Journal of Coastal Research	11	4	1026–1036	Fort Lauderdale, Florida	Fall 1995

East Louisiana Continental Shelf Sediments: A Product of Delta Reworking

Gregg R. Brooks[1], Jack L. Kindinger[2], Shea Penland[3], S. Jeffress Williams[4] and Randolph A. McBride[3]

[1]Marine Science Department
Eckerd College
St. Petersburg, FL 33711, U.S.A.

[2]U.S. Geological Survey
St. Petersburg, FL 33711, U.S.A.

[3]Louisiana State University
Coastal Studies Institute
Baton Rouge, LA 70803, U.S.A.

[4]U.S. Geological Survey
Reston, VA 22902, U.S.A.

ABSTRACT

BROOKS, G.R.; KINDINGER, J.L.; PENLAND, S.; WILLIAMS, S.J., and McBRIDE, R.A., 1995. East Louisiana continental shelf sediments: a product of delta reworking. *Journal of Coastal Research,* 11(4), 1026–1036. Fort Lauderdale (Florida). ISSN 0749-0208.

Data from 77 vibracores were integrated with 6,700 line-km of high-resolution seismic reflection profiles collected off the eastern Louisiana coast in the region of the St. Bernard Delta, the first of the Holocene highstand deltas of the Mississippi River. Seismic facies and sediment facies were integrated in order to establish the stratigraphic details within this relict delta. Results provide a regional geologic framework from which comparisons can be made with other areas. Holocene deposits in the study area overlie a heavily dissected surface interpreted to represent a lowstand erosional surface. Resting on this surface is a thin unit of relatively clean, quartz sand interpreted to have been deposited during early transgression. This unit is overlain by sediments of the St. Bernard Delta, a seaward-prograding, coarsening-upward wedge of sands and muds that contain vertically-stacked units of deltaic succession. Two or more prograding units separated by an unconformity, delineated from regional seismic profiles, may represent laterally shifting subdelta lobes. Surficial sediments consist of a thin unit of sands and muds derived from and reflecting the individual subenvirons of the underlying delta. Holocene inner-shelf development off eastern Louisiana has been controlled by relative sea-level rise and sediment supply. Sediment supply and deposition are a product of delta progradation and delta-lobe switching. The modern shelf configuration and surficial sediment distribution patterns reflect reworking of underlying deltaic deposits. The lack of modern sediment input helps to maintain the imprint of this ancient delta on the modern shelf surface.

ADDITIONAL INDEX WORDS: *Deltaic sedimentation, shelf development, Mississippi River delta, and nearshore processes.*

INTRODUCTION

The northeast Louisiana continental shelf (Figure 1) is the site of the St. Bernard Delta complex, the earliest of the Holocene sea-level highstand deltas that was active about 4.6 to 1.8 ka (FRAZIER, 1967; BOYD *et al.,* 1989). Most research on this part of the continental margin has concentrated on the Chandeleur Islands where development has progressed by transgressive submergence. Predictions suggest that the islands will eventually become sand shoals as a result of the depletion of barrier sand sources (SUTER *et al.,* 1988). Based upon high-resolution, seismic-reflection data, the open shelf is interpreted to have evolved in five stages since the early Wisconsinan (KINDINGER, 1988; KINDINGER *et al.,* 1989). Stage 1 was characterized by erosion of the shelf surface during the early Wisconsinan sea-level lowstand. Stage 2 consisted of the deposition of a thin transgressive unit during the mid Wisconsinan sea-level rise. Stage 3, taking place during the late Wisconsinan sea-level fall, consisted of fluvial channelization across the shelf and deposition of a shelf-margin delta and a contemporaneous upper-slope sediment wedge. Stage 4 entailed the deposition of a thin transgressive sediment package over the shelf during the Holocene sea-level rise. Stage 5 included the last major depositional episode on the shelf, which was the progradation of the St. Bernard Delta complex.

This paper examines the late Holocene development of the study area by integrating seismic and sediment facies, including those within the St. Bernard Delta complex, which may not be resolved using conventional seismic reflection techniques exclusively. Finally, development of the modern shelf surface is examined.

94023 received 1 March 1994; accepted in revision 10 September 1994.

