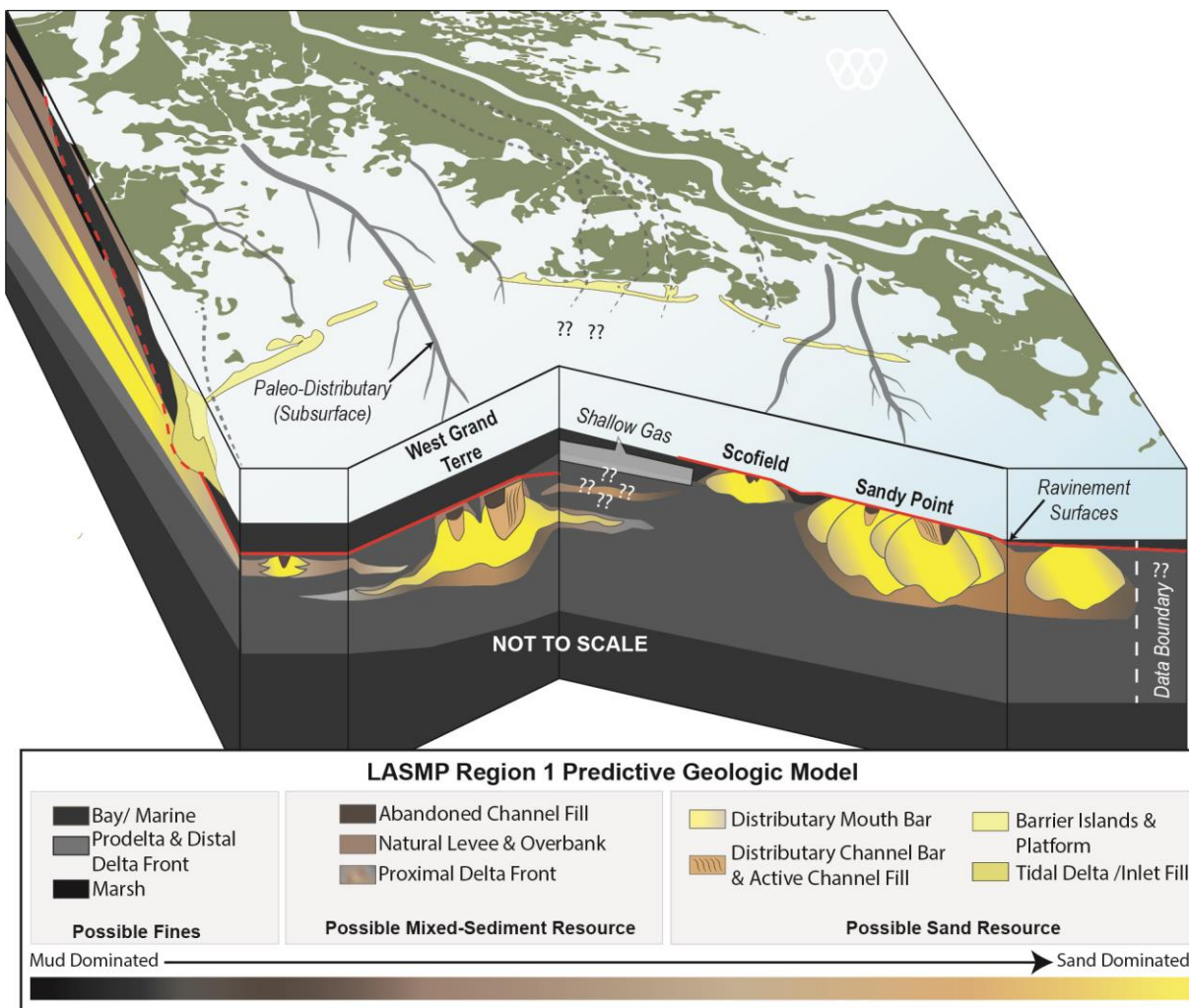


Inventory of Restoration Quality Sediment to Improve Coastal Resiliency in Louisiana - *Louisiana Sediment Management Plan (LASMP) Central Coast Region Sediment Resource Inventory*



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DISCLAIMER

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Glossary

Disclaimer: the definitions regarding sediment resources and reserves used in this report follow CPRA's classification scheme is based on the Society for Mining, Metallurgy & Exploration (SME) and the BOEM with some modifications to meet CPRA's specific restoration needs and addresses the differences in data and data density in Louisiana. CPRA (2024).

Accessible volume: Volume of sediment remaining in each mapped deposit after excluding sediment within the oil and gas infrastructure safety buffers.

Available volume: Total volume of sediment within each mapped deposit.

Avulsion: The process in which river flows are diverted out of an established channel into a new, more hydraulically efficient course at a lower elevation on the adjacent surface.

Accommodation: The space available for potential sediment accumulation.

Bar finger sand: Mouth bar morphology of deep water, elongate deltas, such as the modern Balize/Birdfoot Delta. These are thick, stacked mouth bars in areas of high accommodation.

Borrow Area: A sediment resource area delineated on the basis of engineering scale survey during engineering and design of a restoration project where its sediment characteristics, volume, and overburden is known and wherein the borrow pit could be delineated and designed.

Borrow pit: Delineated on the basis of engineering scale survey including cultural resources survey during design of a restoration project and created following the extraction or dredging of some or all of the sediment from the borrow area.

Coffee grounds (organics): Organic flecks resembling coffee grounds, which are the result of wave and current reworking of larger organic material.

Crevasse or overbank splays: Deltaic sedimentary packages form from small breaks in natural distributary channels. Formation and abandonment act on decadal scales. The resulting wedge-shaped package is only a few meters thick. Splays are fifth order components in the deltaic depositional hierarchy.

Delta front sand sheet: Mouth bar morphology of lobate or shallow water deltas forms a laterally variable, coalesced mouth bar "sheet" morphology from wave reworking of the multiple terminal distributaries in areas of lower accommodation.

Delta cycle: Process of delta growth and subsequent destruction by marine or fluvial processes.

Delta plain: Deltaic sedimentary packages separated by flooding surfaces, facies successions, and stacking patterns. Delta plains are first-order components in deltaic depositional hierarchy and consist of many delta complexes.

Delta complex: Deltaic sedimentary packages forming over 1,000-to-2,000-year timescales, produce marshlands of over 15,000 km², and sedimentary packages of 30 m thick. They can have multiple main distributaries. Delta complexes are second-order components in deltaic depositional hierarchy and consist of many delta lobes.

Delta lobe: Deltaic sedimentary packages linked to a main distributary. Delta lobes are third-order components in deltaic depositional hierarchy and consist of many subdeltas.

Deltaic depocenters: Location where deltaic deposition is concentrated and usually where accommodation is highest.

Delta switching: A shift of the deltaic depocenter resulting from an upstream river avulsion, usually in favor of an area of higher accommodation.

Distributary channel: A natural flume which accommodates and directs a portion of the discharge and transports sediment from the parent river system to the receiving basin.

Distributary mouth bar: An area of shoaling associated with the seaward terminus of the distributary mouth. Shoaling is a direct consequence of flow velocity and carrying power of a stream as it leaves the confines of its channel.

Engineering-scale survey: Final examination of specific portions geological features with the goal of determining restoration compatible sediment. The geophysical survey should include, but is not limited to navigational positioning, bathymetric survey, sub-bottom survey, sidescan sonar survey, and magnetometer survey. The geological sampling must include sufficient grain size and shell content data to determine its potential compatibility. This survey is characterized by much finer geophysical survey trackline spacing than reconnaissance scale varying from 30–50 m (100–150 ft).

Fluvial abandonment: When river flow and sediment discharge diminish and shift for another more favorable channel.

Inferred sediment resources (CPRA, 2024): Quantity and/or quality are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply, but not verify, geological and/or quality continuity.

Indicated sediment resources: Quantity and/or quality are estimated with sufficient confidence to support further evaluation of the economic viability/restoration compatibility of the sediment deposit. Geological evidence is derived from adequately detailed and reliable exploration, sampling, and testing (data less than 1 mile apart) and is sufficient to assume geological and/or sedimentological (textural) continuity between points of observation.

Measured Sediment Resource: Quantity and/or quality are estimated with confidence sufficient to allow detailed planning and final evaluation of the deposit to develop and delineate a borrow area based on detailed high-resolution engineering scale geophysical survey and appropriately spaced vibracores. Thus, the geological evidence is derived from detailed and reliable exploration, sampling and testing and is sufficient to confirm geological and/or quality continuity between points of observation.

Mixed-sediment resources (as defined by CPRA): Sediment with sand content between 30% to 70% and remaining fraction made up of fines (silt/clay).

Predictive geologic model: A simplified three-dimensional representation of the subsurface geology along with sediment deposits, visualizing their general location, thickness, composition, and relative position in the subsurface.

Progradation: Lateral building of sediment or shoreline in a seaward direction.

Reconnaissance-scale survey: Preliminary examination of the general geological features and characteristics of a region. The geophysical survey should include, but is not limited to navigational positioning, bathymetric survey, sub-bottom survey, sidescan sonar survey, and magnetometer survey. Geophysical survey and geological sampling with insufficient data density for borrow area delineation. It differentiates itself from engineering scale survey on the basis of wider spaced tracklines.

Regressive deposit: A shallowing-upward and coarsening-upward sequence of deltaic deposits that are related to the fluvially-dominated, constructional phase of delta growth or progradation.

Sand resource (as defined by CPRA): sediment comprised predominantly (70–100%) of sand with <30% fines (silt/clay).

Sediment deposit: a deposit delineated based on data that is spaced less than 1 mile apart.

Sediment reserve: Portion of an identified sediment resource that restoration quality sediment sufficient data and design studies to be legally and economically extracted under current conditions.

Sediment resource (CPRA, 2024): A sediment resource is a sediment deposit of economic interest that has a reasonable prospect for economic extraction (i.e., dredging for use in a coastal or habitat restoration project). The location, quantity, quality, continuity, and other geological characteristics are known, estimated, or interpreted from geological evidence and knowledge, including sampling. CPRA’s classification scheme divides sediment resources into several subcategories in order of increasing geoscientific confidence (Unknown, Unusable, Inferred, Indicated and Measured).

Source-to-sink: Understanding of the processes and drivers of sediment erosion, transport, and deposition in the fluvial to marine transition zone over various timescales.

Subdelta: Deltaic sedimentary packages operating on ~200-year timescales, which fill shallow bays flanking major distributaries and form from secondary distributaries. The resulting sedimentary package is usually less than 10 m (33 ft) thick. Subdeltas are fourth-order components in deltaic depositional hierarchy.

Transgression: Landward migration of a shoreline position as land is flooded and an overall deepening of water depth occurs.

Transgressive ravinement: The process of reworking of existing sediment by coastal and marine processes as the shoreline translates landward, resulting in a lag surface, and representing a missing time period of the sediment record.

Transgressive deposit: Deposits resulting from reworking of existing sediment by coastal and marine processes, in this case deltaic headlands, as fluvial input is diminished and abandoned, resulting in the landward translation of the shoreline.

Unknown sediment resources CPRA, 2024): There is no (or very limited) geological evidence and sampling. Quantity and/or quality cannot be estimated. This designation is subject to change if additional geoscientific data become available.

Unusable Resources (CPRA, 2024): Resources that are not suitable for dredging /extraction due to geological characteristics for restoration purposes, e.g., *Fines*: sediment comprised predominantly (>70%) of silt/clay.

List of Abbreviations and Acronyms

ACRE	Applied Coastal and Research Engineering
APTIM	Aptim Environmental & Infrastructure, LLC
APTIM-CPE	APTIM (formerly known as Coastal Planning & Engineering, Inc.)
BICM	Barrier Island Comprehensive Monitoring
BISM	Barrier Island System Management
BOEM	Bureau of Ocean Energy Management
bsfl	Below seafloor
CB&I	CB&I Government Solutions, Inc.
CPE-LLC	Coastal Protection Engineering LLC
CPRA	Coastal Protection and Restoration Authority
ft	Feet
Hz	Hertz
km	Kilometer(s)
ka	Kilo annum (1,000 years)
LASAAP	LouisianA Sediment Availability and Allocation Program
LASARD	LouisianA SAnd Resource Database
LASMP	Louisiana Sediment Management Plan
LSU	Louisiana State University
MCM	Million cubic meters
MCY	Million cubic yards
m	Meter(s)
mi	Mile(s)
MMIS	Marine Mineral Information System
MMP	Marine Minerals Program
NMFS	National Marine Fisheries Services
NOAA	National Oceanic and Atmospheric Administration
OCS	Outer Continental Shelf
OSI	Ocean Surveys, Inc.
PSO	Protected Species Observer
RSLR	Relative sea level rise
RSM	Regional Sediment Management
S2S	Source-to-sink
SWAMP	System Wide Assessment and Monitoring Program
UNO	University of New Orleans
USGS	United States Geological Survey
USACE	United States Army Corps of Engineers

Executive Summary

A core principle of coastal restoration management in Louisiana as led by the Coastal Protection and Restoration Authority (CPRA) in the 2023 Louisiana Comprehensive Master Plan for a Sustainable Coast, referred to as the Coastal Master Plan (CMP), is that restoration-compatible sediment is a scarce commodity to be managed for cost-effective and sustainable protection of coastal communities, resilient infrastructure, and ecosystem restoration. The 2023 CMP identifies a need for ~800 million m³ (MCM; 1,046 million yd³ [MCY]) of sediment for marsh creation and land restoration over a 50-year time horizon (CPRA, 2023). Additionally, it is estimated that ~5–11 billion m³ (6.5–14.4 billion yd³) of sediment could be required to offset future land losses over the next 50 years, with comparatively minimal identified resources available for this purpose (Blum and Roberts 2009; Khalil, Freeman, et al. 2018).

The Louisiana Sediment Management Plan (LASMP) is designed to identify, manage, and efficiently use compatible sediment across the Louisiana coast for restoration. The Louisiana coastal system is divided into several regions based on initial CPRA priorities for mitigating coastal land loss. The first area funded and implemented is composed of Barataria Bay, Terrebonne Bay, and the offshore Barataria Bight and is referred to as Region 1. LASMP regions were initially defined based on funding and project needs, and it is anticipated that the boundaries will be modified to more fully integrate with CMP planning areas in the future. Barataria and Terrebonne basins are identified in the 2023 CMP as having a high demand for compatible sediment and is the focus of this LASMP implementation effort (CPRA, 2023). CPRA considers both sand (70% or greater sand content) and mixed-sediment (30–70% sand) important for barrier island and marsh restoration. The geologic, coastal, and ecological systems of each LASMP region are responsible for the occurrence and relative distribution of sand, silt, and clay. River, delta, and coastal processes interact over time to form and preserve sediment deposits that could be compatible to coastal restoration. Sediment deposits that are documented in this report include ancient, buried river channels and various deltaic deposits found across the Louisiana coast. Understanding where these deposits are located and how much sediment is economically accessible within each is crucial to managing the allocation of sediment resources to maximize coastal resilience.

Understanding where these deposits are located, how much sediment is economically accessible within each, and communicating these findings and actionable next steps to diverse stakeholders and end-users is crucial to building coastal resilience. This study developed a strategic approach to address the following objectives:

1. Analyses of available/existing geotechnical, geophysical, and sedimentological data, construct initial predictive geological models of restoration compatible sediment distribution, and develop field data acquisition plans in consultation with CPRA to maximize value of new data investments and resulting resource inventories.
2. Acquisition and interpretation of new geological and geophysical data that address key sediment resource knowledge gaps as identified in the preliminary predictive geological models.
3. Delineate and characterize sediment resources through refinement of prior sediment resource targets, expansion of existing proven borrow areas, and exploration of new areas with no known identified resources. Subsequent sediment resource inventories include comprehensive assessments including sediment resource plan-form extent, potential volumes, sediment properties, geologic origin and evolution, and other criteria specified by BOEM/CPRA and as data allows.
4. Develop a region-specific predictive geological model that incorporates existing data and studies and new insights provided by LASMP data collection and interpretation. Predictive geological models are intended to aid in the correlation of surficial geomorphic features and subsurface

geology, predict how extensive or variable geological deposits may be across a region, and guide cost-effective, efficient future resource exploration and reduce key uncertainties. These products are intended to be immediately actionable by planners, restoration specialists, and project engineers in guiding where suitable sediment is most likely to occur and streamlining the process of locating sufficient sediment for each restoration project's design requirements.

This investigation provides a cost-efficient resource exploration strategy for future investigators to expand to other areas of Louisiana or modify for different geologic settings. The first task of this holistic approach involved a comprehensive synthesis and reinterpretation of archival data. Over 1,000 sediment core description information, from 28 separate efforts, were recovered from UNO's holdings and digitally submitted to LASARD for public use. Roughly 450 archival cores already available in LASARD and 5,150 km (3,200 mi) of geophysical data collected for regional monitoring under SWAMP and additional data from USGS were also integrated and reinterpreted using all archival data. Previous borrow sites were characterized in a geologic framework based on initial findings, a preliminary geologic model was developed to guide new data collection, and a survey plan was created to refine possible resource extents. Between June and July 2022, personnel from The Water Institute, Louisiana State University, and APTIM collected 394 km (245 mi) of full-suite geophysical data offshore of Barataria Bight. A total of 100 vibrocores were collected by APTIM and UNO between December 2022 and June 2023 to verify sub-bottom interpretations. UNO processed 545 grain size subsamples to verify sediment composition and resource compatibility. Insights to the geologic evolution and timing of the deposits were provided by 42 new radiocarbon estimates. All geoscientific data interpretations led to the development of the LASMP Region 1 predictive geologic model. This simplified visual communication of the complex source-to-sink processes highlights the distribution and composition of sediment resource areas expanded within LASMP Region 1. One goal of LASMP is to develop predictive geologic models for the entire coast of Louisiana to help communicate and manage sediment resources holistically and in an efficient cost-effective manner. This will add to the list of sediment management tools developed during the last two decades like the Delta Sand Search Model, LASARD, and SSD map. The implementation of LASMP Region 1 provides a streamlined sediment resource identification workflow for further development and can be applied to other regions.

A holistic assessment of sediment resource composition, distribution, and inventory of first-order volumes was provided for LASMP Region 1. This investigation mapped three major sediment resource areas that are significant expansions of previously delineated borrow areas, as well as several potential resource areas. The resources are related to subsurface, paleo-distributary mouth bar sand located offshore Barataria Bight and were extended landward to major paleo-distributary networks buried in Terrebonne and Barataria Bays. This investigation characterized a relative hierarchy of distributary channels, demonstrating channels that led to significant offshore sediment deposits. This source-to-approach can guide future exploration strategies.

The West Grand Terre, Scofield, and Sandy Point paleo-delta deposits mapped in this investigation contain an estimated 244 MCM (319 MCY) of sand and 469 MCM (613 MCY) of mixed-sediment resources based on viability criteria determined by CPRA. These first-order estimates are for the expanded area around the dredged pits. These numbers are expected to be greatly refined with future investigation. This investigation also provided estimates for the accessible sediment resources considering dredging exclusion buffers surrounding in-place oil and gas infrastructure as well as proven borrow sites that have been previously utilized and excavated. It is important to account for the accessibility of resources even at the reconnaissance-scale to aid in future investigations and planning decisions. Accessible sediment resources in the Barataria offshore region are estimated to contain 144 MCM (189 MCY) of sand resources and 232 MCM (304 MCY) of mixed-sediment resources. The Scofield and Sandy Point paleo-delta deposits saw the greatest obstruction of available sediment volumes due to the high concentration of in-place pipelines in the OCS West Delta Area. These sediment resource estimates,

constrained by geophysical and geologic sampling, are further de-risked by linking to previously dredged or designed borrow areas. Areas categorized as potential sediment resources were determined using geologic interpretation of geotechnical and sub-bottom geophysical data but did not have the required data density for resource quantification and represent areas for further investment of strategic data collection.

Sediment resource prospecting is an iterative approach and strategies should be continually improved to better utilize allocated funding and timing. Future investigations should employ data collection and survey design recommendations, reference successfully verified seismic-lithofacies, and general prospecting strategies learned through this investigation. These recommendations are detailed in Appendix F. Future research should further develop sediment resources to delineate borrow areas that can be allocated for restoration projects. The proposed inferred sediment resources, such as offshore of the Scofield and Sandy Point paleo-deltas and other local areas should be investigated to assess their viability and potential development.

LASMP provides actionable results and frameworks to support the immediate and growing need for additional sediment resources to reinforce Louisiana coastal restoration goals. This report details the development of LASMP, the implementation of a new predictive approach to sediment resource prospecting, and the outcomes, recommendations, systematically applied to the entire Louisiana coast. Finally, the LASMP Region 1 investigation identifies accessible sediment resource estimates that can be directly linked to stakeholder and project needs demonstrates the restoration-value of holistic sediment management.

1 Introduction

Louisiana's barrier islands, headlands, and wetlands are rapidly eroding and converting to open water in response to high rates of relative sea-level rise (RSLR), diminished sediment supply, and anthropogenic alterations to the landscape that affect hydrology and sediment dynamics. The integrity of these ecosystems as well as the protection they provide to critical infrastructure and over 2 million residents will be compromised without continued commitment by the state and federal partners to mitigate coastal land loss and build resilience. The Mississippi River Delta Plain (MRDP) is sediment-starved relative to the high rates of subsidence, receiving a fraction of river sediment input compared to the pre-levee period (Blum and Roberts 2009). High rates of land loss in part driven by the system-wide sediment deficit requires a comprehensive sediment management plan to support the planning and successful execution of coastal restoration programs. The 2023 Louisiana Coastal Master Plan (CMP) identifies a need for ~800 million m³ (MCM; 1,046 million yd³ [MCY]) of sediment for marsh creation and land restoration over a 50-year time horizon (Coastal Protection and Restoration Authority of Louisiana [CPRA] 2023). Additionally, it is estimated that ~5–11 billion m³ (6.5–14.4 billion yd³) of sediment could be required to offset future land losses over the next 50 years, with comparatively minimal identified resources available for this purpose (Blum and Roberts 2009; Khalil, Freeman, et al. 2018). Compatible sediment resources—“mixed sediment” (30–70% sand content) for marsh creation with enough coarser sediment (70% or greater sand content) for barrier island restoration—are relatively scarce in the muddy MRDP. Transporting sediment from outside of the system (e.g., offshore and riverine sources) is optimal to reduce the sediment deficit; however, it may not be cost-effective to use out-of-system sources for all projects. Therefore, a detailed understanding and evaluation of sediment dynamics, regional sediment budgets, and available sediment resources is critical to the success of Louisiana's restoration program.

The Louisiana Sediment Management Plan (LASMP) was developed by CPRA to inform long term restoration planning and management of scarce and declining sediment resources (Khalil, Freeman, et al. 2018). LASMP is a systematic approach toward a comprehensive regional sediment management (RSM)

strategy (Khalil et al. 2010; Khalil, Freeman, et al. 2018; Khalil et al. 2020; Khalil, Raynie, and Forrest 2023a; Khalil, Raynie, Forrest, et al. 2023b). This holistic RSM approach considers key aspects of successful restoration strategies; including sediment resource inventories, modeling of the benefits and effects of sediment extraction and placement, and comprehensive investigations of the underlying drivers of sediment dynamics. The demand for restoration quality sediment requires managers to strategically allocate sediment dredged from relict geologic deposits across the broader Louisiana coastal zone and the diversion or dredging of modern riverine sediment to alleviate land loss and associated impacts. LASMP provides the framework to efficiently identify sediment resources and inform iterative development of those resources.

Crucial to LASMP is the integration of CPRA investments in past projects and programs that were designed to allow the eventual development of a holistic sediment management approach. These key programs and datasets include the Louisiana Sand Resources Database (LASARD), the Barrier Island Comprehensive Monitoring Program (BICM), and the System-wide Assessment and Monitoring Program (SWAMP), among others. LASARD catalogs and characterizes on a regional scale surficial sediment caliber and distribution as well as provides a data portal to the location of geophysical and geotechnical datasets (Khalil et al. 2010; Underwood 2012; Underwood et al. 2015; Khalil, Forrest, et al. 2018; Khalil et al. 2020; Forrest et al. 2023). BICM provides data documenting trends in long- and short-term barrier island system sediment dynamics and large-scale coastal behavior (Miner et al. 2009; Raynie et al. 2020). As part of SWAMP (Raynie et al. 2020), a comprehensive hydrographic and geophysical dataset for coastal Louisiana was collected (CB&I 2016; APTIM 2019). The geophysical data collected as part of SWAMP are leveraged by LASMP here to create an inventory of sediment resources. A fundamental underpinning of LASMP is that the goals and outcomes of these investigations have immediate, actionable utility to broader planning, engineering, ecosystem restoration, geoscientific, and management end-users. The incorporation of datasets and drivers of sediment needs framed by these stakeholders helps differentiate LASMP from solely research focused investigations.

LASMP divided the Louisiana coastal system into six regions and was developed and later implemented in phases based on initial CPRA priorities for mitigating coastal land loss. Barataria Bay, Terrebonne Bay, and the offshore Barataria Bight represent one of the most deserving areas of need for restoring coastal systems and offsetting sediment deficits and comprise Region 1 of the LASMP planning areas (Figure 1). Region 1 is the first implementation of the LASMP approach to develop a predictive geologic model. A predictive geologic model allows for a science-driven approach to sediment resource exploration based on source-to-sink concepts to deliver sediment inventories that can be linked to planned restoration projects as well as predictive geologic models to inform economic investment in future geotechnical data collection. Additionally, the underlying technical work provides new insights of regional sedimentary processes and impacts. Together, these provide an actionable path forward for diverse users and stakeholders including the engineering, planning, ecosystem restoration, and management communities. This approach is designed for portability and application to the entirety of the Louisiana coast and serve as an innovative model to the coastal restoration community. This data synthesis, new data collection, and comprehensive geologic framework understanding of each region can provide the foundation for advancing other key CPRA initiatives such as operational sediment budget updates and input to the CMP development process (Reed and Yuill 2017; ACRE 2018; Fitzpatrick et al. 2020; The Water Institute 2023a). (Reed and Yuill 2017; ACRE 2018; Fitzpatrick et al. 2020; The Water Institute 2023a).

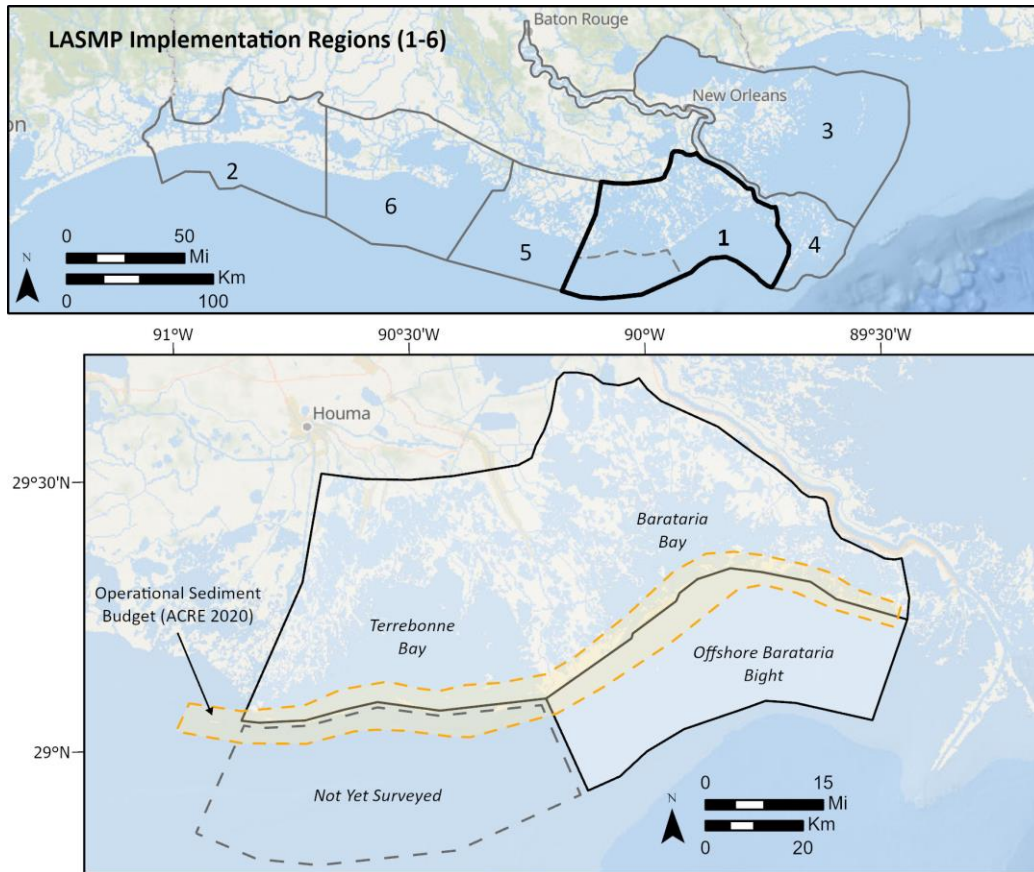


Figure 1. Map of the Louisiana Sediment Management Plan implementation regions highlighting current investigation area, LASMP Region 1. Sediment resources were assessed within Terrebonne and Barataria bays and the offshore Barataria Bight focus areas

Important to maximizing the investment of limited restoration funding is providing actionable data to planners and project engineers. LASMP is designed to advance not only sediment resource inventories but also anticipate the potential benefits of their use in coastal restoration projects. Two complementary projects assessed scenarios of borrow pit evolution and potential effects of renewable riverine and non-renewable in-system (within Barataria Bay) sources (The Water Institute 2023b; The Water Institute 2023c) to aid in resource allocation and management decisions. The first study designed a hypothetical in-system borrow site based on newly identified potential mixed-sediment resources from initial results of this LASMP investigation. The evolution of the borrow pit and what effect its presence had to the broader Barataria Bay and coast in terms of tidal prism, possibility to capture sediment otherwise lost from the system, and other management parameters were modeled using an advanced Delft3D-FM landscape evolution approach (The Water Institute 2023b). The second study used observations and numerical modeling to estimate infilling rates of in-river pits within the Lowermost Mississippi River. It also assessed whether upstream point bar dredging appreciably reduces the rate of downstream deposition and required navigation maintenance dredging which could provide significant cost savings (The Water Institute 2023c). This multi-objective approach showcases the utility and effectiveness of LASMP as a holistic, science-based, management framework.

The U.S. Department of Interior, Bureau of Ocean Energy Management (BOEM) is responsible for managing offshore sediment resources in Federal waters and (along with its predecessor agency, Minerals Management Service) has partnered with Louisiana for over two decades in developing an inventory of offshore sediment resources in Louisiana for coastal restoration. CPRA work helped to emphasize that sediment resource management has impacts across jurisdictions, and that BOEM interests in stewardship

of federal resources are served by Louisiana's proactive leadership in identifying state resources and placing all sediment sources (state waters, federal waters, and in-river sources) into a holistic context. The approach developed in the LASMP, such as predictive geologic model driven resource evaluation, helps ensure sustainable management of finite sediment resources for coastal resiliency and should serve as a model for best practices within other states as well as policies proposed at the federal level through BOEM's National Offshore Sand Inventory (NOSI). The NOSI management framework mirrors many concepts implemented by LASMP and aims to provide a standardized approach to managing sediment resources on the Federal Outer Continental Shelf (OCS) by meeting the growing demand of OCS sediment through targeted new data investments driven by science-based resource occurrence frameworks linked to national coastal restoration needs. Accurate assessments of proven and potential resources within the continental shelf are also required to manage the potentially growing multi-use conflicts emerging through wind energy installations, transmission corridors, offshore carbon capture use and sequestration (CCUS), and other stakeholders of the shelf region. The scale of unmet sediment demands for Louisiana will likely require the use of state and federal resources, and LASMP Region 1 has identified new significant sediment resource inventories across jurisdictions. LASMP provides a model of science-informed sediment prospecting, economically effective management, and mutual benefit across jurisdictions.

The current inventory of restoration-quality sediment resources does not meet the demand needed for planned and future restoration projects in coastal Louisiana, especially in Barataria and Terrebonne Bays and offshore of the Barataria Bight. This investigation aims to efficiently identify and characterize sediment deposits to create actionable sediment resources and reserves using a science-based approach. The following hypotheses were proposed:

1. Large volumes of unconventional sediment resources related to subsurface, paleo-distributary mouth bar sands are located offshore Barataria Bight and may serve as a valuable sediment resource.
2. Paleo-distributary networks extend from Terrebonne and Barataria Bays into the offshore region and are major sediment pathways for paleo-mouth bar deposits. Characterization of these paleo-distributaries may aid in exploration strategies.
3. A detailed evaluation of geological data will reveal distinct depositional sinks and sources of erosion, as well as quantify textural distributions, ultimately providing insight for sediment management decisions along the highly dynamic central coast of Louisiana.

In order to achieve the objective of the investigation, initial tasks required a comprehensive data compilation, recovery, and reinterpretation of historical spatial geological and geophysical data sets to build an initial predictive geologic model of the region. The second task involved targeted geophysical and geological data collection, reducing uncertainty regarding resource areas and filling critical data gaps identified in task one. A regional geologic framework of the central coast was generated conceptualizing source-to-sink processes and highlighting the distribution and composition of unidentified sediment resource areas within Region 1 as a third task. A fourth task provided a holistic assessment of sediment resource composition, distribution, and inventory of first-order volumes based on new and legacy data. The final task of the report includes cataloging all data and interpretations in spatial databases for use in future investigations and coastal management decisions. The results provided will inform science-based management decisions critical to the implementation of the CMP, improve resource exploration strategies, and can be expanded to other basins.

2 Geologic Setting of the Study Area

A holistic RSM approach such as LASMP requires a scientific framework of geological processes responsible for the creation and evolution of the current landscape and near subsurface. This study delivers a synthesis of the region's geology, with an emphasis on implications for sediment resource occurrence and prediction. LASMP Region 1 encompasses Terrebonne and Barataria bays, the Barataria Bight and the Bight's offshore region located between the modern Mississippi River and Morgan City, Louisiana (Figure 1). The bays are sheltered from the Gulf of America by 165 km of a series of highly dynamic barrier islands and deltaic headlands spanning from Raccoon Point to Sandy Point. Subsidence rates within Terrebonne and Barataria bays generally increase southward toward the modern coastline, ranging from ~4–8.5mm/yr., with RSLR rates at Grand Isle as high as 9.2 mm/yr. (ACRE 2022). The high rates of RSLR and minimal sediment input, combined with recurrent tropical storms and annual passage of 10–30 winter frontal systems force high rates of shoreline erosion, landward migration and fragmentation of barrier islands, increased tidal prism, deepening and widening of tidal inlets, and conversion of inland and backbarrier wetlands to open water (Georgiou et al. 2005; FitzGerald et al. 2007; Miner 2007; Miner et al. 2009). From 1932–2016, roughly 1,302 km² and 1,120km² of land has been converted to open water in Terrebonne and Barataria basin, respectively (Couvillion et al. 2017). These rates of land loss and associated degradation of local community protection, thriving bay ecosystems, and resilient economic futures emphasize the importance of LASMP Region 1 in addressing these challenges.

2.1 The Delta Cycle and Mississippi River Delta Plain Development for Terrebonne and Barataria Basins

The following provides a generalized synthesis of the delta cycle, key geomorphic and sediment transport processes, and Mississippi River Delta geologic history that together are necessary for understanding why specific sediment resources were located, formed, and preserved in each location of the study area. The Holocene MRDP evolved over the past ~8,500 years by deposition of multiple, spatially and temporally offset, *deltaic depocenters* (location where deltaic deposition is concentrated) fed by a network of distributary channels to construct a *delta complex* (Russell 1936; Fisk 1944; Kolb and Van Lopik 1958; Frazier 1967; Coleman 1982; Roberts, 1997). Over time, the location of the deltaic depocenter shifted (*delta switching*) due to upstream river *avulsions* that involved abandonment of a major distributary channel for a new, more hydraulically efficient route. With each avulsion event, a new distributary network was formed resulting in an upstream shift in the location of the depocenter and the birth of a new delta complex. After a river avulsion, as the new distributary grows seaward, the deltaic depocenter shifts closer to the coast and ultimately onto the shelf as open-water *accommodation* is filled with new deltaic deposits. This process of seaward delta growth is termed *progradation* and produces *regressive* deltaic deposits. Capture of flow by the new distributary results in reduced sediment delivery from the river to the former depocenter and ultimately *fluvial abandonment* of the older delta complex. Reduced fluvial sediment supply results in erosion of the former delta by marine processes such as waves, tides, and storms to create sandy *transgressive* coastlines that migrate landward. This landward-encroaching zone of erosion along the transgressive coast results in *transgressive ravinement*, destruction and reworking of the former delta deposits and concentrating sands as *transgressive deposits* such as barrier islands and headlands, tidal deltas, and submarine shoals. Due to high rates of RSLR in the rapidly subsiding delta plain, as fluvial sediment supply is reduced to the abandoned delta complex, interior wetlands convert to open water bays and lagoons and freshwater wetlands become more saline. In this way, transgression manifests in the abandoned delta complex not only by erosion along the retreating coast, but also by disintegration of delta plain interior as former wetlands are converted to open water. This results in the creation of accommodation space for the regressive deposits of a new delta complex to fill, bypassing the transgressive shoreline reworking the abandoned complex, and prograding onto the shelf. This process of delta growth and subsequent destruction by marine processes is termed the *delta cycle* (Roberts 1997) and

produces a complex stratigraphy often comprising multiple, stacked sequences of regressive deposits truncated by transgressive ravinement, sometimes with locally concentrated transgressive coastal deposits. An understanding of the delta cycle and the stratigraphy produced is critical to sediment resource prospecting in Louisiana and reinforces the value of a source-to-sink (S2S) approach to predict occurrence of high-quality sediment resource deposits.

The Holocene MRDP consists of six delta complexes: Maringouin (7,500–5,000 yrs ago¹), Teche (5,500–3,800 yrs ago), St. Bernard (4,000–2,000 yrs ago), Lafourche (2,500–400 yrs ago), Plaquemines-Balize (1,000 yrs ago–present), and Atchafalaya (400 yrs ago–present; Kolb and Van Lopik 1958; Frazier 1967; Penland, Boyd, et al. 1988; Tornqvist et al. 1996; Roberts 1997; Coleman et al. 1998). Each delta complex consists of smaller scale delta lobes. Frazier (1967) identified the spatial extent and chronology of 16 delta lobes, 14 of which are associated with the Teche, St. Bernard, and Lafourche complexes (Figure 2).

