Journal of Coastal Research	SI 50	805 - 809	ICS2007 (Proceedings)	Australia	ISSN 0749.0208

Tidal Versus Shoreface Ravinement and Tidal Inlet Fill Preservation Potential for Transgressive Tidal Inlets, Mississippi River Delta Plain, U.S.A.

M.D. Miner†, M.A. Kulp†‡, and D.M. FitzGerald∞

† Pontchartrain Institute for Environmental Sciences,
University of New Orleans,
New Orleans, LA, 70148, USA
mminer@uno.edu

‡ Dept. of Earth and Environmental Sciences,
University of New Orleans,
New Orleans, LA, 70148, USA

∞ Dept. of Earth Sciences,
Boston University,
Boston, MA, 02215, USA

ABSTRACT

MINER, M. D., KULP, M. A. and FITZGERALD, D. M., 2007. Tidal Versus Shoreface Ravinement Surfaces and Tidal Inlet Fill Preservation Potential, Mississippi River Delta Plain, U.S.A. Journal of Coastal Research, SI 50 (Proceedings of the 9th International Coastal Symposium), 805 – 809. Gold Coast, Australia, ISSN 0749.0208

Barrier island and tidal inlet systems along the Mississippi River Delta Plain are undergoing rapid morphological change due to shoreface retreat and increasing bay tidal prism, driven by high rates of relative sea-level rise (RSLR) (1 cm/yr) and interior wetland loss, respectively. Two adjacent tidal inlets, Little Pass Timbalier and Raccoon Pass, exhibit contrasting morphology and sediment regimes. Little Pass Timbalier is ebb-dominated with a deep main channel (10 m), enlarging ebb-tidal delta, and negligible flood tidal delta. Contrastingly, Raccoon Pass is flood-dominated with a shallow main channel (4 m), negligible ebb-tidal delta, and enlarging flood-tidal delta.

Sediment cores, shallow subbottom profiles, and comparisons of historic bathymetric maps (since the 1800's) and recent bathymetric data allowed a determination of the depth of shoreface ravinement and the geometry and extent of tidal inlet fill deposits preserved by retreating tidal inlets. Results show that the depth of shoreface ravinement in this area is greater than 10 m, which exceeds the deepest tidal ravinement depths. Raccoon Pass has a low preservation potential due to its shallow depth and small sized ebb delta. In contrast, the prograding ebb delta at Little Pass Timbalier protects and stabilizes its deep ebb channel, which will allow backfilling of the channel to occur before complete excavation during shoreface retreat. The subsidence driven RSLR coupled with ebb-tidal delta progradation increases the potential of tidal inlet fill preservation because the distance between the tidal ravinement and shoreface ravinement surfaces is continually increasing with time.

ADDITIONAL INDEX WORDS: *tidal delta, tidal prism, inlet throat*

INTRODUCTION

The Mississippi River delta plain (MRDP) coastal zone (Figure 1) is currently undergoing an erosional transgression (*sensu* CURRAY, 1964) driven by high rates of relative sea-level rise (RSLR) in excess of 1 cm/yr (PENLAND and RAMSEY, 1990). These high rates of RSLR result in shoreface retreat-driven landward migration of the shoreline at rates of over 3 km per century and are the dominant control on coastal lithosome development and preservation potential for the modern MRDP coastal zone.

The stratigraphic architecture produced during transgression is dependent upon the rate of RSLR, sediment supply, wave energy, tidal range, and antecedent geology (BELKNAP and KRAFT, 1981; DEMAREST and KRAFT, 1987). Erosional truncation of paralic strata by shoreface processes produces the shoreface ravinement surface (STAMP, 1922). In a continuously retreating shoreline system such as the abandoned Lafourche deltaic headland of the MRDP, the basal portion of the tidal inlet system has the highest preservation potential (KUMAR and SANDERS, 1974; DEMAREST and KRAFT, 1987). This is due to the deep incision at tidal inlet locations by tidal scour into underlying sediments. As the shoreline and active tidal inlet throat migrate landward, accommodation space created by the tidal scour is subsequently backfilled and ebb tidal delta deposits override the filled inlet channel. If the depth of tidal ravinement is deeper than that of