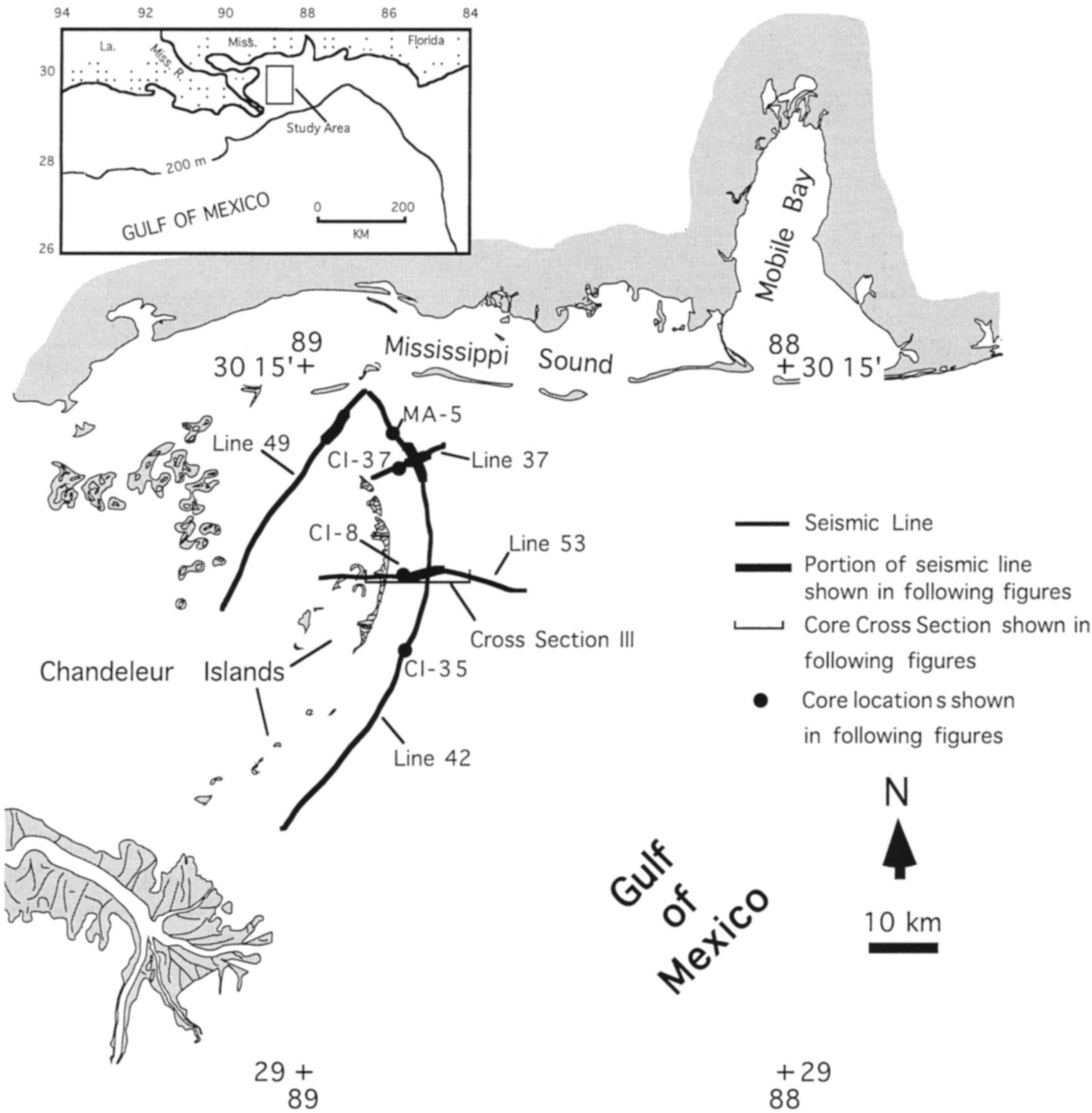

Figure 1. Location map of the northeast Louisiana shelf showing the study area including locations of cores, cross sections and seismic lines referred to in the following figures.

METHODS

Seventy-seven vibracores were collected in the study area (Figure 1) in 1987. Maximum core retrieval was 12 m. Cores were photographed and visually described as a basis for the interpretation of depositional environments. Core data were integrated with over 6,700 line-km of high-resolution, seismic-reflection data collected in the study area between 1981 and 1988. Seismic equipment included a 400-joule minisparker, ORE Geopulse Boomer System and 3.5 kHz transducer.

RESULTS AND DISCUSSION

Three seismic stratigraphic units have been defined on the basis of unconformities and correl-

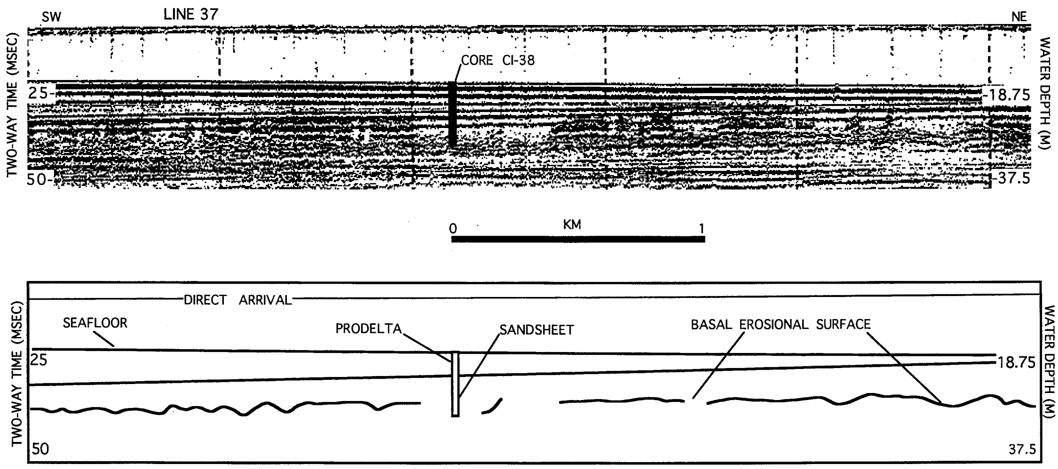

Figure 2. Seismic line 37 (top) and interpretation (bottom) showing a basal eroded surface overlain by two units interpreted to represent a transgressive sand sheet and the St. Bernard prodelta. Refer to Figure 1 for location.

ative conformities. These units represent transgressive and highstand systems tracts as defined by VAN WAGONER *et al.* (1988). The basal boundary of these units is an irregular surface that is heavily dissected locally exhibiting channelization and cut and fill structures (Figures 2 and 3). It is interpreted as a lowstand erosional surface producing a Type 1 sequence boundary as lowering of base level and subaerial exposure enabled streams to entrench underlying deposits. This surface correspond to KINDINGER's (1988) Horizon C formed during the late Wisconsinan and separating his Stages 3 and 4.