Additionally, smaller scale subdeltas and localized crevasse- or overbank-splays may develop as secondary channels within individual delta lobes. This hierarchy of deltaic landforms proposed by Roberts (1997) captures the concept of larger deltas being made of smaller deltas that collectively represent the constructive regressive phase of the delta cycle (Figure 3).

At times, delta switching initiated by an avulsion is gradual as flow of the main distributary may be simultaneously shared between two (or more) active deltaic depocenters (Penland and Boyd 1985). Abandoned deltas also continue to evolve through wave and tidal processes reworking and winnowing sediment sourced from the regressive deltaic headland into flanking and eventually barrier islands as outlined in Figure 4; Penland et al. (1988); and Scruton (1960). The accommodation created by these transgressive processes and subsidence may later allow reoccupation by younger complexes exhibiting regressive sedimentation (Boyd and Penland 1988). Due to the high rates of RSLR and rapid sediment burial there is high preservation of subaqueous regressive deposits that lie below the depth of transgressive ravinement, such as deltaic mouth bar and channel fill facies. However, incomplete preservation of the regressive delta sequence is common due to the reoccupation or cross-cutting of abandoned distributaries by new delta lobes or the truncation of distributaries due to storm and wave processes. Overall, these processes have produced a dynamic and stratigraphically complex depositional environment, with unique patterns of local sediment composition and sequestration across the study area.

¹ Years before present (years BP; with “present” being 1950 Common Era)

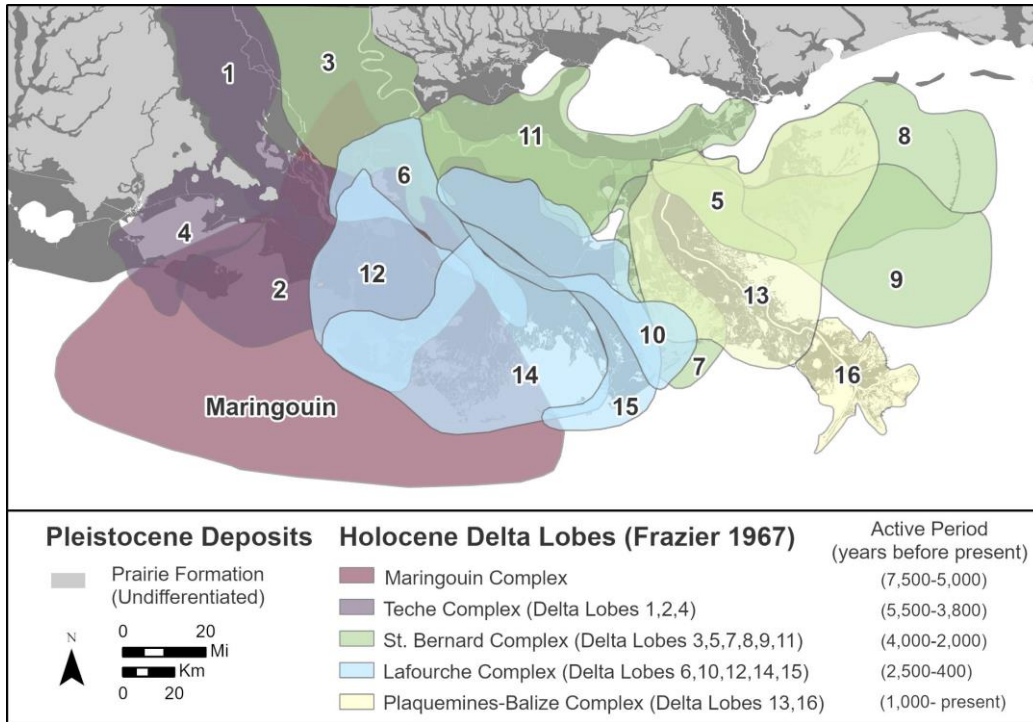


Figure 2. Delta lobes of the Maringouin, Teche, St. Bernard, Lafourche, Plaquemines-Balize complexes (modified from Frazier 1967)

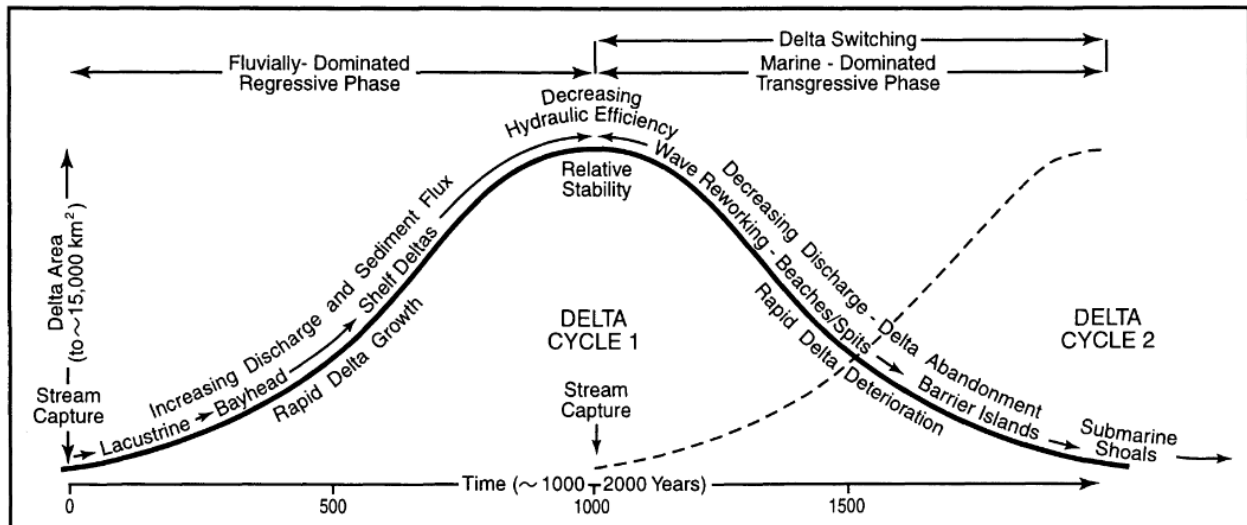


Figure 3. The Delta Cycle. Initial delta growth and high rates of sediment flux to the coast define the regressive phase, while decreasing discharge, sediment delivery, and eventual delta abandonment and erosion form the transgressive phase. From Coleman et al. (1998). Modified from Roberts (1997)

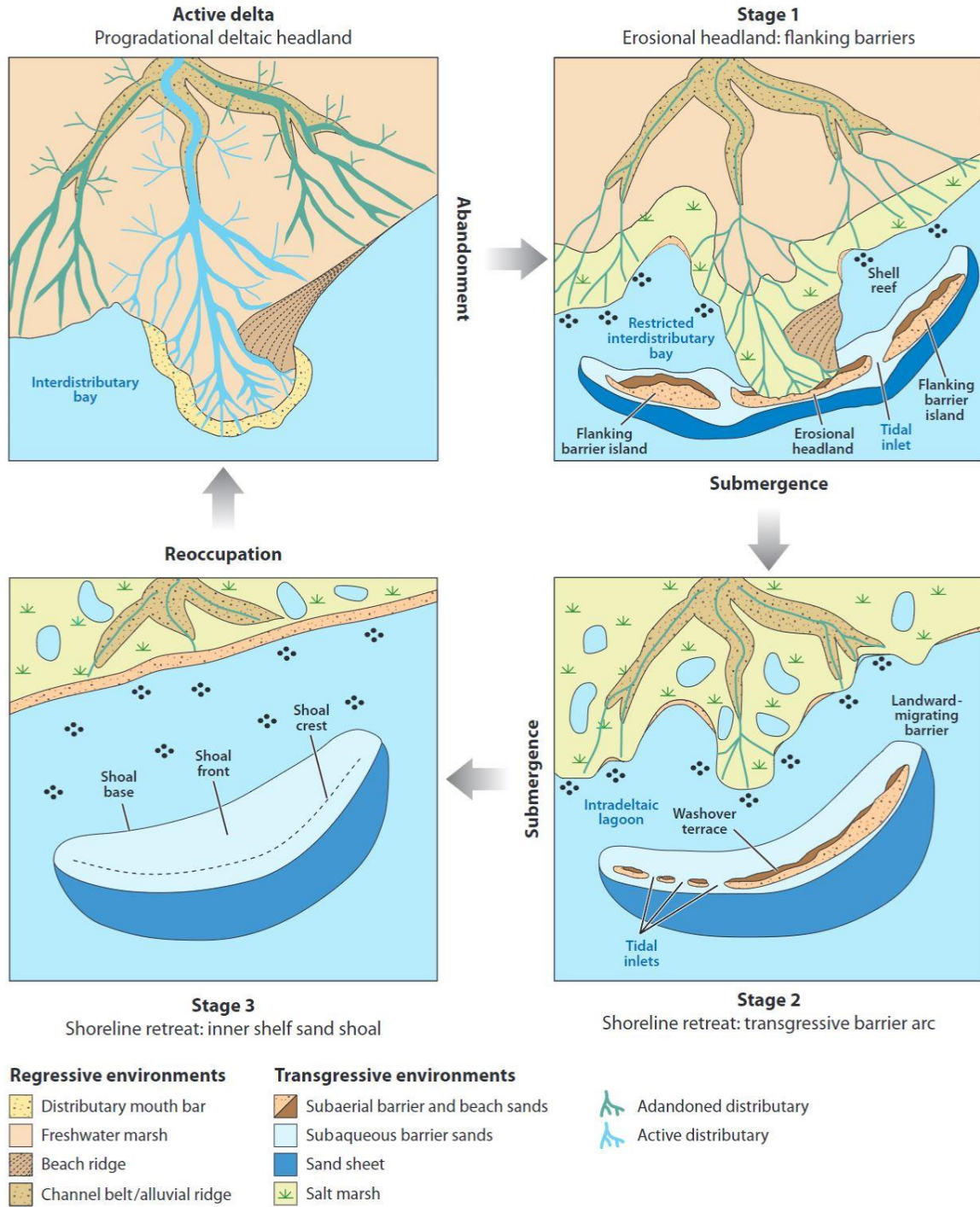


Figure 4. The conceptual delta cycle displays the evolution of a prograding delta undergoing abandonment after an avulsion. Stage 1 displays an actively prograding delta, delivering coarse-grained sediments to the coast. As fluvial input diminishes, the deltaic headland is reworked by coastal processes creating flanking barrier islands (Stage 2). The headland undergoes transgressive submergence, where the land area subsides and is continually reworked. The marsh shoreline translates landward creating a barrier island chain detached from the mainland (Stage 3). Continued transgressive submergence results in an inner shelf shoal, completely reworked by marine processes (Stage 4). The accommodation created can lead to reoccupation of deltaic deposition (from Blum and Roberts 2012; modified from Penland et al. 1988)

2.1.1 Terrebonne and Barataria Bays Regional Geologic Setting

The Terrebonne and Barataria basins are located in south-central Louisiana and consist of overlapping delta lobes of the Maringouin-Teche, Lafourche, St. Bernard, and Plaquemines delta complexes (Frazier 1967). The Teche Delta was actively prograding into shallow water bay environment from 5,800 to 3,500 years ago (McFarlan 1961; Frazier 1967; Smith et al. 1986). Major distributaries trend southeast, extending from the Bayou Black trunk channel of Teche-Mississippi River course (Smith et al. 1986; Figure 5) suggesting the Teche depocenter was located near Terrebonne Bay (Weinstein and Gagliano 1985; Penland et al. 1987). Regressive Teche deltaic deposits are 10–12 m (32–39 ft) thick on average (Figure 6). The St. Bernard delta complex progradation began around 4,000 years ago when an avulsion upstream diverted dominant river flow from the Teche course to the east (Frazier 1967). The Bayou Des Families lobe of the St. Bernard delta complex was actively prograding within Barataria Basin between 3,600 and 2,000 years ago (Frazier 1967; Figure 5). Bayou des Families built seaward past the site of Grand Isle (Penland and Boyd 1985), likely creating an extensive deltaic headland system. Buried channel-form morphologies associated with this lobe are identifiable in geophysical data within Barataria Bay, and are likely genetically connected to depositional features offshore of the modern shoreline (Kindinger et al. 2001; Flocks et al. 2006). Meanwhile, the abandoned Teche Delta experienced transgressive submergence, as waves and currents reworked the upper portions of the delta complex. The landward translation of the Teche deltaic shoreline reached as far north as Lake Penchant, marked by a transgressive beach truncating the Teche distributaries (McIntire 1958; Smith et al. 1986; Figure 5). The resulting regional ravinement surface is commonly represented by a coarse-grained shell lag deposit and is correlated throughout most of Terrebonne and some of Barataria Basins (Kosters 1987; Penland et al. 1987; Penland, Boyd, et al. 1988; McBride et al. 1990; Kosters and Suter 1993). The Teche ravinement surface deepens seaward, mapped at 9 m (30 ft) underlying Isles Dernieres and 10 m (33 ft) underlying Ship Shoal (Penland et al. 1987; Figure 6) but is less constrained in southern Barataria Bay. This regional unconformity separates Teche age deposits below and overlying bay and deltaic deposits above and have formed between ~3,000 and 2,000 years ago (Penland et al. 1987; Boyd et al. 1989; Kosters and Suter 1993).

Approximately 2,500 years ago flow shifted back toward the Terrebonne region following an avulsion near Donaldsonville (Figure 5). The newly active Lafourche delta complex began to build seaward into the accommodation created by transgressive submergence of the Teche complex (Smith et al. 1986). Four delta lobes, Bayou du Large (active 2,490 to 1,620 years ago), Bayou Terrebonne (active 2,600 to 830 years ago), Bayou Grand Caillou (active 910 to 400 years ago), and Bayou Lafourche (active 710 to 300 years ago) radiated into the shallow bay environment from a bifurcation point near Thibodaux (Penland et al. 1987; Figure 5). More recently, mouth bar sand related to Lafourche complex progradation is ~1.3 to 2.9 m thick and demonstrated fluvial input and sediment dispersal was active simultaneously between major distributaries of the Lafourche complex (Chamberlain et al. 2018). Diminished flow between various lobes of the Lafourche complex resulted in transgressive processes translating deltaic shorelines landward resulting in separate transgressive paleo-shorelines (Penland et al. 1987). The Terrebonne shoreline, which is landward of the modern shoreline and is 5–10 m (16–32 ft) thick, consists of Caillou Island, Brush Island, Casse-tete Island, and Fifi's island (north side of Grand Isle), and is a result of the abandoned and reworked Bayou Blue (active 2,600 to 1,200 years ago) and Pointe-au-Chien (active 1,270 to 830 years ago) subdeltas of the Terrebonne delta lobe (Penland et al. 1987). The formation of the Terrebonne shoreline is further supported by the formation of brackish to salt marsh between 400 and 700 years ago in the backbarrier (Culling 2018). This major geomorphic feature displays discrete paleo-tidal inlets and paleo-tidal deltas formed during transgressive reworking of deltaic deposits (Kulp et al. 2002).

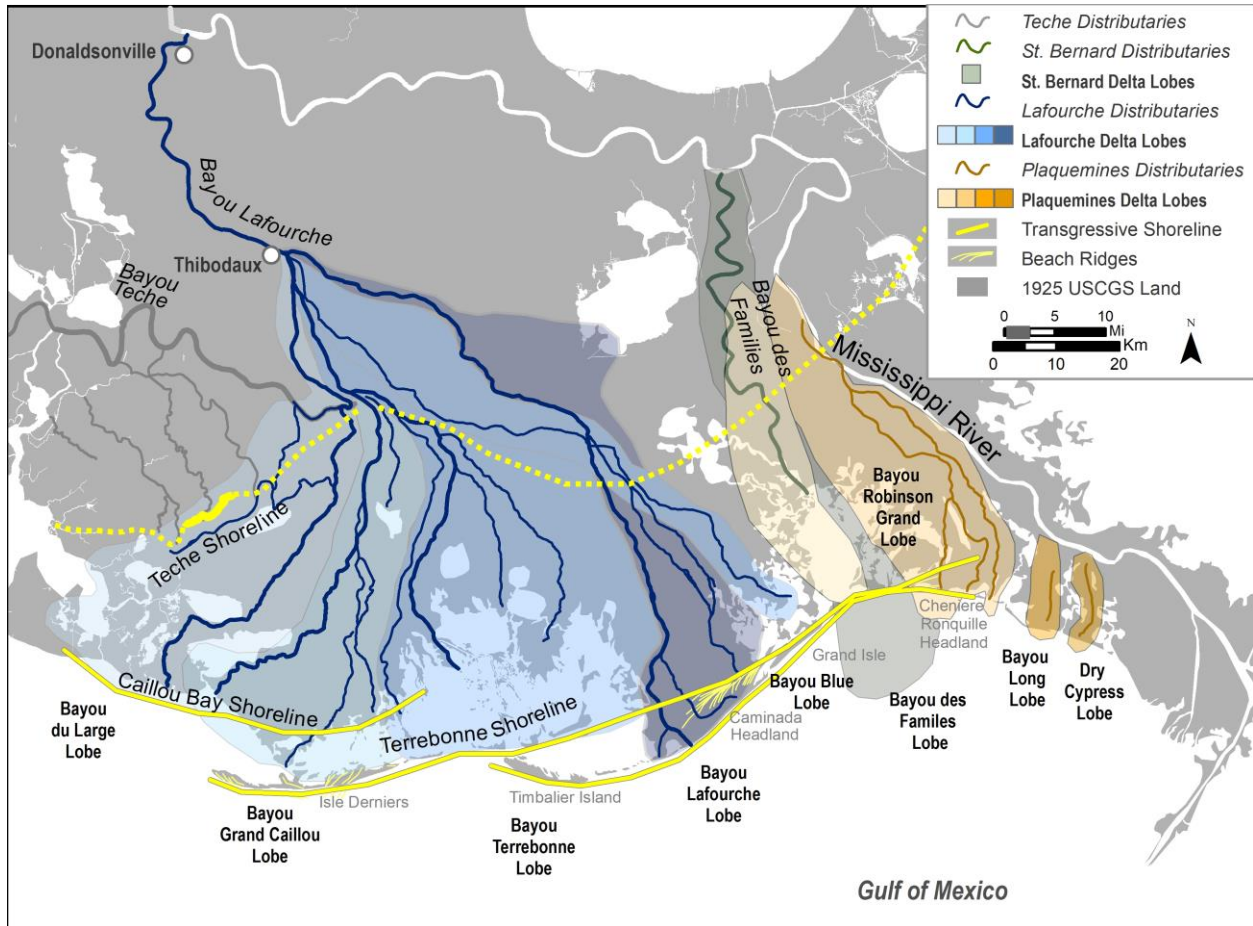


Figure 5. Geomorphic features related to phases Mississippi River delta development, abandonment, and reworking in Terrebonne and Barataria Basins. Deltas lobe related to the St. Bernard and Lafourche delta complex are represented by cooler colored polygons while delta lobes related to the Plaquemines delta complex are highlighted in warmer colors. Transgressive shorelines and beach ridge deposits are shown in yellow. The inferred Teche shoreline is indicated by dashed a yellow line (Modified from (Smith et al. 1986; Penland et al. 1987; Levin 1991; Kulp et al. 2005; ACRE 2021)

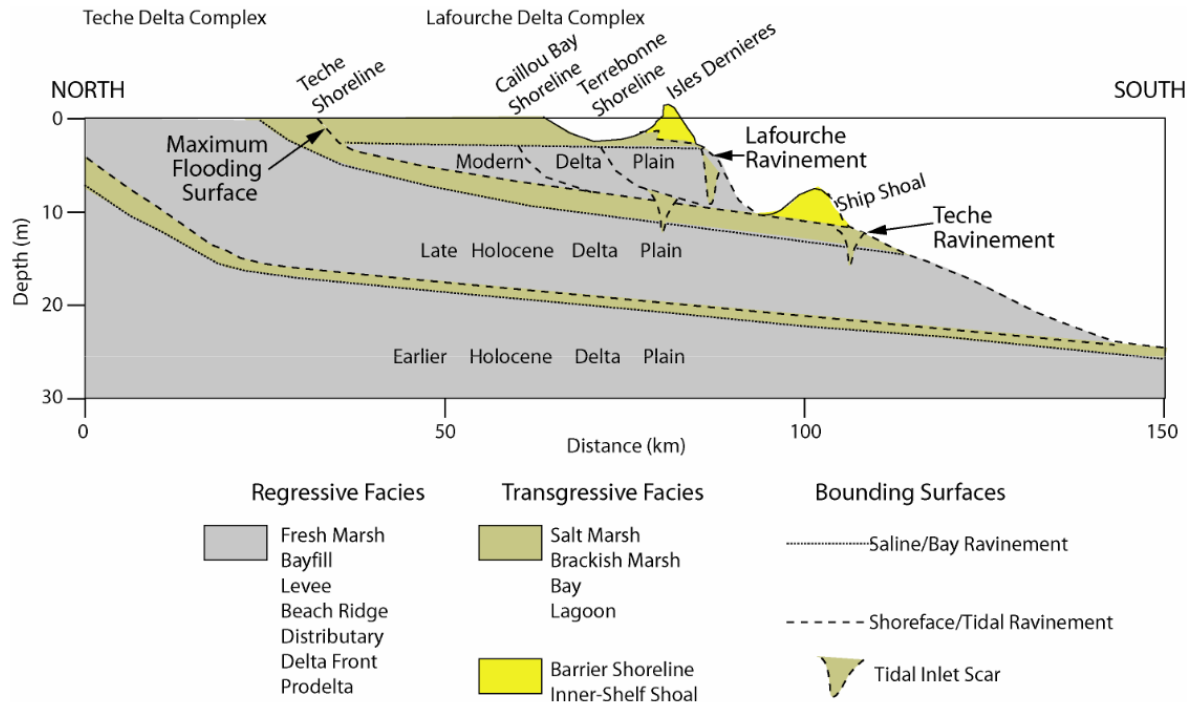


Figure 6. Idealized cross-section of the Caillou Headland (Figure 2), displaying regressive deposits related Teche and Lafourche delta complexes separated by transgressive facies and regional erosional unconformities. The seaward dipping Teche regional ravinement surface is the result of transgressive submergence processes acting on the Teche Delta. The accommodation space created allowed for reoccupation of regressive Lafourche deposits. Subsequent phases of transgressive reworking of younger Lafourche delta lobes supplied coarser-grained sediment to littoral systems, resulting in the relict Caillou and Terrebonne shorelines (From Miner 2007; modified from Penland et al. 1987)

Around 950 years ago, the Plaquemines delta lobe began its advance into eastern Barataria Basin (Frazier 1967). This was concurrent with the progradation of the Bayou Lafourche and Bayou Grand Caillou delta lobes of the Lafourche Complex beyond the Terrebonne shoreline (Kulp et al. 2005). The Plaquemines lobe featured southeast trending major distributaries, including bayous Robinson, Grand, Long, and Dry Cypress, which rapidly prograded over the subsided delta lobes of the St. Bernard Complex (Flocks et al. 2006; Penland & Boyd 1985; Saucier 1994; Figure 5). These distributaries likely received the majority of the flow from the mainstem of the Mississippi River during this time. Abandonment of Bayou Lafourche around 300 years ago in favor of the Plaquemines/modern Mississippi main trunk distributary initiated transgressive reworking of the delta lobe and development of the transgressive Caminada Headland. As the headland erodes through transgressive ravinement, it sources sand to the coastal system that is transported laterally by wave-induced longshore currents to form the flanking barrier islands of Grand Isle to the east and the Timbalier Islands to the west (Penland and Boyd 1985; Kulp et al. 2005). In some cases, reworked deltaic headlands provide the sediment to produce beach ridge complexes on updrift sides of newly prograding delta lobes (Kulp et al. 2005). The relatively recent progradation of the Bayou Grand Caillou and Bayou Lafourche deltas (Lafourche Complex) and Bayou Robinson and Grand Bayou deltas (Plaquemines Complex) captured sediment transported alongshore to create the Caillou beach ridges, Caminada-Moreau, and Cheniere Ronquille beach ridge complexes (Kulp et al. 2005).

The geomorphology of the prograding Plaquemines Delta changed dramatically when it neared the shelf edge around 300 years ago, marking the initiation of the Balize or modern delta lobe, often referred to as the Birdfoot Delta due to its shape (Coleman and Gagliano 1964; Frazier 1967; Saucier 1994). The modern Birdfoot Delta represents the deepwater, shelf edge delta model of Fisk (1961), with thick, elongate, mouth bar “finger” sands. This architecture contrasts to the shallow water or lobate deltas of the previously mentioned Teche, St. Bernard, Lafourche, and Plaquemines delta complexes, where mouth bar sand forms “delta front sand sheets” due to the numerous terminal distributaries and coalescing nature of the deposit due to waves and currents and limited accommodation space due to the shallower shelf (Fisk et al. 1954). The variable architectures of these delta models (Figure 7) are largely controlled by the accommodation space (water depth) of the receiving depocenter (Fisk et al. 1954; Fisk 1961; Kulp et al. 2005). The interplay of regressive fluvial input delivering sediment to the coast and transgressive ravinement redistributing, or partially preserving, those sediments as depocenters shift creates a complex evolutionary story of the deltaic plain of Louisiana’s coast. The resulting stratigraphy of Terrebonne and Barataria basins represent episodes of regressive and transgressive phases creating discrete coarse-grained deposits in a mud-dominated deltaic environment (Kindinger et al. 2001).

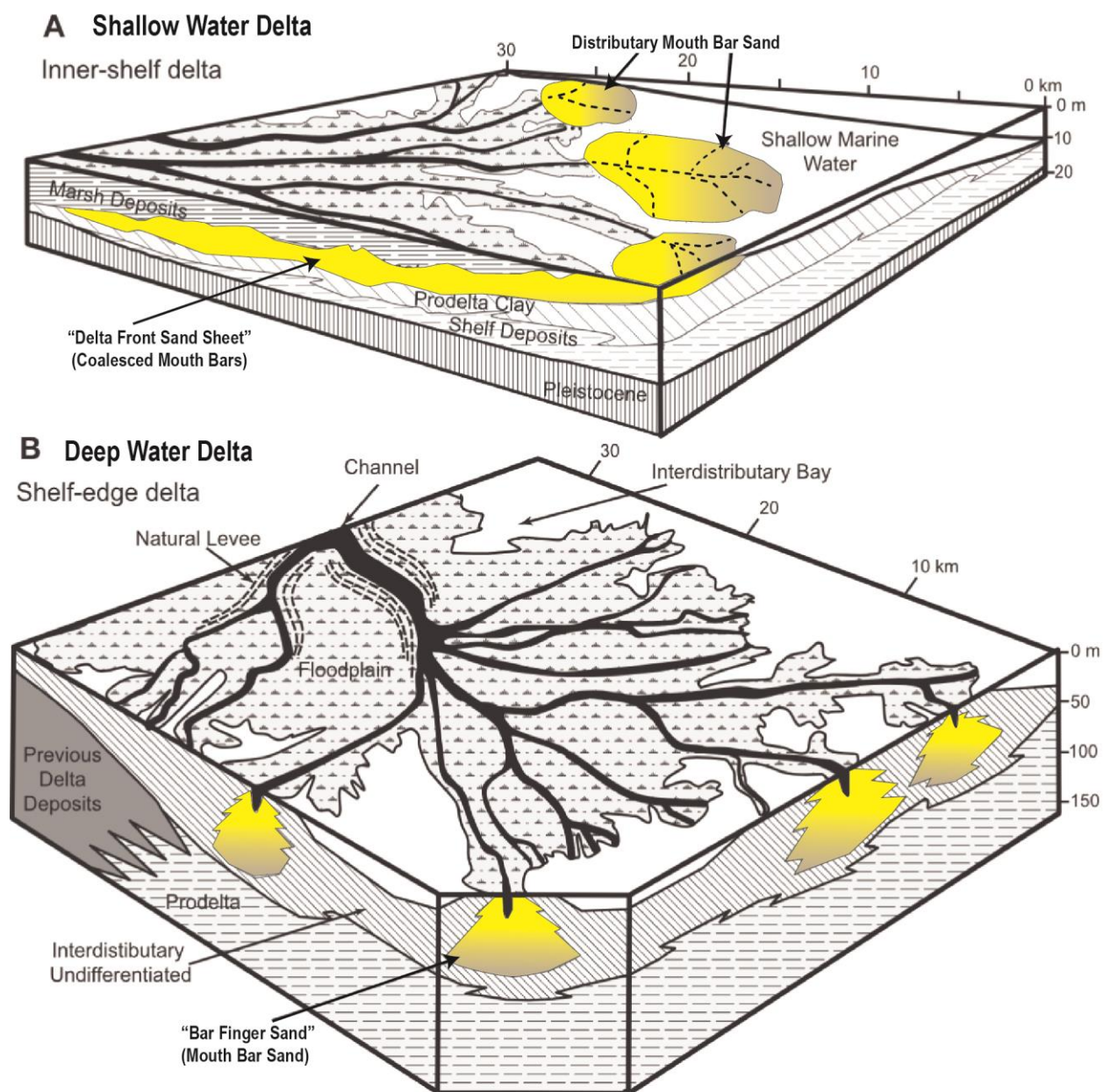


Figure 7. Shallow and deep-water delta models, yellow color highlights sand-rich mouth bar deposits and geometries in deltaic systems (Modified from Kulp et al. 2005; Fisk et al. 1954; Fisk 1961)

3 Sediment Resource Prospecting Approach and Methodology

3.1 Predictive Methodology to Advance Sediment Resource Prospecting

The growing demand for sand and mixed sediment in Louisiana to support the CMP has increased significantly to fulfill the restoration goals. Much of offshore resource prospecting in Louisiana, and nationally, has traditionally targeted surficial sand (e.g., Ship Shoal) as well as buried paleochannel deposits located in the uppermost subsurface geology of the continental shelf. Typical of these investigations is a geophysical and/or geotechnical data collection campaign attempting to find sediment linked to a specific planned project (e.g., West Grand Terre; OSI 2019). This approach often leverages existing practitioner and academic knowledge of the geology of the region and its potential to host required sediment, and can be further refined by previous large-scale reconnaissance datasets (Kindinger et al. 2001; Flocks et al. 2006). While having been successful in finding necessary sediment and enabling numerous projects across Louisiana and the nation, these discrete and project-focused investigations are not commonly placed into the broader regional framework in a way that supports the prediction of undiscovered sediment resources. LASMP provides the platform to advance sediment resource prospecting by leveraging the opportunity created by CPRA’s regional monitoring programs, SWAMP and BICM, and the geoscientific database LASARD, among others. This plan also provides a holistic approach to sediment resource exploration that includes a portable workflow to build predictive geologic models that provide a roadmap for efficient future data investments (Figure 8). Existing proven resources and potential deposits are placed into a unified framework that can help understand why sand and mixed sediment are located in specific areas and where to go to locate more, what regions are not likely to have resource occurrence, de-risk uncertainty regarding overburden dredging limitations and likely geotechnical compatibility of an identified resource, and provide meaningful advancement in outstanding scientific questions regarding the nature and processes of these coastal and deltaic environments.

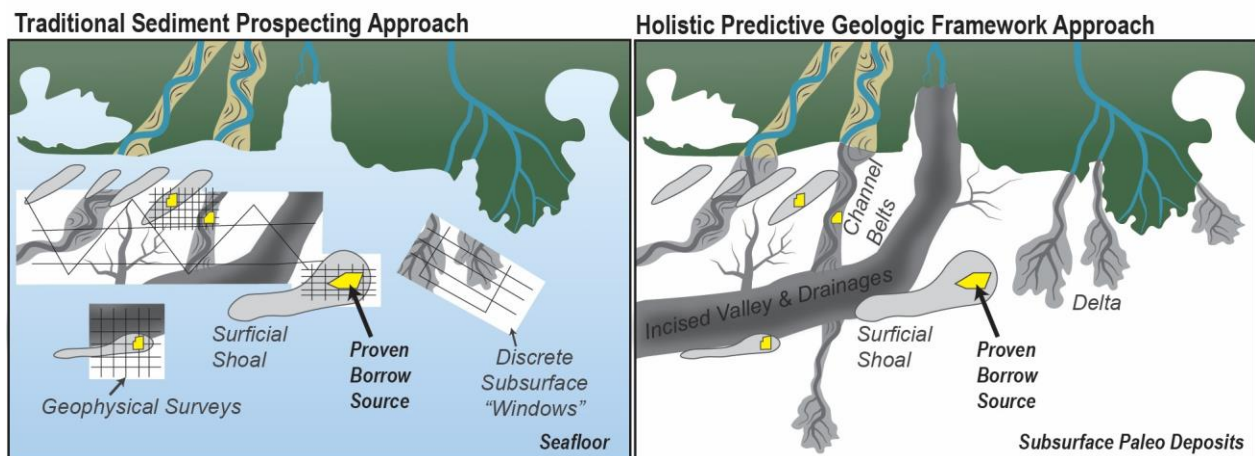


Figure 8. Left panel shows a series of disconnected reconnaissance and project scale sediment investigations providing localized but detailed views of the subsurface geology and surficial deposits. Right panel shows the holistic synthesis of these previous investigations into an initial geologic framework and predictive geologic model details the genetic links to the distribution of particular sediment and their viability as resources, allows for the expansion of proven borrow sources, and provides a predictive tool of where to invest for the future development of new resources

The predictive geologic model approach to sediment resource prospecting incorporates a series of high-level steps and workflows (Figure 9):

1. Compilation of available legacy datasets, whether collected specifically for sediment resource evaluation or others that can be useful, and synthesis of available geologic studies or other knowledge sources that provide understanding into the current and past processes and geologic history of the chosen region. This step includes elements of what is commonly referred to as a desktop analysis in prior investigations, but crucially includes new analyses and synthesis of archival data and reports where required.
2. Identification of proven borrow sites or mapped potential resource areas if any exist, characterization of their geologic origin, and initial placement into a regional context. This step includes initial reanalysis of original datasets and investigations where possible.
3. Construction of an initial geologic framework using the data sources, literature, and state of knowledge compiled previously. This framework includes an assessment of the region’s geologic history, major depositional units and their formational processes, differentiation of the region based on likely subsurface geology, and first-order assessments of the explanatory power of these compilations in explaining available proven projects and ground-truth data.
4. Strategic data collection in the most promising areas predicted by the initial geological framework. Sub-regions can be targeted based on likelihood of resource occurrence and specific questions regarding possible resource types or other stakeholder interests answered. This strategic approach helps ensure that often limited data collection funds are thoughtfully invested to maximize their impact on regional goals.
5. Development of predictive geologic models based on the strategic data collection results. Initial high-uncertainty variables such as “fuzzy” boundaries between depositional units, geomorphologic process regimes, or limiting factors in resource accessibility can be refined.
6. Sediment resource quantification and inventory assessment. New and prior datasets are combined to delineate and quantify specific sand and mixed sediment resources where possible. Maps and geospatial products of resource location and boundaries are created, along with volumetric estimations, geotechnical properties, and overburden factors. Where it is not possible to fully quantify a sediment resource, interpretations and geospatial products are produced of lower confidence, indicated or inferred sediment resource occurrence or, equally importantly, areas of likely absence of sediment resources (CPRA 2024). These provide a roadmap to inform future targeted strategic investigations driven by stakeholder needs (step 4).

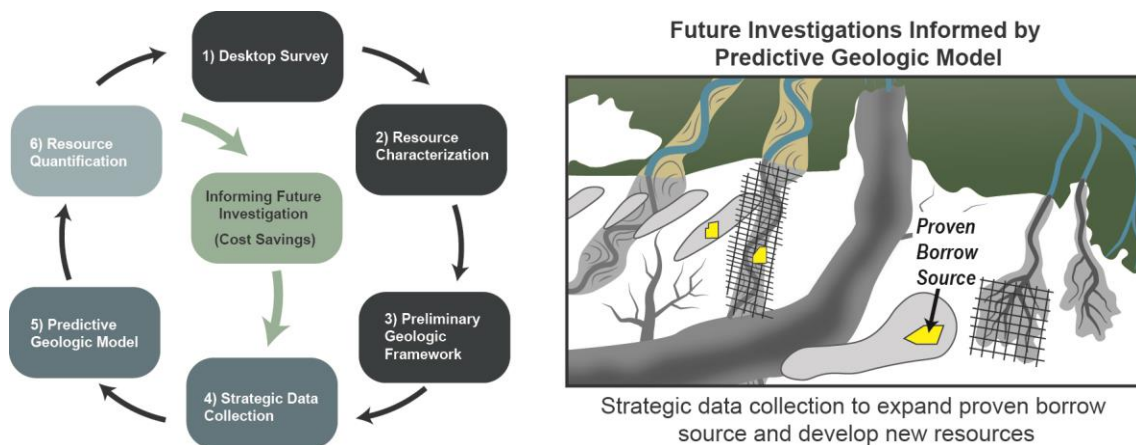


Figure 9. Schematic illustrating the predictive geologic model approach to sediment resource prospecting and its potential cost savings by informing more detailed investigations to develop sediment resources into sediment reserves. This transferrable methodology was developed to be portable to any coastal or marine system

This investigation utilizes a S2S approach to develop a geologic model that predicts sediment resource occurrence at a reconnaissance scale to inform future exploration and quantify sediment resource

estimates. This S2S approach involves interpretation of regional framework geology based on an understanding of the processes and drivers of sediment erosion, transport, and deposition in the fluvial to marine transition zone over various timescales. In this way, areas of sediment production (e.g., fluvial inputs, erosional sources, etc.) are linked to sediment transfer or dispersal corridors (deltaic distributary channels, tidal channels, shorelines) and ultimately locations of sediment deposition as preserved in the stratigraphy and landforms (Figure 10). In simple terms, the S2S approach considers the MRDP system holistically throughout its evolution with a focus on coarser-grain sediment delivery to the coast from upland fluvial sources via the deltaic distributary network and potential subsequent reworking and concentration of sand by coastal processes. These concepts are ingrained in the formation of the initial geologic framework and predictive geologic model, as they are the linkage between an observation or type of sediment resource found in one location and the prediction of additional sediment outside of existing data coverage. Much of the development and advancement of S2S approaches has been, in part, funded and championed by the petroleum exploration industry as a predictive tool for locating new reservoirs and holistic assessments of petroleum plays or field development, as geologic factors are closely linked to engineering concerns and economic viability (Covault and Graham 2010; Pyrcz and White 2015; Romans et al. 2016; Allen 2017). These challenges to prediction and characterization of specific types of sedimentary deposit are strikingly similar to those confronting sediment resource prospecting in support of coastal restoration and provide a broad base of science and support to the development of the approach here. It is worth mentioning that similarities in geological setting are not the sole criteria for prediction of specific mineral deposits.

