significant marine flooding surface to form within a sequence, separating the LST and TST. The downlap surface forms when HST parasequences prograde over and onto the TST. This surface coincides with the maximum flooding surface and represents a transition from transgression to aggradation and progradation. The onlap surface is coincident with the sequence boundary and represents backstepping of depositional environments updip. An unconformity is an erosional surface separating younger and older strata and represents a significant hiatus. Mitchum (1977) defines an unconformity to also include periods of nondeposition in place of erosion. A conformity separates older and younger strata without a significant hiatus and may be coincident with a condensed section. A condensed section is a thin marine unit deposited at a very slow rate (Loutit et al., 1988). These deposits develop offshore during periods of relatively slow pelagic and hemi-pelagic deposition and correlate to regional transgression (Loutit, 1988).

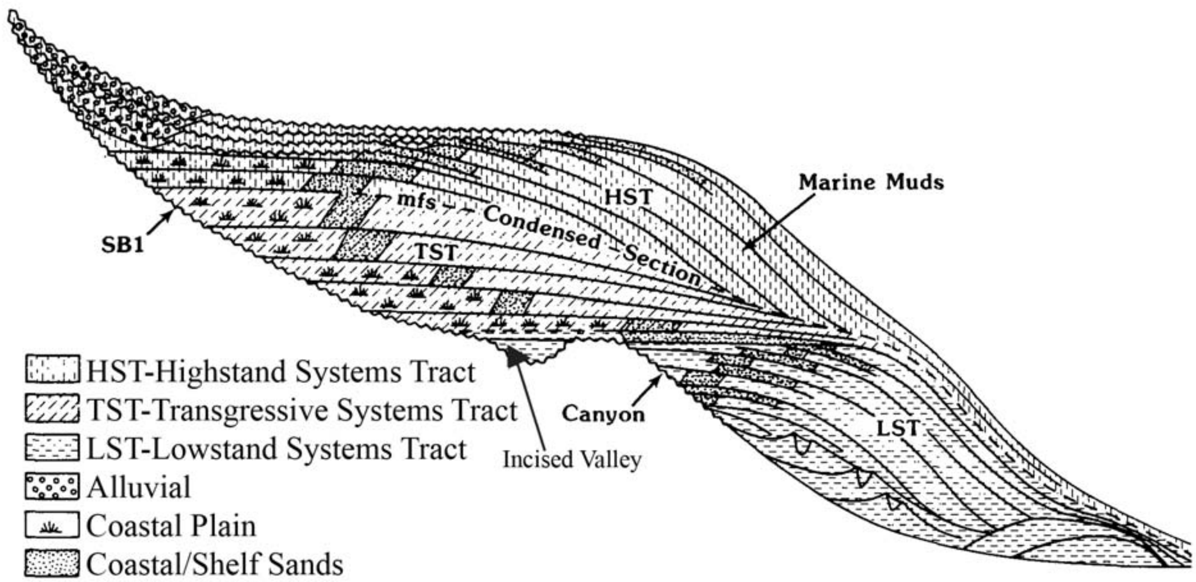

Figure 1.2—Dip oriented cross-section displaying erosional sequence boundary, LST, TST, mfs, condensed section and HST. Depositional facies are included. (Modified from Boyd et al., 1989b after Vail et al., 1987). The sequence boundary (SB1) represents an erosional unconformity and its correlative conformity where no erosion has taken place.

SYSTEM TRACTS

Lowstand systems tracts (LST) are deposited during rapid sea level fall, lowstand and the early part of sea-level rise (figure 1.2, 1.3) (Van Wagoner et al., 1988). They directly overlie a type 1 sequence boundary. A lowstand wedge is deposited during the later portion of eustatic fall or the early rise and consists of progradational and aggradational parasequence sets (Van Wagoner et al., 1988). The LST can be divided into several parts—the basin floor fan, lowstand wedge, and slope fan (Posamentier et al., 1988). A basin floor fan is an accumulation of submarine fans on the lower slope or basin floor (Posamentier et al., 1988). Formation of the basin floor fan is related to valley incision that occurs during falling sea level and may also be related to slope fan formation (Posamentier et al., 1988). A slope fan is composed of turbidites and debris-flows deposited at the middle or base of the slope (Posamentier and Vail, 1988). This deposition may occur at the same time as basin floor fan formation or the lowstand wedge during the late portion of sea-level fall and early rise (Posamentier et al., 1988). The upper surface of a lowstand wedge is the top of the lowstand systems tract and is a transgressive marine flooding surface (Van Wagoner et al., 1988).

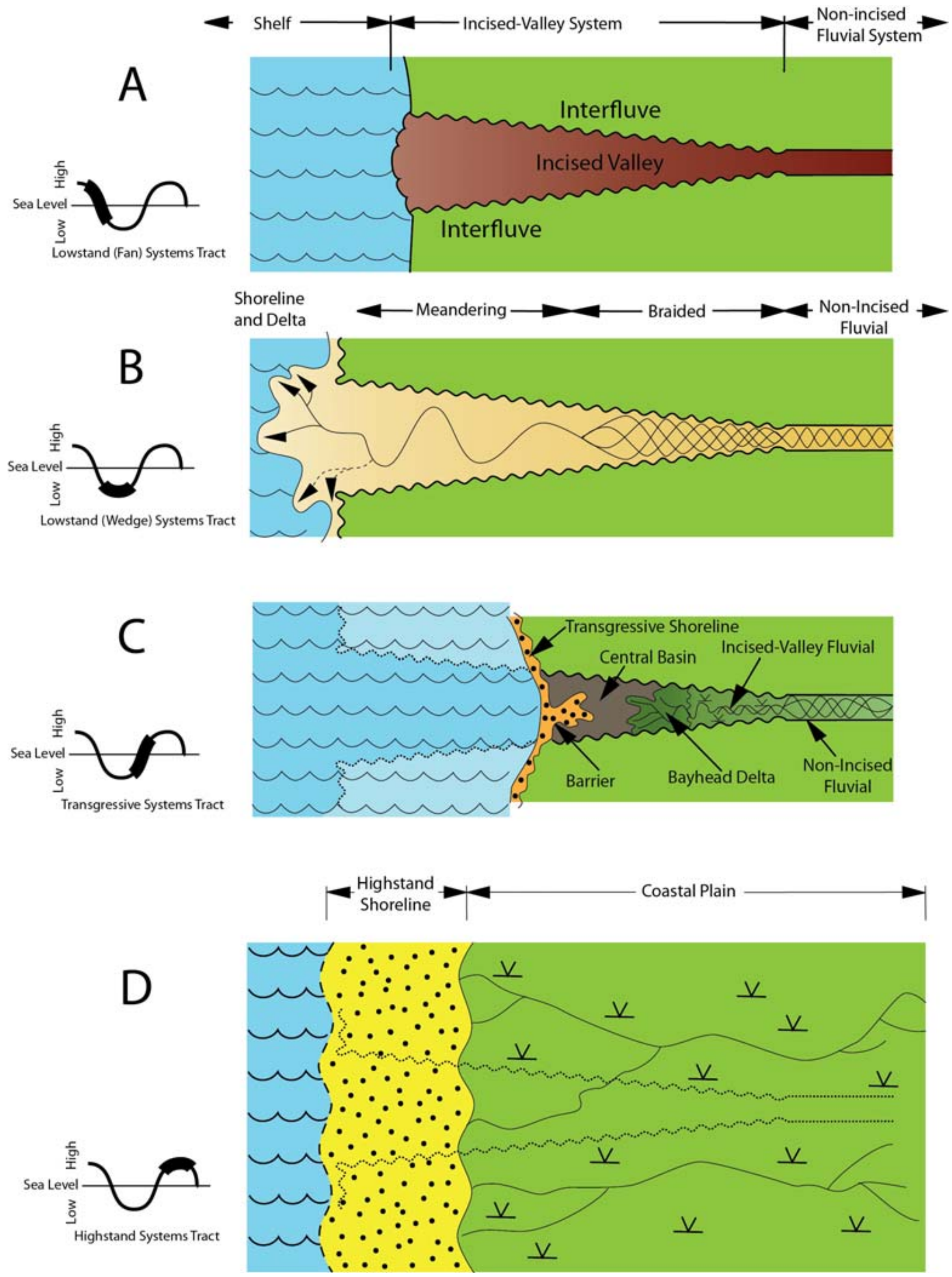

Figure 1.3—Conceptual model showing incised valley evolution through a full eustatic sea level cycle. To the left of each map-view drawing is a figure representative of changing sea level through time. The bold section of the line indicates the relative time and sea level position correlative with the drawing at right. A) *Lowstand (Fan)Systems Tract:* Falling sea level and rapid incision form a lowstand fan. B) *Lowstand (Wedge) Systems Tract:* At lowstand a shelf margin wedge delta develops while braided and meandering fluvial morphology exist in the incised valley. C) *Transgressive Systems Tract:* During sea level rise bayhead deltas form, overlain by central basin deposits and reworked transgressive shoreline sands. D) *Highstand Systems Tract:* As sea level stabilized at highstand the shoreline progrades and widespread coastal plain environments develop. (Modified from Zaitlin et al., 1994.)

In the case that a type 2 SB forms the LST is replaced with a shelf margin systems tract. A shelf-margin systems tract is the lowermost depositional systems tract that may develop in relation to a type 2 sequence boundary (Posamentier et al., 1988). Deposition is characterized by aggradational and progradational parasequence sets that onlap the sequence boundary in the updip direction and downlap the sequence boundary or correlative conformity downdip (Posamentier et al., 1988). This systems tract is bounded at the top by the transgressive surface and at the base by a type 2 sequence boundary.

Transgressive system tracts (TST) begin to develop as accommodation space is added at a rate that is greater than the sediment supply, resulting in shoreline transgression (Van Wagoner et al., 1988; figure 1.2, 1.3). TST include all sediments that accumulate from the beginning of shoreline transgression to maximum transgression (Van Wagoner et al., 1988). The base of the TST is marked by the transgressive marine flooding surface at the top of the LST (Posamentier et al., 1988). The top of the TST is the downlap surface upon which HST parasequences prograde. Transgressive deposits generally fine upward as depocenters shift landward (Van Wagoner et al., 1988). Erosion may be significant during transgression; erosion of shelf, delta plain, and coastal plain sediments by wave and tidal energy result in wave and tidal ravinement.

Highstand system tracts (HST) are deposited during late eustatic rise, stillstand, and early eustatic fall (figure 1.2, 1.3). Deposition is usually widespread on the shelf and may be a combination of aggradational followed by progradational parasequences as rates of relative sea level rise decrease (Van Wagoner et al., 1988). Highstand parasequences onlap the sequence boundary updip and downlap transgressive or lowstand systems tracts downdip. Highstand systems tracts are bounded on their upper surface by a type 1 or 2 sequence boundary and on their lower surface by the downlap surface (Van Wagoner et al., 1988).

Incised Valley Stratigraphy

SIGNIFICANCE

Incised valleys play a key role in our understanding and documentation of geologic evolution and climatic history. Incised valleys are topographic surfaces of negative relief that have a greater potential to preserve the chronostratigraphic record at a relatively high resolution compared to surrounding geomorphic basins (Zaitlin et al., 1994). Recognizing unconformable surfaces on interfluves and correlating them to unconformities or correlative conformities within incised valleys allows better documentation of the stratigraphic record and allows for comparison of sedimentary response to sea level variations on a global scale.

Incised valleys and their filling sediments are economically important as proven in the Viking Formation in Alberta (Zaitlin, 1994), the Denver Basin in Colorado and many examples from the geologic record (Lin et al., 2004; Quinn, 2006; Salazar et al., 2003; Salem et al., 2005; Stoeckinger, 2002; Trevino et al., 2003). It is in the best interests of the global community to understand how and where incised valleys form as well as what geologic settings are most conducive to generating significant and economically recoverable quantities of hydrocarbons.

A large portion of the world's population lives at or near sea-level with many population centers built on deltas underlain by incised valleys (Syvitski et al., 2009). Understanding how depositional systems within incised valleys respond to rising sea level will allow better and more effective prediction of and adaptation to sea level changes in the coming decades and centuries. Deltaic environments within incised valleys are also zones of high subsidence, further exacerbating the effects of a eustatic rise in sea level (Penland and Ramsey, 1990; Roberts et al., 1994). In the case of the Mississippi River delta, high rates of subsidence are documented (Roberts et al., 1994; Dokka, 2007) but there is still no comprehensive understanding of the incised valley fill stratigraphic framework or its contribution to the overall high rates of subsidence.

With incised valleys playing such an important role in our understanding of chronostratigraphy, sedimentary response to sea level changes, hydrocarbon resources and the impacts of climate change, it is surprising that the Mississippi River incised valley has not

received more attention following the time that attention was brought to it by Fisk (1944). It was not until the late 1970's as the concepts of sequence stratigraphy became widespread that incised valleys began to receive more attention (Vail et al., 1977).

New and more precise models of incised valley development and filling are important to the petroleum industry and the exploration for hydrocarbon resources. The rich ecosystems that develop where rivers debouche their sediment and nutrient laden waters into the sea will continue to be vital to supporting our growing world population. It is for these reasons that incised valleys, and in the case of this study, the Mississippi River incised valley, should continue to receive the attention of geoscientists in an effort to develop an understanding of their stratigraphic framework and chronological evolution.

MORPHOLOGY, PROCESSES AND STRATIGRAPHY OF INCISED VALLEYS

An incised valley is a fluvially-eroded, elongate topographic low that is typically larger than a single channel form, and is characterized by an abrupt seaward shift of depositional facies across a regionally mappable sequence boundary at its base (Zaitlin et al., 1994). The fill typically begins to accumulate during the subsequent base-level rise, and may contain sediment deposited during the highstand that follows and subsequent sea-level cycles (Zaitlin et al., 1994; figure 1.3). The geographic extent of an incised valley is limited to the distal terminus of lowstand deltaic deposition and updip to the point where changes in base level cease to effect fluvial deposition or erosion (Zaitlin et al., 1994). The size of the fluvial system has a strong effect upon the overall extent of incised valley development and form (Zaitlin et al., 1994).

Incised valley formation may be a result of one or more of the following factors: 1) a relative fall in base level caused by eustatic sea-level fall or local tectonic uplift (Schumm, 1993), both of these processes will generally act to increase the local stream gradients, resulting in increased fluvial energy, erosion, and incision (Zaitlin et al., 1994), 2) an increase in discharge from climatic changes within a drainage basin (Zaitlin et al., 1994). Stream capture may also result in greater discharge and incision (Zaitlin et al., 1994). For example, Late Quaternary deglaciation events caused massive meltwater floods that initiated incision followed by quiescence and aggradation (Rittenour et al., 2007). Incised valleys formed by changes in base

level are more commonly preserved than those formed by increased discharge because the former are associated with the presence of sequence boundaries (Zaitlin et al., 1994).

TYPES OF INCISED VALLEYS AND THEIR PARTS

Two primary types of incised valleys have been identified: piedmont and coastal plain incised valley systems (Zaitlin et al., 1994; figure 1.4).

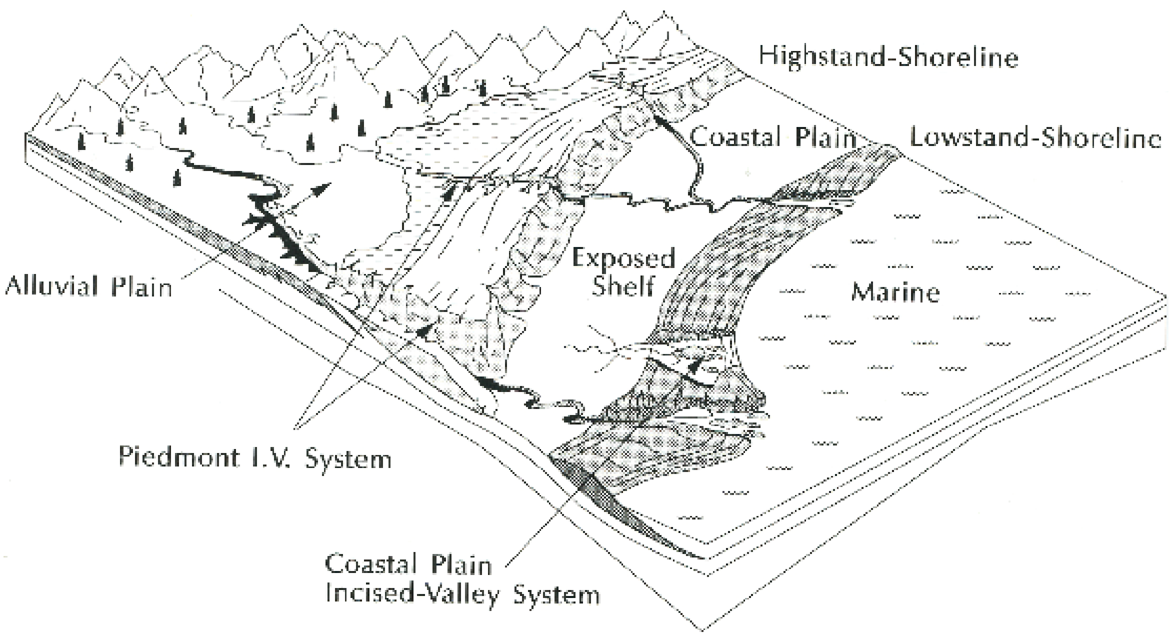

Figure 1.4—Conceptual model showing incised valley types. Piedmont incised valleys are connected to highstand fluvial systems whereas costal plain incised valley systems develop below the highstand shoreline on the exposed shelf and exist only during lowstand. From Zaitlin et al, (1994).

Piedmont incised valley systems have their headwaters in mountainous upland terrain and somewhere along their course crosses a “fall line” seaward of which there is a reduced gradient (Zaitlin et al., 1994). A coastal plain incised valley is generally smaller than a piedmont system and is formed on a low gradient coastal plain. Sediments within a coastal plain incised valley are usually finer-grained reworked coastal plain sediments compared to a piedmont incised valley system, which is typified by less mature fluvial derived sediment.

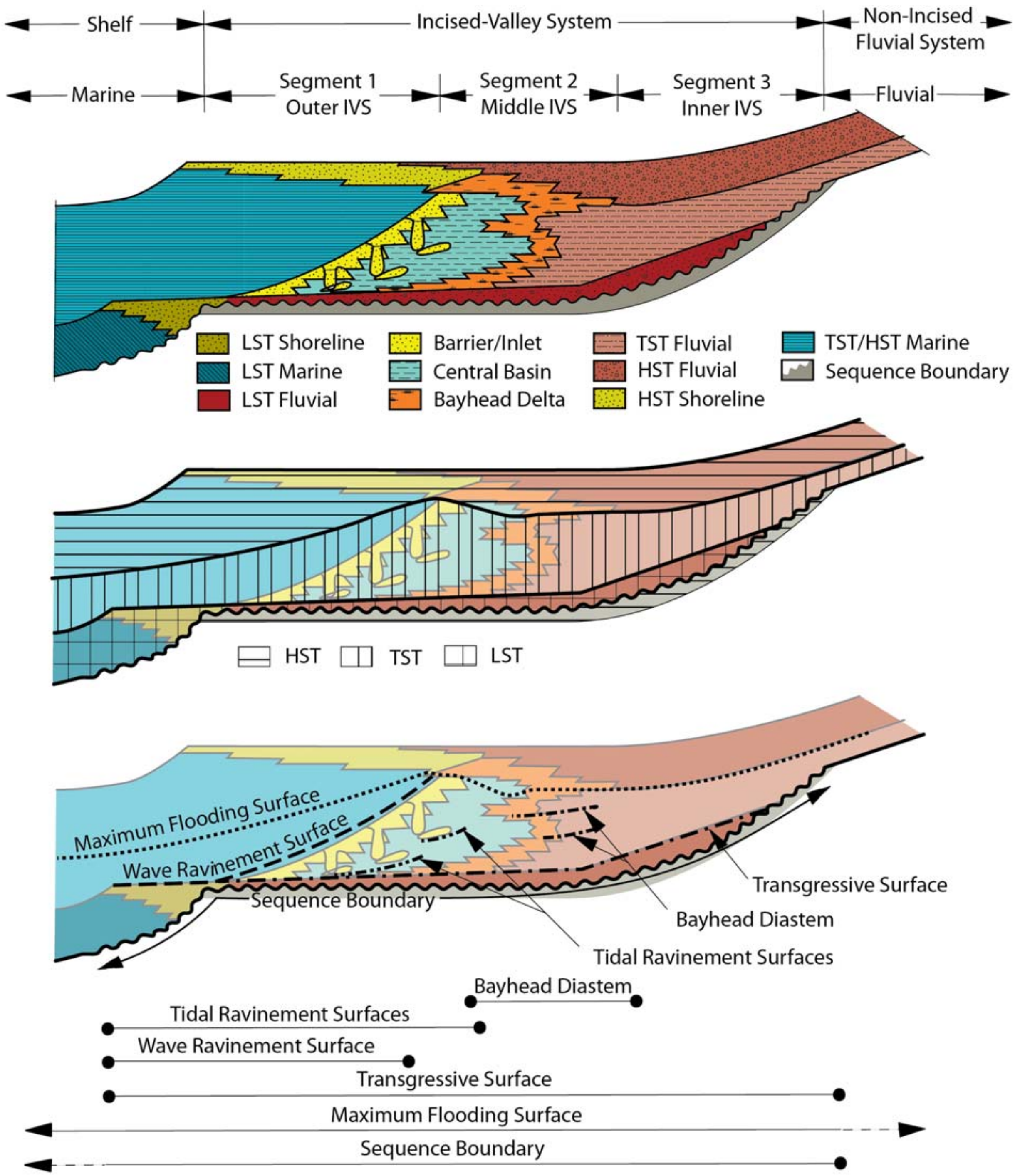

Figure 1.5—Diagram of incised valley segments, depositional facies, system tracts, and surfaces. Modified from Zaitlin et al. (1994). An incised valley system (IVS) can be divided into 3 segments based on the relative influence of fluvial and marine energies. A) Diagram showing depositional facies and associated systems tracts, B) system tracts overlain onto facies diagram, C) Important sequence stratigraphic surfaces. Wave ravinement does not extend beyond the limit of marine influence at the segment 1-2 boundary. Tidal ravinement may extend into segment 2. Transgressive surfaces do not develop beyond the limits of incision. Maximum flooding surfaces may

extend updip into the unincised fluvial valley. Sequence boundaries form downdip of the headward limit of incision.

Incised valleys can be divided in a dip direction into three distinct segments (Zaitlin et al., 1994; figure 1.5). Segment one is predominately marine and includes the outer incised valley extending from the mouth at lowstand to the shoreline at the beginning of highstand progradation (Zaitlin et al., 1994), this segment elongates during transgression. Segment two lies between segments one and three and represents the flooded estuary formed at maximum transgression. Low gradient coastal plains will have a long segment two as a result of the wide continental shelf coincident with the low gradient (Dalrymple et al., 1992). The estuary will be shorter where sediment supply is high relative to sea-level rise due to the supplied sediment filling the available accommodation space. Segment three extends from the upstream limit of estuarine influence after transgression to the upslope limit of incision and is progressively shortened with continuing transgression (Zaitlin et al., 1994). The length of the incised valley depends upon the magnitude and duration of lowered sea-level. The greater the fall in sea-level and the greater length of time that it remains lowered will result in a longer and deeper incised valley. Broad shallow sloping coastal plains also contribute to lengthening of incised valleys (Dalrymple et al., 1992).

Segment One

Segment one of an incised valley is the first to be incised by falling relative sea level (figure 1.5). During falling sea level the sediments eroded from the upper valley are bypassed to the valley mouth where a lowstand delta develops above the concomitantly forming sequence boundary (Zaitlin et al., 1994). Segment one becomes the locus of fluvial and estuarine deposition rather than a channel for sediment transport upon the following rise of sea level as transgression encroaches upon the incised valley (Zaitlin et al., 1994). Continued transgression will not only result in a change in the primary location of deposition but also the style of fluvial deposition. Sea level change will be recorded in the sediments and represent ongoing transgressive processes driven by a decrease in fluvial energy, for example a transition from braided to meandering accompanied by a decrease in sediment grain size. These changes in

depositional nature may correlate to and represent the landward equivalent of a marine flooding surface. As estuarine conditions continue to migrate landward up the incised valley the fluvial deposits will be overlain by bay-head delta deposits followed by central basin deposits and an estuarine barrier or tidal ravinement surface (Zaitlin et al., 1994). A wave or tidal ravinement surface often truncates the estuarine deposits (Zaitlin et al., 1994). This phase of deposition has been recognized in the geologic record where transgressive sands overly the wave ravinement surface (Penland et al., 1989). Open marine muds in turn overlie the transgressive sands (Zaitlin et al., 1994).

Segment Two

The second segment of incised valley fill is similar to that of segment one (figure 1.5). The sequence boundary is overlain by lowstand and early transgressive fluvial deposits followed by transgressive estuarine facies (Zaitlin et al., 1994). Bay-head deltaic deposits develop with continued transgression and are overlain by central basin deposits that are in turn overlain by estuary mouth barrier sands (Zaitlin et al., 1994). No open marine muds are deposited in segment two; rather highstand fluvial-deltaic sediments form the upper portion of the incised valley fill (Zaitlin et al., 1994). For example, the terminal landward limit of segment two is defined by the limit of detectable marine influence, tidal influence and evidence of brackish environments (Zaitlin et al., 1994).

Segment Three

Fluvial processes dominate segment three (figure 1.5). Lowstand deposits within segment three are limited due to the erosional nature of an incised valley during lowstand and the concomittant sediment bypassing to the shelf (Zaitlin et al., 1994). Coarse-grained deposition begins during transgression, and in general is characterized by fining upward stratigraphy that corresponds to decreasing stream gradient and carrying capacity (Zaitlin et al., 1994). Floodplain deposits consist of channel belt and overbank deposits that accrete laterally and vertically, respectively, and are overlain by freshwater organic facies and other aggradational deposits due to downslope deltaic progradation (Zaitlin et al., 1994).

An incised valley may contain valley-fill sediments that are considered either simple or compound depending on the presence or absence of multiple sequence boundaries (Zaitlin et al., 1994). Valleys filled during one sequence of lowstand-transgressive-highstand deposition are called “simple fill” (Zaitlin et al., 1994). “Compound fill” develops if valley-filling occurs during more than one sequence of lowstand-transgressive-highstand deposition and may contain multiple sequence boundaries above an initial primary sequence boundary (Zaitlin et al., 1994). Piedmont incised valley systems typically consist of compound fill because they are present through multiple cycles of sea level, whereas coastal plain incised valleys are more likely to exist through only one cycle of sea level and therefore retain the characteristics of a simple fill incised valley (Zaitlin et al., 1994).

Preservation potential must address two things, preservation of the incised valley fill and the incised valley itself. The primary valley fill will not be entirely preserved because of the development of a tidal or wave ravinement surface during transgression. Preservation of the incised valley is dependent upon whether it is bedrock controlled (Zaitlin et al., 1994); incised valleys that cut into unconsolidated coastal plain sediments have a much greater potential for destruction than incised valleys that cut through bedrock. The forces of tidal and wave ravinement have the potential to remove much of the incised valley fill as well as the sediments that make up the valley walls flanking the incised valley in coastal plain settings relative to an incised valley bounded by bedrock. Also, deeper incised valleys are more likely to be preserved.

The Delta Cycle and Construction

THE DELTA CYCLE

The delta cycle consists of delta growth and decay, regression and transgression, respectively. During active deposition a delta will prograde, or grow seaward. Eventually the growing delta will be abandoned and deprived of sediment at which point transgression begins. Transgressive processes of wave or tidal ravinement and subsidence cause the delta to erode and submerge over time (Fisk, 1944).

Regressive delta development begins when sediment supply becomes abundant enough to outpace the creation of accommodation space. Lacustrine deltas form first as inland lakes are filled with sediment (Roberts, 1997). Bayhead deltas develop at the coastline followed by shelf phase deltas at the shelf edge (Roberts, 1997). Lacustrine deltas form rapidly as supplied sediment fills the many small shallow lakes as the discharge makes its way to the receiving marine basin (Roberts, 1997). As an example, the lakes of the Atchafalaya Basin filled with sediment in only a few centuries (Tye and Coleman, 1989). Lacustrine deposits are less than 5 m thick, sandy at the base and overlain by highly organic, burrowed, fine-grained swamp deposits (Roberts, 1997). After the river's sediment discharge has filled the lacustrine accommodation space, development of a bayhead delta begins within incised valley estuaries as well as beyond them (Roberts, 1997). They prograde seaward onto the shelf as shelf phase deltas; coarsening upward sedimentary units overlain by rich organic deposits. The shelf edge phase of delta growth occurs when the distributary system reaches the shelf edge and begins to deposit sediment into deeper water (Roberts, 1997; figure 1.6). Progradation slows drastically due to the increased thickness of the deposits. The rate of areal growth is also reduced.

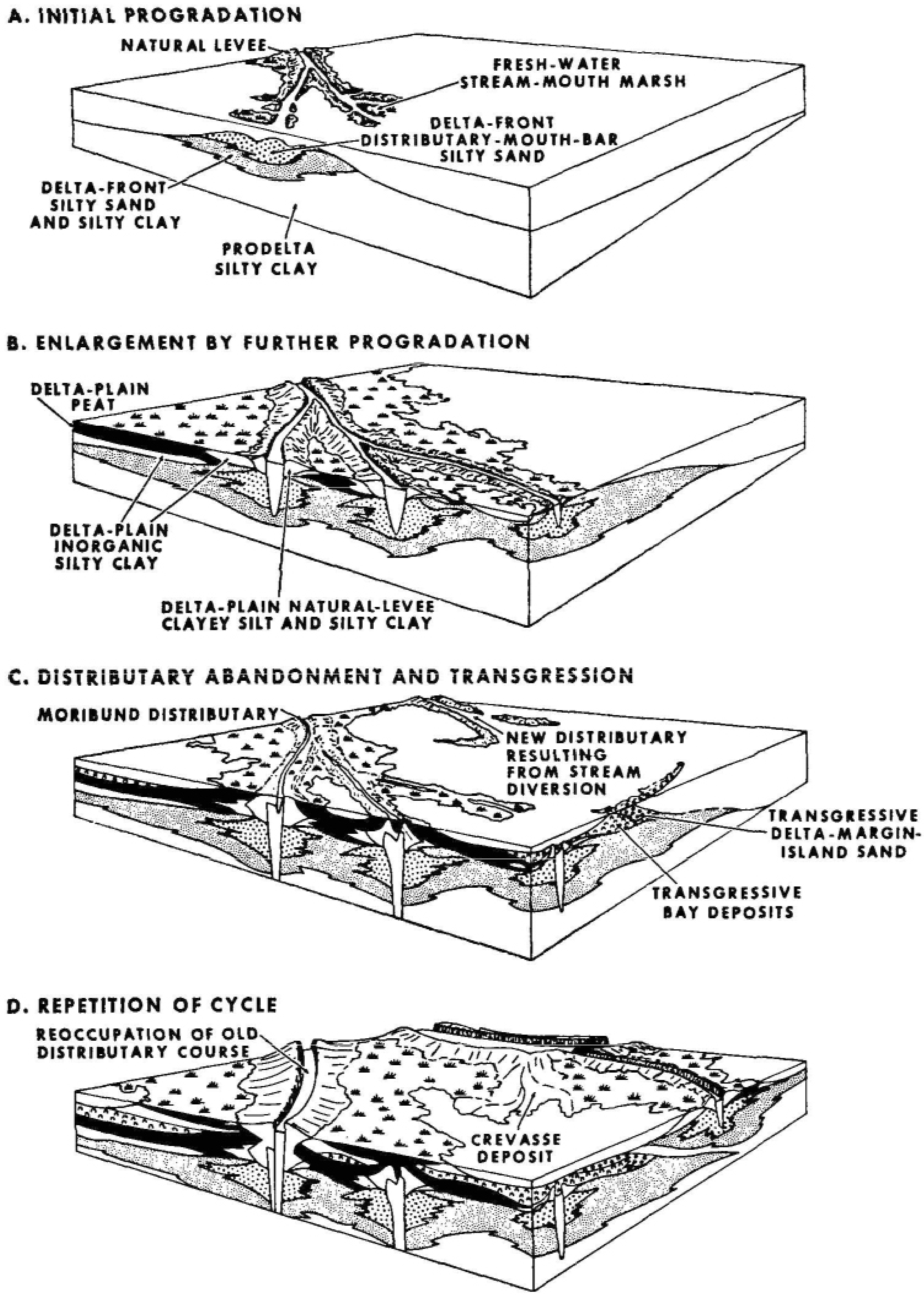

Figure 1.6—Diagram depicting progradational delta growth into relatively shallow water (Frazier, 1967). Fine-grained facies are more widespread than coarse-grained facies found adjacent to distributaries.

Distributary networks of any scale are eventually abandoned due to diversion upstream. Upstream avulsion requires the presence of: 1) a gradient advantage, 2) erodible river bank substrate, and 3) the presence of pre-existing channels capable of enlargement by erosion and scour (Aslan and Autin, 2005). In general, avulsion is impeded by fine-grained clay rich sediments and enabled by sandy coarse-grained easily erodible sediments (Aslan and Autin, 2005). As the abandoned delta surface becomes starved of fresh water and sediment it begins to subside, be eroded by waves, and convert into saline marsh (figure 1.7). With continuing subsidence and marine reworking the delta is slowly submerged and eroded. Wave erosion forms small lakes within the delta surface that can grow from meters in size to several kilometers (Kolb and Van Lopik, 1966). Waves also rework the seaward edge of the delta by carrying away fine-grained sediments and concentrating relatively coarse grained sands (Penland et al., 1988). Deltaic headlands evolve into barrier island arcs that eventually undergo transgressive submergence to become subaqueous sand shoals (Penland et al., 1988; figure 1.7).

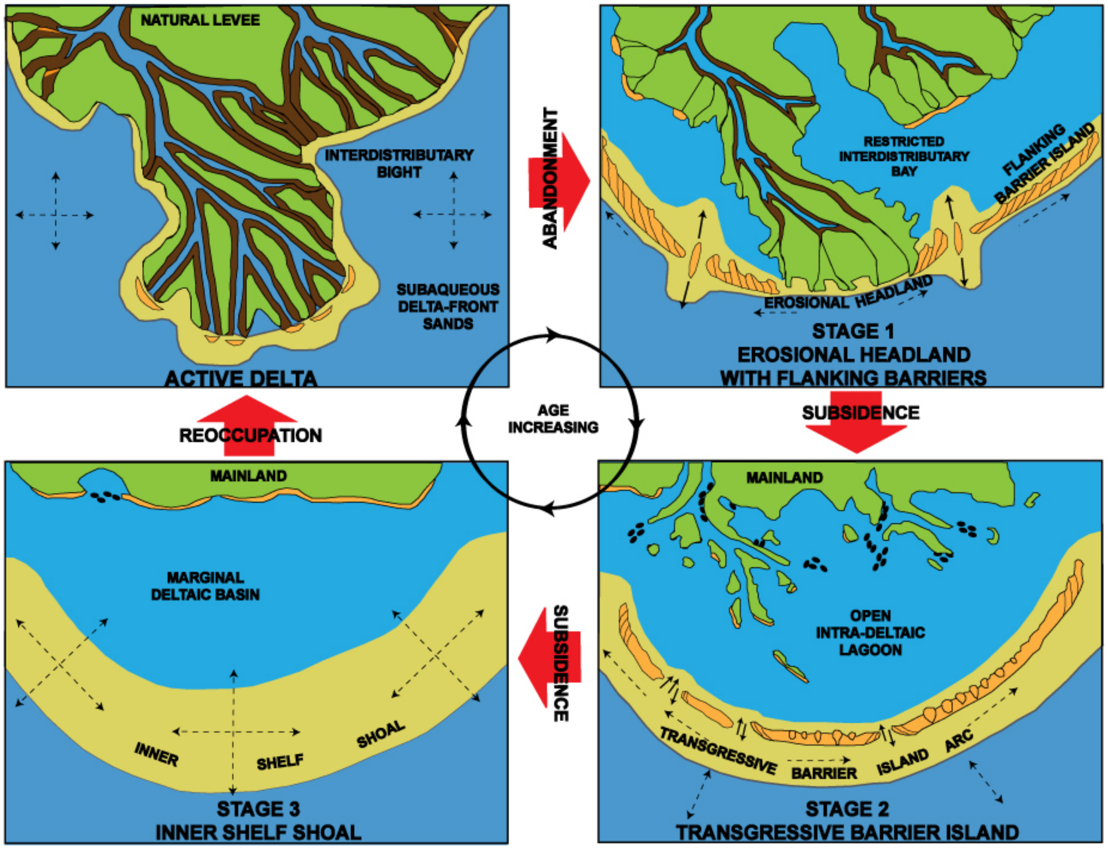

Figure 1.7—Transgressive model of barrier island formation. A prograding deta lobe is abandoned due to an upstream avulsion and erosional headlands begin to develop. Subsidence and erosion leads to separation of the abandoned deltaic headland from the mainland producing a barrier island arc. Continued submergence and a net loss of sand from the coastal system results in development of an inner-shelf shoal. The process repeats when a new active delta progrades into the area. Modified from Penland et al. (1988).

DELTA CONSTRUCTION

The hierarchy of Holocene deltaic deposits from 1st order to 5th order is as follows: 1) delta plain, 2) delta complex, 3) delta lobe, 4) subdelta, 5) crevasse-splay or overbank splay (Roberts, 1997). This hierarchy is a result of cyclic deposition occurring on differing spatial and temporal scales (Roberts, 1997). Each delta plain is composed of delta complexes that in turn contain delta lobes made up of subdeltas, crevasse-splays and overbank splays. Each successive order deposit is emplaced in a shorter period of time, over a smaller areal extent and to a lesser thickness (Roberts, 1997). The 1st through 3rd order deltaic sediments are deposited by major and minor distributaries while 4th and 5th order deposits develop from secondary channels that form at natural levee breaks (Roberts, 1997).

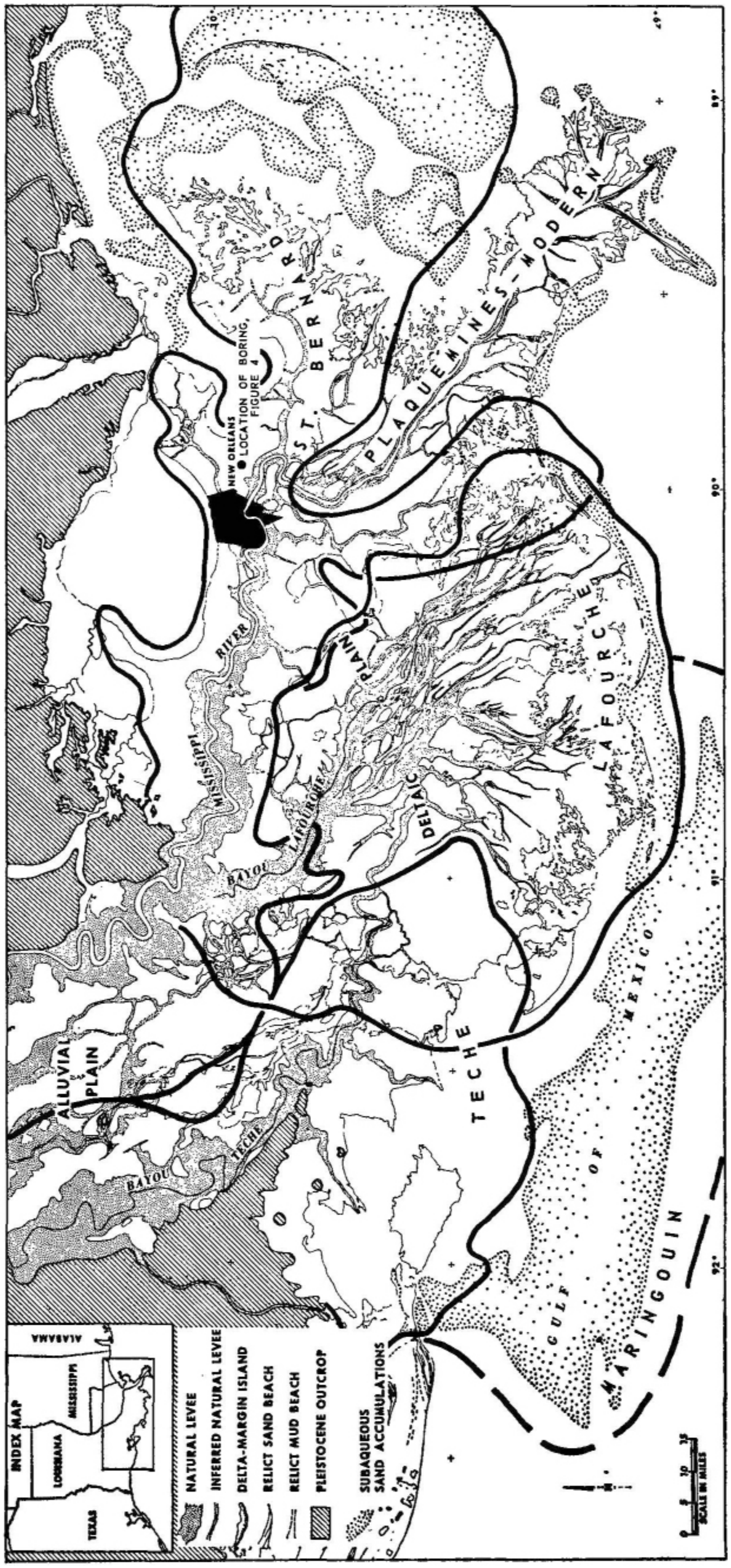

Figure 1.8—Map showing modern delta plain and the individual delta complexes (Frazier, 1967).

The Holocene delta plain of the Mississippi River encompasses all fluvio-deltaic deposits delivered by the Mississippi River since ~7 kya. Six delta complexes have been identified within the delta plain (figure 1.8); in order of deposition they are the 1) Maringouin 7.5-6.2 kya, 2) Teche 5.7-3.9 kya, 3) St. Bernard 4.6-0.6 kya, 4) Lafourche3.5-0.1 kya, 5) Balize 0.95 kya to present, and 6) Atchafalaya 0.1 kya to present (Frazier, 1967). Delta complexes prograde for 1000-2000 years, and can cover an area of up to ~15,000 km^2, and reach a thickness of 30 m (Roberts, 1997). Subdeltas are usually less than 10 m thick, up to 300 km^2, and complete the cycle of growth and abandonment in 150-200 years. Crevasse and overbank splays are typically less than 5 m thick, a few tens of km^2, and develop over a few decades (figure 1.9).

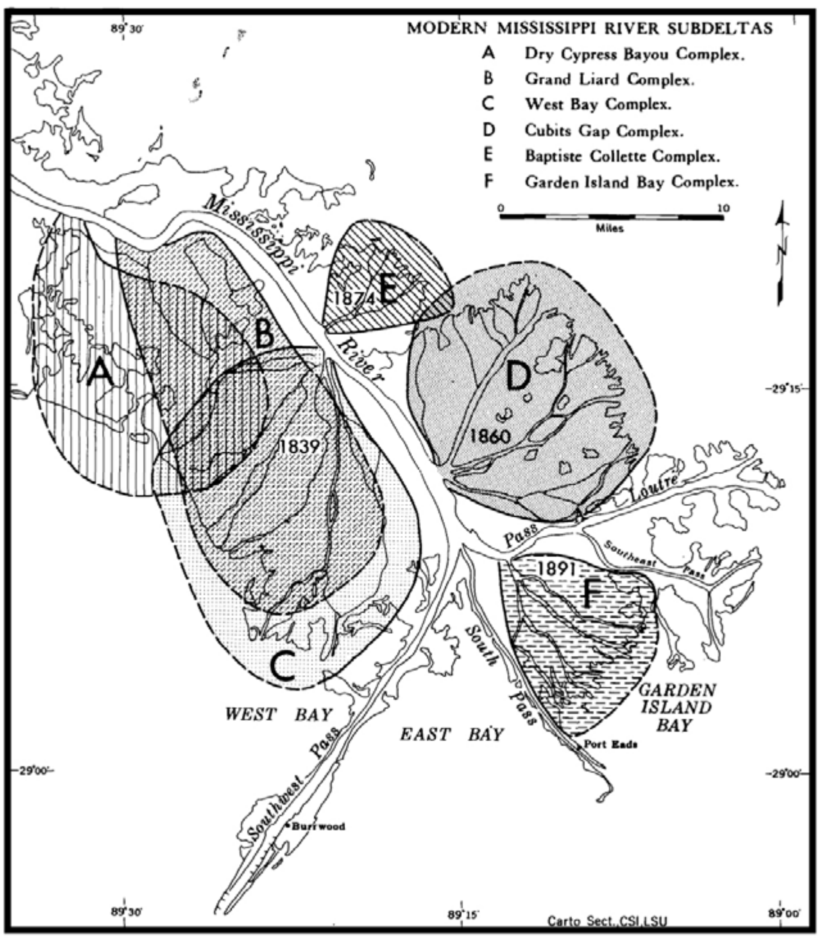

Figure 1.9—Map of modern Balize birdfoot delta (Coleman and Gagliano, 1964). Six individual subdeltas have formed in the area in the past ~200 years. (Coleman and Gagliano, 1964). The numbers on each subdelta represent the year of initiation. Each short-lived subdelta is a subcomponent of the greater delta lobe and delta complex.

Northern Gulf of Mexico History—Isotope Stage 5 to Stage 2

The use of oxygen isotope analysis has been proven to be useful as a proxy for past climate conditions and intensity of glaciations (Emiliani, 1955). This can be accomplished by comparing the relative concentrations of O^{18} to O^{16} found in carbonate tests of forams in ocean sediments (Emiliani, 1955). Sea water evaporates into the atmosphere at low lattitudes and eventually returns as precipitation. Water containing the heavier O^{18} isotope precipitates more readily (Shackleton, 1969) and becomes depleted in precipitation at high latitudes. During glacial periods, high latitude precipitation sequesters large amounts of this O^{18} depleted water as ice and in turn increases the concentration of O^{18} in marine waters (Shackleton, 1969). This variation in the concentration of O^{18} relative to O^{16} can be used to estimate the volume of glacial ice present on the earth's surface at a given point in history, provided that a sediment core with the appropriate foraminifera is available (Shackleton, 1969). The present oxygen isotope stage (OIS) is OIS 1. The most recent glaciation corresponding with the Last Glacial Maximum (LGM) was OIS 2. Interglacial periods have odd numbered isotope stages and glacial periods are denoted by even numbers isotope stages.

The Northern Gulf of Mexico coast (figure 1.10) is an excellent site for performing scientific research on clastic sedimentary systems because of its microtidal setting, wide variability of depositional settings and systems, and the existing body of research that has accumulated. This research has been carried out in part due to the prevalence of oil and gas in the Gulf of Mexico as well as a need to understand the processes that occur within the basin. The Northern Gulf of Mexico is a passive margin tectonic setting characterized by subsidence rates that range from 0.5-5.2 mm/yr (Penland and Ramsey, 1990; Anderson et al, 2004; Dokka et al, 2006; Törnqvist et al., 2008). These high subsidence rates afford relatively high preservation potential for primary sedimentary deposits. Depositional settings vary from wide continental shelves and slopes with low gradients found from southern Texas to the Mississippi coast with the exception of the central Texas coast being a steep ramp margin similar to the Alabama and Florida margins (Anderson et al., 2004). Drainage basins range in size from 13,000 km^2 for the Sabine River basin to 3.1 million km^2 for the Mississippi River (Anderson et al., 2004; Mann and Thomas, 1968). In addition to hosting drainage basins that vary in size by two orders

of magnitude, there exists a wide range of climates that are drained by these rivers. Rivers in the east drain humid climates with rainfall in excess of 150 cm/yr (Anderson et al., 2004). Climates become progressively drier towards the west receiving less than 20 cm/yr of precipitation in the upper Rio Grande valley and western reaches of the Mississippi River drainage basin (Anderson et al, 2004). Fluvial discharges range from 75 m^3s^{-1} from the Guadalupe river of central Texas (Anderson et al, 2004) to 15,631 m^3s^{-1} from the Mississippi River (Coleman, 1976). West of the Mississippi River the fluvial morphology is broad and meandering and is steep and incised to the east of the Mississippi River. Sediment discharge follows a similar pattern in that the western rivers are muddy with high sediment flux whereas rivers east of the Mississippi River are sandy and carry a smaller volume of sediment to the basin. River deltas of the northern Gulf of Mexico range in size and are largely dictated by their sediment flux and may be wave, storm or fluvially dominated (Anderson et al,. 2004). Rivers draining to the northern Gulf of Mexico possess great variability in their attributes. Each fluvial setting allows the study of a unique combination of morphological attributes that result from variable controlling parameters.

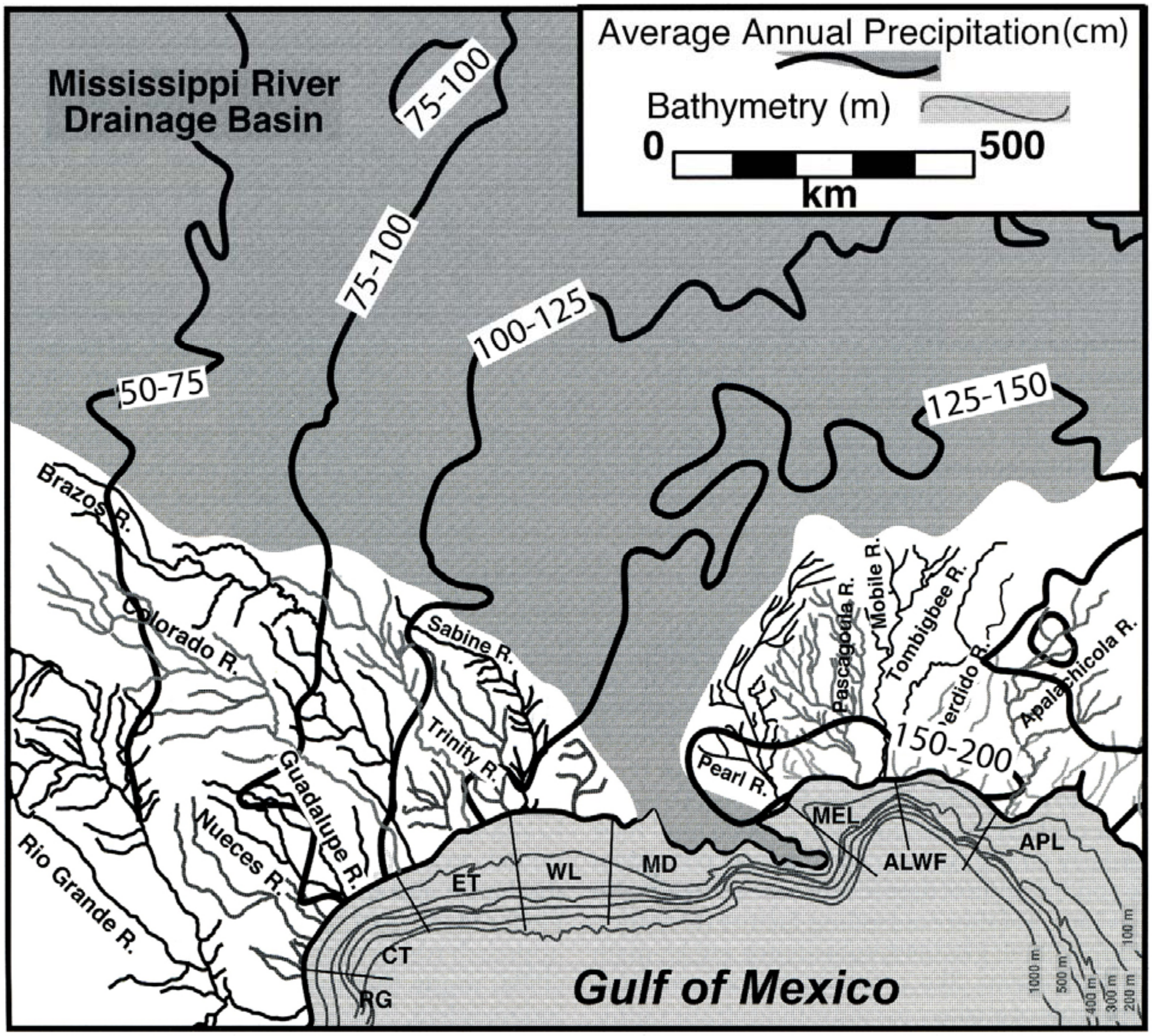

Figure 1.10—Map of Northern Gulf of Mexico rivers and their drainage basins. Contour lines depict average annual precipitation. From Anderson et al. (2004).