Unit 1: Transgressive Sand Sheet

Overlying this basal erosional surface is a thin (generally a few meters) deposit (Figures 2 and 3) designated as Unit 1. This unit is not identifiable on all seismic profiles, due possibly to its thinning below seismic resolution. The upper boundary is planar to gently undulating, and internal reflectors are parallel and continuous to hummocky and chaotic. Vibracores penetrated the surface of Unit 1 where overlying sediments are thin. Sediments consist of clean, fine-grained, well-sorted quartz sands exhibiting various degrees of bioturbation and little or no evidence of structure. Unit 1 is interpreted as a transgressive sand sheet deposited during a relative rise in sea-level. It corresponds to KINDINGER'S (1988) Stage 4 and represents a transgressive systems tract as defined by VAN WAGONER *et al.* (1988).

Unit 2: St. Bernard Delta

Seismic Data

Overlying the transgressive sand sheet is the seaward-prograding St. Bernard Delta complex, deposited between approximately 4.6 and 1.8 ka (FRAZIER, 1967; BOYD *et al.*, 1989) when ancestral Mississippi River deposition dominated the region. St. Bernard Delta sediments range from several meters to a few 10's of meters in thickness. Seismic facies are dominantly parallel, continuous to discontinuous and low amplitude in lower sections of the sequence representing the more distal portions of the delta (Figures 2, 3 and 4). The upper section of the sequence, and commonly overlying the facies described above, is a channelized section characterized by reflection free or hummocky to chaotic reflectors (Figure 5), representing the more proximal portion of the delta. Except for this upper, channelized section, individual delta facies cannot be resolved on seismic profiles. The channelized portions are interpreted to represent localized unconformities created by the lateral migration of distributary channels.

St. Bernard Delta sediments thin below seismic resolution and appear to pinch out against the underlying transgressive sand sheet in distal por-

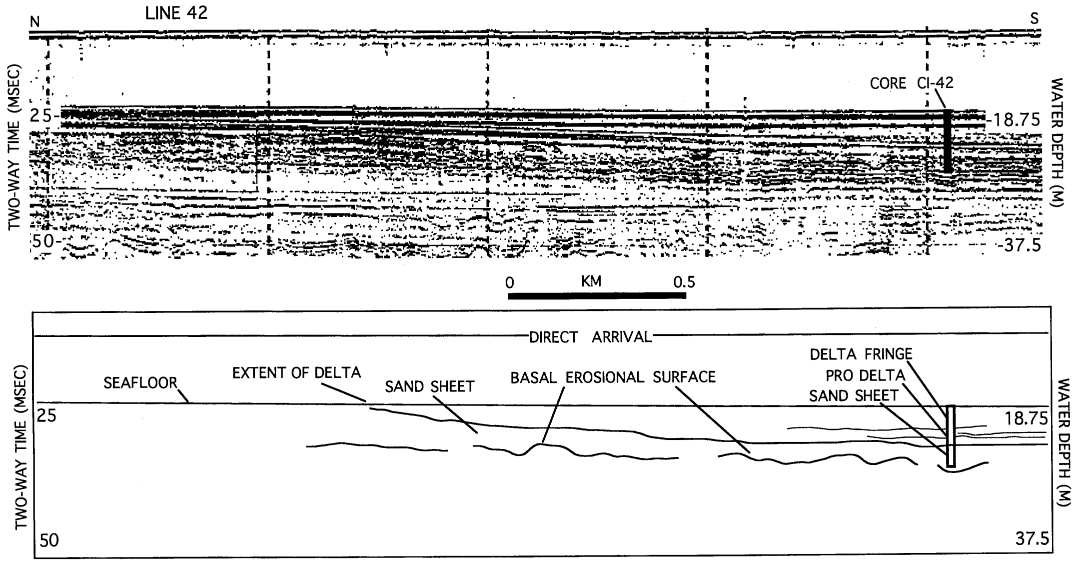

Figure 3. Seismic line 42 (top) and interpretation (bottom) showing a basal eroded surface overlain by a transgressive sand sheet and St. Bernard prodelta/delta fringe sediments. Note how the St. Bernard Delta thins below resolution (and eventually pinches out) to the north. Refer to Figure 1 for location.