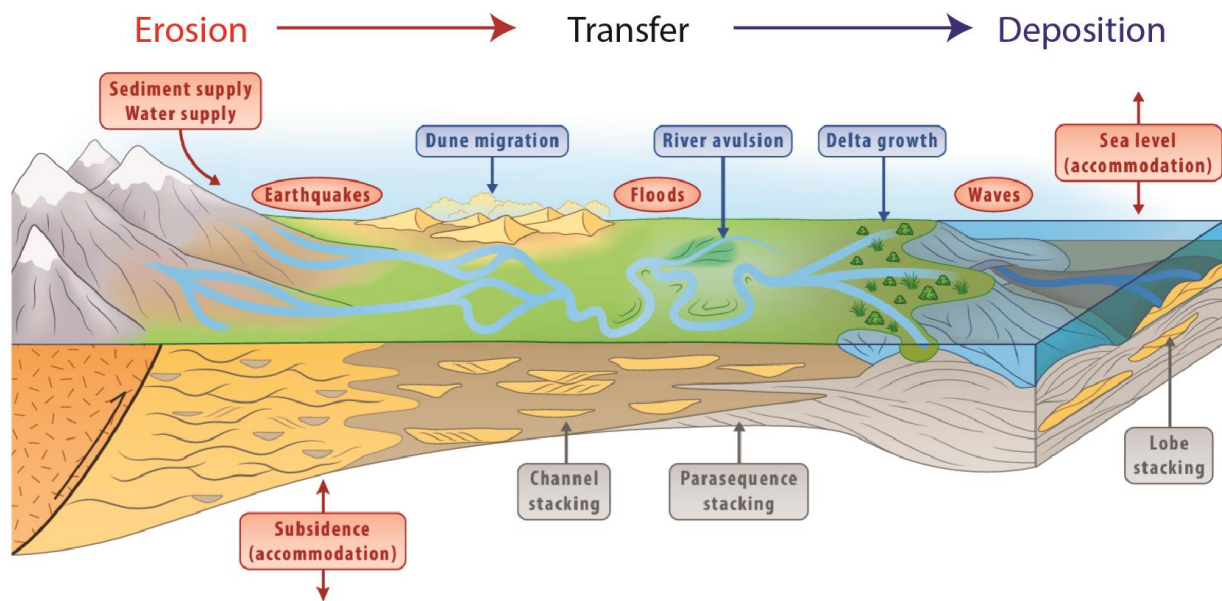


Figure 10. General illustration of S2S concepts. The MRDP is located within the transfer and deposition domains. Synoptic views of rivers and delta systems emphasize the predictability of changes in sedimentary processes and possible deposits as a function of location along the axis of the total system. Key to recognition and effective use of sediment resources is placing observed sediments within a broader process context that aids in the prediction of deposit size, continuity, geotechnical properties, and compatibility with restoration projects (modified from Hajek and Straub 2017)

Implementation of S2S concepts is not limited to understanding linkages between specific depositional environments as a function of location (e.g., if a smaller-scale delta distributary channel has been identified in the data, where is the main river channel likely to be?). Key to the predictive geologic models built here is the incorporation of foundational depositional and erosional processes associated

with specific landforms and environments, how they interact over time, and what the overall pattern of resulting sedimentary deposits is likely to be (Figure 11). Many of these concepts originated in the Mississippi River Delta (e.g., Fisk et al. 1954; Fisk 1961; Frazier 1967; Penland 1990), where early workers quickly recognized the geomorphic and stratigraphic complexity formed by delta evolution and abandonment over geologic and modern timescales. Accurate understanding of the relative history and formational processes of each specific region is required to explain the patterns of occurrence for sand and mixed sediment resource deposits.

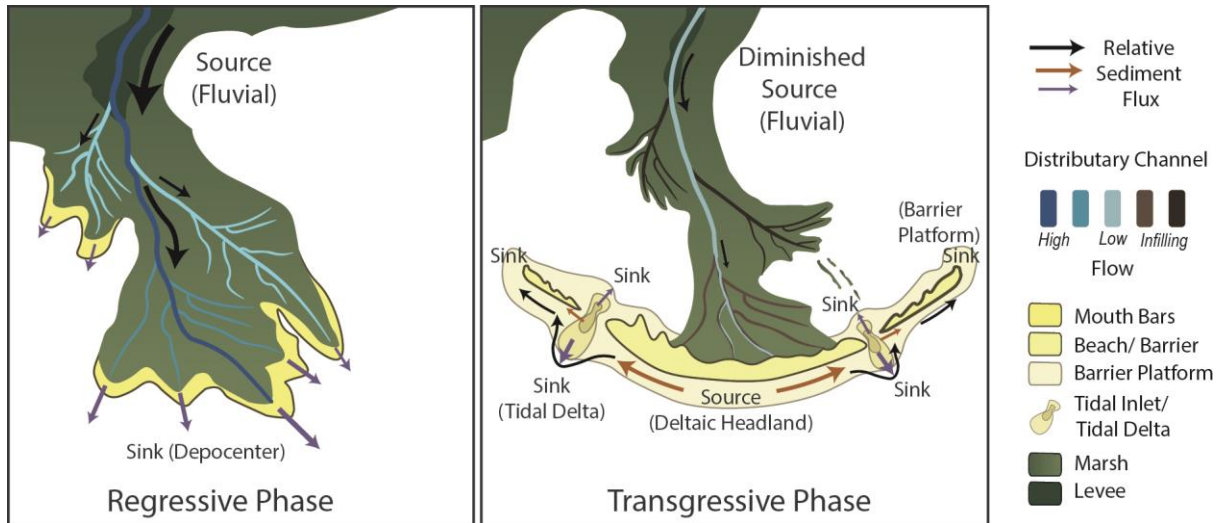


Figure 11. Conceptual S2S diagrams in a deltaic environment highlighting the regressive phase, where coarse-grained sediment is delivered to the coast through distributary networks, and the transgressive phase where the deltaic headland becomes a source of sediment by coastal reworking to flanking barrier and tidal deposits as fluvial input diminishes over time (adapted from Penland et al. 1988)

3.2 Historical Data Review and Synthesis

A comprehensive survey was performed to compile and synthesize available data and findings to develop a preliminary predictive geologic framework in order to maximize new data collection efforts and begin building a comprehensive view of LASMP Region 1 geology and priority areas for investigation. This initial effort includes what is commonly referred to as a desktop analysis (e.g., Finkl and Khalil 2005; Khalil 2019), where legacy datasets are brought in to a common platform. This stage also involved a significant data recovery effort of sediment cores within University of New Orleans (UNO) data holdings that had not been previously brought into the LASARD system. In total, 1,011 sediment core data from 28 archival projects that existed in physical paper copies have been digitally submitted to LASARD. These physical description sheets were scanned, and geospatial data was created and formatted in adherence to LASARD guidelines. This represents a significant data recovery effort being made publicly available for future investigators and greatly refined interpretations in data gap areas in this investigation. See Figure 12 for compiled geophysical and geological data used for interpretation with LASMP Region 1. Interpretations from all compiled data were used to create a conceptual geologic framework as a prelude to the development of the predictive geologic model and guided future survey design efforts. Use of archival datasets wherever possible is a pillar of the holistic approach developed here, as many older studies or datasets did not necessarily interpret the same stratigraphic interval or have the same objectives as the current sediment resource needs. Looking solely at presence or absence of data in a region (i.e., a data gap assessment) can lead to over-confidence in how those prior studies fit into the current objectives, and miss the significant value provided by these prior investments.

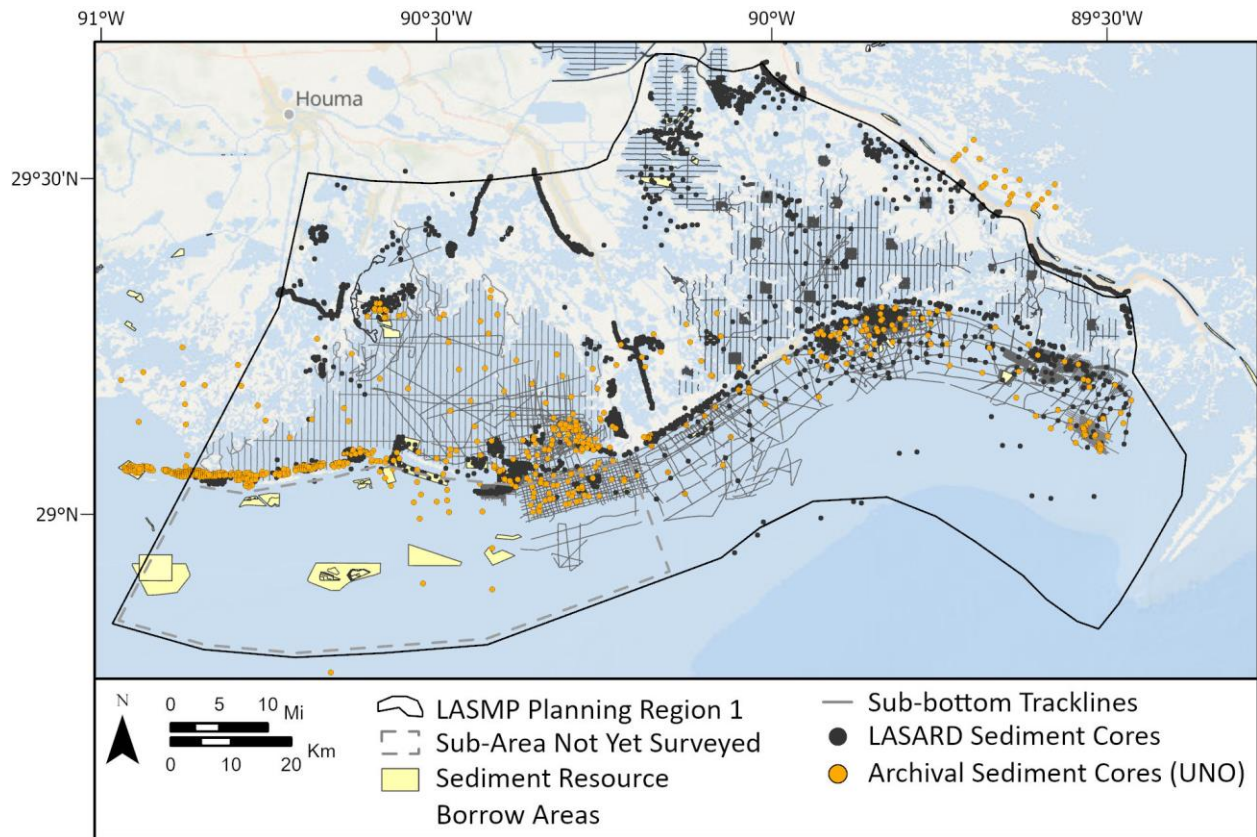


Figure 12. Archival data synthesized as part of LASMP initiative to build initial geologic framework and drive new data collection survey design plans

General positioning, architecture, mapping of onshore distributaries, and genetic relationships of delta lobes established in previous studies (Fisk 1944; Kolb and Van Lopik 1958; Frazier 1967; May et al. 1984; Smith et al. 1986; Penland 1990; Suter et al. 1991; Kosters and Suter 1993; Dunbar et al. 1994; Saucier 1994; Kindinger et al. 2001; Kulp et al. 2005; Flocks et al. 2006) and previous efforts such as LASARD, SWAMP (CB&I 2016; APTIM 2019; Raynie et al. 2020), BICM, and various USGS datasets (Calderon, Dadisman, Flocks, et al. 2003; Calderon, Dadisman, Kindinger, et al. 2003; Calderon et al. 2004) among others, were fundamental when reinterpreting compiled sub-bottom and geologic data in a regional framework context. Historically, sand resource investigations follow an iterative approach of finer and finer levels of data investigation (e.g., Khalil 2019). Ideally, reconnaissance-level investigations inform detailed investigations. Finally, engineering scale surveys provide the resolution and have specific criteria needed to constrain a borrow site for restoration projects. The mentioned surveys are intentionally designed at various scales to identify and further characterize the suitability of sediment deposits. Rarely do they consider geological framework context, or genetic link to processes controlling the distribution of these sediment bodies. This reconnaissance-level investigation for LASMP Region 1 contextualizes previously developed successful borrow sites in a geologic framework and reintegrates and refines findings from larger regional studies. The opportunity to reverse-engineer previously utilized or designed borrow sites provides successful seismic and sediment core facies to target. Due to the wealth of archival data within the investigation area, it also allows for testing resource distribution and occurrence predictions and further developing prospecting strategies in a low-cost manner.

Previous sand search and borrow designs provide detailed seismic and core data to identify facies that host suitable sediment resources, and when contextualized in a geologic framework, can be expanded and mapped along sediment pathways beyond the extent of the borrow design surveys using data from

regional studies. Suter et al. (1991) conducted one of the initial nearshore sand resources studies along central Louisiana identifying 55 sand targets within the study area, consisting of various deltaic distributary channel, coastal, and marine shoal environments. The expansive study footprint provided the basis for future investigations but lacked the data density needed for more refined interpretations at smaller spatial scales (Kindinger et al. 2001). Motivated by the Coast 2050 Management Plan (CWPPRA Task Force and WCRA 1998), which focused on restoring Louisiana's barrier shoreline and coastal resources, Kindinger et al. (2001) further refined the previous mapping investigation of Suter et al. (1991) in the Barataria Bight offshore region from Belle Pass to Sandy Point. This investigation was pivotal in that it was one of the first sand-resource mapping efforts to consider system evolution and historic coastal response, providing a baseline for human-induced modification to the natural sediment budget. This investigation also followed a set of criteria for economic sand resources 1) must contain more than 60% sand, 2) surficial sands must be at least 1 m (3 ft) thick or greater than 1.5 m (5 ft) thick if sand deposit had overburden, and 3) sand deposits must be shallower than 18 m (60 ft) below mean sea level (CWPPRA Task Force and WCRA 1998). The use of both low and high frequency sub-bottom profilers verified with sediment cores and grainsize analysis allowed for a much higher level of detailed interpretation and resource characterization. Their findings suggest nine sand targets within the study area, interpreted as ebb tidal delta, distributary mouth bar, and distributary channel fill environments.

Flocks et al. (2006) developed a conceptual geologic model at the subdelta lobe scale depicting lobe progradation and preservation after abandonment. The study provided key seismic and lithologic examples and stacking patterns of sand-rich mouth bar facies and sandy delta front and channel fill deposits and the general gradational nature of these deposits. Flocks et al. (2006) suggests the mapped paleo delta lobe is related to the Bayou des Familles lobe (Frazier 1967) and underlies Barataria Bay. The suggested Bayou des Familles delta lobe's regressive channel fill and mouth bar deposits were the target of the Bay Joe Wise (BA-35) borrow site investigation developed by CEC (2005). The original BA-35 borrow site was extended further by iterative reconnaissance and detailed investigations (OSI 2018a; OSI 2018b; OSI 2019). The prospecting strategy showcased the development from regional investigations (Suter et al. 1991; Kindinger et al. 2001) to an engineering-scale survey meant for designing borrow areas (CEC 2005; OSI 2019) contextualized in a high resolution conceptual geologic framework (Flocks et al. 2006), and is the basis for the current investigation. Similar examples of sand-rich regressive deposits developed and refined from reconnaissance investigations (Suter et al. 1991; Kindinger et al. 2001) in other locations in the Barataria offshore, such as Sandy Point investigations (Finkl et al. 2003) and Scofield (Forrest-Vandera et al. 2011) show the utility of this prospecting strategy. These designed borrow sites can be expanded due to the large footprint of these regressive paleo-deltaic deposits preserved offshore.

Similarly, sediment resources prospecting strategies related to transgressive deposits were developed from reconnaissance level investigations (Suter et al. 1991; Kindinger et al. 2001; Kulp et al. 2002) leading to further refined investigations and conceptual models that concentrate sand in a muddy deltaic environment (Kulp et al. 2005). Geologic model comparisons of abandoned deltaic headlands, such as Caillou Bay, Caminada, and Chenier Ronquille headlands compared to riverine dominant depocenters such as the Balize or Atchafalaya, highlight the importance of coastal processes (waves, tides, and other currents) and suggest a higher prevalence of tidal and beach ridges than previously assumed (Kulp et al. 2005). Previous borrow sites for restoration projects along the Raccoon, Whiskey, Isles Dernieres, East and West Timbalier, West Belle Pass, and East Grand Terre shorelines excavated sediment from transgressive tidal delta or barrier island platform deposits. A detailed summary of distribution, textural information, and seismic examples of sand-rich facies found in the delta plain is compiled in Flocks et al. (2009).

These regional reconnaissance investigations provided foundational information that led to detailed and engineering-scale geophysical and sediment sampling investigations for borrow area design, and

ultimately extraction for marsh and beach restoration projects (Figure 13). Since the early 1990s restoration efforts have developed borrow sites and utilized resources to restore the majority of the barrier shoreline and backbarrier marsh environment in the study area. CPRA defined sand greater than 70%, and mixed-sediment resources were defined and included in sediment management as (30–70% sand). Preference is given to borrow sites outside the active littoral system (Khalil, Raynie, and Forrest 2023). Sediment dredged or removed from within the system may have negative impacts to natural sediment transport and shoreline change patterns. A compilation of proven sand and mixed-sediment volumes of designed and extracted borrow sites for restoration projects are shown in Table 1. The utilized borrow areas or borrow pits were characterized in a geologic framework context as part of this investigation, which provided successful target facies that could be mapped elsewhere in the investigation area. CPRA restoration projects along the Terrebonne barriers and BA-30 (East Grand Terre) targeted tidal delta or paleo-shoreline barrier platform facies for sand, with more distal tidal delta areas providing finer sediment for marsh restoration. Chaland Headland, Bay Joe Wise, Pelican Island, Scofield Island, and West Grand Terre restoration projects utilize borrow sites consisting of deltaic distributary mouth bar, active channel fill sand for beach restoration. Most of these projects also utilize the portions of proximal delta front or overbank sediment for marsh platform creation, instead of considering it non-viable overburden, efficiently accessing the sand deposits below. The borrow site for West Grand Terre (BA-197) is a southern extension of the Bay Joe Wise (BA-35) borrow site and is a good example for the possibility to expand the mapping of these regional continuous deltaic deposits further offshore, increasing sediment reserves. A detailed summary of project specific restoration efforts can be found in ACRE (2020) and project specific monitoring reports in the Coastal Information Management System (CIMS) database. The CIMS database provides documents and various geospatial data related to CPRA's restoration projects, various monitoring programs, and large-scale data collection efforts.

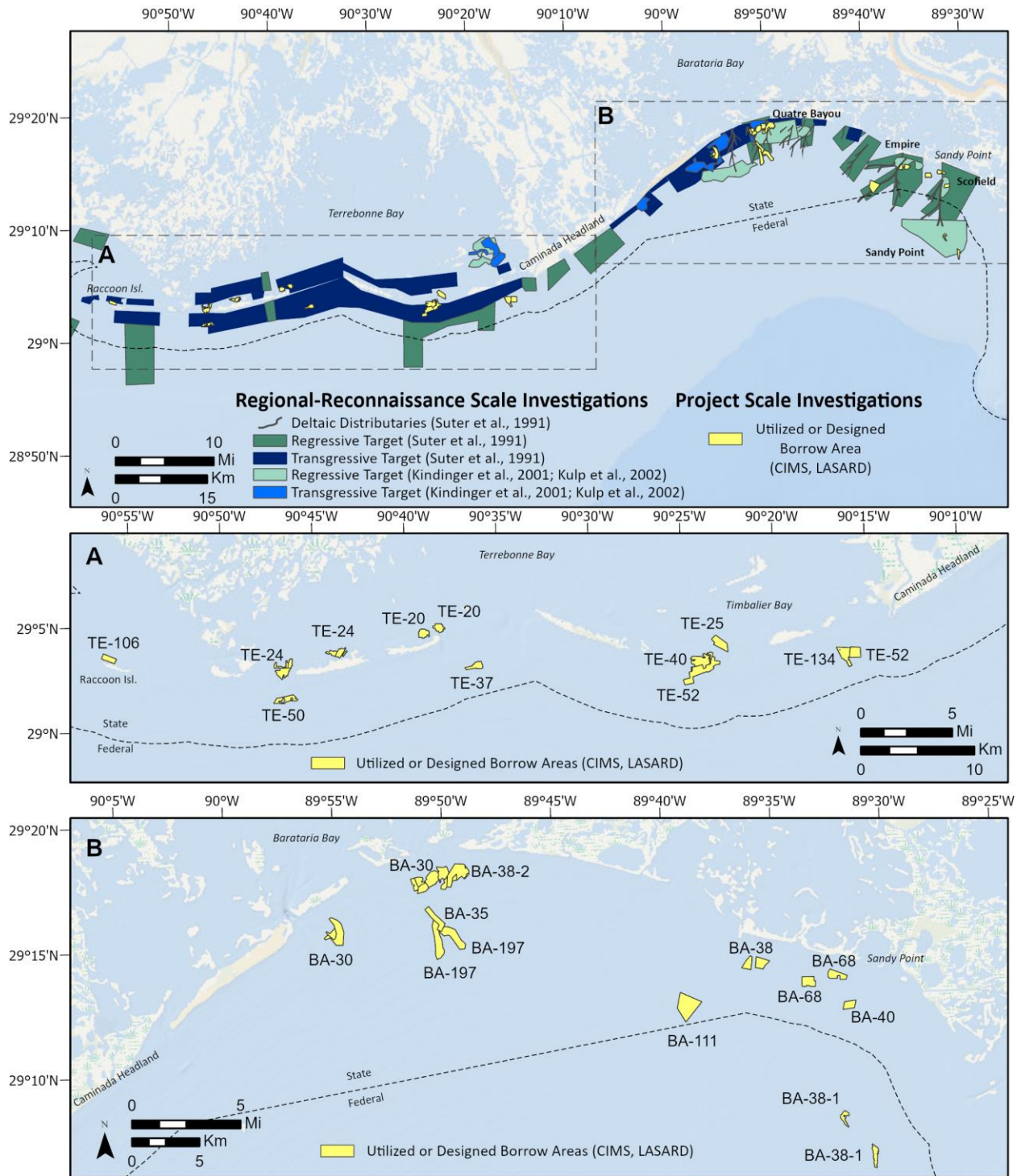


Figure 13. Summary of regional reconnaissance-scale investigation for distributaries, deltaic and coastal sediment resource targets, and engineering-scale borrow areas. Regressive targets identified by previous investigations include deltaic distributary channel and mouth bar deposits and transgressive targets include tidal and barrier or shoreface deposits. 13A and 13B show insets of utilized or designed borrow areas cataloged in the CIMS and LASARD databases

Table 1. Summary of previously designed or utilized offshore borrow areas in the vicinity of regional sediment resource targets mapped in this investigation. *Note, volumes that were reported as general sediment rather than providing sand and mixed-sediment estimates. **Note, identified sediment that required expansion due to storm damage during project construction

CPRA Project ID	CPRA Project Name	Date	Borrow Area	Identified Sand Volume MCM (MCY)	Extracted Sand Volume MCM (MCY)	Identified Mixed-Sediment Volume MCM (MCY)	Extracted Mixed-Sediment Volume MCM (MCY)	Source	Facies
TE-106	Racoon Island	1994	Caillou Bay	5.31 (6.95)	1.11 (1.45)	NA	NA	Completion Report, ACRE 2020	Tidal Delta?
TE-27	Whiskey Island	1998	F1, F2, F3, K	NA	2.18 (2.85)	NA	NA	As-Built, Penland et al., 2003	Paleo-Shoreline/ Tidal Delta
TE-24	Trinity Island (Isles Dernieres)	1998	F1, F2, K, H1, H2, H7	NA	2.26 (2.95)	NA	NA	As-Built, Penland et al., 2003	Paleo-Shoreline/ Tidal Delta
TE-20	East Island (Isles Dernieres)	1998	J1, J2	NA	3.01 (3.94)	NA	NA	As-Built, Penland et al., 2003	Paleo-Shoreline/ Tidal Delta
TE-25/ TE-30	East Timbalier Phase 1 & 2	1999	Little Pass Timbalier C	NA	2.06 (2.70)	NA	NA	As-Built, Monitoring Report	Tidal Delta
TE-40	Timbalier Dune and Marsh Creation	2004	Little Pass Timbalier	NA	3.52 (4.60)	NA	NA	As-Built Report	Tidal Delta
TE-37	New Cut & Marsh Restoration Trinity Island	2007	Offshore Wine Island	3.33 (4.35)	0.56 (0.73)	NA	NA	As-Built Report	Tidal Delta
TE-50	Whiskey Island Marsh Creation	2009	2A	0.88 (1.15)	0.28 (0.36)	2.33 (3.05)	2.16 (2.82)	95% Design, As-Built Report	Paleo-Shoreline/ Tidal Delta
TE-52	West Belle Pass Headland	2012	Little Pass Timbalier	3.52 (4.61)	2.14 (2.80)	3.06 (4.0)	1.09 (1.42)	95% Design, Completion Report	Tidal Delta
BA-38-2	Chaland Headland	2006	Quatre Bayou	2.81 (3.67)	1.87 (2.44)	3.27 (4.28)	0.71 (0.93)	30% Design, Completion Report	Active Channel Fill+ Mouth Bar
BA-35	Bay Joe Wise	2009	BA-35	1.62 (2.12)	1.98 (2.59)	2.12 (2.78)	0.83 (1.08)	95% Design, Completion Report	Active Channel Fill+ Mouth Bar
BA-30	East Grand Terre	2010	M1 & M2	NA	NA	1.59* (1.59*)	0.90 (1.18)	Completion Report	Distal Tidal Delta
BA-30	East Grand Terre	2010	D1	3.26* (4.27*)	0.03 (0.04)	NA	0.27 (0.35)	Completion Report	Tidal Delta
BA-30	East Grand Terre	2010	WGT A, B, C	4.48* (5.86*)	2.06 (2.69)	NA	0.21 (0.27)	Completion Report	Tidal Delta
BA-38-1	Pelican Island	2012	Sandy Point SE	2.96 (3.87)	2.67 (3.49)	1.01 (1.32)	0.89 (1.17)	30% Design, Completion Report	Mouth Bar
BA-38-1	Pelican Island	2012	Empire West	1.96 (2.56)	NA	1.05 (1.37)	0.76 (0.99)	30% Design, Completion Report	Channel Fill, Mouth Bar, Delta Front
BA-38-1	Pelican Island	2012	Empire East	1.96 (2.56)	NA	1.86 (2.43)	0.35 (0.46)	30% Design, Completion Report	Channel Fill, Mouth Bar, Delta Front
BA-40	Scofield Island	2013	Scofield	NA	NA	1.00 (1.31*)	1.15 (1.51)	Design, Completion Report	Channel Fill, Mouth Bar, Delta Front
BA-68	Grand Liard Marsh and Ridge	2015	East, West	NA	NA	7.61 (9.96)	2.16 (2.83)	Final Design, Completion Report	Channel Fill, Mouth Bar, Delta Front
BA-111	Shell Island West	2017	35-E	NA	NA	6.72 (8.80)	0.84 (1.10)	Final Design, Monitoring Report	NA (Rehandling Area)
BA-197	West Grand Terre	2022	BAE	2.19+2.46** (2.87+3.22**)	3.27 (4.28)	NA	NA	Completion Report	Active Channel Fill+ Mouth Bar
BA-197	West Grand Terre	2022	BAW	0.97 (1.27)	0.79 (1.03)	NA	NA	Completion Report	Active Channel Fill+ Mouth Bar

3.3 Interpretation of Historical Data and Preliminary Predictive Geologic Model Development

Central to LASMP's approach is the creation of predictive geologic models. These models, or three-dimensional block diagrams, act as visual communication tools for stakeholders to convey the components of the modern environment and subsurface geology that matter most for system-based restoration planning, management, and implementation. Elements of predictive geologic models are commonly used in petroleum exploration, geothermal energy development, and scientific research, but have not previously been developed at a regional scale to develop estimates of restoration-quality sediment resources or reserves and inform subsequent project-scale sediment searches (e.g., Seni and Finley 1995; Siler et al. 2019). Predictive geologic models allow for easier understanding of the location and distribution of particular sediment types, how extensive or thick these deposits could possibly be, and where in a given region additional sediment resources are most likely to be found. Successful system-based restoration planning, management, and implementation relies on interdisciplinary expertise, where misunderstandings of the complex relationships of sediment resources and factors leading to their distribution can be cost-prohibitive.

As a result of the synthesis of existing literature and data, a preliminary predictive geologic model was developed to inform new data collection strategies in order to refine the model in the S2S context. Major sediment pathways were identified within Barataria Bay and offshore in the Barataria Bight region. These large paleo-distributary channels, when active, served as coarse-grained sediment transfer pathways to the coast. Varying levels of preservation, geometries, and positioning of indicated subsurface deposits that could be used as sediment resources were observed. Archival data suggested the location of major depocenters based on these major sediment transport pathways that needed refinement with strategic newly collected data. The predictive model also visualizes previously successful borrow sites into the regional geologic framework context, providing textural composition data for verified seismic facies, and allows for the probable expansion of semi-verified resources with new data collection. A series of predictive three-dimensional models focusing on sand and mixed-sediment deposits were developed for the offshore region (Figure 14) with continuity into bay (Figure 15; Figure 16) environments. Using a S2S regional geologic framework approach, the model captures major sediment pathways, redistribution of sediment and ultimately, the preservation of sediment bodies over varying time scales.

Potential Mixed-Sediment Deposits

- Natural Levee
- Proximal Delta Front
- Abandoned Channel Fill

Potential Sandy Deposits

- Channel Belt & Terrace
- Distributary Mouth Bar
- Distributary Channel Bar
- Barrier Islands & Beaches
- Tidal Delta
- Shoal

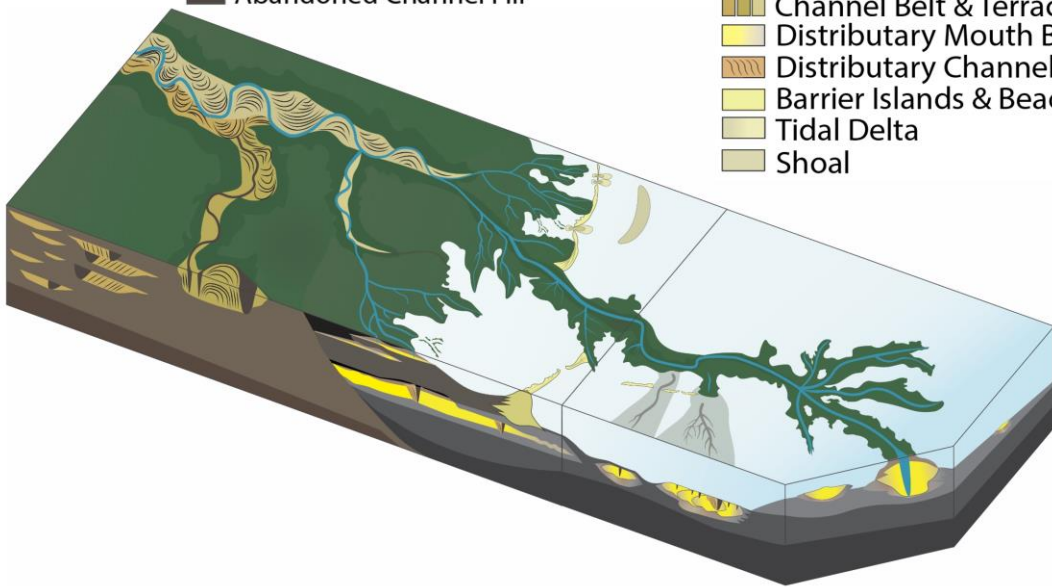


Figure 14. Three-dimensional predictive geologic model of the Louisiana deltaic plain focusing on the distribution of desired sediment resource types and associated depositional environments. Transparent deltaic lobes represent a subaerial view of subsurface features

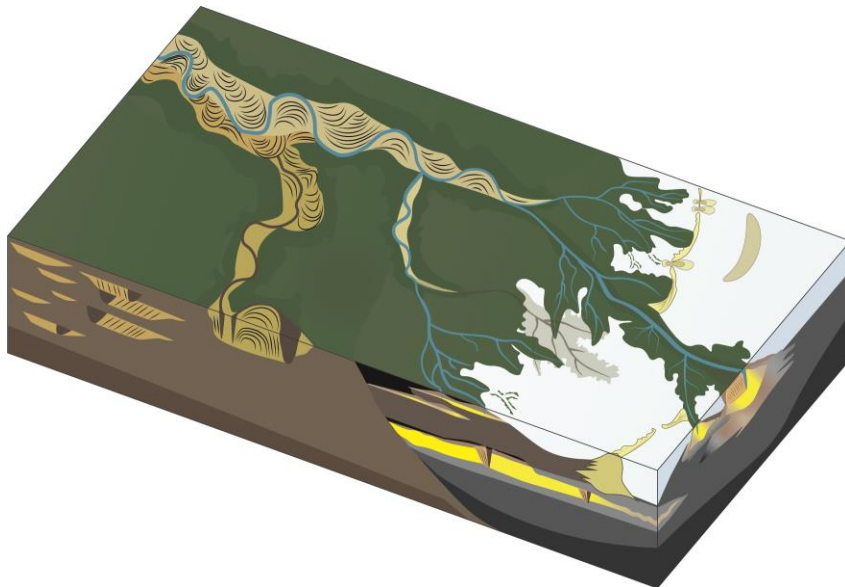


Figure 15. Three-dimensional predictive geologic model of the Louisiana deltaic plain focusing on the distribution of desired sediment types and associated depositional environments that extend from the modern bays seaward of the modern shoreline. Transparent deltaic lobes represent a subaerial view of subsurface features

Potential Mixed-Sediment Deposits

- Natural Levee
- Proximal Delta Front
- Abandoned Channel Fill

Potential Sandy Deposits

- Channel Belt & Terrace
- Distributary Mouth Bar
- Distributary Channel Bar
- Barrier Islands & Beaches
- Tidal Delta
- Shoal

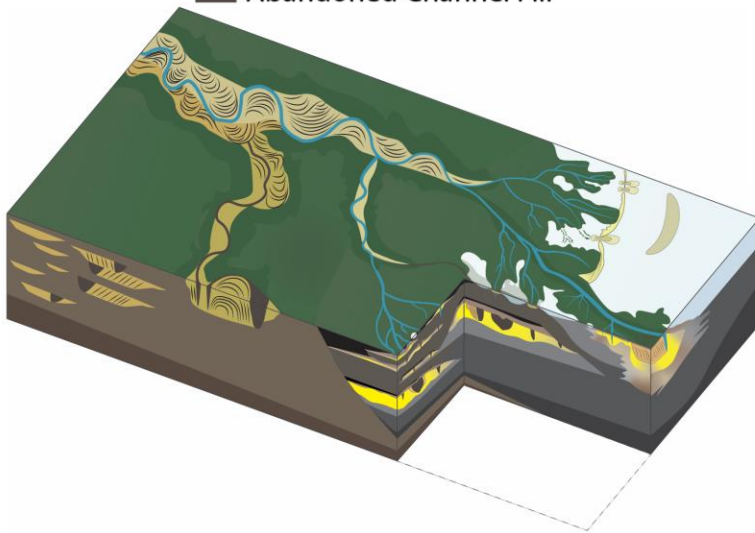


Figure 16. Three-dimensional predictive geologic model of the Louisiana deltaic plain focusing on the distribution of desired sediment types and associated depositional environments within the modern bays

3.3.1 Sand-Rich Regressive Target Facies

Since it is natural coastal erosion of abandoned delta lobes that sources the coarse-grained sediments to the local beach and barrier systems, those preserved delta deposits with high sand content are the logical deposits to target for restoration-quality sediment resources. This investigation targets relict paleo-distributary channel bar and paleo-mouth bar environments for sand resources because they provide viable coarse-grained sediment resources at a regional scale. Natural levee/overbank, distributary channel fill, and proximal delta front sediment are target depositional environments for mixed-sediment resource targets. Using the historical maps that captured distributary network distribution with connections to major trunk distributary channels, a regional stratigraphic and geomorphic understanding was developed. Together in an S2S context this provides a roadmap that reduces uncertainty for planning future, more detailed investigations, verifies seismic facies that are typical to sand-rich deposits, and provides information about textural properties of those seismic facies suitable for appropriate project types (barrier island vs. marsh).

