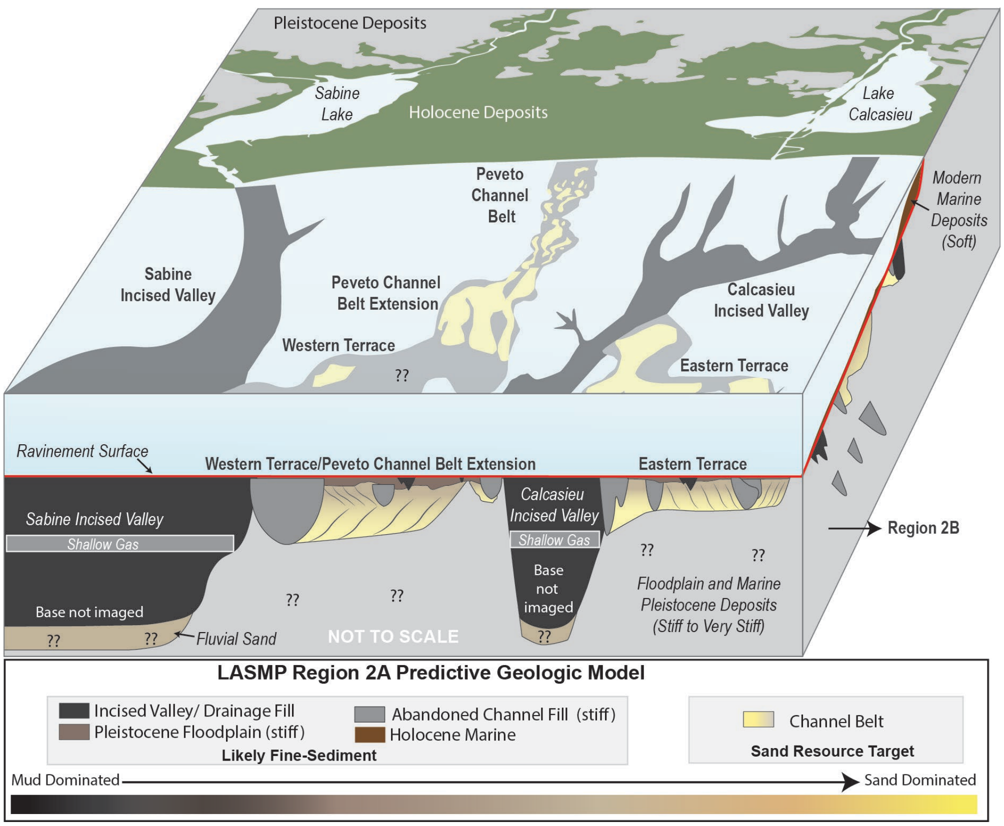
Inventory of Restoration Quality Sediment to Improve Coastal Resiliency in Louisiana: *Louisiana Sediment Management Plan (LASMP) Western Louisiana Region 2A Sediment Resource Inventory*



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Inventory of Restoration Quality Sediment to Improve Coastal Resiliency in Louisiana: *Louisiana Sediment Management Plan (LASMP) Western Louisiana Region 2A Sediment Resource Inventory*

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DISCLAIMER

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CPRA: Syed Khalil – Principal Investigator; responsible for project concept development and funding acquisition, overall supervision and administration, refinement of sampling strategies, conceptualization and presentation of the geologic model, and report review and contributions. Matthew Vincent – Contributed to resource identification and reporting, geological model presentation, and report review.

The Water Institute: Rob Hollis and John Swartz were responsible for project formulation, research design, and execution including data synthesis and analysis, survey design, field data collection, interpretation, development, and refinement of geologic models, and were the primary authors of this report. Mike Miner, Water Institute Principal Investigator, was responsible for project inception, implementation oversight, execution, hypotheses development and research design, interpretation, development, and refinement of geologic models, and provided major contributions to the report. Micah Weltmer was responsible for project management, coordination, and execution. Joseph Hankerson and Maricel Beltran-Burgos were responsible for data synthesis, interpretation, and report contributions to the following sections: Historical Data Review and Synthesis and Sediment Resource Estimates.

APTIM: Beth Forrest and Patrick Bryce led geophysical and geological data collection, processing, formatting, and report contributions to the following sections: Appendix A Desktop Report and Appendix B Geophysical and Geological Data Collection and Processing.

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Glossary

Note on terminology:

The definitions of sediment resources and reserves used in this report follow CPRA's classification scheme, which is based on the guidelines of the Society for Mining, Metallurgy & Exploration (SME) and BOEM with some modifications to meet CPRA's specific restoration needs and address 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.