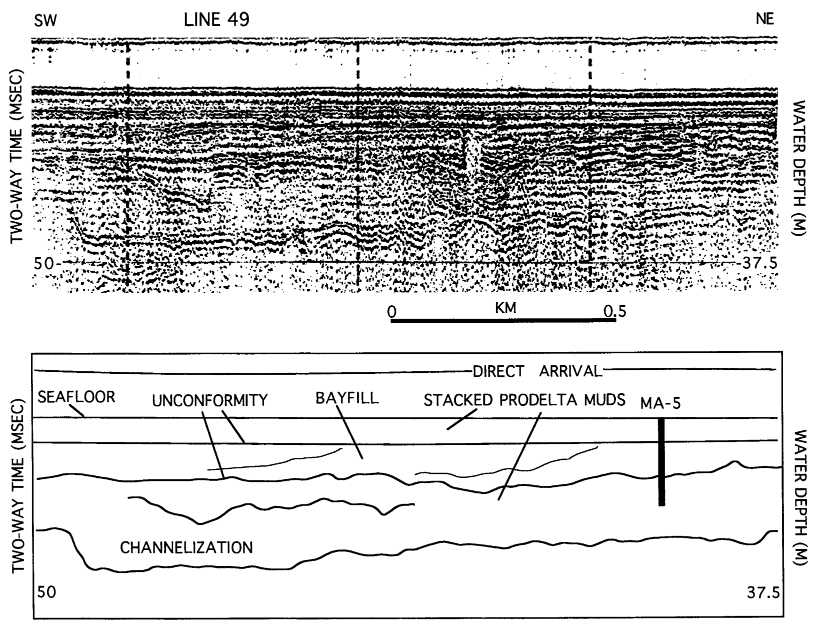

Figure 4. Seismic line 49 (top) and interpretation (bottom) showing a basal channeled surface overlain by two, vertically-stacked delta lobes, separated by a bayfill unit. Refer to Figure 1 for location.

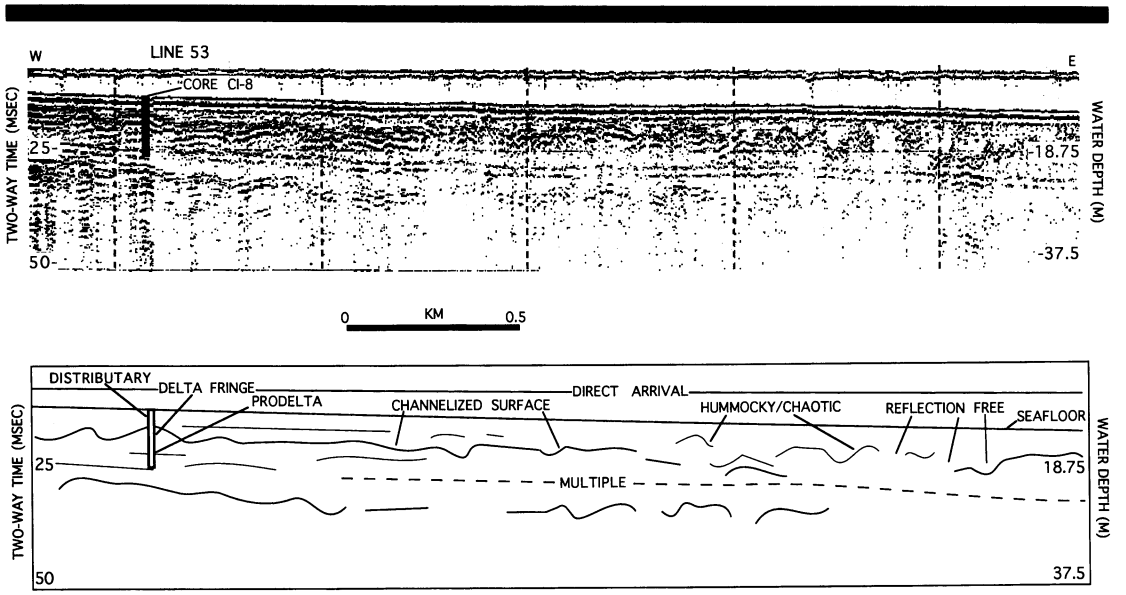

Figure 5. Seismic line 53 (top) and interpretation (bottom) showing a channelized surface separating the St. Bernard Delta distributary facies from underlying delta fringe and prodelta sediments. Refer to Figure 1 for location.

tions of the delta (Figures 2 and 3) representing the seaward extent of the delta complex. The lateral extent of the delta has been determined and mapped previously (see FRAZIER, 1967; PENLAND *et al.*, 1988; and KINDINGER *et al.*, 1991).

High-amplitude, flat-lying reflection surfaces are present locally in the study area, separating two distinct units within the delta (Figure 4). Seismic facies of the lower unit are commonly flat-lying to hummocky and low-amplitude. Facies of the overlying unit are conformable, characterized by flat-lying, low-amplitude and parallel horizons. The two units are often separated by a thin deposit characterized by low-relief channeling or low-angle clinoforms. These features are interpreted to represent vertical stacking of separate depositional lobes of the delta. Sediment core data, which is discussed in the following section, support this interpretation.

Sediments

St. Bernard Delta sediments consist of a coarsening-upward wedge of sands and muds containing vertically stacked units of deltaic succession typical of a seaward prograding delta. Individual facies, most of which cannot be resolved on seismic profiles, include the prodelta facies, delta fringe facies and distributary facies.

The prodelta facies consists of homogeneous to finely-laminated silts and clays (Figure 6). Sediments are generally dark gray to black in color and relatively featureless. They are interpreted to have been deposited as the prodelta, or most distal extension of the delta. Prodelta muds are represented on seismic profiles as low-amplitude, discontinuous, flat-lying reflectors (Figures 2, 3 and 4). Prodelta muds extend throughout almost the entire study area (Figure 7) sometimes comprising the entire length (up to 12 m) of core.