3.3.1.1 Distributary Mouth Bar

Distributary mouth bars are depositional features, with high accumulation rates of coarse sediment due to rapid decreases of flow velocity as sediment is transported from terminal distributary channels to the receiving basin (Scruton 1960; Coleman 1982). Mouth bars can consist of silt and clay laminations due to various flood conditions during formation (Wright and Coleman 1974; Olariu and Bhattacharya 2006; Edmonds and Slingerland 2007; Esposito et al. 2013), but reworking by marine processes (waves and currents) winnow and re-suspend fine-grained sediment, resulting in concentrated sand-rich deposits (Coleman 1982). In Louisiana, the river-dominated delta lobes are further classified relative to inferred basin accommodation, as elongate (deep water) or lobate (shallow water) deltas (Fisher and McGowen 1969). The resulting interplay between stream flow gradient, sediment accumulation, and channel stability results in variable mouth bar extents. Mouth bars of lobate or shallow water deltas form a

laterally variable, coalesced mouth bar “sheet” morphology from wave reworking of the multiple terminal distributaries (Fisk et al. 1954; Olariu and Bhattacharya 2006). This is compared to the thick, stacked mouth bars of elongate deltas (Fisk 1961; Figure 17). The shallow-water and deep-water delta characterizations should be considered endmembers along a spectrum, and many physical factors control mouth bar internal architecture and composition. The mechanisms resulting in natural complexities of mouth bar architecture and preservation detailed in other areas (Olariu and Bhattacharya 2006; Feng et al. 2019; van Yperen et al. 2020; Reynolds 2022), can be used to refine prospecting strategies in Louisiana. Mouth bar deposits are important to sediment resource prospecting as they:

- have a high preservation potential near receiving basins (Flocks et al. 2009)
- contain some of the coarsest sediment within the delta system (Coleman 1982)
- demonstrate suitable thicknesses for resource development
- are generally spatially continuous along a distributary channel axis
- contain the coarsest sediment proximal to the distributary channel and fine distally from the channel source (Fisk et al. 1954; Fisk 1961)
- are a natural source of Louisiana beach sand from reworking ensuring restoration sediment compatibility (Flocks et al. 2009)

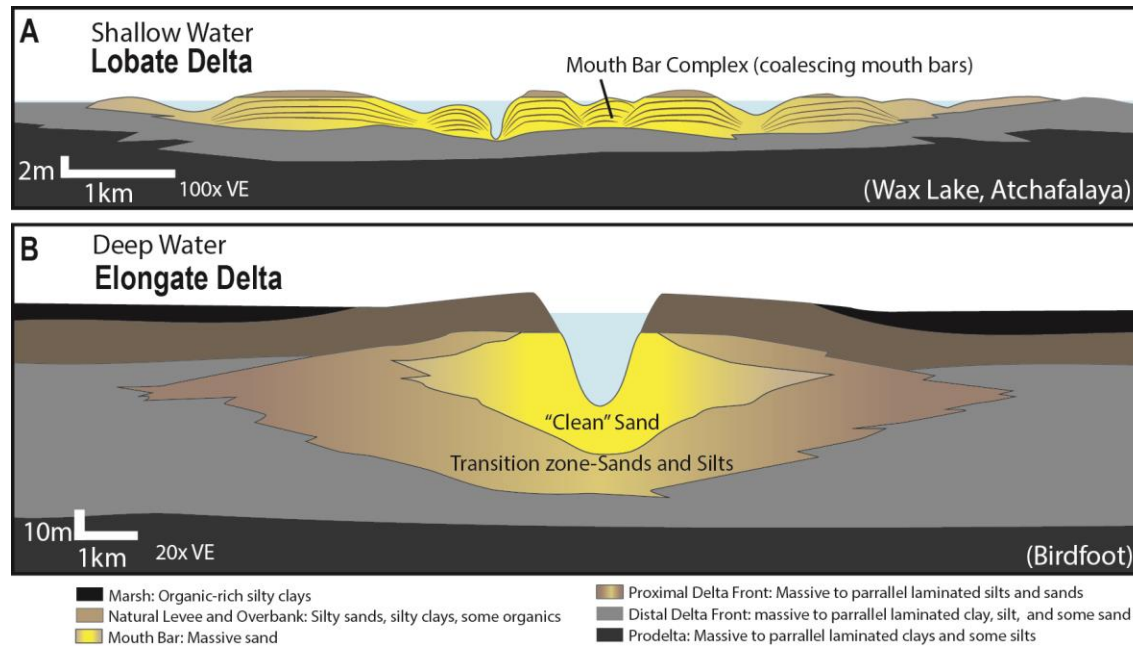


Figure 17. Comparison of relative geometries and continuity of mouth bar sands in lobate and elongate deltas. The relative thickness differences between the mouth bar deposits are controlled dominantly by the water depth or accommodation of the receiving basin. Figure modified from Olariu and Bhattacharya (2006) and Fisk (1961)

3.3.1.2 Channel Fill and Channel Bar

Distributary channels are the conduits or sediment dispersal pathways from upland tributary sources, through the trunk river, and finally to the coast. Distributary channels receive a fraction of flow and sediment from the parent river (Coleman 1982) which vary based on the number of bifurcations and stream gradient. Trunk channels divert flow between a few major distributaries, which then bifurcate farther downstream, decreasing in channel size and percentage of flow (Olariu and Bhattacharya 2006). Channels with lower angles of bifurcation from the parent channel tend to be larger and have a higher capacity for sand transport compared to higher angle bifurcated channels (Meckel 1967). As flow is

diverted elsewhere in the delta plain, channel velocity decreases resulting in fine-grained sediment infilling. Channel fill is highly variable but is likely to contain the highest concentration of coarser sediment at its base, deposited as the channel still received active flow (active channel fill) with interbedded to fine-grained sediment in its upper section as the channel was abandoned (abandoned channel fill; Meckel 1967). Channel bars migrate downflow as bedload sediment occurs or as the channel laterally migrates, although this is rare in the delta plain (Meckel 1967). Active channel fill sand can be ~12 m (40 ft) thick depending on the channel's sediment carrying load. Both deposits generally follow a fining upward sequence and can have high concentrations of organic material that may inhibit sub-bottom imaging and require geologic sampling to determine their suitability.

3.3.1.3 Overbank and Natural Levees

Overbank deposits form as natural levees along distributary channels and are overtopped during flood conditions. These deposits consist of laminated sands and silts, fining and thinning distally from the source. These deposits are subaerially exposed and contain high degrees of bioturbation (Coleman 1982). These facies usually flank distributary channels and collectively could represent mixed-sediment type resource material if further developed.

3.3.1.4 Proximal Delta Front

The delta front is the subaqueous seaward sloping margin of a prograding delta lobe and consists of interbedded sand, silt, and clay. Sedimentation consists of entrained sediment that are transported beyond the mouth bar environment (Coleman 1982). This investigation differentiates the proximal and distal delta front based on the gradational nature of the coarsest sediment deposited most proximal to the source, or the terminal distributary mouth. The proximal delta front consists of a higher coarse fraction of sand and silt compared to the distal delta front which is dominated by silt and clay (Figure 17). The delta front is a coarsening upward sequence, which should be considered when exploring borrow site designs, as borrow sediment quality may degrade with depth or laterally from the paleo-distributary source. The delta front is laterally continuous, has high preservation potential, and provides thicknesses suitable for development (Flocks et al. 2009). Only the most proximal delta front environment is considered to have a high likelihood of containing "mixed sediment" compatible sediment and should be confirmed with geologic sampling to address this gradational lateral and vertical variability.

3.3.2 Sand-Rich Transgressive Target Facies

Coarse-grained sediment delivered to the coast by fluvial-deltaic processes resulting in regressive facies undergo redistribution by waves and currents as fluvial input diminishes or is abandoned. The high-energy environments along the coast concentrate sand by winnowing fine-grained sediment that can be strategically targeted for sand-resource investigations, highlighting the importance of transgressive processes in deltaic environments (Kulp et al. 2002; Kulp et al. 2005; Miner et al. 2007). These transgressive facies have very similar sediment properties to the modern barrier coast making them suitable borrow sediment. However, careful consideration should be given to impacts of shoreline change when removing sand from the active littoral system.

3.3.2.1 Tidal Inlet Fill

Migrating tidal inlets scour underlying deposits and infill with sediments delivered by waves and tidal currents, leaving the inlet fill sequence in their retreat path. The lower channel fill consists of shelly sand near its base, with a fining upwards sequence transitioning to a coarsening upwards sequence as the inlet fill grades into tidal delta deposits (Miner 2007). Preservation of this deposit is variable and its spatial extent is limited (Miner 2007) and depending on the inlet fill characteristics it can be a prospective sand or mixed-sediment target suitable for restoration.

3.3.2.2 Tidal Delta

Tidal deltas retain sediment being transported alongshore due to the deceleration of tidal current velocity within the inlet. Flood tidal deltas occur on the landward portion of the inlet and ebb tidal deltas occur on the seaward portion. Tidal deltas grow larger as the bay interior wetlands convert to open water, increasing the tidal prism and the sediment trapping efficiency of littoral transported sediment (Walton and Adams 1976; List et al. 1994; FitzGerald et al. 2004; Miner et al. 2007). Tidal deltas have the highest sand content proximal to the inlet throat, where current velocity is highest. However, the preservation potential of tidal deltas is quite variable, especially as the dynamic shoreline migrates (FitzGerald et al. 2004; Miner et al. 2007; Flocks et al. 2009). Tidal deltas have been utilized for restoration due to their minimal overburden and proximity to restoration projects, but due to the adverse impact of removing sediment from active littoral system, it is normally avoided in current restoration practices in Louisiana.

3.3.2.3 Paleo-Barrier Platform

The paleo-barrier platform results from partial preservation of a remnant barrier island chain. A paleo-barrier island chain marking the extent and reworking of an abandoned delta lobe fronts Terrebonne Bay, landward of the modern coastline (Penland et al. 1987). The coarsening upwards sequence consists of clayey sand grading into sandy deposits and can be up to 5–10 m (16–32 ft) thick (Penland et al. 1987). The paleo-barrier has been partially reworked due to storm and tidal currents. Paleo-barrier island platforms represent fairly continuous sediment sources of sand and mixed sediment with minimal overburden.

3.3.2.4 Inner-Shelf Shoal

Inner-shelf shoals, such as Ship Shoal, Tiger Trinity shoal, and Sabine Bank represent large positive bathymetric expressions of thick sand relative to the surrounding flat, clayey shelf surface. These shoals represent the final stages of transgressive submergence, where a barrier island became submerged due to RSLR and loss of subaerial sand to deep water sinks (Penland, Boyd, et al. 1988). The inner shelf shoals have minimal to no overburden, are on the order of 5 m (16 ft) thick, have an average of 95% sand (Kulp et al. 2002; Flocks et al. 2009), have been previously utilized as borrow source, and represent a low-risk sand resource target. However, Ship Shoal is located relatively far offshore, around 15 km, and has a dense network of pipelines greatly reducing accessible sand volumes. BOEM and the State of Louisiana are working closely together to ensure that abandoned pipelines are removed from priority areas of this important resource.

3.4 Application of Predictive Geologic Model to Inform New Data Collection Strategy

Regional paleo-deltaic, paleo-distributary channels, and paleo-shoreline features in the subsurface were delineated, and areal extents were mapped based on all synthesized data. A survey design plan was developed in coordination with CPRA and BOEM to 1) fill in data gaps or extend the mapping of these inferred sediment resources and provide sufficient data measures for archeological clearance for future coring efforts and 2) improve understanding of the regional geologic framework of the investigation area. The goal of the investigation was to create a comprehensive inventory of inferred sand and mixed-sediment resources at the regional reconnaissance level for future coastal restoration efforts. The survey design considered previous data coverage and data quality of available geophysical and geological investigations, which varied due to the technology available during collection, collection methods, or natural phenomena such as sea state. A survey plan of 394 km (245 mi) of full-suite geophysical data collection (chirp sub-bottom profiler, sidescan sonar, magnetometer, and single-beam bathymetry) was proposed for the Barataria Bight offshore region between Caminada Headland and Sandy Point building

on previous investigations and the location successful borrow sites and the dense data coverage previously collected within Terrebonne and Barataria bays as part of archival SWAMP and USGS efforts.

3.5 Geophysical and Geological Data Acquisition

A summary of geophysical and geological data acquisition completed for the LASMP Region 1 reconnaissance investigation is presented here, which builds upon initial interpretations from the historical data review phase. Between June and July 2022, personnel from The Water Institute, Louisiana State University, and APTIM collected 394 km (245 mi) of full-suite geophysical data over two survey legs aboard the R/V Coastal Profiler (Figure 18). The geophysical surveys simultaneously collected chirp sub-bottom, side scan sonar, magnetometer, and single-beam bathymetry. Equipment included Odom Echotrac Hydrotrac single-beam, Geometrics G882 Magnetometer, Edgetech 512i sub-bottom profiler, and Edgetech 2000 combined sidescan sonar and 216i sub-bottom profiler. During geophysical data collection certain mitigation protocols were implemented to reduce potential impacts to marine mammals during high-resolution geophysical survey data collection. These mitigation efforts reflected the most recent federal regulatory coordination document to address high-resolution geophysical systems, the Final Environmental Assessment on Sand Survey Activities for BOEM’s Marine Mineral Program produced by BOEM (May 2019), specifically Appendix B of that document: Survey Requirements and Mitigation Measures.

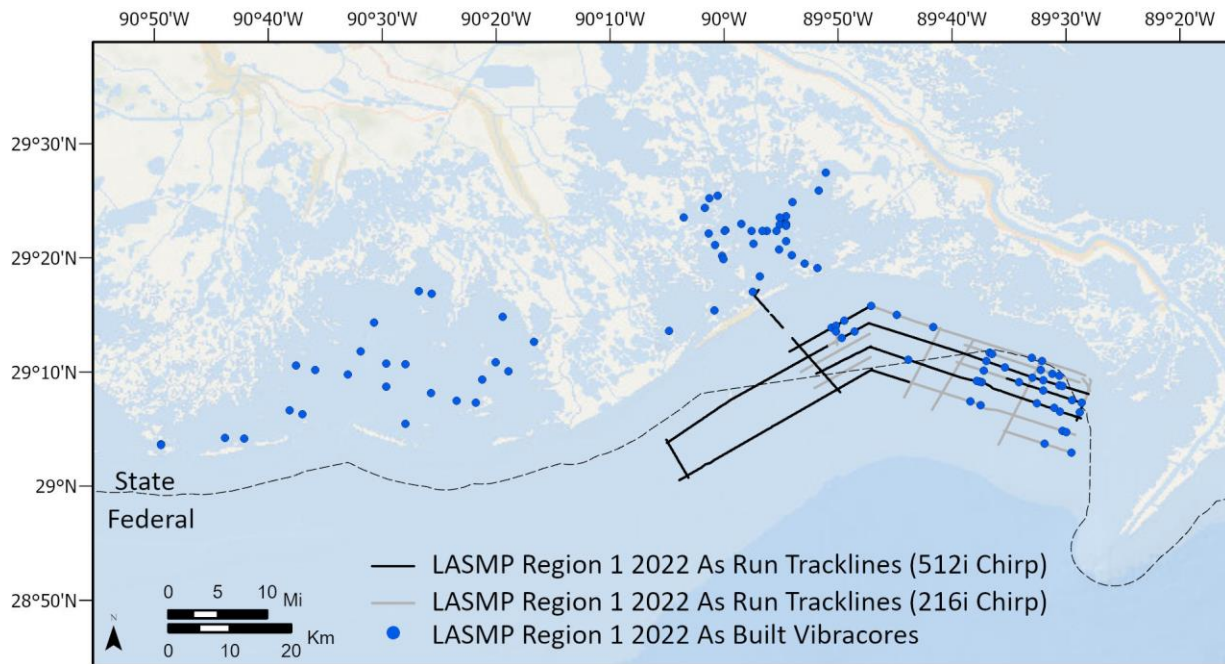


Figure 18. Vibracore sample locations and survey tracklines where full-suite geophysics was collected as part of this investigation. Due to equipment malfunctions various sub-bottom profilers were used in collection. Vibracores in Terrebonne and Barataria bays ground-truthed sub-bottom collected (APTIM, 2019; CB&I, 2016) as part of the SWAMP initiative (Khalil et al., 2020; Raynie et al., 2020)

Chesapeake Technologies, Inc.’s Sonarwiz 7 software was used to process and interpret both archival and newly collected sub-bottom data. Interpretations from the historical data review phase were extended or refined with newly collected sub-bottom data. Additional geologic sampling objectives were to verify textural compositions of inferred sand or mixed-sediment deposits (e.g., grain size, percent sand, etc.) or

could aid in the refinement of geologic framework understanding. In total, 120 possible vibracore sites were selected for archeological and hazard clearance in coordination with BOEM and CPRA. APTIM's Qualified Marine Archeologist reviewed vibracore sites for clearance following BOEM's guidelines. A total of 100 vibracores were collected within the LASMP Region 1 investigation area (Figure 18). APTIM geologists used M/V *Rachel K Goodwin* and M/V *John Padgett* to collect 90 vibracores, up to 8.3 m (29 ft) between December 2022 and March 2023. Due to water depth constraints within Terrebonne and Barataria bays, an additional 10 cores were collected by UNO's shallow draft vessel in June 2023. Sediment cores were processed (split lengthwise, visually described and logged, and photographed) and sampled for grain size and radiocarbon analysis by The Water Institute and UNO geologists. A total of 545 grain size samples were analyzed using a Malvern Panalytical Mastersizer 3000E with discrete sample outputs providing D50 and percent sand for representative facies in each core for sand or mixed sediment deposits. See **Appendices A through E** for details pertaining to geophysical and geological data collection, field notes, mitigation efforts, and archeological hazard clearance practices.

A total of 42 new radiocarbon age estimates were obtained from newly acquired cores to help constrain the deltaic evolution of the study area (Figure 19; Table 2). Samples of in-situ shell and organic material were cleaned and prepared for analysis based on protocols from National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) of the Woods Hole Oceanographic Institution. Twenty-seven radiocarbon date estimates from articulated shells, preserved in-life position, were obtained using the MICADAS gas interface system at the NOSAMS facility. Additionally, 15 radiocarbon date estimates from in-situ peats or root horizons, were obtained using an accelerator mass spectrometer (AMS). All radiocarbon dates were calibrated using either the Marinecal20 or Intcal20 calibration curves (Heaton et al. 2020; Reimer et al. 2020) for articulated shells or organics, respectively. The updated global 550 year-marine reservoir correction (Heaton et al. 2020) was applied to shell calibration, with no additional local reservoir correction due to the limited data available in Louisiana. All final age estimates are presented generally as "years ago." These ages are the median probability associated with two sigma ranges in calendar years before present (BP) with present being 1950 Common Era. All elevations are presented as meters and feet down core or below sea floor (bsfl). Note the organic sample from core 37 is likely transported material and should be used as a minimum age estimate of the deposit.

After completion of this investigation a series of recommendations and lessons learned were developed for future data collection efforts and sediment prospecting strategies. Some key observations include 1) the use of high and low frequency sub-bottom such as a 512i chirp and boomer system provides the best combination of internal architecture for geologic interpretation as well as delineation of the sediment body in thicker sand-rich deposits, 2) verified seismic facies in a system-wide context are produced in this investigation and should be utilized in future prospecting, and 3) identifying major sediment pathways and depocenters has proven a successful strategy for locating sediment resources. A detailed description of the observations and lessons learned is provided in **Appendix F**.

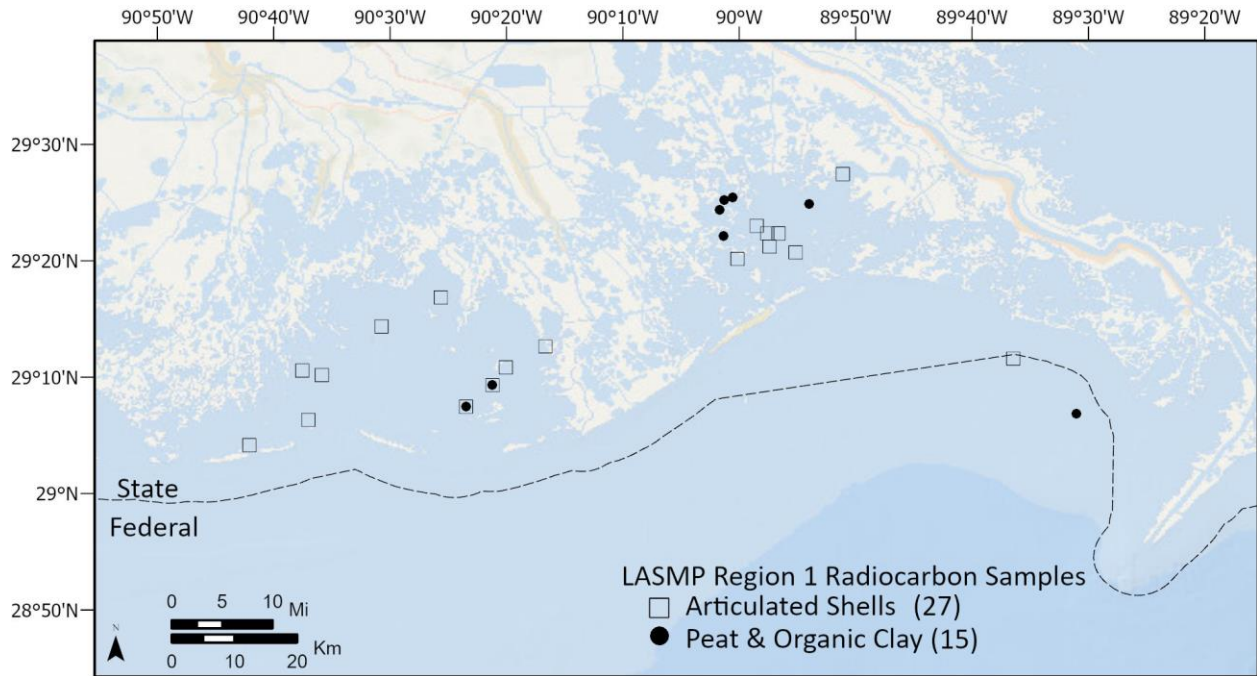


Figure 19. Locations of articulated shell and peat and organic clay radiocarbon samples. Note some cores have multiple radiocarbon samples down core

Table 2. Radiocarbon age estimates. Marine samples were calibrated using the Marinecal20 curve (Heaton et al. 2020). Terrestrial organic samples were calibrated using the Intcal20 curve (Reimer et al. 2020). Note (*) sample 2 is likely transported and not in-situ, consider the presented calendar age as a minimum age of the deposit

ID	Core	M bsfl	Ft bsfl	Sample	C ¹⁴ Age	Median ± Cal. 2σ Age	Facies	NOSAMS Accession #
1	LASMP-Reg1-2022-19-3A	0.66	2.17	<i>Nuculana concentrica</i>	525 ± 50	Modern	Delta Front?	OS-174999
2	LASMP-Reg1-2022-37-1A	6.16	20.21	Peat*	840 ± 15	735 ± 18	Mouth bar	OS-175742
3	LASMP-Reg1-2022-42-1A	6.49	21.29	<i>Nuculana concentrica</i>	2040 ± 55	1438 ± 164.5	Bay/Delta Front?	OS-175000
4	LASMP-Reg1-2022-43-3A	2.86	9.38	<i>Rangia cuneata</i>	2040 ± 55	1438 ± 164.5	Delta Front	OS-175001
5	LASMP-Reg1-2022-46-1A	5.87	19.26	<i>Crassostrea virginica</i>	4650 ± 60	4683 ± 205	Bay	OS-175002
6	LASMP-Reg1-2022-48-3A	5.45	17.88	<i>Crassostrea virginica</i>	3430 ± 55	3126 ± 201.5	Bay	OS-175003
7	LASMP-Reg1-2022-53-3A	3.55	11.65	<i>Mulinia lateralis</i>	2060 ± 50	1457 ± 164	Bay/Rav/ lag	OS-175004
8	LASMP-Reg1-2022-53-3A	3.96	12.99	Peat	3540 ± 20	3832 ± 37	Teche Marsh	OS-175743
9	LASMP-Reg1-2022-59-2A	4.20	13.78	<i>Crassostrea virginica</i>	2030 ± 55	1428 ± 163.5	Bay/Rav/ lag	OS-175005
10	LASMP-Reg1-2022-59-2A	4.24	13.91	<i>Crassostrea virginica</i>	2150 ± 55	1561 ± 180.5	Bay/Rav/ lag	OS-175006

ID	Core	M bsfl	Ft bsfl	Sample	C ¹⁴ Age	Median ± Cal. 2σ Age	Facies	NOSAMS Accession #
11	LASMP-Reg1-2022-59-2A	4.47	14.67	Peat	3750 ± 30	4112 ± 47.5	Teche Marsh	OS-175750
12	LASMP-Reg1-2022-60-2A	0.83	2.72	<i>Macoma mitchelli</i>	1100 ± 50	532 ± 132.5	Bay	OS-175007
13	LASMP-Reg1-2022-62-1A	1.05	3.44	<i>Rangia cuneata</i>	845 ± 50	312 ± 166.5	Bay	OS-175008
14	LASMP-Reg1-2022-74-3A	1.65	5.41	<i>Crassostrea virginica</i>	2060 ± 55	1458 ± 171.5	Bay	OS-175009
15	LASMP-Reg1-2022-77-2A	3.60	11.81	Peat	2550 ± 25	2708 ± 25	Marsh	OS-175744
16	LASMP-Reg1-2022-77-2A	4.22	13.85	Rooted horizon	2970 ± 20	3137 ± 71.5	Marsh	OS-175745
17	LASMP-Reg1-2022-79-1A	0.22	0.72	<i>Mulinia lateralis</i>	595 ± 50	Modern	Bay	OS-175010
18	LASMP-Reg1-2022-79-1A	1.10	3.61	<i>Rangia cuneata</i>	870 ± 55	336 ± 165.5	Bay	OS-175011
19	LASMP-Reg1-2022-80-1A	0.92	3.02	<i>Rangia cuneata</i>	865 ± 50	332 ± 162.5	Upper Bay	OS-175012
20	LASMP-Reg1-2022-80-1A	2.67	8.76	<i>Mulinia lateralis</i>	2930 ± 60	2529 ± 189.5	Lower Bay	OS-175013
21	LASMP-Reg1-2022-81-1A	0.37	1.21	<i>Mulinia lateralis</i>	485 ± 50	Modern	Upper Bay	OS-175014
22	LASMP-Reg1-2022-81-1A	0.61	2.00	<i>Mulinia lateralis</i>	875 ± 50	341 ± 160	Upper Bay	OS-175015
23	LASMP-Reg1-2022-81-1A	0.83	2.72	<i>Rangia cuneata</i>	510 ± 50	Modern	Upper Bay	OS-175016
24	LASMP-Reg1-2022-81-1A	0.95	3.12	<i>Rangia cuneata</i>	655 ± 50	119 ± 128.5	Upper Bay	OS-175017
25	LASMP-Reg1-2022-81-1A	1.08	3.54	<i>Rangia cuneata</i>	1090 ± 55	523 ± 142	Upper Bay	OS-175018
26	LASMP-Reg1-2022-81-1A	1.16	3.81	<i>Rangia cuneata</i>	935 ± 50	389 ± 138	Upper Bay	OS-175019
27	LASMP-Reg1-2022-82-1A	0.10	0.33	<i>Tagelus plebeius</i>	820 ± 50	284 ± 174.5	Upper Bay	OS-175020
28	LASMP-Reg1-2022-85-1A	4.15	13.62	<i>Crassostrea virginica</i>	4010 ± 60	3843 ± 220.5	Lower Bay	OS-175021
29	LASMP-Reg1-2022-89-1A	0.19	0.62	<i>Mulinia lateralis</i>	Modern	-	Bay	OS-175022
30	LASMP-Reg1-2022-90-1A	3.49	11.45	<i>Mulinia lateralis</i>	1910 ± 55	1307 ± 169.5	Delta Front/ lag?	OS-175023
31	LASMP-Reg1-2022-90-1A	5.00	16.40	<i>Mulinia lateralis</i>	3140 ± 55	2779 ± 188.5	Bay/ Lag	OS-175024
32	LASMP-Reg1-2022-91-1A	0.77	2.53	Rooted horizon	1490 ± 20	1365 ± 29.5	Marsh	OS-175746
33	LASMP-Reg1-2022-91-1A	0.82	2.69	Rooted horizon	1520 ± 15	1386 ± 26	Marsh	OS-175747
34	LASMP-Reg1-2022-94-1A	0.71	2.33	Rooted horizon	1700 ± 15	1581 ± 35	Upper Marsh	OS-175748
35	LASMP-Reg1-2022-94-1A	1.60	5.25	Peat	2320 ± 15	2344 ± 9.5	Lower Marsh	OS-175749

ID	Core	M bsfl	Ft bsfl	Sample	C ¹⁴ Age	Median ± Cal. 2σ Age	Facies	NOSAMS Accession #
36	LASMP-Reg1-2022-95-2A	0.60	1.97	Rooted horizon	1550 ± 15	1411 ± 22.5	Marsh	OS-175753
37	LASMP-Reg1-2022-95-2A	0.68	2.23	Rooted horizon	1610 ± 20	1476 ± 33	Marsh	OS-175754
38	LASMP-Reg1-2022-95-1A	0.83	2.72	Peat	1560 ± 15	1458 ± 19	Marsh	OS-175751
39	LASMP-Reg1-2022-95-1A	0.88	2.89	Peat	1620 ± 15	1482 ± 21	Marsh	OS-175752
40	LASMP-Reg1-2022-97-1A	1.15	3.77	Peat	1760 ± 15	1652 ± 34.5	Marsh	OS-175755
41	LASMP-Reg1-2022-97-1A	1.20	3.94	Peat	1730 ± 15	1616 ± 31.5	Marsh	OS-175756
42	LASMP-Reg1-2022-100-1A	0.10	0.33	<i>Rangia cuneata</i>	Modern	-	Bay/ lag	OS-175025

Final interpretation and integration of sediment core and sub-bottom data was completed using Chesapeake Technologies, Inc. Sonarwiz 7. Any regional bounding surfaces, or geologic features were characterized and exported as along-trackline shapefile data. Isopachs and volume estimates of possibly sand-bearing deposits were quantified using a modified open-source Northern Gulf Sediment Availability and Allocation Program (NGSAAP) tool (Di Leonardo et al. 2022) using linear interpolation. Interpolated surfaces and subsurface feature polygons were created in Esri ArcPro.

4 Geophysical and Geological Results and Interpretations

4.1 Seismic-Lithofacies

Recognizing distinct facies, specifically with the highest concentration of mixed-sediment and sand, and mapping their distributions are crucial to develop predictive geologic models to predict the occurrence of compatible sediment resources. Many researchers have developed criteria of sedimentological and seismic characteristics, as well as relationships of certain environmental associations that allow for delineation and building regional geologic frameworks in Louisiana (Fisk et al. 1954; Fisk 1961; Coleman 1982; Smith et al. 1986; Penland, Boyd, et al. 1988; Kulp et al. 2002; Kulp et al. 2005; Flocks et al. 2006; Miner 2007; Flocks et al. 2009; Miner et al. 2009). This investigation further refines the geologic framework and strong research foundation from the citations above and has identified 12 seismic-lithofacies units, including several erosional unconformity surfaces in the study area. In a sediment mapping context for future investigations, gas signatures are also described in case any clues of sediment composition from sub-bottom data could be observed. The term “coffee grounds” is used to describe a concentration of woody, organic, fragments that were once river transported organic material (logs and other organic debris) subject to reworking by nearshore wave action (Coleman 1982). This term is widely used throughout deltaic geology and helps infer process over more general terms such as “organic fragments.” See Table 3 for a summary of seismic and sedimentological characteristics and facies associations of these units. See **Appendix G** for interpreted sub-bottom data examples to aid in future investigations.

Table 3. Summary of seismic-lithofacies found in LASMP Region 1

Facies	Sedimentological Characteristics	Seismic Characteristics	Facies Association	Sediment Resource Potential
Prodelta	Parallel laminated or massive clay with rare silt beds. Color laminated clay of lower/distal zones grade to clay lenticular silt laminae in proximal zones. Rare burrowing and shell material	Horizontally laminated reflectors of variable amplitude, draping sheet morphology	Base of vertical deltaic sequence, overlies marine or other deltaic deposits	Sand %: None Preservation: High Geometry: thick and extensive
Delta Front	Laminated clay and silt, with lenticular to laminated sand. Lower zone highly bioturbated, shell fragments. Upper/proximal portions, small-scale cross-laminae, current ripples, scour, and fill, contain silt and silty sand beds	Horizontal to low-angle parallel to wavy reflectors. Draping sheet to basin fill. Occasional deformation	Overlies prodelta or bay. Underlies mouth bar offshore and upper delta plain in bays. Grades laterally into prodelta or mouth bar	Sand %: Med-Low (Proximal) Preservation: High Geometry: thick and extensive
Distributary Mouth Bar	Offshore: Generally, massive, well-sorted, very fine-medium sands. Coarsening upwards sequence. Some cross-bedding, current ripple drift, and flaser laminations. Lower/distal portions contain higher silt and clay beds. Some wood fragments and coffee ground organics, trace shell fragments. Bays: Generally interbedded sands and silty sands and silts (sand dominated)	Offshore: Generally transparent, to faintly dipping reflectors, usually capped by strong amplitude reflectors. Mounded complex or lenticular morphology. Basal reflector is poorly imaged. Bays: Horizontally laminated or transparent reflector package, sheet morphology. Stronger amplitude top reflector, can extend beyond channel form	Grades vertically and laterally into delta front. Stratigraphically below or at same position as distributary channel	Sand %: High Preservation: Med-High Geometry: Variable

Facies	Sedimentological Characteristics	Seismic Characteristics	Facies Association	Sediment Resource Potential
Distributary Channel Fill (Active)	Very fine-medium sand and silty sand, medium scale to small scale cross bedding, organics common. Erosional basal contact with fining upwards sequence	Transparent to chaotic reflectors contain with the channel form. Base is usually not imaged, contained within incisional "U" shaped channel form	Base or sides of distributary channel form, underlies fine-grained abandoned fill	Sand %: Med-High Preservation: Med-High Geometry: Elongate with clayey overburden
Distributary Channel Fill (Abandoned)	Poorly sorted, silt and clay. Lenticular to interbedded fine-grained material inter-fingering locally with peats and transported organic debris. Gradational to sharp erosional basal contact depending on presence of active channel fill	Laminated, faintly, draping fill of variable amplitude. Local gas blanking may obscure bottom of channel	Contained within distributary channel form, overlies active channel form where present	Sand %: Low Preservation: Med Geometry: Elongate
Channel Bar	Very fine-fine sand and silty sand, medium to small scale cross bedding. Fining upward sequence. Sharp basal contact. Transported organics common	Dipping reflector packages, sharp basal reflector where imaged, sometimes blanked under gas window. Laterally grades into incisional channel form or is contained within the basal channel form	Overlies delta front, or distributary mouth bar. Laterally adjacent to overbank facies and channel-fill	Sand %: Med Preservation: Med Geometry: Discontinuous
Overbank/ Natural Levee	Laminated very fine sands, silts, silty clays, and organics. Climbing current ripples and small scale-cross laminae.	Horizontal, parallel to transparent reflectors. Seismic integrity decreases w distance from channel form	Overlies delta front, mouth bar facies. Laterally bounds distributary channel.	Sand %: Med (proximal) Preservation: Med Geometry: Discontinuous
Interdistributary Bay	Highly bioturbated sandy silts and clays. Rare preservation of lenticular to horizontally laminations. Brackish faunal assemblages dominate. Shell fragments very common. Small oyster reefs common. Some transported organics	Horizontal to wavy parallel reflectors of variable amplitudes, occasionally acoustically transparent packages. Sheet or basin fill morphology	Underlies delta front, overlies a variety of deltaic facies. Confined within distributary network and grades laterally from channel features or marsh environments.	Sand %: Low Preservation: High Geometry: Extensive
Marsh	Peat and organic clays, brown to dark gray soil and rooting horizons, poorly sorted and mottled clays, silts, and sands.	Generally characterized by strong, thick horizontal, parallel reflector. Gas blanking below in most cases	Uppermost portion of normal deltaic sequence, continuous marsh peats more common distally from distributary channels and landward portions of delta lobes	Sand %: Low Preservation: Low Geometry: Thin and variable
Tidal Delta	Coarsening upward, massive to faintly laminated fine sand. Shell fragments and coffee grounds organics common. Bioturbation common. Sharp to gradational basal contact	Transparent to chaotic reflectors to dipping reflectors, mounded external form. Base is not usually resolved but locally shows distinct basal reflector where imaged	Laterally grade into marine or bay deposits	Sand %: High Preservation: Low-Med Geometry: Discontinuous, Fan shape

Facies	Sedimentological Characteristics	Seismic Characteristics	Facies Association	Sediment Resource Potential
Inlet Fill	Upper: Fine sand, interbedded, flaser, wavy, lenticular, and horizontal laminations. Multiple fining upward sequences separated by sharp contacts. Overall gradational basal contact Lower: Massive fine sand, with flaser or inclined, wavy, lenticular beds, rip up clasts common. Shell fragments and bedded organics abundant. Sharp basal shell hash contact	Transparent to chaotic reflectors to dipping reflectors, incisional channel form. Base is not usually resolved but locally shows distinct basal reflector of where imaged	Laterally grade into tidal delta or marine deposits. Usually overlies deltaic deposits	Sand %: Med Preservation: Low-Med Geometry: Discontinuous, Elongate
Barrier Platform	Coarsening upward, massive to faintly laminated fine sand. Shell fragments and coffee grounds common, some rooting. Bioturbation common. Sharp to gradational basal contact	Transparent to dipping reflectors with distinct basal reflector where imaged	Overlies variable deltaic deposits	Sand %: Med-High Preservation: Low-Med Geometry: Semi-Continuous
Ravinement Surface	Shell fragments in sandy matrix, erosional basal contact. Also represented as a thin coarser bed compared to underlying sediment	Strong to medium amplitude reflector truncating underlying reflector sets	Variable vertical sequences	Sand %: Med Preservation: Low-Med Geometry: Thin, Variable

Note: Sources from (Meckel 1967; Coleman 1982; Kosters 1987; Kulp et al. 2005; Flocks et al. 2006; Miner 2007; Flocks et al. 2009; Miner et al. 2009; Reijnenstein et al. 2011; Feng et al. 2019; Souza et al. 2022)

4.2 Mapping Regional Subsurface Architecture and Key Geologic Features

The development of the predictive geologic models and delivery of an updated sediment resource inventory relies on accurate interpretations of the subsurface as it can be observed through sediment cores and geophysical methods. However, the succession of sediments observed in the MRDP is not a continuous, complete record of all the sedimentary and sea level processes responsible for its creation. There has been significant erosion and reworking of past delta deposits, in a manner analogous to the modern land loss and coastal processes observed today. Accurate determination of the relative position, timing, and preservation of coarse-grained sediments to the coast requires a correlation framework to understand what elements may have been missing in the geologic record and why (e.g. fluvial channels are observed in the subsurface of a bay, but the delta lobes they were linked to and building, have been completely eroded and removed from the record). This study provides a detailed analysis of observed transitions in the subsurface sedimentary record that relate to these regional periods of erosion and reworking, referred to as transgressive ravinement surfaces. Section 4.2.1 includes specific details, observations, and advanced geologic concepts that are not themselves necessarily of interest to project planners and engineers, but without which the resulting frameworks and maps cannot be built. Additionally, the following sections provide detailed observations of the distribution and sedimentary character of various encountered sedimentary deposits and hypotheses for their deposition, preservation, and sediment resource potential. Together the mapping and discrete characterization of these subsurface architectural elements provides the necessary scientific basis for confidently assessing sediment resources and aiding in holistic system management.