Accommodation: The space/void available for potential sediment deposition/accumulation.

Borrow area: A sediment resource area delineated on the basis of engineering-scale surveys during engineering and design of a restoration project where the area's 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 surveys and cultural resources surveys during design of a restoration project and created following the extraction or dredging of some or all of the sediment from the borrow area.

Engineering-scale survey: Survey conducted with the goal of defining a dredge template and extractable sediment volumes. 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 should include grain size measurements and shell content data to determine its potential compatibility. This survey is characterized by much higher-resolution geophysical survey trackline spacing than used in reconnaissance-scale surveys, varying from 30–50 m (100–150 ft).

Highstand: A period when sea level is at its highest level and shorelines are positioned the most landward.

Inferred sediment resources: 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.

Inferred- Unverified sediment resources: Resource estimated based on indirect evidence (acoustic data/ bathymetry and/or polling only) that have not been ground-truthed by direct sampling.

- **Inferred- Unverified sand resource:** Unverified resource where sediment is comprised predominately (70–100%) of sand with <30% fines (silt/clay)
- **Inferred- Unverified mixed-sediment resource**: Unverified resource where sediment is comprised of a mixture of sand (30–70%) with the remaining fraction made up of fines (silt/clay).

Inferred- Semi-verified resource: Resource estimated on the basis of limited geological evidence and sampling (grab samples with core boring data > 1 mile apart).

- **Inferred- Semi-verified sand resource:** Semi-verified resource where sediment is comprised predominately (70–100%) of sand with <30% fines (silt/clay)
- **Inferred- Semi-verified mixed-sediment resource**: Semi-verified resource where sediment is comprised of a mixture of sand (30–70%) with the remaining fraction made up of fines (silt/clay).

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.

Lowstand: A period when sea level is at its lowest level and shorelines are at their most basinward position.

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, 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 that is a mixture of sand (30–70%) with the 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.

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 surveys 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 of either sand or mixed-sediment delineated based on data that is spaced less than 1 mile apart.

Sediment reserve (as defined by CPRA): The economically extractable/dredgeable part of a Measured and/or Indicated Sediment Resource. This category applies to borrow areas and specifically borrow pits.

Sediment resource (as defined by CPRA) 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 confidence (Unknown, Unusable, Inferred (unverified), Inferred (semi-verified), 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.

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 processed as the shoreline translates landward, resulting in a lag surface, and representing a missing time period of the sediment record.

Unknown sediment resources (as defined by CPRA): 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 geologic or geophysical data become available.

Unusable Resources (as defined by CPRA): Resources that are not suitable for dredging/extraction due to geological characteristics for restoration purposes.

List of Abbreviations and Acronyms

ACRE	Applied Coastal and Research Engineering
APTIM	Aptim Environmental & Infrastructure, LLC
BICM	Barrier Island Comprehensive Monitoring
BISM	Barrier Island System Management
BOEM	Bureau of Ocean Energy Management
bsfl	Below seafloor
CPE	Coastal Planning & Engineering
CPRA	Coastal Protection and Restoration Authority
ft	Feet
km	Kilometer(s)
LASARD	LouisianA SAnd Resource Database
LASMP	Louisiana Sediment Management Plan
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

Executive Summary

Coastal restoration and 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] herein) recognizes that beach and marsh restoration-compatible sediment is limited and needs to be managed in an efficient and cost-effective manner for sustainable protection of coastal communities, resilient infrastructure, and ecosystem restoration. The 2023 CMP identifies a need for ~800 million m^3 (MCM; 1,046 million yd^3 [MCY]) of sediment for marsh creation and land restoration over a 50-year duration (CPRA, 2023). Additionally, it is estimated that ~5–11 billion m^3 (6.5–14.4 billion yd^3) 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 as part of a systematic regional sediment management (RSM) strategy (Khalil et al. 2010; Khalil, Freeman, et al. 2018; Khalil et al. 2020; Khalil, Raynie, and Forrest 2023; Khalil, Raynie, Forrest, et al. 2023). LASMP Region 2 is composed of western Louisiana, roughly bounded by Sabine Pass to the west and White Lake to the east. It was designated as Region 2 based on the high demand for compatible sediment (CPRA 2023) and potential future offshore infrastructure development associated with wind energy areas (WEA), particularly U.S. Bureau of Ocean Energy Management (BOEM) lease OCS-G37334. LASMP Region 2 results provide an updated inventory of classified sediment resources to aid in CMP implementation. CPRA considers both sand (70% or greater sand content) and mixed-sediment (30–70% sand) important for beach 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. Sediment resources that are documented in this report include ancient, buried river deposits across the western Louisiana coast. This study implemented a strategic approach to address the following objectives:

1. Analyze and synthesize available/existing geotechnical, geophysical, and sedimentological data to create predictive geologic models depicting compatible sediment distribution, and develop field data acquisition plans in consultation with CPRA to maximize value of new data investments and resulting sediment resource inventories.
2. Acquire and interpret new geological and geophysical data between Sabine Pass and Calcasieu Pass, referred to as Region 2A, that address key sediment resource knowledge gaps as identified in the preliminary predictive geologic 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 which provide sediment resource extent, potential volumes, sediment properties, geologic origin, and evolution as data allows.
4. Develop a region-specific predictive geologic model that incorporates existing studies and new LASMP data interpretation. Such models are intended to aid in the correlation of surficial 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 reduction of 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.

The first task involved a comprehensive synthesis and reinterpretation of archival data within the entire Region 2. Information for 33 sediment core descriptions was obtained from University of New Orleans

(UNO) holdings and digitally submitted to the Louisiana Sand Resource Database (LASARD). Approximately 200 archival cores available in LASARD and 2,900 km (1,800 mi) of geophysical data of variable data quality from USGS were also integrated and reinterpreted. Lease block hazard survey derivative digital map products that outline subsurface channels for 122 lease blocks on the outer continental shelf were also integrated to the synthesis portion of the desktop analysis. 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 extensions.

LASMP Region 2 was divided by CPRA into two regions—Region 2A and 2B—for the purposes of data collection, interpretation, and resource reporting. Region 2A was the first region to be implemented, as it is the site of potential wind energy development and transmission corridors in western Louisiana. APTIM collected 562 km (349 mi) of full-suite geophysical data in the western portion of Region 2 (Region 2A), between March 4–16, 2023. A total of 35 vibracores up to 5.9 m (19.5 ft) in length were collected by APTIM during September 8–13, 2023 to verify preliminary interpretations based on sub-bottom data. APTIM processed 83 grain size subsamples to verify sediment composition and resource compatibility. These new data interpretations led to the development of the geologic model for LASMP Region 2A. This simplified visual communication of the complex source-to-sink processes highlights the distribution and composition of sediment resource areas expanded within LASMP Region 2A. This will add to the list of sediment management tools developed during the last two decades, starting from the Delta Sand Search Model, LASARD, and the Surficial Sediment Distribution (SSD) map.

An assessment of sediment resource composition, distribution, and inventory of first-order volumes was provided for LASMP Region 2A. This investigation mapped three major sediment resource areas that are either significant expansions of previously identified borrow areas or previously unidentified, as well as localized inferred resource areas that hold promise. The resources are related to subsurface, paleo-channel belts located offshore of western Louisiana likely related to Pleistocene age river courses.

The expanded Peveto Channel Belt, previously identified by Coastal Planning and Engineering LLC (CPE; 2002), eastern terrace, and western terrace fluvial channel belt deposits mapped in this investigation contain an estimated 703 MCM (920 MCY) of sand resources. These first-order estimates are made up of both inferred (semi-verified and unverified) and indicated resources and need to be refined with further development. This investigation also provided estimates for the accessible sediment resources; these estimates include consideration of 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. Excluding infrastructure safety buffers, the western Louisiana region is estimated to contain 505 MCM (662 MCY) of accessible sand resources. These sediment resource estimates, constrained by geophysical and geological sampling, are further de-risked by linking to previously dredged or designed borrow areas. Inferred (semi-verified) sand and mixed-sediment resources related to localized channel belts were identified on the eastern boundary of Region 2A using available geotechnical and sub-bottom geophysical data. The inferred resources did not have the required data density for resource quantification and represent areas to be further investigated. Based on derivative map products these channel belts appear to extend into Region 2B.

In collaboration with BOEM, and building upon previous synthesis efforts by Heinrich et al. (2020), derivative map products from the outer continental shelf (OCS) lease block hazard surveys were integrated into the interpretations of this investigation. The repurposing of detailed interpreted maps created from surveys with 30 m (100 ft) line spacing supports the regional scale framework interpretation and constrains the channel geomorphology and extent, such that the maps can supplement areas of lesser data coverage in this Region 2A investigation. Preliminary target deposits and channel belts systems were identified in Region 2B from archival digital sub-bottom complemented with the OCS lease block hazard survey derivative map products. This example of repurposing open-source data to cost-efficiently strengthen resource interpretations and de-risk areas of future investments shows the importance of interagency collaboration and creative problem-solving.