The delta fringe facies consists of slightly-burrowed, sandy muds (Figure 8). Commonly, sediments are featureless, distinguishable from underlying prodelta sediments only by the slight gradational increase in sand content. When present, a variety of structures exist including lenticular bedding and ripple cross-stratification. These sediments are interpreted to have been deposited in the delta fringe environment. The increase in sand-sized material reflects relative proximity to the sediment source. Seismic facies of the delta fringe consist predominantly of low-amplitude, discontinuous, and flat-lying reflectors (Figures 2 and 5), and therefore, cannot be delineated from underlying prodelta sediments. The delta fringe facies is present throughout much of the study area. Thickest deposits are in the south-central portion (Figure 7) where they often comprise the entire length (up to 12 m) of core. The delta fringe

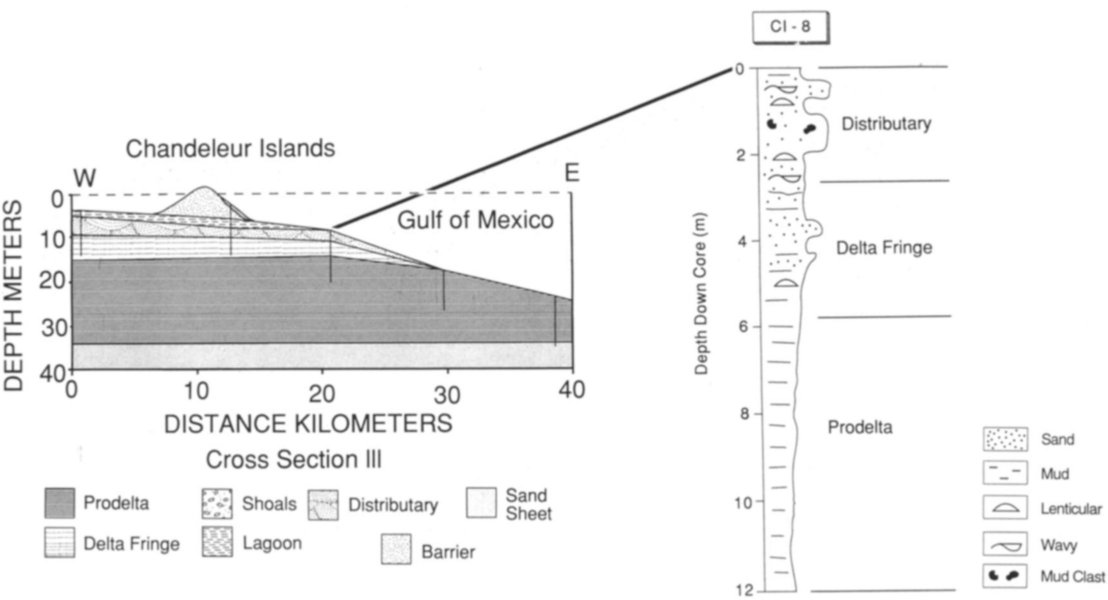

Figure 6. Core cross-section III and description of core CI-8 showing extensive prodelta sediments overlain landward by delta fringe and distributary sediments. Refer to Figure 1 for location.

facies is absent in the northeast through east-central portion of the study area.

The overlying distributary facies consists of alternating layers of sands and muds (Figure 8). Individual layers vary in thickness from a few millimeters to 10's of centimeters. The contact between layers may be gradational or distinct. Both sands and muds exhibit evidence of burrowing and a variety of structures are present including lenticular, wavy and flaser bedding, and ripple cross stratification. This facies is interpreted to have been deposited by the delta distributary and reflects the seaward-most progradation of the delta plain. Alternating deposition of sands and muds reflects the fluctuating energy regime in the distributary environment and may result from laterally migrating distributary channels. Localized erosional unconformities, possibly representing erosion by migrating distributary channels are identified on seismic data (Figure 5). These unconformities separate delta distributary deposits from underlying delta fringe deposits and represent the only delta facies change identifiable on seismic data. The distributary facies is not always present. It has been found to occur mostly in the south-central portion of the study area (Figure 7) where it represents the most extensive distributary development.

Occasionally, sediment cores record a vertical stacking of the same delta facies type. Core MA-5, collected in the northern region of the study area, contains stacked prodelta muds separated by a layer of organic-rich, sandy mud interpreted as bayfill (Figure 9). Prodelta units are almost identical in that both are approximately 3-m thick and contain heavily bioturbated, homogeneous muds. The bayfill facies is represented by a 4-m thick sandy-mud unit exhibiting flaser and lenticular bedding and containing abundant organic material with large roots (Figure 9). The base of the bayfill facies is represented on seismic data as an erosional surface (Figure 4) and is interpreted as the temporary abandonment of that portion of the delta lobe. Erosion probably occurred by shallow-marine processes as prodelta sediment accumulation ceased, followed by the establishment of a bay environment represented by the deposition of sandy muds and organic material in a fluctuating energy regime. Finally, the prodelta lobe shifted back into the area, burying bayfill sediments and producing the flat-lying, high-amplitude reflection surface identified in Figure 4. The lower erosional surface and overlying bayfill facies are not always present. In such cases the flat-lying reflector separates two prodelta facies and is interpreted to represent delta-

Figure 7. Three-dimensional diagram depicting sediment distribution patterns within the study area.