OXYGEN ISOTOPE STAGE 5

In the last 120 ka eustatic sea level has varied by as much as 120 meters (Waelbroeck et al., 2002; figure 1.11). The Ingleside paleoshoreline is evidence of a maximum highstand 120 ka at the beginning of Stage 5 when sea level was at an elevation a few meters higher than it is today (figure 1.11) (Graf, 1966; Otvos and Howat, 1997). At this higher sea level elevation the shoreline was located landward of the modern shoreline. Because of its higher elevation and more landward location it has not been exposed to either transgressive or regressive shoreline erosion since emplacement. Following the highstand, continental scale ice sheet growth forced

sea level to fall. By the time Stage 5 came to an end, sea level had fallen by 40-60 m and the new shoreline had shifted seaward to the middle shelf (Anderson et al., 2004). This period of time, Stage 5, was the last major highstand interval with maximum sea level at a similar elevation to the present sea level (Waelbroeck et al., 2002). There was an increase in sediment supply during Stage 5 as well as fluvial incision, and sediments were deposited primarily on the inner shelf (figure 1.12) resulting in low preservation potential due to relatively low rates of subsidence on the inner shelf (Anderson et al., 2004).

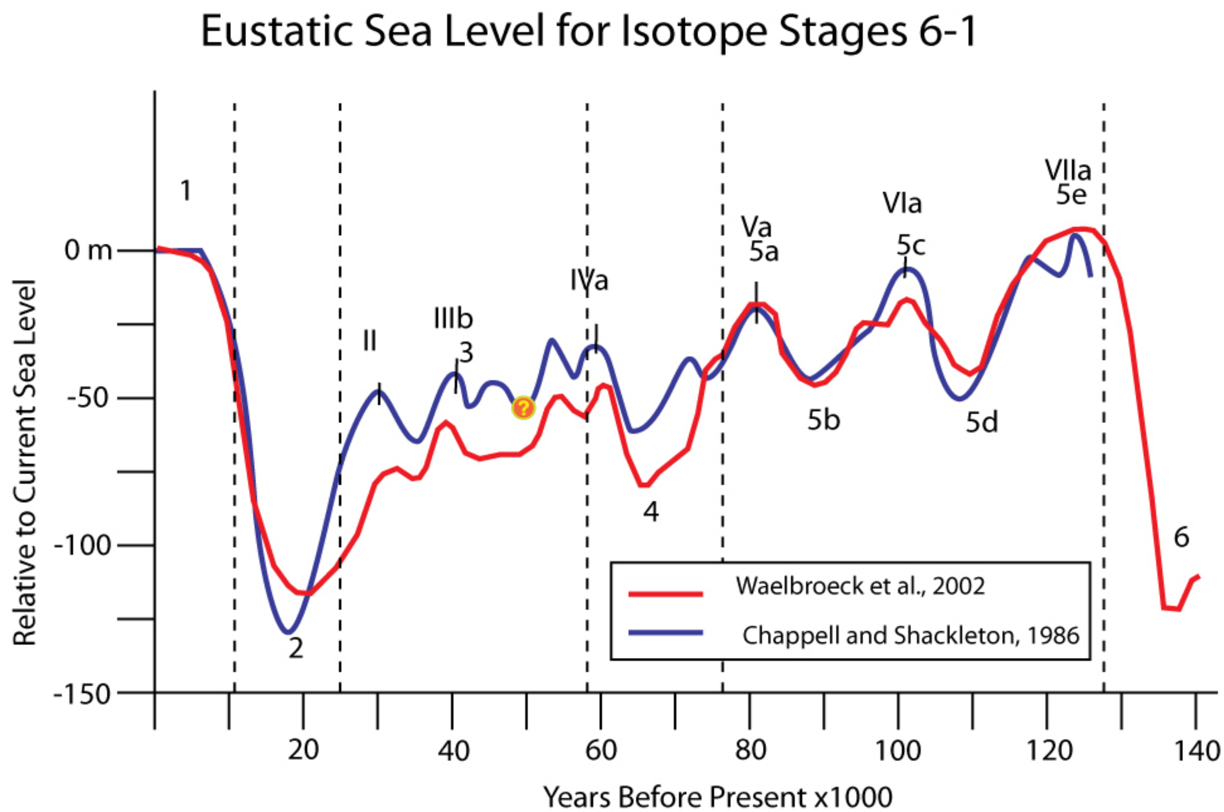

Figure 1.11—Eustatic sea level for the past 120+ ka. Lower sea level indicates increased glaciation. Adapted from Waelbroeck et al. (2002), and Chappel and Shackleton,(1986).

Mississippi River sediments were directed to the western Louisiana shelf during the Stage 5 highstand (Coleman and Roberts, 1990; Wellner et al, 2004). The rivers to the east in Mississippi, Alabama and Florida and to the west in Texas and western Louisiana also formed highstand deltas on the shelf (Anderson et al., 2004; Wellner et al., 2004; Bart and Anderson, 2004). Falling sea level forced regression and progradation of deltas resulting in significant

fluvial and wave erosion of deltaic deposits. The consequence of extensive erosion and low subsidence rates is poor preservation potential. The only exception to this was the western Louisiana Delta (figure 1.12); higher subsidence rates in response to high depositional rates reduced the volume of sediment exposed to erosive wave energy (Wellner et al., 2004). Shelf deltas from other rivers had their upper stratigraphy and sand-rich delta front facies truncated and eroded by regressive ravinement, stream incision, and subaerial weathering (Anderson et al., 2004). Truncation of upper deltaic facies resulted in preservation of only the relatively deeper water deltaic facies consisting of stratigraphically stacked prodelta and muddy distal bar deposits (Anderson et al, 2004). Smaller rivers did not form large-scale delta complexes during the highstand and the remaining sediments from Stage 5 are thin and discontinuous (McKeown et al., 2004). The central Texas coast does not have any rivers with large sediment fluxes and therefore the shoreline prograded via longshore and onshore transport of clastic material (Eckles et al., 2004). As a result the subsiding shelf was starved of sediment; this process is thought to have resulted in the steep ramp shelf setting offshore of the modern central Texas coast (Rodriguez et al., 2004).

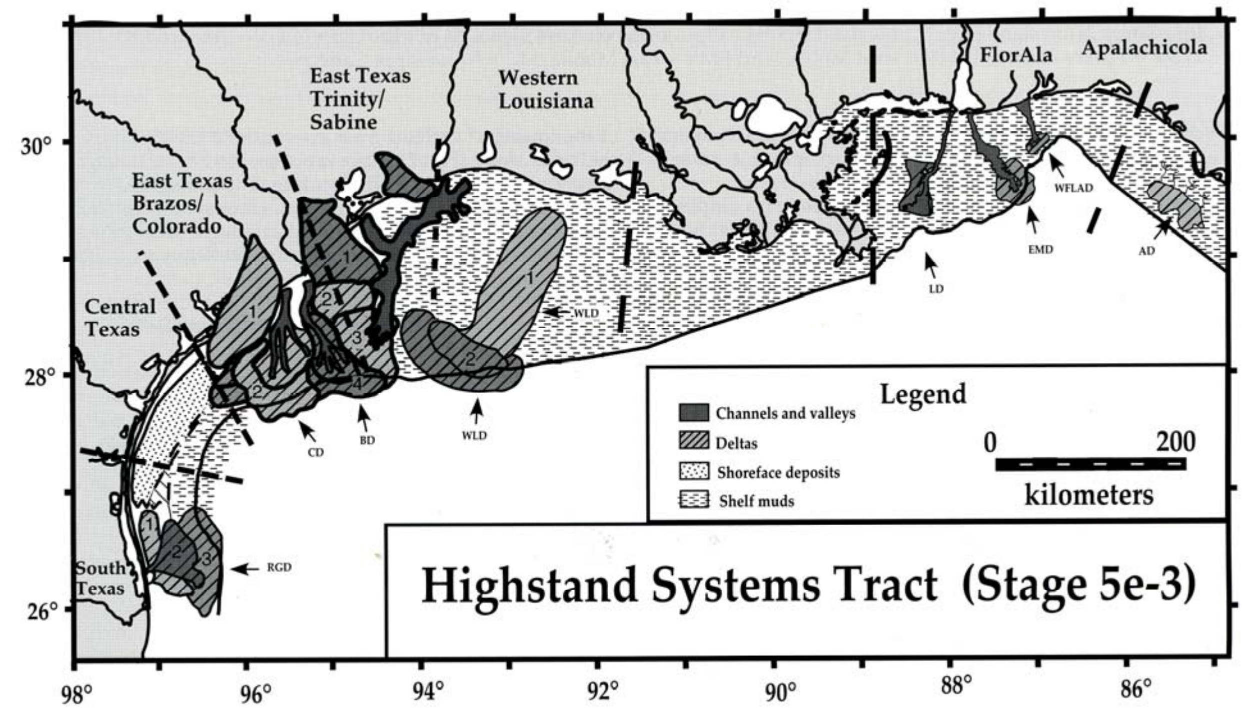

Figure 1.12—Northern Gulf of Mexico HSTs developed during OIS 5e-3. Note the location of the West Louisiana Delta (WLD) and the relative areal extent of deltaic deposits east and west of the Mississippi River. From Anderson et al. (2004b).

OXYGEN ISOTOPE STAGES 4 AND 3

Oxygen Isotope Stage 4 began approximately 70 ka with a rapid fall in sea level followed by a rapid rise that created the Stage 3 flooding event. During the Stage 3 highstand sea level was as high as 15 m below sea level (figure 1.11; Waelbroeck et al., 2002). During Stage 3 sea level continued to fall and shorelines gradually shifted seaward from the falling base level and resultant progradation. Deltas of stage 3 contain more sediment than those of stage 5 even though they were similar in duration (figure 1.12; Anderson et al., 2004). Stage 3 deposition was the most substantial on the outer shelf where subsidence rates and preservation potential are high. Cannibalization of stage 5 deltas also contributed to the large flux of sediment offshore (Anderson et al., 2004).

Northwestern Gulf of Mexico deltas of the Rio Grande, Colorado, Brazos and western Louisiana all extend onto a shallow sloping continental shelf relative to the northeastern Gulf of Mexico, and contain low-angle clinoforms (Abdulah et al., 2004; Anderson et al., 2004; Banfield

and Anderson, 2004; Wellner et al., 2004). These deltas all consist of prodelta muds that are overlain by sandy distributary mouth bars and delta front sands (Abdulah et al., 2004; Anderson et al., 2004; Banfield and Anderson, 2004; Wellner et al., 2004). Northeastern Gulf of Mexico deltas of west Florida and Alabama are steeply dipping relative to deltas of northwestern Gulf of Mexico and have no significant prodeltaic beds, hence they are interpreted to be highly sand prone. In addition, deltas of the northeastern Gulf of Mexico are located on a portion of the margin that is characterized by low subsidence rates and consequently low rates of accommodation space creation (Anderson et al., 2004; Bart et al., 2004, Bartek et al., 2004). Limited accommodation space led to frequent delta switching events and large lateral deviations of depocenters. The largest rivers continued to prograde in the midst of the sea level fall of stage 3 and eventually reached the shelf margin by the end of the interglacial period (Anderson et al., 2004). Because of variations of sediment flux and accommodation space the smaller deltas did not reach the shelf margin at the same time as larger deltas (Anderson et al., 2004). For example, a late stage 3 Colorado river delta prograded over an earlier stage 3 Brazos delta; these deltas are truncated by the stage 2 sequence boundary and overlain by lowstand and transgressive deposits (Anderson et al., 2004; Abdulah et al., 2004). These sedimentary relationships indicate that shelf edge deltas do not develop solely during lowstand and this is useful in understanding the extent and scale of shelf edge deltaic complexes. There are no shelf sand bodies on the central Texas coast because of a lack of coarse-grained sediment supply (Anderson et al., 2004; Eckles et al., 2004). Sandy progradational shorelines transition to shelf muds during sea level fell in stage 4.

OXYGEN ISOTOPE STAGE 2

During the Last Glacial Maximum eustatic sea levels were as much as 118 m lower than the present day (figure 1.11; Fairbanks, 1989) and the shoreline was at or near the shelf edge. Lowered sea level forced fluvial incision across the continental shelf and in conjunction with subaerial exposure of interfluves formed a Stage 2 sequence boundary (Boyd et al., 1989b). This sequence boundary is laterally extensive and separates Stage 5-3 highstand systems tracts

from Stage 2 lowstand systems tracts (Anderson et al., 2004). Incised fluvial channels, lowstand deltas, slope fans, and sediment gravity flows represent typical lowstand features (figure 1.13).

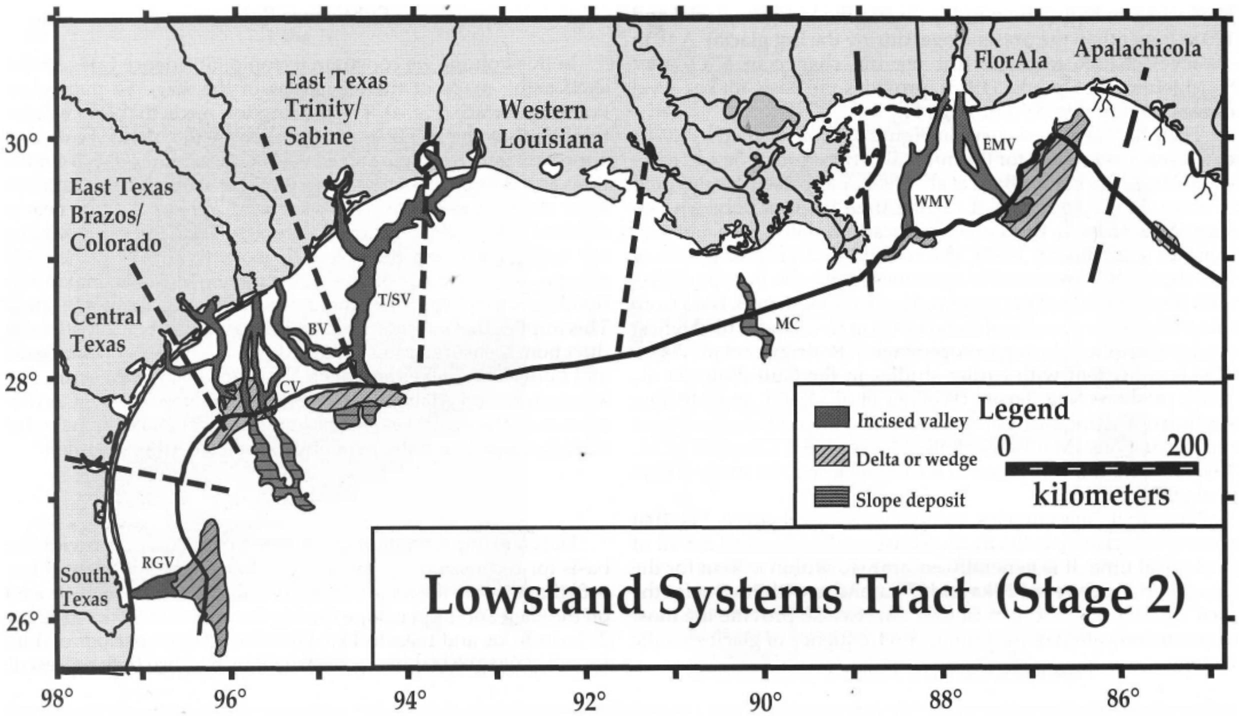

Figure 1.13—LSTs of the Northern Gulf of Mexico during Stage 2. Lowstand deltas and wedge deposits are at or very near the shelf edge. Note the incised channel of the Mississippi River extending off of the shelf. From Anderson et al. (2004).

Incised valleys on the western Louisiana and Texas shelves become broad and shallow as they cross the shelf. Average relief within incised valleys are similar, approximately 40 m (Blum and Price, 1998) at the modern shoreline. This suggests that fluvial response to lowered base level is similar for these systems despite variations in gradient and discharge. The Brazos and the west Louisiana systems were diverted from their former courses that were occupied at the beginning of the Stage 2 lowstand, abandoning highstand deltas and forming lowstand deltas without downdip slope fans (Anderson et al., 2004). The Rio Grande and Colorado Rivers did not abandon their former highstand channels and incised into the shelf and highstand deposits leading to the development of sandy downdip slope fans (Anderson et al., 2004). The Sabine and Trinity rivers have shared a channel through previous cycles of sea level and have

bypassed sediments to form slope fans within several minibasins (figure 1.13; Anderson et al., 2004).

Rivers on steep ramp margins, such as those along the central Texas or western Florida shelves, formed shallow fluvial channels on the inner shelf (Anderson et al., 2004; Eckles, 2004; McKeown et al., 2004). River morphology and the character of shelf sediments of the two areas vary based on the character of the sediment load in coastal plain streams. Rivers on the central Texas coast have abundant fine-grained sediment, meandering fluvial morphology and muddy shelf conditions (Eckles et al., 2004). Western Florida rivers carry predominately sandy sediment and therefore have braided morphology and a sandy shelf environment (McKeown et al., 2004).

Each northern Gulf of Mexico coastal plain fluvial system is unique and responds differently to changes in sea level. Significant morphological variation of the incised valleys formed during the last lowstand of stage 2 is a consequence of the diversity of stream gradients, sediment load, discharge, shelf width and gradient, and substrate conditions. The result is that patterns of delta growth through aggradation and progradation are not consistent from one system to another. Some deltas were more active from highstand to the beginning stages of transgression while others were active during lowstand and transgression.

TRANSITION FROM OXYGEN ISOTOPE STAGE 2 TO 1

At the close of the Last Glacial Maximum sea level had fallen by more than 100 m due to sequestration of large volumes of water in continental scale ice sheets. After this event of maximum lowstand deglaciation led to sea level rise to within a few meters of its present day elevation by ~6 ka (Fairbanks, 1989; Penland et al., 1989; Törnqvist et al., 2004). Depositional features in the northern Gulf of Mexico associated with this lowstand and subsequent transgression include deltas at the shelf margin, fluvial and wave dominated deltas, thick shelf muds, incised valleys fill sequences, sand banks, waves and ridges, and transgressive sand sheets (figure 1.14; Anderson et al., 2004).

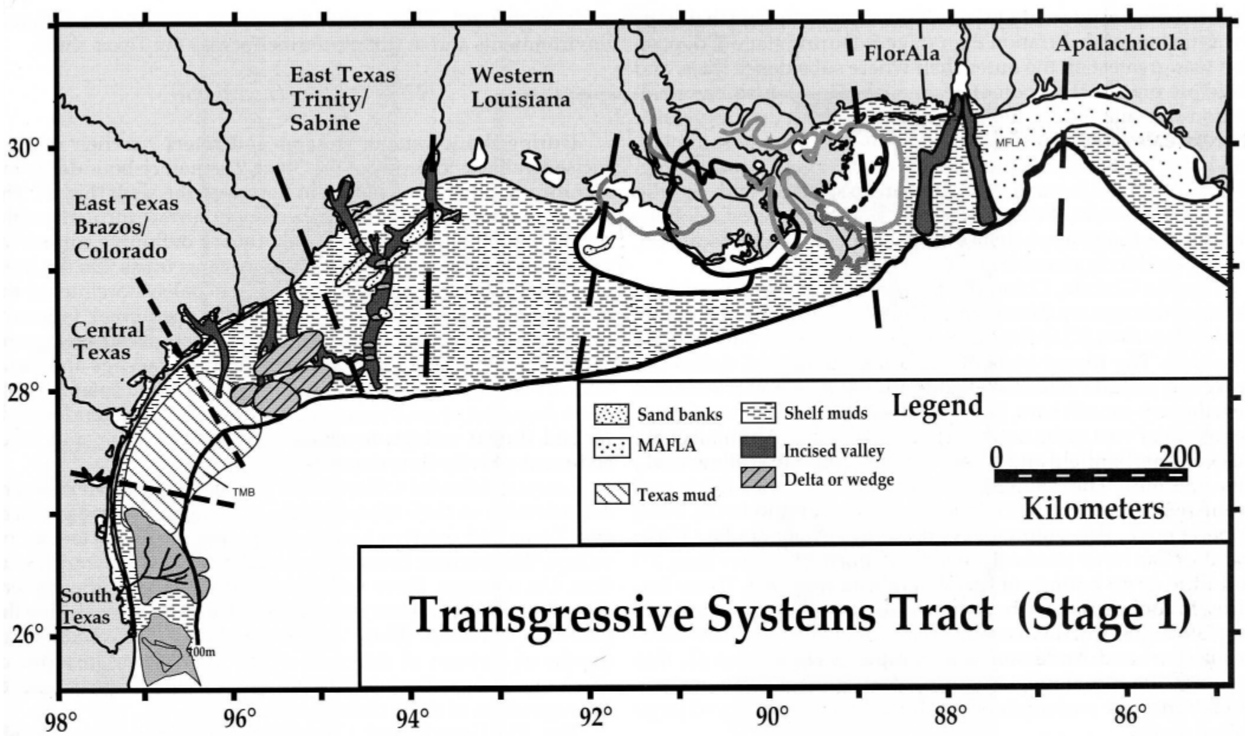

Figure 1.14—Northern Gulf of Mexico TSTs that formed early in Stage 1. Note the variability of transgressive deposits, specifically the Mississippi Alabama Florida (MAFLA) sand sheet in the northeastern Gulf of Mexico resulting from reworking and erosion of sandy deltas (McBride et al., 2004) compared to the Texas mud on the central Texas shelf and shelf muds on the remainder of the shelf. From Anderson et al. (2004).

The rivers with the largest sediment supplies—the Apalachicola, Brazos, Colorado, Rio Grande and the Mississippi—were capable of swiftly developing short-lived backstepping deltas in spite of rapidly rising eustacy (Anderson et al., 2004). Delta growth during this time was influenced by changes in sediment supply that are climatically forced (Abdulah et al, 2004). For example, precipitation increased as semiarid climates became subhumid in the watersheds of the Colorado and Brazos rivers causing a net decrease in sediment transport by the two rivers due to the increased potential for vegetation growth in the watersheds (Abdulah et al., 2004). Therefore the age of maximum delta formation rate varies between the different fluvial systems (Anderson et al., 2004).

The Trinity-Sabine incised valley fill consists of backstepping fluvial and estuarine facies interrupted by aggradational valley filling sediments (Wellner et al., 2004). One or more sedimentary facies were not deposited in some areas and represent a flooding surface

associated with a rapid landward shift of facies (Thomas and Anderson, 1994). On the eastern Louisiana to Mississippi shelf lie 1-9 m of transgressive estuarine, sound, and neritic facies were deposited between 14.30-9.22 cal kya (Fillon et al, 2004). Deposition on the western Louisiana shelf is similar to that found on the Alabama shelf; a trend of fluvial, estuarine, and marine facies indicating increasing relative sea level and water depths (Anderson et al., 2004). The Brazos and Colorado rivers have a greater sediment supply compared to the Trinity-Sabine system and were capable of filling their incised valleys. Once the valleys were filled the rivers changed course to occupy more shallow valleys (Abdulah et al., 2004). Because this occurred in conjunction with rising sea levels the younger valleys do not cut as deep into the continental shelf and therefore have a lower preservation potential than older, deeper incised valleys.

The Heald and Sabine banks on the east Texas shelf represent paleoshorelines (figure 1.14) associated with the Trinity-Sabine incised valley system that were abandoned during Holocene transgression (Rodriguez et al, 2004). Cores from the area show a vertical succession of back barrier estuarine conditions, barrier, lower shoreface, and ebb tidal deltas (Rodriguez et al., 2004). The same vertical succession was found in boring MP288 on the relict Lagniappe delta on the western Louisiana-Mississippi shelf (Roberts et al, 2004). Offshore of the central Texas coast lies a mud blanket (up to 45 m thick) derived from sediment contributions of rivers as far south as the Rio Grande and as far east as the Mississippi river (Shideler, 1981). To the east on the Mississippi-Alabama-Florida shelf is a 24,000 km^2 transgressive sand ridge field composed of late highstand and lowstand sands (McBride et al, 1999). This sand ride field is immediately underlain by the transgressive ravinement surface and above is the maximum flooding surface (McBride et al., 1999).

The Mississippi Canyon

The fall of eustatic sea level after the stage 3 interglacial period of the Late Wisconsinan began about 30 kya (Lambeck and Chappell, 2001). Continental scale glaciers, including the Laurentide Ice Sheet, expanded during stage 2 to their maximum extent between 21.0-19.6 cal kya (Brown and Kennett, 1998) and began to recede soon after. These features account for most of the water removed and sequestered from the ocean basins during stage 2. In response

to ice sheet expansion the sea level in the Gulf of Mexico fell to about 120m bsl (Fairbanks, 1989; Sydow et al., 1992). Rapidly falling sea level resulted in shorelines and deposition migrating basinward, fluvial incision, and shelf edge instability due to emplaced sediment loads.

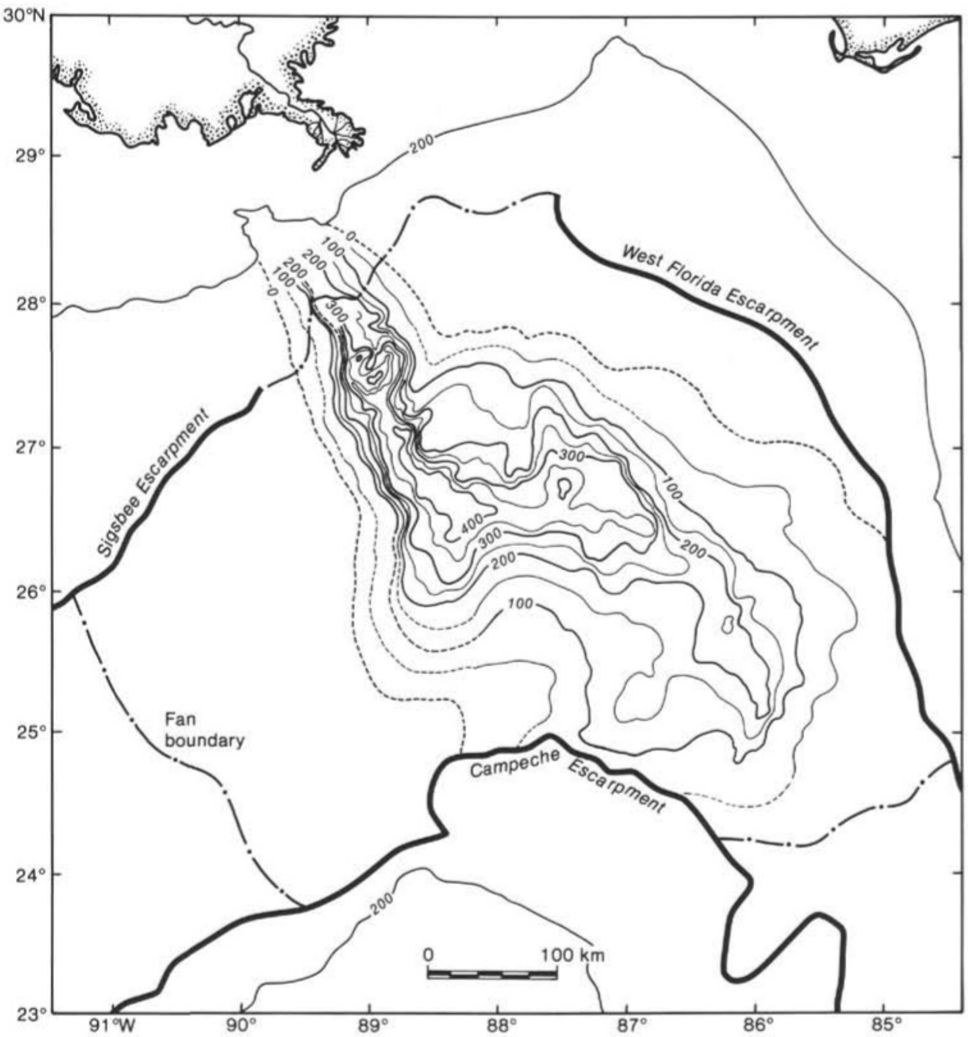

Figure 1.15—Isopach map of the youngest lobe of the Mississippi Fan emplaced during the most recent lowstand of sea level. This sedimentary unit represents the lowstand fan systems tract. Contours in meters. From Stelting et al. (1986).

The head of the Mississippi Canyon is approximately 150 m below modern sea level and therefore was not subaerially exposed during the most recent lowstand of sea-level (figures 1.1, 1.11, 4.2). The gradient of the canyon bottom is 0.3-0.5˚, which is significantly less than the gradient of the continental shelf strata that it cuts through. These shelf deposits are inclined approximately 1.5˚ and the excavated volume of the canyon is 1500 km^3. The canyon floor is

relatively flat and the walls are steep (23-25˚). Slump features are pervasive in the canyon and are thought to have provided the initial infilling sediments found at the base of the canyon (figure 1.15). The slumps formed contemporaneously with canyon formation.

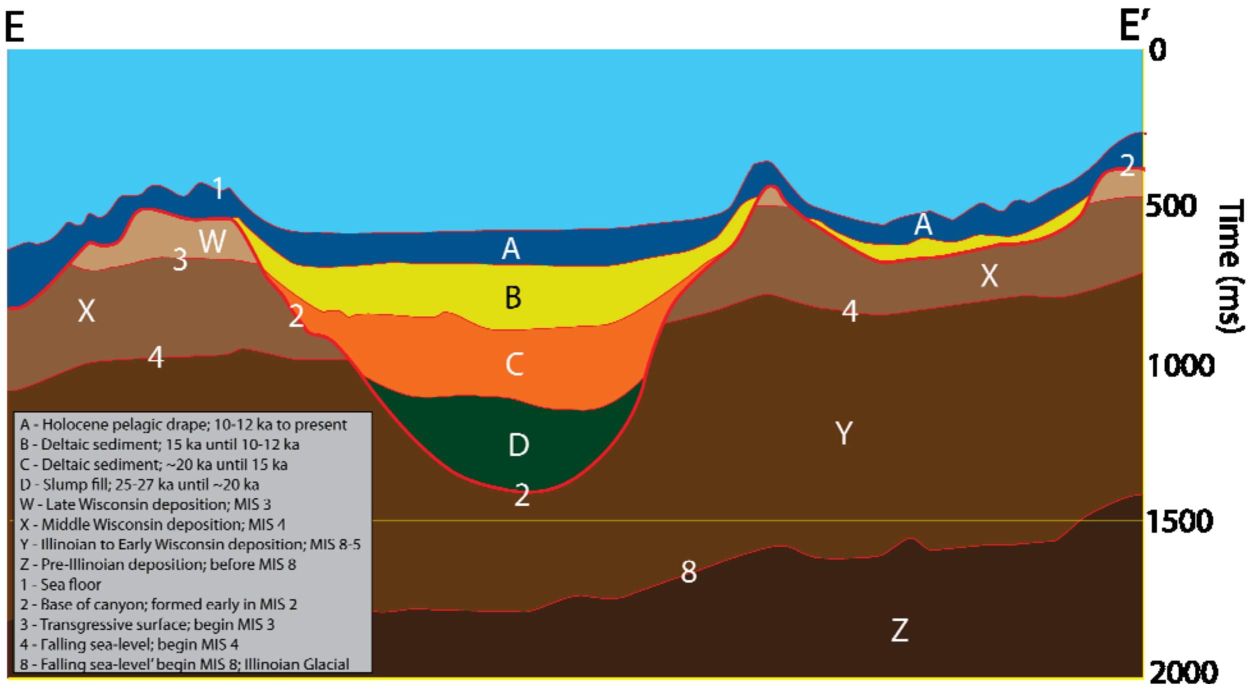

Figure 1.16—Cross section of the Mississippi Canyon, offshore Louisiana. The canyon formed during Stage 2 and is filled with slump deposits (D), deltaic sediments from the Late Wisconsin (C), the early Holocene (B), overlain by a pelagic drape (A). (Modified from Coleman et al., 1983.)

Coleman et al. (1983) determined that the Mississippi Canyon formed between 32-30 cal kya based on cross-cutting relationships between the canyon base (figure 1.16; surface 2) and horizon 40 (not shown, above surface 3) that dates to 32-30 cal kya. Canyon infilling began by 22 cal kya and was complete by 11.5 cal kya. Deep-water pelagic sediments drape the 11.5 cal kya surface. Given these relationships, the canyon must have formed over a period of about 5 ky or less.

The canyon does not cut surface 8 (fig 1.16) at the base of the deltaic and fluvial plain deposits from the Illinoian to Early Sangamon. Deposition shifted to the east of the canyon around 100 kya and a delta developed near the location of the presently active birdfoot delta of the Mississippi River. Sea level was similar to the present at 80 kya and subsequently fell, forming surface 4. About 100 m of deltaic sediments were deposited from 65-50 kya capped by

the conformable flooding surface 3 (fig 1.16). Surface 40 (not shown in fig 1.16), dated to be 32-30 cal kya, represents very shallow water deposition during falling sea-level, probably associated with a nearby deltaic depocenter. Small coral and coralgal reefs are present at this surface which is the last identifiable depositional surface that predates canyon formation.

Sediments of unit C (fig 1.16) within the canyon are finely laminated clays with stringers of fine sand and silt with a shallow water faunal assemblage deposited between 24-18 cal kya. Rates of sedimentation during this period range from 1.5-2.0 cm/yr and large foresets were distinguishable on seismic lines. This high sedimentation rate agrees with nearby active delta growth. The Holocene pelagic drape contains deep water fauna with occaisional silty layers containing shallow water fauna. This unit is deposited above both the canyon and the adjacent shelf. Unit D represents the slump fill that ended by 24 cal kya. Late Wisconsin delta lobes to the north of the canyon provided fill material from 24-11.5 cal kya followed by deposition of draping pelagic sediment until the present.

Canyon formation must have initiated sometime after 32-30 cal kya, represented by horizon 4, and began filling by 24 cal kya. Therefore there were at most 8 ky available for formation of the canyon by removal of 1500-2000 km^3 of material. The canyon most likely formed due to large scale slumping on an unstable continental margin that experienced rapid deltaic sedimentation leading up to the intiation of slump events (Coleman et al., 1983). The best evidence is the lowest canyon fill from slumps along the canyon walls, which also represents the last stage of canyon formation. Slope failures began to occur at the shelf-break and continued migrating upslope to the present head of the canyon. Once initiated the canyon served as a conduit for material displaced in future slumps and slope failures. The instability that eventually caused the initial slope failure was likely due to rapid sedimentation at the continental margin during a period of delta building and eustatic fall.

Fluvial Incision

Because of the rapidity of sea level fall during stage 2, the unconsolidated nature of preceding deposition on the shelf and salt diapirism, many fluvial channels formed on the shelf during sea level fall and lowstand (Suter et al., 1987). Lowstand deposition on the shelf or at

the shelf edge is enabled by sediment bypassing and actively eroding in the incised valley. During this phase the sediment load is relatively coarse due to erosion and incision into shelf deposits as well as the bypassing of flood plains (Posamentier and Vail, 1988). Incised channels begin to fill with coarse fluvial sediment after sea level reaches its lowest point and incised channels reach equilibrium between erosion and aggradation. Fluvial channel fill reaches as much as 60 m thickness and 20 km wide while individual channels reach depths greater than 30 m deep and more than 1 km in width (Suter et al., 1987). The period of lowered sea level was brief, however, and there may not have been adequate time for the development of large deep incised channels on the shelf. Filling of fluvial channels may not have occurred until well into transgression. At the time when incision was occurring, the regional water table would have been lowered, resulting in oxidation and weathering of the exposed interfluves and generation of a distinctive erosional unconformity on the Pleistocene Prairie terrace (Fisk, 1944).

Shelf Edge Deltas

Deposition progressively shifted basinward during falling sea level, forcing a regression. Deltaic progradation across the shelf formed thin widespread sediment fans with low gradient clinoforms that are similar to modern deltas (Suter et al., 1987). These early deltaic deposits become subaerially exposed and erode rapidly, leaving behind laterally extensive thin and discontinuous deposits (Suter and Berryhill, 1985). As the rate of sea level fall decreased and the shoreline approached the shelf edge a series of shelf margin deltas began to form. The Mississippi River formed a multi-lobate lowstand delta (figure 1.17) within several interdiapiric basins that lie within the “Pleistocene trend” described by Woodbury et al. (1973) and is proposed to represent at least part of the Late Wisconsinan lowstand deposition of the Mississippi River (Suter et al., 1987). Suter et al. (1987) recognized three stacked shelf margin deltas that represent at least two fluctuations in sea level after lowstand was reached and before transgression began. Sediment deposited at the shelf margin and slope tends to form steeper clinoforms than on the shelf; clinoforms lie at 2-4° versus 0.5°. The wedge of sediment at the shelf edge is easily distinguished on dip section seismic lines. Because of the steep setting at the shelf margin, sediment gravity flows are common. Erosional troughs from slope

failures similar to the Mississippi Canyon but not as large are found under portions of the lowstand delta. Shelf margin deltas can be identified where incised channels on the shelf connect to steeply dipping clinoforms at the shelf edge (Suter and Berryhill, 1985).

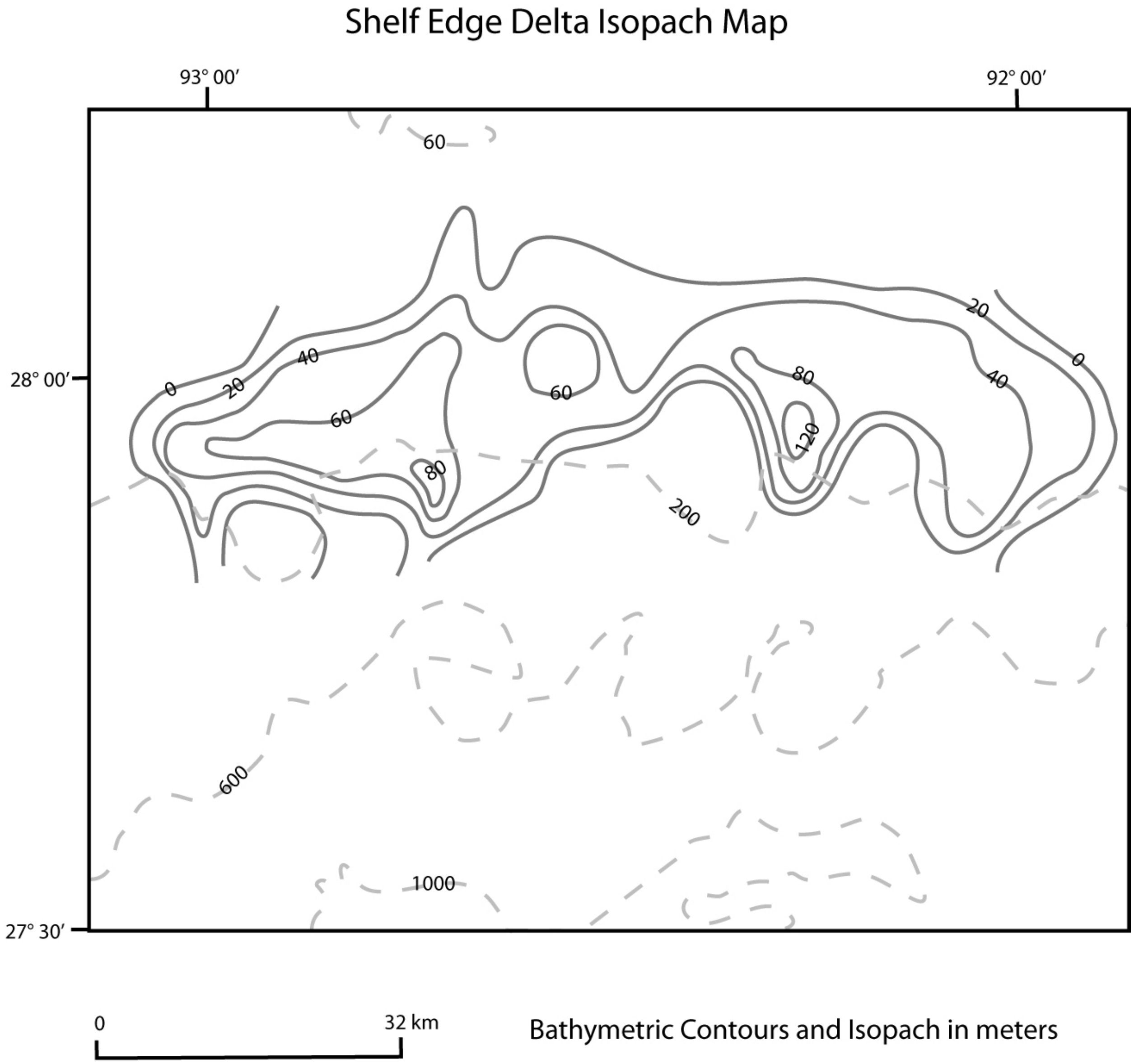

Figure 1.17—Isopach map of the shelf edge delta at the western Louisiana shelf edge. See figure 1.1 for location. (Modified from Suter and Berryhill, 1985).

Transgression and Sea Level Rise

After the Last Glacial Maximum that lasted from 21-19.6 cal kya (Leventer et al., 1982; Brown and Kennett, 1998) the continental scale glaciers began to melt, returning the sequestered water to the ocean basins. Eustatic sea level has risen about 120 m (figure 1.11,

1.18) from the time that the Laurentide and other ice sheets began melting to the present (Chappell and Shackleton, 1986; Fairbanks, 1989; Blanchon and Shaw, 1995; Lambeck and Chappell, 2001; Peltier, 2001). Several glacial meltwater lakes developed at the margins of the Laurentide ice sheet and periodically discharged massive volumes of water through four major routes, one being the Mississippi River (Teller et al., 2002). These glacial meltwater floods contributed significant volumes of water to the oceans in a rapid and catastrophic manner. There has been debate whether sea level rise occurred episodically or progressed in a constant manner (figure 4.5) (Curray, 1961; Coleman and Smith, 1964; Penland et al., 1989; Blanchon and Shaw, 1995; Törnqvist et al., 2004; Otvos, 2005). The preceding topics will be discussed in detail in the following paragraphs as well as the coastal and fluvial response along the Louisiana coast.

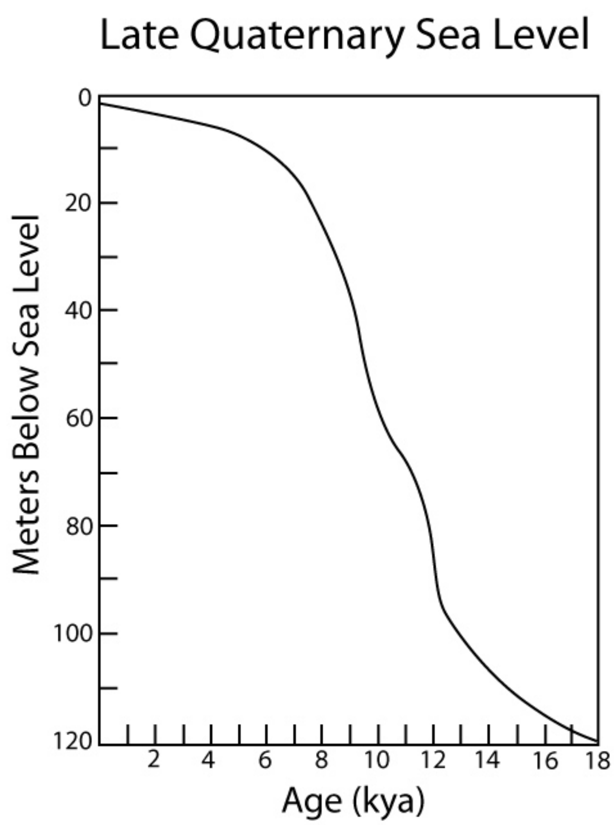

Figure 1.18—Record of eustatic sea level during transgression after the last glacial maximum. Derived from corals offshore Barbados by Fairbanks (1989).

Nelson and Bray (1970), Frazier (1974), Penland et al. (1989), Thomas and Anderson (1994), and Blanchon and Shaw (1995) argue that sea level rose episodically, with abrupt rises separated by still stands (figure 1.19). The main body of evidence used to support this claim is the development of shelf phase deltas during transgression (Frazier, 1974; Penland et al., 1989) and relict shorelines (Rodriguez et al., 2004). Others, such as Curray (1961), Coleman and Smith (1964), Fairbanks (1989), Peltier (2001), Törnqvist et al. (2004), Otvos (2005), and Milliken et al. (2008) present sea level records that support a continuously rising sea level albeit with some variation in the rate of rise (figure 1.19). These two perspectives can be reconciled when the interplay between rising sea level increasing accommodation space and sediment supply are considered. Stated simply, when sediment supplied to the coast is greater than the creation of accommodation space then the shoreline will prograde, and when it is less than the shoreline will transgress (Muto and Steel, 1997). There has yet to be an analysis of sediment supply during the Holocene that determines the relationship of sediment supply and relative sea level rise. It is known that there were catastrophic meltwater floods at the end of the Pleistocene during deglaciation and into the Holocene. These floods may have caused sea level to rise rapidly and subsequently sea level rise may have continued at a reduced rate.

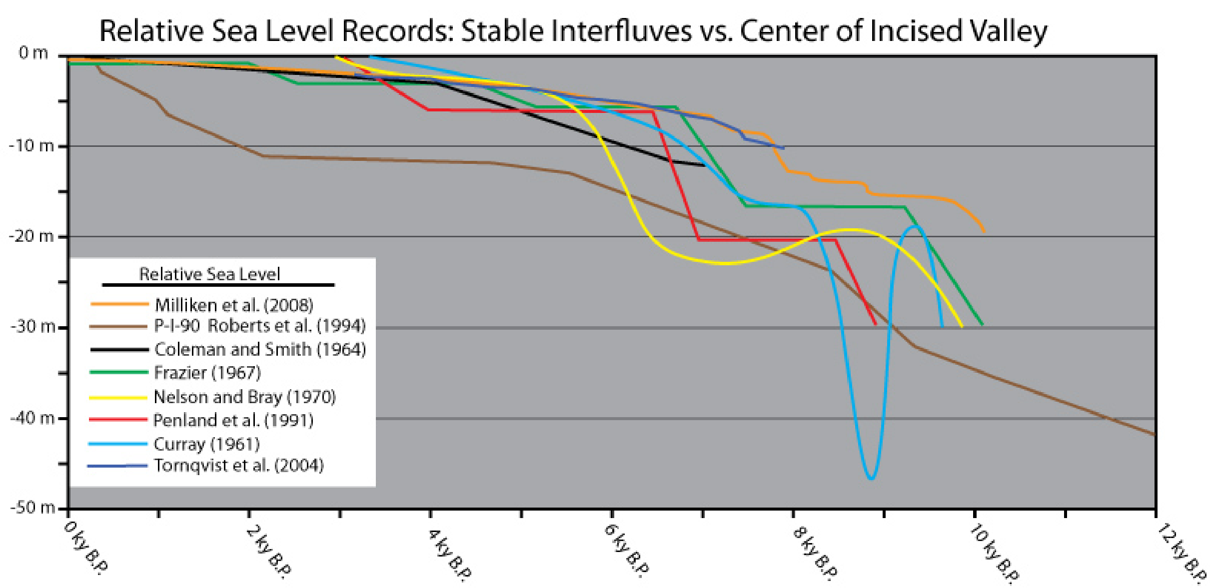

Figure 1.19—Eustatic sea level records published by Milliken et al. (2008), Coleman and Smith (1964), Nelson and Bray (1970), Penland et al. (1991), Curray (1961), Frazier (1967), and Törnqvist et al. (2004). The record from Roberts et al. (1994) is a relative sea level curve derived from radiocarbon dated peats within the Mississippi River incised valley.

According to Frazier (1967) the Maringouin-Teche delta complexes were deposited while sea level was still rising (figure 1.8). The Maringouin delta developed from 11.5-7.4 cal kya and the Teche from 6.5-4.3 cal kya (Frazier, 1967). The Maringouin-Teche deltas are overlain by lagoonal deposits in portions of Barataria Bay (Kosters and Suter, 1993) signifying continued transgression following delta development. Abandonment of the Maringouin-Teche occurred around 3.7 cal kya near the end of the period of rapid sea level rise that typified the Early and Middle Holocene. Early delta lobes of the St. Bernard complex were also abandoned during this time. Relative sea level stabilized about 3.2 cal kya and the Teche Shoreline that developed represents the Shoreline of Maximum Transgression and the lagoonal deposits overlying the Maringouin-Teche deltas represent the Maximum Flooding Surface and the upper bound of the transgressive systems tract (Boyd et al., 1989b).

METHODS AND DATA

To determine the nature and character of the incised valley filling deposits requires data.