Sediment resource prospecting is an iterative approach and continual improvement of the strategies used in prospecting can enable better utilization of allocated funding and time. Below are a series of recommendations to improve the efficiency of future sediment resource investigations in the area:

1. Further development of the indicated and inferred channel belt sediment resources identified in this investigation would benefit from increased geological sampling and the use of lower and higher frequency survey methods to constrain sediment variability and geometries. Longer sediment cores would help constrain the composition of the channel belt deposit with depth and should generally target areas of transparent facies with loss of acoustic chirp imaging below.
2. The two localized channel belts found along the Region 2A boundary may be potential sand and mixed-sediment resources with minimal overburden and proximity to future restoration projects. Further geological and geophysical surveying is needed to constrain its extent in Region 2B and quantify resource volume estimates.
3. The fluvial terrace deposits could represent thick, up to 20m (60ft), fluvial sand-rich deposits and should be further characterized with the use of deeper geologic sampling methods and geophysical instrumentation capable of deeper penetration such as boomer seismic. Although the overburden may be greater, and if sand resources are verified throughout the base of the deposit, they could represent significant resources.
4. Special dredging technique and efficiency considerations should be given to areas of Pleistocene stiff fine-grained overburden above the Peveto Channel Belt Extension and Fluvial Terrace deposits.
5. Special utilization of OCS lease block hazard survey derivative map products should be integrated into resource prospecting efforts where possible to maximize investment of data collection.
6. Correlations of sediment composition and acoustic signatures, such as the loss of acoustic signal below transparent facies correlating to higher sand content, should be continually refined and shared when more information is available. Although this provided the best correlation to higher sand content, there was still variability in the sampled sediment composition across deposits.
7. The strategies and findings presented in this resource investigation are portable and should be adapted to areas of similar geologic settings.

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 implementation of a new predictive approach to sediment resource prospecting, and the outcomes and recommendations, which are systematically applied to the entire Louisiana coast to implement LASMP. Finally, the LASMP Region 2A investigation identifies accessible inferred sand resources for further development that can be directly linked to stakeholder and project needs and demonstrates the restoration-value of sediment management.

1 Introduction

Louisiana's beaches, headlands, and wetlands are rapidly eroding and converting to open water in response to storms, diminished sediment supply, and various other natural 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 (CPRA, 2023). High rates of land loss, primarily driven by a system-wide sediment deficit, requires a comprehensive sediment management plan to support the planning and successful execution of coastal restoration programs. It is estimated ~800 million m^3 (MCM; 1,046 million yd^3 [MCY]) of sediment is required over a 50-year time horizon to implement the Louisiana Coastal Protection and Restoration Authority's (CPRA) Coastal Master Plan (CMP; CPRA 2023), with an additional 5–11 billion m^3 (6.5–14.4 billion yd^3) of sediment needed to offset projected land loss (Blum and Roberts 2009; Khalil, Freeman, et al. 2018). CPRA considers both sand (70% or greater sand content) and mixed-sediment (30–70% sand) important for barrier island and marsh restoration, yet compatible sediment resources are relatively limited in the muddy Chenier Plain. 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, especially in the Chenier Plain. 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 2023; Khalil, Raynie, Forrest, et al. 2023). This holistic RSM approach considers key aspects of successful restoration strategies, including sediment resource inventories, models of the benefits and effects of sediment extraction and placement, and comprehensive investigations into 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 as well as modern sediment sourced from the diversion or dredging of rivers to alleviate land loss and associated impacts. LASMP provides the framework to understand present and future drivers of sediment need and availability, and to enable the most economic and project-appropriate allocation of sediment from the sources available to coastal planners.

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 sediment type and distribution on a regional scale, and provides a data portal with 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). The geophysical data collected as part of SWAMP are leveraged by LASMP here to create an inventory of sediment resources. A foundation of LASMP is that the goals and outcomes of these investigations offer direct, actionable value to a wide range of end-users, including those in planning, engineering, ecosystem restoration, geosciences, and resource management. The incorporation of datasets and drivers of sediment needs framed by these stakeholders help to differentiate LASMP from solely research focused investigations.