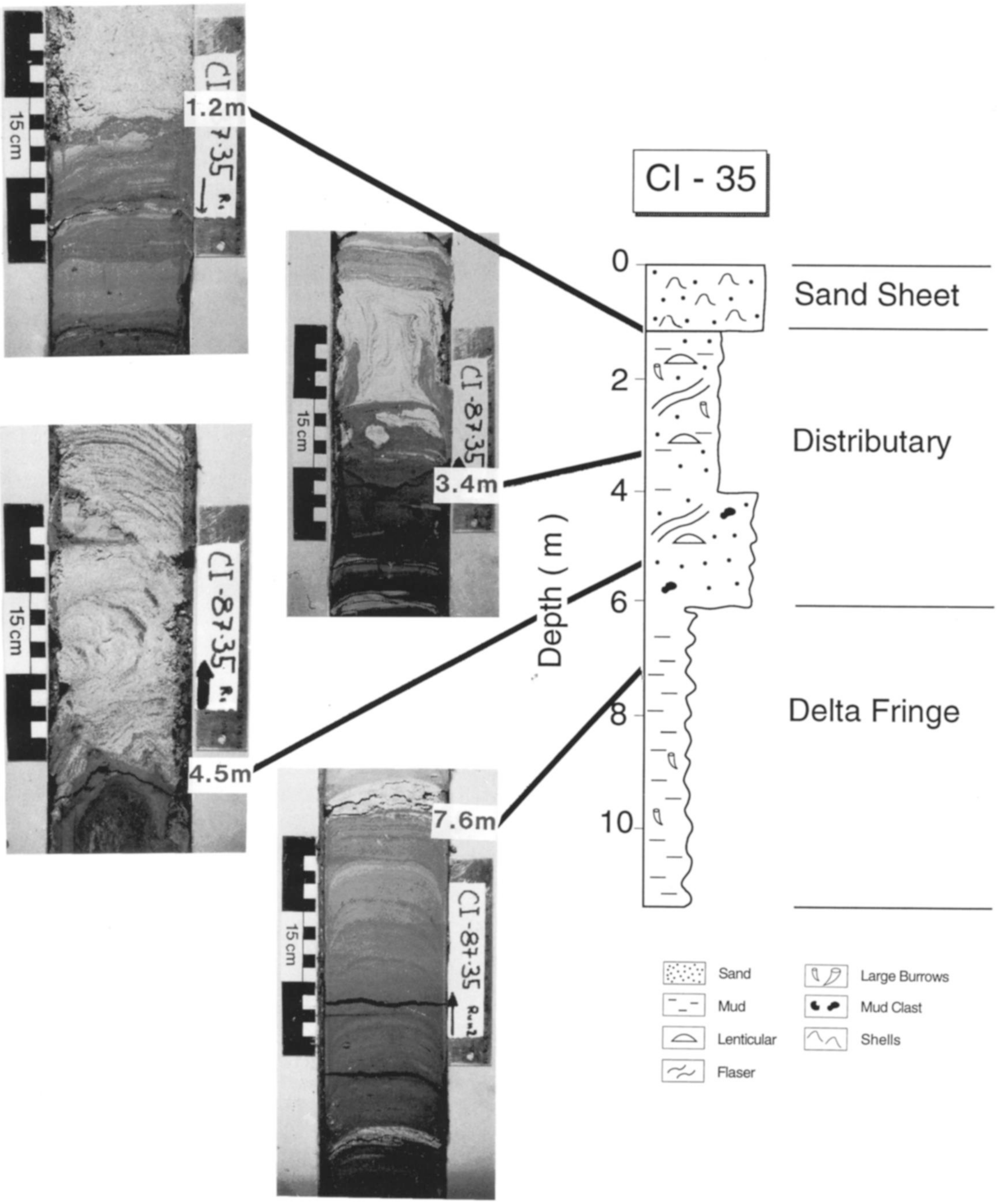

Figure 8. Description and photographs of core CI-35 showing slightly-burrowed sandy muds of the delta fringe, overlain by alternating layers of sands and muds interpreted to represent distributary sediments. Surficial sands are interpreted to represent reworked distributary sediments. Refer to Figure 1 for location.

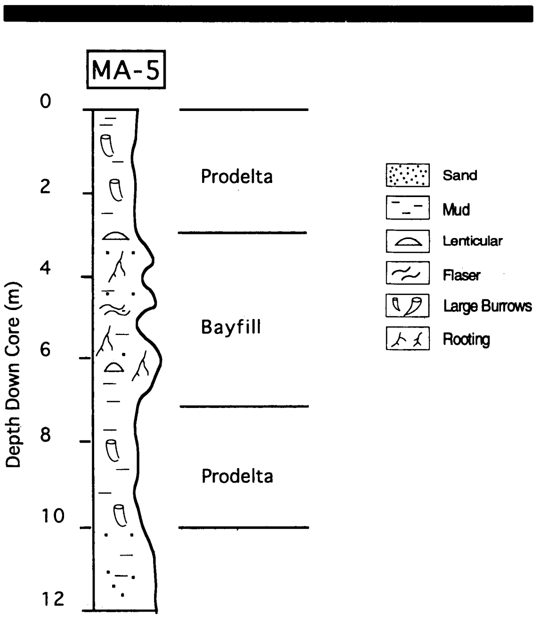

Figure 9. Description of core MA-5 showing vertically-stacked layers of prodelta sediments separated by organic-rich, sandy muds interpreted as a bayfill deposit. Refer to Figure 1 for location.

lobe shifting with no interim erosion and deposition. The St. Bernard Delta represents a highstand systems tract according to the definition of VAN WAGONER *et al.* (1988), and corresponds to KINDINGER'S (1988) Stage 5.