Data for this study includes interpreted borehole descriptions derived from U.S. Army Corp of Engineers (USACE) atlases (Dunbar et al., 1994, 1995), deep borings with logs, photographs, and radiocarbon dates from the U.S. Geological Society (USGS), and a deep boring log from the Louisiana Geological Society. The USACE borings were interpreted already, however the USGS and LGS borings required interpretation of depositional environments. Depositional environments were determined by comparing log descriptions and photographs with published environmental descriptions (Frazier, 1967; Coleman and Gagliano, 1964; Kolb and Van Lopik, 1966; McBride et al., 1990). Because each publication includes a slightly different assemblage of depositional facies, it was necessary to consolidate the list of facies as much as possible into a final group of facies that represent the major depositional environments in a way that is useful for interpreting the available borehole data.

U.S. Army Corp of Engineers Boreholes

Regional quadrangle maps and associated stratigraphic cross sections published by the United States Army Core of Engineers as a part of a project focused on mapping the Lower Mississippi River Alluvial Valley provided borehole data used to develop regional stratigraphic cross sections (Dunbar et al., 1994, 1995; figure 2.1, 2.2). The methods used to acquire the borehole data are unknown and no description of this process is included with the published atlases.

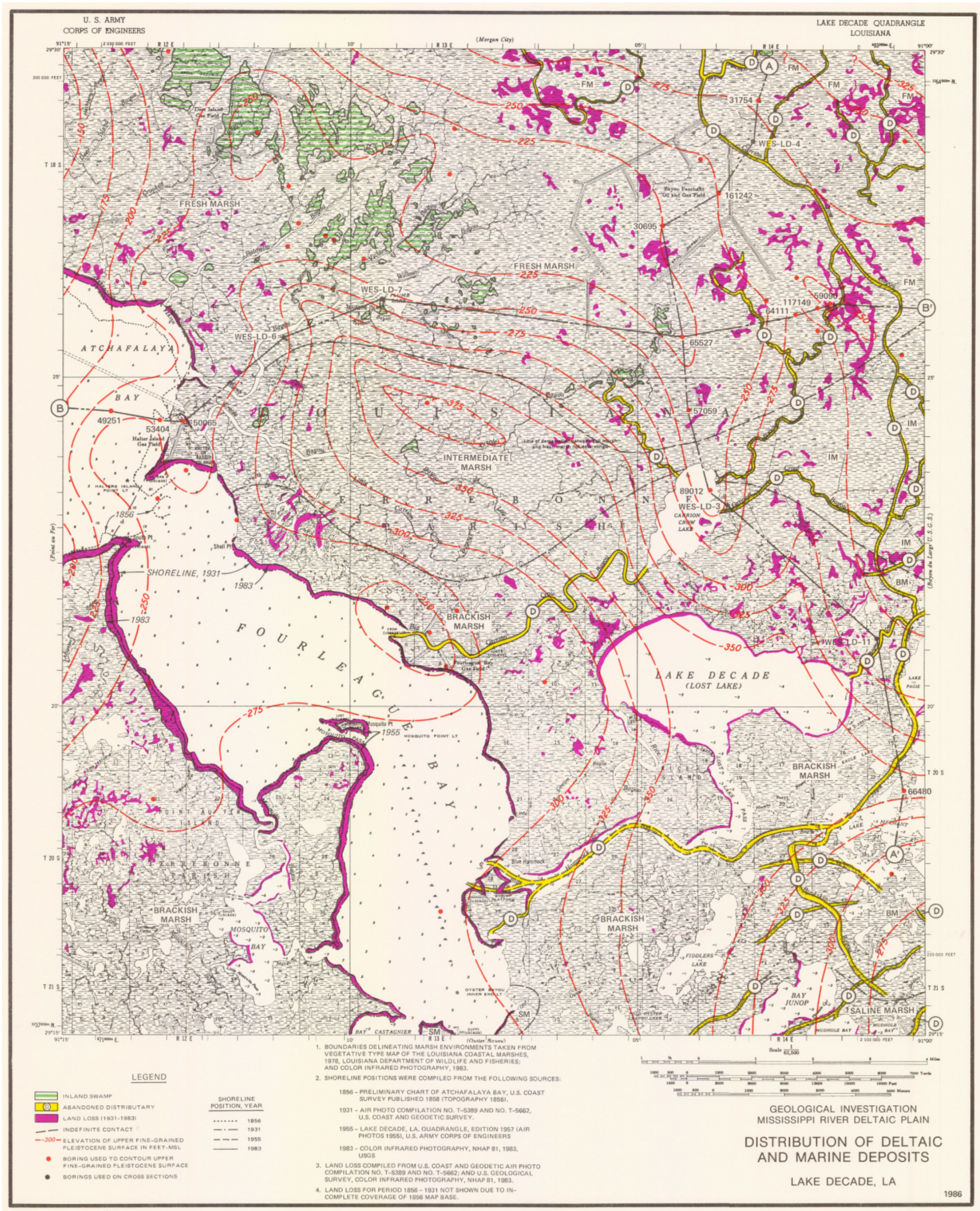

Figure 2.1—Sample U.S. Army Corps of Engineers quadrangle of Lake Decade area. Note cross sections A-A' trending north to south and B-B' running west to east. The cross sections are composed of several boreholes each. Cross section B-B' can be seen in figure 2.2. From Dunbar et al. (1994).

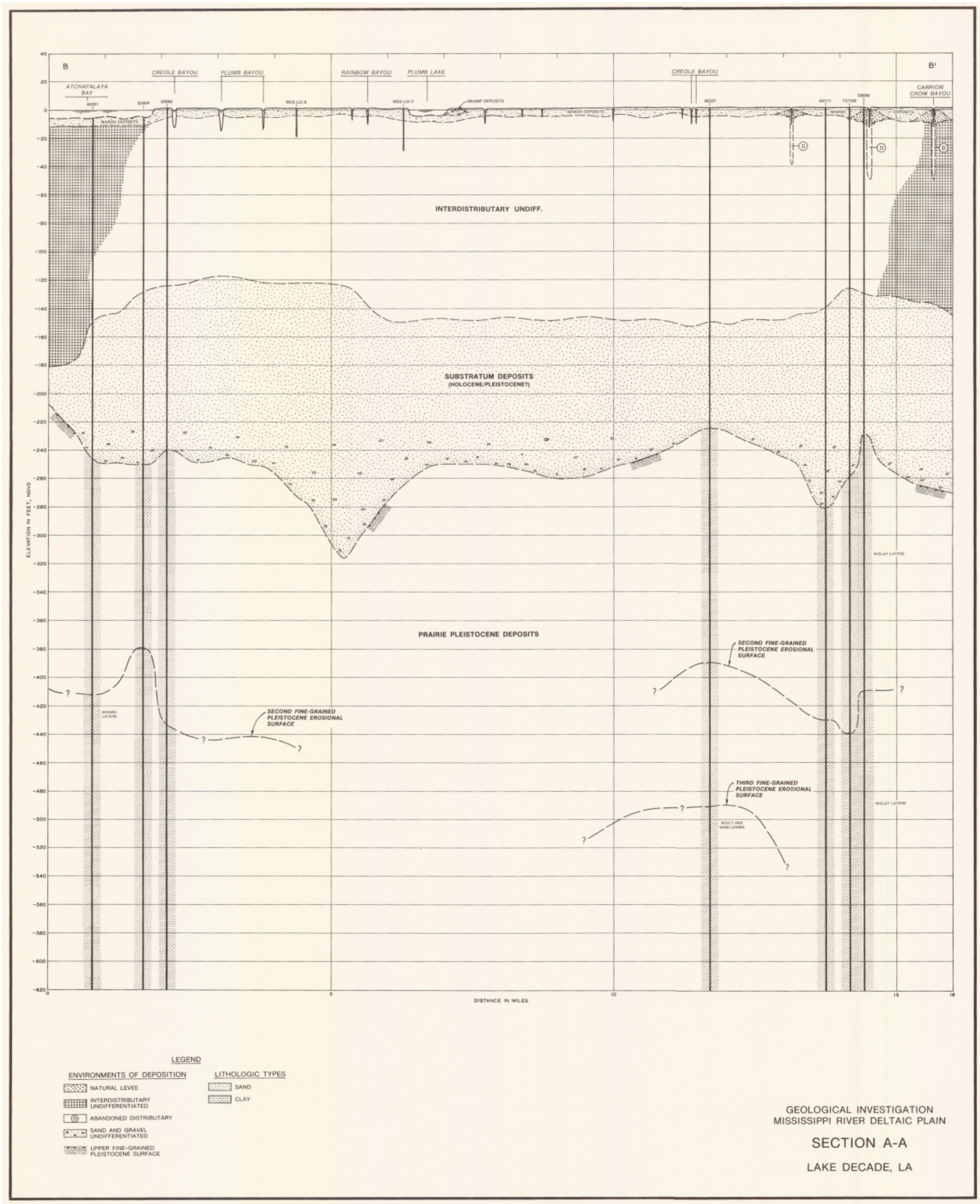

Figure 2.2—Sample cross section from USACE Lake Decade Quadrangle in which borehole data was derived. Information on depositional environments and lithology is at a relatively low resolution in this example, showing

Pleistocene deposits, substratum, and topstratum—labeled as interdistributary undifferentiated. Multiple Pleistocene erosional surfaces are suggested by borehole data as well, but are not relevant to this study. From Dunbar et al. (1994).

Boreholes were initially selected for use in regional cross sections if they penetrated the substratum. Cross section construction began by using the most detailed boreholes available that also lay in relatively straight east-west or north-south trending lines. An emphasis was made to select boreholes that could be used to tie intersecting cross-sections together. Borehole locations were calculated from measurements made using the available quadrangles and mapped using ArcGIS to assist in determining which boreholes would provide the most useful information regarding the incised valley fill.

The quality of USACE borehole data available for this study varied substantially. For example, borehole 5256 from the Thibodaux Quadrangle used in cross-section D-D’ records the natural levee deposits on the surface underlain by interdistributary, and substratum facies at the base. When compared to the highly detailed cores taken by the USGS and LGS it is apparent that what is termed interdistributary could, with higher quality data, be subdivided along facies boundaries into individual facies relatable into cyclic depositional units. Some boreholes, however, have greater information density, such as LB-13 from the Leeville Quadrangle used in cross-section C-C’. Borehole LB-13 records marsh facies above barrier island sands underlain by two cyclic units, nearshore gulf facies, point bar sands, and finally the substratum. This borehole is one of the most detailed available from the USACE.

U.S. Geological Society Boreholes

The auger cores supplied by the USGS were taken using a continuous-coring hollow-stem auger system designed, developed and implemented by personnel of the St. Petersburg office of the USGS. The Portable Auger Drilling System, or PADS, is designed to be easily assembled, transported, and operated by a crew of four. It can operate either on land or from a 7.5 m barge for coring in shallow water (< 6 m) environments. The PADS uses a 83 mm I.D. hollow-stem auger and a Laskey sediment coring device to obtain deeper (~20 m) cores than those supplied by other coring systems, e.g. Vibracores (< 9 m) or push cores (< 3 m) (Reich, 2003). The auger system provides a nearly continuous core that is useful for high resolution

stratigraphic analysis. Cores can be correlated with high-resolution seismic data to expand understanding of the stratigraphy. Radiocarbon analysis was performed on several marsh peats, wood fragments, and shells taken from the cores. Samples were sent to Beta Analytical in Miami, Florida for age determination. Only the marsh peat dates are used here due to the potential inaccuracy in dating of the other materials. Analysis of $^{13}C/^{12}C$ ratios provides an interpretation of paleosalinity (Chmura et al., 1987).

Boreholes provided by the USGS were used in this study if they penetrated relatively deep (>15m) and had detailed core descriptions and photographs. Data from these boreholes provides the framework and is an essential component to this study.

Louisiana Geological Society Borehole Data

The P-I-90 core was taken by the Louisiana Geological Society (LGS) and the U.S. Geological Survey to better understand wetland subsidence in Louisiana. The boring was drilled by Eustis Engineering and logged by Schlumberger. The core location is near Cocodrie, LA, about 20 km from the Gulf of Mexico barrier shoreline. A combination of a Failing model 3600 wet-rotary mobile drilling rig and 1.5 m long 7.62 cm diameter pushcores reached a total depth of 64.01 m. The core was described by Paul Connor Jr. with the LGS and seven coarsening upward sequences were identified. Hazel (1991) analyzed fossil assemblages to determine the depositional environment and paleosalinity. This core is the keystone used to relate many of the depositional packages of the incised valley. The abundance of radiocarbon dates in conjunction with detailed descriptions that include grain-size analysis enabled the construction of a detailed depositional history and model to be constructed.

Radiocarbon Calibration

Radiocarbon dating of buried biologic material is a critical component in constructing a chronostratigraphic framework of the Mississippi River Incised Valley fill. The interaction between cosmic rays and the upper atmosphere generates $^{14}CO_2$ which is then exchanged through the carbon reservoirs of the biosphere and oceans (Fairbanks et al., 2005).

Radiocarbon dating is incredibly useful, however it is still necessary to correct for the variability of cosmic rays, carbon reservoirs, the global carbon cycle, and deep ocean circulation (Fairbanks et al., 2005). This variability causes calculated radiocarbon ages to differ from

Many radiocarbon age dates have been collected from a wide array of sources for use in this study. The dates used most extensively were acquired from the USGS and LGS boreholes, however some radiocarbon dates have been selected from previously published works (Frazier, 1967; Roberts, 1994). All radiocarbon dates used within this body of research have been calibrated to calendar years (cal kya) using *Fairbanks0107* (Fairbanks et al., 2005).

Paleosalinity: $\delta^{13}C$ Isotope Ratios and Faunal Assemblages

Several peat samples taken from the USGS borings were analyzed for depletion of ^{13}C relative to ^{12}C and compared to values found in the Pee Dee Belemnite. Chmura and others (1987) sampled vegetation and sediments from fresh, intermediate, brackish, and saline marsh environments. Predictions of ^{13}C depletion values were calculated based upon floral assemblage, contribution of an individual species to accumulated biomass, and ^{13}C depletion values for each species. These calculated values were compared with measured values derived from collected biomass and sediment. Average $\delta^{13}C$ values for fresh, intermediate, brackish, and salt marsh were measured to be -27.8‰, -22.1‰, -16.9‰, and -16.2‰, respectively (Chmura et al., 1987). $\delta^{13}C$ values may become further depleted in sediments of brackish and salt marshes due to introduced organic matter from fresher environments and preferential decomposition of less depleted organic matter (Chmura et al., 1987).

Faunal assemblages in the LGS P-I-90 boring were analyzed by Hazel (1991). An account of microfossil species was created and used to interpret the paleo-salinity at that location when the sediments were deposited. Because these results were never officially published, they are primarily used to verify other salinity values rather than as a definitive guide to paleo-salinity.

RESULTS

Depositional Facies

Many authors have described the depositional facies encountered in the Mississippi River Delta region (Fisk, 1944; Fisk and McFarlan, 1955; Coleman and Gagliano, 1964; Kolb and Van Lopik, 1966; Frazier, 1967; Coleman, 1976; Coleman and Prior, 1980; McBride et al., 1990; Saucier, 1994; Kuecher et al., 1994; Ferina et al., 2005). For the purpose of this study and in scope of available data, the list of depositional facies related to the Mississippi River and Mississippi River Delta has been simplified to include the most widespread and fundamental environments.

Substratum

Owing to its relatively great depth, the substratum is a poorly understood sand and gravel body lying at the base of the incised valley that was deposited by a braided fluvial system during lowstand and rising sea level (Fisk and McFarlan, 1955; Kolb and Van Lopik, 1966). The unit is upward fining and the coarsest first percentile grain size is greater than 350 μm (Kuecher et al., 1994). Upper portions of the substratum are assumed to be from the same glacial cycle as the overlying topstratum deposits (Rittenour et al., 2007); however, repeated cycles of sea level cut and fill may have resulted in the deeper portions of the substratum being from previous glacial periods (Blum and Törnqvist, 2000). There is not enough data available to distinguish individual units within the substratum or the base of scouring during the last glacial stage (Saucier, 1994).

Topstratum

The topstratum is a relatively fine-grained unit overlying the substratum, both within and beyond the bounds of the incised valley (Saucier, 1994). It began forming in the lower alluvial valley when the Mississippi River switched from a braided fluvial system to a meandering fluvial system as discharge and the proportion of fine grained sediment increased (Blum, 2007). The topstratum includes all of the deltaic and fluvial sedimentary environments

described except the substratum. The topstratum is composed of sandy alluvial meanderbelts surrounded by fine-grained highly organic backswamp deposits (Fisk, 1944).

Shelf Facies

The shelf facies is the distal-most facies described here, and is an environment that receives limited terrigenous clastic sediment due to its distance away from distributary mouths. Abundant calcareous material such as shells, organic debris, foraminifera tests are found in a matrix of intensely burrowed massive gray clays (Coleman and Gagliano, 1964). Updip slope failures may introduce slump deposit units with coarse material and no internal bedding to the shelf (Coleman, 1976).

Prodelta Facies

Prodelta deposits represent the first significant terrigenous deltaic sediments deposited from suspension in marine waters onto the inner shelf or shelf edge (Kolb and Van Lopik, 1966). The depositional rate is greater than the shelf environment, and burrowing is rare to absent as a result. Prodelta deposits are dark gray or olive-gray poorly sorted silty clays and clayey silts containing parallel laminae and high lateral continuity and homogeneity (Coleman and Prior, 1980; Ferina et al., 2005). Laminae thicken and grain size coarsens both upward and landward. Laminae are identified by color variations at the base of the deposit and by silt layers in shallow proximal waters that represent seasonal changes in sedimentation (Coleman and Gagliano, 1964). There may be some thin layers of yellow or red sediment that are indicative of secondary mineralization of carbonates or detrital organic matter (McBride et al., 1990). The thickness of prodelta deposits is governed by water depth; deeper water results in thicker prodelta accumulation (Coleman, 1976).

Distributary Facies

The distributary facies is a combination of all progradational deltaic facies with measurable sand content. These environments include the intradelta, delta front, distributary mouth bar, the inner and outer fringes, point bars, and distributary channel fill. All of these facies lie adjacent to one another and the distributary, are subaqueous, and are directly related

to a prograding distributary. This facies is underlain by and often incises downward into prodelta muds. It is overlain by abandoned channel, marsh, natural levee, or interdistributary bay facies depending on the distance from the distributary.

The base of the distributary facies is equivalent to the delta front or the fringes of LeBlanc (1972). Wavy to lenticular bedded clays, silts, and sands are often burrowed due to the mixing of nutrient-rich freshwater and marine water supporting abundant fauna (Coleman, 1976). Other sedimentary structures include current stratifications, cross-laminae, current ripples, scour and fill, and erosional truncation (Coleman and Prior, 1980). This interval of the distributary facies has the greatest lateral continuity of all environments, but the lateral continuity is still less than that of the prodelta facies. Sand content continues to increase vertically upward and 2-10 cm thick sand layers interlaminated with silt and clay are common (McBride et al., 1990).

The less widespread upper portion of the distributary facies is the distributary mouth bar. This feature forms at the distributary mouth where a channel no longer restricts the flow of sediment-laden water, shoaling occurs, and the coarsest sediments settle out rapidly (Coleman, 1976). Mouth bar sedimentation rates are the highest of all progradational deltaic environments. Wave energy reworks and winnows the fine-grained particles that are deposited here. Mica flakes are common and coffee-ground organic debris is often found near the top of the distributary mouth bar (Coleman and Gagliano, 1964). Dewatering structures, climbing ripple drift, and cross-laminae are typical (Coleman and Prior, 1980). Distributary mouth bars may be much thicker than the surrounding delta plain due to syndepositional compactional subsidence.

As a distributary extends seaward it will incise a channel downward into former distributary mouth bars and delta front deposits. When the channel is abandoned it begins to fill with a wedge of coarse sediment at the head and distal end of the channel by way of a fluvial or tidal source. Fine-grained highly organic sediment, peat, plant debris, limbs and logs fill the upper channel (Kolb and Van Lopik, 1966; Coleman, 1976).

Interdistributary and Lacustrine Facies

Lacustrine environments are grouped with the interdistributary bay due to their positions landward of the distributary mouth, limited detrital sediment input, and the similar influence of wave reworking. Stratigraphically there is little information available to differentiate these two environments. The main difference between the two is that interdistributary bays lie between two bifurcating distributary channels and transition seaward to the open bay/gulf environment (Coleman and Gagliano, 1964) while lakes occur as a result of marsh degradation from animals, waves and subsidence, usually inland of interdistributary bays, but may eventually merge with the interdistributary bay environment (Kolb and Van Lopik, 1966). Both interdistributary bays and lakes are shallow (<4 m) and receive sediment from seasonal overbank floods and storms (Coleman, 1976). Interdistributary bays may also receive sediment from tidal currents. In both environments wind generated waves serve to scour and winnow bottom sediments, carrying away fine-grained material and concentrating coarse-grained sediments. Deposits are poorly sorted gray clay, silty clay, and fine silt with some paper-thin sand beds (Kolb and Van Lopik, 1966). Shell fragments, foraminifera, and detrital organic matter are common. Parallel laminations occur in fine-grained sections and lenticular bedding in sandy beds. Bioturbation and burrowing are abundant. Interdistributary bays and lakes grade upward into marshes and downward into prodelta clays.

Natural Levee Facies

Natural levees form behind the distributary mouth adjacent to the distributary channel (Coleman and Gagliano, 1964). They represent the first aggradational deposits overlying the distributary mouth bar and are composed of the coarsest portion of the suspended sediment load deposited by overbank flow during seasonal flooding (Kolb and Van Lopik, 1966). Natural levee deposits decrease in grain size, width, height, and thickness in a downstream direction and represent a fining upward facies. Gray clay, silt and fine sand make up the majority of natural levee deposits with occasional organic laminae. Climbing ripple drift, cross laminations and wavy bedding are the dominant bedforms (Coleman, 1976). Where natural levee deposits extend above the seasonal low water table they become oxidized, forming iron carbonates and

reddening the soil. Subaerially exposed natural levees are heavily rooted and bioturbated (Coleman and Prior, 1980).

Marsh

Marshes are low-lying periodically inundated areas at or near mean sea level and make up ~90% of the vegetated delta plain surface (Kolb and Van Lopik, 1966). They have the ability to produce and preserve abundant organic material due to the stagnant water and reducing conditions (Coleman, 1976). Marsh deposits accumulate as the delta plain subsides, effectively maintaining a relatively constant elevation as older deposits sink deeper and the marsh platform thickens. Fine-grained clastic detritus accumulates in marshes during seasonal overbank floods, storms, and from tidal currents (McBride et al., 1990). Seasonal river floods have the largest influence on fresh marsh environments while storms and tidal currents have a dominant effect on salt marshes (McBride et al., 1990). Clastic sediments are clays and silty clays with high organic content. The organic fraction is greater in freshwater marsh relative to salt marsh and is in some circumstances is high enough to form true peats (Kolb and Van Lopik, 1966). Rooting structures, in place roots, and burrows are common (Coleman and Prior, 1980).

Swamp

Cypress and tupelo swamps develop inland of freshwater marshes and deposit highly organic clays and peats (Coleman and Gagliano, 1964). Decaying tree stumps and trunks are common (Kolb and Van Lopik, 1966). Clays (50-70%) and some silt reach inland swamps during seasonal floods if the natural levees are overtopped (Tye and Kosters, 1986). Poorly drained swamps preserve greater amounts of organic material and have iron sulfides and vivianite mineralization while well-drained swamps form iron oxides and carbonates and less organic matter is preserved (Kolb and Van Lopik, 1966). Dewatering structures, rooting by cypress trees and thin rootlets, and burrowing are common and leave behind little of the original parallel laminations (McBride et al., 1990).

Transgressive Lag Facies

The nearshore gulf environment is similar to the sand sheet described by McBride et al. (1990), and the bay-sound environments described by Coleman and Gagliano (1964), Kolb and Van Lopik (1966), and Frazier (1967). These environments are comparable lithologically, share similar stratigraphic positions and are grouped together as transgressive shell lag. Nearshore gulf and bay deposits can be found on the lower shoreface of the inner shelf, both landward and seaward of barrier island arcs. The unit lies above an erosional unconformity and is often buried under prodeltaic muds upon the subsequent advance of the delta plain. These deposits are formed by wind generated wave energy winnowing out the finest sediment and concentrating the coarsest fraction. The fine-grained material is washed offshore or into nearby salt marshes (Kolb and Van Lopik, 1966; Miner et al., 2009). Tidal currents deliver some sand as ebb tidal delta deposits. The unit consists of fine-grained sand and shell hash with clayey silts in areas less affected by wave energy. The nearshore gulf and bay environment is highly favorable for mollusk colonization (Frazier, 1967). Shells and bioturbation are common, resulting in a massively bedded unit. This facies overlies an erosional unconformity that forms following abandonment of a distributary network or relative sea level rise subsequent erosion by wave energy (McBride et al., 1990).

Secondary Depositional Facies

BARRIER ISLANDS, BEACHES, AND SHOALS

Marine reworking of regressive deltaic deposits generates delta plain barrier islands, beaches, and shoals. Wave energy winnows out fine sediment and concentrates coarse-grained sediment. Shell beaches form on the inland margins of bays and sounds where there is little sand available (Kolb and Van Lopik, 1966). Sand beaches are composed of fine-grained clean quartzose sands (Coleman and Gagliano, 1964). They form as deltaic headlands are eroded by waves and eventually detach from the mainland and become barrier islands (Penland et al., 1988). With time the barrier island is fully inundated and becomes a subaqueous shoal, a process termed transgressive submergence (Penland et al., 1988).

OYSTER REEFS

Oyster (*Crasostrea virginica*) reefs develop in the shallow (<3 m) brackish waters of interdistributary bays and sounds (Coleman and Gagliano, 1964). Oysters prefer to colonize firm substrate such as a subsided natural levee (Kolb and Van Lopik, 1966). Successive generations build upward on dead shells below.

Borehole Facies Interpretations

USGS Boreholes

Interpreted borehole facies are shown in the tables below with the corresponding interval, radiocarbon dates, and salinity data when available. Facies interpretations are shown graphically in figures 3.1 and 3.2.

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	$^{=12}C/^{13}C$; Salinity
05BS02	7.61-10.50	Marsh	10.46-10.50; 4740±50 BP; 5482±79 BP	-15.2‰; Saline/Brackish
	10.66-12.18	Lacustrine		
	12.18-12.57	Marsh		
	12.57-13.10	Lacustrine		
	13.10-13.85	Marsh		
	13.85-15.45	Lacustrine		
	15.45-16.90	Swamp	15.69-15.71; 6620±90 BP; 7506±70 BP	-24.8‰; Intermediate
	16.90-19.58	Distributary		
	19.80-20.00	Prodelta		
	20.00-20.60	Marsh	20.60; 7410±50 BP; 8232±63 BP	-26.4‰; Fresh/Int.

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	$^{12}C/^{13}C$; Salinity
05BS01	3.05-4.94	Distributary		
	4.94-8.05	Prodelta		
	8.05-8.30	Interdistributary		
	8.30-8.90	Marsh	8.82-8.85; 4310±70 BP; 4871±75 BP	-26.4‰; Fresh/Int.
	9.14-9.50	Natural Levee		
	9.50-10.15	Distributary		
	10.15-11.10	Prodelta		
	11.10-14.66	Interdistributary		
	14.66-14.80	Transgressive Lag		
	14.80-16.77	Marsh	15.23-15.25; 6170±50 BP; 7065±81 BP 16.50-16.51; 6560±30 BP; 7458±38 BP	-27.8‰; Fresh
	16.77-17.20	Natural Levee		
	17.20-19.81	Distributary		
	19.81-21.01	Interdistributary		
	21.01-21.33	Marsh	21.24-21.25; 7290±40 BP; 8104±55 BP	-30.2‰; Fresh

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	$^{12}C/^{13}C$; Salinity
04BS02	4.57-5.84	Interdistributary		
	6.10-6.43	Distributary		
	6.43-8.27	Prodelta		
	8.27-8.73	Interdistributary		
	8.73-8.88	Transgressive Lag		
	8.88-12.21	Distributary		
	12.21-13.75	Prodelta		
	13.75-14.20	Marsh	Untested	Untested
	14.20-16.81	Distributary		
	16.81-19.85	Prodelta		
	19.85-19.98	Transgressive Lag		
	19.98-20.53	Marsh	19.98; 6560±50 BP; 8079±63 BP	-28.8‰; Fresh
	20.53-20.84	Natural Levee		
	20.84-21.24	Distributary		

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	$^{12}C/^{13}C$; Salinity
04BS01	0.00-1.36	Marsh	Untested	Untested
	1.36-2.16	Natural Levee		
	2.16-5.74	Distributary		
	6.22-6.98	Prodelta		
	6.98-7.30	Marsh	Untested	Untested
	7.30-7.49	Natural Levee		
	7.49-8.20	Distributary		
	8.20-10.00	Prodelta		
	10.00-13.86	Distributary		
	13.86-19.95	Prodelta		

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	$^{12}C/^{13}C$; Salinity
05COCO-01	3.05-3.27	Marsh	Untested	Untested
	3.27-4.04	Natural Levee		
	4.57-5.19	Distributary		
	6.09-8.58	Prodelta		
	8.58-8.64	Transgressive Lag		
	9.14-9.98	Marsh	Untested	Untested
	9.98-12.84	Interdistributary		
	12.84-16.55	Distributary		
	16.76-21.08	Prodelta		

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	$^{12}C/^{13}C$; Salinity
03K14	0.00-2.52	Marsh	Untested	Untested
	2.52-5.00	Distributary		
	5.00-8.20	Prodelta		
	8.20-8.26	Transgressive Lag		
	8.26-10.08	Interdistributary		
	10.08-10.64	Marsh	Untested	Untested
	10.64-15.24	Distributary		
	15.24-21.36	Prodelta		

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	$^{12}C/^{13}C$; Salinity
03CH02	0.00-0.60	Interdistributary		
	0.60-1.22	Marsh	Untested	Untested
	1.22-2.46	Interdistributary		
	2.46-5.12	Distributary		
	5.12-7.62	Prodelta		
	7.62-9.96	Interdistributary		
	9.96-15.32	Distributary		
	15.32-21.36	Prodelta		

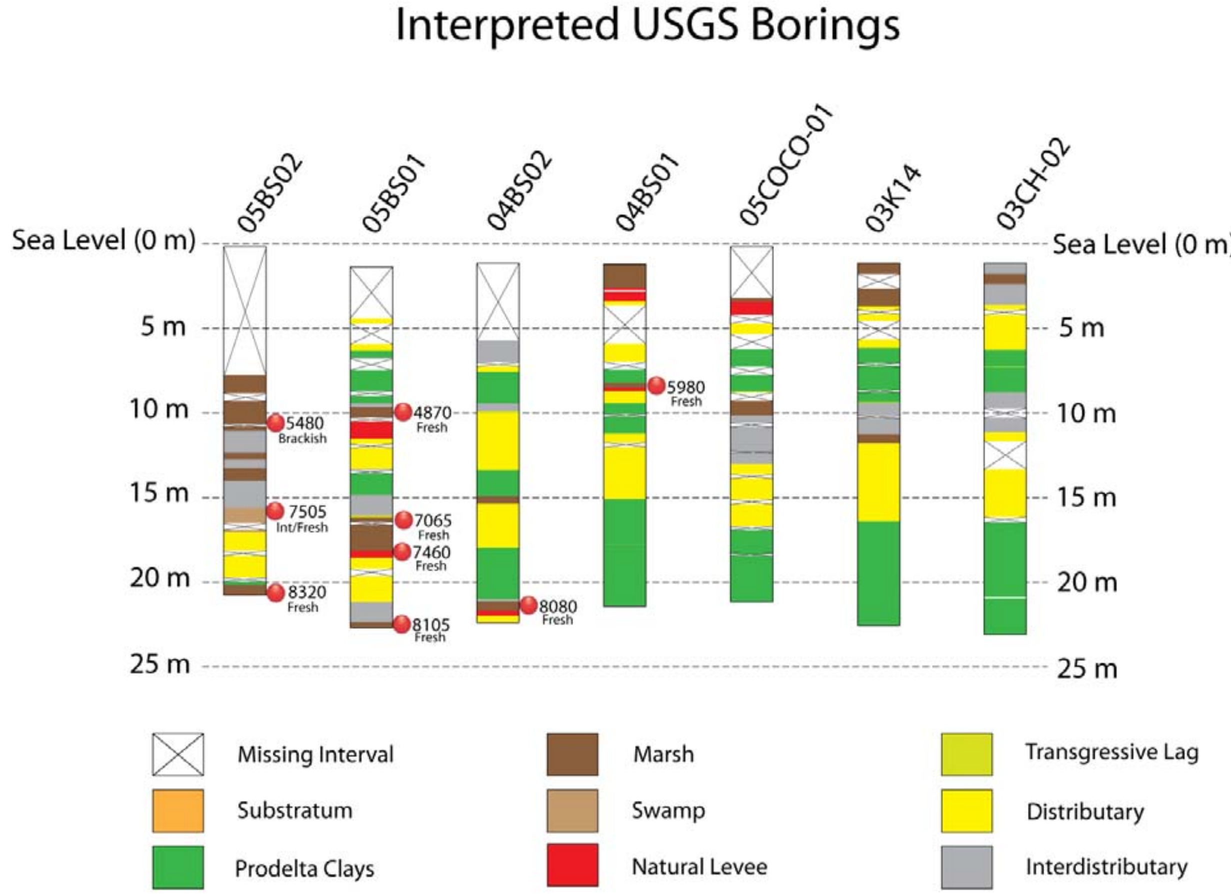

Figure 3.1—Interpreted lithofacies of USGS boreholes. Deposits are classified into one of eight depositional facies based on grain size, sedimentary features, and organic content. Available calendar ages are provided for sampled intervals as well as salinity at the time of deposition.

LGS Core Data

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	Sample Int. (m); Sample Type; Salinity
P-I-90	00-2.60	Marsh	0.90; 310±60 BP; 363±84 BP	0.00-0.20; Agglutinated forams; Saline 1.20; Trochammina; Saline
	2.60-3.82	Natural Levee		
	4.57-4.77	Marsh	4.65; 1065±125 BP; 977±129 BP	
	4.77-6.20	Natural Levee		
	6.20-6.77	Marsh	6.20-6.30; 1180±120 BP; 1097±131 BP	
	6.77-8.30	Distributary		
	8.30-10.20	Prodelta		9.40-9.60; Cytherura, nonionids, Ammonia, Elphidium; Brackish/Saline
	10.20-11.55	Transgressive Lag		10.30-10.60; Ilyocypris, Cyprideis, Actinocythereis subquadrata, Megacythere, Loxoconcha, Perissocytheridea, Ammonia, Elphidium; Brackish/Saline 11.00-11.20; Actinocythereis subquadrata, Perissocytheridea, Loxoconcha moralesi, Elphidium, Ammonia, Quinqueloculina, Actinocythereis subquadrata; Brackish/Saline
	11.55-12.98	Marsh	11.55-11.75; 4140±160 BP; 4662±222 BP 12.85; 4740±170 BP; 5463±202 BP	
	13.74-15.03	Interdistributary		
	15.26-16.78	Distributary		

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	Sample Int. (m); Sample Type; Salinity
P-I-90 (cont.)	16.90-23.60	Prodelta		21.90; Leptocythere, Paracytheroma stephensoni, Perissocytheridea, Aurila laevicula, Ammonia, Elphidium, Cytherura, Loxoconcha moralesi, Candona, Quinqueloculina; Intermediate/Fresh
	23.60-25.70	Marsh	23.60-23.70; 7625±240 BP; 8436±252 BP	
	25.70-28.53	Distributary		
	28.53-31.19	Prodelta		
	31.19-32.00	Transgressive Lag		31.60; Cytherura, Cyprideis, Ammonia, Elphidium; Oligohaline 31.80-31.90; Cytherura. Perissocytheridea, Cyprideis, Ammonia, Elphidium; Intermediate
	32.00-33.70	Marsh	32.20-32.30; 8285±110 BP; 9726±152 BP 33.47-33.57; 9085±135 BP; 10242±155 BP	
	33.70-34.40	Natural Levee		
	34.40-38.55	Distributary		
	38.55-40.90	Prodelta		39.70-39.80; Perissocytheridea, Cyprideis, Ammonia, Elphidium; Oligohaline 40.60; Perissocytheridea, Ammonia beccarii, Elphidium; Oligohaline/Brackish
	40.90-43.55	Marsh	46.20-46.40; 10250±150 BP; 11986±289 BP	41.30-41.50; Rangia, Trochammina, Ammonia beccarii, Campylodiscus; Brackish
	43.55-45.98	Interdistributary		45.60-46.00; Perissocytheridea; Brackish

Borehole	Interval (m)	Facies	Tested Interval (m); RC Age; Calendar Age	Sample Int. (m); Sample Type; Salinity
P-I-90 (cont.)	45.98-46.19	Transgressive Lag		
	46.19-47.87	Swamp	46.19-46.39; 11300±190 BP; 13151±193 BP	
	48.77-57.22	Distributary		
	58.54-62.20	Lacustrine		
	62.20-64.01	Substratum		61.60; Ostracodes; Fresh

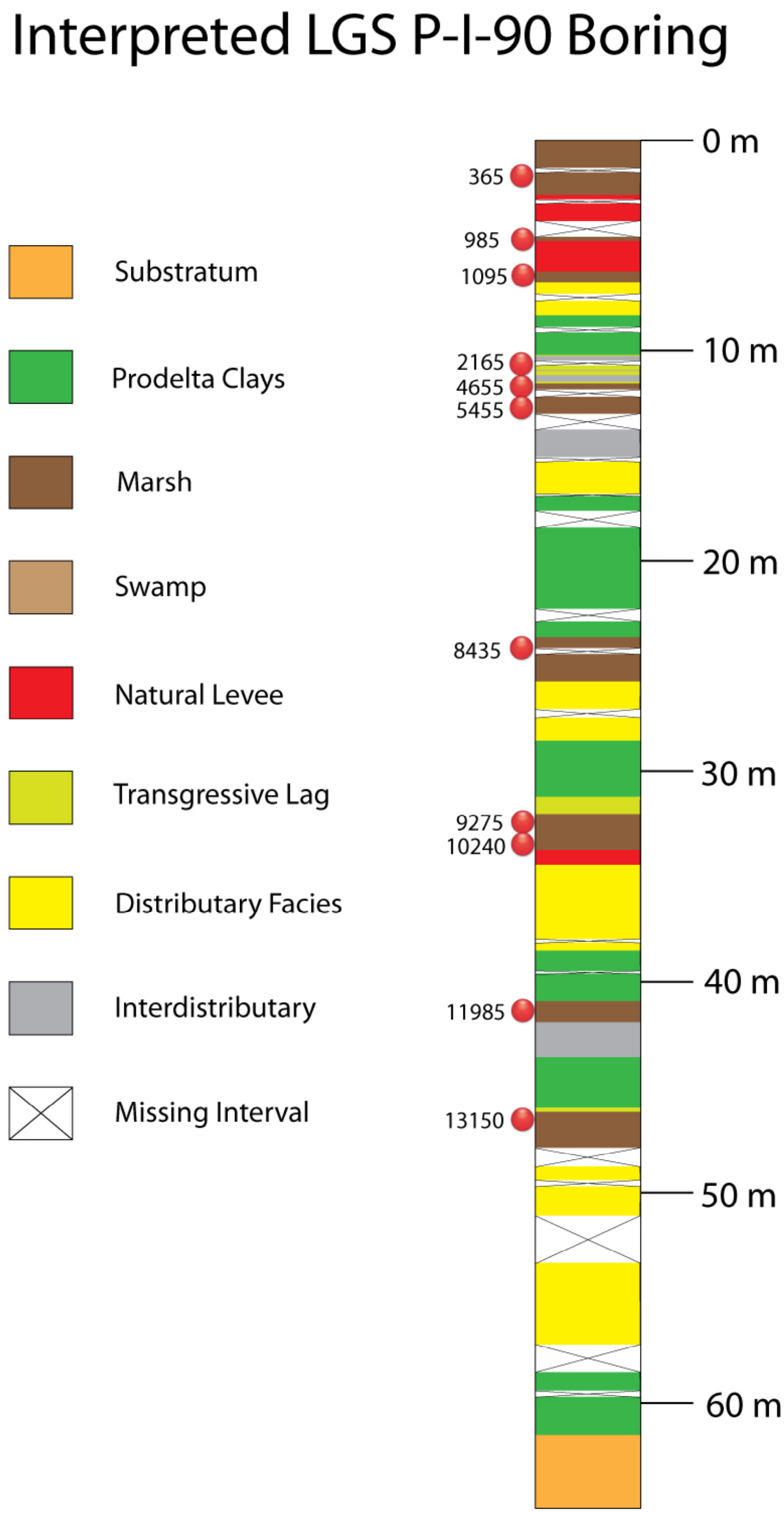

Figure 3.2—Interpreted depositional facies of the P-I-90 borehole. Deposits are classified into one of eight depositional facies based upon grain size, sedimentary features and organic content. Calibrated radiocarbon ages for organic units or shells are provided.

Regional Cross-Sections

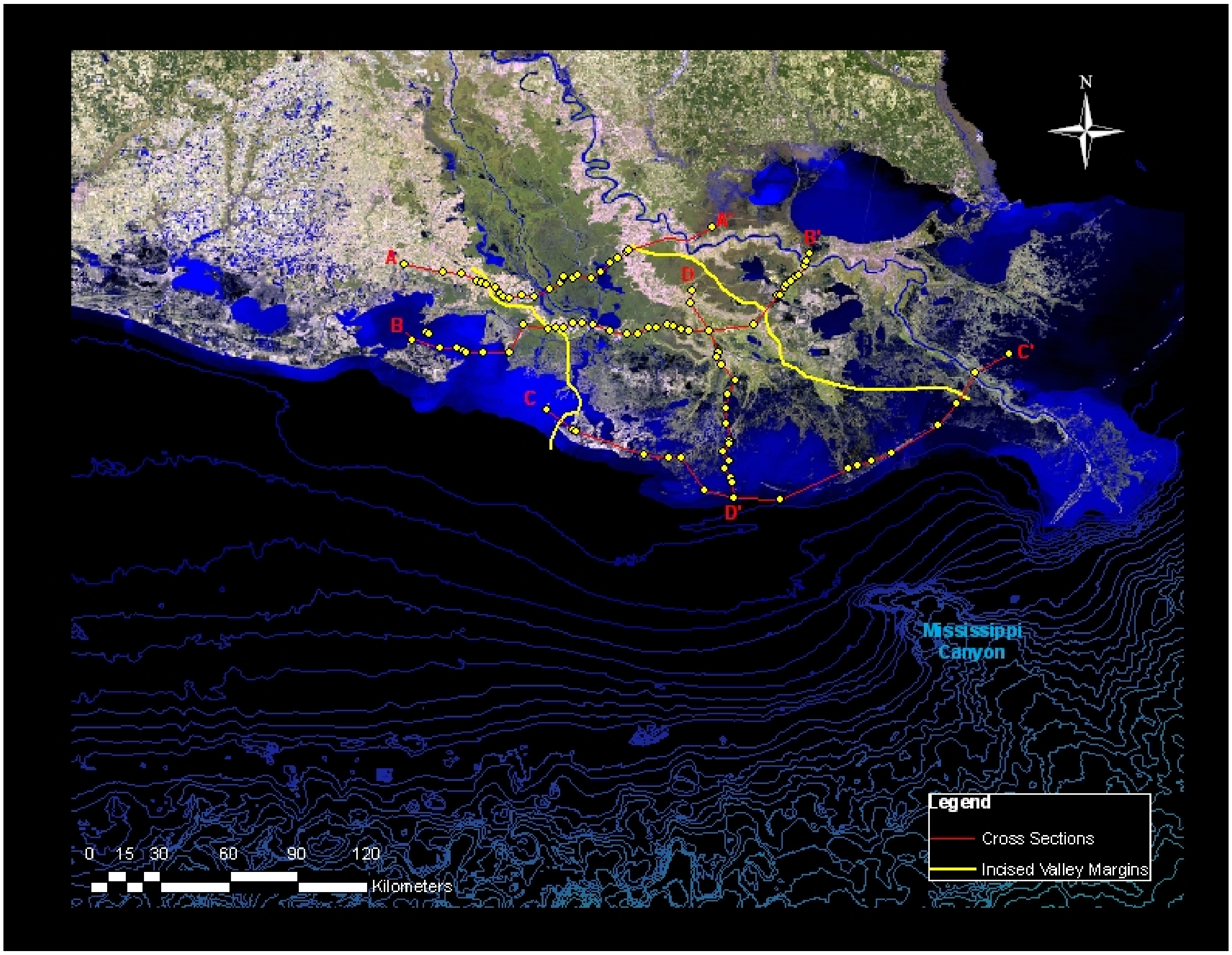

Figure 3.3—Basemap showing location of cross sections, boreholes, and incised valley margins.

A-A'

The A-A' cross-section begins between Lake Peigneur and Avery Island on the Prairie Pleistocene surface (figures 3.3, 3.4). It extends to the east to Franklin, LA along Bayou Teche, then to the east northeast across the Atchafalaya Basin and Lake Verret to Paincourtville, LA. The section crosses the upper reaches of the Barataria Basin to Convent, LA and then extends in the direction of Lake Maurepas and ends at U.S. Highway 61 north of Grand Point, LA. A total of 29 boreholes were used to construct this cross-section, all of them sourced from USACE

quadrangles (Dunbar et al., 1994; Dunbar et al., 1995). This section A-A' intersects D-D' at borehole P-4 from the Napoleonville Quadrangle (Dunbar et al., 1994).

There are two distinct incisions into the Pleistocene deposits separated by an interfluve composed of Pleistocene sediments that extends upward to 5 m depth. The main valley underlies the area between Bayou Teche and the Mississippi River and is approximately 70 km wide as measured along section. A second smaller incised valley is located about 10 km west of Bayou Teche and is approximately 5 km wide. This smaller incised valley is ~65 m deep and is filled with substratum deposits to a depth of ~10 m. Attention will be focused upon the larger incised valley as this is the only location where a separate incised valley is present.

Substratum deposits within the main incised valley indicate the base of most recent incision; depths are 115 m below sea level in the western incised valley and 130 m below sea level in the eastern incised valley. The upper surface of the substratum deposits range from 10-40 m below sea level. Substratum sediments were likely as shallow as 10 m below sea level or less prior to erosional scouring by the subsequent meandering Mississippi River. The topstratum within this cross-section is composed of point bars overlying the substratum, lacustrine, and lacustrine deltaic deposits in a matrix of fine-grained freshwater backswamp deposits. At 5-10 m depth to the surface are natural levee and distributary facies of the modern delta plain. The lacustrine and lacustrine deltaic deposits are isolated and usually < 5 m thick but can be as much as 10 m thick.

Marine waters did not influence this portion of the valley during regional transgression as indicated by backswamp and lacustrine depositional environments. The area probably looked very similar to the present day after the transition to a meandering fluvial architecture. Freshwater lakes and cypress swamps would have been widespread, collecting fine-grained sediment during high discharge events. Development of lacustrine deltas within existing lakes, similar to that of Wax Lake (Tye and Coleman, 1989), would occur after major avulsions. It is also possible that the lacustrine deltaic deposits are crevasse splays that formed near the active river channel.

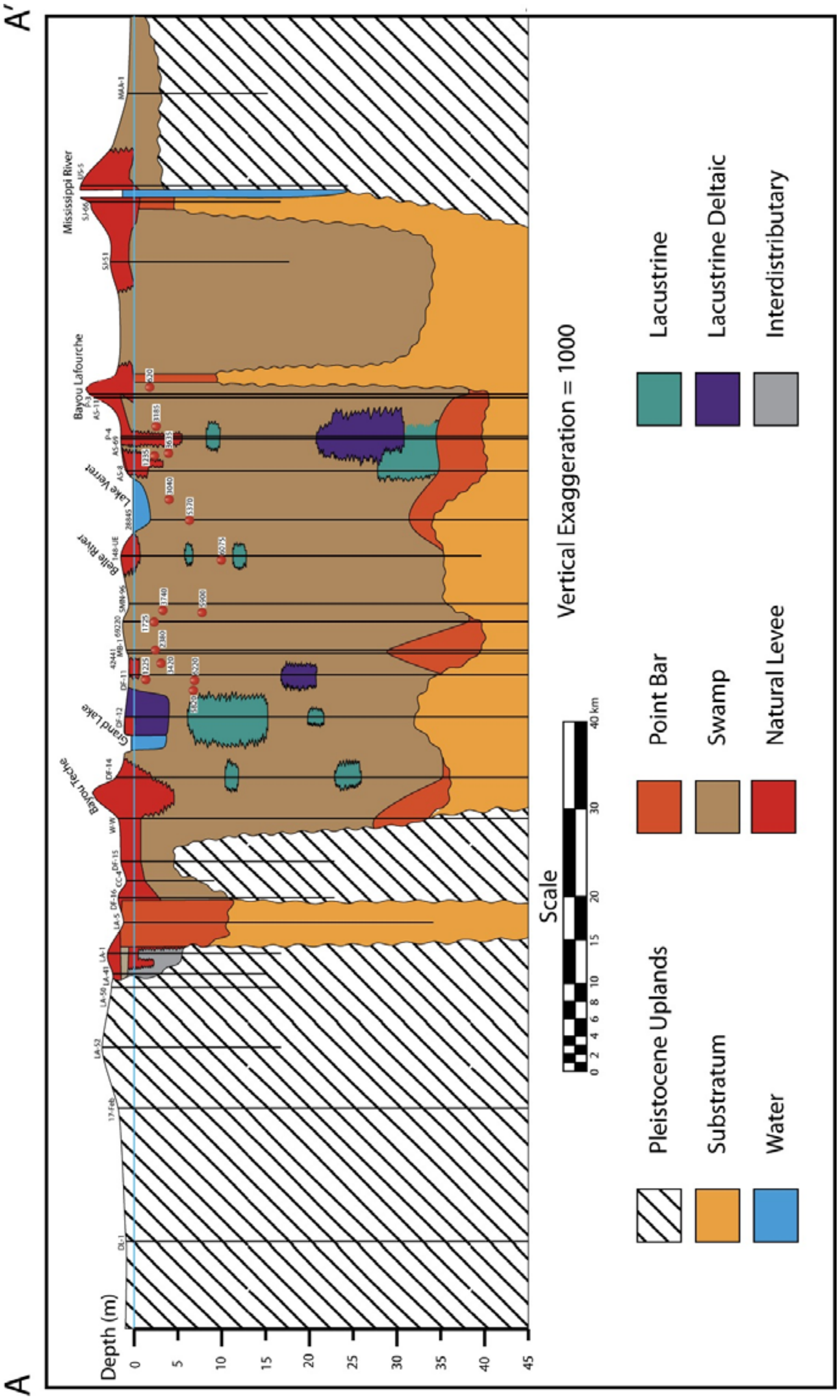

Figure 3.4—Cross section A-A′. Valley filling sediments are classified into depositional environmental facies based upon USACE borehole interpretations. At this location the incised valley is filled with freshwater fluvial deposits. Coarse-grained substratum is overlain with point bar sands that are in turn overlain by swamp and lacustrine deposits. See figure 3.3 for location.