LASMP divides the Louisiana coastal system into six regions for phased implementation by CPRA. The LASMP Region 2 planning area is located between Sabine Pass and White Lake (Figure 1). Region 2 has a high potential for sediment resource occurrence based on previous investigations and high potential for multi-use conflicts associated with oil and gas and wind energy infrastructure. Region 2 contains proposed wind energy area (WEA) transmission cable routes from BOEM lease OCS-G37334 that could impact accessibility of sediment resources This investigation included the development of a predictive geologic model based on the geology of Region 2A. A predictive geologic model allows for a science-driven approach to sediment resource exploration based on source-to-sink concepts. This produces sediment inventories that can be linked to planned restoration projects and informs economic investment in future geotechnical data collection. Additionally, this investigation's underlying technical work provides new insights into regional sedimentary processes and impacts that can inform restoration strategies. Together, these provide an actionable path forward for diverse users and stakeholders including the engineering, planning, ecosystem restoration, and management communities. This portable approach is designed to be applicable to the entirety of the Louisiana coast.

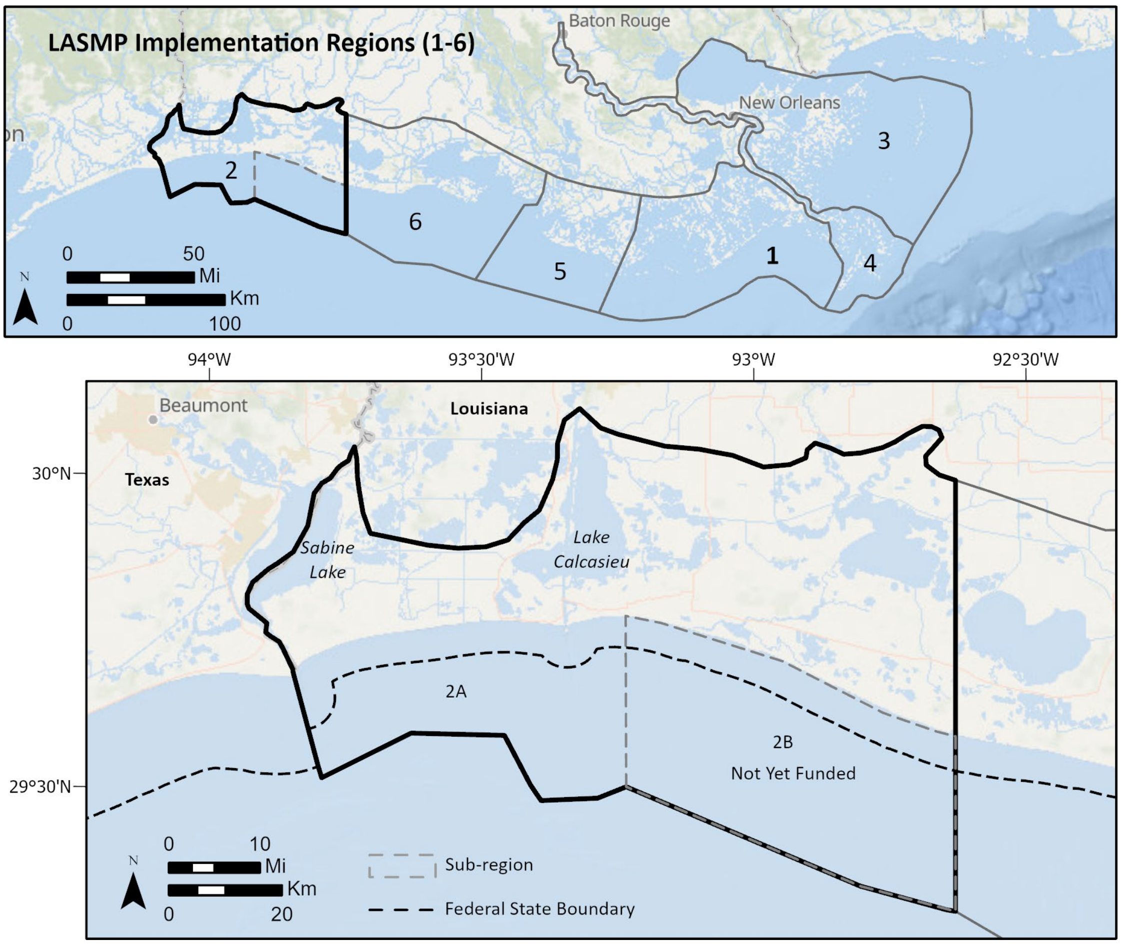

Figure 1. Map of the Louisiana Sediment Management Plan implementation regions highlighting current investigation area, LASMP Region 2. Sediment resources were assessed within Region 2A generally constrained by Sabine and Calcasieu Pass.