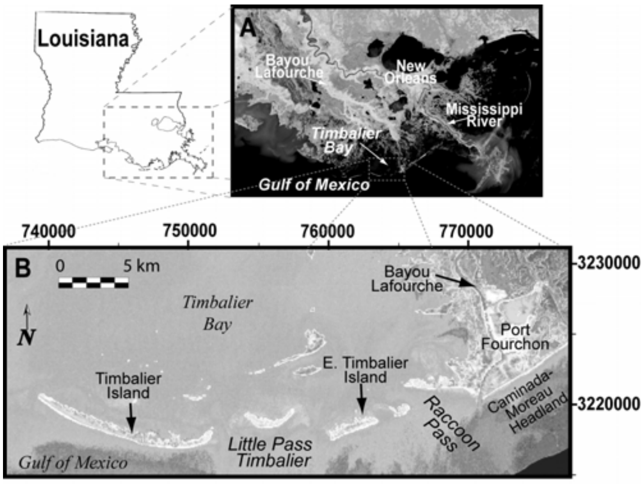

Figure 1. Satellite images of the study area showing the Mississippi River delta plain (A) and the Timbalier shoreline (B). Raccoon Pass and Little Pass Timbalier are the conduits for the daily tidal exchange between Timbalier Bay and the Gulf of Mexico. Image A is from 2004 and image B is from 2002. Grid coordinates in image B are in meters UTM Zone 15.

shoreface ravinement, the inlet fill sedimentary unit will be preserved seaward of the modern shoreline. Due to this relatively high preservation potential for moderate to large-size tidal inlets relative to penecontemporaneous barrier deposits, the recognition of transgressive inlet channel fill and their basal bounding surfaces are important criteria for identifying former barrier positions and their associated deposits of transgressive systems tracts and improving the understanding of former sea level positions.

The high rates of RSLR and associated landward migration of the shoreline make the MRDP coastal zone an ideal study area for the investigation of transgressive processes and resulting stratal architecture. Two adjacent tidal inlets along the abandoned Lafourche deltaic headland, Raccoon Pass and Little Pass Timbalier, exhibit contrasting morphological regimes (Figure 1). Raccoon Pass is flood dominated with a shallow ebb channel (4 m) and Little Pass Timbalier is ebb dominated with a 10 m deep ebb channel. Both inlets have migrated over 3 km in a landward direction since the 1880's but have remained relatively fixed in alongshore (lateral) position (MINER *et al*., 2005; KULP *et al*., 2006).

Another consequence of the RSLR in the MRDP is that the loss of interior wetlands results in increased open water area and a greater tidal exchange. Ongoing conversion of backbarrier and interior wetlands to open water bays and lagoons increases inlet tidal prisms, which in turn has enlarged the flow area of the associated tidal inlets (*sensu* O'BRIEN, 1931).

The goal of this study is to first construct morphologic evolutionary models for both inlets, and then apply these models to interpret stratigraphy in sediment cores and shallow subbottom reflection profiles. Ultimately a relationship between the tidal ravinement and shoreface ravinement depth for each system is examined in order to determine preservation potential of the tidal inlet lithosome for two differing inlet morphologies in a regime of increasing tidal prism and coastal retreat.

METHODS

Historical bathymetric surveys (1880's - 1980's) compiled by LIST *et al*. (1994) provide the framework for examining long-term trends. Recent (2005) bathymetric data of the study area were gathered using the University of New Orleans Coastal Research Laboratory single-beam bathymetric rig mounted on the 21-foot *R/V Mudlump*. This bathymetric survey rig consists of an *Odom Hydrographics Hydrotrac* echosounder with depth soundings collected through a side-mounted *Odom Hydrographics* 200 kHz transducer with a beam width of 3°. The echosounder unit is equipped with a *Starlink Invicta 210L* differential global positioning system (DGPS) for navigation. Heave, pitch, and roll of the vessel are recorded using a *VT TSS Dynamic Motion Sensor Series-25* that is mounted vertically in-line with the DGPS antenna and the transducer. The bathymetric, motion correction and navigation data are recorded and integrated using *Coastal Oceanographics Hypack Max* hydrographic survey software.