B-B’

Cross-section B-B’ runs west to east beginning just north of Marsh Island in West Cote Blanche Bay (figures 3.3, 3.5). It runs directly east to near Gordy, LA then shifts north of the Intercoastal Waterway to Centerville, LA. The section extends east roughly following U.S. Highway 90 all the way to Raceland, LA. From here the section continues to the northeast along U.S. Highway 90 to Luling, LA and ends on the east bank of the Mississippi River east of Hahnville, LA. The cross-section includes 37 boreholes in total, all sourced from the USACE atlases (Dunbar et al., 1994; Dunbar et al., 1995).

The weathered Pleistocene surface on interfluves lies at 10-15 m below sea level on the western flank of the valley and ~20 m below sea level to the east. Incision into Pleistocene deposits reaches depths as great as 140 m below sea level near Morgan City, LA but incision in most areas only reaches ~100-120 m below sea level (Dunbar et al., 1994). The breadth of the incised valley is similar to that measured on the A-A’ cross-section, approximately 85 km. This distance is measured somewhat oblique to the orientation of the incised valley and therefore is greater in magnitude than the actual width of the incised valley.

The substratum deposits in the valley extend from the base of incision upward to 20-45 m below sea level. The upper surface of the substratum is highly irregular most likely due to erosion at the base of large meandering channels. Topstratum deposits include point bar deposits locally overlying the substratum and proximal to large distributaries associated with the modern delta plain. Approximately 10 m of lacustrine deltaic sediments also overlie the substratum near where the section crosses Bayou Teche. Other lacustrine deposits are present, about 2-5 m in thickness at a depth of ~15 m. The upper surface of a coarse distributary deposit is intersected under Bayou Blue at a depth of ~8m extending to 14 m depth. Freshwater swamp deposits are present in several locations in the western incised valley as deep as 20 m below sea level. Prodelta sediments overlie the Pleistocene surface on the eastern interfluve. Modern deltaic distributary, natural levee, and swamp facies are found at the surface and extend 5-15 m below sea level. West of Bayou Sale are marshes influenced by marine waters; much of these marsh deposits are now submerged. An oyster reef is established on a subsided natural levee deposit.

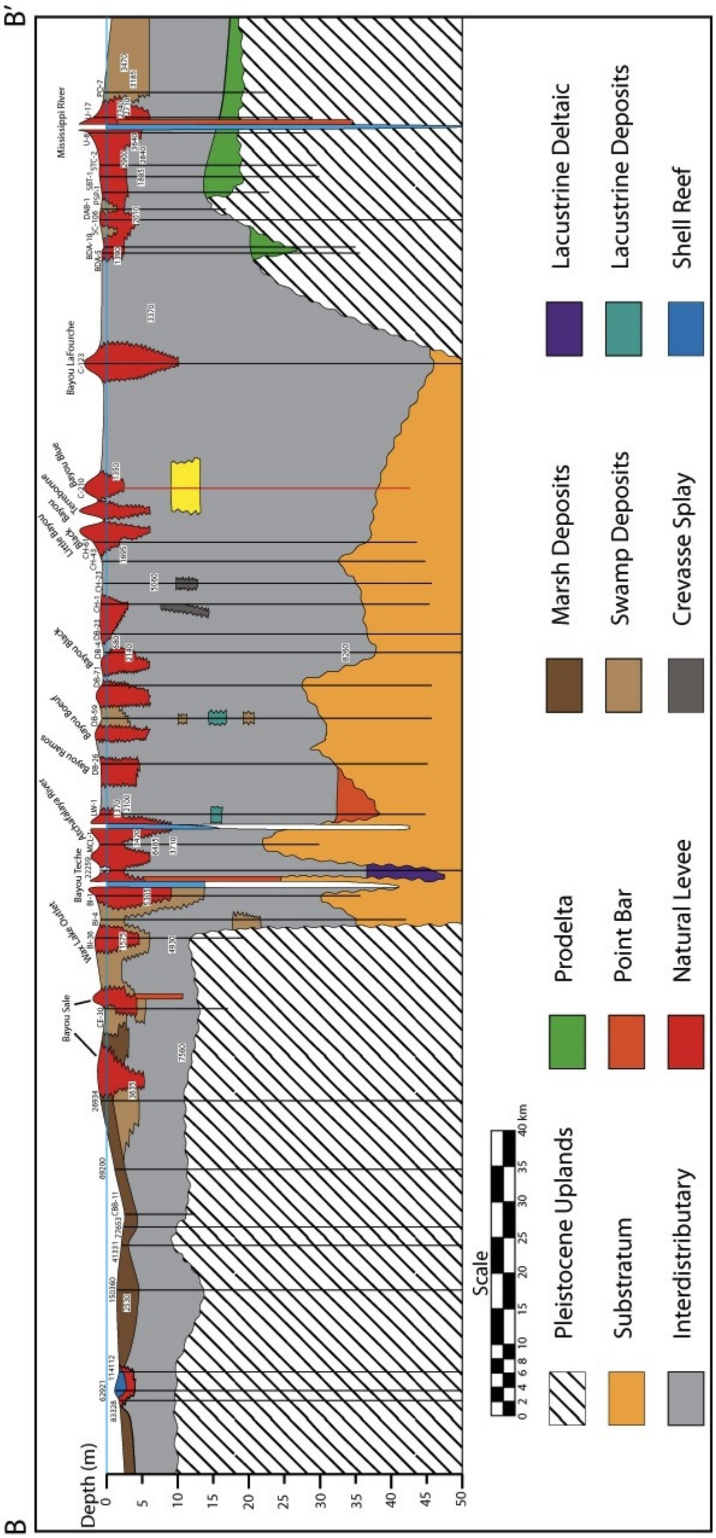

Figure 3.5—Cross section B-B′. The valley fill depicted in this cross section is substratum at the base of the incised valley overlain by primarily fine-grained interdistributary deposits. There exist some localized swamp, lacustrine, distributary, and crevasse splay deposits. Natural levee deposits interfinger with marsh, swamps and interdistributary facies at the surface. See figure 3.3 for location.

As sea level rise during deglaciation the braided fluvial network that deposited the substratum was abandoned in favor of a meandering fluvial morphology. Initial flooding of the incised valley formed lakes that subsequently filled with deltaic sediments likely sourced by nearby crevasse splays. Erosion of the upper surface of the substratum continues to the present day as channels migrate laterally within the incised valley. This migration emplaced the point bar sands found overlying the substratum. Prodelta facies overlying the eastern interfluve and coarse distributary facies under Bayou Blue indicate marine flooding and subsequent deltaic advance. The initial deltaic advance in this cross section was followed by development of the widespread modern delta plain.

C-C'

Cross-section C-C' is composed of 17 USACE boreholes (figures 3.3, 3.6). It begins between Point Au Fer and the Atchafalaya Delta and extends east southeast just south of Caillou Lake. The next boreholes are gulfward of the Isles Dernieres and Timbalier Island. The section then continues east northeast to Port Fourchon, along Grand Isle and the Grand Terre Islands. Turning to the northeast the section crosses the Mississippi River and ends in Black Bay.

The deepest incision recorded by Dunbar et al. (1994) in this cross-section is about 110 m below sea level. However, this may not be the deepest incision in the area because the base of the substratum is not indicated in the Leeville Quadrangle (Dunbar et al., 1995). The incised valley across C-C' (155 km) is much wider than in A-A' or B-B'. This is due to both the broadening of the incised valley as it approaches the shelf edge and the non linear path that the cross-section follows. The weathered Pleistocene interfluve surface lies at a depth of 25 m to the west and ~40 m to the east.

The upper surface of the substratum within the incised valley is at a depth of 35-95 m. These braided fluvial deposits may have accumulated to a greater thickness but have been scoured away by large migrating channels. The topstratum west of borehole CAL-1 is lacking in detail. Salt marsh, natural levee and the associated distributary facies are present at < 10 m depth. East of CAL-1 there is much more information available. Point bar sands and prodelta

clays overlie the substratum surface and are overlain by transgressive lag and distributary facies respectively. Swamp deposits and prodelta clays are overlain by distributary and interdistributary deposits. At the surface are transgressive lag, salt marsh, and barrier island facies.

Sea level rise, reduced discharge and a subsequent reduction in sediment supply resulted in abandonment of braided fluvial morphology in favor of meandering processes. Initial point bar deposits formed at this time as did prodelta and backswamp facies. Wave reworking of point bar and Pleistocene deposits resulted in widespread transgressive lag deposits. Deltaic advance of prodelta and distributary facies overlain by marsh deposits represent the modern day delta plain.

D-D'

The cross-section D-D' is the only dip section developed for this study (figure 3.3, 3.7). Twenty-one boreholes were used to develop D-D'. The USACE atlas provided 12 borehole descriptions (Dunbar et al., 1994), 8 boreholes were supplied by the USGS, and one borehole was sourced from the LGS. The section begins near Plaquemine, LA and stretches south east along Bayou Lafourche to Thibodaux, LA. From here the section continues south to Houma, LA, through Lake Boudreaux to Cocodrie, LA. From Cocodrie the section continues south to the Isles Dernieres.

The elevation of upper surface of the substratum within the valley in this cross-section is not uniform. Depths vary from 35-62 m below sea level with local relief as great as 15 m. The depth to the substratum generally increases downdip toward the south. Local relief is likely generated by fluvial channels scouring into the substratum. The topstratum in this cross-section can be divided into two segments separated by a lack of lithologic information. Updip there are point bar sands overlying the substratum. These sands are in turn overlain by lacustrine and lacustrine deltaic deposits and eventually the natural levee deposits of Bayou Lafourche. In the downdip segment there are a series of coarsening upward sedimentary units composed of prodelta and distributary facies overlain by marsh or swamp peats. These coarsening upward units are bounded by flooding surfaces and are increasingly influenced by

marine processes in upward and seaward directions. The lower units developed in lacustrine or backswamp environments while middle to upper units were deposited in a deltaic setting.

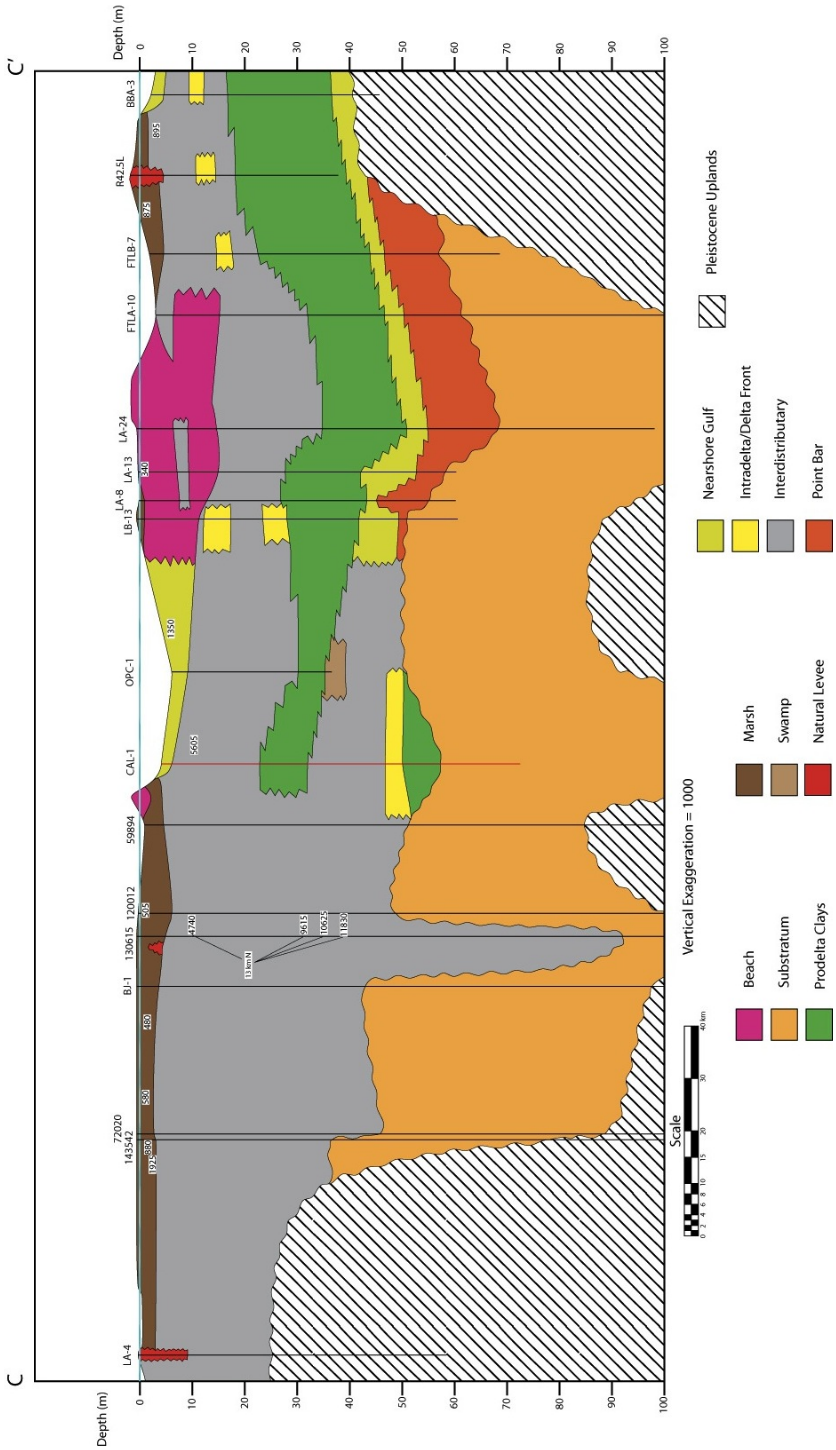

Figure 3.6—Cross section C-C′. The incised valley is much wider and has less overall relief compared to areas to the north. Substratum deposits account for the majority of the valley filling sediments. There is one deep incision into the substratum at borehole 130615. The substratum is overlain by point bar sands, nearshore gulf, prodelta, distributary, swamp, and interdistributary depositional facies. Marsh, nearshore gulf, and beach environments dominate the exposed surface with limited natural levee deposits exposed. See figure 3.3 for location.

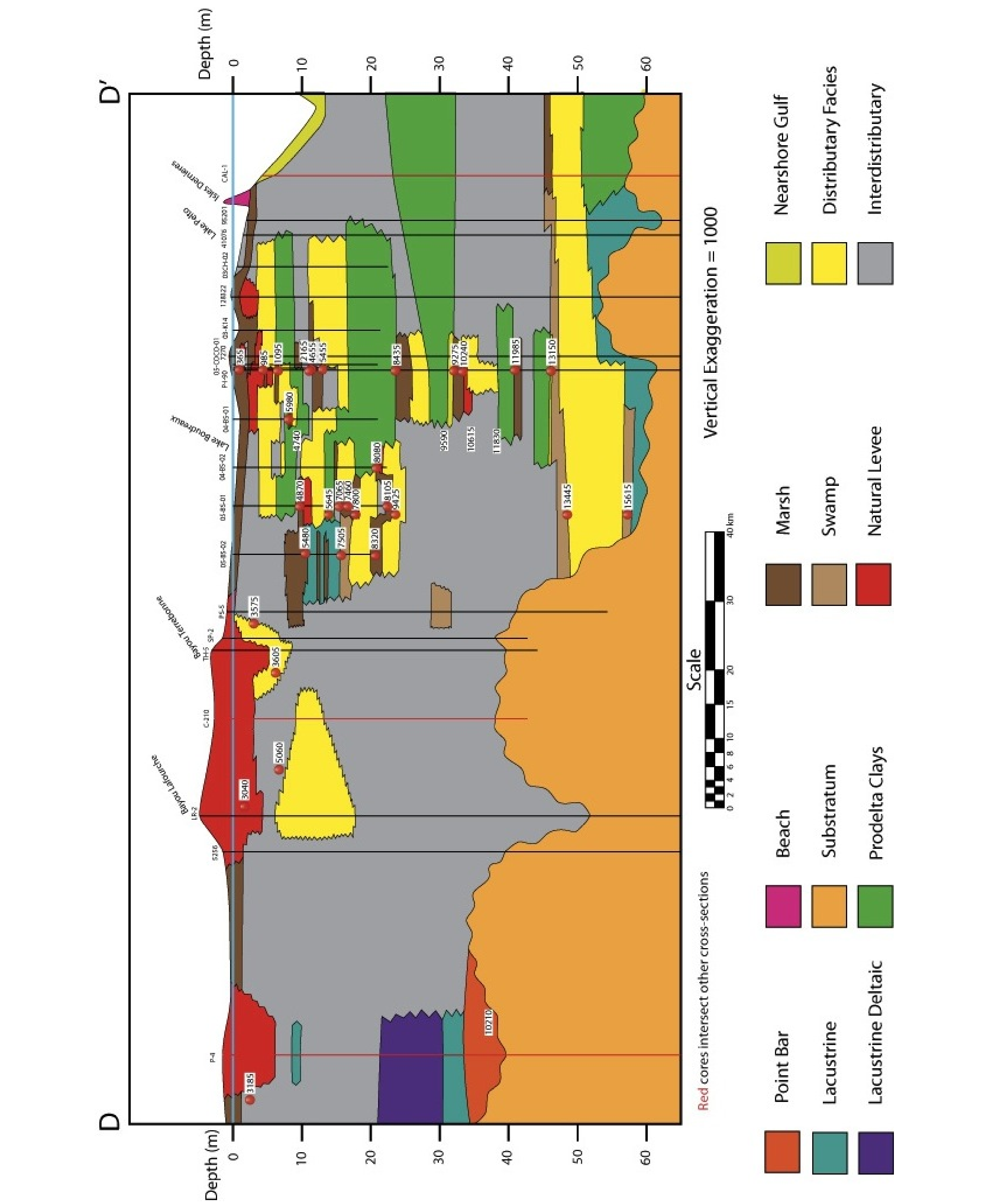

Figure 3.7—Dip oriented cross section D-D′. A series of coarsening upward sedimentary units topped by organic swamp or marsh deposits overly the substratum. Marine influence increases in an upward and seaward direction as indicated by the presence of marsh deposits in place of swamp deposits found deeper and landward. See figure 3.3 for location.

DISCUSSION

Northern Gulf of Mexico: 24 ka to Present

Leading up to the Last Glacial Maximum (LGM), sea level fell resulting in the Mississippi River incision into older sedimentary units (Fisk, 1944; Blum et al., 2007, 2008) and deposition shelf phase deltas increasingly closer to the shelf edge (Suter and Berryhill, 1985). Some time before the last glacial maximum the Mississippi Canyon developed at the continental shelf edge (Coleman et al., 1983) and contributed a large volume of sediment to the Mississippi Fan. Development of a lowstand delta complex by the Mississippi River at the shelf edge occurred during the last glacial maximum, forming a lowstand systems tract (Suter and Berryhill, 1985). Sea level rose as the continental scale glaciers began to melt, resulting in shoreline transgression and ravinement. The period of transgression is marked by massive meltwater floods in the Mississippi River from drainage of proglacial lakes (Teller et al., 2002) resulting in fluvial incision and eventually braid plain development. Meltwater floods eventually ceased although sea level continued to rise into the Holocene, punctuated by intermittent stillstands of relative sea level. Deposition filled the incised valley of the Mississippi River and a series of backstepping delta complexes developed at 11-2.5 cal kya when maximum transgression was reached, signaling the end of the transgressive systems tract and the beginning of the highstand systems tract. The formation of the modern highstand delta complex took place after sea level stabilized near its current elevation approximately 7 cal kya (Törnqvist et al., 2004).

MELTWATER FLOOD FLUVIAL INCISION

Fluvial incision occurred due to massive meltwater floods that occurred as the Laurentide Ice Sheet disintegrated (Blum et al., 2008) despite ongoing sea level rise. Zaitlin et al. (1994) noted that fluvial incision can occur from base level lowering or an increase in discharge. During Laurentide Ice Sheet decay, fluvial discharge increased by 5-8 fold above average annual flow levels (Dinnel and Wiseman, 1986; Aharon, 2003). This increased discharge in conjunction with a higher sediment load would have the potential to incise deeply into pre-existing sedimentary deposits.

Braid belts in the Lower Mississippi Alluvial Valley represent the termination of glacial meltwater floods (figure 4.1). Three major braid belts were formed after the Last Glacial Maximum (Rittenour et al., 2007). The Sikeston (19.7±1.6 to 17.8±1.3) and Kennett (16.1±1.2 to 14.4±1.1 ka) braid belts formed respectively during Erie and Mackinaw Interstades as meltwater was diverted to the North Atlantic by way of the Hudson River (Licciardi et al., 1999). The Morehouse braid belt (12.4±1.0 to 11.3±0.9 ka) correlates to the Younger Dryas period (12.8-11.5 cal ka) when the drainage of Lake Agassiz was diverted again to the North Atlantic. Overbank mud lying immediately above the Morehouse belt was dated to be 10.1 ± 0.4 cal ka (Guccione et al., 1988), and therefore represents a minimum age for the transition from braided fluvial deposition to a meandering system. Dates for the braid belts were determined using optically stimulated luminescence of quartz sand grains within the braid belts (Rittenour et al., 2007).

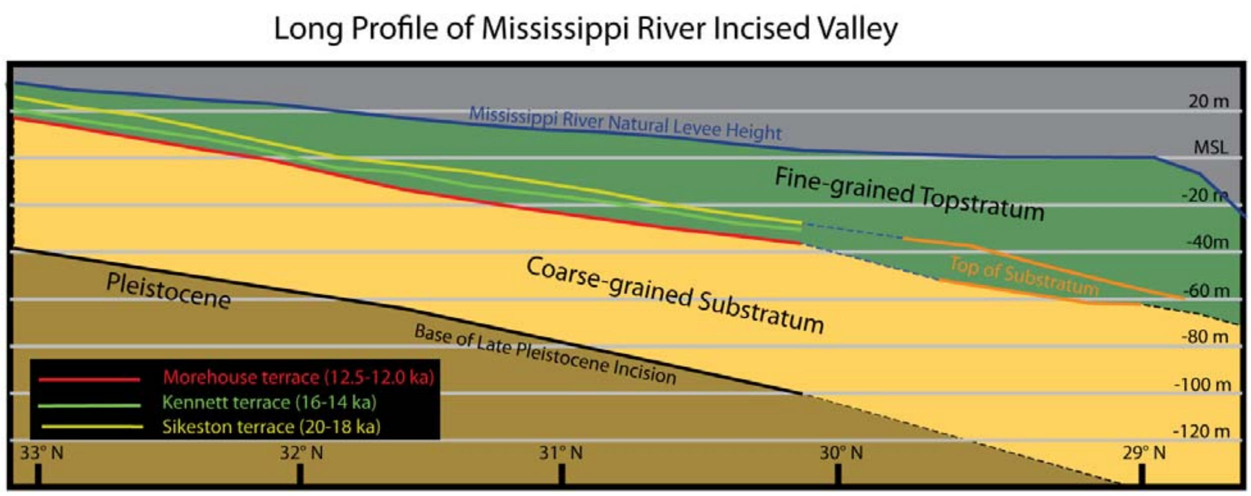

Figure 4.1—Profile of the Mississippi River incised valley and Lower Mississippi Valley. Mississippi River natural levee height, braided terraces, and base of Late Pleistocene incision are from Blum et al. (2008).

Existing Model for Transgressive Deposition

From the time when transgression commenced, about 17 ka, to approximately 9 ka, the Mississippi River was restricted to its incised valley and much of the sediment was directed to the area surrounding the Mississippi Canyon (Penland et al., 1989). From 10.1-3.7 cal kya (Törnqvist et al., 1996) the rate of sea level rise periodically slowed enough, relative to sediment supply, that shelf phase transgressive deltas began to form. Penland et al. (1989)

recognized four large sand shoals that developed during the most recent transgression. These sand shoals mark the approximate position of former shorelines behind which transgressive shelf phase delta complexes had formed. The transgressive deltas directly overlie the late Wisconsin Unconformity unconformity. Outer Shoal lies at -20 m elevation and developed around 10 cal kya (Frazier, 1974; Penland et al., 1989). Trinity Shoal and Ship Shoal lie at -10 m elevation and are associated with the 6.8 cal kya shoreline elevation (Penland et al., 1987; Penland et al., 1989). During these two phases of delta building the sediment supply of the river exceeded the total relative sea level rise at the site of deposition. Suter et al. (1987) documented three zones of strike parallel fluvial channel deposits that lie basinward of lagoonal deposits that developed during transgression and suggested that these deposits may actually be tidal inlet facies that represent former shorelines. Suter et al. (1987) also identified a deltaic body under Trinity and Ship Shoals that would have formed between 11.5-6.8 cal kya using dates from Frazier (1967). The St. Bernard Shoals are anomolous when compared to other shallow shelf shoals because they are proposed to have developed subaqueously contemporaneously with the St. Bernard Delta Complex during the late Holocene (Rogers et al., 2009).

Highstand

After the Laurentide Ice Sheet's final disintegration the rate of sea level rise slowed around 6.8 cal kya and sea level stabilized near its present position between 3.2-4.5 cal kya (Fairbanks, 1989; Lambeck and Chappell, 2001; Otvos, 2005; Milliken et al., 2008). Relative sea level continues to rise on the Louisiana coast due to the combined factors of tectonic subsidence, compaction of recently deposited sediment and eustatic sea level rise (Penland and Ramsey, 1990; Roberts et al., 1994; Kulp, 2000).

The modern highstand delta plain developed after maximum transgression and is composed of the St. Bernard, Lafourche, and the Plaquemines-Modern delta complexes. Frazier (1967) identified 16 major delta lobes within the delta plain, 13 of which developed after highstand was reached. According to Törnqvist et al. (1996) the St. Bernard Delta was initiated 3.9 cal kya and portions remained active until about 600 years ago. The Lafourche

delta developed beginning about 1.5 cal kya and largely waned by 800 cal ya (Saucier, 1994). The Plaquemines-Modern delta complex began forming about 1.3 cal kya and is still active today (Frazier, 1967; Tye and Kosters, 1986).

Sequence Stratigraphy of Isotope Stages 2 and 1

This research recognizes nine distinct depositional packages within the incised valley. Only three of these have been studied previously, the Lafourche, Teche, and Maringouin (Fraizer, 1967). Borehole data provided by the USGS has made it possible to distinguish an upper and lower Maringouin deltas that are time equivalent with established Maringouin delta chronology. Preceding deltas—the Early Holocene Delta Complex, Late Wisconsin Delta Lobe, and the Late Wisconsin Delta Complexes 1, 2, and 3—have not been identified prior to this study. These early depositional packages developed as sea level was rising rapidly and there is much about them that remains unknown. The depositional packages described herein are named by their accepted name in former publications (Maringouin, Teche) or based upon the time when they developed (Late Wisconsin, Early Holocene). Each package is termed either a delta complex or delta lobe *sensu* Roberts (1997) depending on the duration of active deposition and thickness of the deposits. Generally, a delta lobe is much shorter lived, smaller in area, and thinner than a delta complex; there are usually several delta lobes within a delta complex. Description and analysis of each depositional package begins with a list of borings containing sediments from the package of interest, if available, and a short interpretation of depositional events at the borehole location.

Lowstand Systems Tracts

During OIS 3, sea level fell from approximately 50 m below sea level to 100 m below sea level (figure 1.11, 4.2) (Waelbroeck et al., 2002). The fall was erratic and interrupted by periodic rises and then subsequent falls of sea level. The last relative highstand of OIS 3 occurred from ~33-31 cal kya. Sea level was 75-80 m below sea level.

Approximately 30-26.5 cal kya, gravitational instability at the shelf edge and subsequent mass movement processes resulted in the excavation of 1,500-2,000 km^3 of material to form

the Mississippi Canyon (Coleman et al., 1983). At this time, fluvial sediment was funneled to the Mississippi Fan (figure 1.15), a large sea-floor fan that was a site of deposition throughout the Quaternary (Stelting et al., 1986) during lowstands of sea level. Sedimentation rates on the fan averaged 6-11 m/1000 years (Kohl et al., 1986). The sediment of the fan was derived from the load of the Mississippi River combined with sediment excavated from the Mississippi River Incised Valley and the Mississippi Canyon. In total, approximately 12,000 km^3 of sediment was delivered to the basin floor to form the most recent lobe of the lowstand Mississippi fan (Kohl et al., 1986).

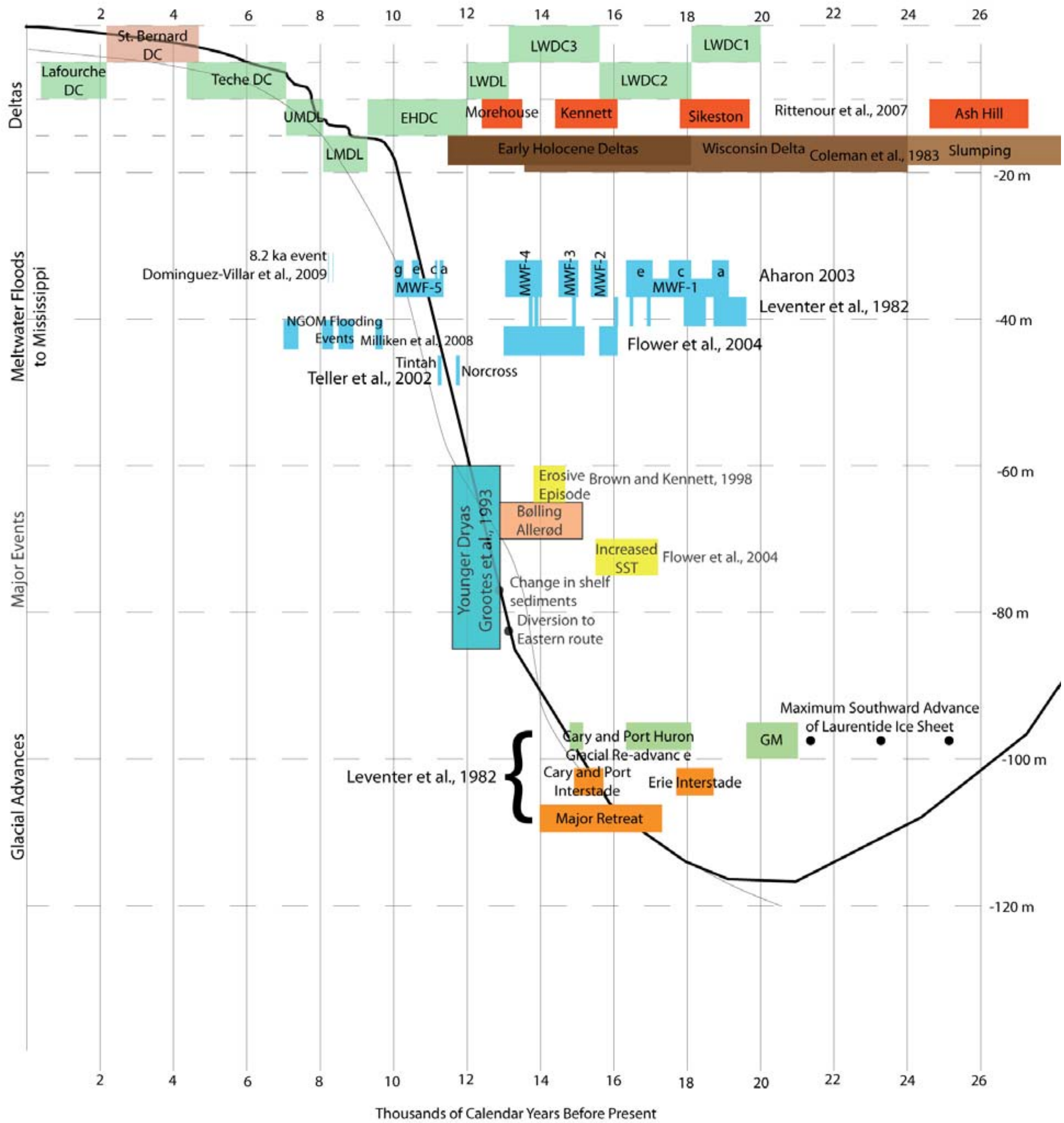

Figure 4.2—Chronology of events and sea level during the past 26 ka grouped by event type overlain onto eustatic sea level cuves. The green deltas are identified in this study within the incised valley. The pink St. Bernard delta does not lie within the incised valley. Braid belts are identified in orange in the deltas section, while depositional packages within the Mississippi Canyon are in brown shades. Meltwater floods are in blue. Major events include the Bølling Allerød and Younger Dryas climatic phases as well as a period of increased sea surface temperatures (SST) and a significant erosive episode within the Mississippi Alluvial Valley. Laurentide Ice Sheet advances are shown in green and periods of retreat are in orange. Sea level curves (in bold) from Waelbroeck et al. (2002) 26-10 ka, and Milliken et al. (2008) 10 ka to present, and (fine line) Fairbanks (1989).

At the peak of the Last Glacial Maximum (LGM), 21 cal kya, sea level fell to -117 m elevation (figure 4.2) (Waelbroeck et al., 2002) producing an erosional unconformity and oxidation surface (Type 1 sequence boundary *sensu* Possamentier et al. 1988) on the subjacent Pleistocene Prairie formation (Fisk and McFarlan, 1955; Boyd et al., 1989b). Localized slumping within the Mississippi Canyon from 26.5-24 cal kya (figure 4.8) provided the sediments for the initial filling of the canyon (Coleman et al., 1983). As sea level began to rise following the LGM, a series of late Wisconsin deltas developed at the shelf margin, both in the vicinity of the Mississippi Canyon (Coleman et al., 1983) and offshore of west Louisiana (Suter and Berryhill, 1985). The Wisconsin deltas in the vicinity of the Mississippi Canyon formed between 24-18.1 cal kya (figures 4.3, 4.4) (Coleman et al., 1983) whereas the western shelf edge Wisconsinan deltas developed between 21-13.5 cal kya (figures 4.4, 4.7) (Suter and Berryhill, 1985).

Eustatic sea level began to rise after the LGM peaked at 21 cal kya (Waelbroeck et al., 2002). Several retrogradational parasequences developed as sea level rose and a portion of the sediment supplied by the Mississippi River continued to travel down the Mississippi Canyon to the Mississippi Fan (Coleman et al., 1983).

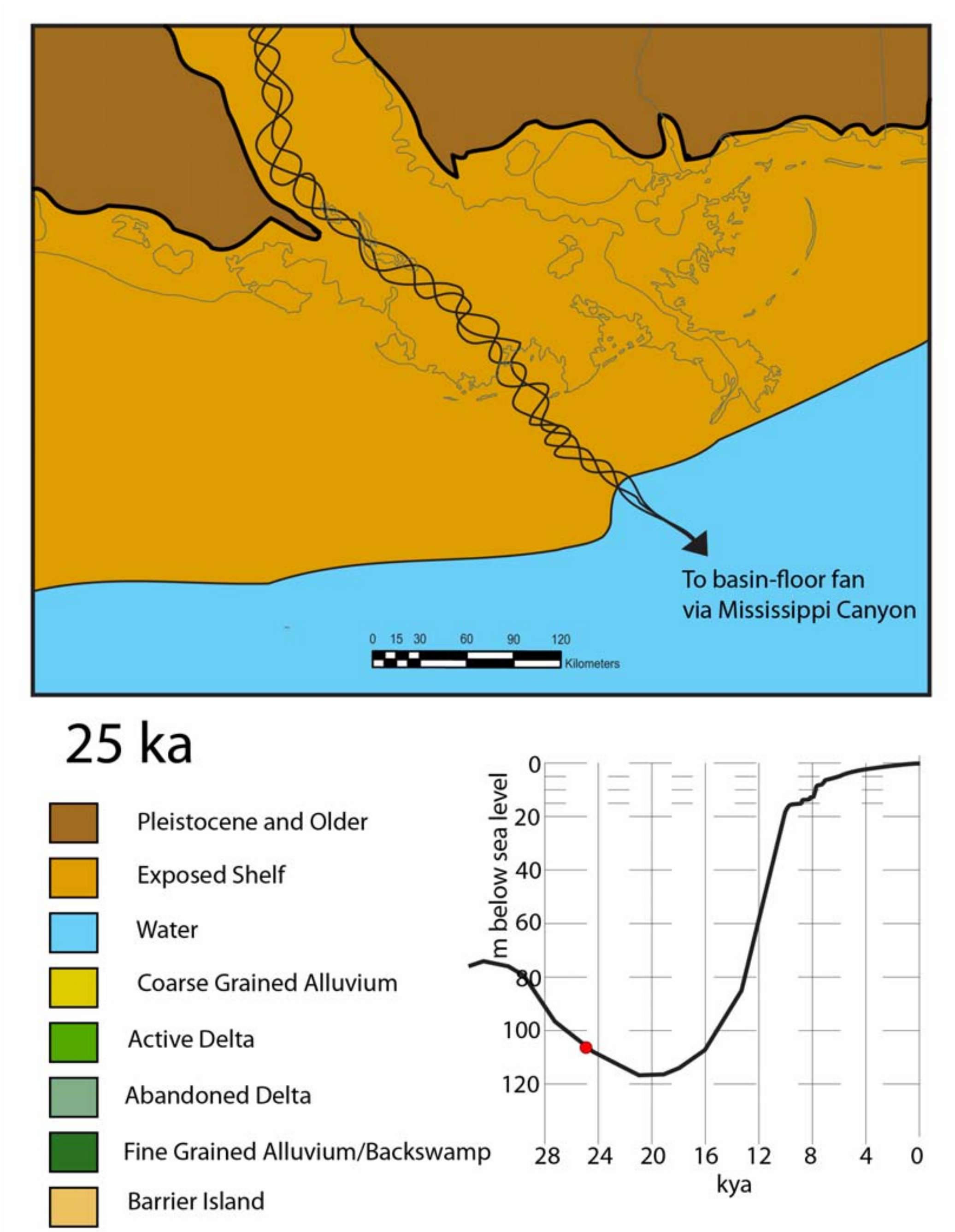

Figure 4.3—Paleogeographic reconstruction of the Louisiana continental shelf and coastline at 25 kya. The Ash Hill braid belt (Rittenour et al., 2007) feeds deposition at the shelf edge and supplies sediment to the Mississippi Fan.

LATE WISCONSIN DELTA COMPLEX 1

There is no detailed lithologic record of this unit. It is only found within the P-2-91 borehole and lies immediately over the braided substratum. Peat formed in a freshwater environment at the upper surface of this unit has an age of 18.12 cal kya.

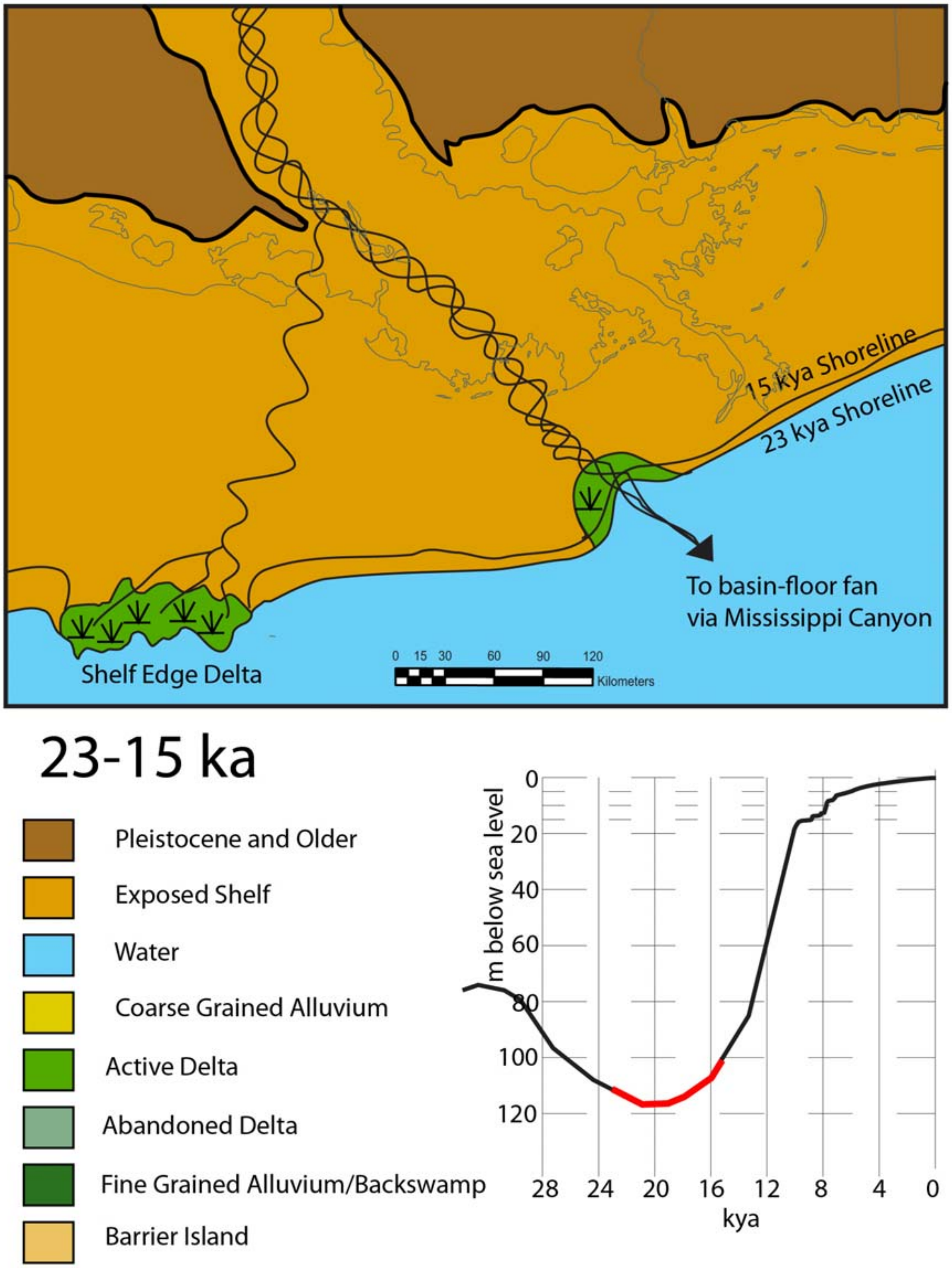

Figure 4.4—Meandering and braided fluvial channels supply sediment to shelf edge deltas at the Mississippi Canyon and the west Louisiana shelf edge delta. The Sikeston and Kennett braid belts (Rittenour et al., 2007) aggrade within the Mississippi River incised valley. The Late Wisconsin Delta Complexes 1, 2, and 3 develop during this period of time.

The last deposits of the LST formed from 20-18 cal kya and are located within the Mississippi Canyon as well as at the shelf margin of west Louisiana (figure 4.4). Coleman et al (1983) and Suter and Berryhill (1985) referred to them as Wisconsin Deltas. During this period of time sea level rose less than 5 m, at a of 2.5 $mmyr^{-1}$ (Waelbroeck et al., 2002). This rate is comparable to modern rates of relative sea level rise (Bindoff et al., 2007). This period of delta growth coincides with formation of the Sikeston braid belt from 19.7±1.6-17.8±1.3 cal ka in the Lower Mississippi River Valley (Rittenour et al., 2007) established on the basis of optically stimulated luminescence dating. A peat from borehole P-2-91 formed at 18.1 cal ka agrees with the proposed timing of abandonment of the Sikeston braid belt and is the oldest dated material within the incised valley that can be correlated with lowstand deposits at the shelf edge and basin floor. The upper surface of this peat would represent the transgressive surface.

Transgressive Systems Tracts

Transgression of late LST Wisconsin deltas began as sea level rise outpaced sedimentation. Landward movement of the shoreline was relatively slow at first and accelerated as rates of sea level rise increased (Fairbanks, 1989; Waelbroeck et al., 2002). The exact time when transgression began is not well known or understood because there has yet to be a study that reveals the paleoshoreline locations for successive intervals of time. Using average rates of eustatic sea level rise it is possible to estimate when transgression began. Penland et al. (1991) suggested that the shelf phase deltas were abandoned when relative sea level rise exceeded 20$mmyr^{-1}$. This value will be used as a best estimate for a delta abandonment threshold due to the fact that there has not been any study focused on determining the relative sea level rise threshold for abandonment of shelf edge deltas of the Mississippi River. Modern subsidence rates on the shelf have not been quantified.

Dates provided herein for parasequence development are best approximations established from the available radiocarbon dates. Initiation of delta parasequences is based upon the youngest radiocarbon date from the preceding delta surface, which provides a maximum age of deposition for the overlying parasequence. Abandonment of delta surfaces is based upon the youngest radiocarbon date ascertained from the delta surface. Actual initiation

and abandonment dates may vary considerably, however these are the best approximations possible using the published, unpublished, and radiocarbon age dates acquired during this study.

LATE WISCONSIN DELTA COMPLEX 2

While there are no detailed lithologic records of this stratigraphic unit, radiocarbon dates from peat samples can be used to provide chronological constraint. At the upper surface of this unit in borehole P-2-91 a peat was dated to 15.62 cal kya. Below this unit an age of 18.12 cal kya was obtained from freshwater swamp peat.

The first parasequence of the TST is the late Wisconsin delta complex 2 (LWDC2) that developed between 18.2-15.6 cal kya (figure 4.4). These ages are from peats penetrated by the P-2-91 borehole. The time of initiation agrees with the date of 18.1 cal kya put forth by Coleman et al. (1983) for the end of Wisconsin delta development within the Mississippi Canyon and the beginning of early Holocene delta deposition. During development of LWDC2, MWF-1c and e took place, from 18.1-17.5 cal ka and 17.1-16.3 cal ka respectively (Aharon, 2003). The peak of MWF-1c occurred at 17.9 cal ka, about the same time as abandonment of the Sikeston braid belt as documented by Rittenour et al. (2007). The Kennett braid belt began to form at 16.1 cal ka (Rittenour et al., 2007), shortly after the end of MWF-1e. At the earliest date for delta initiation, eustatic sea level was at 114.5 m below sea level and rose to 104 m below sea level by the time LWDC2 was abandoned (Waelbroeck et al., 2002) resulting in an average sea level rise rate of approximately 4 $mmyr^{-1}$. Abandonment of LWDC2 occured in conjunction with the peak of Meltwater Flood 2 (MWF-2) of Aharon (2003), during which sea level rose by approximately 24 m (Fairbanks, 1989).

Between abandonment of the Sikeston braid belt to the initiation of the Kennett braid belt the Mississippi River established a meandering morphology in the Lower Mississippi River Valley. Swamps would have been widespread, with seasonal floodwater deposition and aggradation with the alluvial valley. Deltaic deposition continued at the site of the west Louisiana shelf-margin deltas (Suter and Berryhill, 1985) as well as in the area of the Mississippi Canyon (Coleman et al., 1983). Sedimentation at the Mississippi Fan and slope fan continued

by way of mass movement processes within the canyon and at the shelf edge (Coleman et al., 1983).

The LWDC2 is the first transgressive parasequence within the TST. The rate of accommodation space creation outpaced the sediment supply for the first time during the sea level rise that followed the LGM. This parasequence onlaps braided fluvial deposits within the Lower Mississippi River Valley and is bounded by marine flooding surfaces. The flooding surface at the base of the unit represents the transgressive surface.

LATE WISCONSIN DELTA COMPLEX 3

P-I-90—57.22-46.19 m. The basal lacustrine delta lobe of the P-I-90 core site is composed of distributary facies and marsh deposits. This is the first deltaic package deposited within the study area after the Mississippi River changed to a meandering morphology. A peat sampled for radiocarbon was found to be 13.15 cal kya. This interval is relatively thick and coarse grained when compared to other coarsening upward intervals. The initiation of the unit would have occurred after formation of a deeper peat found in the P-2-91 dated to 15.62 cal kya and after abandonment of the underlying braided fluvial system of the substratum.

The late Wisconsin delta complex 3 (LWDC3) developed between 15.6-13.1 cal ka according to radiocarbon dates from peat at the surface of and immediately underlying this unit within the P-I-90 and P-2-91 boreholes, respectively (figure 4.4). MWF-2 took place from 15.8-15.4 cal kya with the peak coinciding with earliest possible initiation of the LWDC3 at 15.6 ka (Aharon, 2003). LWDC3 was abandoned at the end of MWF-4 (Aharon, 2003), when sea level rose approximately 10 m within 400 yrs (Fairbanks, 1989) or about 25 $mmyr^{-1}$. This is penecontemporaneous with meltwater floods from the LIS that were diverted to the St. Lawrence River after the LIS retreated north beyond the St. Lawrence River (Leventer et al., 1982). This was shortly before a change in shelf sediments occurred from sand and gravel to silt and clay (Fisk and McFarlan, 1955), the end of the Bølling Allerød warm period, and the beginning of the Younger Dryas (Grootes et al., 1993). Additional events that took place during the deposition of LWDC3 include the following: 1) MWF-3 from 15.0-14.5 cal ka (Aharon, 2003); 2) a significant erosional event within the Mississippi River drainage basin that delivered large

quantities of Cretaceous nanofossils to the Gulf of Mexico between 14.7-13.8 cal kya (Brown and Kennett, 1998); 3) abandonment of the Kennett braid belt at 14.4 cal kya (Rittenour et al., 2007); 4) formation of the Morehouse braid belt at 13.5 cal ka (Rittenour et al., 2007); and 5) the majority of the Bølling-Allerød warm period from 14.7-12.9 cal kya (Stuiver et al., 1995) Sea level rose from 104 m below sea level to 84 m below sea level (Waelbroeck et al., 2002) at an average rate of 13mmyr^{-1}.