The current inventory of restoration-quality sediment resources does not meet the demand for planned and future restoration projects in coastal Louisiana, especially in western Louisiana's Chenier Plain (CPRA 2023). This investigation intends to identify additional sediment resource deposits within Region 2A that can be further developed into constructed borrow areas. Based on recent work conducted on the eastern

Texas shelf funded by BOEM and the Texas General Land Office (APTIM and The Water Institute 2021; APTIM and The Water Institute 2022; APTIM and The Water Institute 2024), it is hypothesized that there is previously unidentified restoration-quality sand preserved on the shelf in the form of Pleistocene fluvial channel belts that likely extend into LASMP Region 2, and that proven borrow areas such as Peveto Channel may be larger in area and potential resources than previously quantified.

The following approach and methodology were employed to identify and quantify potential sediment resources within LASMP Region 2, communicate subsurface geological complexity and implications to diverse end-users, and provide recommendations for future investigations:

1. Analyze and synthesize available/existing geotechnical, geophysical, and sedimentological data, construct initial predictive geologic models of compatible sediment, and develop field data acquisition plans in consultation with CPRA to maximize value of new data investments and resulting resource inventories.
2. Acquire and interpret new geological and geophysical data between Sabine and Calcasieu Pass, referred to as Region 2A, that address key sediment resource knowledge gaps as identified in the preliminary predictive geologic 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 extent, potential volumes, sediment properties, geologic origin, and evolution as data allows.
4. Develop a region-specific predictive geologic model that incorporates existing data, studies, and new insights provided by LASMP data collection and interpretation. Predictive geologic models are intended to aid in the correlation of surficial 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 reduction of 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.

2 Region 2 Geologic Setting

The Region 2 geologic framework is the result of geologic processes acting on various time scales. The shifting of major sediment pathways and depocenters controlled by sea level rise and fall are responsible for the distribution and preservation of compatible sediment resources. The coastal plain setting of LASMP Region 2 has several differences from the deltaic plain setting of LASMP Region 1 (CPRA, 2023) and therefore requires a different sediment resource target strategy.

The coastal plain and inner continental shelf of the western Louisiana study area, roughly constrained by Sabine Pass in the west to White Lake in the east and north of Sabine Bank, was constructed through fluvial to shallow-marine sequences associated with changes in sea level and subsidence (Young et al. 2012). The clastic wedges of basinward-gradational terrestrial to coastal deposits have resulted in a series of coast-parallel terraces (Young et al. 2012; Heinrich et al. 2020). The most recent Pleistocene unit is the Prairie Allogroup, which consists of the Beaumont Alloformation. This unit is characterized by oxidized sand and stiff clay (paleo-soil horizons) due to subaerial exposure during the most recent sea-level lowstand (e.g., Heinrich et al. 2020). Relict Pleistocene meandering channel belts that are only partially eroded can be identified in modern LiDAR on the landward equivalent deposit (Shen et al. 2012). A summary of the geologic framework evolution of the area is presented here to inform the sediment resource prospecting strategy. A detailed discussion of the Quaternary geology of southwestern Louisiana can be found in Young et al. (2012) and Heinrich et al. (2020).

Coastal and fluvial response to sea-level changes have dominated the study area's geomorphic evolution (deposition and erosion of sediments) since the mid-Pleistocene, approximately ~900,000 years ago. Glacial-driven eustasy resulted in relative sea-level changes on the order of hundreds of meters and result in Gulf of America shorelines migrating basinward towards the shelf edge during low-stands. Conversely, melting glacial ice results in sea-level rise, a process referred to as transgression*,* resulting in sea-level highstands, or stable shoreline high points of a rising stage sea level.

For the purpose of this discussion of sediment resources within the study area, an understanding of the most recent glacio-eustatic cycle (beginning ~120,000 years ago) offers important linkages to major sediment pathways and depocenters (Figure 2). During this time, sea-level was approximately 9 m (30 ft) above present levels in the northern Gulf (Simms et al. 2013). The preserved highstand shoreline is the Ingleside Shoreline, which dates to approximately 120,000 years (Simms et al. 2013) and extends from Corpus Christi, Texas to eastern Louisiana. It is locally absent through much of the study area due to fluvial reworking or burial by aeolian processes (Anderson et al. 2016). After this highstand, sea levels underwent cyclic, rapid fluctuations throughout the falling stage, depositing numerous fluvial channel networks and shelf margin deltas (Suter and Berryhill, Jr. 1985; Suter 1986; Wellner et al. 2004; Figure 3). The originally mapped fluvial network and associated shelf margin deltas were separated into two drainage basins by later researchers (Anderson et al. 2016). The eastern drainage complex is thought to be associated with a Pleistocene Mississippi River Complex, consisting of moderately sinuous channel belts displaying lateral accretion of roughly 1 km (3,280 ft). On land, an ~85,000-year-old Lafayette meander belt system of similar geometry (Otvos 2005; Shen et al. 2012) is likely the landward extension of the deposits mapped on the shelf. This channel system includes large meander scroll bars that continue under the White Lake area toward the modern coast (Fisk 1948a). The western network is roughly 80 km (50 mi) wide, channel thalwegs are up to 35 m (115 ft) deep, and channel systems appear to converge seaward.