4.2.1 Transgressive Ravinement Surfaces

As part of the reconnaissance-level mapping effort, any regional surfaces (contacts between sedimentary units) that aided in the interpretation of the geological framework were identified and correlated with previous framework investigations. These erosional unconformities or transgressive ravinement surfaces

represent a missing portion of the sedimentary record, separating sequences of regressive deltaic deposition from transgressive bay or marine units. Ravinement surfaces form as waves or tidal currents erode underlying deposits as the shoreline translates landward, typically leaving a coarse-grained, shelly lag or sheet in its retreat path (Penland et al. 1987; Kulp et al. 2005). In the Terrebonne Bay area at least one regional erosional unconformity ravinement surface has been identified in the subsurface that correlates with the previously identified Teche ravinement surface (Smith et al. 1986; Penland, Ramsey, et al. 1988; Figure 20A). Locally, other surfaces demonstrating incisional scour that could represent the Terrebonne ravinement surface (Penland, Ramsey, et al. 1988) are present but lack geologic sampling to ground truth and were not correlated in this investigation. This possible ravinement surface was located seaward of the Terrebonne paleo-shoreline where data are limited. In sub-bottom data, the Teche ravinement surface is represented by a strong amplitude, semi-continuous, horizontal reflector that separates faint laminated reflectors above and truncates underlying reflectors. Due to shallow gas and poor acoustic imaging in some areas, especially in western and central Terrebonne Bay, sediment core data was relied on to identify and differentiate the surface from other flat lying reflectors in the sub-bottom. It is defined by an interval of shell hash in a fine-grained sand matrix or an erosional contact in sediment cores (Figure 20B) and ground-truthed in the Teche ravinement surface throughout Terrebonne Bay (Figure 20A). The surface ranges from 2.5 m (8.2 ft.) deep in the northern portions of the bay and dips seaward, in some local instances up to 8.7 m (28.5 ft.) below seafloor. The surface has some topography likely due to increased ravinement depths by migrating tidal inlets (Miner et al. 2007). Both the depth of the surface and the missing interval of time above and below the surface constrained by radiocarbon samples further supports the interpretation that it is the Teche ravinement surface (Penland et al. 1987; Kulp et al. 2005).

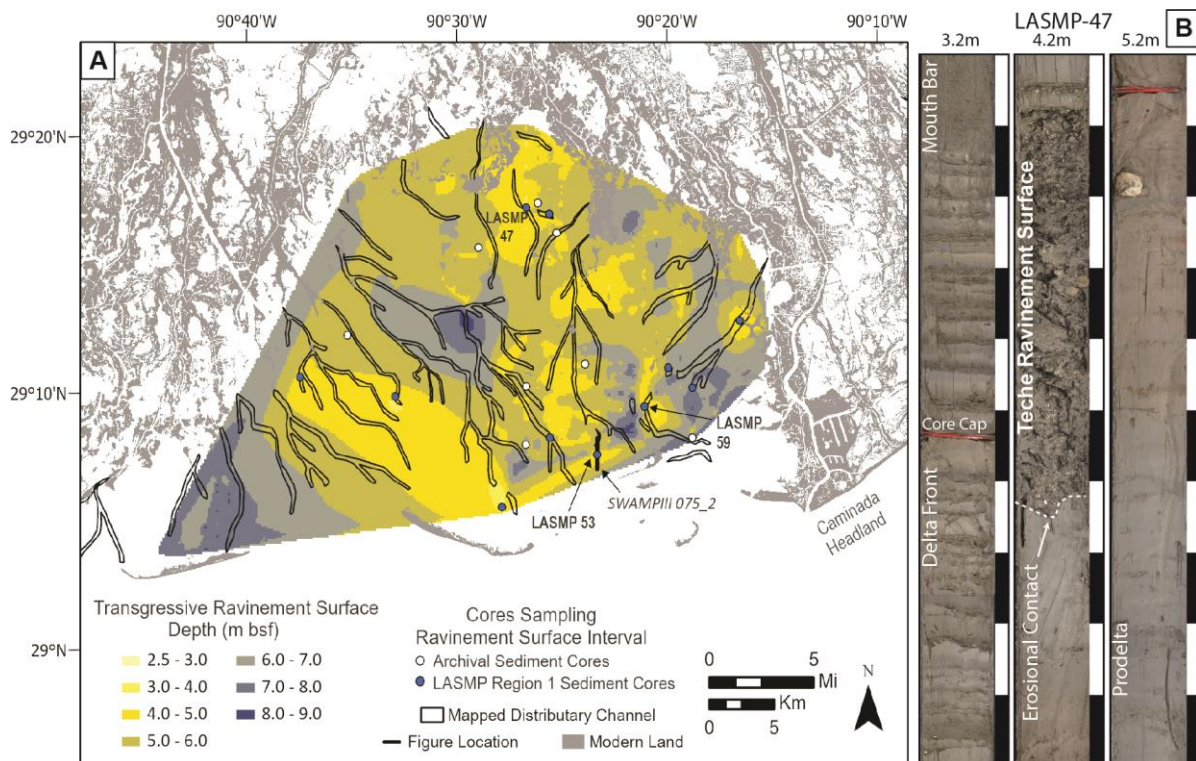


Figure 20. A) Regional transgressive ravinement surface within Terrebonne Bay derived from sub-bottom profile and sediment core data. B) An example vibracore section sampling the ravinement surface, which is represented by a shell lag or coarse grain interval with a sharp erosional contact of underlying sediment. This ravinement surface correlates to the previously identified Teche ravinement surface of Penland et al. (1988). Subsequent sub-bottom figure location displayed by trackline identifier

The Teche ravinement surface separates the underlying Maringouin-Teche delta complex from the younger, Lafourche complex. Sub-bottom and vibracores within Terrebonne Bay show marsh deposits overlain by a thin interval of bay or prodelta clay, underlying the shell lag of the Teche ravinement surface (Figure 21). Articulated oyster (*Crassostrea virginica*) and *Mulinia lateralis* samples from directly landward of Cass-Tete Island, within the ravinement surface interval are 1,428 to 1,561 years ago (Figure 21). Other *M. lateralis* and *Rangia cuneata* samples from the shell lag interval are 1,307 to 2,779 years ago (Table 2). These radiocarbon samples provide minimum age constraints of the deposit since they are transported material and not in-situ. The samples from within the lag represent fresh or brackish to saline environments demonstrating an amalgamation of environments in the lag deposit resulting from the shoreline translating landward. Below the Teche ravinement surface is a thin sequence of bay or prodelta clay overlying marsh deposits. In-situ peat samples from these organic rich marsh deposits range in age from 3,832 to 4,112 years ago (Figure 21). The formation of marsh ~4,000 years ago correlates to the age of Teche deposition (Frazier 1967; Penland et al. 1987; Kulp et al. 2005), although further geologic sampling would better constrain the continuity of the marsh throughout Terrebonne Bay.

In the Barataria offshore region there are two regional transgressive ravinement surfaces within the upper 6 m (20 ft.) in the subsurface (Figure 22). The area offshore Cheniere Ronquille has a high occurrence of gas blanking, making it difficult to map these two surfaces and see how they are stratigraphically related. The transgressive surface is represented by the truncation of underlying reflector packages in sub-bottom profile data but is sometimes obscured by gas blanking. In core data it is sometimes represented by a coarser sediment-interval or shell lag with a sharp basal contact whereas other times it is a much more subtle contact in finer-grained sediment (also observed by Flocks et al. 2006). Offshore of West Grand Terre the ravinement surface is variable, ranging from 1.2–5.8 m (2–19 ft.) below seafloor. The only radiocarbon age constraint comes from organic material within channel fill below the ravinement surface identified in an archival core (Flocks et al. 2006). It is interpreted as an upper estimate of diminishing channel flow and abandonment occurring around 3,600 years ago (Flocks et al. 2006). With no in-situ age estimates in the West Grand Terre offshore region, it is difficult to constrain its timing.

In the eastern portion of the investigation, the ravinement surface is mostly coincident with the seafloor, or in the upper 0.6–1.2 m (2–4 ft) in the subsurface. An articulated *Nuculana concentrica* from within the shell lag deposit returned a “modern” age, representing a minimum age, as this is not likely an in-situ sample. Archival age estimates from landward extensions of these systems demonstrate peat formation occurring between roughly 500–1,000 years ago (Kulp 2000), suggesting the Scofield and Sandy Point deposits are related to Plaquemines delta deposition. There is correlation of the mapped paleo-delta lobes (see Section 4.2.4) and presence of ravinement surfaces coincident with the seafloor, which suggests the positive topographic expression of these paleo-delta lobes were truncated as the lobes experienced transgressive ravinement as they were abandoned and reworked by coastal processes (destructural delta phase). The deeper and older West Grand Terre paleo-lobe has preserved levee and other upper deltaic facies, suggesting a higher degree of preservation compared to the younger, stratigraphically higher area Scofield and Sandy Point where only lower deltaic facies are preserved. Bathymetric change analysis show zones of erosion in the Scofield and Sandy Point from the 1930s to 2010s (ACRE 2020), further supporting these Plaquemines age paleo-deltas are actively eroding. Relevant to sediment resource prospecting, the likely Plaquemines age Scofield and Sandy Point paleo-delta mouth bar deposits should have less fine-grained overburden of the upper deltaic sequence as it was eroded during ravinement.

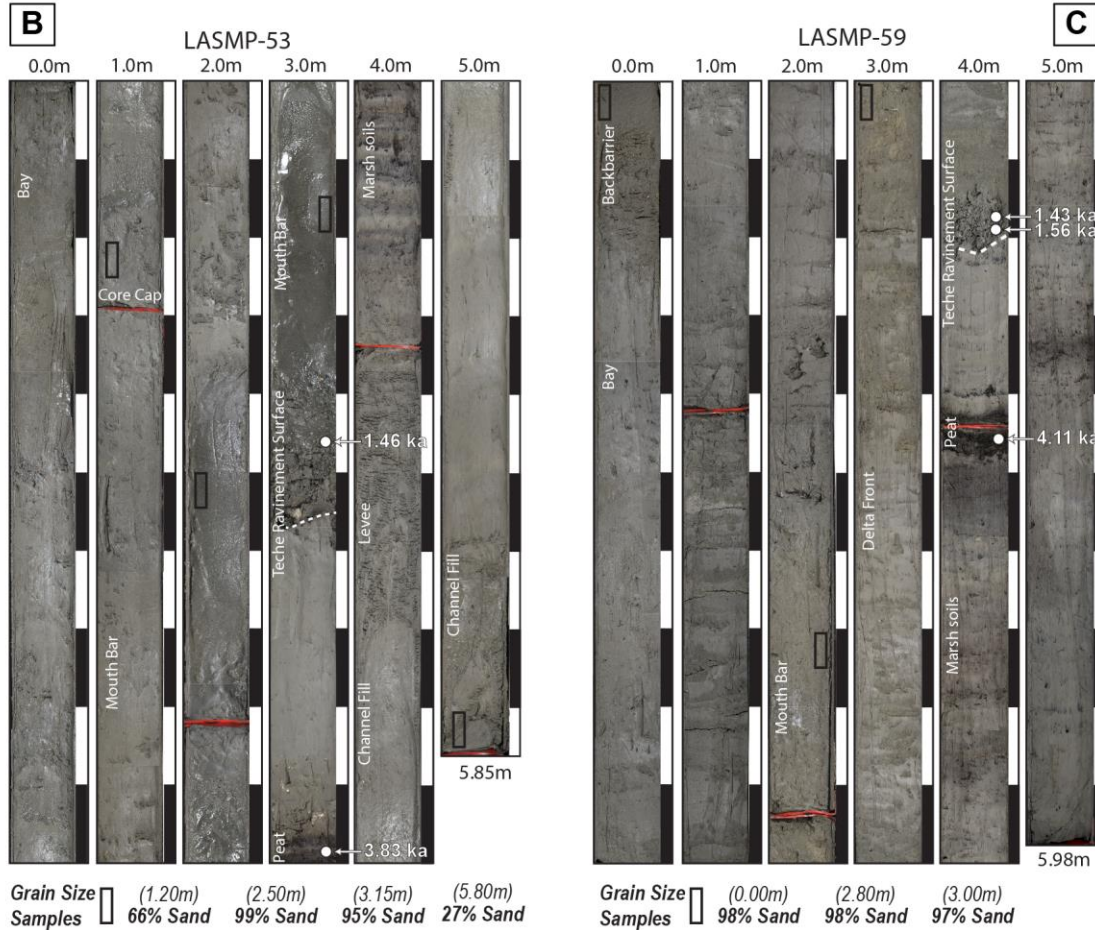
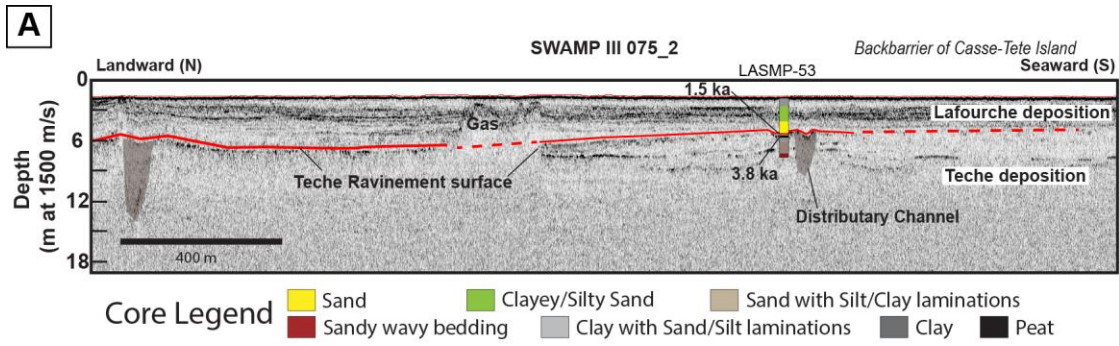


Figure 21. A) Example of interpreted sub-bottom profile data and cores within Terrebonne Bay displaying the regional erosional unconformity ravinement surface and deeper distributary channels likely related to Teche deltaic deposition. This surface is correlated to the previously described Teche ravinement surface, separating Lafourche from Teche age deposits (Penland et al., 1987). Highlighted sediment cores (B) LAMSP-53 and (C) LASMP-59 have articulated *Crassostrea virginica* (oyster) and *Mulinia lateralis* samples dated to ~1,500 years ago, from within the ravinement surface interval. The ages provide a minimum age estimate for the timing of the ravinement surface. Peat samples from below the erosional unconformity date to ~4,000 years ago, likely representing a Teche-aged marsh deposit. See Figure 20 for locations

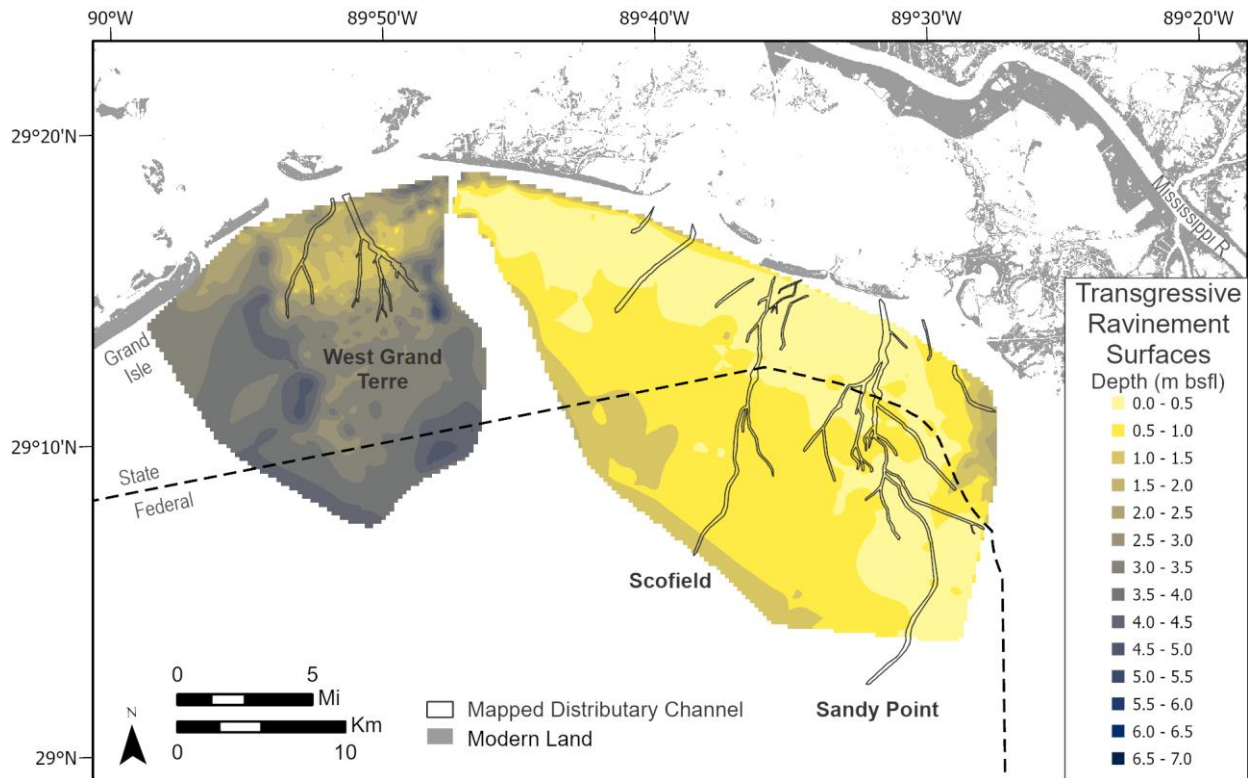


Figure 22. Regional transgressive ravinement surface depth below sea floor. See Section 4.2.4 for sub-bottom examples of the ravinement surfaces

4.2.2 Terrebonne Subsurface Deposits

Terrebonne Bay's subsurface is characterized by phases of delta lobe deposition, abandonment, subsidence, and reworking by marine processes. From previous framework studies, the resulting stratigraphy should consist of the relatively thin, shallow water delta of the Lafourche delta complex overlying the older and thicker Maringouin-Teche delta complex (Smith et al. 1986; Penland, Ramsey, et al. 1988; Hollis et al. 2023). The extent of these two delta complexes is roughly constrained by transgressive paleo-shorelines from post abandonment reworking and the degree of preservation, and geometries can be refined by the holistic synthesis of data in this investigation.

Within Terrebonne Bay, a series of subsurface distributary channels radiate seaward and coincide with previously mapped onshore channels related to Lafourche deposition. These shallow subsurface distributary channels are truncated by the bay floor, indicating the bay is deepening and widening as interior marsh converts to open water. The distributary channels are above the Teche ravinement surface and radiocarbon samples from this investigation further support the interpretation that the shallow network of channels are subsided portions of the Lafourche delta complex. Finally, these Lafourche shallow subsurface distributaries terminate at a linear feature fronting the bay landward of the modern shoreline, which correlates to the Terrebonne shoreline of previous framework studies (Penland et al. 1987; Figure 23). In sections of the bay landward of the Terrebonne shoreline, there are preserved marsh and channel deposits dating to ~4,000 years ago, which are inferred as remnant Teche aged deltaic deposits (Figure 21). Further refinement is needed to map the distribution of Teche deposits, as future mapping efforts could provide clues to major sediment pathways related to Teche depocenters further offshore. The central portion and periphery of the bay had limited acoustic penetration attributed to the organic content of the Terrebonne lobe. There is a strong correlation between shallow gas blanking and remnant marsh area from historic charts (Figure 23).

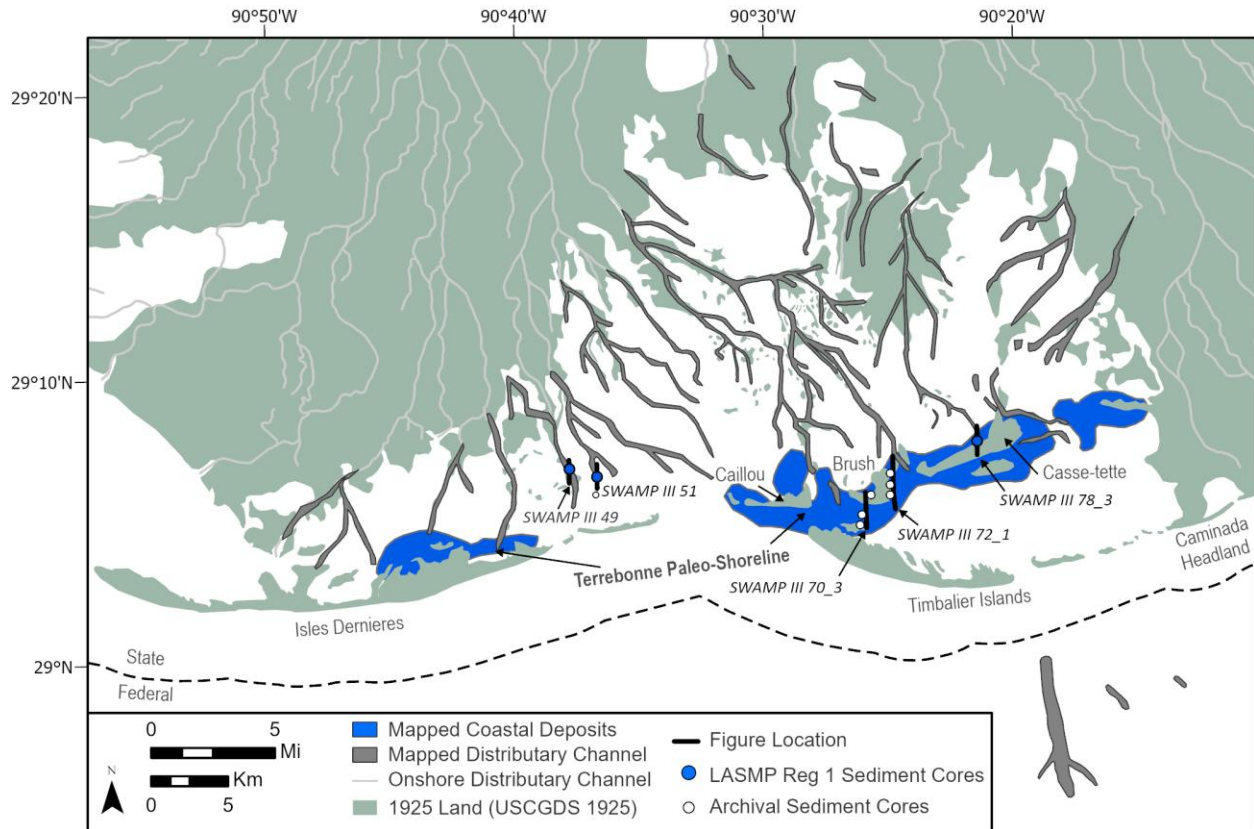


Figure 23. Mapped subsurface distributary channels and coastal deposits in Terrebonne Bay and offshore. Previously mapped onshore distributary channels and land area from 1925 are displayed for reference in this highly dynamic environment. Sub-bottom profile locations are displayed in black with a trackline identifier, representing archival SWAMP data verified with newly collected LASMP and archival sediment cores. The subsurface coastal deposits, made up of barrier platform and tidal deposits, correlate to the previously identified Terrebonne Shoreline (Penland, Ramsey, et al. 1988). Note land area is from USCGDS (1925) “United States- Gulf Coast: Mississippi River to Galveston” 1:459,000

The Bayou Terrebonne delta formed from the Bayou Blue, Bayou Petit Caillou, Bayou Saint Jean Charles, Bayou Pointe-au-Chien, and Bayou Terrebonne subdeltas. This multi-bifurcating distributary network was active between 830–1,270 years ago and was located between the Bayou du Large and St. Bernard delta complex (Penland et al. 1987). Abandoned Bayou Terrebonne distributaries extend to the transgressive Terrebonne shoreline and have since been abandoned and in-filled. Distributary channels are mostly represented as incisional “U” shaped channel forms that truncate underlying reflectors, although their geometries greatly vary throughout the investigation. Distributary network interpretation was aided by historic charts that captured remnant distributary channel levees that had not yet been converted to open water in this highly dynamic setting (Figure 23). Larger distributaries have small channel bars, active channel fill, or mouth bars that display dipping reflectors flanking the channel form itself or mounded transparent features near the channel base or below. The distributary channel fill represents a highly variable, fining upward sequence with any sand concentrated near the base. Channel bars represent some of the high sand percentage deposits but are discontinuous and uncommon in Terrebonne Bay. The high number of terminal distributaries and shallow water accommodation have resulted in a thin layer of laminated sand and silt roughly 1–3 m thick at the base of the Lafourche deltaic sequence. These coalesced mouth bar deposits represent the “delta front sand sheet” shallow water delta of Fisk et al. (1954). The “delta front sand sheet” or proximal delta front is a laminated silty sand and silt

that fines distally from distributary channels. Its composition is variable, geometry is fairly extensive, but thin, with mostly fine-grained overburden. See Figure 24 for examples.

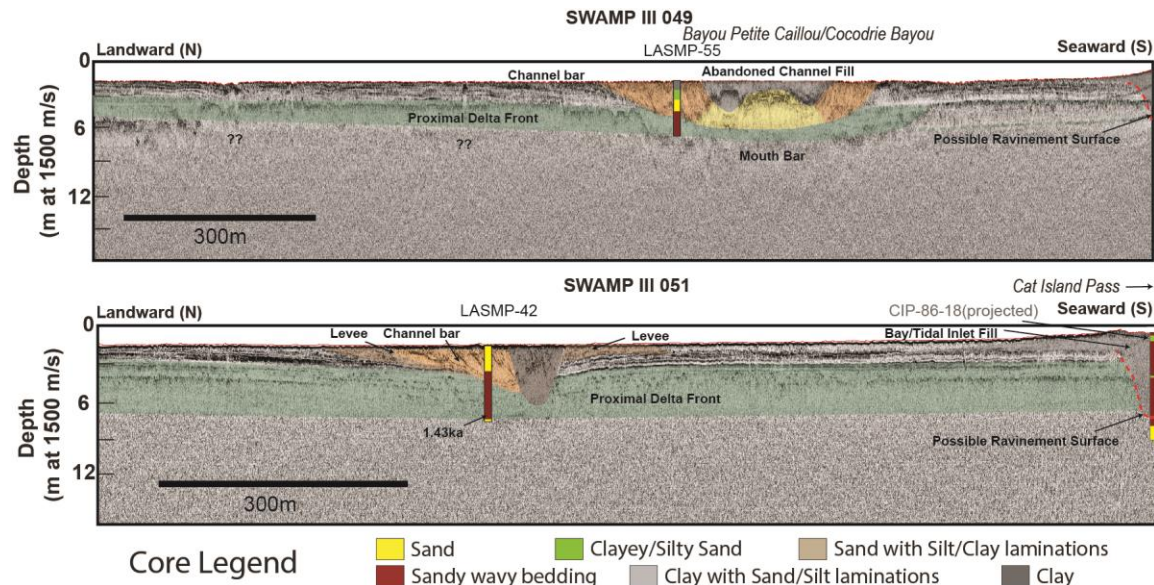


Figure 24. Sub-bottom profiles from the western side of Terrebonne Bay with highlighted distributary deposits. These deposits are related to Bayou Petite Caillou/Cocodrie Bayou and an adjacent abandoned distributary. Mouth and channel bars are highlighted in orange, delta front deposits are in green, levees are brown, and the channel forms are highlighted in gray. See Figure 23 for locations

As flow was shifted elsewhere in the delta plain, the Bayou Terrebonne delta lobe entered the transgressive phase. The coarse-grained deposits related to the Bayou Terrebonne distributary network were concentrated in the Terrebonne shoreline through coastal reworking. Previous framework studies state the roughly 600-year-old Terrebonne shoreline is 5–10 m (16–32 ft.) thick, and consists of Caillou Island, Brush Island, Casse-tete Island, and Fifi’s Island (north side of Grand Isle), and is a result of the abandoned and reworked of the Terrebonne delta lobe (Penland et al. 1987; Culling 2018). This investigation maps a linear feature interpreted as coastal deposits consisting of barrier platform, tidal inlet, and tidal delta deposits landward of the modern shoreline, fronting Terrebonne Bay (Figure 23). The linear feature correlates to the Terrebonne paleoshoreline (Penland et al. 1987) and volumetrically represent the most significant concentration of sand and mixed-sediment deposits in the Terrebonne Bay region. The most extensive coastal deposits were mapped between Lafourche headland and Timbalier Island. These deposits are predominantly sandy to shelly clayey sand with limited, variable overburden roughly 0–3 m (0–10 ft.). The mapped Terrebonne paleoshoreline coastal deposits are up to 6 m (20 ft.) thick, although deeper geologic sampling would improve delineation of the base of the deposit.

In sub-bottom profiles, the mapped coastal deposits represent a generalized footprint of a more discrete barrier platform, tidal inlets, and tidal delta facies but it is difficult to discern their individual extents with the current data coverage. Where defined, barrier platform or beach ridge deposits are characterized by dipping to transparent reflectors and a hard amplitude top and basal reflector where imaged. They are laterally extensive alongshore. Tidal inlets are differentiated from distributary channels based on the facies association to tidal deltas or barrier platform, wider channel shape, and less spatial continuity landward and seaward compared to extensive distributary networks. Tidal deltas grade into tidal inlets and exhibit a lobate geometry consisting of chaotic, slightly dipping, laminated-to-transparent reflectors (Figure 25). Terrebonne shoreline’s coastal deposits are massive to laminated shelly sand with some organics, plant rooting, and bioturbation.

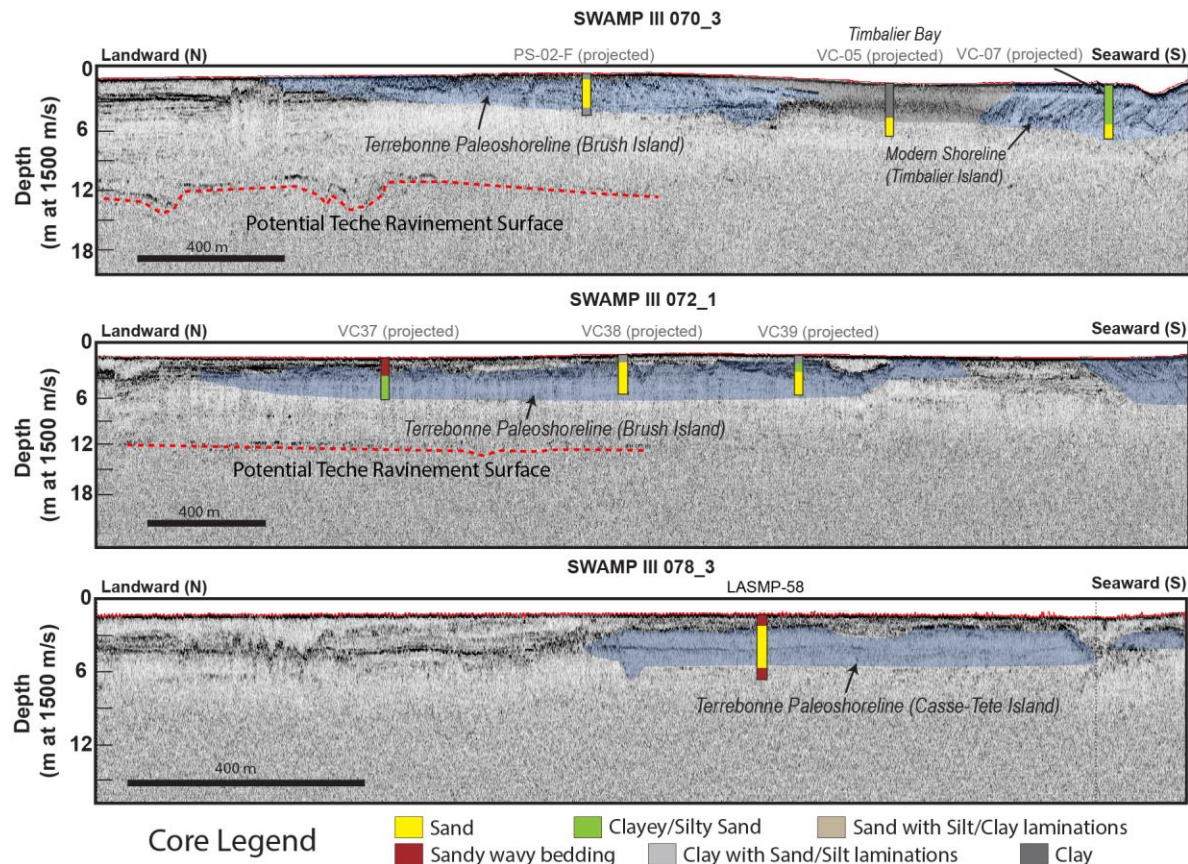


Figure 25. Sub-bottom profiles with interpreted coastal deposits, highlighted in blue, in Terrebonne Bay. These deposits are related to the Terrebonne paleoshoreline, most notably Brush and Casse-Tete Island. Modified from (Hollis et al. 2023). See Figure 23 for locations

4.2.3 Barataria Subsurface Deposits

Barataria Bay consists of a complex stratigraphic framework due to the interplay of multiple phases of depositional sources that are likely from the St. Bernard, Lafourche, and Plaquemines deltaic systems (Boyd et al. 1989; Kusters and Suter 1993). These deltas have left their imprint on the region through regressive and transgressive processes, characterized by multiple, often stacked, lithofacies and parasequence sets which correlate to varying phases of deltaic advance, retreat, and submergence. The region is also characterized by numerous channel forms of varying depth, size, and orientation, which incise these lithofacies (Hollis et al. 2023). Three major paleo-delta lobe sediment pathways were identified in the subsurface. The deepest delta (Lobe 1) likely correlates to the Bayou des Families lobe of the St. Bernard delta complex and continues offshore of the modern shoreline to its respective depocenter (Frazier 1967; Levin 1991; Flocks et al. 2006). Within Barataria Bay the suggested Bayou des Families lobe demonstrates thick layers of overbank splay aggradational units. As this lobe underwent transgressive reworking, shallow water deltas likely related to Bayou Blue (Lobe 2) and delta lobes of the Plaquemines complex (Lobe 3) prograded into Barataria Bay (Figure 26). Unlike in Terrebonne Bay, historical charts do not provide clues of distributary network geometries as all remnant distributary levee deposits converted to open water prior to historic charting periods except in the southeastern portion of the investigation area by Empire. Similar to Terrebonne, sub-bottom data is obscured by shallow gas blanking in areas of remnant marsh such as in areas by Empire that converted to open water in the 1930–

1950s (Couvillion et al. 2017). Several oyster lease areas in Barataria Bay also correlate to poor sub-bottom imaging, which added to the difficulty in this mapping effort.

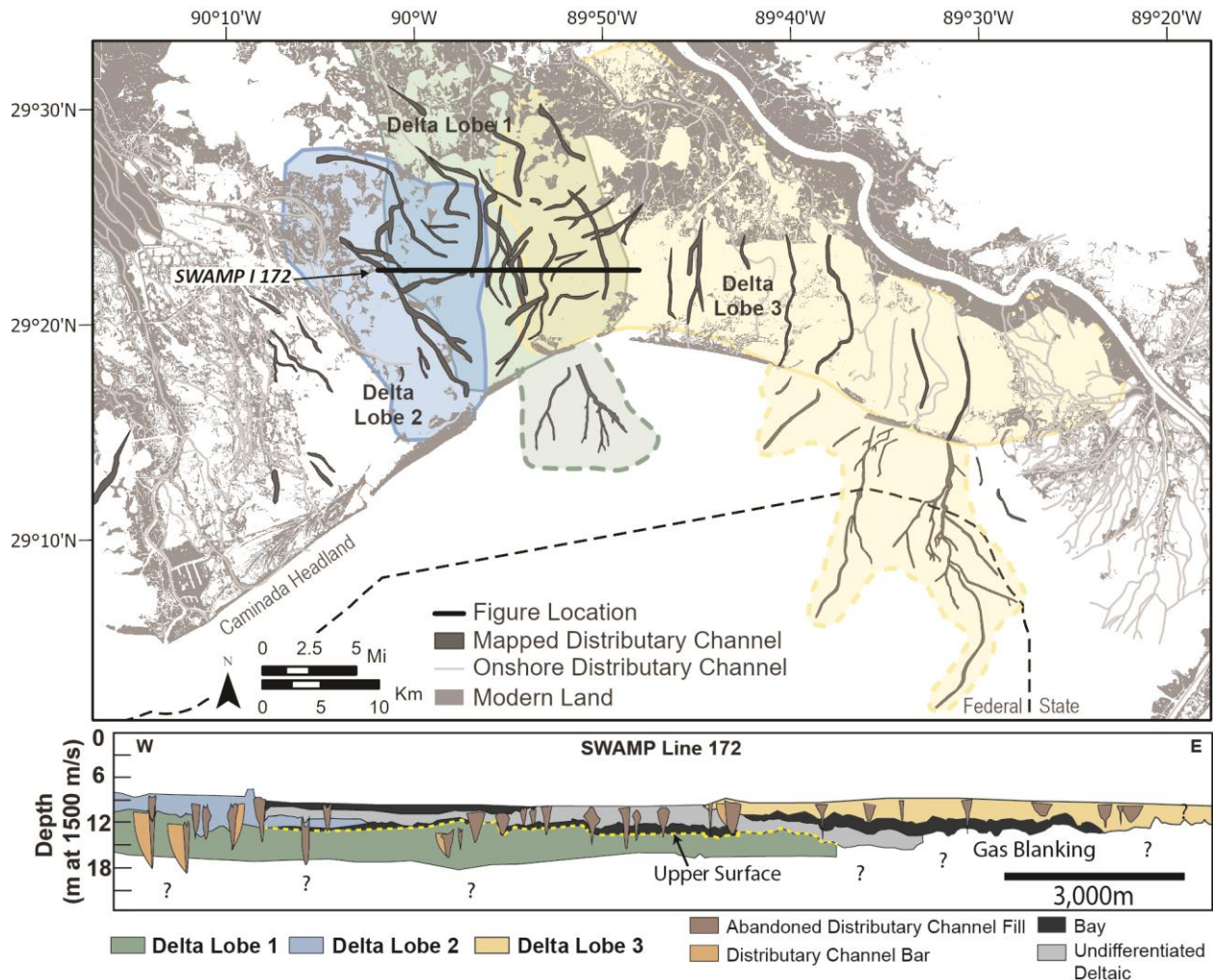


Figure 26. Three stacked delta lobes and a series of distributary channel systems within Barataria Bay were identified in this investigation. Simplified regional cross section derived from sub-bottom data demonstrates the vertical relationship of the mapped delta lobes in the subsurface and partial separation by bay sediment. Partially preserved extensions of Delta Lobe 1 and 3 are identified in the offshore. Delta Lobe 1 appears thickest with the highest sand composition, although the bottom could not be resolved in sub-bottom data. Western Barataria Bay has a high occurrence of sandy distributary channel bar features compared to the east

Bayou des Families was the first delta lobe to prograde into a semi-enclosed bay environment in central Barataria Basin according to Kusters and Suter (1993). Previous framework research suggests the Teche ravinement surface should underlie the Bayou des Families lobe with its maximum flooding extent just north of Barataria Bay and outside the investigation area (Penland et al. 1987; Kusters and Suter 1993). Erosional surfaces above the Bayou des Families lobe are much more subtle, with only discrete contacts between bay and deltaic facies observed in sediment cores, similar to findings from previous research (Levin 1991; Kusters and Suter 1993; Flocks et al. 2006). This is compared to the thick shell lags found in the Terrebonne area subsurface (Penland et al. 1987). A continuous surface marking the transition between deltaic progradation facies and bay facies was mapped in the subsurface of Barataria Bay (Figure 27). Delta Lobe 1, or the suggested Bayou des Families lobe's upper boundary, is a strong amplitude

acoustic reflector package, which corresponds to shelly, clayey, bay deposits. In central Barataria Bay, an articulated *Mulinia lateralis* radiocarbon sample from the bay interval occurred about 2,500 years ago (Figure 28). Below the bay deposits, either overbank or discontinuous marsh deposits are present. Peat samples show marsh formation occurring between 2,708–3,137 years ago in the northeastern section of Barataria Bay (LASMP-Reg1-2022-77; Table 2). Additional age estimates would help constrain the timing and extent of Delta Lobe 1, but the data provided correlates well with age ranges of Bayou des Families activity in previous framework research (Frazier 1967; Levin 1991; Kusters and Suter 1993; Flocks et al. 2006; Flocks et al. 2009). As flow shifts elsewhere in the delta plain, the suggested Bayou des Families lobe subsides, and Lafourche and Plaquemines deposition prograde into the new depocenter of Barataria Bay (Figure 26).