The survey lines were tracked using *Hypack* having a line spacing of approximately 800 m for both shore normal and shore parallel lines. In the proximity of the inlet channel line spacing was reduced to approximately 50 m. Tide corrections were integrated using 6-minute interval data from NOAA tide gauge station (# 8762075) at Port Fourchon, Louisiana.

After processing, the bathymetric data and historical datasets were used to make a series of grids and ultimately digital elevation models (DEMs) for each date (1880's, 1930's, 1980's, and 2005). The grids and DEMs were constructed using *Golden Software Sufer 8* contouring software. A kriging geostatistical algorithm was used to create the grid. Each DEM was then rectified and scaled relative to the other DEMs, allowing for the construction of a time series model that shows the morphological evolution of Little Pass Timbalier and Raccoon Pass for the period from 1880 to 2005.

A team of USGS/UNO coastal scientists collected 875 line-km high-resolution single-channel seismic reflection (HRSP) and CHIRP sonar reflection profiles during 2001, 2004, and 2005 summer cruises aboard the *USGS R/V G. K. Gilbert*. The high-resolution, single channel seismic and sonar reflection profiles were collected using BOOMER and CHIRP systems, respectively. The BOOMER system uses an acoustic source with a range from 2.0 to 6.0 kHz and a resolution of approximately 1.0 m. The CHIRP system is an FM sonar source with a range from 4.0 to 24.0 kHz and a resolution of approximately 0.2 to 0.6 m. Raw acoustic data were collected in the field and post-processed at the USGS Center for Coastal and Regional Marine Studies in St. Petersburg, Florida.

The collection and analysis of 18 vibracores provided the means for interpreting the seismic sections and defining the sedimentary facies, bounding surfaces, and stratal geometry. The 18 vibracores were split in half lengthwise and described using standard sediment logging methods including sedimentary texture and structures, percent sand, physical characteristics, stratification type, sample type, and stratal relationships.

Two recent sand resource studies, KULP *et al*. (2002) and OCEAN SURVEYS, INC. (2002), which compiled the results of 161 vibracore descriptions, supplied background sedimentologic and stratigraphic information for this study.

RESULTS

Inlet Evolution

The results of the bathymetric change analysis are presented in a series of DEMs, one representing each time period covered by the study (Figure 2). Inlet morphology for each time period is described using the terminology of HAYES (1975).

The evolution of Little Pass Timbalier is closely related to the long-term increase in tidal prism, rapid RSLR, and the impact of major storms. These forcings have induced a landward migration of the inlet throat, widening and deepening of the inlet channel, formation of new stable channels within the same inlet system, and enlargement and seaward progradation of the ebb tidal delta. A westward lateral shift in inlet position resulted from a channel avulsion to a breach on Timbalier Island between 1880 and 1930. During the subsequent time period (1980 to 2005), both ebb channels remained open and continued to deepen in response to increasing tidal prism size. Between 1980 and 2005 lateral migration of Timbalier Island and deterioration of East Timbalier Island resulted in lateral migration of both channels in opposite directions leading to inlet widening. The channels are separated by Timbalier Shoal, which is submerged after tropical storm impacts but becomes subaerially exposed as swash bars migrate landward across the ebb delta, weld to the shoal, and amalgamate during extended periods of calm weather. Seaward progradation of the ebb tidal delta occurred as the barrier/inlet system migrated landward between 1930 and 1980. This rapid seaward progradation slowed and eventually ceased between 1980 and 2005 and erosion of the updrift side of the ebb tidal delta increased downdrift deposition. The inlet system evolves from a balanced flood/ebb dominance with flood and ebb tidal deltas and a 7 m deep ebb channel in the 1880's to an inlet morphology displaying no prominent ebb or flood deltas with sediment bodies separating multiple channels within the throat in the 1930's. Little Pass Timbalier later became morphologically stable as a two-channel