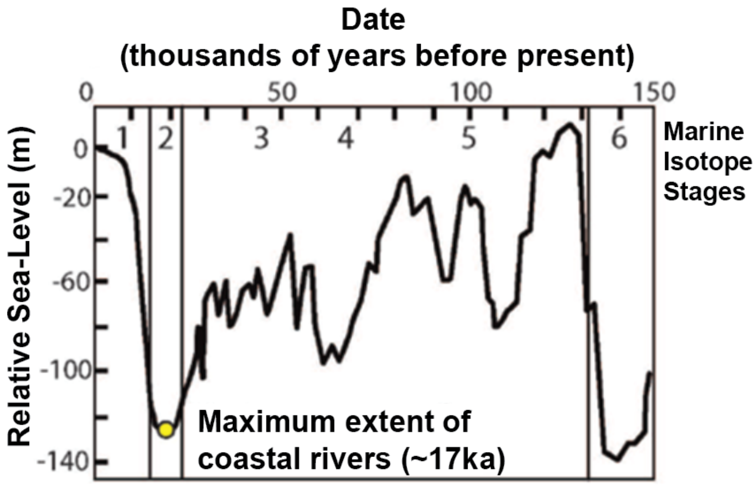

Figure 2. Sea-level history of the northern Gulf of America. Note coast reached its current position near present, with periods of sea-level rise and fall linked to patterns of rivers extending across the continental shelf from 120,000 to 22,000 years ago, and deposition of river and delta deposits from 22,000 to present. Marine Isotope Stage (MIS) numbers on curve correspond to deposits mapped in Figure 3. Modified from Swartz (2019) and Anderson et al. (2016).