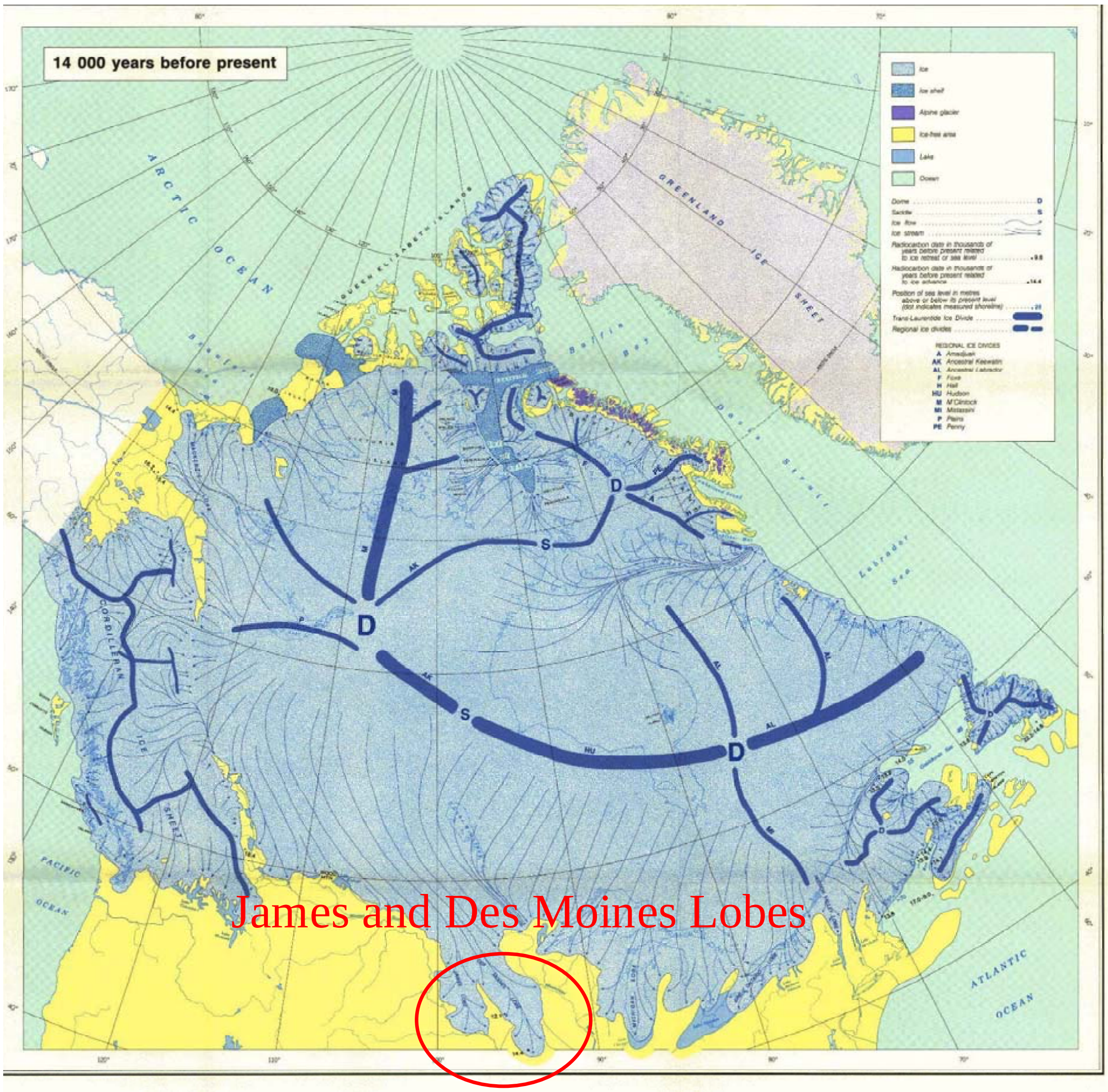

Figure 4.5—Paleogeographic reconstruction of the extent of the Laurentide Ice Sheet at 14 kya. At this time the James and Des Moines Lobes advanced southeast in the Missouri River drainage basin. By 13 kya the James and Des Moines Lobes had fully disintegrated. From Dyke and Prest (1987).

The Lower Mississippi River Valley was occupied primarily by a braided fluvial system during LWDC3 deposition, with meandering patterns dominating between 14.4-13.5 cal ka (Rittenour et al., 2007). Backswamp environments would have been more extensive during the meandering phase than during braided intervals due to morphological differences. Meandering channels are relatively narrow and deep when compared to wide and shallow braided channels. Wider channels in an alluvial valley of constant width leave less area for backswamp development. The large erosive event from 14.7-13.8 cal kya (Brown and Kennett, 1998) coincides chronologically with regularly spaced sand beds interbedded with clay units at an interval of 3.3 cm within the P-I-90 borehole. These repeated intervals are also unique because of the yellowish color that is in contrast with the typical grey and olive-grey colored units within the topstratum. Based on the abundance of Cretaceous carbonates in the drainage basin of the Missouri River (Hattin, 1986) and the position of the James and Des Moines Ice Lobes at that time (Dyke and Prest, 1987), this sediment was may have been delivered to the Gulf of Mexico by annual glacial margin meltwater runoff (figure 4.5). Freshwater swamps were present at the latitude of Cocodrie, Louisiana before transgression, and marsh environments were at the present latitude of the Isles Dernieres. The Mississippi Canyon continued to capture sediments from the Mississippi River and divert it downslope to the Mississippi Fan and slope (Coleman et al., 1983). The shelf edge deltas on the western Louisiana shelf were also still active at this time (Suter and Berryhill, 1985).

The LWDC3 is bounded above and below by marine flooding surfaces and continues the trend of updip onlap within the alluvial valley.

LATE WISCONSIN DELTA LOBE

P-I-90—46.19-40.90 m. At the base of this delta lobe are ~20 cm of transgressive lag interpreted to have developed by wave winnowing of fine-grained deposits in the area. The location of the core was likely within a lake after the previous unit's marsh surface subsided below mean sea level. Fine-grained interdistributary deposits eventually raised the substrate

surface enough for colonization by marsh grasses, forming a thick series of peaty clays. A radiocarbon date of peaty clay near the top of the marsh deposits formed 11.99 cal kya.

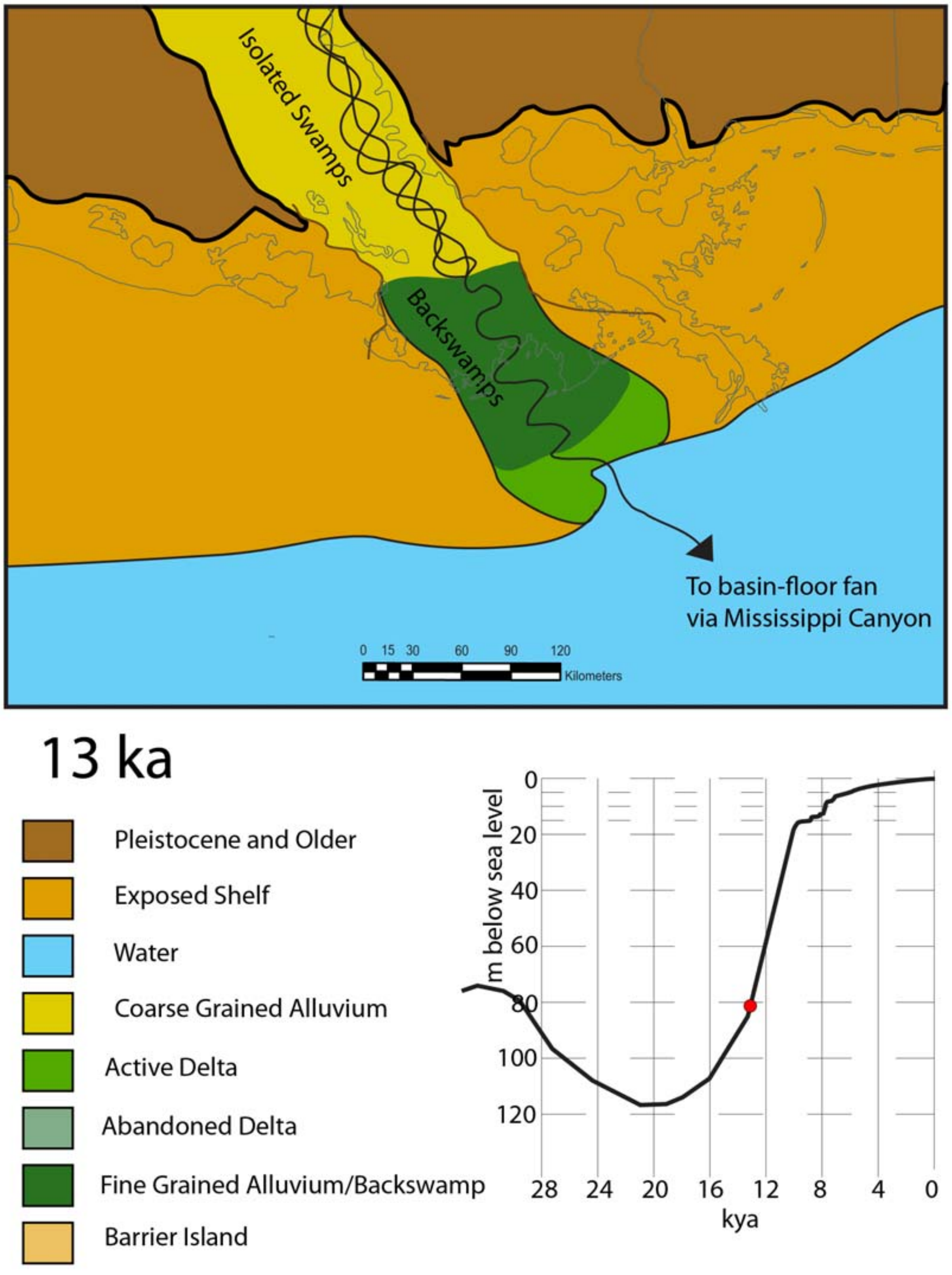

Figure 4.6—Coarse-grained braided fluvial substratum sediments of the Morehouse belt continue to aggrade within the incised valley. Fine-grained topstratum deposits onlap the substratum to the latitude of Houma, LA as fluvial gradients diminish due to rapid sea level rise. The last of the Late Wisconsin Delta Complexes is abandoned and the short lived LWDL begins to form.

The Late Wisconsin Delta Lobe was deposited between 13.1-12.0 cal kya based on radiocarbon analysis of two peats from the P-I-90 borehole and is therefore relatively short lived (4.6). The initiation of the delta lobe occurred at approximately the same time as the end of MWF-4 at 13.0 cal kya, documented by Aharon (2003), diversion of meltwater floods to the St. Lawrence River (Leventer et al., 1982), and abandonment of the LWDC3. There are no known events coincident with abandonment of the LWDL; therefore based upon data from this study, it is interpreted that abandonment occurred due to sea level rise, stream capture and avulsion or some combination of the two. The Morehouse braid belt continued to be active until 12.4 cal kya (Rittenour et al., 2007). The LWDL was largely deposited during the Younger Dryas, which extended from 12.9-11.6 cal kya (Grootes et al., 1993). Fisk and McFarlan (1955) discovered that early on in the formation of the LWDL there was a marked change in shelf sedimentation offshore of Louisiana at 12.8 cal kya, about the same time that the Younger Dryas began. Sea level rose from 81.5 m below sea level to 59 m below sea level (Waelbroeck et al., 2002). The average rate of rise was approximately 20 $mmyr^{-1}$; enough to prevent formation of a well developed delta plain regardless of subsidence rates and sediment supply.

At the site of the P-I-90 borehole within the alluvial and incised valley freshwater swamps deposits progressively onlap the downdip equivalent of the Morehouse braid belts. Widespread delta plain development was unlikely due to the high rate of sea level rise. Sediments continued to be deposited within and around the Mississippi Canyon, some of which was deposited on the slope and sea floor fans. Sedimentation on the west Louisiana shelf had ceased by this time (Suter and Berryhill, 1985), and is evidence for rapid transgression inhibiting shelf phase delta formation.

The LWDL is bounded at the base and top by marine flooding surfaces and onlaps braid belts within the Lower Mississippi River Valley.

EARLY HOLOCENE DELTA COMPLEX

P-I-90—40.90-32.00 m. After relative sea level rise inundated the previous delta plain, prodeltaic deposition initiated in this area. Freshwater influx to the immediate area must have been significant due to the freshwater fossil assemblage. The core location is relatively close to

the advancing distributary as noted by the presence of natural levee deposits overlain by marsh instead of distributary facies followed by interdistributary and marsh like that found in settings where the distributary is some distance away from the core location. Two radiocarbon samples were taken from the marsh of this delta complex, one at the base and the other at the top of the marsh interval. The basal marsh sample was dated to be 10.24 cal kya and the upper marsh sample is 9.28 cal kya.

The upper organic facies of the underlying LWDL dates to 11.99 cal kya while radiocarbon samples of the marsh unit at 32.10 m and 33.70 m returned dates of 9.28 cal kya and 10.24 cal kya respectively. Prodelta mud deposition began sometime after abandonment of the former swamp surface following 11.99 cal kya. By 10.24 cal kya deposition had filled the available accommodation space and peat began forming at the surface. Fine-grained sedimentation continued until at least 9.28 cal kya followed by abandonment and transgression of the delta surface.

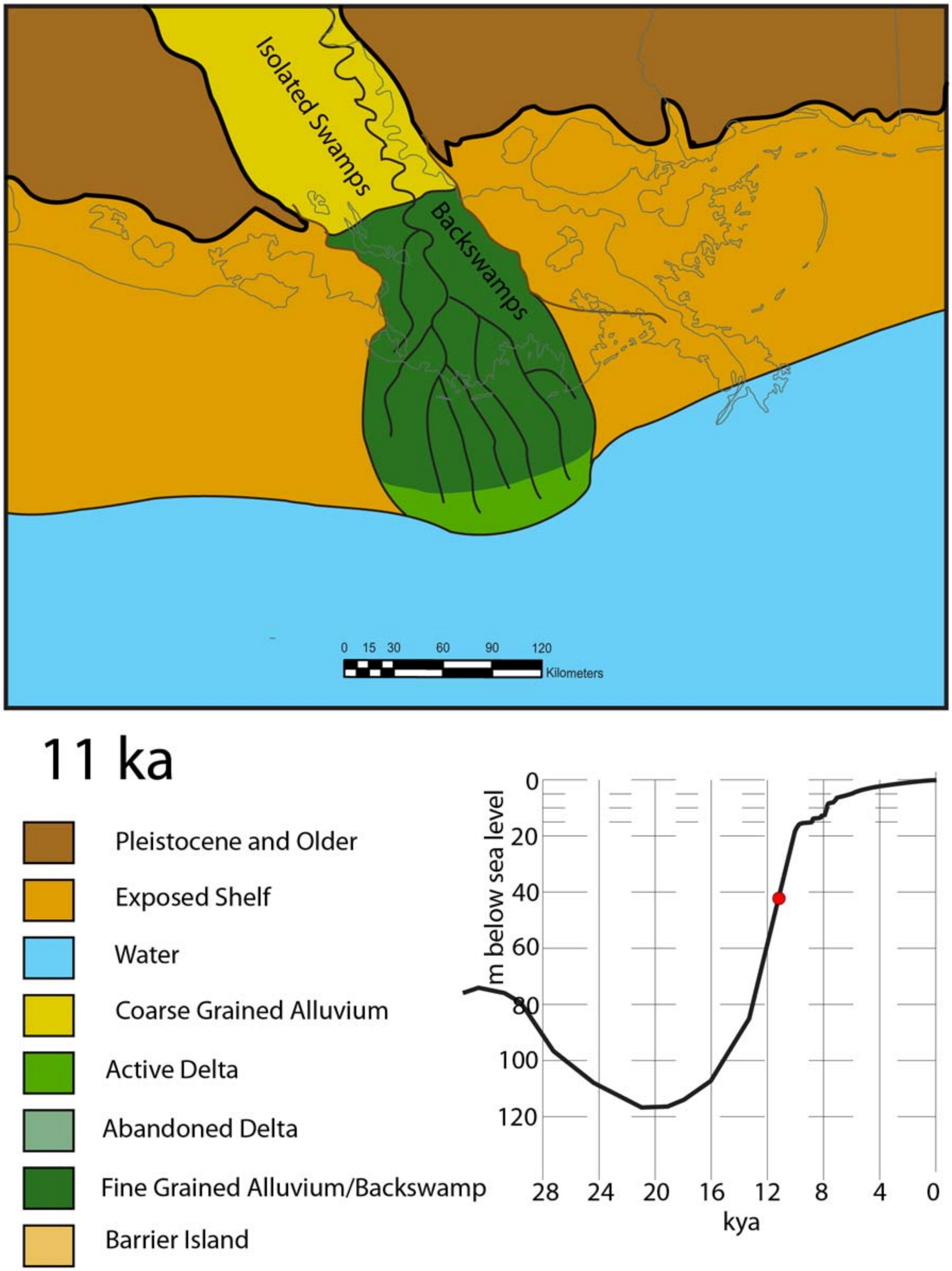

Figure 4.7—Coarse-grained substratum aggradation ceases while fine-grained topstratum backswamps onlap the underlying substratum to Plaquemine, LA (Kesel, 2008). The LWDL has been abandoned for 1ka and the EHDC is growing rapidly.

The EHDC was deposited by the Mississippi River after abandonment of the LWDL at 12.0 cal kya until 9.3 cal kya. The date of abandonment is based on the most recent marsh peat at the surface of the EHDC, which is found in the P-I-90 borehole. Soon after initiation of the EHDC the Younger Dryas came to a close at 11.6 cal kya (Grootes et al., 1993). There were several meltwater floods routed to the Mississippi River during EHDC formation, the earliest of which were documented by Teller et al. (2002) as the Norcross and Tintah floods at 11.7 cal kya and 11.2 cal kya respectively. Aharon (2003) also documented MWF-5a, c, e, and g between 11.35-10.03 cal kya with peaks at 11.34 cal kya, 11.09 cal kya, 10.62 cal kya, and 10.26 cal kya. During the growth of the EHDC sea level rose from 59 m below sea level to 15.3 m below sea level (Waelbroeck et al., 2002; Milliken et al., 2008), an average rate of 16 $mmyr^{-1}$.

Backswamp depositional environments had onlapped braided fluvial deposits within the alluvial valley to the location of Plaquemine, Louisiana by 10.2 cal kya (Guccione et al., 1988; Kesel, 2008). Deposition at the shelf edge ceased by this point and a condensed section within the Mississippi Canyon began accumulating (Coleman et al., 1983). Relatively stable conditions persisted from 10.24 cal kya until abandonment at 9.3 cal kya, suggested by radiocarbon dates at the base and top of a 1.70 m thick peat unit in the P-I-90 borehole. Offshore of the modern delta at 20 m below sea level lies Outer Shoal (Penland et al., 1989). If the EHDC was abandoned while sea level was 15.7 m below sea level then a subsidence rate of only 0.5 $mmyr^{-1}$ is required to place these shoals at the same elevation, assuming these shoals developed at sea level. This rate is in agreement with subsidence modeled by Blum et al. (2008) along the modern coastline. These shoals are therefore likely to be genetically related to the EHDC, making this delta complex the first shelf phase delta after the LGM. Locations beyond the continental shelf only receive pelagic and hemi-pelagic sedimentation from this time on as well as less frequent shelf-slope failures.

Backswamp deposits continued to onlap older braided fluvial deposits within the alluvial valley. The EHDC is bounded above and below by marine flooding surfaces. Offshore a condensed section began to form (Coleman et al., 1983).

LOWER MARINGOUIN DELTA LOBE

05BS02—20.60-20.00 m. The marsh unit at the top of this interval is all that was intercepted at the very bottom of the core. The remaining portion of the coarsening upward interval lies below the maximum penetration of the borehole, and probably extends ~10 m below this marsh unit. Peat from 20.60 m dated to have developed 8.23 cal kya.

05BS01—21.33-21.01 m. Only ~30 cm of the upper marsh surface of this unit was intercepted by the core. It is assumed that a genetically related coarsening upward interval that extends below this portion of marsh by up to 10 m based on correlation with the coarsening upward intervals in the P-I-90 borehole. Peat at the upper surface of this unit is 8.10 cal kya.

04BS02—21.24-19.98 m. Only the upper portion of the coarsening upward interval was recovered at the base of this core. Distributary, natural levee and marsh facies are present. The coarsening upward interval is assumed to extend below the base of the core by about 4 m based on stratigraphic correlation with a similar unit in the P-I-90 core. Organic sediment from the top of the marsh unit was dated to be 8.08 cal kya.

P-I-90—32.00-23.60 m. A relatively thick (~80 cm) transgressive lag unit overlies the previous delta surface, suggesting there was a significant amount of time for the underlying deposits to be exposed to erosional activity and may be a sign that the shoreline shifted radically landward. Deltaic advance resumed after shoreline retreat and deposited prodelta muds, distributary facies and marsh deposits. Marsh peat at the top of this interval was formed 8.44 cal kya.

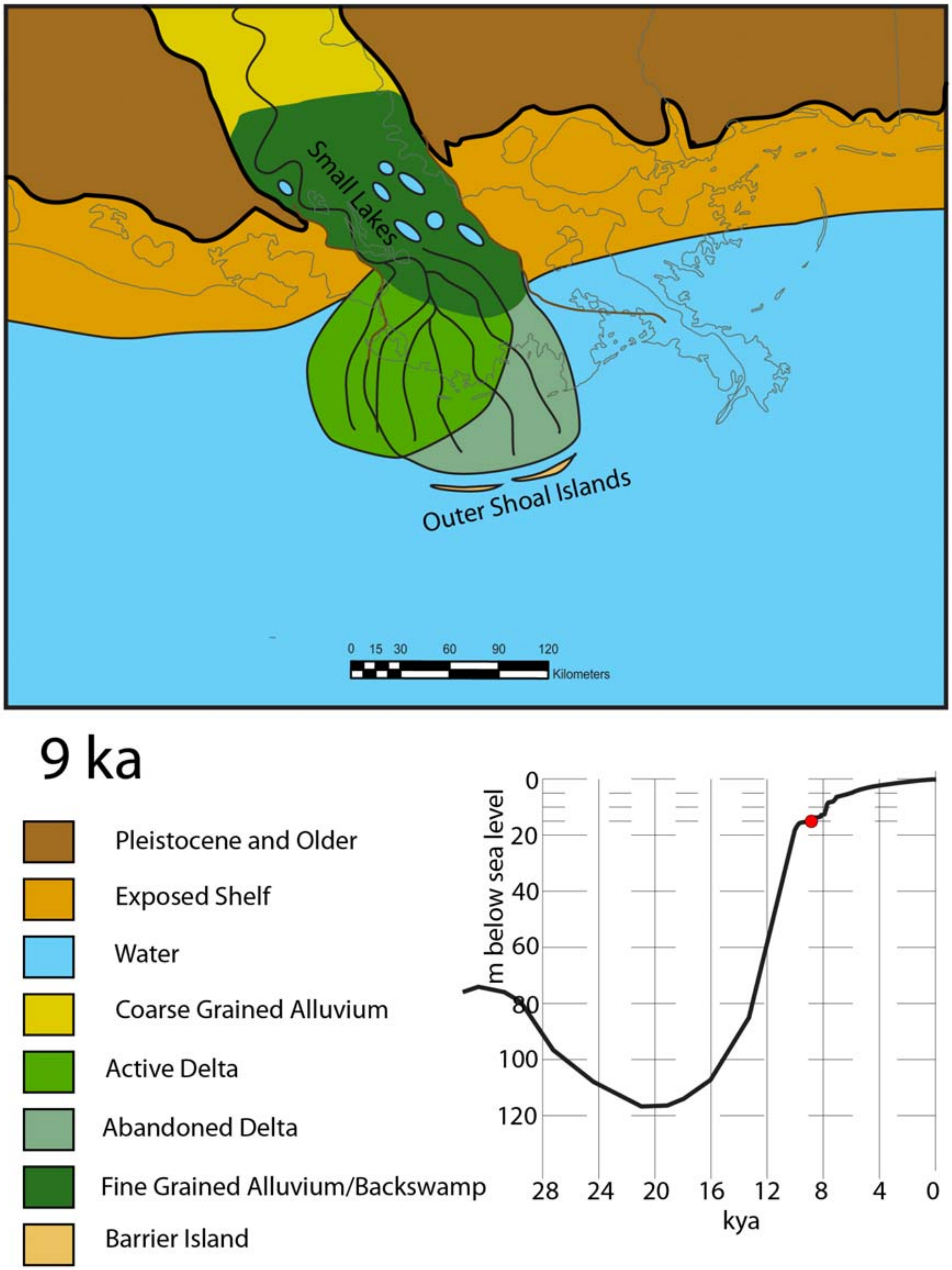

Figure 4.8—The EHDC is abandoned in favor of the LMDL and transgressive processes begin to form the Outer Shoal barrier island(s). A myriad of small lakes develop within the backswamp environment that continues to onlap the substratum. These lakes are subsequently filled with deltaic sediment at approximately the same time as the LMDL is initiated.

In boreholes 05BS02 and 05BS01, only marsh units are present with thicknesses of 0.60 m and 0.32 m respectively. In borehole 04BS02 there are distributary, natural levee and marsh facies present with thicknesses of 0.40 m, 0.31 m, and 0.55 m respectively. The distributary facies in this borehole is incomplete as it lies at the very base of the borehole. The P-I-90 borehole contains a transgressive lag at the base overlain by prodelta, distributary and marsh facies.

Marsh peat from the underlying EHDC in the P-I-90 dated to have an age of 9.28 cal kya and another peat from borehole TM14D-83U located 18 km west of borehole 04BS01 dated to be 9.65 cal kya. These two peats were found at 32.25 m and 31.30 m depth, and are therefore interpreted to be from stratigraphically similar units. Peats formed at the top of the lower Maringouin delta range in age from 8.08 cal kya in 04BS02 to 8.44 cal kya in the P-I-90. This is interpreted to represent submergence and cessation of marsh accretion at the P-I-90 location prior to submergence and abandonment at the updip locations.

Development of the Lower Maringouin Delta Lobe (LMDL) (figure 4.8) is constrained to 9.3-8.1 cal kya based upon radiocarbon age dates from the P-I-90 and USGS borehole 04BS02. Other peats at the top of this interval have ages of 8.44 cal kya (P-I-90, 23.70 m below sea level), 8.23 cal kya (05BS02, 21.60 m below sea level), 8.10 cal kya (05BS01, 22.25 m below sea level) and 8.08 cal kya (04BS02, 20.98 m below sea level). Milliken et al. (2008) identified two flooding events within the Northern Gulf of Mexico during this time at 8.9-8.5 cal kya and 8.4-8.0 cal kya where sea level rose 1.6 m and 1.0 m respectively. Rise rates for the two flooding events were 4 $mmyr^{-1}$ and 2 $mmyr^{-1}$, respectively. The later flooding even is coincident with the 8.2 ka event documented by Dominguez-Villar et al. (2009) with floods of < 10 years duration centered at 8.345 cal kya and 8.222 cal kya. Throughout the formation of the LMDL eustatic sea level rose by 2.5 m from ~15.3 m below sea level to 12.8 m below sea level.

The flood at 8.9-8.5 cal kya may have forced overstepping and drowning of the barrier islands at Outer Shoal (figure 4.2). The flood at 8.4-8.0 cal kya is documented in the stratigraphy of the incised valley. The initial delta plain was gradually inundated between 8.4-

8.0 cal kya, possibly during the 8.2 ka event. Later, a short-lived, thin and isolated subdelta developed and reached maturity by 8.08 cal kya as recorded in the 04BS02 borehole.

At the latitude of Plaquemine, Louisiana borehole P-4 contains lacustrine delta deposits (figure 3.7) whereas at the latitude of Houma, Louisiana borehole PS-5 contains freshwater swamp sediments; both are found at stratigraphically equivalent depths to the LMDL (Dunbar et al., 1994, 1995). The delta plain would have extended as far as Outer Shoal until the 8.9-8.5 cal kya flood, at which point the shoreline may have abruptly shifted as far north as present day Lake Boudreaux.

The LMDL is part of the TST and is bounded by marine flooding surfaces above and below. Onlap of braided fluvial deposits by backswamps in the alluvial valley and formation of a condensed section offshore continued.

UPPER MARIGOUIN DELTA LOBE

Based on the depositional timeframe of 6.5-10 ka used by Frazier (1967), the Maringouin delta can be divided into upper and lower units. The upper unit penetrated by USGS boreholes 05BS02, 05BS01 and 04BS02 (figure 3.7). The unit is 5.66 m thick on average in the three boreholes. The unit is not found in any boreholes located downdip, although several of them penetrate to similar depths, rather prodelta facies of the overlying Teche delta complex are present. The upper bound of the interval ranges from 13.75 m to 15.45 m depth with a lower bound ranging from 19.98-21.01 m depth.

Prodelta, distributary, and swamp facies are present in the 4.55 m of sediment recovered in borehole 05BS02. Borehole 05BS01 contains interdistributary facies overlain by distributary, natural levee, and marsh facies totaling 6.21 m. In borehole 04BS02 there is a transgressive lag at the base overlain by prodelta, distributary and marsh facies totaling 6.23 m.

The upper Maringouin delta began forming after 8.08 cal kya as indicated by the most recent date from the underlying lower Maringouin delta. The earliest dated peat sample from the upper Maringouin comes from the P-2-91 borehole and formed 7.80 cal kya. This is interpreted to represent the beginning of peat formation on the upper Maringouin delta. In

borehole 05BS01 two dates were obtained from marsh peats, 7.46 cal kya and 7.07 cal kya. A date of 7.51 cal kya was acquired from a swamp peat in borehole 05BS02.

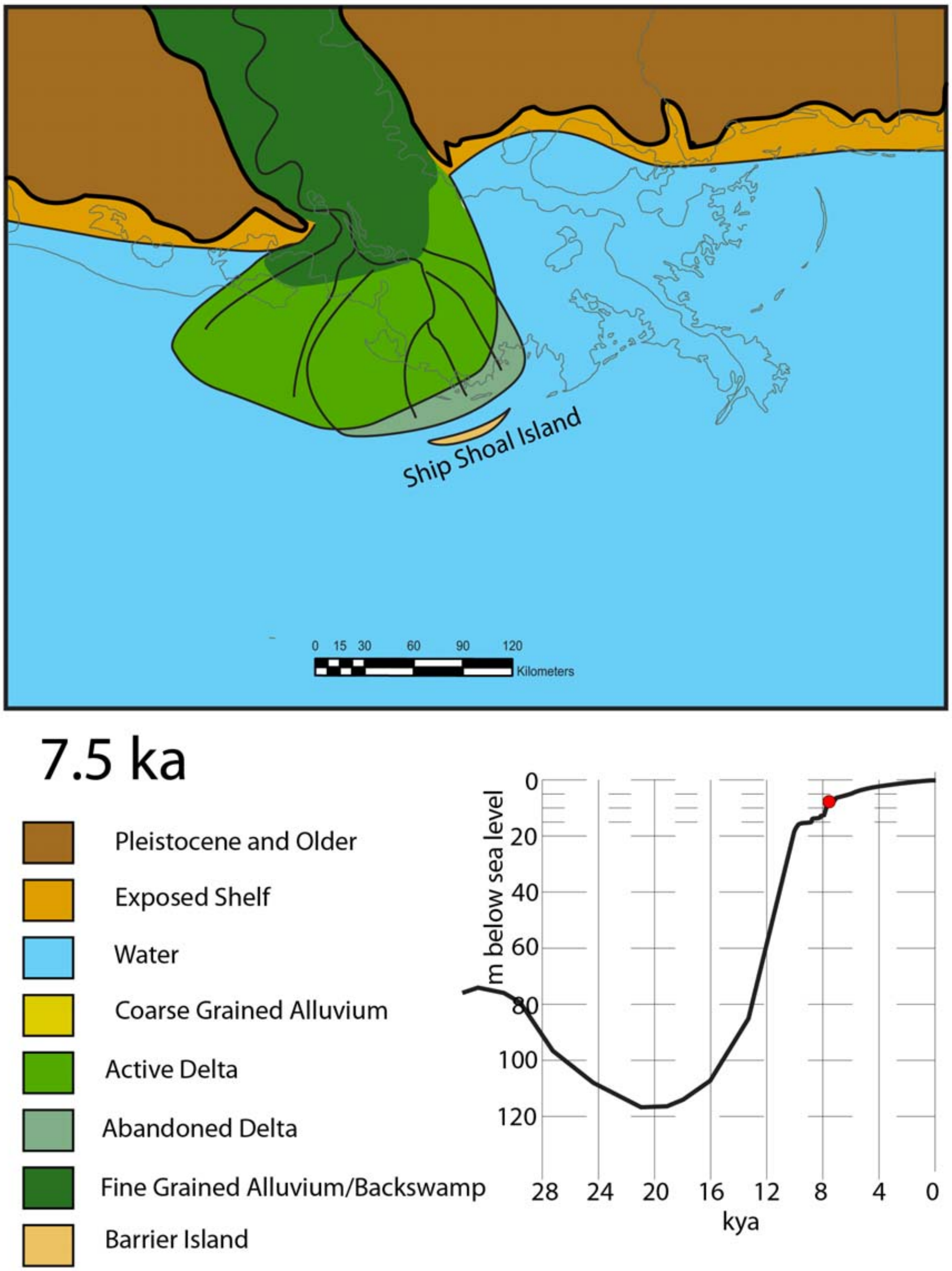

Figure 4.9—The LMDL is abandoned and Ship Shoal island develops while the UMDL becomes active.

Transgressive lag in borehole 04BS02 indicates that transgressive wave ravinement progressed onshore beyond borehole 04BS02, but not to 04BS01, although this area would have likely been flooded at the time of transgression. Fine-grained prodeltaic and interdistributary sediments are thin in boreholes 05BS02 and 05BS01 respectively, suggesting that the flooding surface extends only a short distance beyond 05BS02. Interdistributary facies downdip from prodelta facies suggests that the previous delta may have prograded in from the west. Thick (>3m) prodelta sediments overlying the transgressive lag in borehole 04BS02 indicate a more distal position. Distributary facies within the three cores are of remarkably similar thickness, 2.68 m, 2.61 m, and 2.61 m in boreholes 05BS02, 05BS01, and 04BS02 respectively. The distributary facies in borehole 05BS02 is overlain by 1.45 m of swamp peat, indicative of a freshwater environment resultant of impoundment of the local area by prograding distributaries or a sufficient distal buffer zone able to prevent the influence of saline waters. Borehole 05BS01 contains 1.97 m of marsh deposits and 04BS02 has 0.45 m of marsh deposits. Marsh accretion was likely taking place for a much longer period of time at 05BS01 than 04BS02. The overall thinness of this delta unit is a result of shallow water depths during progradation.

The Upper Maringouin Delta Lobe (UMDL) began developing 8.08 cal kya at the earliest and was abandoned by 7.07 cal kya (figure 4.9). Four peat samples from the upper surface of the UMDL were radiocarbon dated; they are 7.80 cal kya (P-2-91, 17.78 m below sea level), 7.50 cal kya (05BS02, 16.70 m below sea level), 7.46 cal kya (05BS01, 17.50 m below sea level) and 7.07 cal kya (05BS01, 16.24 m below sea level). Milliken et al. (2008) documented approximately 7.5 m of eustatic sea level rise between 7.9-7.6 cal kya, a rate of 25 $mmyr^{-1}$. This event was forced by the final disintegration of the Laurentide Ice Sheet (Blanchon and Shaw, 1995). Delta development and formation of Trinity and Ship Shoals probably began after this event, and it is possible that abandonment of the LMDL did not occur until this flood took place.

Ship Shoal and Trinity Shoal presently lie at 10 m below sea level (Penland et al., 1989). These shoals are accepted to be barrier island remnants associated with the Maringouin and Teche deltas (Penland et al., 1989). If these barrier islands are associated with these deltas

they would have formed at 8-5 m below sea level and subsided 2-5 m after formation. This amount of subsidence is agreement with estimates produced by modeling in Blum et al. (2008) (figure 4.10).

Backswamps in the alluvial valley continue to onlap up the valley onto coarse-grained substratum deposits. Freshwater swamps extended south to the current north shore of Lake Boudreaux, whereas the coastline would have been in the proximity of Ship and Trinity Shoals. This deltaic unit is part of the TST and is bounded by flooding surfaces. The condensed section continues to be deposited offshore.

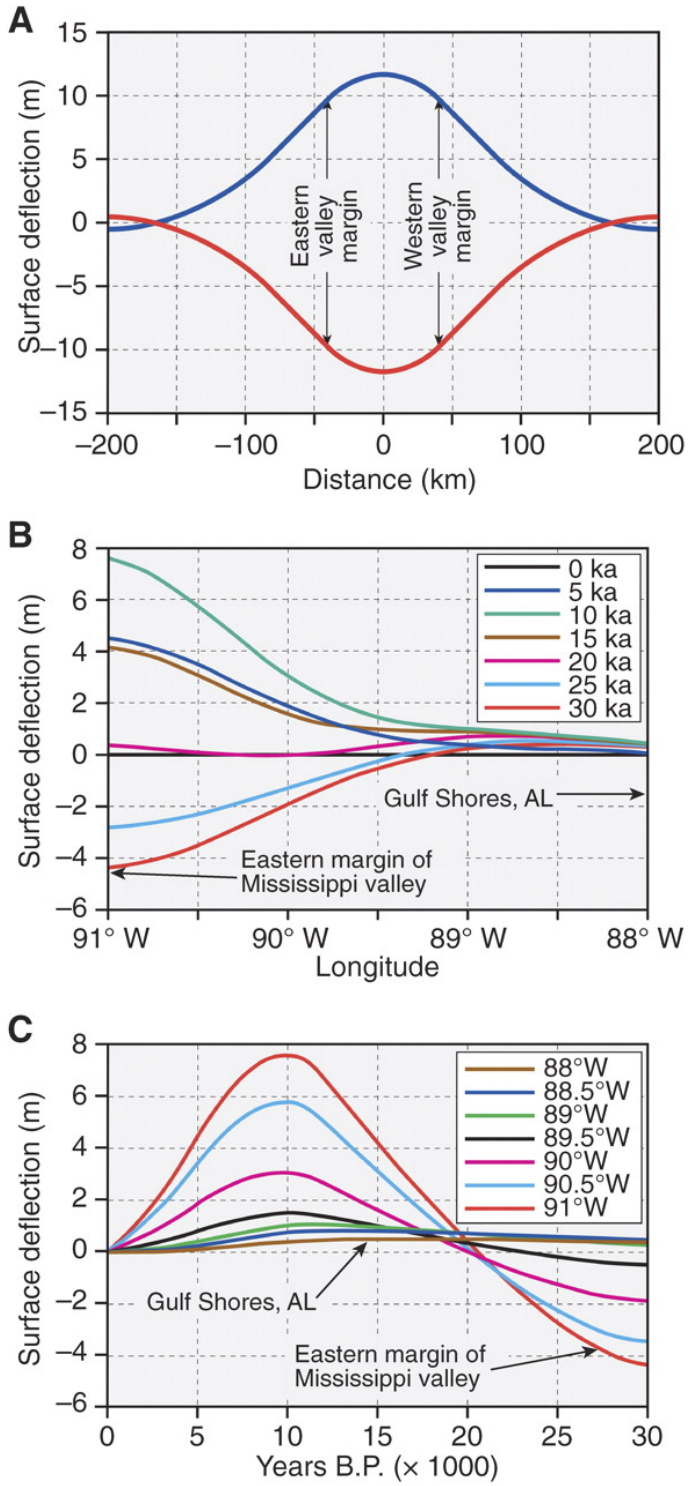

Figure 4.10—Models of surface deflection through time and varying longitude at the Mississippi River incised valley. Sediment removed during incision resulted in uplift. Filling of the incised valley induced subsidence. A: Modeled along strike surface deflection resultant from removal and emplacement of sediment in the Mississippi River incised valley. B: Along strike deflection of surface at 30°N during excavation and depositional loading. C: Deflection through time of differing locations along the Gulf of Mexico shoreline at 30°N. From Blum et al. (2008).

TECHE DELTA COMPLEX

05BS02—15.45-13.10 m. This interval is relatively thin, and includes lacustrine and marsh facies. It is not a typical coarsening upward interval because there is no coarsening upward sequence, however it is bounded above and below by flooding surfaces. The former swamp surface would have submerged followed by continual overbank sedimentation. The organic marsh unit may be derived from flotant freshwater marsh. The area would have remained behind the farthest seaward advance of the delta plain and accumulated fine-grained sediments from overbank processes until the substrate aggraded sufficiently for marsh grass colonization.

05BS02—13.10-12.18 m. This coarsening upward interval is also very thin, just less than one meter and is representative of a late phase of deposition during sea level rise. Lacustrine and marsh facies are present, indicating flooding of the former marsh surface, overbank deposition, and eventual recolonization by marsh grasses or flotant marsh species.

05BS01—14.80-8.30 m. Fifteen cm of transgressive lag are at the base of this coarsening upward interval, followed by interdistributary, prodelta, distributary, natural levee and marsh facies. After abandonment and transgression of the former delta plain surface this area received only fine-grained sedimentation from a relatively distant source. Eventually a distributary prograded into the area and supplied the coarse sediment of the distributary facies and natural levee. Abandonment of the distributary allowed for thick marsh deposits to aggrade, keeping pace with relative sea level rise until the rate of relative sea level rise became greater than aggradation. Radiocarbon analysis of organic sediment at 8.85-8.82 m returned an age of 4.87 cal kya.

04BS02—13.75-8.88 m. This unit consist solely of prodelta and distributary facies. Overlying natural levee and marsh facies may have been eroded during the subsequent Teche Ravinement or never deposited due to insufficient progradation.

04BS01—19.95-10.00 m. This interval contains only prodelta and distributary facies. Therefore, the core location at the time was not subaerially exposed, was not colonized by marsh grasses, and was located seaward of the farthest advance of the distributary or these upper delta plain facies have been eroded during the Teche Ravinement.

P-I-90—23.60-11.55 m. Prodelta muds overlie the former marsh surface followed by distributary facies deposits. Interdistributary deposits occur in the interval between distributary and marsh facies, indicating that the distributary was some distance away and prograded beyond the core location. Overbank sedimentation served to bring the substrate surface near enough to mean sea level for marsh grass colonization. Two radiocarbon samples were retrieved from the marsh interval, one at the top of the marsh unit, and the other from a wood fragment at the base of the marsh unit. The wood fragment is from 5.46 cal kya and the peat is from 4.66 cal kya.

05COCO-01—21.08-9.14 m. At the base of this interval are prodelta silty clays overlain by distributary facies, interdistributary facies, and marsh deposits. Sediment grain size coarsened upward as the nearby distributary prograded to the core location. Sediments began fining upward after the distributary mouth moved beyond the core location and supplied sediment was restricted to overbank processes. Aggradation of interdistributary deposits eventually allowed for the area to be colonized by marsh grasses and peat formation at the base of the marsh unit. Above the peat are dark organic muds that developed in a brackish to salt water marsh.

03K14—21.36-10.08 m. Prodelta clays and silts coarsen upward into interbedded mud and sandy silts. Marsh deposits overlie the distributary facies. This interval records the advance of a nearby distributary within a bayhead delta complex. The marsh unit at the top is thin with relatively low organic content for a marsh, suggesting that relative sea level rise drowned the marsh vegetation at this location.

03CH02—21.36-9.96 m. This bayhead delta complex includes both the prodelta facies and the distributary facies. No marsh deposits are present which indicates that the distributary did not prograded to this location or the marsh deposits were eroded. There is no evidence of an erosional contact however.

Teche delta complex sediments are identifiable in all of the detailed USGS and LGS cores. The Delta complex is thin (2-6 m) in the cores 05BS01, 05BS02, and 04BS02, and thickens seaward to 10-12 m thickness in boreholes 004BS01, P-I-90, 05COCO-01, 03K14, and 03CH02 (figures 3.7). The increase in thickness is due to progradation into progressively deeper water

in the area. The upper surface of the Teche delta complex lies at 7-10 m depth below mean sea level, shallower in the updip boreholes and deepening seaward. The base of the Teche delta complex is at 14-15 m depth in boreholes 05BS01, 05BS02, and 04BS02 where the thickness is low. Downdip the base of the Teche delta complex reaches > 20 m depth, below the base of the USGS boreholes. The P-I-90 borehole records the base of this delta complex at 23.60 m.

The Teche delta complex (figures 4.11, 4.12), as represented by the data used in this study, began forming after abandonment of the previous delta plain which occurred at latest 7.07 cal kya based on a radiocarbon dated peat from the 05BS01 borehole. Peat aggradation, indicating maturation of the delta plain surface, took place between 5.48-4.66 cal kya as shown by radiocarbon dated peats from the 05BS02 and P-I-90 boreholes respectively.

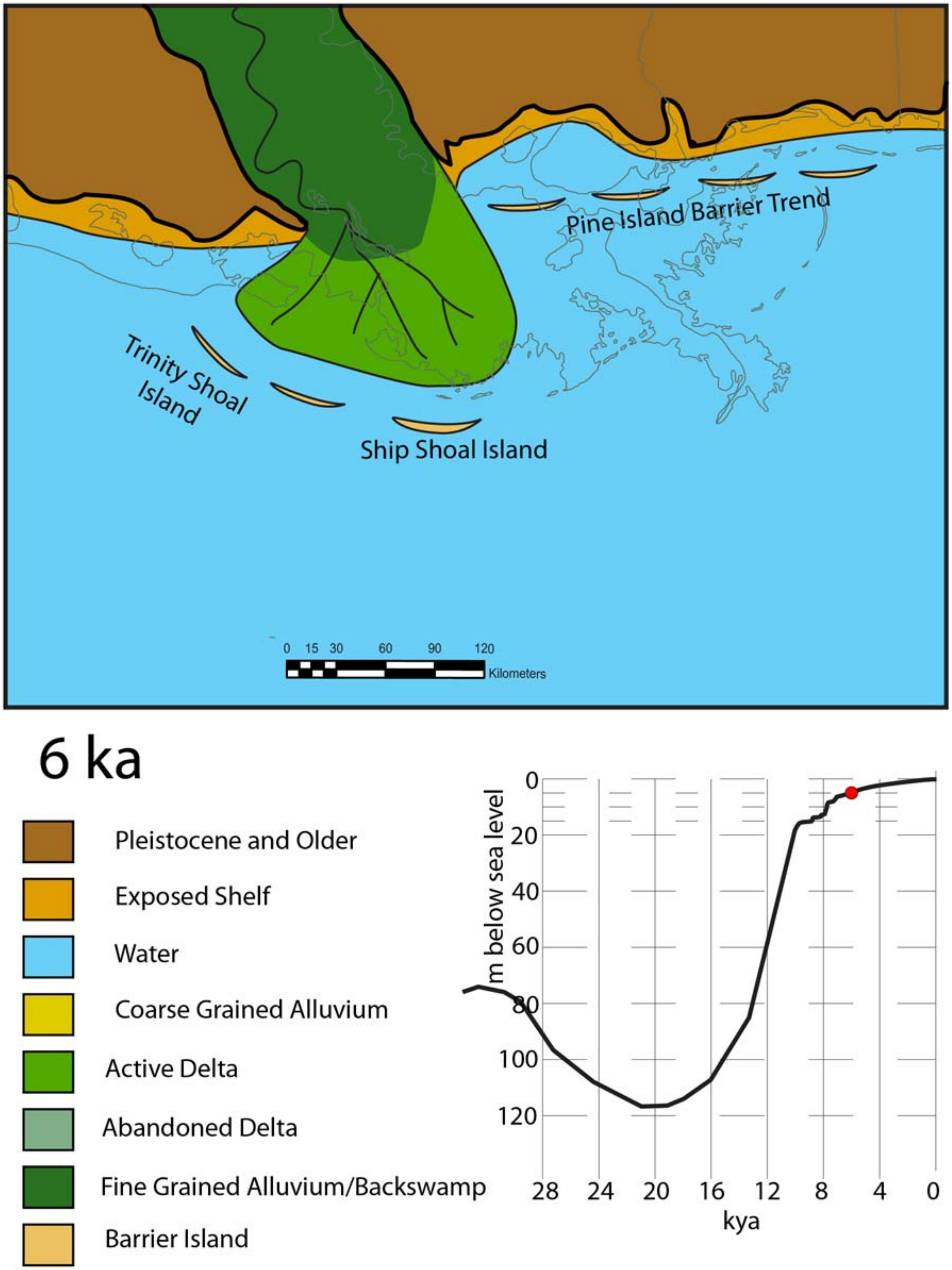

Figure 4.11—The UMDL is abandoned and Trinity Shoal island develops on the western flank of the delta. Stabilization of sea level allows the Pine Island Barrier Trend to mature. The Teche delta complex enters a phase of rapid growth into shallow waters.

Transgression following the deposition of the upper Maringouin delta complex extended updip to the 05BS02 core and probably a short distance beyond 05BS02 as evidenced by a lack of prodelta deposits at the base of this Delta complex and interdistributary facies respectively. Progradation occurred initially into shallow water as indicated by the thin repeated intervals in boreholes 05BS01 and 04BS02. The delta complex thickness increases dramatically in successively offshore boreholes, doubling on average; water depth was greater in this area. Maturation of the delta plain surface allowed marsh grass colonization and subsequent peat formation. No peats were recovered in boreholes 04BS02, 04BS01, or 03CH02. The absence of peats at 04BS02 and 04BS01 is due to wave ravinement and truncation of the delta surface in the following transgressive event leading to the formation of a maximum flooding surface. The lack of peat in borehole 03CH02 may be a result of either erosion of the delta peat or lack of marsh grass colonization due to insufficient deltaic progradation.

The Teche Delta Complex began developing after abandonment of the UMDL at 7.07 cal kya. The UMDL abandonment is coincident with a 1.6 m rise in sea level during an interval of about 250 years—a rate of 6.5 $mmyr^{-1}$ (Milliken et al., 2008). Delta plain peat deposits from the upper surface of the Teche have been dated to 5.64 cal kya (P-2-91, 13.90 m below sea level), 5.48 cal kya (05BS02, 11.48 m below sea level), 5.46 cal kya (P-I-90, 11.80 m below sea level), 4.87 cal kya (05BS01, 9.84 m below sea level), and 4.66 cal kya (P-I-90, 11.10 m below sea level). These dates agree with figures from Frazier (1967) for development of the Teche Delta Complex and abandonment of Bayou Salé, however they do not include later dates of ~4.36 cal kya for abandonment of Bayou Cypremort which is located outside of the incised valley. An avulsion near Vicksburg, Mississippi forced abandonment of the Teche Delta Complex (Aslan et al., 2005). During development of the Teche Delta Complex the eustatic sea level rose 1.6 m at an average rate of 6.5 $mmyr^{-1}$ (Milliken et al., 2008; Törnqvist et al., 2004), however this rate of sea level rise was not rapid enough to interrupt delta growth.

In the alluvial valley the backswamps continued to migrate to the north beyond Vicksburg, Mississippi (Aslan and Autin, 1999), onlapping substratum braided fluvial deposits. The delta plain expanded on the shallow shelf as pelagic sedimentation contributed to the condensed section offshore.