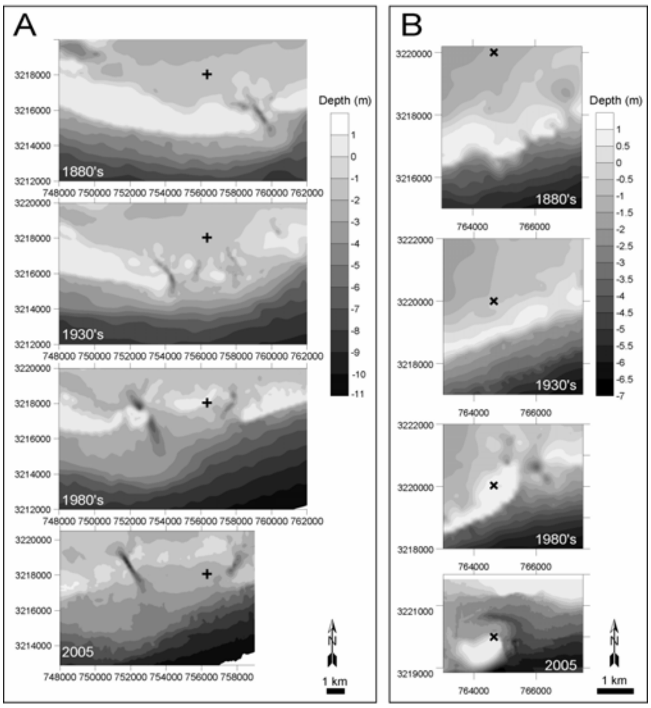

Figure 2. Digital elevation models showing the morphologic evolution of Little Pass Timbalier (A) and Raccoon Pass (B) from 1880 to 2005. Note the + (A) and x (B) that identify a fixed geographic position for Little Pass Timbalier and Raccoon Pass, respectively. Coordinates are in meters UTM Zone 15. The vertical and horizontal scales vary between A and B. 1880's to 1980's bathymetric data is from LIST *et al*. (1994).

inlet with a large ebb delta, insignificant flood tidal delta, and a 10 m deep main ebb channel.

Raccoon Pass shows a similar evolution in response to increasing tidal prism and rapid RSLR. The inlet underwent widening and deepening at the throat as it migrated over 3 km in a landward direction. Maximum throat depths increased from approximately 1 m in the 1880's to over 4 m in 2005. Between 1980 and 2005, a well defined ebb channel developed. The inlet also maintained a laterally stable position as it retreated landward (KULP *et al*., 2006). In contrast to Little Pass Timbalier's morphologic evolution, Raccoon Pass developed a broad flood tidal delta during 1880 - 2005 (KULP *et al*., 2006). Moreover, no significant ebb tidal delta deposits formed at Raccoon Pass during its evolution.

The morphology of the two nearby inlets are in sharp contrast to each other with respect to ebb channel depth and tidal shoal distribution. Little Pass Timbalier displays an ebb dominated morphology with a large ebb tidal delta and two ebb channels that are 10 and 7 m deep. Raccoon Pass has a flood-dominated morphology with a 4 m deep ebb channel, a large flood tidal delta, and negligible ebb shoal deposits. However, both inlets are deepening and migrating landward in response to increasing tidal prism size and RSLR, respectively.

Inlet Fill Stratigraphic Architecture

A stratigraphic investigation of Raccoon Pass conducted by KULP *et al.* (2006) determined that no tidal inlet channel fill deposits or basal scour surfaces were preserved seaward of Raccoon Pass. Based on the morphological evolutionary model constructed for Raccoon Pass, it was determined that there are no inlet fill deposits preserved seaward of the modern throat. The morphologic evolutionary model for Little Pass Timbalier showed that there is high preservation potential for inlet fill deposited since the 1930's and that the preservation potential of inlet sediments deposited as early as the 1880's was low.

Vibracore and shallow subbottom profile data sampled along the inlet retreat path at Little Pass Timbalier were used to determine inlet fill lithofacies and define the tidal inlet fill stratal geometry (Figure 3). The inlet fill at Little Pass Timbalier is characterized by a basal scour surface that is marked by abraded shell material in a muddy fine sand matrix. Overlying the basal scour surface is the lower channel facies, which consist of a 0.5-1.0 m thick massive fine shelly sand with flaser beds, mud clasts, and organic material. The lower channel facies is gradational with the overlying upper channel facies that consists of 5.0-20.0 cm thick fining upward intervals that transition from flaser to wavy to lenticular bedded clay and fine sand with rare shell material and bedded organics. Scour surfaces separate the fining upward intervals and burrowing is rare. The inlet channel upper is up to 6 m thick and generally coarsens upward. The upper contact is sharp to gradational with the overlying ebb tidal delta deposits. Ebb tidal delta deposits cap the inlet fill interval in cores sampled along the