Unit 3: Surficial Sands and Muds

The surficial sedimentary unit consists of a thin (less than a few meters) layer of sands and muds that locally reflects the individual subenvirons of the underlying delta. In the south-central portion of the study area surface sediments consist dominantly of well-sorted, shelly, quartz sands (Figure 8), forming a series of shoals rising to 10 m above the surrounding seafloor (Figure 7). Underlying the shoals in this region are dark-colored, fine-grained sediments containing layers of peat and root fragments. Based upon the obviously high organic content of these sediments, which distinguish them from prodelta sediments, they are interpreted as lagoon or bay deposits. Flanking the shoals on all sides are massive sands differing from shoal sands only by the absence of cross stratification and lack of relief. These surficial sand bodies are interpreted to have formed by the reworking of underlying delta distributary deposits and, once again, represent the position of the most advanced development and seawardmost progradation of the distributary. Once abandoned as a result of delta switching, distributary sediments become reworked by shallow marine processes and subside as sea level continues to rise (albeit very slowly at this time). This relative sea-level rise causes a backstepping or landward migration of the sands so that they bury the organic-rich sediments formed in what was previously a protected, low-energy environment behind the shoals. These organic-rich sediments, therefore, are not formed by deltaic processes and the landward migration of sand shoals represents the switch from a regressive to transgressive system. The flanking sand sheet deposits may result from a combination of resedimentation of shoal sands and winnowing of the less well-developed part of the distributary.

Surficial sediments of the inner shelf, lying landward of the shoals, consist principally of fine-grained, bioturbated and reworked delta fringe and prodelta deposits (Figure 7). The existence of fine-grained surface sediments landward of the shoals is surprising as it would be expected that the distributary would be even better developed and, hence, sand-sized sediments would dominate. One possible explanation is that overlying distributary sediments have been eroded away, thereby exposing underlying delta fringe and prodelta deposits. The process responsible for this erosion while maintaining the integrity of the shoal-forming part of the distributary, however, is difficult to explain. Another possibility is that fluvial input and the associated distributary may not have developed immediately landward of the present position of the shoals. It may have formed either more to the north or south. Distributary sands are exposed on the inner shelf in both of these regions (Figure 7). Also a possibility is that the shoals themselves have migrated laterally from a previous position, although no evidence of lateral migration was found.

Landward of the inner-shelf muds, surface sediments consist of relatively clean, cross-stratified barrier sands of the Chandeleur Island chain (Figure 7). The sand source is probably the St. Bernard Delta distributary network, which is interpreted to be the same source that formed the middle-shelf sand shoals. Sands were winnowed and reworked by shallow-water processes accompanying the most recent sea-level rise. A full account of Chandeleur Island development is given in SUTER *et al.* (1988). In open areas between islands, surface sediments consist dominantly of massive or finely laminated, bioturbated, shelly muds interpreted to represent reworked delta fringe and prodelta deposits.

Surface sediments in Chandeleur sound, located landward of the islands, consist of sands and muds (Figure 7). Commonly a thin veneer of fine-grained quartz sands overlies organic-rich muds. Muds are interpreted to have been deposited in the low-energy lagoon protected by the island barrier. The overlying sand veneer has the same characteristics as barrier sands and probably represents washover fan deposits reflecting the landward migration of the Chandeleur Island chain.

In the northeast portion of the study area surface sediments are considerably different from those just described. Surface sediments consist of clean quartz sands (Figure 7) similar to those in the nearshore areas of Mississippi and Alabama (KINDINGER *et al.,* 1991). In this portion of the study area St. Bernard delta sediments are absent and surface sediments, as well as those underlying, are interpreted to be a direct result of shoreface retreat and landward barrier migration during sea-level transgression.

The surficial sediment unit represents the upper portion of the highstand systems tract according to the definition of VAN WAGONER *et al.* (1988), and the upper portion of KINDINGER'S (1988) Stage 5. Even though surficial sediments are of deltaic origin, they are reworked by modern physical and biological processes and, therefore, are distinguished as a separate unit.

Recent Development and Modern Configuration

Holocene development of the northeast Louisiana continental shelf has been controlled by sea-level rise and sediment supply. During the most recent lowstand 18 ka the shelf surface was exposed, which formed the basal, erosional unconformity. Early flooding of the shelf during the ensuing sea-level rise resulted in the deposition of the thin, flat-lying transgressive sand sheet identified throughout much of the study area. Delta switching forced the development of the St. Bernard Delta, which initiated the transition from a transgressive to regressive depositional pattern. Increased sediment supply became the dominant control as St. Bernard Delta sediments prograded seaward over the shelf forming a thick, coarsening-upward deposit containing vertically stacked units of deltaic succession. Active for approximately 3,000 years (FRAZIER, 1967; BOYD *et al.,* 1989), the delta deposited at least 12 m of prodelta, delta fringe and distributary sands and muds throughout the study area. Facies distribution patterns (Figure 7) suggest that the distributary, or depositional center of the delta, may have switched occasionally as distributary sediments are present in the north-central and southern inshore, as well as southern offshore portions of the study area. Seismic data support this interpretation. An unconformity surface identified within the delta (Figure 4) is interpreted to represent the stacking of two distinct lobes within the delta proper. The process responsible for delta lobe stacking, may be delta switching on a much smaller scale.