Highstand Systems Tracts

ST. BERNARD AND LAFOURCHE DELTA COMPLEXES

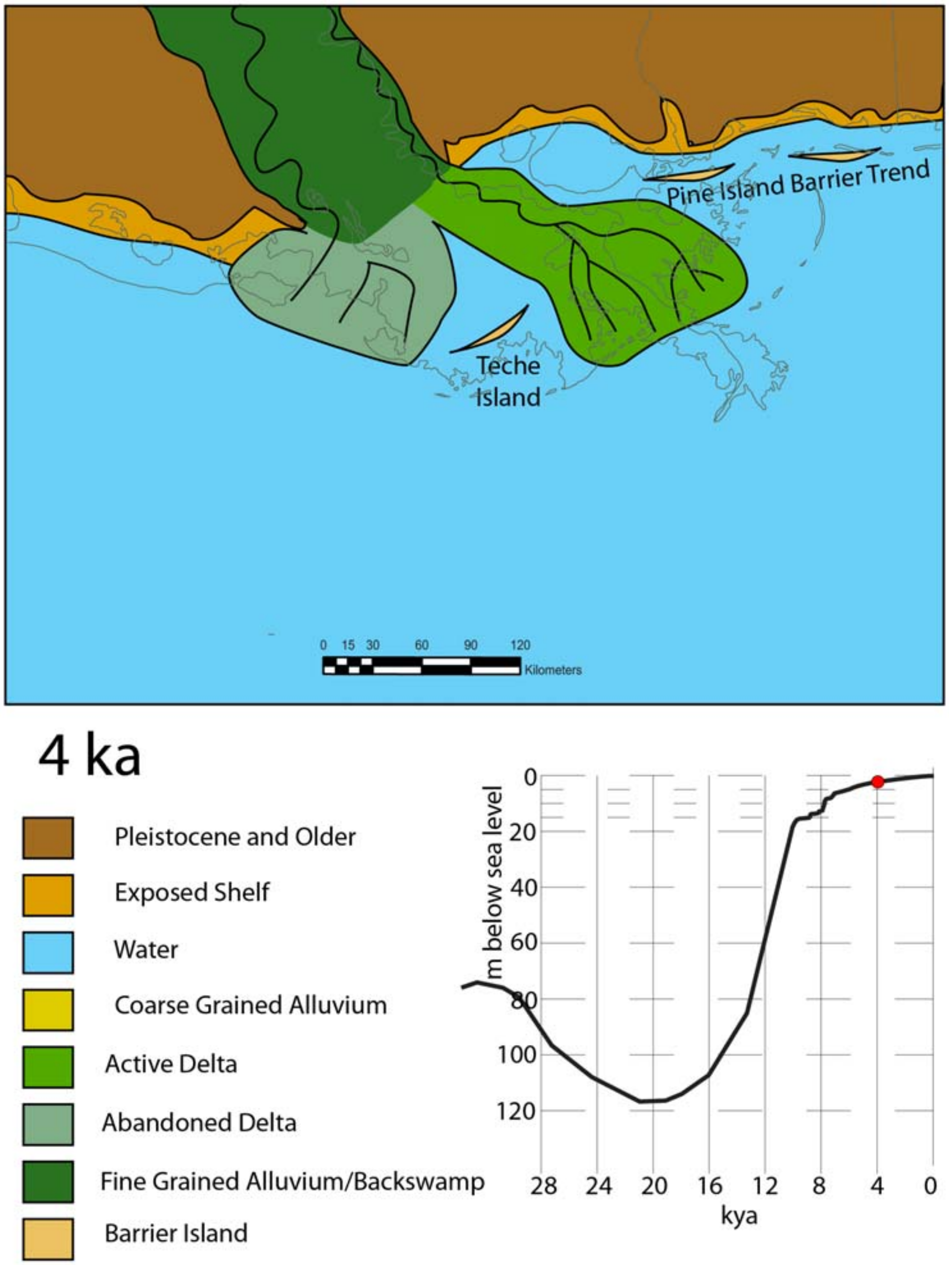

Figure 4.12—Abandonment of the Teche delta complex in favor of the St. Bernard delta complex. A barrier island on the eastern flank of the Teche delta complex may have developed at this time.

The St. Bernard Delta Complex lies completely outside the bounds of the Mississippi River incised valley. According to Frazier (1967) the St. Bernard delta developed from 5.36-0.62 cal kya (figures 4.12, 4.13) and the Lafourche delta complex was deposited between 3.74 cal kya and the present. Maximum transgression occurred at some point during the development of these two delta complexes. Kosters and Suter (1993) suggest that maximum transgression occurred between 3.7-3.2 cal kya but possibly as late as 2.5 cal kya. Peat from the P-I-90 with an age of 2.16 cal kya indicates that maximum flooding and transgression had already occurred. Therefore delta lobes of the Lafourche and St. Bernard deltas stratigraphically straddle the maximum flooding surface.

The St. Bernard Shoals that lie at a depth of ~20 m below sea level formed contemporaneously with the Bayou La Loutre of the St. Bernard delta, from 2.7-1.5 cal kya (Rogers et al., 2009).

Lafourche Delta Complex

This bayhead delta complex is exposed at the surface and is present in all USGS and LGS cores. It extends to a depth of 8.30-11.55 m with an average thickness of 9.54 m, assuming that bypassed intervals extend upward to mean sea level. This unit was not fully recovered in boreholes 05BS01, 04BS02, and 05COCO-01 because the upper 3.05-7.61 m were bypassed. The cores P-I-90, 04BS01, and 04BS02 contain multiple coarsening upward intervals, most likely due to crevasse splay development or abandonment and subsequent reoccupation of the most proximal distributary. This delta complex does not extend updip into the 05BS02 borehole, as it lies landward of the final Teche shoreline that developed during and following the Teche ravinement.

Lafourche delta sediments are absent in borehole 05BS02. Borehole 04BS02 has two coarsening upward intervals, the lower unit has a transgressive lag at the base overlain by interdistributary, prodelta, and distributary facies and the upper unit has interdistributary deposits. The upper 4.57 m of 04BS02 were bypassed. In borehole 04BS01 there are two coarsening upward intervals. The lower unit has prodelta, distributary, natural levee and marsh facies preserved; the upper unit, which extends to the ground surface, has the same succession

of facies. Three coarsening upward intervals are present in borehole P-I-90. The lowest unit has a thick transgressive lag at the base followed by prodelta, distributary and marsh facies. The upper two splay deposits have only natural levee and marsh facies. In the 05COCO-01 borehole, a transgressive lag is at the bottom overlain by prodelta, distributary, natural levee and marsh facies; the upper 3.05 m were bypassed. Boreholes 03K14 and 03CH02 were fully recovered and contain interdistributary, transgressive lag, prodelta, distributary, and marsh facies and interdistributary, prodelta, distributary, interdistributary and marsh facies, respectively.

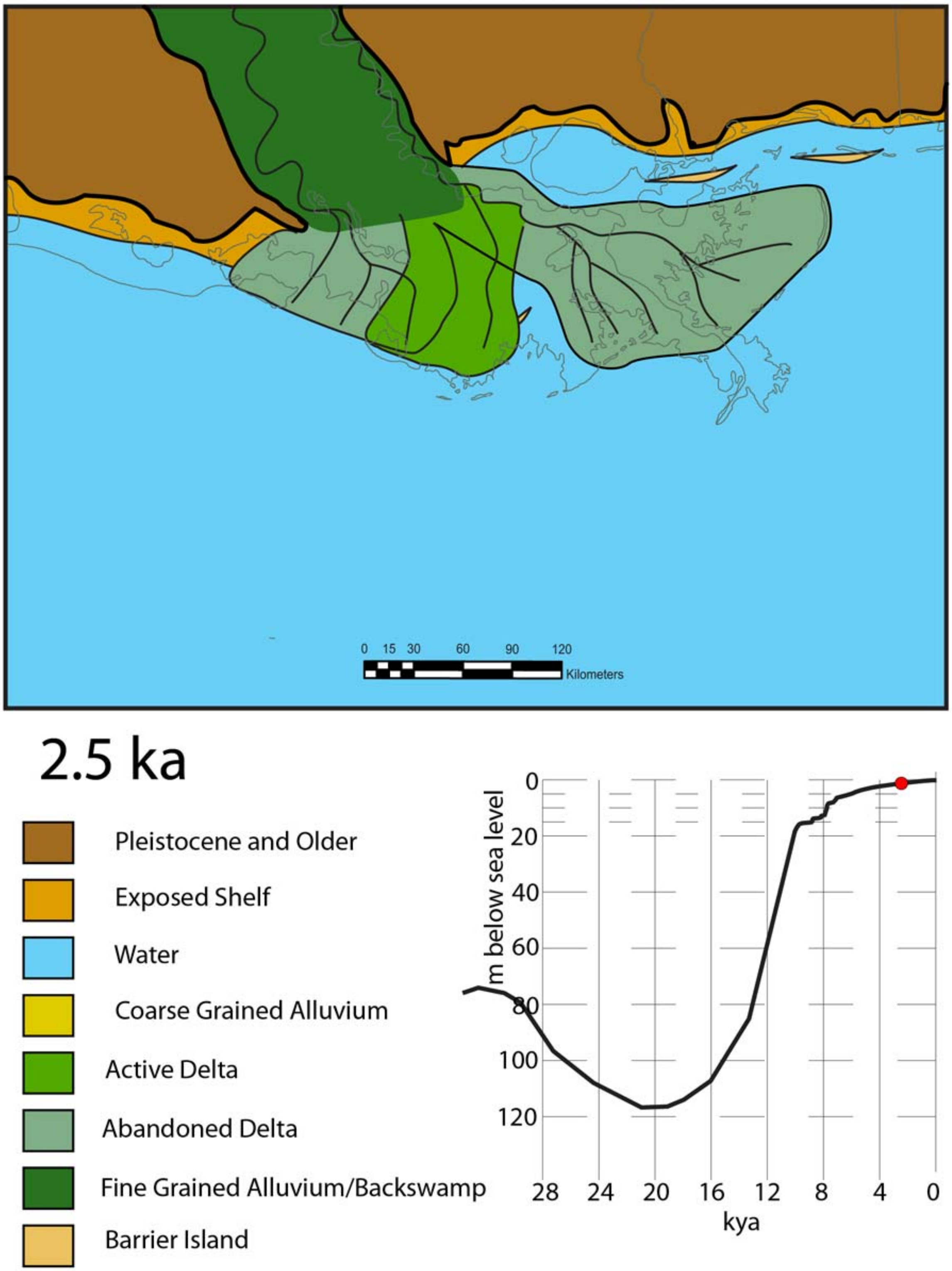

Figure 4.13—The Teche shoreline, the shoreline of maximum transgression is reached. The St. Bernard delta complex is abandoned and begins transgressive reworking as the Lafourche delta complex is initated. Early growth of the Lafourche delta complex buries Teche Island that developed at the Teche shoreline.

Directly underlying this delta complex is the Teche ravinement surface that developed after the preceding delta complex was deposited. Radiocarbon dates from the P-I-90 borehole place the ravinement event between 4.66-2.16 cal kya. Radiocarbon dates from the three marsh surfaces within this delta complex in the P-I-90 borehole date to 1.10 cal kya, 1.00 cal kya, and 0.36 cal kya. The uppermost and youngest radiocarbon date was taken from peat 0.90 m below the ground surface, therefore much younger peats exist above this location and continue to accumulate to the present day.

The Teche ravinement that preceded deposition of this bayhead delta complex progressed onshore to somewhere between the 05BS02 and 05BS01 boreholes. There is the potential that the ravinement surface extends to borehole 05BS02 and lies within the 7.61 m bypassed interval, however this would place the ravinement surface 2-4 m above the conjugal surfaces found in other boreholes and therefore is unlikely. Progradation of the delta surface progressed rapidly, emplacing prodelta and distributary facies deposits. Areas where interdistributary facies overlie distributary facies, such as in borehole 03CH02, the distributary network prograded beyond the sample location and fine-grained overbank sedimentation was responsible for raising the substrate surface adequately for marsh grass colonization. Repetition of coarsening upward intervals in borehole 04BS01 is the result of an early distributary prograding some distance into previously open waters. The overlying coarsening upward interval is most likely genetically related to the deposits found at similar depths in adjacent cores. Repeated intervals in borehole P-I-90 are likely due to development of subdeltas or crevasse splays.

The earliest transgressive parasequences developed at the shelf edge, both within the Mississippi Canyon and offshore of western Louisiana (Coleman et al., 1983; Suter and Berryhill, 1985). Deltaic sedimentation most likely shifted back and forth between the two depocenters from 18-11.5 cal ka as sea level rose and transgressed the continental shelf. The first shelf phase delta was the EHDC that developed between 12.0-9.3 cal kya and is genetically related to Outer Shoal. The shelf phase deltas that followed continued the overall backstepping trend until maximum transgression was reached at the Teche shoreline (McBride et al., 1990).

Highstand delta complexes prograded seaward above the maximum flooding surface to form the modern delta plain.

Filling of the Incised Valley

The incised valley filled initially with substratum deposits, and is overlain by topstratum parasequences that onlap the substratum surface. Knowledge of the substratum remains limited, however, understanding of the topstratum is expanded by the boreholes used in this study. Overlying the substratum are nine parasequences separated by flooding surfaces. Parasequences are differentiated and placed into a chronostratigraphic framework based upon radiocarbon age dates of swamp and marsh peats that developed at the parasequences' upper surfaces. Bounding surfaces of deltaic units and chronostratigraphic units coincide with flooding surfaces overlying peat deposits (figure 4.14, 4.15).

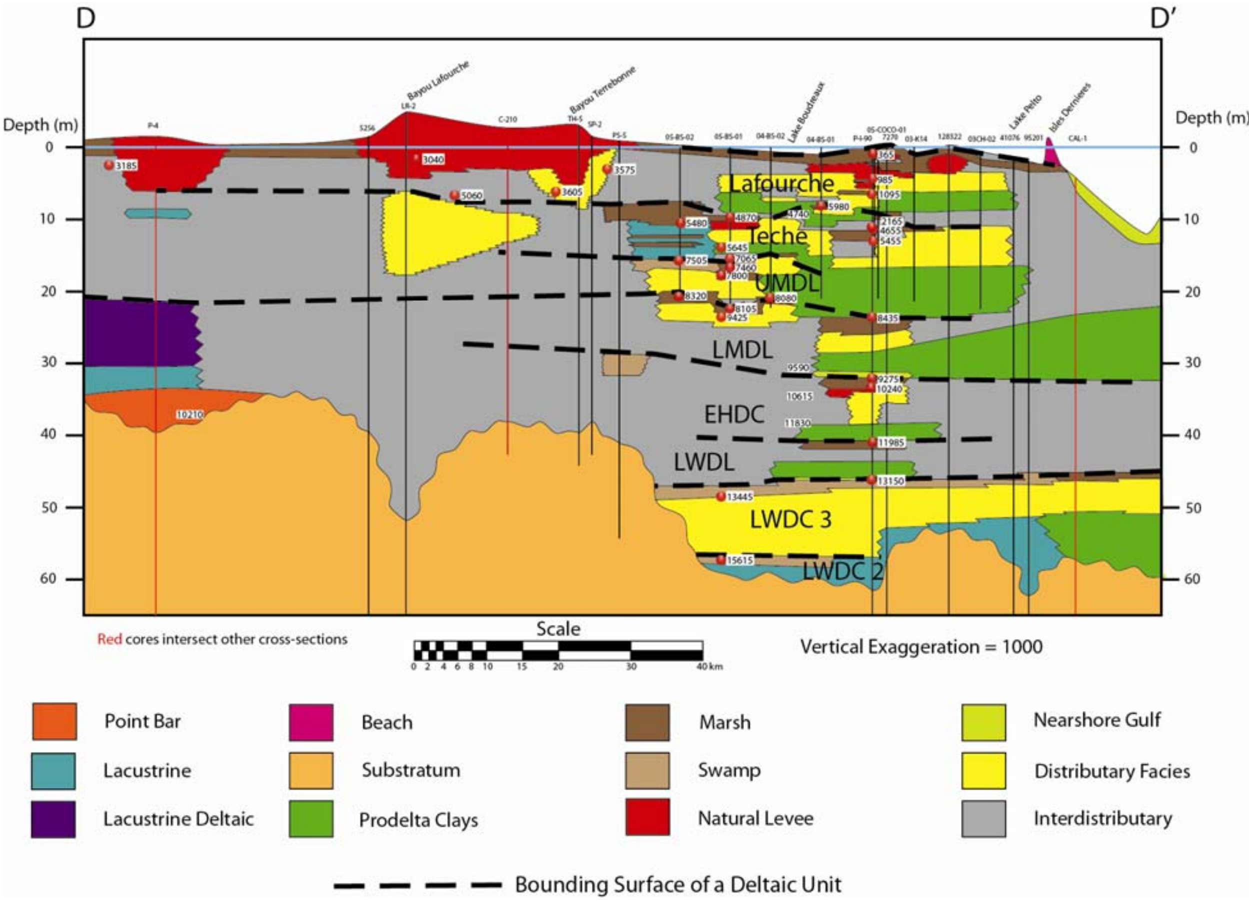

Figure 4.14—Dip section view of incised valley along D-D′ (figure 3.7). Eight parasequences are visible; the deepest ninth parasequences was located in a boring not shown here. A general trend of transgression followed by regression can be identified by the shift in location of depositional facies. Freshwater environments extend at least as far as the modern coastline in LWDC 2 and 3. Freshwater facies shift north to near the center of the section in the EHDC, and farther north in the LMDL. Freshwater facies begin to show regression in the Teche delta; swamp and lacustrine deposition is recorded in the USGS borings.

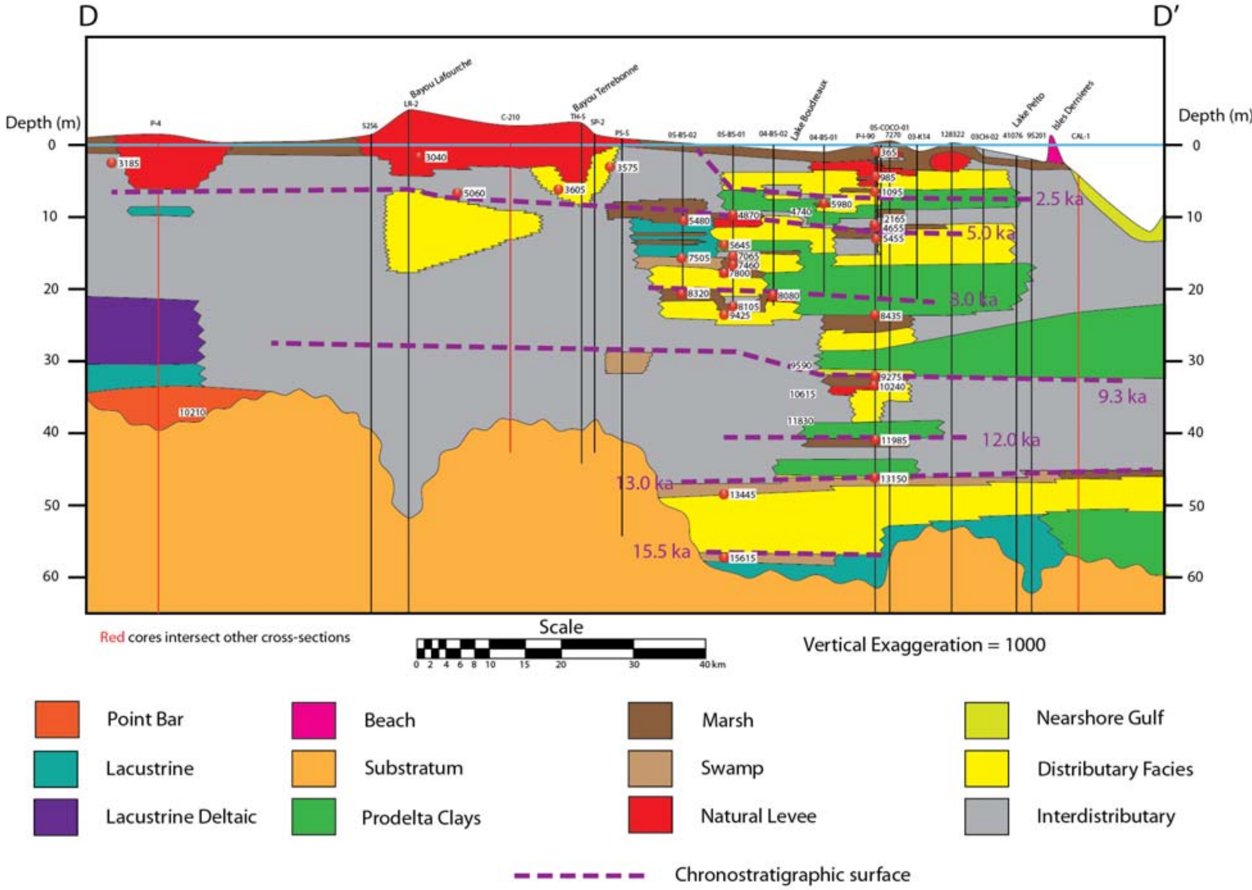

Figure 4.15—Dip oriented cross section showing surfaces of approximately equal time in calendar years. These ages are based upon radiocarbon dated swamp and marsh peats.

CONCLUSIONS

1. A series of nine deltas and their correlative alluvial deposits fill the incised valley and extend to the shelf edge. Six of these delta units are previously undocumented and undescribed. This study extends our knowledge of the Mississippi River deltas and incised valley filling deposits from ~8 cal kya to ~20 cal kya.
2. Transgressive deltaic parasequences of the Mississippi River Incised valley are coarsening upward sedimentary packages bounded by flooding surfaces. They frequently include an organic marsh peat at the upper surface and a transgressive lag at the base.
3. Transgression within the incised valley was initially rapid becoming episodic by approximately 10 cal kya. There were several periods of rapid relative sea level rise that created abundant accommodation that forced abandonment of mature delta plains and overwhelmed sediment supply.
4. The Teche delta complex or a time equivalent delta extends at least 20 km farther east than mapped by Frazier (1967).

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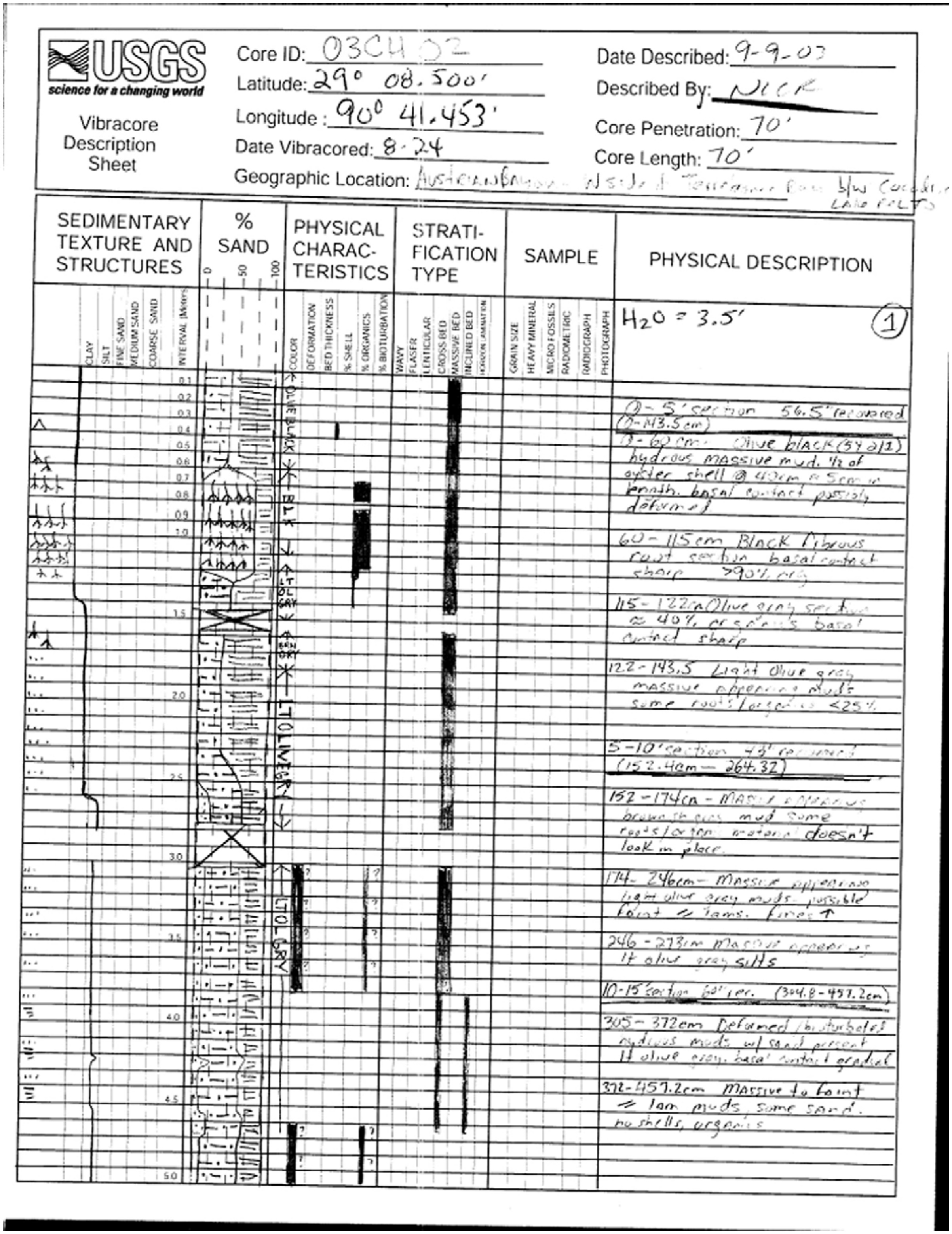
APPENDICES

03CH02 Borehole Description



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Vibracore Description Sheet

Core ID: 03CH 02

Latitude: 29° 08.500'

Longitude: 90° 41.453'

Date Vibracored: 8-24

Geographic Location: Austrian Bayou ... W side of Terrebonne ... b/w Cocodrie ... Lake Felton

Date Described: 9-9-03

Described By: NICR

Core Penetration: 70'

Core Length: 70'

SEDIMENTARY TEXTURE AND STRUCTURES (CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)) | % SAND (0, 50, 100) | PHYSICAL CHARACTERISTICS (COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION) | STRATIFICATION TYPE (WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION) | SAMPLE (GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH) | PHYSICAL DESCRIPTION

Interval (m): 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0

Color: OLIVE BLACK; BLK; LT OL GRY; BRN GRY; LT OLIVE GRY; LT OL GRY

PHYSICAL DESCRIPTION:

H_2O = 3.5' (1)

0-5' section 56.5" recovered (0-143.5 cm)

0-60 cm Olive black (5Y 2/1) hydrous massive mud. 1/2 of oyster shell @ 40 cm ≈ 5 cm in length. basal contact possibly deformed

60-115 cm Black fibrous root section basal contact sharp >90% org

115-122 cm Olive gray section ≈ 40% organics basal contact sharp

122-143.5 Light olive gray massive appearing muds some roots/organics <25%

5-10' section 43" recovered (152.4 cm – 264.32)

152-174 cm - Massive appearing brownish gray mud some roots/organic material doesn't look in place.

174-246 cm - Massive appearing light olive gray muds. possible faint ≈ lams. fines ↑

246-273 cm Massive appearing lt olive gray silts

10-15' section 60" rec. (304.8-457.2 cm)

305-372 cm Deformed/bioturbated hydrous muds w/ sand present lt olive gray. basal contact gradual

372-457.2 cm Massive to faint ≈ lam muds, some sand. no shells, organics

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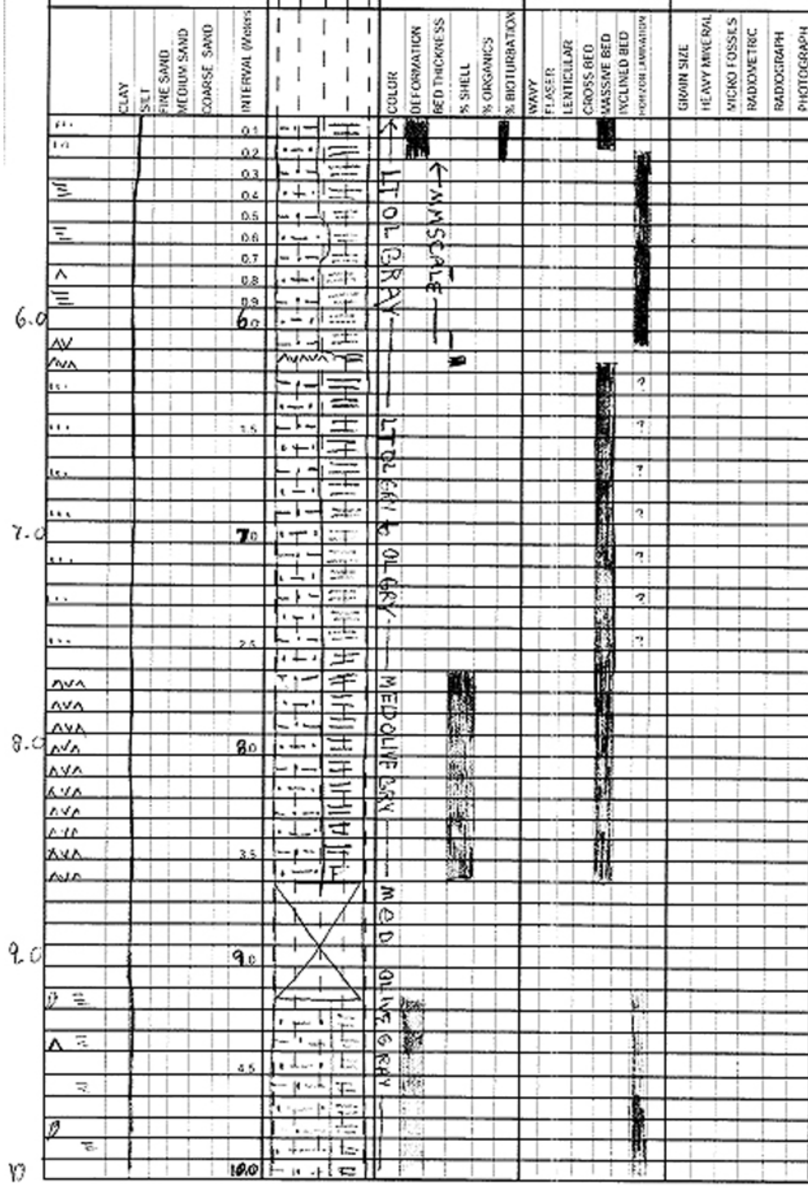
Vibracore Description Sheet

Core ID: 03CH02-pg2
Latitude: 29° 08.500'
Longitude: 90° 41.453'
Date Vibracored: 8-24
Geographic Location: Austrian Bayou, W side of Terrebonne Bay B/W Lake Pelto and Caillou Bay

Date Described: 9-9-03
Described By: NLK
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION



764

H_2O 3.5'

(2)

15-20' section 60" recovery
(457.2-609.6)

457.2-512cm Lt olive gray deformed muds, no shells/organics

512-609.6cm faintly laminated lt olive gray muds, some coarser more visible layers @ 540, 576, 590
small shell @ 576, 601

20-25' sect 60" recovery
(609.6-762cm)

609-612 - Shell hash - mm pieces

612-764 Massive appearing light olive gray (5Y 6/2) to olive gray (5Y 4/1) muds possibly faintly // laminated

25-30' section 38¾" recovery
(762-914.4cm) 98.4 m

762-857cm - Hydrous muds medium olive gray, shell hash throughout section small pieces - cm scale,

30-40' section (53" rec)
(914.4 - 1219.2)

914-996 Medium olive gray deformed muds faint def. lams. Rust colored section 968-972, burrows 972, 993

996-1051cm - Medium olive gray mud/vfg sand couplets (alternating lams) no deformation, some very slight rust coloring bedding mm to cm scale

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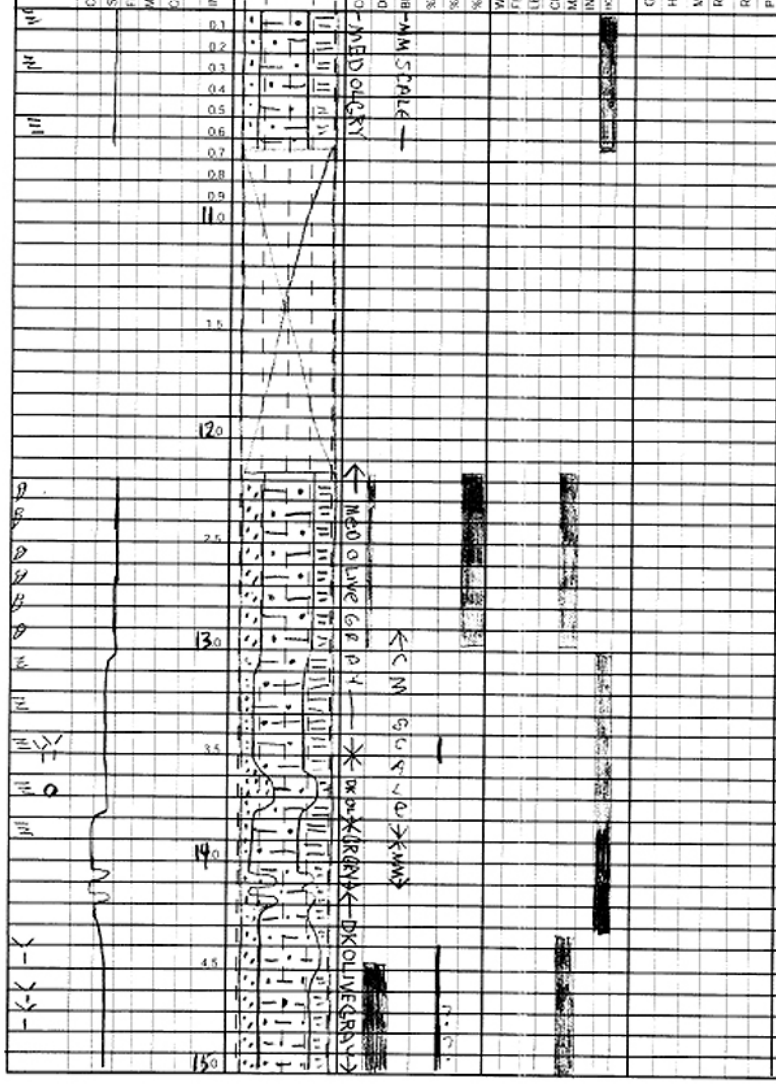
Vibracore Description Sheet

Core ID: 03 CH 02 p3
Latitude: 29° 08.500′
Longitude : 90° 41.453′
Date Vibracored: 8-24
Geographic Location: Austrian Bayou N Terrebonne Bay, Between Caillou & Lake Pelto

Date Described: 9-9-03
Described By: NLL
Core Penetration: 70′
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	H_2O 3.5′ (3)



40-45′ section 60″ recovery
(1219-1372)

1219-1290 Medium olive gray muds w/ v.f.g. sand filled burrows & slight deformation

1290-1347 cm Medium olive gray couplets of mud & vf sand mud sections thicker than previous section ≈ 3.5 cm thick

1347-1372 DK olive gray silts & vf sand laminated, two mm scale coffee ground sections @ 1349 & 1351
some small mica flakes
clay clast 1369-1370

45-50′ section 50″ recovered
(1372-1524)

1372-1407 Greenish Gray faintly lam muds. mm scale, on tan color lamination

1407-1417 Olive gray v.f. g. sandy section

1417-1426 Olive gray lams of mud-sand mm scale

1426-1450 cm Olive gray massive appearing silts, small mica flakes (?)
coffee grounds 1445 - deformed

1450-1498 cm Olive gray hydrous muds. some v.f. g. sands present. seems like there may be organics present - coffee grounds

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Vibracore Description Sheet

Core ID: 07CH02 p4

Latitude: 29° 08.500'

Longitude: 90° 41.453'

Date Vibracored: 8-24

Geographic Location: Atchafalaya W Terrebonne Bay - b/w Caillou & Lake Pelto

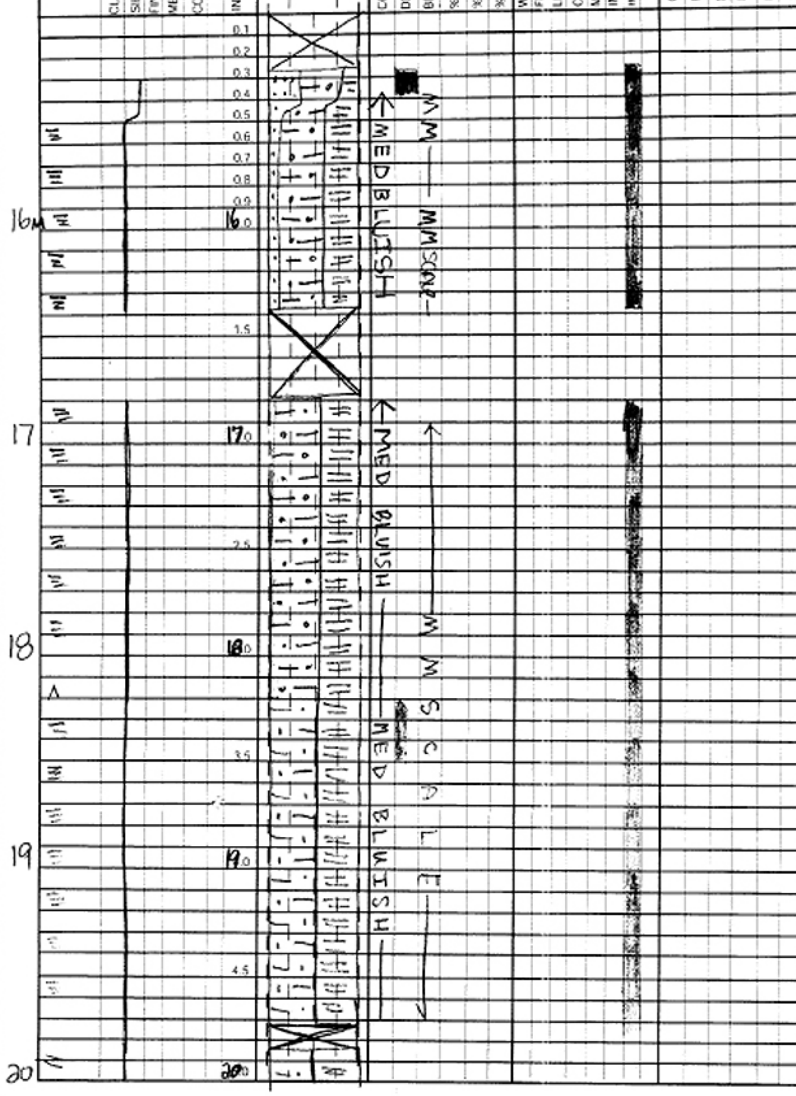
Date Described: 9-9-07

Described By: Nick

Core Penetration: 70'

Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARAC-TERISTICS	STRATI-FICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZONTAL LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	H_2O 3.5' (4)



50-55' section 48.5" recovered (1524-1676.4)

1524-1532cm Hydrous olive gray silty sand - very small shell pieces .5mm,

1532-1647cm Medium bluish faintly laminated muds some coarser laminae sub mm scale. overall lams ≤1mm scale some tan colored laminations

55-60' section 61" recovered (1676.4-1828.8)

1676-1829cm Medium bluish faintly = laminated muds Again some coarser laminations 1705cm, 1716cm, 1747cm
- pieces of metal @ 1803, 1812 from auger? - ?

- large bivalve half @ 1836 6cm in length

60-65' section 57" recovery (1828.8-1981.2)

1829-1973 Medium bluish faintly = laminated muds only one slightly coarser sub mm lam - 1921.5cm again some tan laminations ≤ mm scale
some def. due to coring process from 1830-50.

65-70' 61" recovery 1981.2-2136

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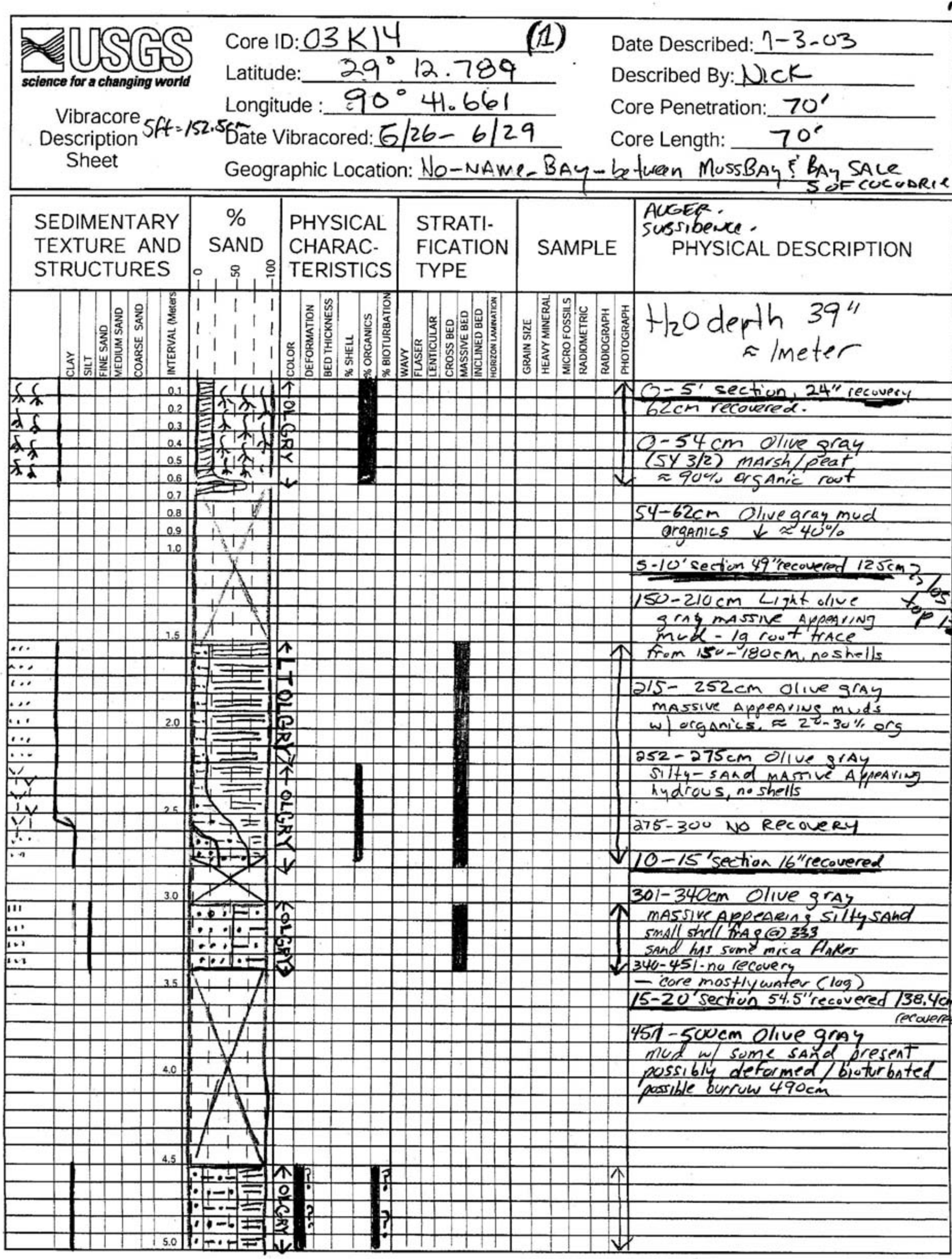
Vibracore Description Sheet

Core ID: 03CH 02 p5
Latitude: 29° 08.500'
Longitude: 90° 41.453'
Date Vibracored: 8-24
Geographic Location: Austrian Bayou - W Terrebonne Bay, b/w Cocodrie & Lake Caillou

Date Described: 9-9-03
Described By: NCCR
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZONTAL LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	(3)
21 — 0.1–1.0 (21.0)		MED BLUISH	MASSIVE BED		65-70' section 61" recovery (1981.2 - 2136)
					MASSIVE appearing medium bluish muds. very small shell frags (mm) @ ~2052, 2109, 2110 cm
					Silty sections 2076 2025 - does not make it across core ≤2cm in length ≤1cm wide
1.5					
22 — 2.0					
2.5					
3.0					
3.5					
4.0					
4.5					
5.0					

03K14 Borehole Description



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Vibracore Description Sheet

5ft = 152.5cm

Core ID: 03K14 (1)

Latitude: 29° 12.789

Longitude: 90° 41.661

Date Vibracored: 6/26 – 6/29

Geographic Location: No-Name Bay – between Moss Bay & Bay Sale S of Cocodrie

Date Described: 7-3-03

Described By: Nick

Core Penetration: 70'

Core Length: 70'

SEDIMENTARY TEXTURE AND STRUCTURES: CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)

% SAND: 0, 50, 100

PHYSICAL CHARACTERISTICS: COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION

STRATIFICATION TYPE: WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION

SAMPLE: GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH

PHYSICAL DESCRIPTION

Auger. Subsidence.

H_2O depth 39" ≈ 1meter

0–5' section, 24" recovery 62cm recovered.