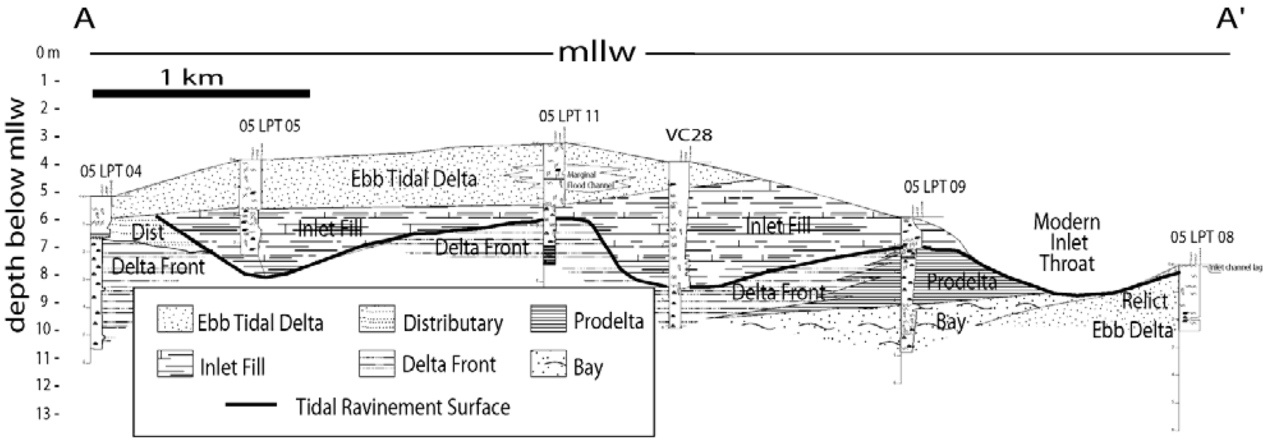

Figure 3. Stratigraphic cross section A-A' that trends shore-perpendicular along the Little Pass Timbalier retreat path.

1930’s inlet channel throat location, but cores sampled along the 1980’s channel show approximately 6 m of inlet fill with no overlying ebb tidal delta deposits (Figure 4). At the 1880’s channel location, a thin (1.5 m) inlet channel fill overlain by a veneer of ebb tidal delta sands is isolated on the shelf and cut off from modern inlet and ebb delta processes. The 1880’s channel fill is in 7 m of water, however 2 m of inlet fill and ebb tidal delta deposits are preserved below the seafloor.

The inlet fill geometry seaward of the modern throat is in the form of a dip-elongate, erosionally bounded asymmetrical channel fill that thins seaward and pinches out at the location of inlet formation. The basal shell lag marks the tidal ravinement surface. The inlet fill sedimentary unit contained within the tidal ravinement surface is overlain by ebb tidal delta deposits that thicken seaward and extend seaward beyond the point of inlet formation. Subjacent and adjacent to the inlet fill lithosome are regressive fluvio-deltaic deposits associated with progradational stages of the Lafourche delta complex of the Mississippi River.

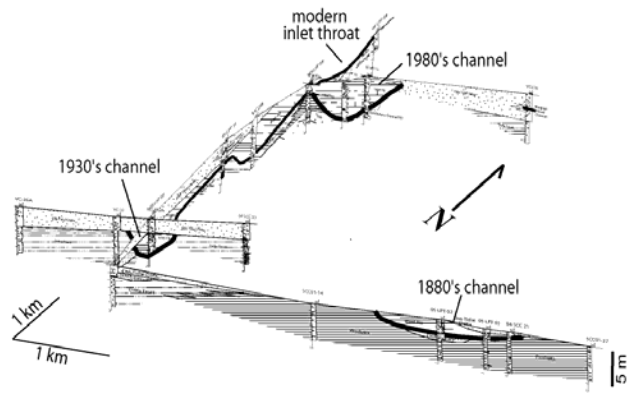

Figure 4. Fence diagram showing the tidal inlet fill stratigraphic architecture for Little Pass Timbalier. See Figure 3 for explanation of symbols.