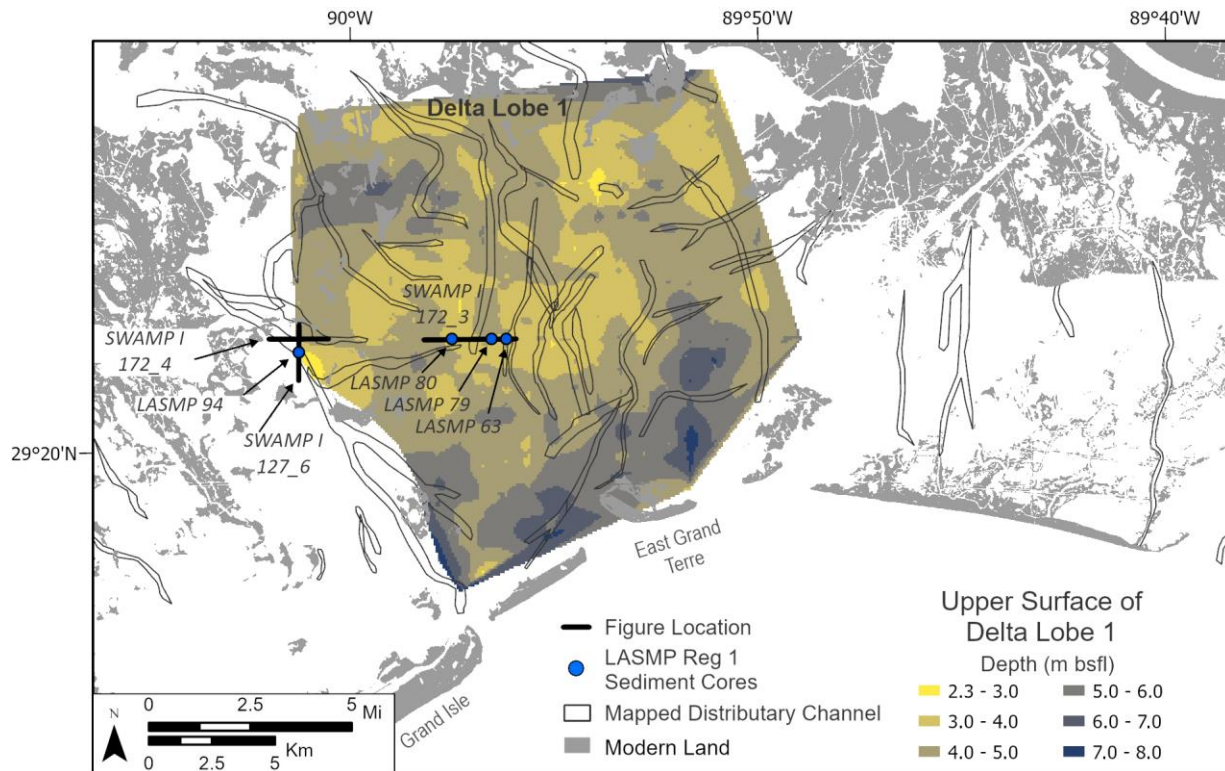


Figure 27. Depth below seafloor of the upper surface of the deepest mappable Delta Lobe 1. Subsequent sub-bottom figures located by trackline identifier

Delta Lobe 2 (Figure 26) trends northwest to southeast and overlies Delta Lobe 1 and displays a complex network of distributary channels with associated overbank and channel bars. The earliest stage of marsh formation from Delta Lobe 2 occurred at 2,344 years ago with renewed organic accumulation occurring ~1,500 years ago (Figure 29; LASMP-Reg1-2022-94; Table 2). Several peat samples directly underlying the upper bay facies in northwest Barataria Bay, range from 1,342–1,630 years ago (LASMP-Reg1-2022-91, 94, 95, 97; Table 2). Delta Lobe 2's marsh formation timing, position, and subsequent abandonment correlate to the Bayou Blue subdelta of the Lafourche complex of previous framework investigations (Penland et al. 1987; Levin 1991; Flocks et al. 2006). Delta Lobe 3 (Figure 26) radiates from the trend of the modern Mississippi River, overlying discontinuous bay and Delta Lobe 1 progradational deposits. Archival peat dates from the landward continuations of distributaries mapped in Barataria Bay for this investigation, and the orientation and proximity to the modern Mississippi River suggest Delta Lobe 3 is part of the Plaquemines delta complex (Frazier 1967; Penland and Boyd 1985; FitzGerald et al. 2004; Kulp et al. 2005; Flocks et al. 2006; Flocks et al. 2009). This delta complex prograded toward the shelf edge from about 1,000 to 300 years ago before the formation of the modern Birdfoot Delta. All delta

lobes mapped within Barataria Bay are capped by an uppermost bay deposit of varying thickness, thickening seaward near the modern shoreline. Articulated bivalve shells demonstrate the uppermost bay environment occurring over the last 500 years (LASMP-Reg1-2022-62, 79, 80, 81, 82.100; Table 2).

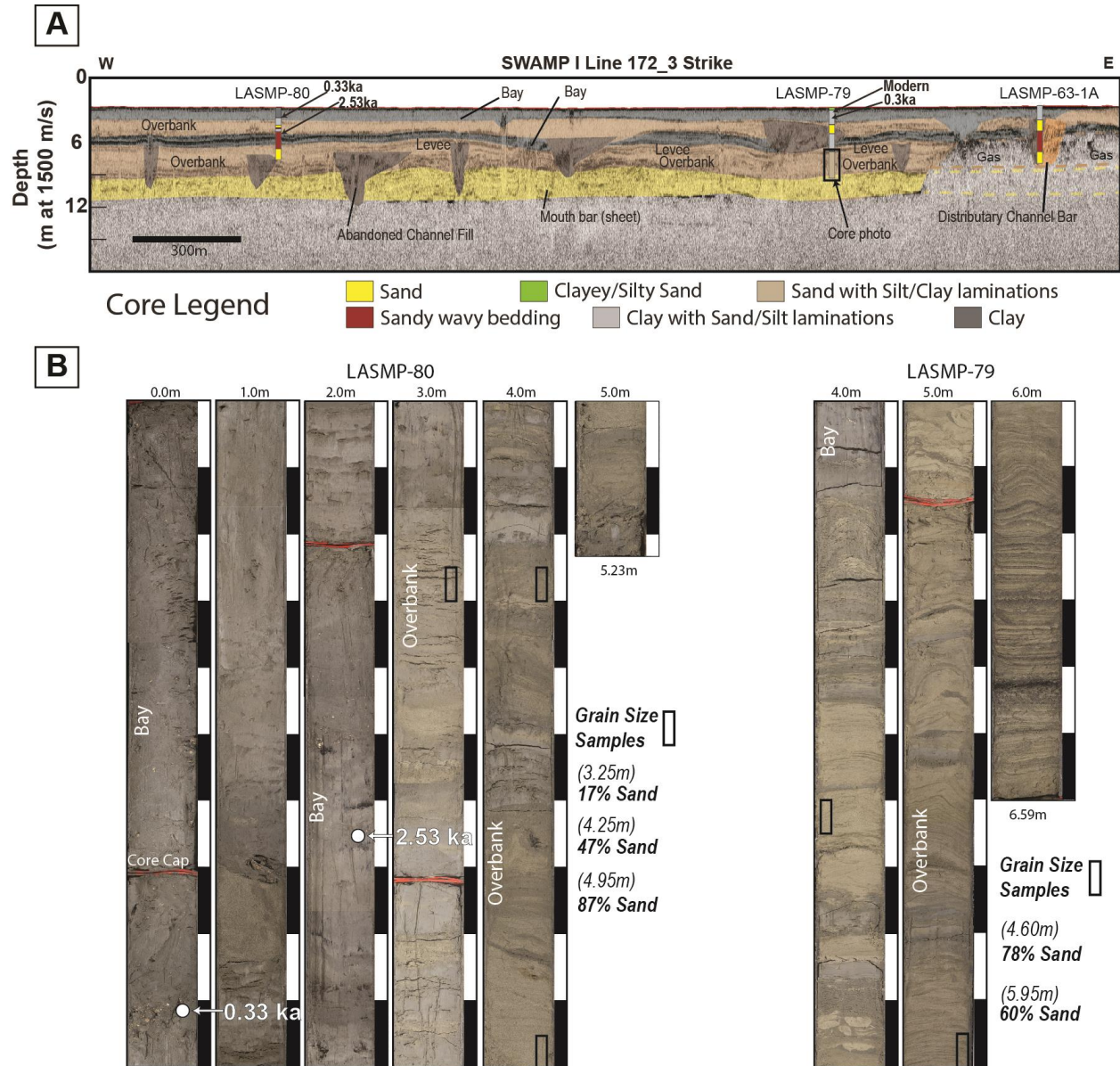


Figure 28. Interpreted sub-bottom profile of central Barataria Bay of multiple generations of paleo-deltaic deposition and thick mouth bar sheet and proximal levee and overbank deposits with high sand percentages. See Figure 27 for location

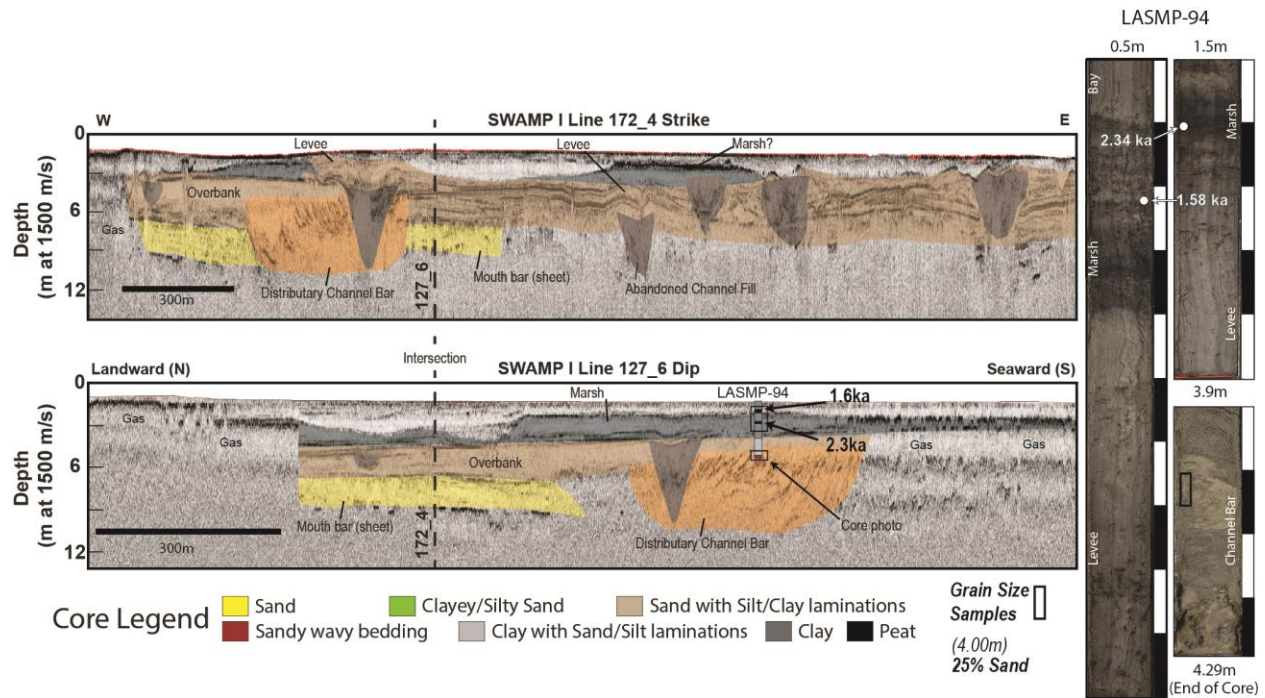


Figure 29. Interpreted sub-bottom profile showing multiple generations of channels of varying size and the occurrence of sand-bearing channel bar deposits at depth. The high degree of preservation in western Barataria Bay has peat and rooting horizons dating to 1,580 years ago and 2,320 years ago. Modified from Hollis et al. (2023). See Figure 27 for location

From a S2S perspective, determining how these delta lobes fit into the previously established geologic framework ties in major sand-bearing depocenters offshore and the degree of preservation and evolutionary timing of these deposits. Stratigraphic positioning and limited age constraint data suggest Delta Lobe 1 likely continues offshore to its major depocenter and high occurrence of quality sediment resources. Two-inferred mixed-sediment resource targets in the form of semi-continuous overbank and likely mouth bar deposits in the upper bay and discrete channel bars associated with large distributaries warrant further investigation. These two inferred target facies are mostly limited to Delta Lobe 1 and 2 but require higher density geologic sampling to assess their viability as a resource. Overbank deposits roughly 3 m (10 ft) thick, consisting of finely laminated sand, silt, and clay, exhibit a sheet morphology with a strong amplitude top reflector with variable transparent to laminated internal seismic facies (Figure 28). Overburden is variable, ranging from 3–9 m (10–30 ft; Figure 27). Large channel bars display dipping reflector sets grading into channel forms, up to ~4 m (13 ft) in sub-bottom, yet only the uppermost unit is sampled (Figure 29). Because it fines upward, the higher sand fraction portion of these deposits is likely to be closer to its basal portion. It is likely these target facies, especially overbank and mouth bar sand sheet deposits of Lobe 1, contain mixed sediment and possibly compatible sand. Additional coring is required to aid in verifying its textural variability and deposit geometries.

4.2.4 Offshore Barataria Subsurface Deposits

Three large paleo-deltas were mapped in the offshore Barataria Bight region (Figure 30). The extensive mouth bar facies represent the higher sand portions of the deltas that could be mapped seaward of the modern shoreline. The paleo-delta mouth bars grade into thick laminated or massive reflector units interpreted as prodelta or distal delta front. The proximal delta front is classified as a mixed-sediment resource and is mapped in this investigation but is highly variable and fines distally from the mouth bar facies. In the nearshore region, smaller delta lobes extend a short distance offshore but do not contain

significant sand fraction. Overlying these nearshore deposits are more recent shoreface, tidal, and marine clayey deposits. The newly collected and archival data compiled in this investigation exhibit average seismic data imaging ranging from 1.5–10.6 m (5–35 ft.) below the seafloor. Most cores penetrate less than 6 m (20 ft) with only a few cores providing information to ~12.2 m (40 ft.). Therefore, most of the mapping results presented are limited to the upper 6–12.2 m (20–40 ft.) below the seafloor and there may be deeper, pre-existing significant sand-rich deltaic deposits but are not fully constrained with the current data. This may be important if overburden criteria changes in the future and deeper coarser-grained sediment deposits are considered viable. These paleo-delta lobes are inferred as St. Bernard and Plaquemines depositional systems and have been previously utilized as successful borrow sites (Figure 13) yet have not been mapped in this extent. The comprehensive mapping and de-risking of sediment composition of seismic facies provides a roadmap for future investigations for similar sediment.

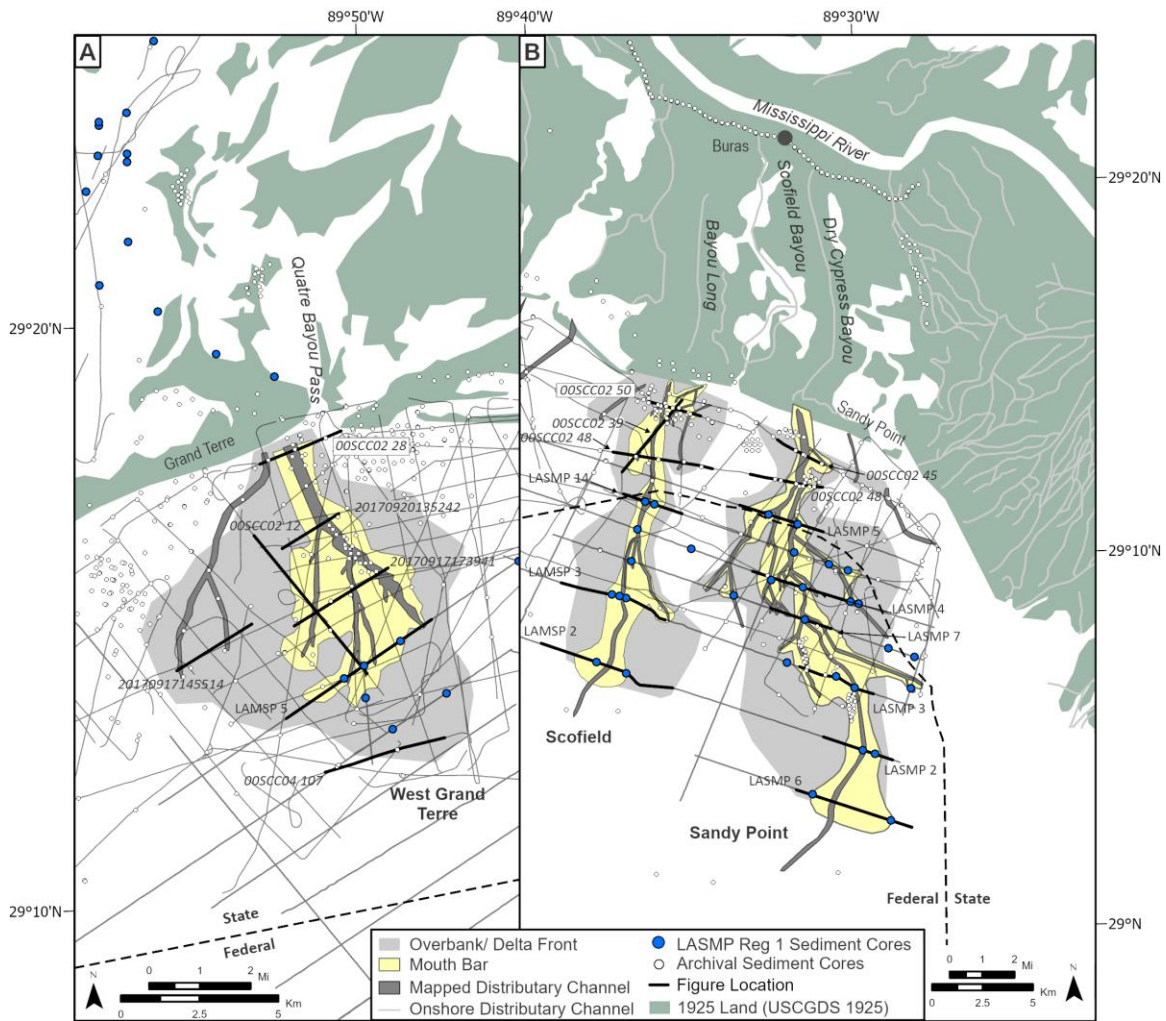


Figure 30. Mapped subsurface deposits representing sand (mouth bar) and mixed-sediment (overbank/ delta front and distributary channel fill) resources. A) Mapped facies of the West Grand Terre paleo-delta or Bayou des Families lobe as suggested by previous research (Levin 1991; Flocks et al. 2006). B) Mapped facies of the Scofield and Sandy Point paleo-delta lobes, which likely represent the Bayou Long and Dry Cypress Bayou Delta of the Plaquemines complex. Sub-bottom profile locations are shown in black with trackline identifiers, representing both newly collected and archival data. Note land area is from 1925 USCGDS chart

Offshore of central Barataria Bight, a large partially preserved delta lobe, the West Grand Terre delta is identified (Figure 30). Due to a lack of absolute age constraints in the offshore region, the geologic interpretations remain preliminary, but distributary channel geometries and major sediment pathways identified in Barataria Bay suggest this is the seaward extension of the deepest Delta Lobe 1, or the Bayou des Families lobe as suggested by Levin (1991), Kusters and Suter (1993), and Flocks et al. (2006). The West Grand Terre delta is truncated by an erosional unconformity (see surface mapped in Figure 22), with partial deltaic sequence preservation below.

The preserved sandy portion of the West Grand Terre paleo-delta that extends about 8.8 km (5.5 mi) offshore is up to 10.7 m (35 ft) thick. The generally north-south trending deposits exhibit seaward thickening overburden, consisting of 3–6 m (10–20 ft) of a fine-grained, laminated reflector package. The lobate paleo-delta displays a main channel that bifurcates about 2.4 km (1.5 mi) offshore into three large secondary distributaries. The channels are characterized by “U” shaped channel forms, yet the base is rarely imaged in seismic. The channel fill contains varying proportions of active channel fill or channel bars and overlying abandoned channel fill. The active channel fill or bars are characterized by transparent or slightly dipping reflectors, while abandoned fill is characterized by draping reflectors with variable amplitude returns and degree of seismic imaging below the channel (Figure 31). In cores, the channel fill sequence is characterized by massive to wavy laminated sand, grading to laminated sand and silt/clays with coffee ground organics and other organic fragments, and intermittently observable bedding planes.

Mouth bar deposits, exhibiting mounded, lenticular, or sheet forms, are found proximal to the distributary channels, with varying degrees of channel incision. Mouth bars are overlain by laminated draping fill where not truncated by the transgressive ravinement surface (Figure 31). These mouth bar deposits are characterized by variably transparent to faintly dipping or wavy laminated reflector sets. The base is rarely imaged in chirp seismic. Compiled archival and newly collected sediment cores were used to characterize these deposits due to their complexity and stratigraphic variability. In cores, the mouth bar deposits are characterized by very fine to medium silty sand, with massive, flaser, laminated, and lenticular bedding. Coffee grounds organics and woody debris were common and usually concentrated in bedding planes (WGT-6). In most cases mouth bar deposits graded into interbedded silts/clays and sand related to the delta front at depth or distally from the channel source (WGT-20, WGT-9, WGT-10).

There are two overburden packages separated by the transgressive ravinement surface that overlie the channel and mouth bar deposits. The lower overburden package, where present, is a horizontal to wavy laminated package of variable amplitudes truncated by the transgressive ravinement surface. Core data show a fining upward sequence of interbedded sand, silt, and clay with minor shell fragments and clay with lenticular bedding and coffee ground organics and root horizons (WGT 14, BSS00-64). The top overburden package is characterized by laminated reflector sets overlaying the transgressive ravinement (Figure 32). Sediment cores show this unit contains high water-content fines with minor shell fragments interpreted as distal delta front and prodelta deposits. These sediment deposits have large fractions of fine-grained sediment and are not considered mixed-sediment resource targets.

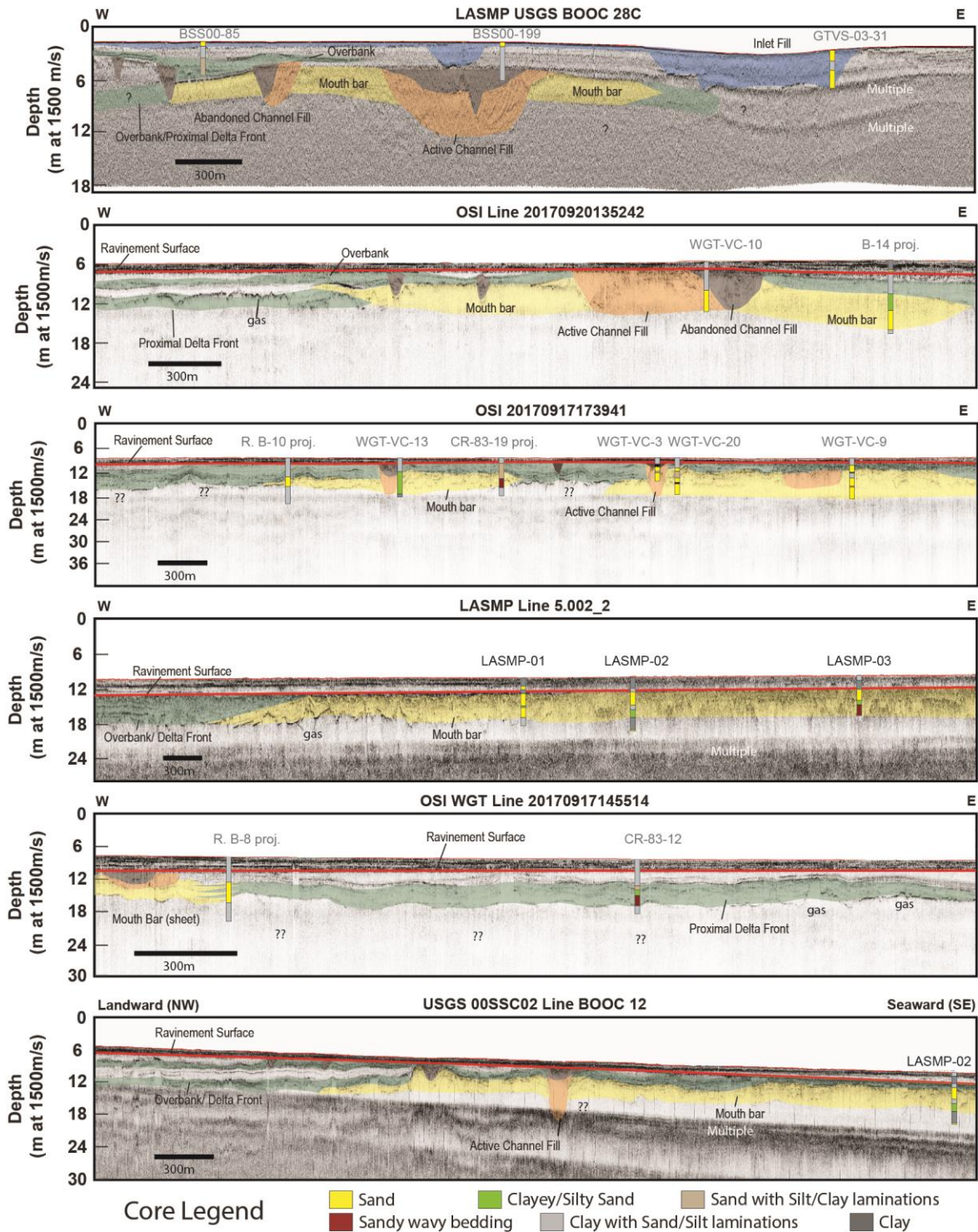


Figure 31. A series of interpreted strike and dip sub-bottom profiles highlighting deltaic environments of the West Grand Terre paleo-delta lobe progressing offshore. The red horizon represents the transgressive ravinement surface. See Figure 30 for location

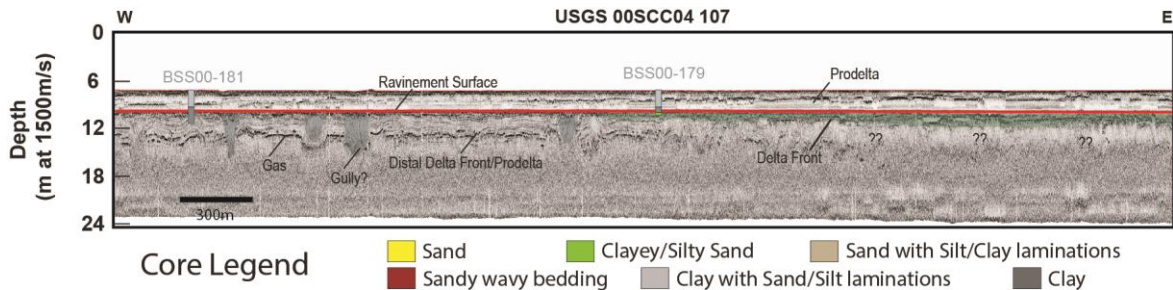


Figure 32. Interpreted sub-bottom profile example of the subaqueous or distal delta front or prodelta environments of the West Grand Terre paleo-delta lobe. Note the eastern portion of the profile is obstructed by gas blanking a meter below the ravinement surface (red horizon) and any features could not be interpreted with confidence. See Figure 30 for location

Scofield Island lies in the vicinity of the large partially preserved Scofield paleo-delta, which extends at least 14.5 km (9 mi) offshore (Figure 30). The Scofield paleo-delta is correlated to the Bayou Long delta lobe of the Plaquemines. While the only radiocarbon age estimate from the offshore Scofield system is modern (Table 2), archival age estimates from the landward correlated distributaries range from 250 to 1,050 years ago (Kulp 2000) corresponding to Plaquemines deposition.

The preserved sandy portion of the Scofield paleo-delta is up to ~6 m (20 ft) thick and is truncated by a shallow transgressive ravinement surface that is mostly coincident with the seafloor (Figure 22). Portions of these sandy subunits are exposed at the seafloor with no overburden (Figure 33). The generally northeast-southwest trending deposit is roughly constrained with the current data extent and displays an elongated shape. The Scofield paleo-delta displays less bifurcation and only the lower portions of the paleo-delta are preserved, contrasting to the lobate West Grand Terre paleo-delta. The main channel is characterized by the “U” shaped channel form, with fill characterized by draping reflectors and the base is not fully resolved in seismic. Moving seaward only the lowest portions of the channel are preserved, with the upper portions possibly removed due to transgressive ravinement or variations of incisional depth while it was active. Proximal to the main channel are transparent to chaotic, or dipping reflector packages, interpreted as the mouth bar facies (Figure 34). The base of the mouth bar is not resolved in sub-bottom. Sediment cores exhibit massive and flaser bedding composed of very fine to medium sand containing coffee grounds and tan clay clasts. Some cores show a sharp basal contact overlying massive clays interpreted as prodelta. The mouth bar facies laterally grade into gently dipping, wavy to laminated reflector packages. Cores from this interpreted proximal delta front facies show horizontally laminated sands, silts, and clays of varying bed thickness with coffee ground organics and some shell fragments. The base of the delta front facies is obscured by gas blanking. The gas is represented by a strong reflector matching the geometry of the surrounding package. The proximal delta front grades laterally into thinly laminated reflector packages that contain massive to laminated silts/clays in sediment cores, which is interpreted as distal delta front and prodelta. The overall paleo-delta displays an overall mounded or lenticular shape. In the nearshore region there are smaller delta sub lobes that extend only a kilometer beyond the modern shoreline. The associated channels are smaller and in some cases are stratigraphically higher or overlie the main Scofield paleo-delta.

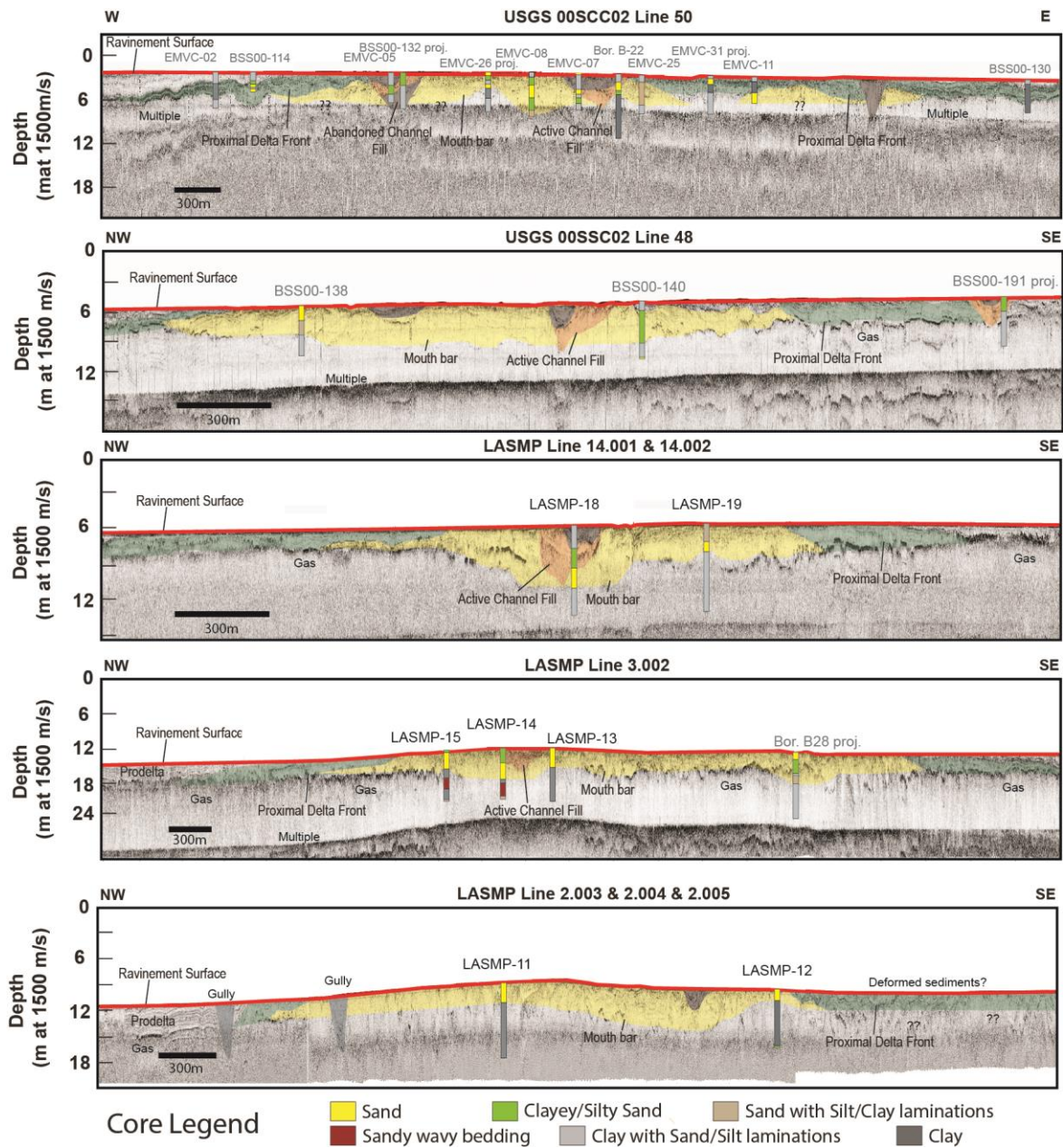


Figure 33. A series of interpreted strike sub-bottom profiles highlighting deltaic environments of the Scofield paleo-delta lobe progressing offshore. The red horizon represents the transgressive ravinement surface. See Figure 30 for location

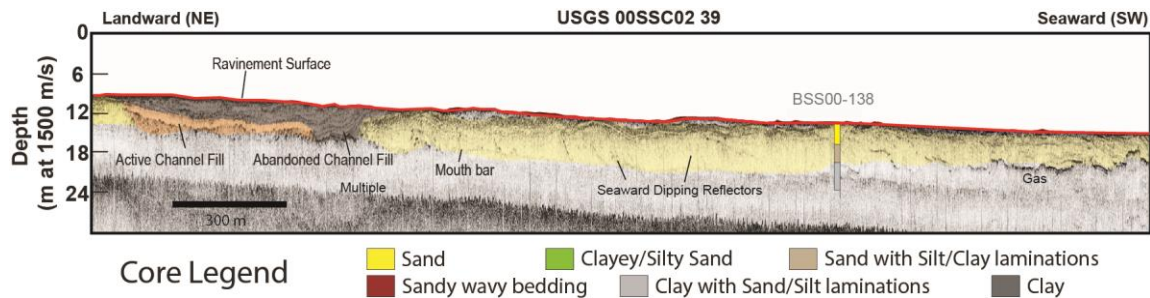


Figure 34. A dip oriented sub-bottom profile highlighting deltaic environments of the Scofield paleo-delta. Notice the transparent to dipping reflector package and sand to laminated sand units in the archival core. The red horizon represents the transgressive ravinement surface. See Figure 30 for location

In the vicinity of Sandy Point, the large, partially preserved Sandy Point paleo-delta extends at least 19 km (12 mi) offshore (Figure 30). The only radiocarbon estimate from the offshore system is a 735 year-old organic material horizon contained within channel fill (Table 2) and is used as a maximum age estimate similar to Flocks et al. (2006). Landward correlations from archival radiocarbon estimates show peat formation in the area occurring about 530 years ago, again suggesting late-stage Plaquemines deposition as the delta prograded to the shelf edge. The Sandy Point paleo-delta identified in this investigation likely correlates to the Dry Cypress Delta of the Plaquemines complex.

The preserved sandy portion of the Sandy Point paleo-delta is up to ~12.2 m (40 ft) thick and is truncated by the transgressive ravinement surface. This is the largest preserved delta mapped in the investigation. Portions of these sandy sub-units are exposed at the seafloor with no overburden. The generally north-south trending deposit is fairly constrained with the current data extent and displays an elongate to lobate, mounded shape (Figure 35; Figure 36Error! Reference source not found.). There is a complex network of bifurcating distributary channels overprinted with sediment deformation processes and possible gullies further offshore. Increased data resolution would help constrain how the several channel pathways are distributed moving offshore, as the base of the deposit was not imaged in chirp-seismic and heavily relied on core data.