0–54cm Olive gray (5Y 3/2) marsh/peat ≈ 90% organic root

54–62cm Olive gray mud organics ↓ ≈ 40%

5–10' section 49" recovered 125cm ? lost top 12"

150–210cm Light olive gray massive appearing mud – lg root trace from 150–180cm, no shells

215–252cm Olive gray massive appearing muds w/ organics, ≈ 20–30% orgs

252–275cm Olive gray silty-sand massive appearing hydrous, no shells

275–300 No recovery

10–15' section 16" recovered

301–340cm Olive gray massive appearing silty sand small shell frag @ 333 sand has some mica flakes

340–451 – no recovery – core mostly water (log)

15–20' section 54.5" recovered 138.4cm recovered

451–500cm Olive gray mud w/ some sand present possibly deformed / bioturbated possible burrow 490cm

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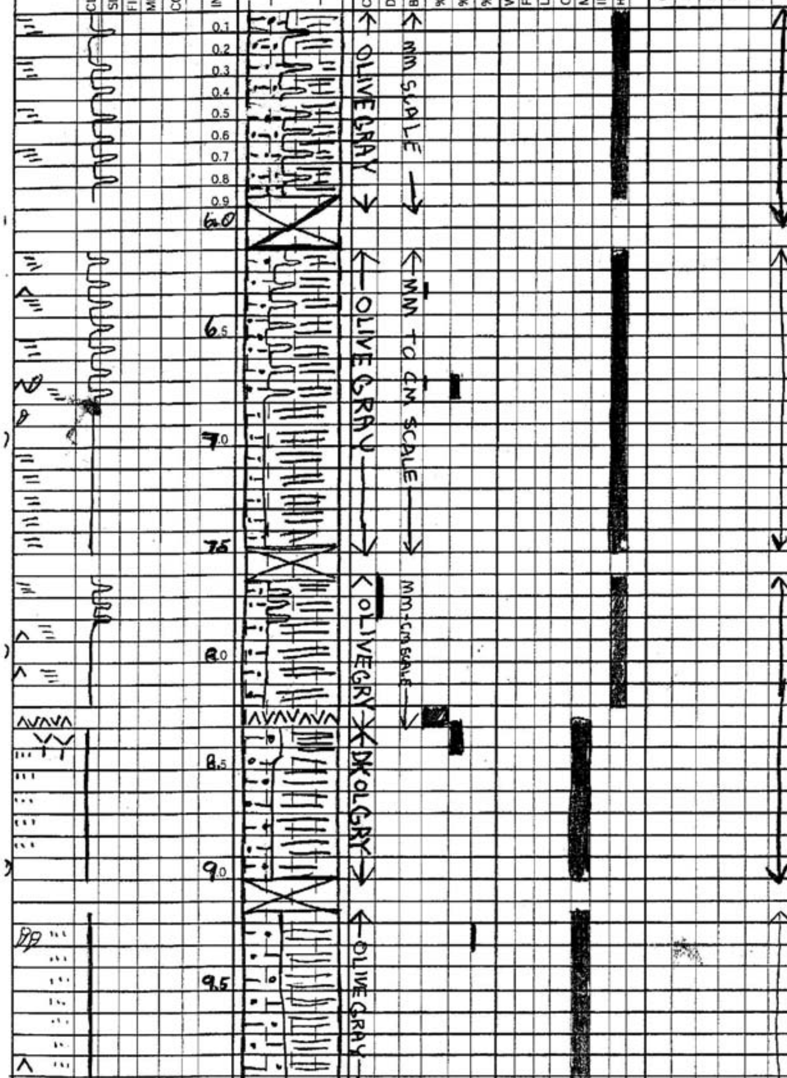
Vibracore Description Sheet

Core ID: 03K14 (Continued 2-)
Latitude: 29° 12.789
Longitude: 90° 41.661
Date Vibracored: 6/26 – 6/29
Geographic Location: No Name Bay - between Moss Bay & Bay Sale South of Cocudrie

Date Described: 7-3-03
Described By: Nick
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	$H_2O \approx 1m$



CONTINUED 15-20' section
500-589 Olive gray faintly laminated somewhat stiff mud w/ occasional silt laminae where noted. no shells or organics. faint lams visible b/c of slight color variations

589-610cm – No recovery

20-25' section 55" recovered

610-748 Olive gray faintly laminated somewhat stiff mud w/ occassional silt laminae. silt laminae decrease down core (same as above section) bivalve pieces at 638 & 670 cm organics (wood?) @ 674cm possible burrows 675, 690

748-762 No recovery

25-30' section full recovery bottom 14cm missing

762-820cm – Same as above section. Olive gray faintly laminated possibly deformed mud w/ occassional silt laminae. shell frag @ 790 and bivalve 808cm

820-826cm Shell lag consisting of cm scale pieces

826-840cm Dark OL. Gray muds w/ organics, mud slightly browner root traces or woody pieces

840-900 Olive gray massive appearing muds. shells 844cm organics 851 cm
900-914 no recovery

5

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Vibracore Description Sheet

Core ID: 03K14 (continued p3)
Latitude: 29° 12. 789
Longitude: 90° 41. 661
Date Vibracored: 6/26 – 6/29
Geographic Location: No Name Bay – Between Moss Bay & Bay Sale – South of Cocodrie

Date Described: 7-3-03
Described By: Nick
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	$H_2O \approx 1m$

Interval (meters): 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 11.0, 1.5, 12.0, 2.5, 13.0, 3.5, 14.0, 4.5, 15.0

Color: OLIVE GRAY; OLIVE GRAY; OLIVE GRAY; OLIVE GRAY

Bed thickness: MM TO CM SCALE

900-914 - no recovery (see pg 2)
30-35' section 60" recovered

914-1064 cm olive gray massive appearing muds. coarsen near bottom
small bivalve pieces 995 cm, 1007
organics - roots from 1008-1056 cm
gastropod (?) @ 1062 cm

35-40' section 60" recovered
40-45' section 60" recovered
45-50' section 60" recovered

1064-1524 cm olive gray parallel laminated sands/muds. vf sand / silt makes up // laminae. deformation where noted

tan intervals 1295 cm
1311 cm
1354 cm
1390 cm

possible burrow @ 1339 cm ≈ 6 cm long 3 cm wide
sandy layer @ 1317 cm

possible burrow 1484 cm

ROOT TRACES

SAMPLED ≈ 1044-1049 cm
ID 03K14

4

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Vibracore Description Sheet

Core ID: 03-K-14 (cont p4)

Latitude: 29°12.789

Longitude: 90°41.661

Date Vibracored: 6/26 - 6/29

Geographic Location: No-Name-Bay - Between Moss Bay & Bay Sale SOUTH OF COCODRIE

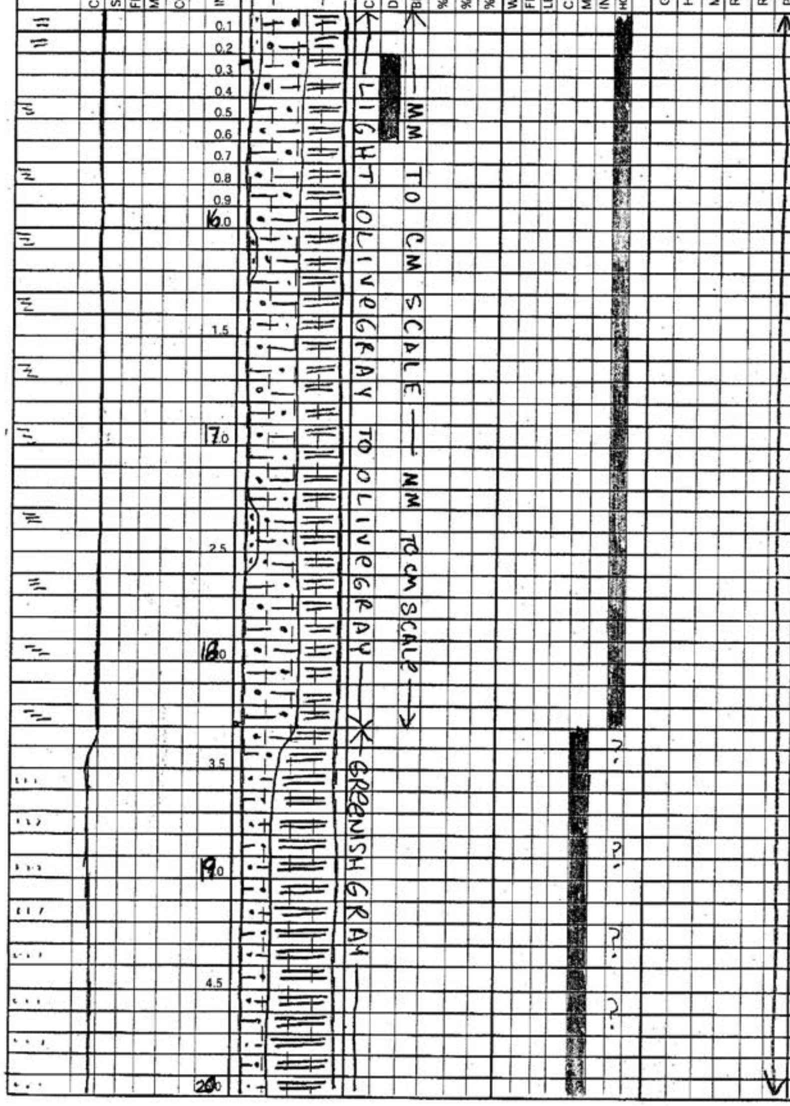
Date Described: 7-3-03

Described By: NICK

Core Penetration: 70'

Core Length: 7

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND (0, 50, 100)	PHYSICAL CHARAC-TERISTICS	STRATI-FICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)		COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	$H_2O \approx 1m$



50-55' section 60" recovery bottom 8 cm empty - "compaction"

55-60' section 60" recovered bottom ≈ 7 cm empty "compaction"

1524-1796 cm Light olive gray to olive gray faintly // laminated muds! some v.f. sand silt lenses. Deformation from 1524-1550 cm

60-65' section 60" recovery ≈ 8 cm empty

65-70' section 60" recovery ≈ 7 cm empty

1796-2136 cm (BTM) Greenish gray massive appearing clays w/ small % silt. Very faint laminations due to slight color variations

small shell frag @ 2046 - can't tell what it is

small shell - looks like bivalve @ 2075 cm ≈ 5 mm in length

1524

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Vibracore Description Sheet

Core ID: 03-K-14 (Cont pg 5)
Latitude: 29°12.789
Longitude: 90°41.661
Date Vibracored: 6/26-6/29-03
Geographic Location: No-Name-Bay-Between Moss Bay & Bay Sale South of Cocodrie

Date Described: 7-3-03
Described By: NICK
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES (Clay, Silt, Fine Sand, Medium Sand, Coarse Sand)	INTERVAL (Meters)	% SAND (0, 50, 100)	PHYSICAL CHARACTERISTICS: Color	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
	0.1		Greenish Gray	Massive bed	Photograph	$H_2O \approx 1m$
	0.2					
	0.3					
	0.4					
	0.5					
	0.6					
	0.7					
	0.8					
	0.9					
	21.0					
	1.5					
	22.0					
	2.5					
	3.0					
	3.5					
	4.0					
	4.5					
	5.0					

04BS02 Borehole Description

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Vibracore Description Sheet

Core ID: 04BS02

Latitude: 29° 22' 47.9"

Longitude: 90° 40' 53.0"

Date Vibracored: 7/25/04

Geographic Location: LAKE GERO / LAKE BOUDREAUX ESE DULAC

Date Described: 6-13-05

Described By: NUR

Core Penetration: 70'

Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	-90.68138889 29.37997222 0-15' Bypassed H_2O = ? PAGE (1)
0.1–1.0	BYPASSED				0-15 feet bypassed 15-20' section 457-584cm 50" recovered 457cm-530cm Deformed hydrous sandy muds, some organics (black)
1.5					
2.0					
2.5–3.5	BYPASSED				
4.0					
4.5–5.0		10 GY			

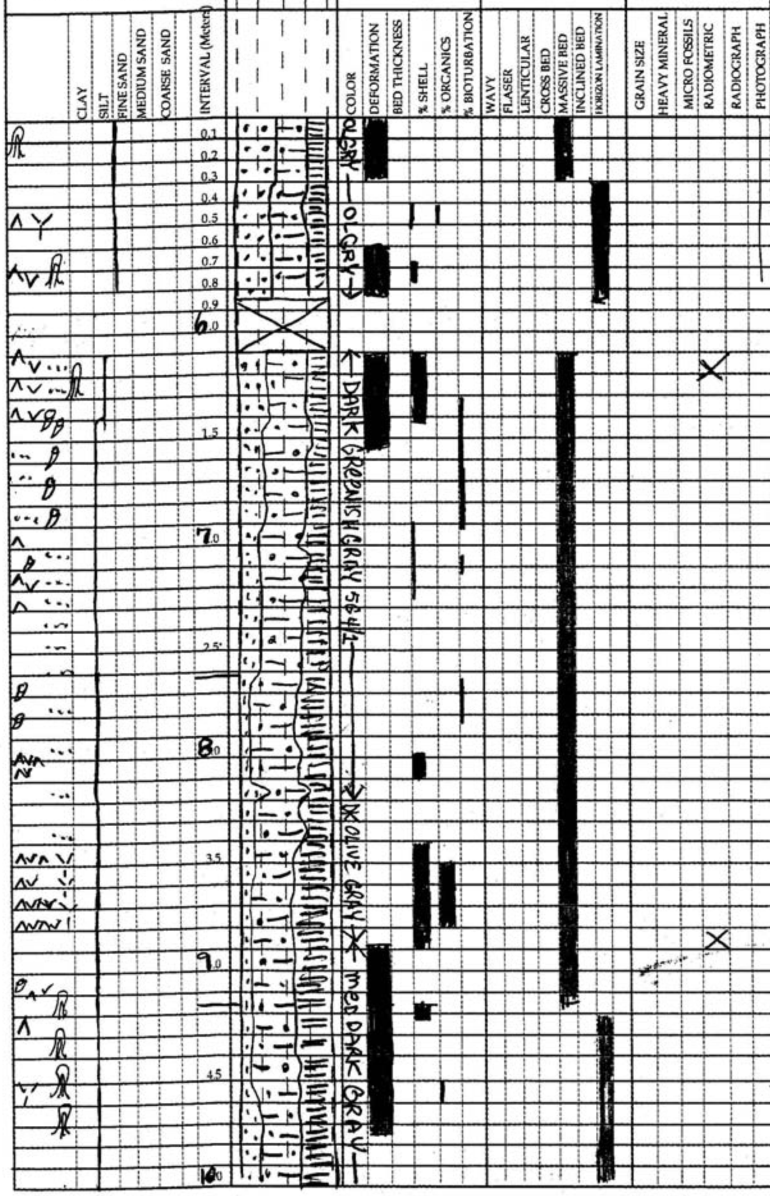
USGS science for a changing world

Vibracore Description

Core ID: 04BSO2
Latitude: 29° 22' 47.9"
Longitude: 90° 40' 53.0"
Date Vibracored: 7|25|04
Geographic Location: Lake Gero/Lake Boudreaux ≈ESE of Dulac

Date Described: 6-13-05
Described By: MVK
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARAC-TERISTICS	STRATI-FICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION



PAGE (2)

15-20' section (continued)

530-584cm Hydrous laminated sandy muds, olive gray, small shell @ 555 bivalve fragment.

20-25' section 60" recovered
610-762cm section
610-643cm Dark greenish gray sandy silt w/ some large ≈5cm oyster shell fragments, smaller bivalve shells mixed. (610-615 and 617-621 large frags. Another cluster @ 630-634
gradual basal contact

643-762cm Dark greenish gray massive appearing mud's small mm scale sand filled burrows where noted shell fragments - mm scaled

25-30' section 60" recovered 762-916

762-827cm DK greenish gray massive appearing mud, small burrows where noted, gradual basal contact marked by color change

827-873 Dark olive gray massive appearing muds. possibly organic rich, has some organic clusters @ 872cm
small shell (bivalve) fragments and mm scale ½ shells. @ 850-853, 860, 868cm

873-888 Bivalve rich zone, look like rangia
some intact halves ≈ 3cm wide

888-916 Deformed dark greenish gray mud, possible burrow 907, shell fragments 9-910cm

615-618cm - 2 oystershell frag. sampled
878cm 2 - ≈4cm rangia sampled

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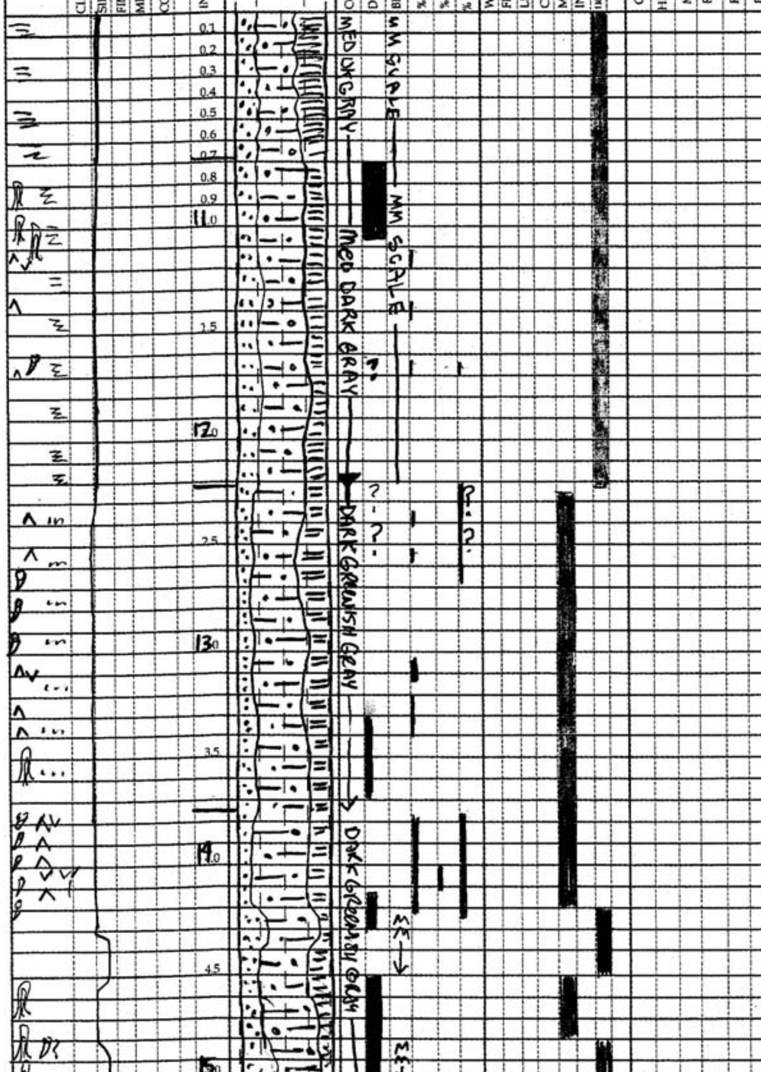
Vibracore Description

Core ID: 04BS02
Latitude: 29° 22' 47.9"
Longitude: 90° 40' 53.0
Date Vibracored: 7/25/04
Geographic Location: Lake Gero / Lake Boudreaux

Date Described: 6-13-05
Described By: M K
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PAGE 3



PHYSICAL DESCRIPTION

30-35 section 60" recovered 916-1068

916-960cm Medium dark gray deformed (once // lamination) muds. large shell (Rangia) ½ @ 920cm ≈ 4cm - sampled

960-1068cm Medium dark gray muds punctuated by mm scale v.f. sand / silt laminations same tan-yellow laminae

35-40' section 60" recovered 1068-1221

1068-1221 Medium dark gray muds more frequent mm scale v.f. sand / silt lams than above section. ½ mulinia (?) shell @ 1115, mm scaled, some brown / oxidized mud near bottom - could be from loose core cap.

40-45' section 60¾" rec, 1221-1375cm

1221-1257 Dark greenish gray deformed / heavy bioturbation? muds - sand filled burrows? mm scale shell fragments where noted

1257-1330cm Dark greenish gray massive appearing muds w/ occassional silt / v.f. sand filled burrows and laminae shell fragment cluster @ 1313cm mm scale frags.

1330-1375cm dark greenish gray w/ some brown discoloration deformed mud

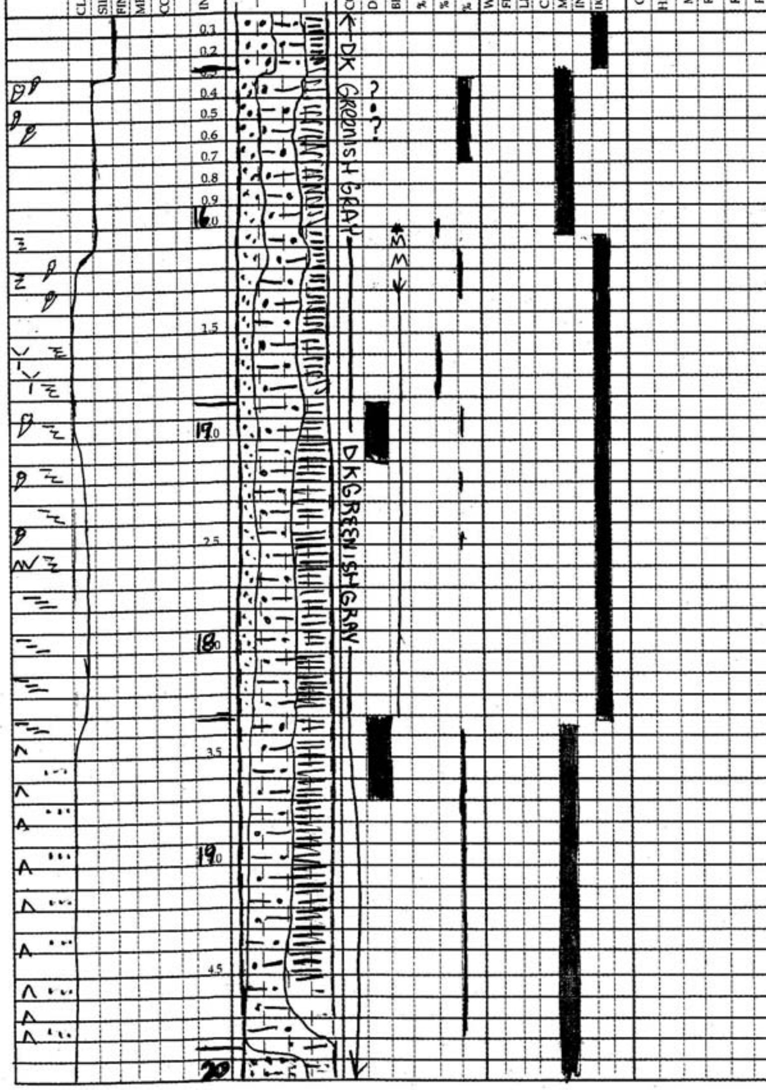
USGS science for a changing world

Vibracore Descriptio n

Core ID: 04BS02
Latitude: 29° 22' 47.9"
Longitude: 90° 40' 53.0
Date Vibracored: 7/25/04
Geographic Location: LAKE GERO/LAKE BOUDREAUX

Date Described: 6-14-05
Described By: NICK
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARAC-TERISTICS	STRATI-FICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PAGE 4



CONTINUED
45-50' 60" recovery 1375-1528cm

1375-1420cm Dark greenish gray massive appearing muds burrows common, shell fragment burrows sand filled, 2cm rangia shell 1380, organics @ 1418cm roots?

1420-1450 // laminated muds w/ some coarser laminae slight deformation dark gr. gray

1450-1480 Dark greenish gray heavily deformed - may be bioturbated muds, small shell frag. 1452cm.

1480-1528cm Dark greenish gray slightly laminated silty sand. mud lams. possible muddy burrow 1490, 1500

50-55' 60" rec 1528-1681cm

1528-1606 DK. greenish gray bioturbated muds. appears deformed, but some burrows intact. organic @ 1600 sharp basal
1606-1630 silt/sand laminations mm scale
1630-1680cm Massive appearing muds similar to above. some black colored muds - weird structures barely visible.

55-60' 60" rec 1681-1833
1681-1833 DK greenish gray very faintly laminated muds deformation present, some coarser lams, shells 1760cm, (some oxidation 1810-btm related to storage?)

60-65' } description next page
65-70'

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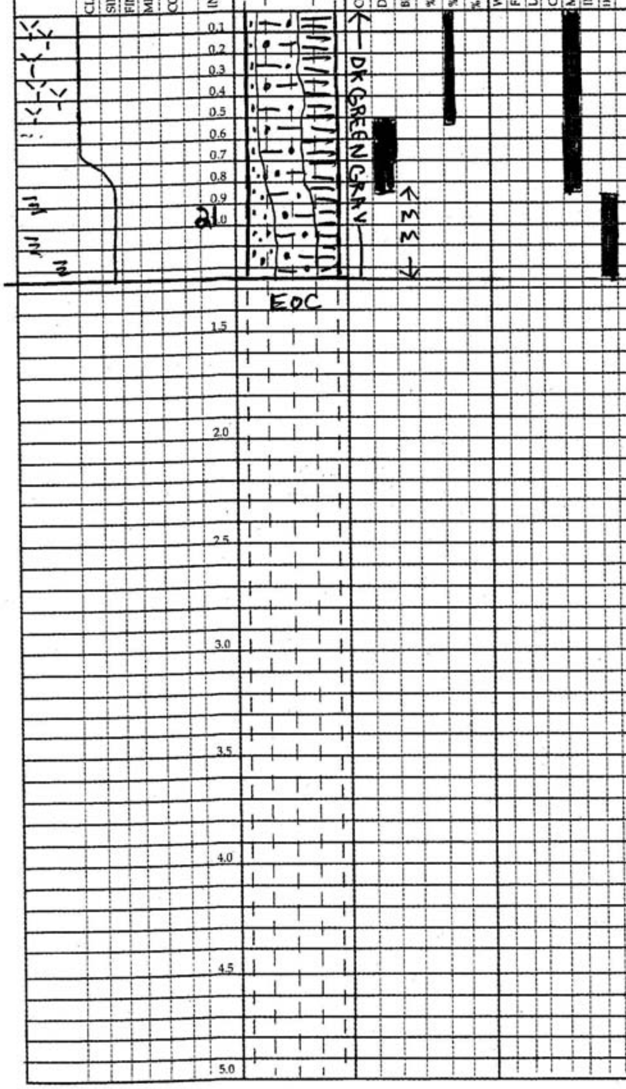
Vibracore Descriptio n

Core ID: 04BS02
Latitude: 29° 22' 47.9"
Longitude: 90° 40' 53.0
Date Vibracored: 7/25/04
Geographic Location: Bayo Gero / Lake Boudreaux

Date Described: 6-14-08
Described By: NLK
Core Penetration: 70'
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARAC-TERISTICS	STRATI-FICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PAGE 5



60-65' 60" recovered 1833-1985cm

1833-1985cm Similar to above section except this section more massive appearing, shells where noted, deformation 1833-1860 possible sharp basal contact

65-70ft 60" rec. 1985-2124

1985-1998 DK greenish gray massive appearing v.f. sand/silt sharp basal contact - deformed

1998-2053 Deformed massive appearing organic ≈50% mud. some drag down evident near edges of barrel root clusters and organic mud predominant

2053-2084cm Massive appearing (possibly laminated) mud. two yellowish tan deformed lams

2084-2124 Alternating // lams of vf sand/silt and muds sand @ 2090 light grayish mm scale lams

05BS02 Borehole Description

USGS science for a changing world

Vibracore Description Sheet

Core ID: 05BS02

Latitude: 3258149 N 29°29.401

Longitude: 725303 E 90°38.865

Date Vibracored: 7-26-05

Geographic Location: BayouChavin – N Lake Boudreaux –

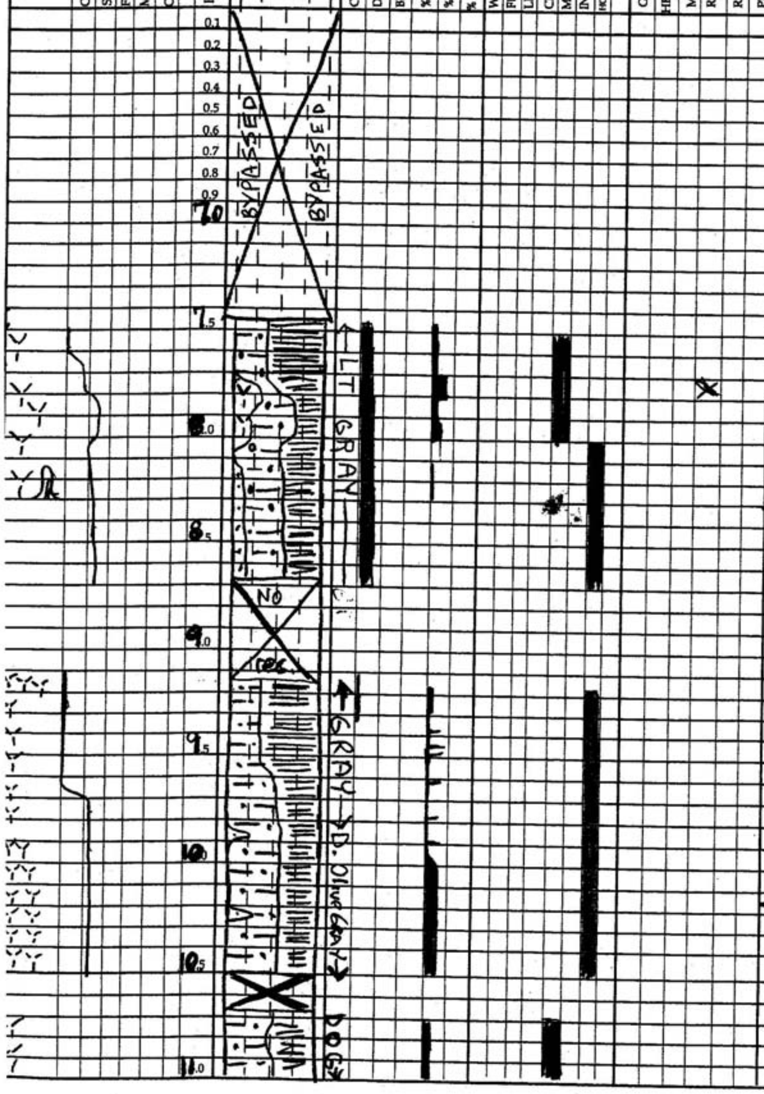
Date Described: 5-30-06

Described By: NICR

Core Penetration:

Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	NOTE: MUNSELL CHART MISSING



0-25 feet bypassed ☆ (1)

25-30' section 41.5 inches recover. 761cm – 867 recovered

761-776cm
Light gray massive muds w/ some organics, deformed basal contact

776-799 Light gray muds. Deformed peat/organics through section, basal sharp but slightly deformed - sand present sampled for C-14

799-867cm Light gray deformed muds. v. fine sand lams present which show most deformation. some organic matter in section

30-35' section 54" recovered. 914-1050cm recovered

914-980cm - Gray very faintly laminated muds. Organic layers and concentrations. basal contact gradational

980-1050 Very faintly laminated gray muds w/ ≈40% organics transitioning to dark olive gray muds w/ 80% organics
1046-1050 sampled C-14
100% organics
some slight color variations and silt vf. sand mm scaled layers @ 996cm, 1026cm & 1035

35-40' section 60" rec., 1066-1218

1066-1092 Dark olive gray organic mud. organics ↓ down section basal deformed

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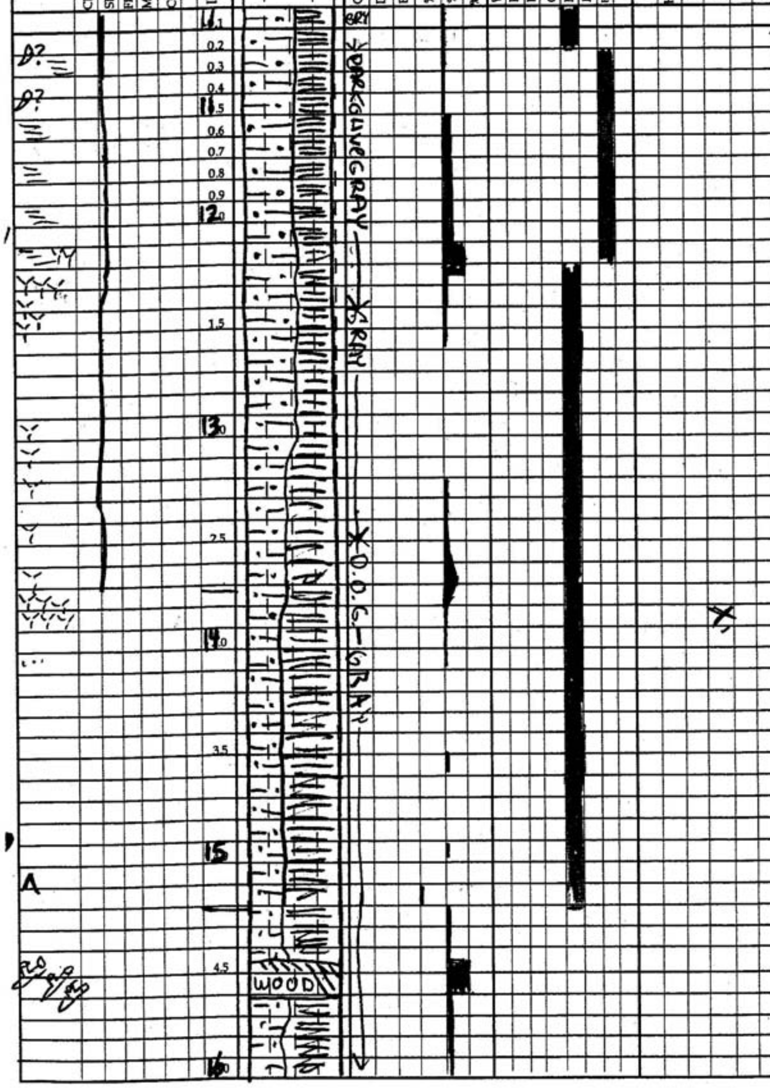
Vibracore Description Sheet

Core ID: 05BS02
Latitude: 3258149N 29° 29.401
Longitude: 725303E 90° 38.865
Date Vibracored: 7-26-05
Geographic Location: Bayou Chavin - North of Lake Boudreaux

Date Described: 5-30-06
Described By: NLC
Core Penetration:
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	2



35-40 section continued

1092-1120 Gray massive muds organic material present 25%.

1120-1218cm Mostly dark olive gray faintly laminated muds. Organic material present in "clumps" and coloring sediment. Some bluish gray v.f. sand lams and filled burrows???

1218-1220 Organic/peat - sampled

40-45' section 60" rec. 1220-1370

1220-1255 - Dark gray massive organic rich muds. basal contact sharp - sand filled burrow(?) @ 1257

1257-1310 Massive gray muds

1310-1370 Dark olive gray massive mud organic content increases down section

45-50' section, 60" rec., 1370-1522cm

1370-1385 Peat. Clastics dominate 1379-1385 - Sampled C-14

1385-1522cm Massive appearing gray - grayish blue mud some organics where noted gastropod @ 1515 - bagged stiff clays.

50-55' section, 44in recovered, 1522-1635

1522-1545 - Dark gray massive muds some organics

1545-1580 - Large chunk of wood. Cypress? Sampled for C-14

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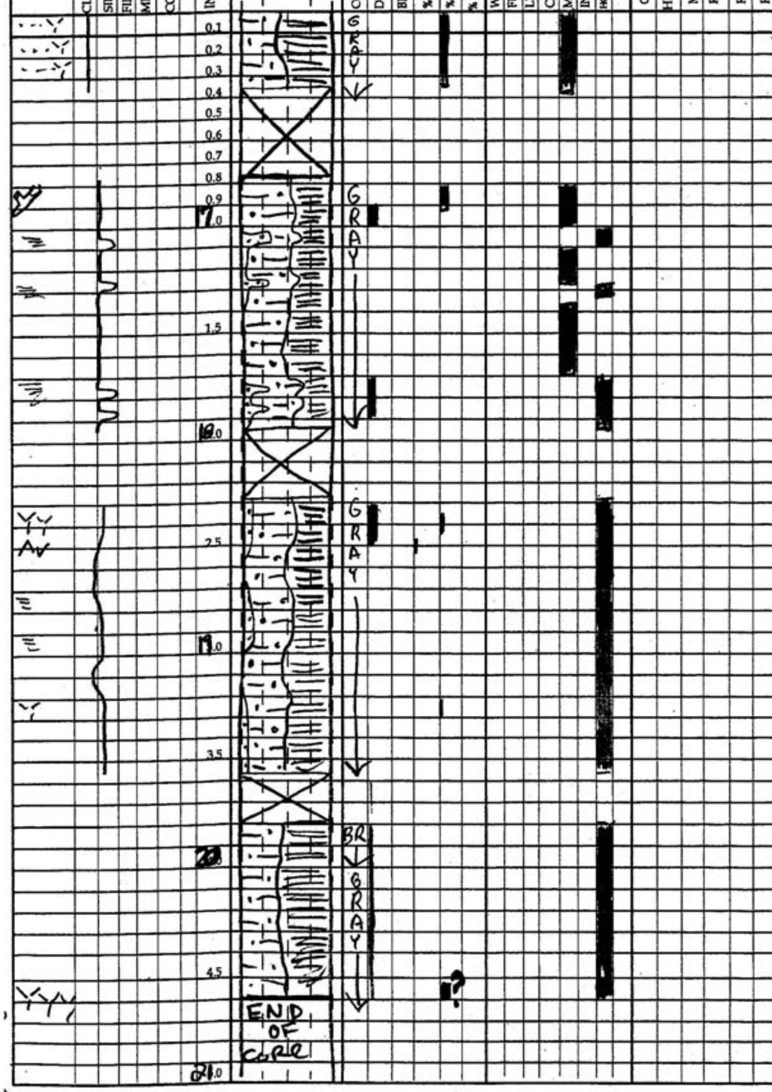
Vibracore Description Sheet

Core ID: 05BS02
Latitude: 3258149N 29° 29.401
Longitude: 725303E 90° 38.865
Date Vibracored:
Geographic Location: Bayou Chauvin- N. of Lake Boudreaux

Date Described: 5-31-05
Described By: NICK
Core Penetration:
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION

CLAY · SILT · FINE SAND · MEDIUM SAND · COARSE SAND · INTERVAL (Meters) · 0 · 50 · 100 · COLOR · DEFORMATION · BED THICKNESS · % SHELL · % ORGANICS · % BIOTURBATION · WAVY · FLASER · LENTICULAR · CROSS BED · MASSIVE BED · INCLINED BED · HORIZON LAMINATION · GRAIN SIZE · HEAVY MINERAL · MICRO FOSSILS · RADIOMETRIC · RADIOGRAPH · PHOTOGRAPH



(3)

50-55' section continued

1580-1635 - Gray - Dark gray massive appearing muds. Lens like detrital organics throughout. Also some root like organics.

55-60' section, 48 in rec., 1675-1797

1675-1690 - Gray massive mud. Large root/piece of wood 10 cm in length

1680-1703 Slightly deformed gray muds

1703-1710 Slightly deformed gry silt ↑ v.f. sand present

1710-1727 - Gray massive muds

1727-1732 Light gray v.f. sand

1732-1770 Massive graymuds. One yellow tan layer ≈ 4mm thick

1770-1797 Deformed laminated silts/mud gray - dark gray

60-65' sec., 51" recovered, 1828-1958

1828-1850 - Gray deformed mud w/ sand - layers may have been // cypress? root

1850-1870 - V. faintly laminated gray muds

1870-1900 - Laminated mud w/ mm scale v.f.s or silt lams shell @ 1872 - pretty broken up

1900-1910 v. faintly lam muds - gray
1910-1958 - Faintly laminated mud, mm scale v.f. sand lams organic piece @ 1928. yellow tan claycast @ 1920

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Vibracore Description Sheet

Core ID: 05BS02
Latitude: 3258149N 29°29.401
Longitude: 725303E 90°38.865
Date Vibracored: 7-26-05
Geographic Location: BAYOU CHAUVIN

Date Described: 5-31-06
Described By: NICK
Core Penetration:
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES: CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)

% SAND: 0, 50, 100

PHYSICAL CHARACTERISTICS: COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION

STRATIFICATION TYPE: WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION

SAMPLE: GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH

PHYSICAL DESCRIPTION

(4)

Interval (Meters): 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0

65-70' section - 31.5" recov. 1980 - 2060 cm - log on previous sheet

1980 - 2000 cm - Brownish v. faintly laminated mud, basal contact gradational

2000 - 2055 - v. faintly laminated slightly deformed gray-dark gray muds - organics(?) as black flecks - 2050 yellow tan layer

2055 - BTM Dark brown organic (?) rich mud. sampled

05COCO01 Borehole Description

Vibracore Description Sheet

science for a changing world

Core ID: 05COCO-01

Latitude:

Longitude :

Date Vibracored:

Geographic Location: South of LUMCON

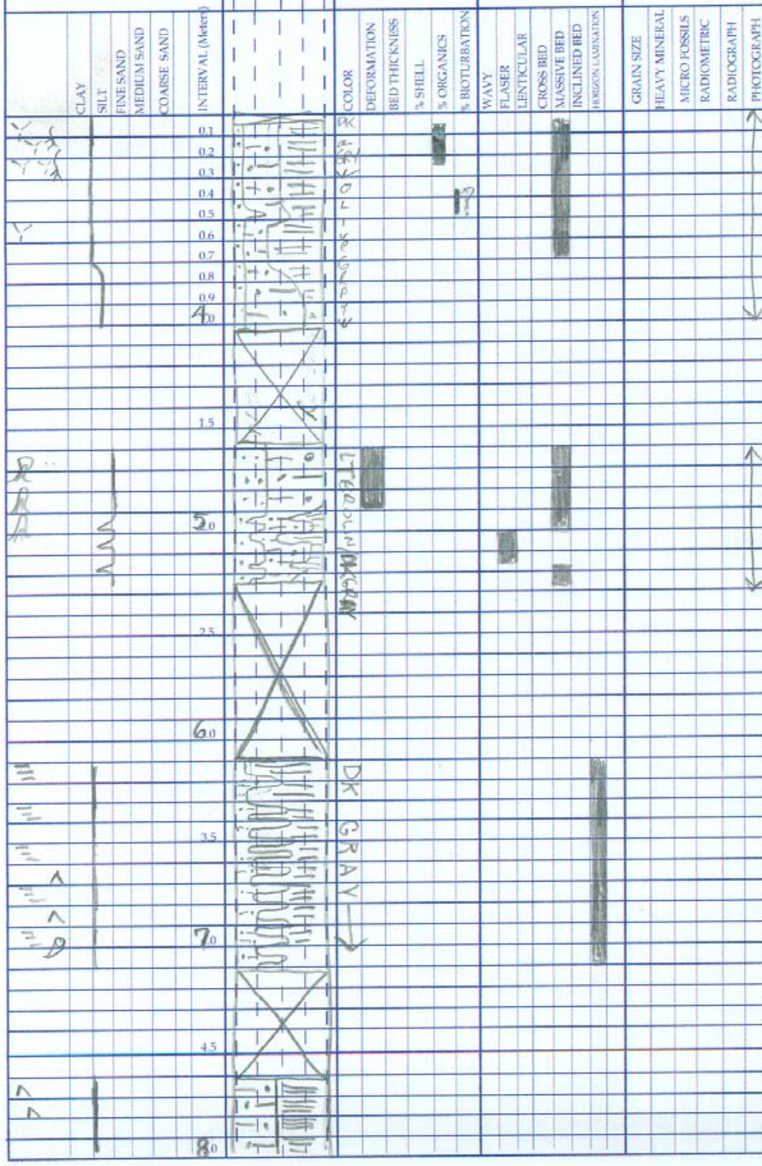
Date Described: 7-11-07

Described By:

Core Penetration:

Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	



0-10 FEET BYPASSED
0-3.05m Bypassed

PAGE 1

10-15' section
305cm - 327cm Dark greenish gray organic rich massive mud. Fibrous roots and one large one (6mm) @ 324cm

327-349 cm olive gray fining upward from silt to clay sequence w/ sharp basal contact! possibly bioturbated

349-404cm Light olive gray alternating lams of silts/mud fining up to massive appearing mud w/ organics @ 357 & 363cm

15-20' section - 64cm recovered

457-492 - Light brown deformed (massive appearing) silt/fine sand. dark gray clay @ 480cm

492-494 - Dark gray clay lam.

494-498 - Light brown silt

498-503 Dark gray faintly laminated mud sharp top & basal contact

503-513 Flaser bedding light brown silts dark gray mud

513-516 - Dk gray mud
516-519 Light brown silt/f sand

20-25' section - 102cm recovered (609.6cm-711cm)
609-711cm Dark gray mud w/ mm scale silt laminae throughout section Mud sections faintly laminated shell frag @ 687
Sand filled burrow 695 & 700

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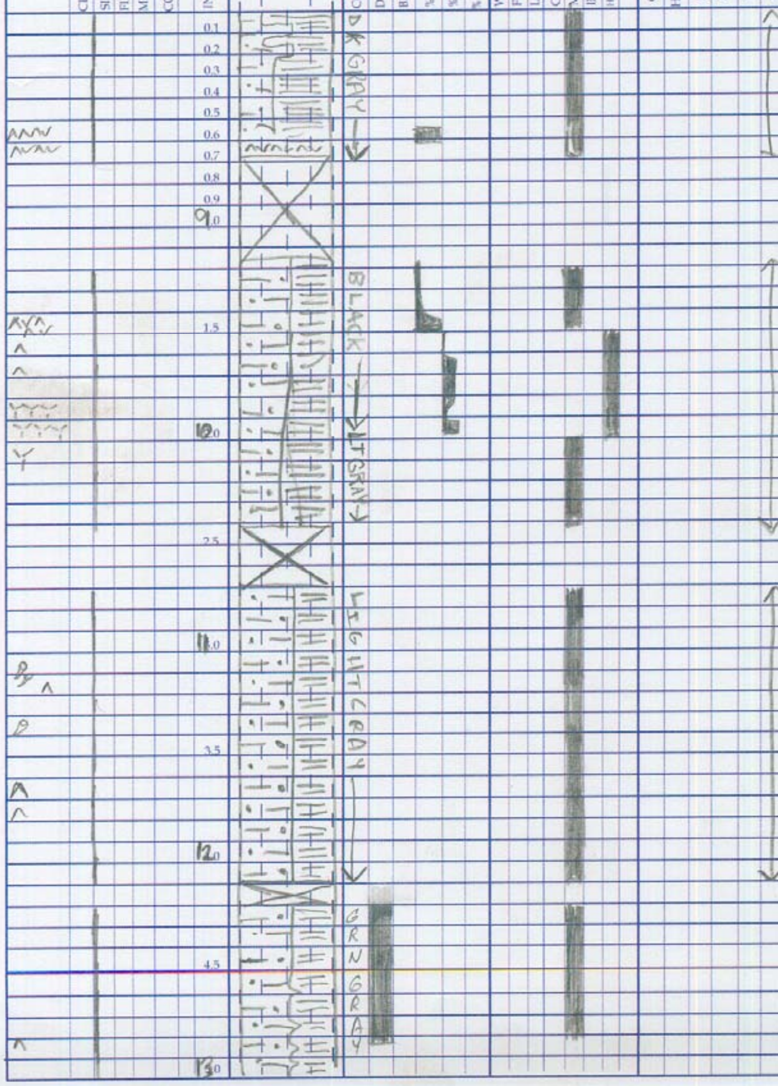
Vibracore Description Sheet

Core ID: OSCOCO 01
Latitude:
Longitude :
Date Vibracored:
Geographic Location:

Date Described: 7-11-07
Described By: NICK F
Core Penetration:
Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PAGE 2



25-30' section 96cm recovered (762-864cm recovered)
762-858 DArk gray massive Appearing muds. small shell @ 780cm burrow - 793, 806, mm scale silt lams @ 810, 814, 847 ← 2.5cm thick, Top 18cm of core has some iron staining

858-864 Must sed missing but mm scale shell fragments remain -

30-35' 126cm recovered

914-945 DArk gray black mASSIVE Appearing mud shell fragments from 920-936 then 936-945 oyster frag shell lag

945-998cm Dark gray - black massive to parallel laminated muds. organic rich seds. shell frags @ 950, 960, 967, 970
986-991cm peat
993-997cm organics - peaty basal pretty sharp

998-1042cm Light grayish massive Appearing muds

35-40' section - 144cm recovered

1066-1210 - Light gray - gray massive appearing muds. bioturbation 1130, 1140, shell frags 1130, 1135, 1148, 1167

40-45' section 127cm recovered

1219cm-1284cm Greenish gray deformed muds. Iron staining along void in sed basal contact @ end of iron stain

USGS science for a changing world

Vibracore Description Sheet

Core ID: 05COC001

Latitude:

Longitude :

Date Vibracored:

Geographic Location:

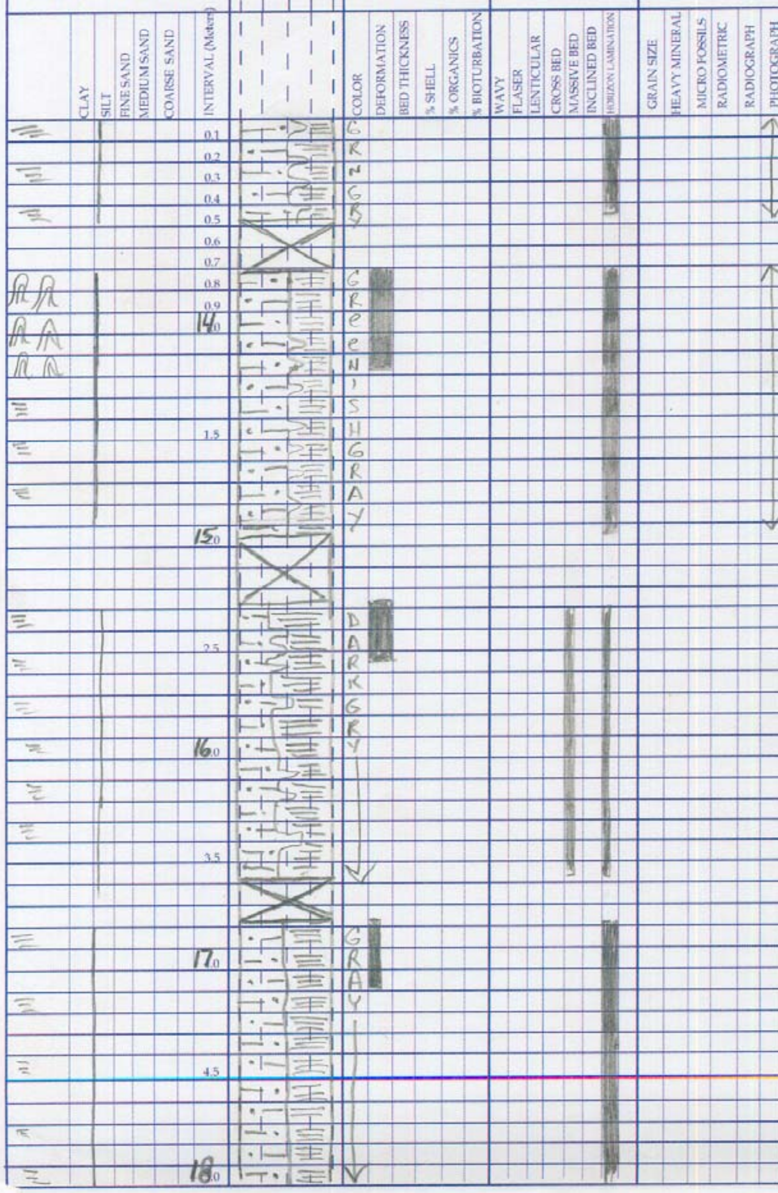
Date Described: 7-12-7

Described By: NICK

Core Penetration:

Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARAC-TERISTICS	STRATI-FICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION



PAGE 3

40-45' section continued
1284-1346 - Greenish gray faintly laminated mud. Possible burrows 1310, 1333 increase in silt lams all mm in scale

45-50' section 125cm recovered
1371-1419cm Greenish gray deformed muds. Burrows(?) @ 1398. From 1410-1419cm silt/fine sand lams light brown in color

1419-1495 Greenish gray laminated mud w/ mm scaled light grayish silt/f sand lams

50-55' section 134cm recovered
CORE SECTION DRIED OUT SOME
1524-1550 DARK gray MASSIVE appearing muds w/ deformation and brownish gray silt lams

1550-1655 DARK gray MASSIVE to very faintly laminated muds w/ brownish silt fine sand lams throughout

55-60 section 139cm recovered

1676-1720 Gray very faintly laminated muds silt laminations deformed, some rust color oxdized seds (from storage?)

1720-1813 Gray very faintly laminated muds w/ occlassional mm thick silts. A few light olive gray sections within unit

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Vibracore Description Sheet

Core ID: OSCOCO 01

Latitude:

Longitude :

Date Vibracored:

Geographic Location:

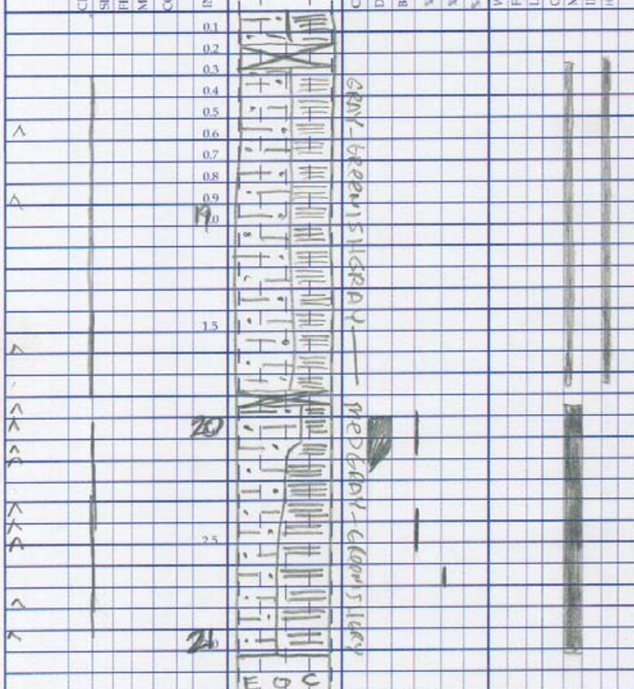
Date Described: 7-12-07

Described By: NICK

Core Penetration:

Core Length:

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PG (4)



60-65' section 150cm recovered

1828-1979cm – GRAY – GREENISH GRAY massive/ very faintly laminated mud. MM scale silt lam 1860, 1875, 1878, 1928 mm shell frag 1896, 1937, 1959

65-70' section 128cm recovered

1981-2010 Medium GRAY deformed clay w/ massive f.sand w/ cm scale shell fragments looks like oyster and bivalve pieces

2010-2050 Medium gray massive appearing mud w/ mm scale bivalve pieces gradual basal transition

2050-2108- Same as above but color darker gray and possible root 2070 cm

04BS01 Borehole Description

USGS — science for a changing world

Vibracore Description Sheet

Core ID: 04BS01 AUGER CORE

Latitude: 29° 19' 03.1

Longitude: 90° 40' 57.3

Date Vibracored: 7/21/04

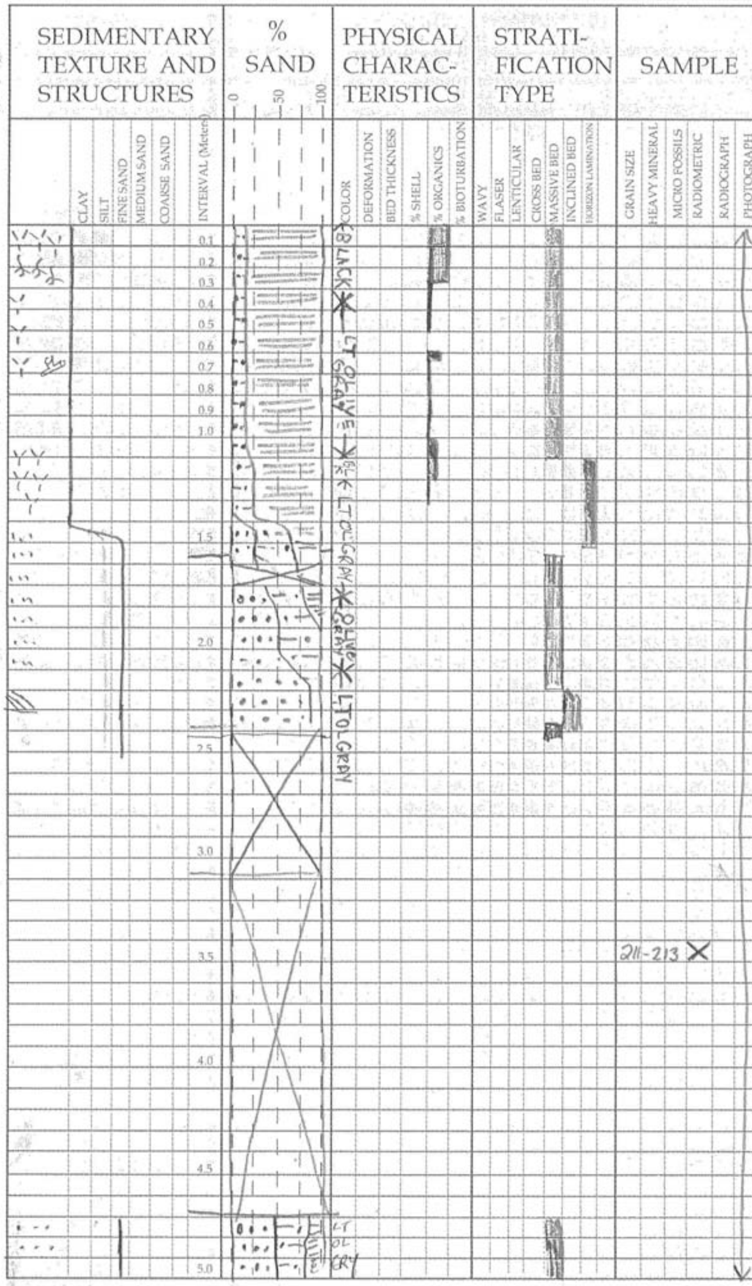
Geographic Location: BAYOU Sale Area in between Bayou Sale & GRASSY BAY NNW of Cocodries

Date Described: 6-9-05

Described By: NICK

Core Penetration: 70 ft

Core Length: 70 ft



PHYSICAL DESCRIPTION

H_2O depth 3.5 ft

PAGE (1)

C-14 SAMPLES 211-213cm, 659cm, 710-715, 822-825cm, 1652, 1652-1654

0-10' section 60" recovered
0-153 cm

0-36cm Black organic rich mud. Root mass (fibrous mm scale) from 15-26cm. drag down along side of core barrel of organic mud to 53cm

36cm-113cm - Light olive gray (5Y 5/2) mud some brown root balls @ 57cm, 63cm, 85, 101cm wood fragment 67-70cm. possibly faintly laminated. other organic's present (black mud) in sub-mm scale @ 73 & 88cm.