DISCUSSION

As the MRDP subsides, and the shoreline retreats landward, the zone of storm wave base influence migrates landward producing a widespread erosional surface called the shoreface ravinement surface. The shoreface ravinement depth for the study area is controlled by rate of RSLR, wave height, and storm intensity and frequency. The depth of shoreface ravinement as determined from bathymetric profiles constructed by LIST *et al*. (1994) ranges from 10 – 16 m in the study area, increasing from west (Little Pass Timbalier) to east (Raccoon Pass). A second ravinement surface produced during a transgression is the tidal ravinement surface that is the result of tidal current scour at tidal inlets. If inlet depths are deeper than the depth of shoreface ravinement, a portion of the inlet system will be preserved on the shelf as the shoreline migrates landward. Based on the 2005 bathymetric data inlet throat depths are 4 and 10 m at Raccoon Pass and Little Pass Timbalier, respectively. Based on the relationship between tidal ravinement depth and shoreface ravinement depth, one would assume that preservation of inlet channel deposits in the study area would be minimal at best due to the greater depths of shoreface ravinement relative to tidal inlet channel depths. However, there are temporal controls that increase the preservation potential of the tidal ravinement surface during the transgression of the Timbalier shoreline. These include: 1) the increase in tidal scour depth with time in response to increased tidal prism size, 2) the increase in sediment volume and seaward progradation of ebb tidal deltas in response to increased tidal prism, and 3) the regional subsidence occurring in the MRDP (Figure 5). Each of these factors contributes to increased preservation potential with time given a relatively constant rate of RSLR and increasing tidal prism.

The two adjacent tidal inlets investigated during this study have contrasting morphologies, but are undergoing similar temporal changes in inlet throat geometry and migrating landward. During the time period covered by this study (1880’s – 2005) the inlet throats underwent continual deepening in response to increased tidal prism size (from 1 to 4 m at Raccoon Pass and 7 to 10 m at Little Pass Timbalier). The increase in throat depths with time results in an increase in the depth of the tidal ravinement surface leading to higher preservation potential with time.

Inlet tidal prism size governs the volume of sediment that is stored in the ebb tidal delta (WALTON and ADAMS, 1976). It has been shown that the increasing tidal prism in the MRDP has led to an increased volume of sediment comprising ebb tidal deltas (LIST *et al*., 1997; FITZGERALD *et al*., 2004), and as a result of this increased sediment supply, the ebb tidal deltas prograde seaward as the inlet and barrier system migrate landward (FITZGERALD *et al*., 2004; MINER *et al*., 2005). At Little Pass Timbalier as the inlet throat migrates landward, the backfilling of the inlet channel is the result of three distinct modes of deposition that include; 1) lateral spit accretion, 2) wave influenced shore processes at the seaward terminus of the channel (e.g. migration of swash bars into channel), and 3) deposition of bed load and suspended load during periods of low velocity currents or increased suspended load concentration. The result of this tidal scour, landward inlet migration, and subsequent backfilling is a tidal inlet fill sedimentary unit located seaward of the modern inlet system laterally and subjacently bounded by a sharp contact (tidal ravinement surface) with deltaic sediments and capped by a second sharp contact (shoreface ravinement surface) and overlying ebb tidal delta deposits. The enlargement and progradation of the ebb tidal delta serves to protect the underlying inlet fill and tidal ravinement surface from shoreface ravinement processes in the vicinity of the inlet.

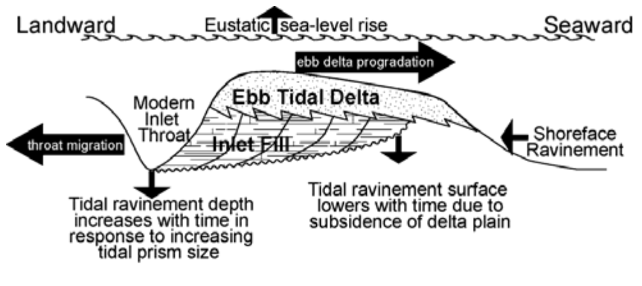

Figure 5. Conceptual model showing controls on preservation potential for a Mississippi River delta plain transgressive tidal inlet in a regime of rapid RSLR and increasing tidal prism size.