The modern shelf configuration is controlled by the underlying St. Bernard Delta. Although active for a relatively short period of time, the delta has had a profound effect on the modern configuration and distribution of shelf sediments. The destructional phase of the delta cycle accompanied the abondonment of the delta approximately 1 ka (FRAZIER, 1967; BOYD *et al.,* 1989). With this drastic decrease in sediment supply, a regressive system is transformed to a transgressive system.

Surface sediments in the Chandeleur Islands area and landward are beginning to reflect modern environmental conditions. Barrier sands, although probably derived from underlying deltaic deposits (SUTER *et al.,* 1988), are currently being deposited in the island areas and beginning to bury low-energy, back-barrier lagoonal sediments. The landward migration of barrier sands over lagoonal muds indicates the transgressive system remains in operation.

Surface sediments on the mid- and inner-shelf region seaward of the Chandeleur Islands are a direct reflection of the former St. Bernard Delta as deltaic sands and muds are exposed on the surface. Although muds may be heavily bioturbated and may have incorporated modern shell fragments and sands may have been physically redistributed to some extent by modern processes (*e.g.,* Chandeleur Shoals), surface sediment distribution reflects the subenvirons of the underlying delta. Reworking of deltaic sediments by shallow marine biological and physical processes is slowly concealing the influence of the delta and probably will continue to do so. The lack of significant modern sediment accumulation will aid in maintaining this influence on the modern shelf surface, although preservation of delta sediments in the rock record is unlikely.

SUMMARY AND CONCLUSIONS

The recent development of the northeast Louisiana continental shelf has been controlled by sea level, sediment supply and delta-lobe switching. Since the last sea-level lowstand, delta evolution involving construction and destruction of a Mississippi Delta lobe has consisted of: (1) a transgressive system (transgressive sand sheet) controlled by a rising sea level; (2) an overlying regressive system (the St. Bernard Delta) controlled by sediment supply; and, (3) a later transgressive system (landward migration of coastal and nearshore environments) controlled once again by relative sea-level rise as delta-lobe switching removed the fluvial sediment input.

The modern distribution of seafloor sediments (for the most part) does not reflect modern processes but is controlled by the underlying, inactive St. Bernard Delta. Surface sediments in the Chandeleur Islands and landward lagoonal areas are beginning to reflect modern transgressive processes. However, seaward of the island chain surface sediments are distinctly those of the St. Bernard Delta. Although reworking of surficial sands and muds by shallow-water biological and physical processes is slowly concealing their deltaic origin, the lack of modern sediment accumulation is helping to maintain the imprint of the delta on the modern shelf surface. As a consequence, however, it is unlikely that the delta will be preserved in the sedimentary record.

LITERATURE CITED

Boyd, R.; Suter, J.R., and Penland, S., 1989. Sequence stratigraphy of the Mississippi Delta. *Transactions—Gulf Coast Association of Geological Societies*, 39, 331–340.

Coleman, J.M. and Roberts, H.H., 1988. Sedimentary development of the Louisiana continental shelf related to sea-level cycles: Part I—sedimentary sequences. *Geo-marine Letters*, 8, 63–108.

Frazier, D.E., 1967. Recent deltaic deposits of the Mississippi River: Their development and chronology. *Transactions—Gulf Coast Association of Geological Societies*, 17, 287–315.

Kindinger, J.L., 1988. Seismic stratigraphy of the Mississippi-Alabama shelf and upper continental slope. *Marine Geology*, 83, 79–94.

Kindinger, J.L.; Penland, S.; Williams, S.J.; Brooks, G.R.; Suter, J.R., and McBride, R.A., 1991. Late quaternary geological framework, north-central Gulf of Mexico. *Coastal Sediments* 91, 1096–1110.

Kindinger, J.L.; Penland, S.; Williams, S.J., and Suter, J.R., 1989. Inner shelf deposits of the Louisiana-Mississippi-Alabama region, Gulf of Mexico. *Transactions—Gulf Coast Association of Geologic Societies*, 39, 413–420.

LeBlanc, R.J., 1972. Geometry of sandstone reservoir bodies. *American Association of Petroleum Geologists Memoirs*, 18, 133–190.

Penland, S.; Boyd, R., and Suter, J.R., 1988. Transgressive depositional systems of the Mississippi delta plain: A model for barrier shoreline and shelf sand development. *Journal of Sedimentary Petrology*, 58, 932–949.

Suter, J.R.; Penland, S.; Williams, S.J., and Kindinger, J.L., 1988. Transgressive evolution of the Chandeleur Islands, Louisiana. *Transactions—Gulf Coast Association of Geological Societies*, 38, 315–322.

Van Wagoner, J.C.; Posamentier, H.W.; Mitchum, R.M.; Vail, P.A.; Sarg, J.F.; Loutit, T.S., and Hardenbol, J., 1988. An overview of the fundamentals of sequence stratigraphy and key definitions. *In:* Wilgus, C.K.; Hastings, B.S.; Kendall, C.G.St.C.; Posamentier, H.W.; Ross, C.A., and Van Wagoner, J.C. (eds.), *Sea-Level Changes: An Integrated Approach.* Tulsa: Society of Economic Paleontologists and Mineralogists, Special Publication No. 42, pp. 39–45.