113-120cm - Black organic mud possibly fibrous roots.

120-136cm Lt Olive gray (≈25% organics) muds. very faintly laminated

136-153cm Lt olive gray laminated mud & v. fine sands. some coffee grounds @ base.

10-15' section 35" recovered
88 cm recovered
153-163 empty barrel
163-211 Olive gray massive appearing silty sand

211-216c Rafted organics large pieces ≈ 1cm in length

216-241 Light olive gray sands inclined bedding, cross beds(?) 216-230, 230-241 deformed (channel, channel fill?)

15-20 not collected

20-25' section
470-485cm - Lt olive gray massive appearing fine sand

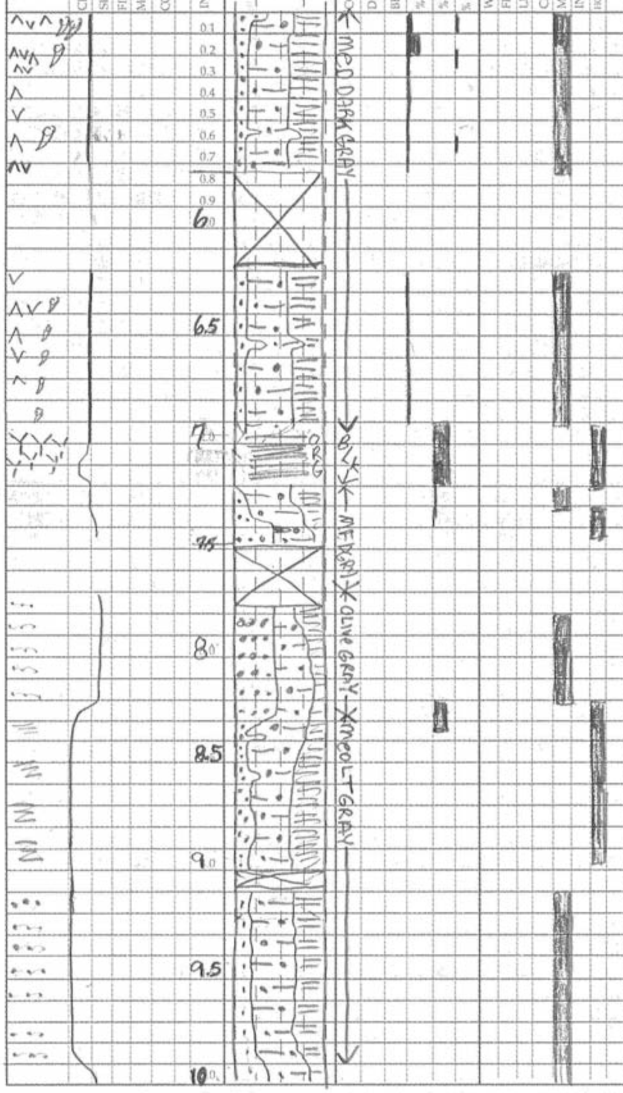
USGS science for a changing world

Vibracore Description Sheet

Core ID: 04BS01
Latitude: 29°19' 03.1
Longitude: 90°40'57.3
Date Vibracored: 7/21/04
Geographic Location: Bayou Sale Area, b/w Bayou Sale & Grassy Bay near Hwy 56

Date Described: 6-9-05
Described By: NICK
Core Penetration: 70 ft
Core Length: 70 ft

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PAGE (2)



PAGE (2)

20-25' section 41" recovered (470-574cm) - continued

485-574cm Medium dark gray massive appearing muds. Shell fragments random through section. Concentration 510-513 possible burrows where noted.

25-30 section 50" rec. 127cm rec. 622-749cm

622-698cm Medium dark gray massive appearing muds. shell fragments randomly through section (section similar to above) - 660 cm oyster piece in sandier section
possible bioturbation where noted.
- section could be faintly laminated
sharp basal contact

698-718cm Slightly laminated organic rich ≈70% sediment basal contact grades into section similar to above

718-730cm Massive appearing medium gray muds organics clasters to 722cm basal sharp

730-749 Light gray sandier unit possibly laminated

30-35' section 53.5" rec
749-885cm
749-820 Medium light gray hydrous massive silty sands.

820-827 Organic rich clay ≈50%
827-885 Medium light gray faintly laminated muds, two tan lams, some silt stringers

35-40ft 60" recovered 901-1054

901-1000cm Massive appearing medium lt gray muds

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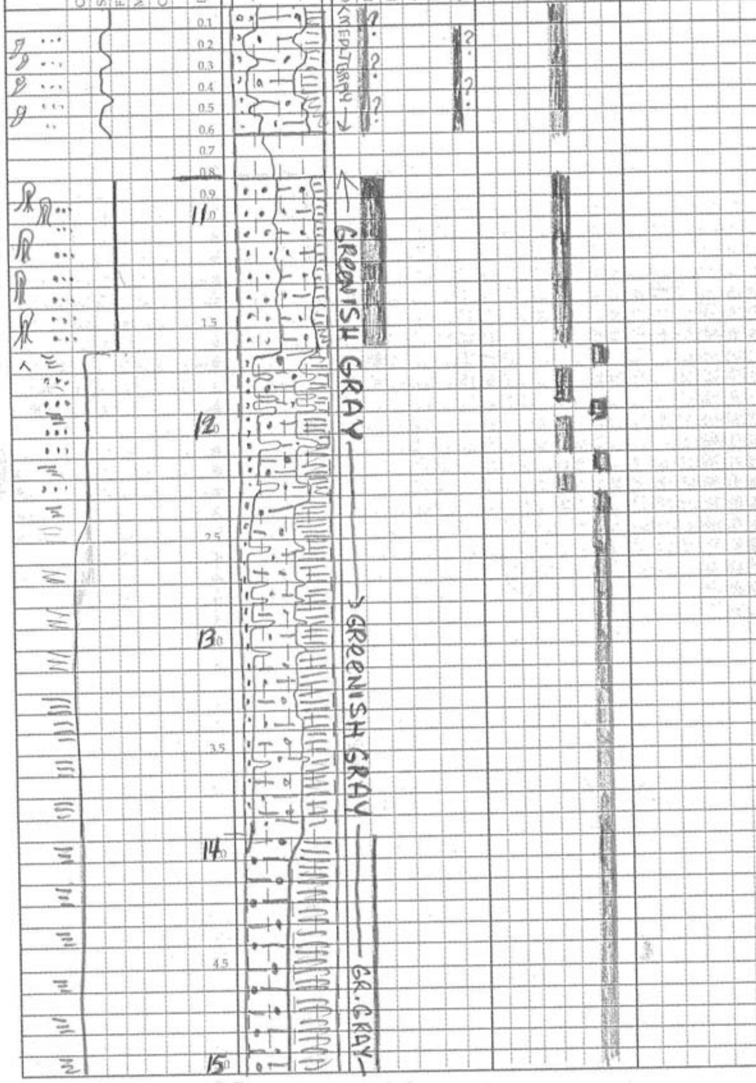
Vibracore Description Sheet

Core ID: 04BS01
Latitude: 29°19' 03.1
Longitude: 90°40'57.3
Date Vibracored: 7/21/04
Geographic Location: Bayou Sale and Grassy Bay near Hwy 56 NNW Cocodrie

Date Described: 6-9-05
Described By: NICR
Core Penetration: 70ft
Core Length: 70ft

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PAGE 3



35-40' section 901-1054
1000-1054 - medium light gray muds w/ brownish silt/sand filled burrows? possibly deformed lams

40-45' section 60" rec. (full)
1080-1233cm
1080-1160 Deformed greenish gray (5GY 6/1) silty sand: hydrous. & deformed tan clay rich areas sharp basal

1160-1233cm Massive appearing (?) greenish gray muds interspersed w/ mm scale v. f. sand/silt massive appearing laminations overall section massive, stiff tan lam @ 1260cm

45-50' section 60" rec.
1233cm-1386cm - Very faintly laminated (massive?) greenish gray muds interspersed w/ mm scale silt vf sands (see above section) stiff

50-55' 60" recovered
1386-1538cm
Same as above section, some faint lams show drag near core barrel (stiff)

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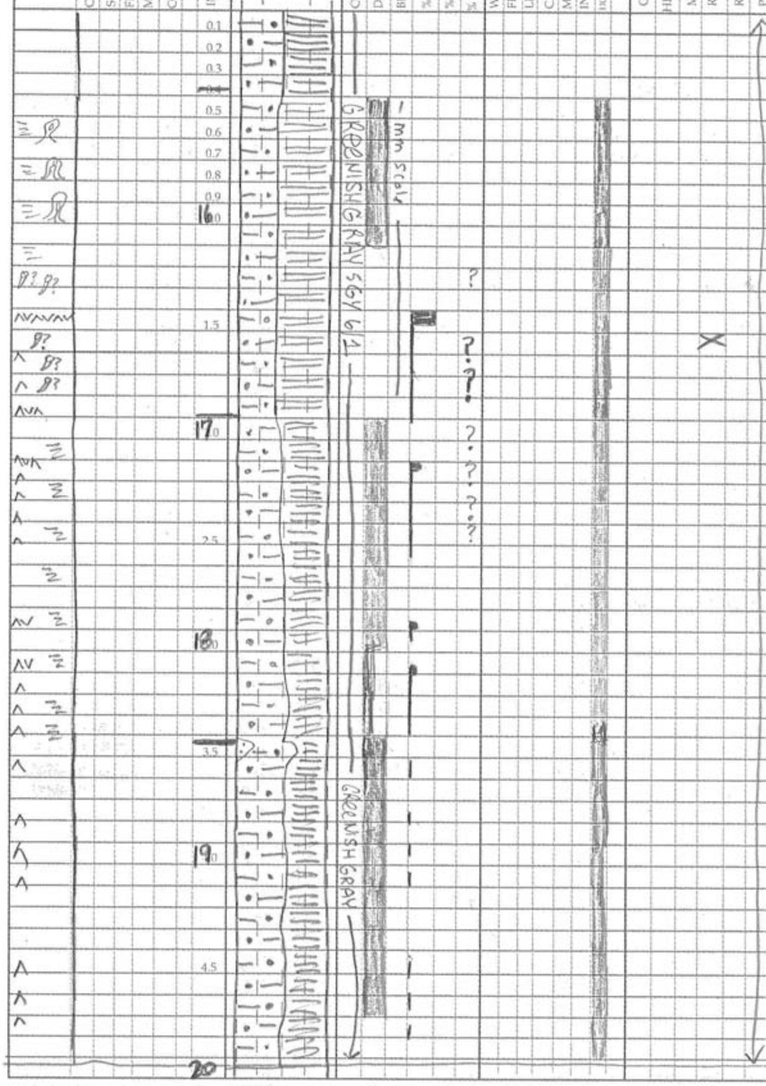
Vibracore Description Sheet

Core ID: 04BS01
Latitude: 29° 19' 03.1
Longitude: 90° 40' 57.3
Date Vibracored: 7/20/04
Geographic Location: Bayou Sale - Grassy Bay near Hwy 56 NNW of Coco.

Date Described: 6-10-05
Described By: NICR
Core Penetration: 70 ft
Core Length: 70 ft

SEDIMENTARY TEXTURE AND STRUCTURES	% SAND	PHYSICAL CHARACTERISTICS	STRATIFICATION TYPE	SAMPLE	PHYSICAL DESCRIPTION
CLAY, SILT, FINE SAND, MEDIUM SAND, COARSE SAND, INTERVAL (Meters)	0, 50, 100	COLOR, DEFORMATION, BED THICKNESS, % SHELL, % ORGANICS, % BIOTURBATION	WAVY, FLASER, LENTICULAR, CROSS BED, MASSIVE BED, INCLINED BED, HORIZON LAMINATION	GRAIN SIZE, HEAVY MINERAL, MICRO FOSSILS, RADIOMETRIC, RADIOGRAPH, PHOTOGRAPH	PAGE 4



PAGE 4

55-60' section 60" recovery (full)
1538-1690cm - Greenish gray (5GY 6/1) muds, deformed (from auger) parallel lams 1538-1600cm. Possible sand/silt filled burrows
1630 - stiff
- shell lag 1652-1654cm = look marine
bioturbation(?) 1654-1690cm
- // lams very faint

60-65' section 60" rec. 1690-1842

1690-1800 Greenish gray deformed once laminated muds(?) some oxidation thru section, heavy ox. from 1720-1750 bioturbation related? small shell pieces scattered through section
- stiff

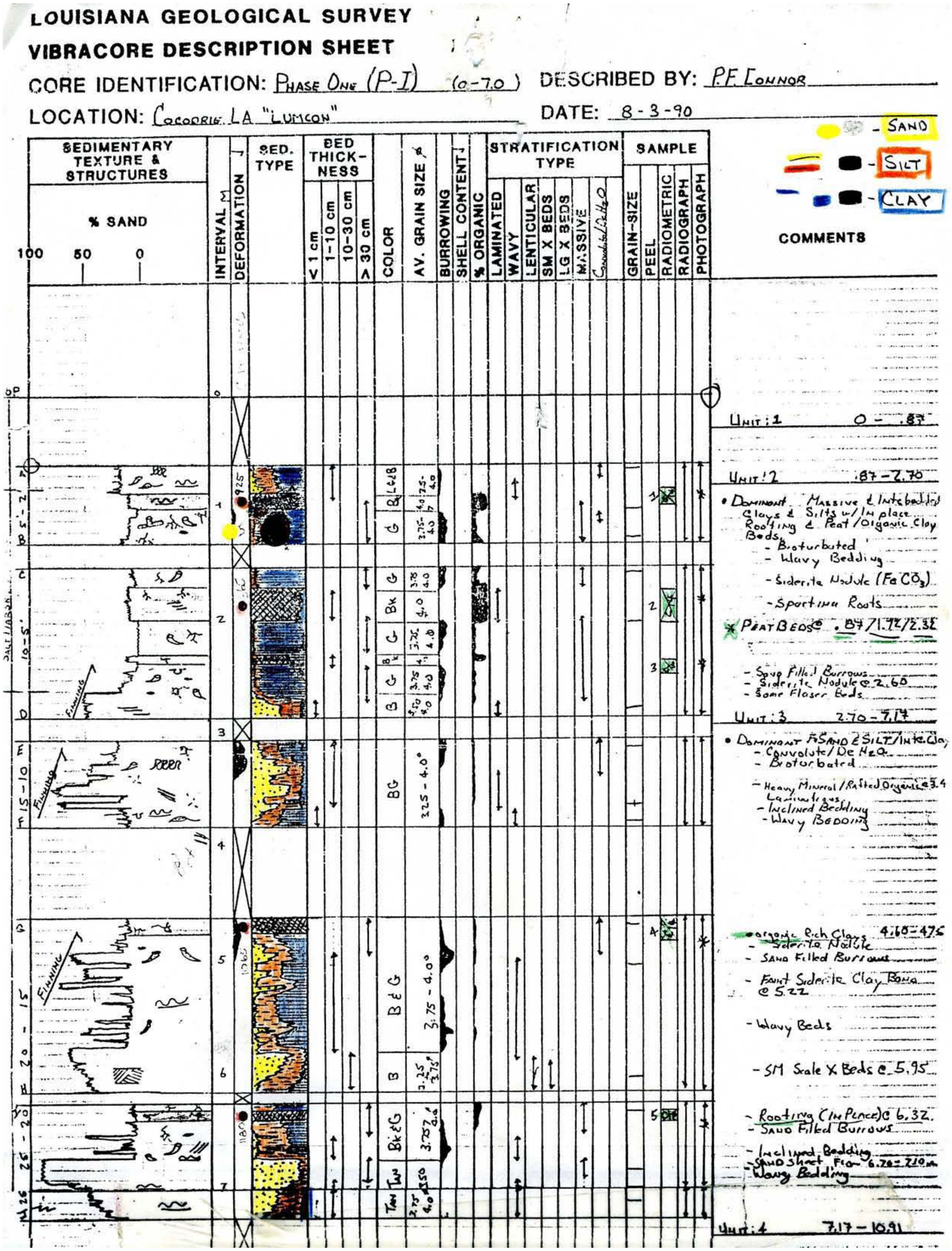
1800-1842 same as above, no oxidation though and less deformed
- stiff

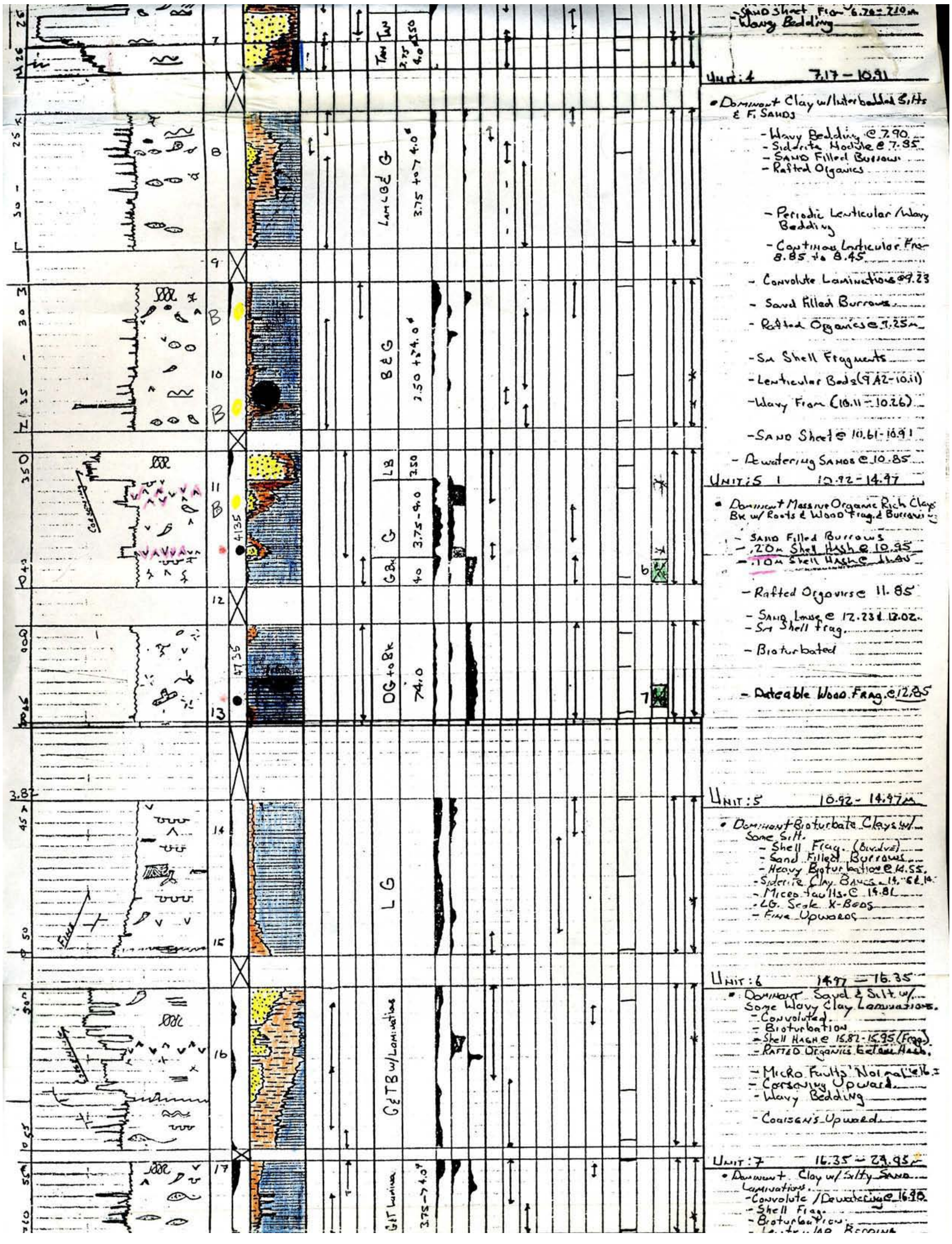
65-70' 60" rec. 1842-1995cm

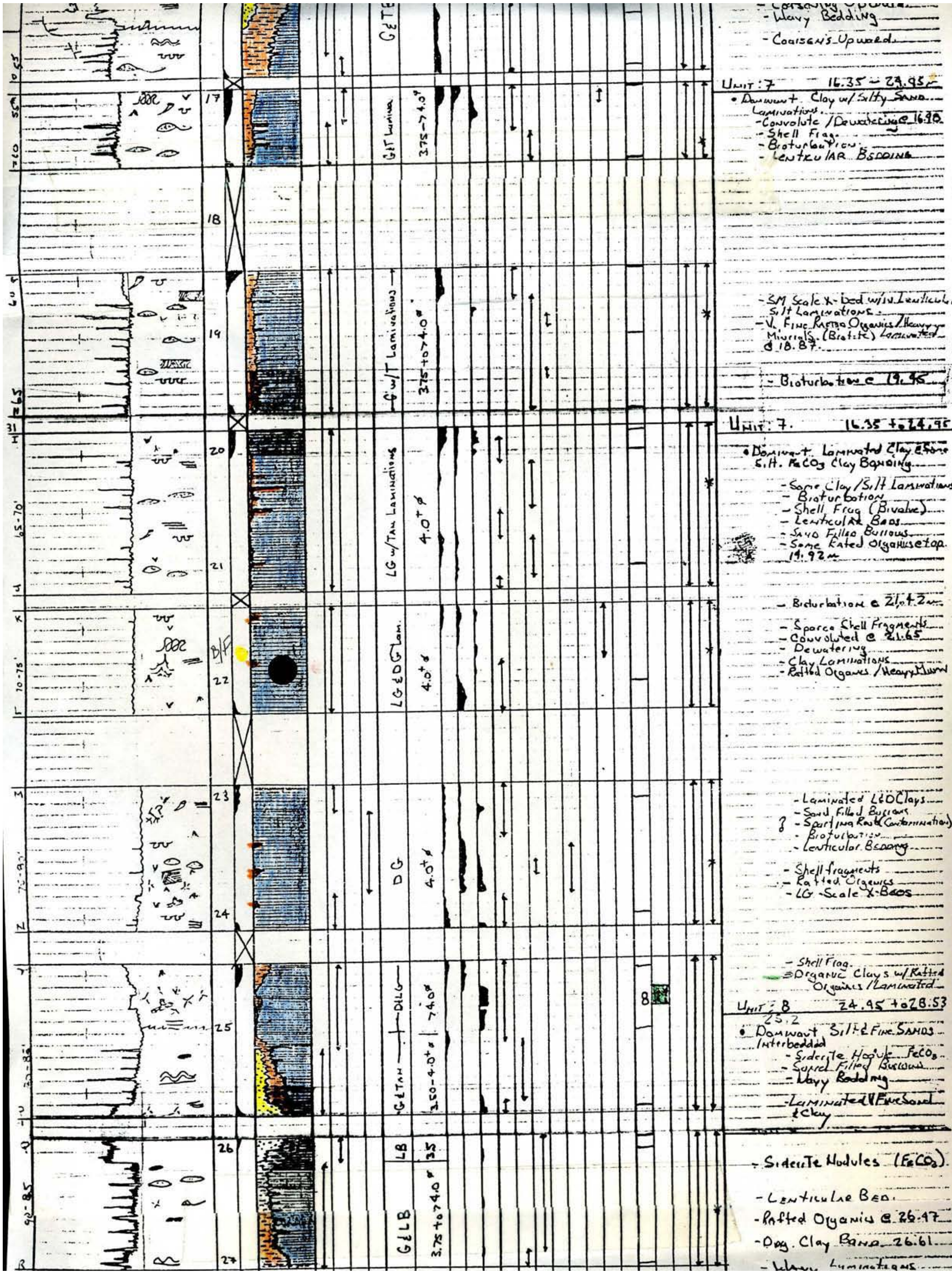
1842-1976cm greenish gray stiff mud, deformation present, once faint lams deformed, shell frags where noted

1976-BTM same as above but no deformation, very faint lams present

P-I-90 Borehole Description




-Sand Sheet From 6.70-7.10m
-Wavy Bedding
Unit: 4 7.17 – 10.91
• Dominant Clay w/Interbedded Silts & F. Sands
- Wavy Bedding @ 7.90
- Siderite Nodule @ 7.85
- Sand Filled Burrows
- Rafted Organics
- Periodic Lenticular / Wavy Bedding
- Continuous Lenticular From 8.85 to 8.45
- Convolute Laminations @ 9.23
- Sand Filled Burrows
- Rafted Organics @ 9.25m
- Sm Shell Fragments
- Lenticular Beds (9.42-10.11)
- Wavy From (10.11 - 10.26)
- Sand Sheet @ 10.61-10.91
- Dewatering Sands @ 10.85
Unit: 5 10.92 - 14.97
• Dominant Massive Organic Rich Clays Bk w/ Roots & Wood Frag. & Burrows
- Sand Filled Burrows
- .20m Shell Hash @ 10.95
- Rafted Organics @ 11.85
- Sm Shell Frag.
- Bioturbated
- Dateable Wood Frag. @ 12.85
Unit: 5 10.92 - 14.97m
• Dominant Bioturbate Clays w/ Some Silt.
- Shell Frag. (Bivalve)
- Sand Filled Burrows
- Heavy Bioturbation @ 14.55
- Micro faults @ 14.81
- LG. Scale X-Beds
- Fine Upwards
Unit: 6 14.97 – 16.35
• Dominant Sand & Silt w/ Some Wavy Clay Laminations.
- Convoluted
- Bioturbation
- Shell Hash @ 15.82-15.95 (Frag.)
- Micro Faults Normal
- Coarsening Upward
- Wavy Bedding
- Coarsening Upward
Unit: 7 16.35 – 29.95
• Dominant Clay w/ Silty Sand Laminations.
- Convolute / Dewatering @ 16.90
- Shell Frag.
- Bioturbation
LG
G&TB w/Laminations
DG to Bk
B&G


- Wavy Bedding
- Coarsens Upward
Unit: 7 16.35 – 24.95
• Dominant Clay w/ Silty Sand Laminations
- Shell Frag.
- Bioturbation
- Lenticular Bedding
- Bioturbation @ 19.95
Unit: 7. 16.35 to 24.95
- Some Clay / Silt Laminations
- Bioturbation
- Shell Frag (Bivalve)
- Lenticular Beds
- Sand Filled Burrows
- Sparse Shell Fragments
- Convoluted @ 21.65
- Dewatering
- Clay Laminations
- Laminated LGD Clays
- Sand Filled Burrows
- Lenticular Bedding
- Shell fragments
- Rafted Organics
- LG Scale X-Beds
- Shell Frag.
Unit: 8 24.95 to 28.53
• Dominant Silt & Fine Sands Interbedded
- Wavy Bedding
- Siderite Nodules (FeCO3).
- Lenticular Bed.
- Rafted Organics @ 26.47
- Org. Clay Band 26.61
17
18
19
20
21
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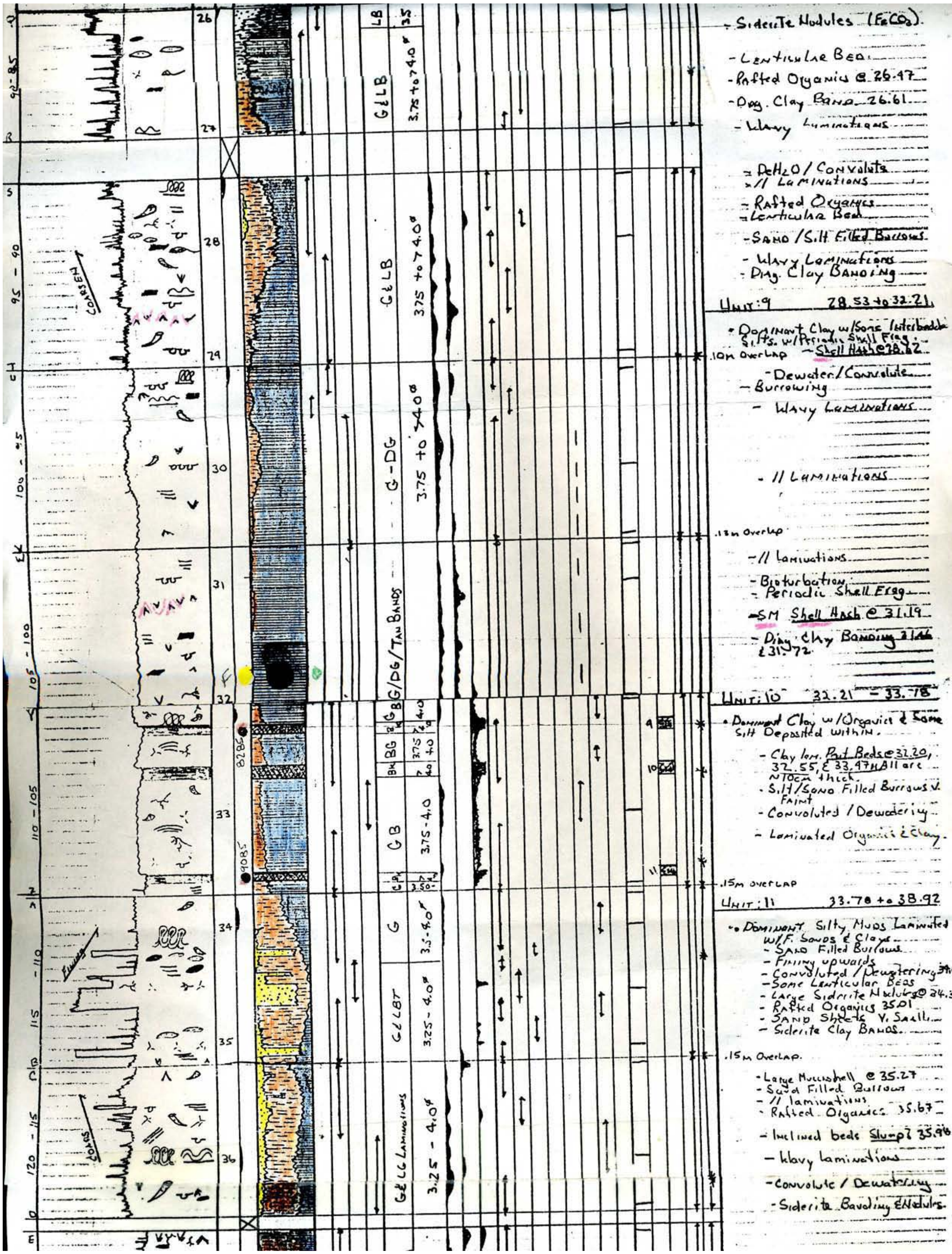
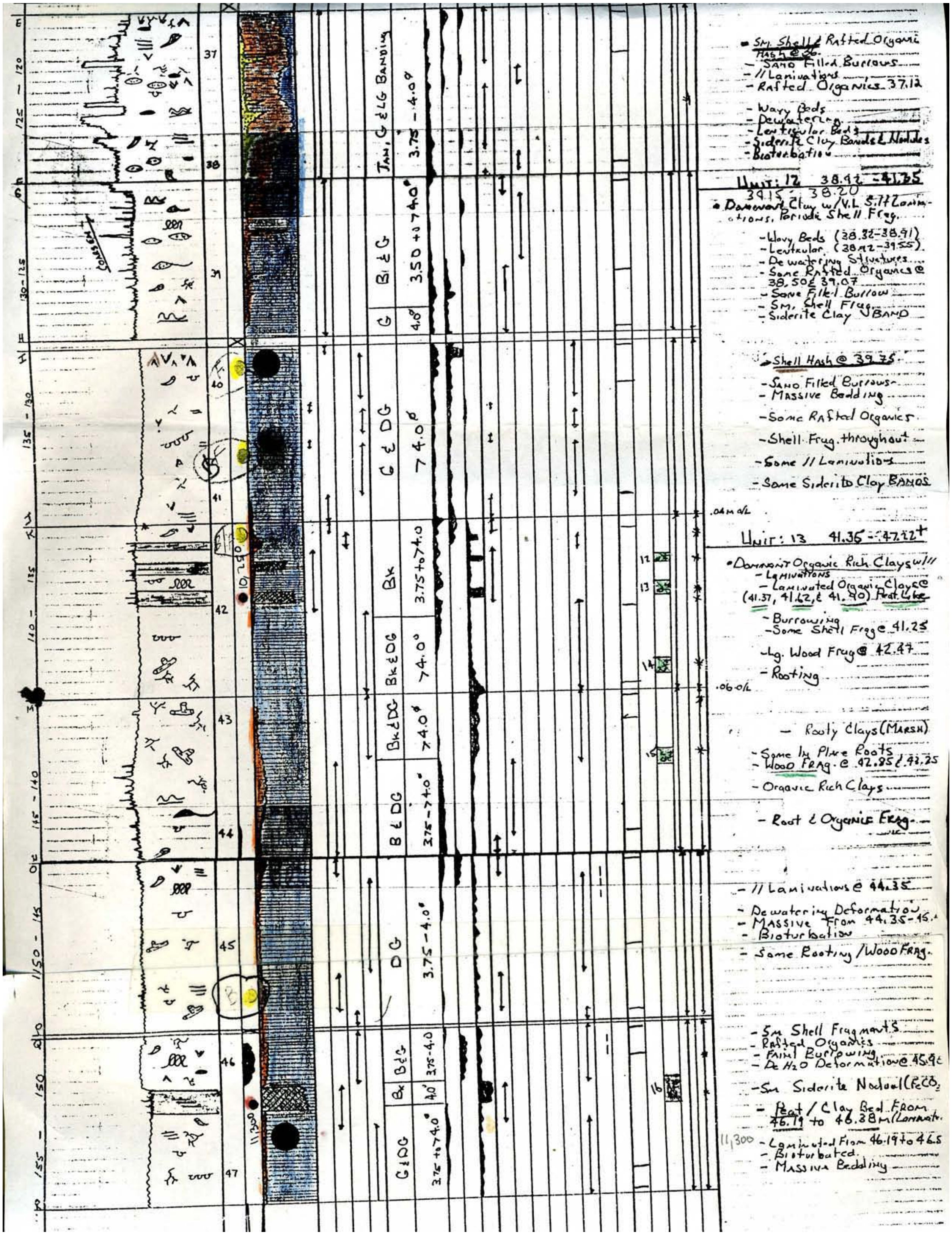
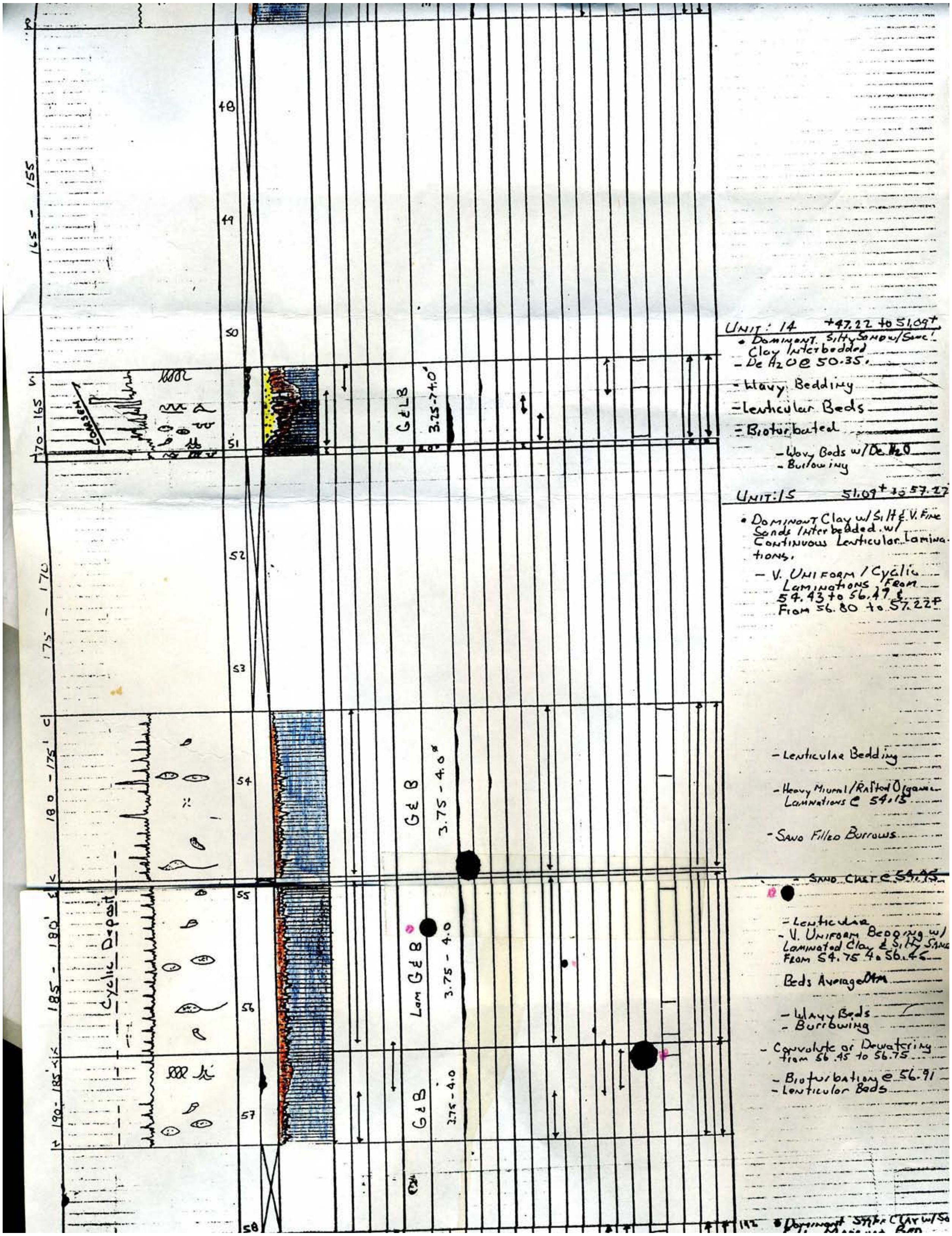
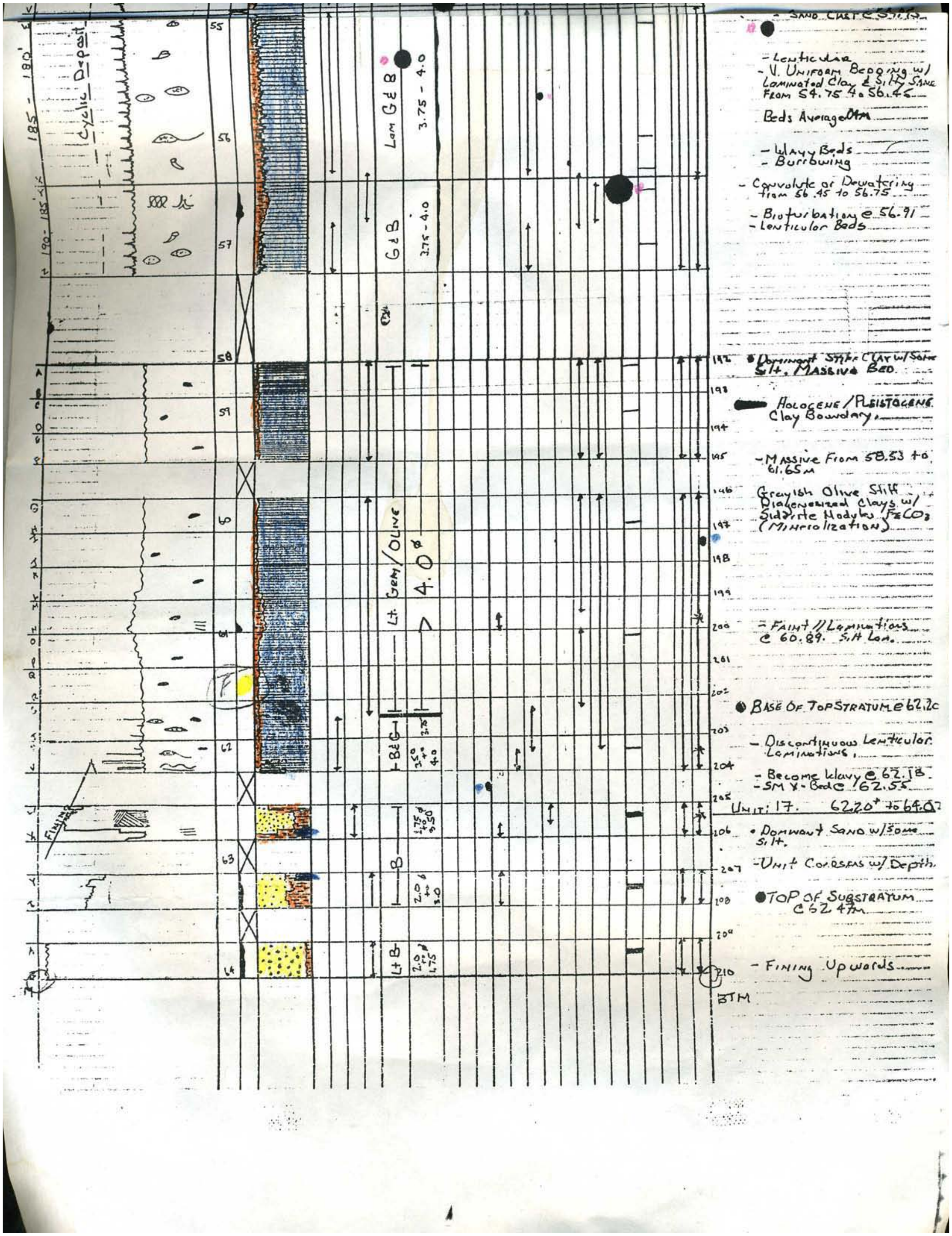
23
24
25
26
27
DG
4.0+ø


- Siderite Nodules (FeCO3).
- Lenticular Bed
- Rafted Organics @ 26.47
- Diag. Clay Band 26.61
- Wavy Laminations
- DeH2O / Convolute
- // Laminations
- Rafted Organics
- Lenticular Bed
- Sand / Silt Filled Burrows
- Wavy Laminations
- Diag. Clay Banding
Unit: 9 28.53 to 32.21
• Dominant Clay w/Some Interbedded Silts. w/Periodic Shell Frag.
.10m Overlap
- Shell Hash @ 28.62
- Dewater / Convolute
- Burrowing
- Wavy Laminations
- // Laminations
.13m Overlap
- // Laminations
- Bioturbation
- Periodic Shell Frag.
- SM Shell Hash @ 31.19
- Diag. Clay Banding 31.46 & 31.72
Unit: 10 32.21 - 33.78
• Dominant Clay w/Organics & Some Silt Deposited within.
- Clay lam. Part Beds @ 32.20, 32.55, & 33.47 All are ~10cm thick.
- Silt/Sand Filled Burrows V. Faint
- Convoluted / Dewatering
- Laminated Organics & Clay.
.15m Overlap
Unit: 11 33.78 to 38.92
• Dominant Silty Muds Laminated w/F. Sands & Clays
- Sand Filled Burrows
- Fining upwards
- Convoluted / Dewatering
- Some Lenticular Beds
- Large Siderite Nodules @ 34.3
- Rafted Organics 35.01
- Sand Sheets V. Small
- Siderite Clay Bands.
.15m Overlap.
- Large Mussel shell @ 35.27
- Sand Filled Burrows
- // laminations
- Rafted Organics 35.67
- Inclined beds Slump? 35.96
- Wavy laminations
- Convolute / Dewatering
- Siderite Banding & Nodules.
26
27
28
29
30
31
32
33
34
35
36
G&LB
3.75 to 4.0
G&LB
3.75 to 4.0
G-DG
3.75 to 4.0
G B
3.75-4.0
G
3.5-4.0
G&LGT
3.25-4.0
G&LG Laminations
3.25 - 4.0
Coarsen
Fining
Coarse



• Sm. Shell & Rafted Organic Hash @ 36.
- Sand Filled Burrows
- // Laminations
- Rafted Organics 37.12
- Wavy Beds
- Dewatering
- Lenticular Beds
- Siderite Clay Bands & Nodules
- Bioturbation
Unit: 12 38.92 - 41.35
39.15 : 38.20
• Dominant Clay w/ V.L. S.H Laminations, Periodic Shell Frag.
- Wavy Beds (38.32-38.91)
- Lenticular (38.92-39.55)
- Dewatering Structures
- Some Rafted Organics @ 38.50 & 39.07
- Some Filled Burrow
- Sm. Shell Frag.
- Siderite Clay Band
Shell Hash @ 39.75
- Sand Filled Burrows
- Massive Bedding
- Some Rafted Organics
- Shell Frag. throughout
- Some // Laminations
- Some Siderite Clay Bands
.04 m o/L
Unit: 13 41.35 - 47.22+
• Dominant Organic Rich Clays w/ //
- Laminations
- Laminated Organic Clays @ (41.37, 41.62, & 41.90) Peat Like
- Burrowing
- Some Shell Frag @ 41.25
- Lg. Wood Frag @ 42.47
- Rooting
.06 o/L
- Rooty Clays (Marsh)
- Some In Place Roots
- Wood Frag. @ 42.85 & 43.25
- Organic Rich Clays
- Root & Organic Frag.
- // Laminations @ 44.35
- Dewatering Deformation
- Massive From 44.35-45.
- Bioturbation
- Some Rooting / Wood Frag.
- Sm Shell Fragments
- Rafted Organics
- Faint Burrowing
- De H_2O Deformation @ 45.9
- Sm Siderite Nodual ($FeCO_3$)
- Peat / Clay Bed From 46.19 to 46.38 m (Laminated)
11,300
- Laminated From 46.19 to 46.5
- Bioturbated
- Massive Bedding
37
38
39
40
41
42
43
44
45
46
47
Jam, G & LG Banding
3.75 - 4.0
B & G
3.50 to 74.0
G
4.0
C & DG
74.0
Bk
3.75 to 74.0
Bk & DG
74.0
Bk & DG
74.0
B & DG
3.75 - 74.0
DG
3.75 - 4.0
Bk
B & G
3.75-4.0
G & DG
3.75 to 74.0


165 - 155
170 - 165
175 - 170
180 - 175
185 - 180
190 - 185
Cyclic Deposit
48
49
50
51
52
53
54
55
56
57
58
G&LB
3.25-4.0
G&B
3.75 - 4.0
Lam G&B
3.75 - 4.0
G&B
3.75 - 4.0
UNIT: 14 +47.22 to 51.09+
• Dominant. Silty Sand w/ Sand Clay Interbedded
- De H_2O @ 50.35.
- Wavy Bedding
- Lenticular Beds
- Bioturbated
- Wavy Beds w/ De H_2O
- Burrowing
UNIT: 15 51.09+ to 57.22
• Dominant Clay w/ Silt & V. Fine Sands Interbedded w/ Continuous Lenticular Laminations.
- V. Uniform / Cyclic Laminations From 54.43 to 56.47 & From 56.80 to 57.22
- Lenticular Bedding
- Heavy Mineral/Rafted Organic Laminations @ 54.15
- Sand Filled Burrows
- Sand Chert @ 54.95
- Lenticular
- V. Uniform Bedding w/ Laminated Clay & Silty Sand From 54.75 to 56.45
Beds Average
- Wavy Beds
- Burrowing
- Convolute or Dewatering from 56.45 to 56.75
- Bioturbation @ 56.91
- Lenticular Beds


185' - 180'
Cyclic Deposit
190' - 185'
Lam G & B
3.75 - 4.0
G & B
3.75 - 4.0
Lt. Gray/Olive
4.0
Fining
- Lenticular
- V. Uniform Bedding w/ Laminated Clay & Silty Sand From 54.75 to 56.45
Beds Average 0.1m
- Wavy Beds
- Burrowing
- Convolute or Dewatering from 56.45 to 56.75
- Bioturbation @ 56.91
- Lenticular Beds
Dominant Stiff Clay w/ Some Silt. Massive Bed.
Holocene/Pleistocene Clay Boundary.
- Massive From 58.33 to 61.65m
Grayish Olive Stiff Diagenesized Clays w/ Siderite Nodules FeCO3 (Mineralization)
- Faint // Laminations @ 60.89. Silt Lam.
Base Of Topstratum @ 62.2c
- Discontinuous Lenticular Laminations.
- Become Wavy @ 62.18.
- SM X-Bed @ 62.55
Unit: 17. 62.20 to 64.07
• Dominant Sand w/ Some Silt.
- Unit Coarsens w/ Depth.
TOP OF SUBSTRATUM @ 62.47m
- Fining Upwards
BTM

VITA

The author was born in Wichita, Kansas. He obtained his Bachelor's degree in geology from Kansas State University in 2007. He joined the University of New Orleans Earth and Environment Science department as a graduate student to pursue a M.S. in stratigraphy and became a member of Professor Mark Kulp's research group in 2007.