A third factor that increases preservation potential of the tidal ravinement surface produced by MRDP transgressive tidal inlets with time is the ongoing regional subsidence driven primarily by dewatering and compaction of deltaic sediments. Subsidence in the study area is occurring at rates of approximately 0.9 cm/yr (PENLAND and RAMSEY, 1990). This results in the lowering of the preserved tidal ravinement surface relative to the modern shoreface ravinement surface, which is increasing in elevation due to eustatic sea-level rise. For example, the tidal ravinement depth determined for Little Pass Timbalier in the 1880's was 7 m based on the bathymetric data (LIST *et al*., 1994). Cores that were sampled in 2005 at the location of the 1880's throat position in 7 m water depth encountered a 1.5 m thick inlet fill and basal scour surface.

Raccoon Pass and Little Pass Timbalier tidal inlets are both deepening with time in response to increasing tidal prism size; however, Raccoon Pass lacks an ebb tidal delta and has only attained a 4 m scour depth. The lack of a protective ebb tidal delta and shallow tidal channel depths result in the rapid destruction of inlet deposits by shoreface ravinement at Raccoon Pass, hence, poor preservation potential. In contrast, Little Pass Timbalier has attained a throat depth of 10 m and has a large ebb tidal delta. The deeper scour depths coupled with the protection of inlet fill provided by the expansive ebb tidal delta at Little Pass Timbalier results in relatively high preservation potential. Because scour depths and ebb tidal delta sediment volume increases with time, the preservation potential also increases with time. Also, the subsidence driven rapid RSLR in the MRDP increases the potential of tidal inlet fill preservation because the distance between the tidal ravinement and shoreface ravinement surfaces is continually increasing with time.

CONCLUSION

The rapid RSLR in the MRDP and associated interior land loss results in a highly transgressive regime in which tidal inlets are increasing in depth and migrating landward. Also, the increasing tidal prism size results in increased sediment volume sequestered in the ebb tidal deltas.

Raccoon Pass has poor preservation potential because of the shallow depths to which tidal currents scour and the absence of an ebb tidal delta. No inlet fill deposits have been identified landward of Raccoon Pass. Little Pass Timbalier has a high preservation potential and inlet fill deposits seaward of the modern throat consist of an erosionally bounded, dip-elongate channel fill that thins seaward and pinches out at the location of inlet formation. The Little Pass Timbalier ebb tidal delta serves to protect the inlet fill and associated tidal ravinement surface from erosion by shoreface ravinement.

The unique set of conditions that include subsidence driven rapid RSLR, and increasing tidal scour depths and ebb tidal delta expansion due to increasing tidal prism size, serve to improve preservation potential of the inlet fill lithosome. By prolonging exposure to the zone of storm wave base, these processes buy time for subsidence and eustatic sea-level rise to increase the distance between the tidal ravinement surface and the zone of shoreface ravinement, further increasing preservation potential.

LITERATURE CITED

BELKNAP, D. F. and KRAFT, J. C., 1981. Preservation Potential of Transgressive Coastal Lithosomes on the U. S. Atlantic Shelf. *Marine Geology*, 42, 429-442.

CURRAY, J. R., 1964. Transgressions and Regressions. *In:* MILLER, R. (ed.), *Papers in Marine Geology, Shepard Commemorative Volume*. New York, Macmillan Press, pp. 175-203.

DEMAREST, J. M., II and KRAFT, J. C., 1987. Stratigraphic Record of Quaternary Sea Levels: Implications for More Ancient Strata. *In*: NUMMEDAL, D., PILKEY, O. H., and HOWARD, J. D. (eds.), *Sea Level Fluctuation and Coastal Evolution*. Society of Economic Paleontologists and Mineralogists Special Publication No. 41, pp. 223-240.