In the nearshore area of the Sandy Point paleo-delta, there are several smaller delta lobes overlapping the central main trunk channel that extends offshore. Large distributary channels are characterized by the “U” shaped channel form, with central fill characterized by draping reflectors that have peripheral dipping to transparent packages. Proximal to the main channel are transparent to chaotic, or dipping reflector mounded packages whose base is not resolved in seismic, and are interpreted as the mouth bar facies. Data from cores show limited sand units in the upper 6 m (20 ft) of the subsurface in the nearshore profiles with thicker mouth bar deposits and less overburden near the bifurcation point (Figure 35). Multiple coalescing mouth bars and bifurcated distributaries exist moving offshore as the feature becomes more lobate (Figure 35; Line 4.002_2; Figure 36Error! Reference source not found.). This is interpreted as a mouth bar complex similar to interpretations from van Yperen et al. (2020). Sediment cores exhibit massive and flaser bedding very fine to medium sand containing coffee ground organics and tan clay clasts. Some cores show a sharp basal contact overlying massive clays interpreted as prodelta, but most cores do not sample below the thick sand offshore. The mouth bar facies laterally grade into gently dipping, wavy to laminated reflector packages. Cores from this interpreted proximal delta front facies show horizontally laminated sand, silt, and clay of varying bed thickness with coffee ground organic and some shell fragments. The base of the delta front facies is obscured by gas blanking. The gas is represented by a strong reflector matching the geometry of the surrounding package. The proximal delta front grades laterally into thinly laminated reflector packages that contain massive to laminated silts/clays in sediment cores that are interpreted as distal delta front and pro delta. The overall paleo-delta displays

an overall mounded or lenticular shape. The seaward thickening of sand and increased deformation signal indicates higher basin accommodation and consolidation in the offshore area. The Sandy Point paleo-lobe is the most proximal to the modern Birdfoot Delta location of the “deep-water” bar finger sands model of Fisk (1961).

Overall, these sandy channel fill, channel bar, and mouth bar, proximal delta front and overbank facies of the three large paleo-deltas offshore West Grand Terre, Scofield, and Sandy Point represent inferred sand and mixed-sediment resources and should be explored at detailed- or design-level investigations. These deposits have been previously utilized for individual, project-scale, restoration efforts as outlined in Section 3.2, but never previously mapped in high-resolution and contextualized in a regional geologic framework at reconnaissance scale.

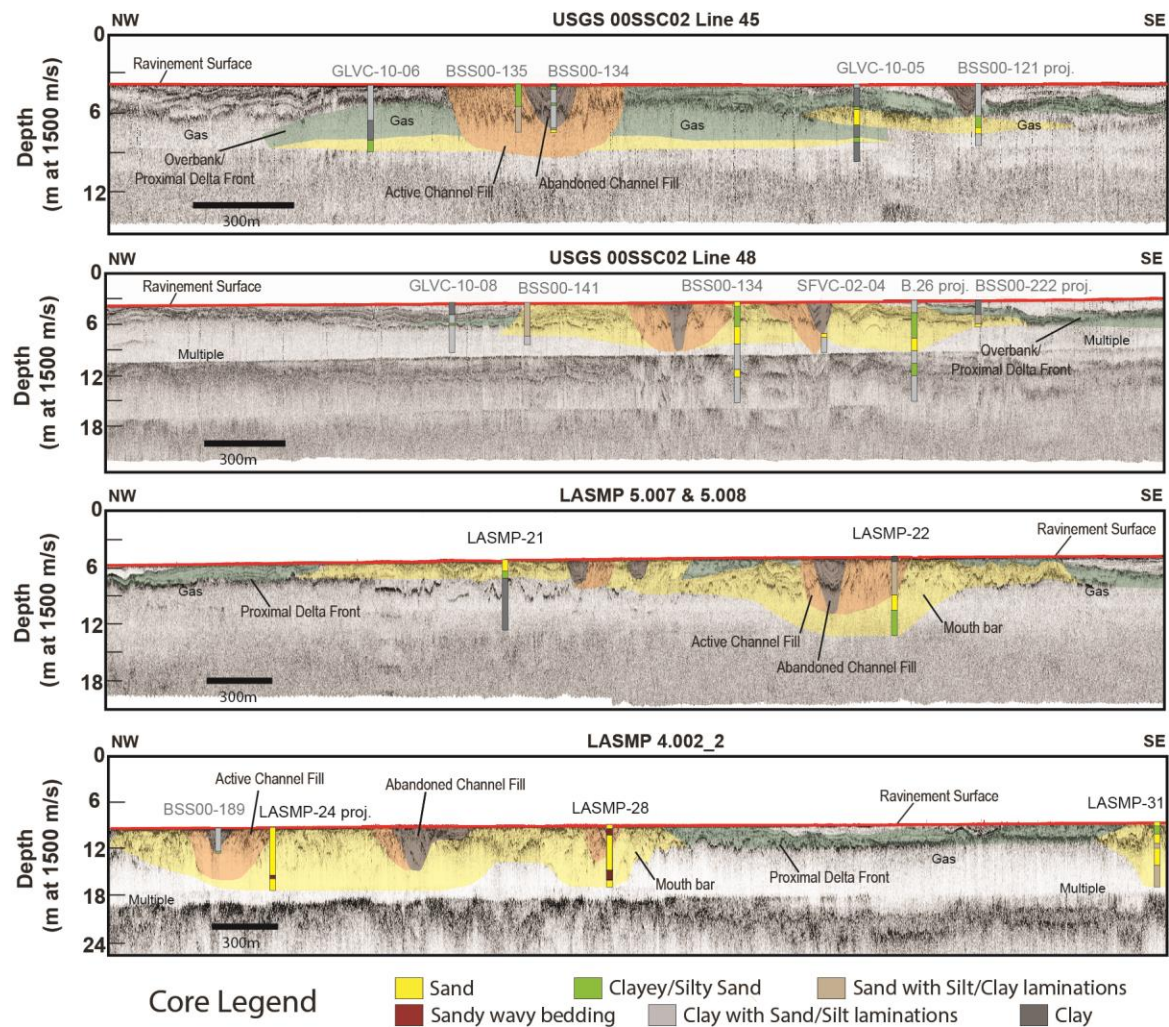


Figure 35. A series of strike oriented sub-bottom profiles highlighting deltaic environments of the Sandy Point paleo-delta progressing offshore. Notice the complex relationship of bifurcating channels further seaward. The red horizon represents the transgressive ravinement surface. See Figure 30 for location

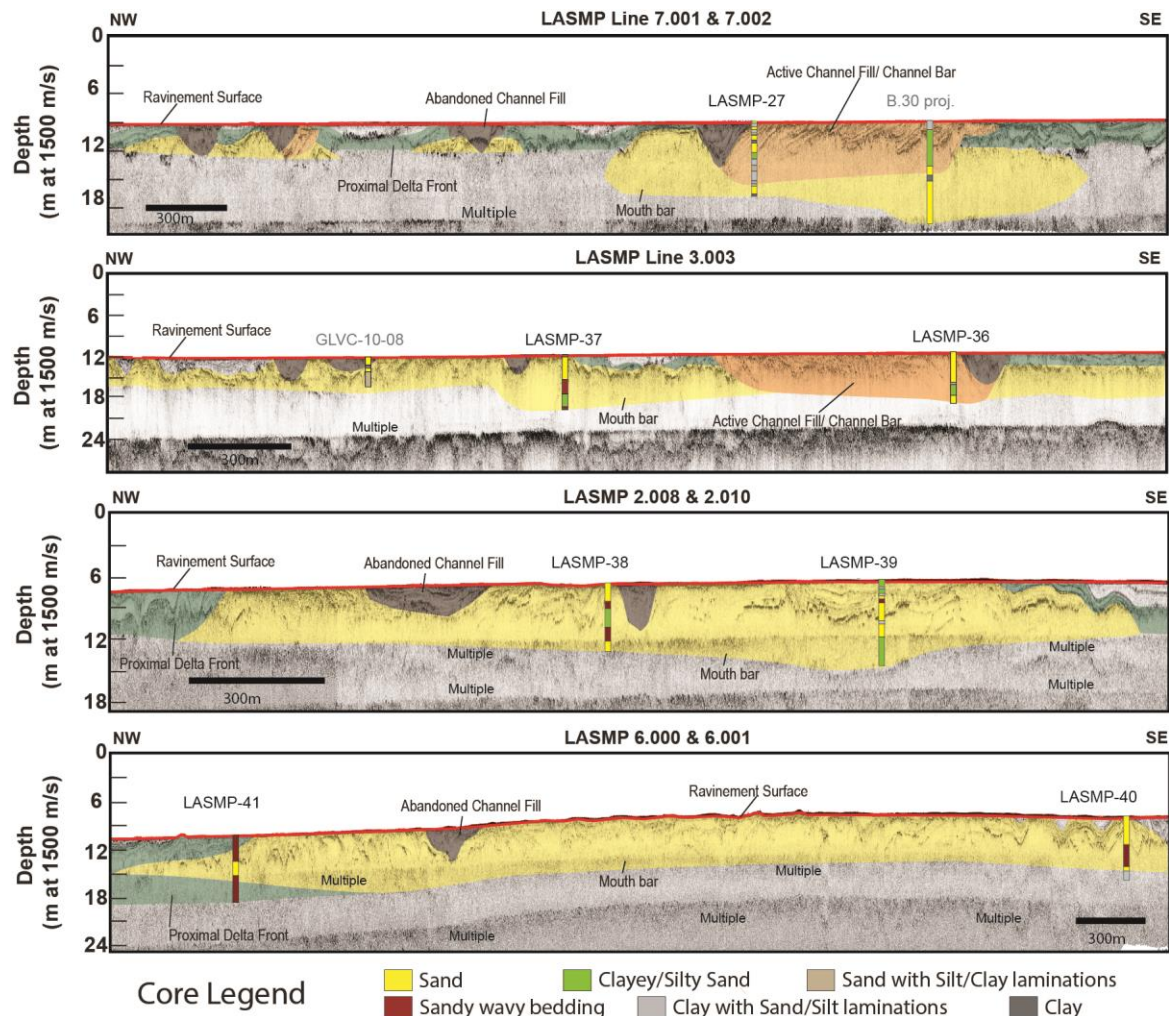


Figure 36. A series of strike oriented sub-bottom profiles highlighting deltaic environments of the Sandy Point paleo-delta progressing offshore continuing from Figure 35. Notice the complex relationship of bifurcating channels further seaward. The red horizon represents the transgressive ravinement surface. See Figure 30 for location

4.2.5 Distributary Channel Classification

Distributary channels are crucial for delivery of coarse-grained sediment to the coast and identifying major sediment pathways can inform where large depocenters exist in the subsurface. Distributary channel fill has previously been utilized as both sand and mixed-sediment borrow sediment for restoration projects. Channel geometry and fill characteristics are highly variable within the modern deltaic plain but follow a hierarchy based on flow conditions and gradients. Acknowledging the challenges with observing only remnant or partially preserved paleo-distributary channels in the subsurface in 2D sub-bottom data, this investigation provides a general classification of observed channel types to attempt to 1) identify fill architectures for sediment resources, 2) provide a roadmap for identifying probable depocenter location that have a high likelihood of sediment resource occurrence, and 3) help visualize and showcase the relationship between surficial geomorphic expressions with subsurface geological settings in the form of 3D predictive geologic models.

Distributaries are generally classified here as the main distributary, secondary, migrating, and abandonment phase channels. Due to complexities of cross-cutting or overprinting relationships, partial

preservation, and sparse reconnaissance level data coverage, no attempt to identify channel order number based on the degree of channel bifurcations was made. Examples of main and secondary distributary channels related to the large paleo-delta lobes identified in this study are presented for comparison (Figure 37). The main distributary channels of Scofield and the larger Sandy Point paleo-delta lobe at similar positions from the Mississippi River exhibit main distributary channels which are at least 304 m (1000 ft.) wide and consist of variable fill packages. Sediment cores from the Scofield main distributary show a general trend of basal, sandy active channel fill overlain by more fine-grained abandoned fill sediment, while the Sandy Point main distributary channel fill is characterized by interbedded sand and clays (Kindinger et al. 2001). The basal portion of the Sandy Point distributary channel fill was not sampled in core and was not resolved in sub-bottom due to gas blanking. The main distributary channel from the offshore West Grand Terre paleo-lobe has a sandy dipping clinoform package nearly 152 m (500 ft.) wide and about 9 m (30 ft.) thick. Within Barataria Bay, attempts were made to correlate this offshore channel landward, but the cross-cutting channels made it too complex to extend the mapping with confidence. However, there is a similar size channel with similar fill characteristics found within central Barataria Bay. These main distributary channels not only contain restoration quality sediment but are also major sediment pathways leading to significant depocenters containing additional inferred sediment resources preserved offshore. This verifies the suggested S2S prospecting strategy, significantly expanding successful borrow sources to regional resources as proven by three paleo-lobes found in this investigation. An example secondary channel located down-dip of at least one bifurcation point in the West Grand Terre paleo-delta lobe found offshore displays the basal sandy active channel fill overlain by organic, fine-grained abandoned fill.

The type of fill is important for various sediment resource project needs and is highly variable and somewhat discontinuous. Highlighting the variability is an example of clinoform packages from migrating channels found within the offshore Sandy Point paleo-delta lobe (Figure 38). These two sub-bottom lines are located roughly 3.2 km (2 mi) apart and are up-dip of the previously designed Sandy Point Northwest and previously utilized Sandy Point Southeast borrow sites. The clinoform package is roughly the same width, and neither base is observed, but the reflector signature offers clues to the sediment composition verified with core data. Line 3.003 shows low-gradient laminated reflectors transitioning to a steeply dipping, faint to transparent clinoform package. Four grain size samples from sand intervals in core LASMP-36 show sand percentages of 90% or higher, sand content that increases with depth, and D50 that ranges from 115–150 microns. Line 7.001 shows strong amplitude, high frequency dipping clinoforms and clear gas blanking. Vibracore LASMP 27 shows much more interbedded sand and fine-grained sediment compared to LASMP 36. Ten grain size samples from sand intervals in LASMP-27 show sand percentages greater than 82% that increases with depth and D50 increases with depth ranging from 105–162 microns. An archival split spoon boring (B.30) on Line 7.001 (Figure 38) demonstrates an overall fining upward silty sand interval of the dipping clinoform package, with grain size samples ranging from 60–85%. This boring also shows sand deposits of at least 4m below the inferred base of the clinoform package. Additional cores constraining the textural variability for comparison cases like these can greatly aid in increasing the confidence of predicting sand content from seismic facies for future investigations.

The changes in channel geometry and fill characteristics are intended to inform general prospecting and design strategies by locating major depocenters or sediment pathways. The examples presented also help visualize semi-conceptual mixed-sediment and sand proportions of various types of distributary channel fill to aid in design strategies that may benefit different types of restoration projects.

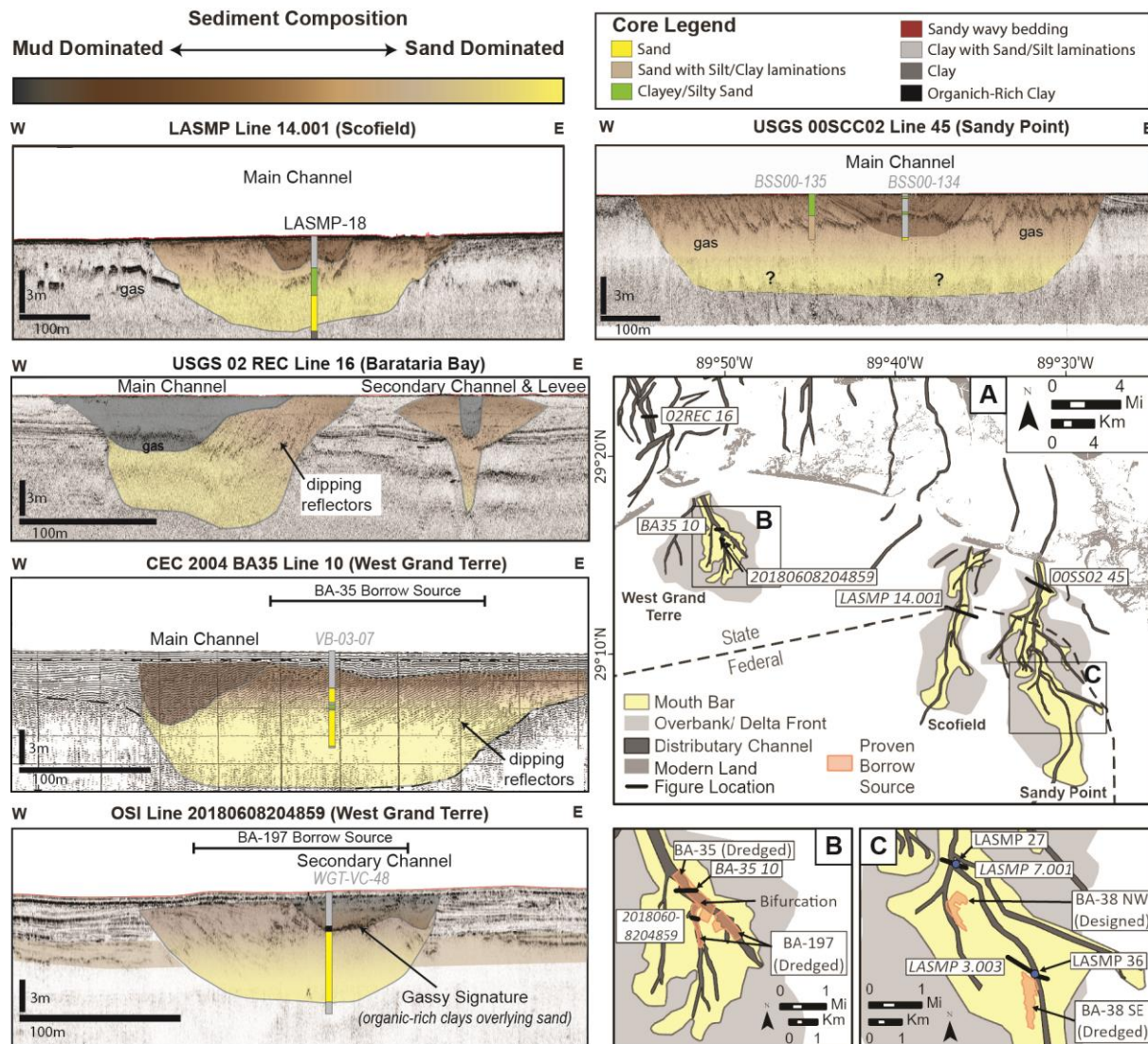


Figure 37. A) Sub-bottom profile examples of main distributaries geometries and fill of the three offshore paleo-delta lobes mapped in this investigation and likely landward continuation of within Barataria Bay. Sediment composition is based on limited sediment core data throughout the investigation and generally represents the channel configurations displayed. B) demonstrates the seaward expansion of the proven (BA-35) Bay Joe Wise beach restoration borrow site and (BA-197) West Grand Terre restoration borrow site within the larger sediment resource mapped in this investigation. C) Demonstrates the expansion of proven (BA-38) Sandy Point restoration borrow sources within the larger resource mapped in this investigation. See Figure 38 for sub-bottom examples

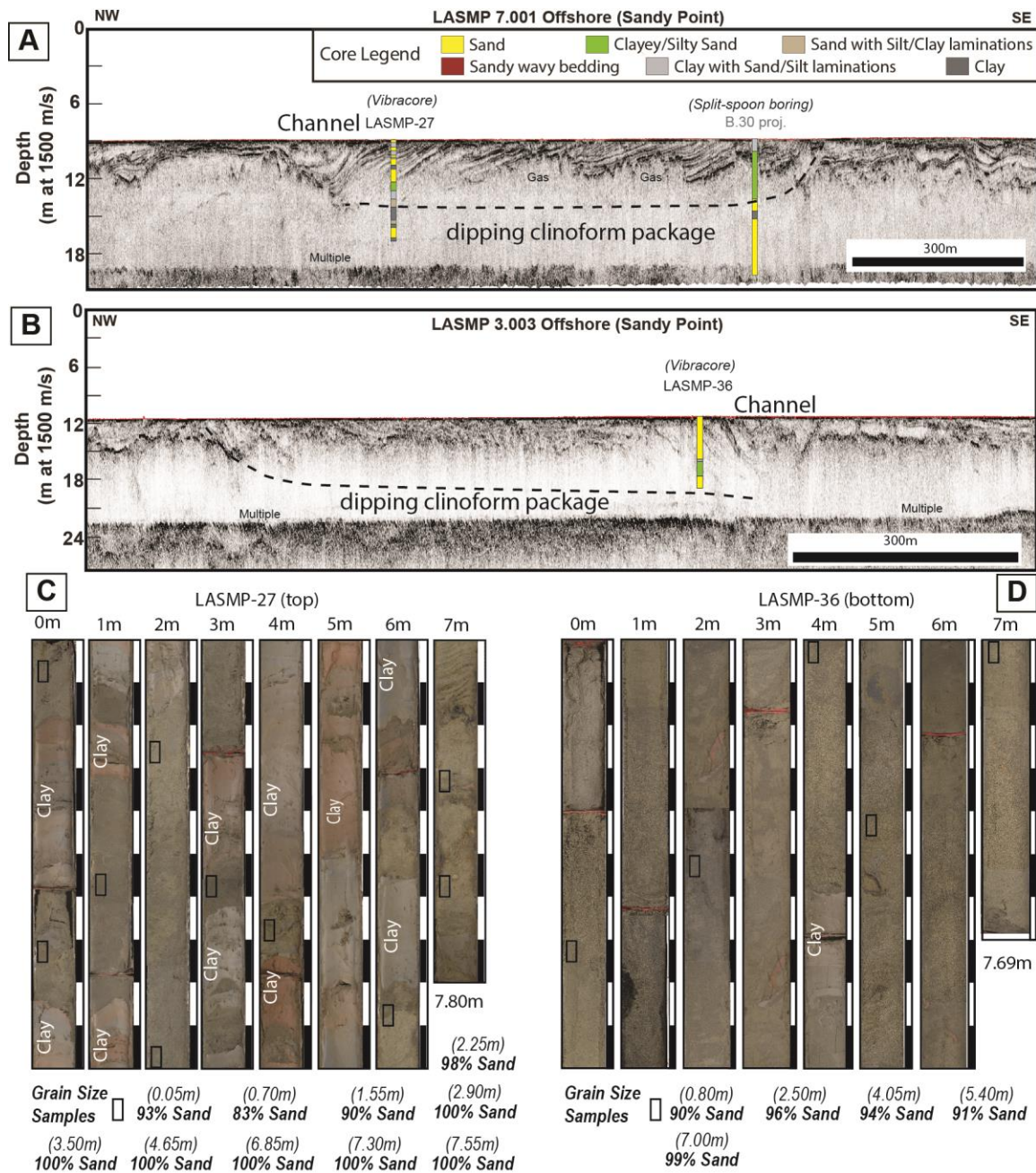


Figure 38. Example sub-bottom data demonstrating sediment composition variability of similar migrating channel, dipping clinoform packages only a few kilometers away. An important consideration for compatibility of sediment resources. A) Smaller clinoform frequency and stronger reflector amplitude of migrating channel bar package compared to B), results in thinner sand unit thicknesses and many clay packages from corresponding vibracore C) compared to more homogeneous thicker sands of D). The previously collected split-spoon boring B. 30 (A) shows sediment composition at greater depths but does not provide continuous sampling for comparison to vibracore data. Both examples shown here are expansions of the successful BA38 borrow sites. See Figure 37C for location

5 Creation of the LASMP Region 1 Predictive Geologic Model

As part of the holistic approach to sediment resource prospecting used in this investigation, a data-driven predictive geologic model was developed on a regional spatial scale (Figure 39). This simplified 3D representation of the subsurface of Barataria and offshore of Barataria Bight was initially developed from archival geophysical and geological data, which was refined with the incorporation of data collected during the current investigation. The S2S approach considers the entire deltaic system, and the delivery, redistribution, and preservation of coarser-grained sediment environments to predict sediment resource occurrence and relative overburden. The predictive geologic model also acts as a visualization tool that allows for easy and simple communication of geologic concepts and linkages between surficial geomorphological features and the underlying subsurface (e.g., what the extent and thickness of a sand body related to an abandoned distributary channel or mouth bar is). Highlighting the preserved sand-rich environments of the broader geologic system can guide more localized and detailed investigations toward borrow site development by understanding sediment deposit geometry. It also allows for the visualization of expanded resource areas developed from delineated borrow areas and dredged borrow pits after being contextualized in the broader geologic framework. Successful implementation of the LASMP RSM approach comes from linking geologic and sedimentological processes to the needs of planners, engineers, ecosystem specialists, and broader stakeholders, and translating specialist concepts into understandable and actionable results.

Within the offshore Barataria Bight exists three major delta distributaries that host proven sediment reserves as well as sediment resources that can be further investigated: the West Grand Terre, Scofield, and Sandy Point lobes. This study places these identified systems into the delta framework built by previous studies (Frazier 1967; Penland and Boyd 1985; Kusters and Suter 1993; Flocks et al. 2006). These distributaries have each been linked to their likely formational delta lobes and associated sediment routing systems. The West Grand Terre distributary seems to be related to growth and deposition of the previously defined Bayou de Families lobe in what is now Barataria Bay. This Bayou de Families lobe is the deepest observed in this investigation and is overlain by a subsequent delta lobe in Barataria that likely correlates to the previously defined Bayou Blue of the Lafourche Complex. These overlapping systems likely contain sand-rich geologic units; the deepest of which built the offshore West Grand Terre system and its associated proven sediment reserves, such as BA-197. Finally, the offshore Scofield and Sandy Point distributary systems are linked to a third delta lobe correlated to the Plaquemines complex within the easternmost Barataria Bay. Sediment routing systems previously defined such as Bayou Long and the Dry Cypress Bayou correlate with the newly defined Scofield and Sandy Point systems preserved offshore. These interpreted linkages help characterize the observed subsurface variability and resulting inferred sediment resource distributions. A conceptual diagram (Figure 40) of deltaic mouth bar thickness, and other various physical factors of the identified paleo-delta lobes are presented along a gradational scale between “shallow” and “deep water” deltas (Fisk et al. 1954; Fisk 1961). This geologic context and the predictive model also aid in understanding why certain geotechnical characteristics of these sediment resources vary with relationship to the formational setting and processes.

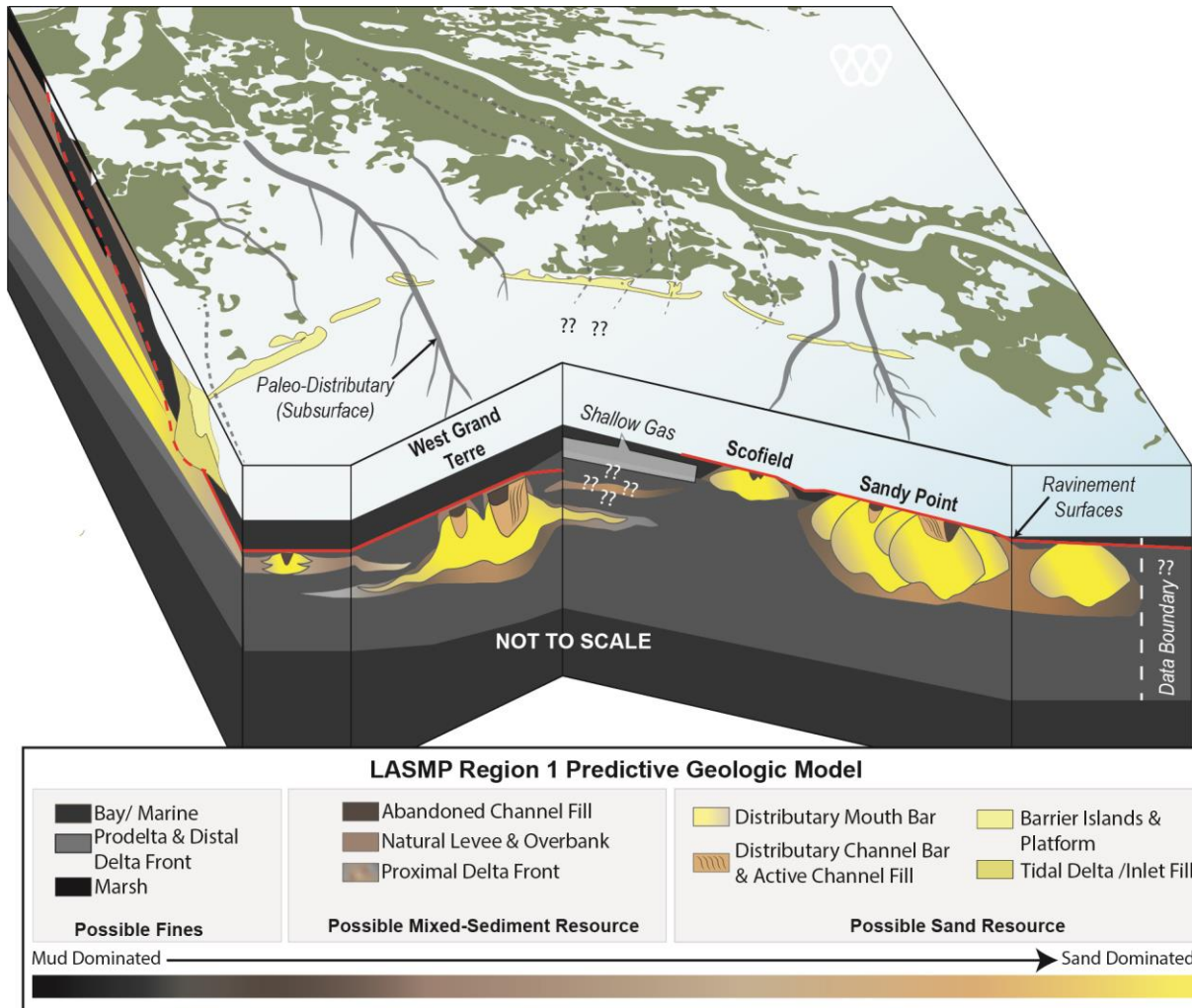


Figure 39. Three-dimensional predictive geologic model of Barataria Bay and the offshore region, highlighting the distribution and relationships of sediment resources and non-viable fine-grained sediments

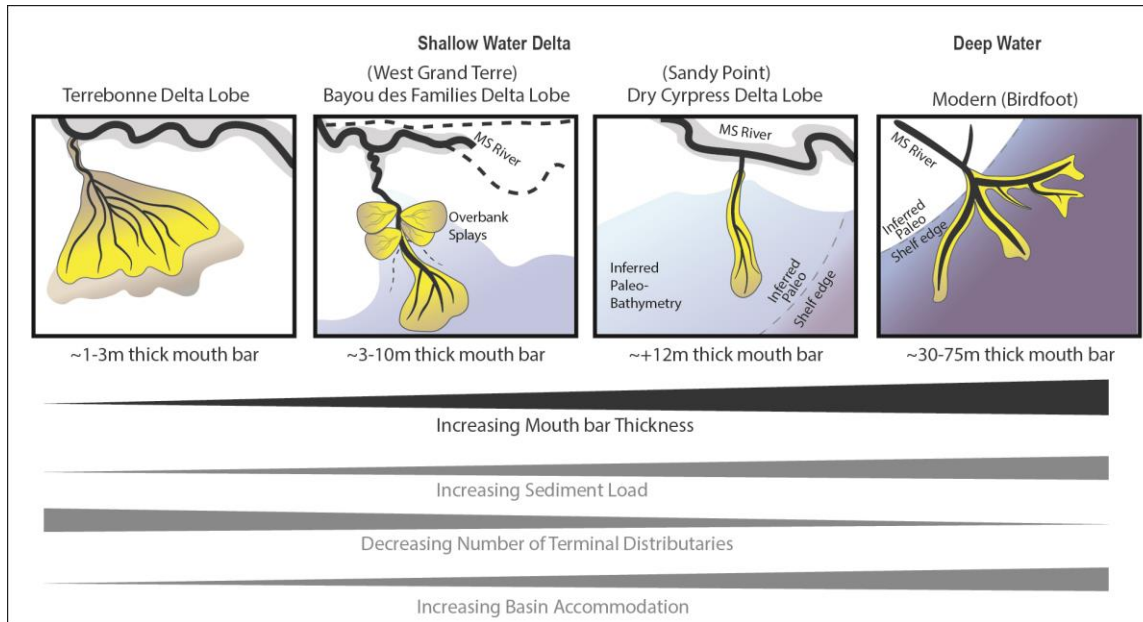


Figure 40. Conceptual model relating mouth-bar thickness to physical processes, sediment load, distributary bifurcation networks, and basin accommodation space

5.1 Informing Future Investigations

A crucial outcome of LASMP is maps, strategies, and recommendations related to the likely occurrence and distribution of sediment resources within each region. This allows planners and project engineers to approach each region with a better understanding of which areas are likely to contain what types of sediment, and where to prioritize future investments. Maps and locations of sediment types with preliminary assessments are critical to link to intended projects, assess limiting factors, and proceed to the next stage of screening and design. Significant cost savings can be realized through improved efficiency of borrow area identification. This study identifies and maps several sediment deposits and sediment resources areas that have vastly expanded upon previously identified, successful borrow areas (Figure 41). These represent the most promising, previously undiscovered sediment resources, which allows for focused, cost-effective project-level sediment investigations. The sediment resources require less than 6 m (20 ft.) of overburden and are at least 1.5 m (5 ft.) thick to be considered viable (CWPPRA Task Force and WCRA 1998; Khalil, Raynie, and Forrest 2023). Equally important to practitioners are areas absent of sand or mixed-sediment resources, which represent areas to exclude from any further investment to develop. This investigation reports areas of sub-bottom shallow signal loss occurred as a result of gas blanking or in some cases, oyster leases. These areas demonstrate very low utility or effectiveness of sub-bottom data and areas to avoid making large future investments in. A summary of areas classified for further investigation can be found in Figure 41.

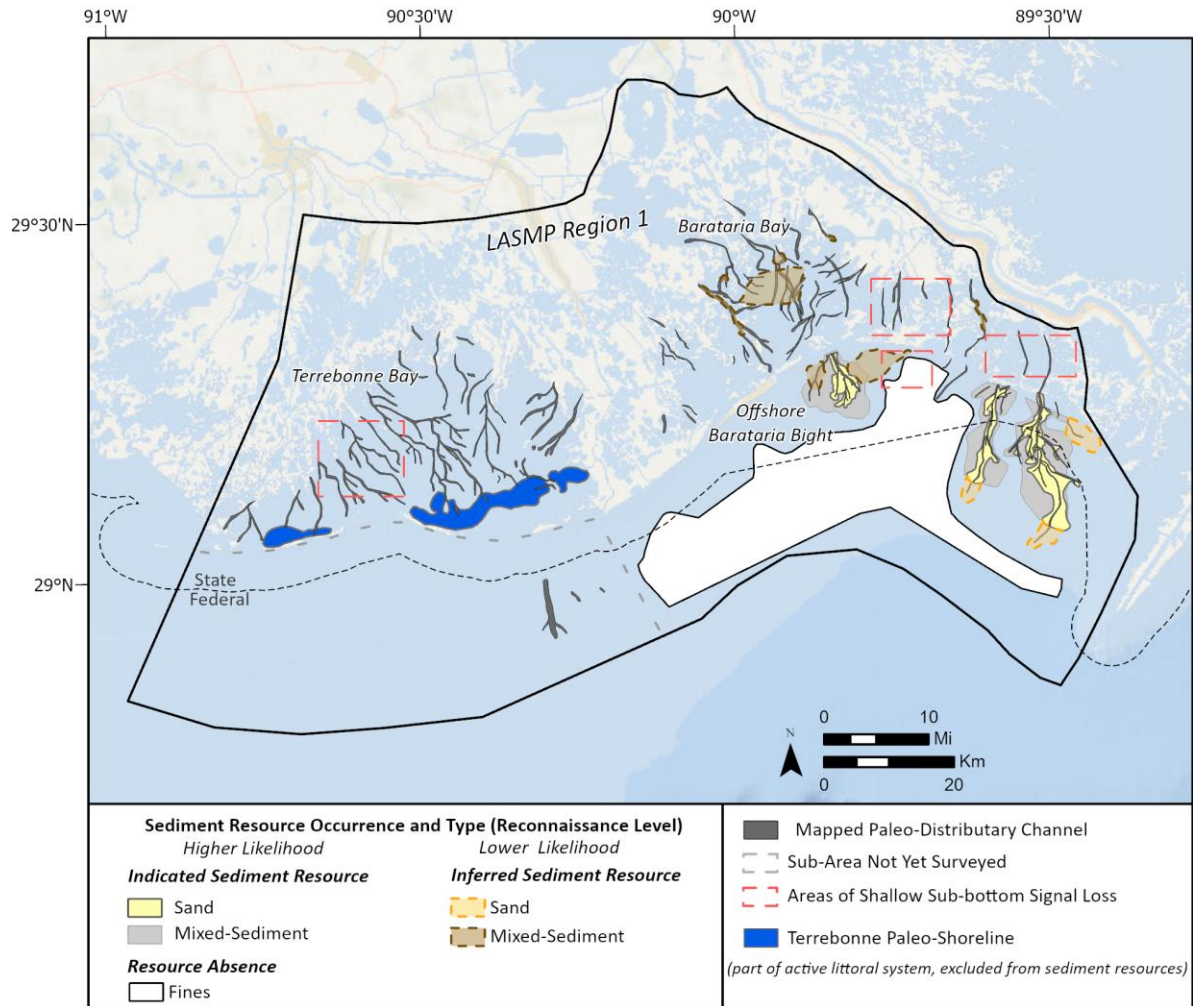


Figure 41. Summary of mapped deposits and resource occurrence and classification. Indicated sand and mixed-sediment resources offshore of the Barataria Bight are expanded from successful, previously designed and utilized borrow areas. Inferred resource areas require further investigation. Note the paleo-shoreline coastal deposits within Terrebbonne Bay are part of the active littoral system and removal of sediment could impact natural shoreline dynamics and are therefore excluded from resource consideration

Of the mapped deposits, the Terrebbonne paleo-shoreline trend (e.g., Penland et al. 1987) consists of relict barrier island platform and tidal deposits. The generally east-west trending shoreline represents a concentration of sand due to transgressive reworking of the abandoned Terrebbonne delta lobe roughly 600 years ago. The paleo-shoreline feature is 3.7 m (12 ft.) thick on average, with overburden ranging from 0–2.4 m (0–8 ft). This deposit is in close proximity to, or partially makes up, the active littoral system and is not recommended for sediment resource consideration. Removal of sediment could negatively affect natural shoreline dynamics.