FITZGERALD, D. M.; KULP, M. A.; PENLAND, S.; FLOCKS, J., and KINDINGER, J., 2004. Morphologic and Stratigraphic Evolution of Muddy Ebb-Tidal Deltas Along a Subsiding Coast: Barataria Bay, Mississippi River Delta. *Sedimentology*, 51, 1157-1178.

HAYES, M. O., 1975. Morphology of Sand Accumulations in Estuaries. *In,* CRONIN, L. E. (ed.), *Estuarine Research*: New York, Academic Press, pp. 3-22.

KULP, M. A.; FITZGERALD, D.; PENLAND, S.; MOTTI, J.; BROWN, M., FLOCKS, J.; MINER, M.; MCCARTY, P., and MOBLEY, C., 2006. Stratigraphic Architecture of a Transgressive Tidal Inlet-Flood Tidal Delta System: Raccoon Pass, Louisiana. *Journal of Coastal Research, Special Issue 39, in press*.

KULP, M.; PENLAND, S.; FLOCKS, J., and KINDINGER, J., 2002. *Regional Geology, Coastal Processes, and Sand Resources in the Vicinity of East Timbalier Island: Report Prepared for the Louisiana Department of Natural Resources,* Baton Rouge, Louisiana, August, 2002, 92 p.

KUMAR, N. and SANDERS, J. E., 1974. Inlet Sequence: A Vertical Succession of Sedimentary Structures and Textures Created by the Lateral Migration of Tidal Inlets. *Sedimentology*, 21, 491-532.

Levin, D., 1995, Occupation of a Relict Distributary System by a New Tidal Inlet, Quatre Bayou Pass, Louisiana, in Flemming, B. W. (ed.), Tidal Signatures in Modern and Ancient Sediments: Special Publication of the International Association of Sedimentologists, v. 24, pp. 71 –84.

LIST, J. H.; JAFFE, B. E.; SALLENGER, A. H., JR.; WILLIAMS, S. J.,MCBRIDE, R. A., and PENLAND, S., 1994. *Louisiana Barrier Island Erosion Study: Atlas of Seafloor Changes from 1878 to 1989*. Reston, Virginia: U.S. Geological Survey and Louisiana State University, Miscellaneous Investigations Series I-2150-A, 81p.

LIST, J. H.; JAFFE, B. E.; SALLENGER, A. H., JR., and Hansen, M. E., 1997. Bathymetric comparisons adjacent to the Louisiana Barrier Islands: Processes of large scale change. *Journal of Coastal Research*, 13(3), 670-678.

MINER, M. D.; FITZGERALD, D. M., and KULP, M. A., 2005. Morphologic Evolution of a Transgressive Tidal Inlet, Little Pass Timbalier, Louisiana. *Gulf Coast Association of Geological Societies Transactions*, 55, 532-542.

O'BRIEN, M. P., 1931. Estuary Tidal Prisms Related to Entrance Areas. *Civil Engineering*, 1, 738-739.

OCEAN SURVEYS INC., 2002. *Final Report: Hydrographic, Geophysical, and Geotechnical Survey Program: Timbalier Island Dune/Marsh Restoration Project:* OSI Report #01ES090, Report Prepared for the Louisiana Department of Natural Resources, Baton Rouge, Louisiana, April, 2002, 25 p.

PENLAND, S. and RAMSEY, K. E., 1990. RSLR in Louisiana and the Gulf of Mexico: 1908-1988. *Journal of Coastal Research*, 6(2), 323-342.

STAMP, L. D., 1922, An Outline of the Tertiary Geology of Burma. *Geology Magazine*, 59, 481-501.

WALTON, T. L. and ADAMS, W. D., 1976. Capacity of Inlet Outer Bars to Store Sand. *Proceedings of the 15th Conference of Coastal Engineering* (Honolulu, Hawaii, ASCE), pp. 1919-1937.

ACKNOWLEDGEMENTS

The authors would like to thank the crews of USGS *R/V G.K. Gilbert*, UNO *R/V Mudlump*, and UNO *R/V Greenhead* for help during fieldwork. Funding was partially provided by Geological Society of America student research grant #8075-05 awarded to M.D.M., through a UNO-USGS cooperative study, and through a Louisiana Department of Natural Resources sand resource investigation.