The indicated sand resources comprising the paleo-delta lobe deposits mapped offshore of Barataria Bight contain active channel fill and mouth bar sands and proximal delta front and overbank facies that have a

high probability of containing indicated sand and mixed-sediment resources, respectively. Further geologic sampling is needed for resource consideration.

Distributary channel fill and channel bars mapped in this investigation are highly variable in their geometry and extent and display complex cross-cutting relationships. In both bays, especially Barataria, a sizable volume of mixed-sediment resources is likely contained within subsurface channel fill and channel bar deposits. With the current reconnaissance-scale data density and wider trackline spacing in the offshore region, it is not possible to confidently create an isopach map or provide volume estimates of sediment resources. These deposits are generally characterized by a sequence of fining upward with the coarse-grained sediments concentrated near the base. The active channel fill is characterized by transparent to chaotic packages at the base of a channel form and are exclusive to larger main or secondary channels of at least 61 m (200 ft) across and roughly 3 m (10 ft.) deep. Migrating channel bars are characterized by dipping reflectors laterally grading into an incisional channel form. The low frequency clinoforms correlate to higher sand content (i.e., larger bed sets) and less textural variability of the bars in this investigation. Due to poor seismic imaging, the base of these deposits were difficult to discern from mouth bar sand in some instances. Intra-channel fill or bars related to lateral channel migration are examples of sand-rich features that have been previously utilized but require much higher density of geophysical data and geological sampling to resolve them for resource consideration. Locations of these channel fill and migrating channel bars are shown along trackline locations (Figure 42) and the highest occurrence of bars are mapped within Barataria Bay as potential mixed-sediment deposits (Figure 41) for future investigations but not quantified in this investigation. Depending on the restoration needs and with better constraint on the deposits' geometry and composition, the entire channel bar deposit could be targeted as a mixed-sediment resource, or focus could be directed to the basal sections for more sand-dominated borrow material. The major utility of these channel bars or distributary channel fill deposits within the bays is their proximal location to marsh restoration projects, relieving transportation expenses compared to a more distally located borrow source. Furthermore, by classifying distributary channels and identifying the network of main distributaries, one could focus mapping efforts on its offshore extension leading to previously unidentified deltaic deposits and possibly viable sediment resources.

In the central-northern portion of Barataria Bay there is a large inferred mixed-sediment deposit related to proximal overbank and natural levee deposits (Figure 41). This large sheet morphology is fairly continuous across available data (e.g., Figure 29), is up to 2.4 m (8 ft.) thick and exhibits 2.1–4.6m (7–15 ft.) of overburden. This sheet pinches out to the south. Sediment cores do not penetrate the entire unit, but where sampled, the unit is composed of 47–96% very fine sand and displays a fining upwards sequence. Longer sediment cores and additional strike (east-west trending) sub-bottom lines would help constrain this potential deposit. Again, depending on marsh restoration project needs within Barataria Bay this proximal source of sediment could aid in keeping project costs lower due to lesser transportation costs. Modeling efforts of borrow pit alternatives in this area show negligible impact to the sediment budget needed for marsh accretion and does not affect tidal prism (Bregman et al. 2023; The Water Institute 2023b). Therefore, the semi-continuous, sheet morphology of inferred mixed-sediment resource interpreted as proximal overbank and natural levee with upper Barataria Bay warrant further development.

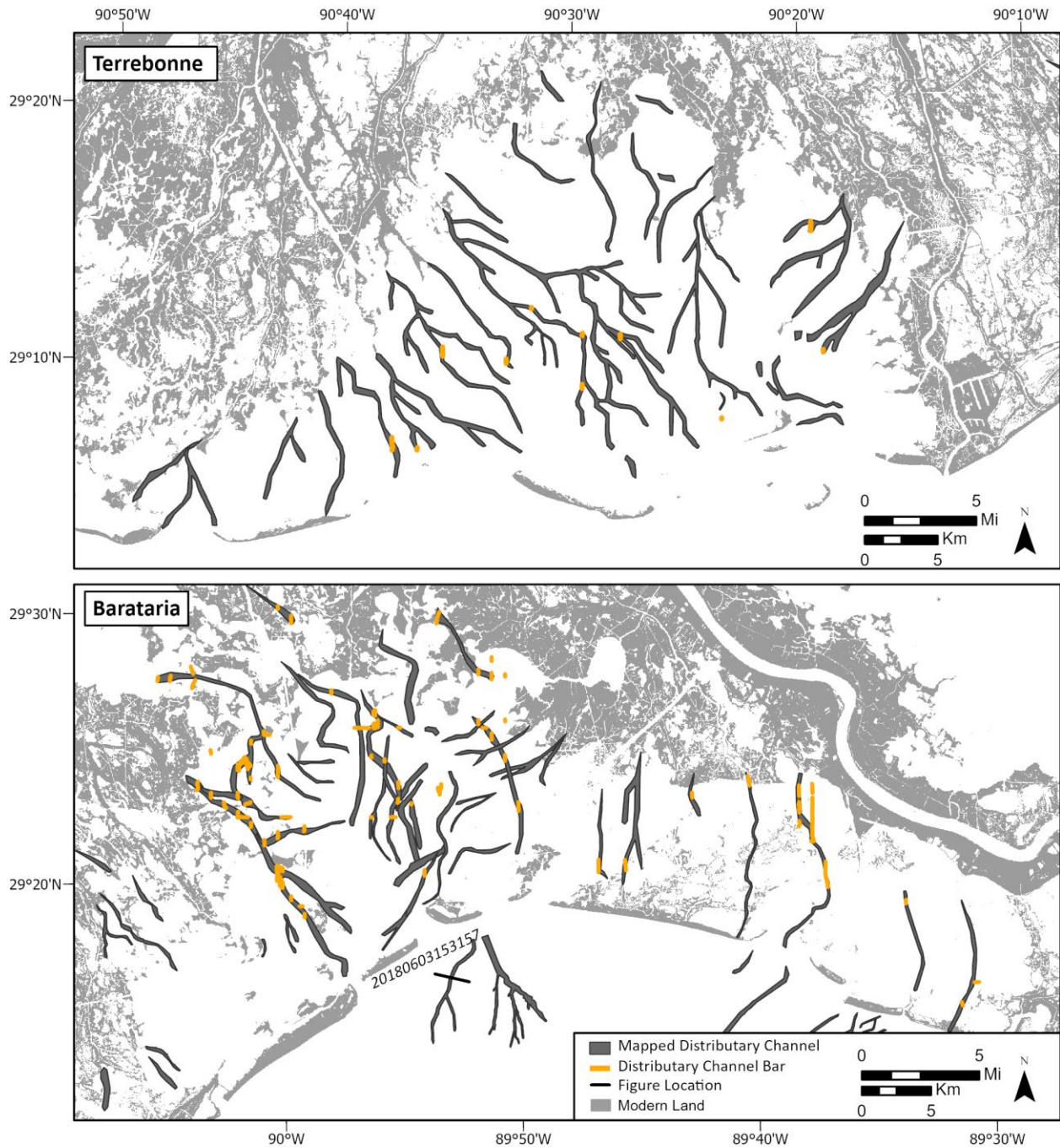


Figure 42. Map of Paleo-distributary channels and channel bars. The channel fill and/or channel bars are excluded from resource quantification estimates due to the discrete nature of the deposits and require further geologic sampling for sediment resource consideration. The highest concentration of coarser-grained sediment is likely near the base of the bars in fining upward sequences and would likely classify as mixed-sediment

Offshore central West Grand Terre Island and the Cheniere Ronquille headland are two inferred mixed-sediment deposits preliminarily interpreted as paleo-delta mouth bar and delta front sheets. Off West Grand Terre Island there are only a few closely spaced geophysical lines but there are no available cores to verify its composition, however this area likely contains some sandy deposit. It is characterized by a

dipping reflector package and the bottom is not clearly imaged but is up to 4.6 m (15 ft.) thick with very minimal overburden (Figure 43) and due to its proximity to the shoreline could be a cost efficient borrow source pending further investigation. Further offshore, the seaward extension of this system has cores that show units of mixed sediment interpreted as proximal delta front, underlying 3 m (10 ft.) of overburden. Offshore of Cheniere Ronquille headland, approximately 15 sediment cores show a basal unit of sand or mixed sediment, ranging from 1.2–2.4 m (4–8 ft.) thick, although the entire deposit is rarely sampled. The combination of noisy acoustic signal occurring at this unit's depth and incomplete core sampling makes delineating the paleo-delta lobe(s) difficult. Overburden thickens seaward, ranging from 3–5 m (10–16 ft). Suter et al. (1991) mapped a large bifurcating distributary channel network in the vicinity of this deposit, but it was not recognized with the higher frequency chirp sub-bottom data, and only limited lower frequency boomer data was available. Both deposits likely contain sand-dominated mouth bar sub-units based on the predictive S2S geologic model but are generally mapped as inferred mixed-sediment and need further refinement.

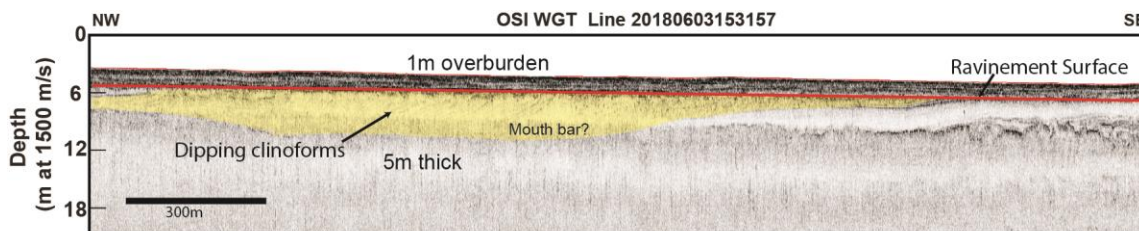


Figure 43. Example localized feature of an inferred sand deposit characterized by a dipping clinoforms package. The red horizon represents the ravinement surface. Could not be correlated with the current data coverage and is not verified by cores. See Figure 42 for location

In the eastern portion of the Barataria Bight offshore area there are three inferred sand resources likely related to paleo-delta mouth bar deposits (Figure 41). However, these deposits likely extend outside the current data coverage and could not be delineated with confidence. Both the Scofield and Sandy Point paleo-delta channel and mouth bar facies represent the coarsest grain sediments delivered to the coast during the constructional progradation phase of these delta lobes before being modified by transgressive coastal processes during the destructional phase. They are flanked by massive fine-grained prodelta and distal delta front deposits. The general trend of the deposits corresponds to bathymetric perturbations or positive relief in modern bathymetry (Figure 44). The amount of overburden is variable but is very minimal at the most seaward portions of the investigation area, with mouth bar sand near or exposed at the seafloor. The fine to medium sand found in 15 m (49 ft) water depths are more erosion resistant or above the threshold to be suspended and transported compared to the surrounding fine-grained prodelta or delta front silt and clay. Additionally, the fine-grained deposits have higher compaction potential than the sand. The two suggested armoring and compaction mechanisms are likely responsible for the seafloor expression found seaward of the investigation area. This bathymetric high extends further offshore so it is logical to assume these paleo-deltas continue 4.8–6.4 km (3–4 mi) offshore beyond the study area (Figure 44), and therefore represent an additional inferred sediment resource to be further constrained and explored.

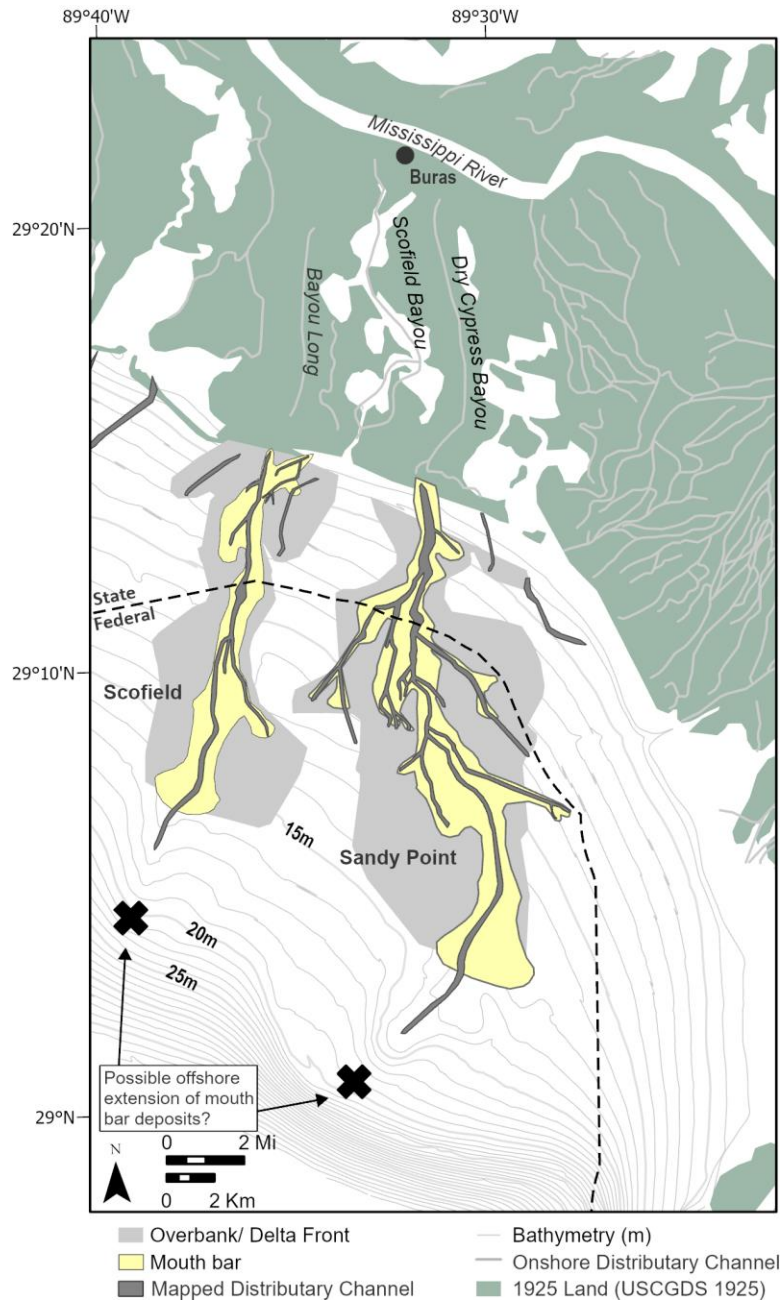


Figure 44. Map showing likely extension of Scofield and Sandy Point paleo-deltaic sandy mouth bar environments another 4.8–6.4 km (3–4 mi) further seaward of the current data extent. Mouth bar sediments in yellow represent high-probability sand-rich deposits, while grey overbank deposits are likely finer grained sediment-dominated. Note bathymetric highs marked with large “x” on map that correspond to subsurface mouth bar deposits. Land area from 1925 to show deltaic headlands related to Bayou Long and Dry Cypress Bayou that extend onto the shelf

East of the Sandy Point paleo-delta lobe, at the eastern boundary of the current data coverage, archival cores sample large mouth bar deposits (Figure 45). The mouth bar deposit interpretation rely heavily on sediment coring information and could not be spatially correlated between sub-bottom lines. The deposits have minimal overburden where sampled, show between 70–90% sand based on grain size analysis (within the mouth bar deposits), and range from 4.9–7.9 m (16–26 ft.) thick. The sandy unit is described

as a coarsening upward interval followed by a fining upward interval with ripple to large scale cross bedding or laminated or massive packages. The sand includes some coffee ground organics and other fragments as well as clay clasts, is absent of plant rooting or shells, and is interpreted as deltaic mouth bar and distributary channel fill. The deposits are not sampled in shallow penetrating cores further seaward, so it is possible these deposits continue landward and east towards the Mississippi River or Venice area and are related to the seaward limits of the Plaquemines Delta before the shelf edge deposition of the modern Birdfoot. Again, both the Scofield and Sandy Point paleo-delta lobe extensions and a possible paleo-delta lobe east of Sandy Point have minimal or no data to define them but warrant further development and investigation.

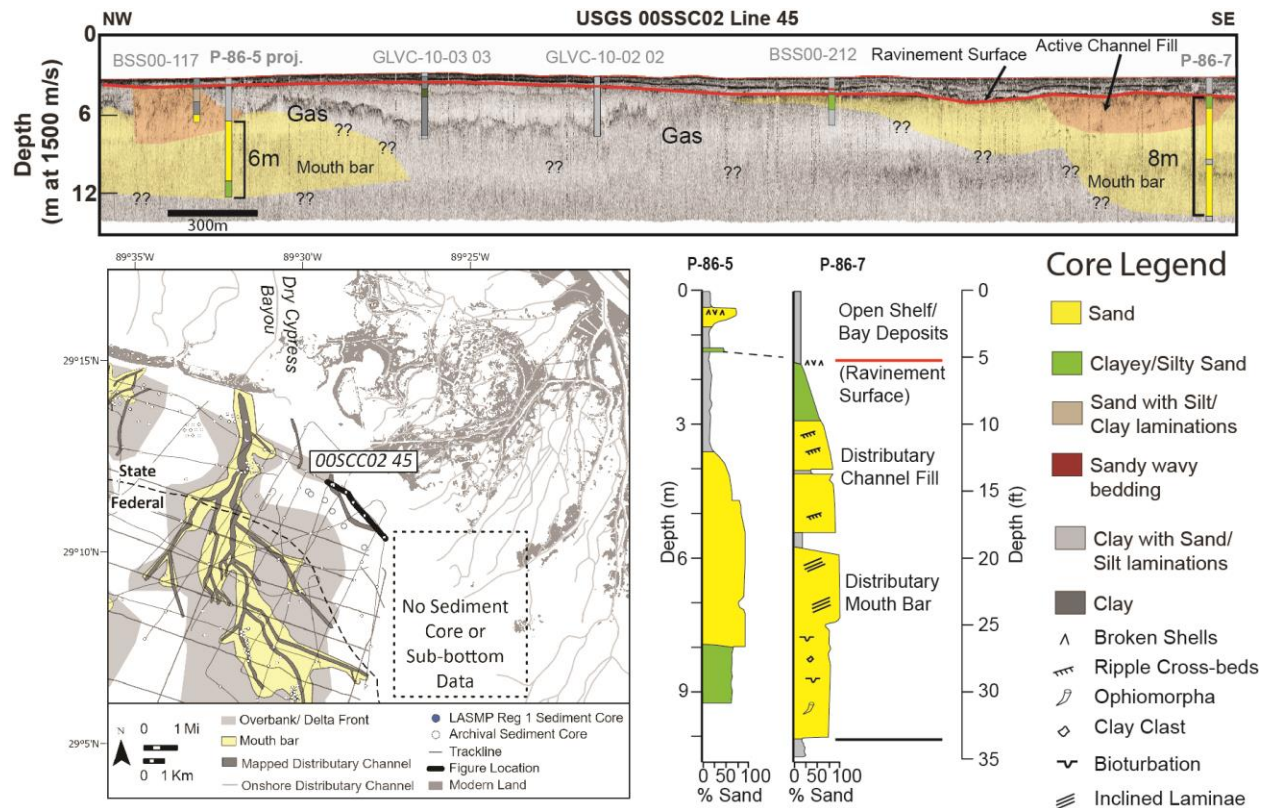


Figure 45. Example of a localized feature east of the Sandy Point paleo-delta, which could not be fully mapped with the current data coverage but represents a potential sediment resource to be developed in further detail. Note these features are 6.0–8.0 m (20–26 ft.) thick with minimal overburden but likely extend further to the southeast towards the Mississippi River. The red horizon marks the ravinement surface

6 Sediment Resource Estimates

Three major subsurface deposits related to paleo-delta lobes in the offshore region of Barataria Bight were identified, classified as indicated sediment resources, and quantified. These regionally correlated subsurface deposits contain sand (or >70% sand) and mixed-sediment (30–70% sand) resources (e.g., (e.g., Khalil, Raynie, and Forrest 2023) and are classified following the definitions of CPRA (2024). The quantified sediment resource volumes presented are only for features that could be regionally correlated with data spacing less than 1.6 km (1 mi) apart, verified by sediment cores, have less than 6.1 m (20 ft) of overburden, and greater than 1.5 m (5 ft.) sand thickness (the overlying non-compatible sediment between the sandy deposit and the seafloor). Interpolating isopachs of highly variable deltaic deposits from sub-bottom data with such irregular spacing and orientation proved difficult. A simple linear interpolation was used in this investigation to avoid any artifacts from more complex interpolation methods using a modified version of the open source NGSAAAP tool (Di Leonardo et al. 2022). The volume estimates are presented as both available and accessible sediment volumes to account for infrastructure exclusions. The exact sand percentage and amount will be highly variable and should be appropriately refined with further detailed geological and geophysical investigations.

Here, only the highest confidence, sand-rich portions of the West Grand Terre, Scofield, and Sandy Point deltaic mouth bar deposits were quantified for indicated sediment resource estimates. They represented logical target facies due to their continuity and potentially thick geometries. Mouth bar deposits are characterized by variable seismic packages ranging from chaotic, transparent, mottled to dipping reflector sets with a strong amplitude top reflector and occur stratigraphically below and/or adjacent to an incisional channel form. It can occur in more of a mounded or sheet-like morphology, where the mounded form has an overall higher sand percentage and thickness. This facies consists of clean, very fine to medium tan sand, with trace organics and shell fragments, grading into more interbedded silty sand and silty clay. It is likely these distributary mouth bar deposits contain sediment most suited for projects requiring sand resources.

Indicated mixed-sediment resources in the form of proximal delta front and overbank deposits were regionally mapped and associated in proximity to mouth bar deposits. The proximal overbank is characterized by laminated to wavy reflectors of high frequency interrupted by variable size channel incisions. These facies consist of interbedded sand, silt, and clay. The proximal delta front represents areas where current velocity is high enough to deposit sand during periods of high flow. The proximal delta front is characterized by dipping to wavy reflectors of variable amplitudes and a stronger amplitude reflector at the top. Reflector frequency is high near the top of this unit and decreases near its base but is often blanked by gas. This deposit grades into mouth bar deposits.

It is important to account for the accessibility of sediment resources even at the reconnaissance level scale to aid in future investigations and planning decisions. **Available volumes** are the total volume quantified within a mapped deposit. **Accessible volumes** are the remaining volume after excluding utilized borrow areas and sediment excluded within oil and gas infrastructure safety buffer (APTIM 2023). Infrastructure safety buffers are 305 m (1000 ft.; 609.6 m or 2000 ft. swath total) surrounding in-place pipelines (Figure 46). In-place pipelines include infrastructure that remains either active or abandoned and has not been physically removed from the seabed. Oil and gas pipeline infrastructure data were compiled from US Bureau of Safety and Environmental Enforcement and Louisiana Department of Natural Resources databases. The Scofield, and Sandy Point paleo-delta deposits saw the greatest reduction to available sediment volumes due to the high concentration of in-place pipelines in the OCS West Delta Area.

To avoid double-counting of resource estimates, previously dredged sediment from the borrow areas were excluded in calculations (e.g., APTIM, 2023). BA-35 and BA-197 restoration projects (CEC 2005; OSI 2019), totaling 6 MCM (7.9 MCY) of sand and 0.8 MCM (1.1 MCY) of mixed-sediment were subtracted from the available West Grande Terre paleo-delta lobe sand and mixed-sediment volumes presented here.

BA-38-1 utilized 1.1 MCM (1.5 MCY) of mixed-sediment from the Scofield paleo-delta and 2.7 MCM (3.5 MCY) of sand and 0.9 MCM (1.2 MCY) of mixed-sediment from the Sandy Point paleo-delta lobe and were excluded from reconnaissance resource estimates. Additionally, BA-68 and BA-40 utilized a combined 3.2 MCM (4.3 MCY) of mixed-sediment from the Sandy Point paleo-delta lobe. A summary of available and accessible sand and mixed-sediment resource targets with and without pipeline buffer exclusions can be found in Figure 46, Table 4, and Table 5.

Table 4. Summary of quantified indicated sand resource volumes (>70% sand) with less than 6.1 m (20 ft) of overburden. These represent regional reconnaissance level volume estimates and need further refinement with future detailed investigations. Accessible volume of sediment excluding sediment within the pipeline safety buffer (305 m [1000 ft]) and previously dredged sediment from borrow pits

Feature	Example Data Figure #	Facies	Area m ² (ft ²) (10 ⁶)	Avg. Unit Thickness m (ft)	Avg. Overburden Thickness m (ft)	Available Sediment Volume MCM (MCY)	Accessible Sediment Volume MCM (MCY)
West Grand Terre	Figure 31	Deltaic Mouth Bar	20.6 (222)	2.4 (8)	2.4–6.1 (8–20)	49.0 (64)	39.8 (52)
Scofield	Figure 33	Deltaic Mouth Bar	24.7 (266)	2.1 (7)	0.0–1.2 (0–4)	51.2 (67)	25.2 (33)
Sandy Point	Figure 35	Deltaic Mouth Bar	59.6 (641)	2.4 (8)	0.3–3.0 (1–10)	143.7 (188)	79.5 (104)
Total Sand						243.9 (319)	144.5 (189)

Table 5. Summary of quantified mixed-sediment resource volumes (30–70% sand) with less than 6.1 m (20 ft) of overburden. These represent regional reconnaissance level volume estimates and need further refinement with future detailed investigations. Accessible volume of sediment excluding sediment within the pipeline safety buffer (305 m [1000 ft]) and previously dredged sediment from borrow pits

Feature	Example Data Figure #	Facies	Area m ² (ft ²) (10 ⁶)	Avg. Unit Thickness m (ft)	Avg. Overburden Thickness m (ft)	Available Sediment Volume MCM (MCY)	Accessible Sediment Volume MCM (MCY)
West Grand Terre	Figure 31	Overbank/Proximal Delta Front	72.0 (776)	3.0 (10)	1.2–6.1 (4–20)	124.6 (163)	90.2 (118)
Scofield	Figure 33	Overbank/Proximal Delta Front	71.8 (773)	2.7 (9)	0.0–1.2 (0–4)	110.1 (144)	50.5 (66)
Sandy Point	Error! Reference source not found.	Overbank/Proximal Delta Front	118.2 (1272)	2.7 (9)	1.0–3.0 (3–10)	234.0 (306)	91.7 (120)
Total Mixed-Sediment						468.7 (613)	232.4 (304)

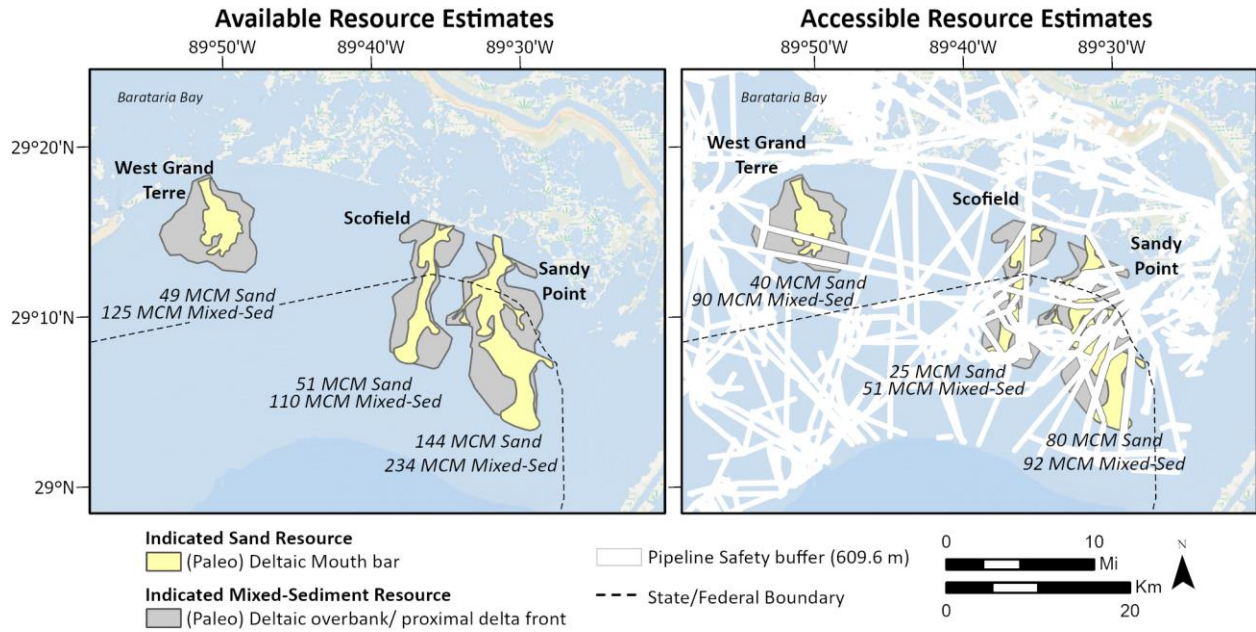


Figure 46. Map of available and accessible subsurface sand and mixed-sediment resources. Volume calculations are first order estimates at the reconnaissance level and will be refined with further investigation. Accessible resources exclude pipeline safety buffer of 305 m (1000 ft). In place pipelines compiled from Bureau of Safety and Environmental Enforcement and Louisiana Department of Natural Resources databases

7 A Method for Automating Use of Sediment Core and Surface Sediment Data for Regional Sediment Management

The availability of sediment resources to build barrier island and wetland restoration projects is a demonstrated need of the Coastal Master Plan. Previous work in Louisiana has developed a littoral sediment budget to inform fluxes of sediment along the Central Coast (ACRE 2020). As part of the larger LASMP Region 1 investigation, this task builds upon previous work by automating the methodology of Georgiou et al. (2010), which used core and grab sample data to quantitatively incorporate information about sediment textural characteristics into the sediment budget, and expand the footprint from Racoon Point to Sandy Point to align with the operational sediment budget (ACRE 2020). A brief summary is presented here; see **Appendix H** for a detailed description of this complementary investigation.

This investigation develops a semi-automated method using available sediment core and grab sample data from the comprehensive LASARD combined with bathymetric change surfaces derived from data assembled from CPRA’s BICM program to automate use of percent sand values for the vertical interval from each core that intersects erosional and depositional zones. This semi-automated method produces a weighted average percent sand for each core from 10 cm (3.9 in) intervals within the overall vertical interval that has been identified as eroded or deposited between two time periods represented by the bathymetric change surface (Figure 47). The weighted average percent sand values for each core are then incorporated into a table containing all core data for the area of interest that is interpolated to derive a percent sand value for each of the littoral cells. This method for automated percent sand calculation creates a consistent, reliable, and likely more cost-efficient methodology (i.e., reducing time and the requirement of professional expertise) that can be applied to future sediment budget analyses to quantify sand transport fluxes and fine-grained sediment losses from the coastal barrier system. This information is important for identifying long-term trends in sediment dynamics along the coast to quantify and characterize erosional sources and depositional sinks that inform sediment management and restoration design strategies, including approaches to managing limited sand resources within the system as a component of the CPRA Barrier Island System Management (BISM) program.

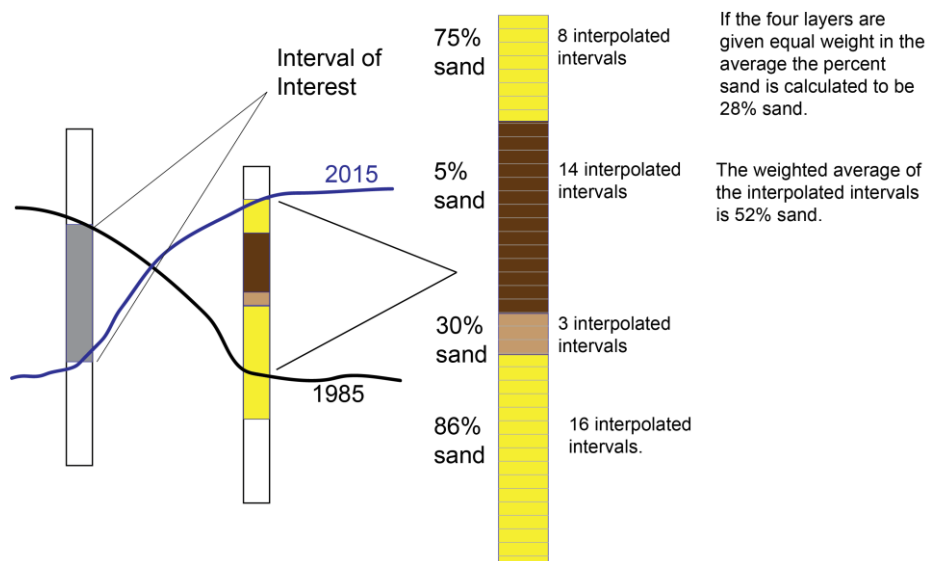


Figure 47. Schematic showing the selection of the Interval of interest and the weighted average procedure for the percent sand calculation

8 Conclusions and Recommendations

This investigation provides a cost-efficient resource exploration strategy for future investigators to expand to other areas of the coast or modify for different geologic settings. The first task of this holistic approach involved a comprehensive synthesis and reinterpretation of archival data. Sediment core descriptions from 28 separate efforts within LASMP Region 1 were recovered from UNO's holdings and digitally submitted to LASARD for public use. Roughly 450 archival cores already available in LASARD and 5,150 km (3,200 mi) of geophysical data from SWAMP and USGS were also integrated and reinterpreted using all archival data. Previous borrow sites were characterized in a geologic framework based on initial findings, a preliminary geologic model was developed to guide new data collection, and a survey plan was created to refine possible resource extents. Between June and July 2022, personnel from The Water Institute, Louisiana State University, and APTIM collected 394 km (245 mi) of full-suite geophysical data offshore of Barataria Bight. A total of 100 vibracores were collected by APTIM and UNO between December 2022 and June 2023 to verify sub-bottom interpretations. UNO processed 545 grain size subsamples to verify sediment composition and resource compatibility. Insights to the geologic evolution and timing of the deposits were provided by 42 new radiocarbon estimates. Synthesis of these geoscientific data interpretations led to the development of the LASMP Region 1 predictive geologic model. This simplified visual communication of the complex source-to-sink processes highlights the distribution and composition of sediment resource areas expanded within LASMP Region 1. One goal of LASMP is to develop predictive geologic models for the entire coast of Louisiana to help communicate and manage sediment resources holistically wherein the relationship between surficial geomorphic features and subsurface geological setting could be visualized. This will add to the list of sediment management tools developed by CPRA during the last two decades such as the Delta Sand Search Model, LASARD, and SSD map. The implementation of LASMP in Region 1 provides a streamlined sediment resource identification workflow for further development and can be applied to other regions.

A holistic assessment of sediment resource composition, distribution, and inventory of first-order volumes was provided for LASMP Region 1. This investigation mapped three major sediment resource areas that are expansions of previously identified borrow areas, as well as several potential resource areas that hold promise. The resources are related to subsurface, paleo-distributary mouth bar sands located offshore Barataria Bight and were extended landward to major paleo-distributary networks buried in Terrebonne and Barataria Bays. This investigation characterized a relative hierarchy of distributary channels, demonstrating channels that led to significant offshore sediment deposits. This source-to-sink approach can guide future exploration strategies.

The West Grand Terre, Scofield, and Sandy Point paleo-delta deposits mapped in this investigation contain an estimated 244 MCM (319 MCY) of sand and 469 MCM (613 MCY) of mixed-sediment resources based on viability criteria determined by CPRA. These are first-order estimates that can be greatly refined with further development. This investigation also provided estimates for the accessible sediment resources considering dredging exclusion buffers surrounding in-place oil and gas infrastructure as well as proven borrow sites that have been previously utilized and excavated. It is important to account for the accessibility of resources even at the reconnaissance-scale to aid in future investigations and planning decisions. Accessible sediment resources in the Barataria offshore region are estimated to contain 144 MCM (189 MCY) of sand resources and 232 MCM (304 MCY) of mixed-sediment resources. The Scofield and Sandy Point paleo-delta deposits saw the greatest obstruction of available sediment volumes due to the high concentration of in-place pipelines in the OCS West Delta Area. These sediment resource estimates, constrained by geophysical and geologic sampling, are further de-risked by linking to previously dredged or designed borrow areas. Areas categorized as potential sediment resources were determined using geologic interpretation of geotechnical and sub-bottom geophysical data but did not have the required data density for resource quantification and represent areas for further investment of strategic data collection.

The semi-automated methodology developed in this investigation was used to evaluate littoral cells' composition and provided insight for connections between relict geology and sand content. Erosional and depositional cells of the operational sediment budget developed by ACRE (2020) were calibrated using geological data to better understand sediment transport dynamics. Initial observations showed the highest sand percentages were cells that coincided with sand-rich paleo-mouth bar or paleo-shoreline deposits identified in the sediment resource mapping portion of this investigation. Further refinement is needed to fully understand this relationship to the underlying geologic framework and its impact to the modern system. Understanding sediment dynamics along the Central Coast barrier islands of Louisiana, especially leveraging archival data, is critical for strategic planning and sediment management when available restoration quality sediment is extremely limited.

Sediment resource prospecting is an iterative approach and strategies could be continually improved and adapted to better utilize allocated funding and timing. Future investigations would benefit from employing data collection and survey design recommendations, reference successfully verified seismic-lithofacies, and general prospecting strategies learned through this investigation. These recommendations are detailed in Appendix F. Future research could further develop sediment resources to create designed borrow areas that can be allocated for restoration projects. The proposed inferred sediment resources, such as offshore of the Scofield and Sandy Point paleo-deltas and other local areas could be investigated to assess their viability and potential development.

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Appendix A: Geophysical and Geological Data Collection and Processing

Appendix B: Geophysical Data Collection Field Notes

Appendix C: Geophysical Data Collection Mitigation Efforts

Appendix D: Protected Species Observer Notes

Appendix E: Archeological and Hazard Clearance for Vibracore Site Selection

Appendix F: Lessons Learned-Sediment Prospecting, Subsurface Interpretation, and Methodology

Appendix G: Seismic-Lithofacies Examples

Appendix H: A Method for Automating Use of Sediment Core and Surface Sediment Data for Regional Sediment Management



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