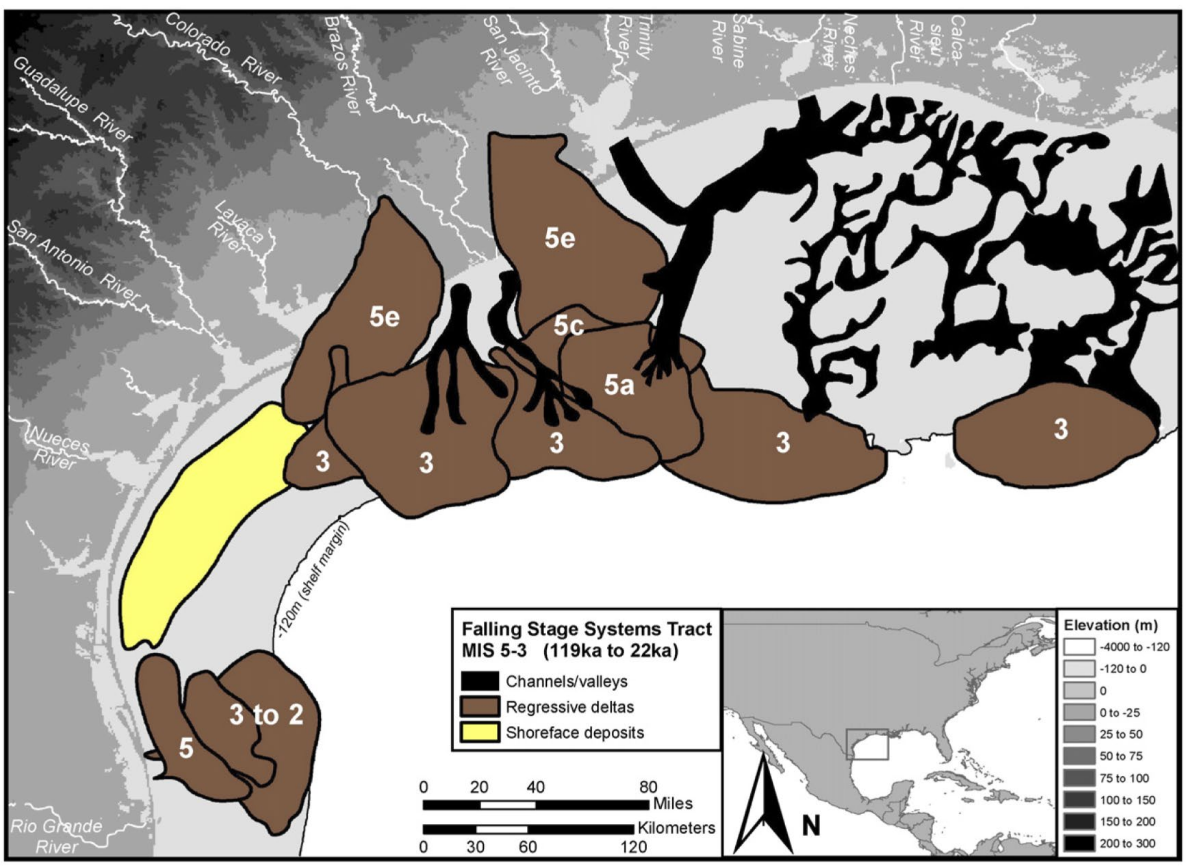

Figure 3. Summary of delta and river deposits offshore of Louisiana and Texas occurring between ~120,000 and 22,000 years ago. Numbered delta deposits correspond to sea level stages numbered in Figure 2. Modified from Anderson et al. (2016).

During the recent lowstand, which occurred approximately 22,000 years ago, sea levels fell roughly 120 m below present levels and the shoreline established near the current shelf edge (Anderson et al. 2004). The subaerially exposed shelf was incised by fluvial networks of the Sabine and Calcasieu rivers as sediment was transported to shelf edge deltas (Anderson et al. 2004). The resulting antecedent microtopography of the fluvial-deltaic Prairie deposits largely controlled the incision of smaller systems west of the Mississippi River, especially that of the present day Mermentau River and the modern Vermilion River (Howe et al. 1935; Swartz et al. 2022). Between 17,000 and 4,000 years ago, sea level rose rapidly ~120 m (~400 ft) to its present position along the modern coastline, flooding the exposed coastal plain deposits (Anderson et al. 2016). The Sabine and Calcasieu Incised Valleys filled with fluvial, deltaic, to marine sequences as the shoreline transgressed landward (LeBlanc 1949; Nichol et al. 1996; Milliken et al. 2008). Well-defined fluvial terraces are found within the Sabine and Calcasieu Incised Valleys (Thomas and Anderson 1994; APTIM and The Water Institute 2022). These under-filled valleys exhibit a classic depositional sequence resulting from low rates of sedimentation compared to the accommodation and rate of sea-level rise (Simms et al. 2006). Therefore, any potential sand or mixed-sediment resources are likely buried basal fluvial sands with large amounts of fine-grained overburden.

3 Sediment Resource Prospecting Approach and Methodology

3.1 Historical Data Review and Synthesis

A comprehensive review and synthesis of existing data was used to create a preliminary predictive geologic framework. This preliminary assessment of LASMP Region 2 geology was used to help define priority areas for new targeted data collection in Region 2A. This initial effort included a desktop analysis (e.g., Finkl and Khalil 2005; Khalil 2019) for the entire Region 2 area, where legacy datasets of varying formats were brought into a common interpretation platform. Digital SEG-Y data from three large 2D seismic geophysical surveys were also recovered (Calderon et al. 2004; Bosse, Flocks, and Forde 2020; Bosse, Flocks, Forde, et al. 2020; Flocks et al. 2023). Additionally, 33 sediment cores within University of New Orleans (UNO) holdings were determined to have been located within Region 2 and were incorporated into LASARD. BOEM provided digital derivative map products and reports from lease block hazard surveys presented in Heinrich et al. (2020). These hazard surveys contained 30–50 m (100–165 ft) trackline spacing of both higher and lower frequency seismic for clearance from potential geological hazards and cultural resources areas for oil and gas leases. In total, 122 of the 350 lease blocks reports were deemed usable and digitized by Heinrich et al. (2020), spanning western Louisiana and eastern Texas. There were no original geophysical data available from the roughly 5.5×5.5 km (3×3 mi) grid surveys, only derivative map products interpreted by a geologist. Even the derivative map products provide detailed insight to channel geometries and geomorphologies, although inconsistencies in reporting made it difficult to correlate between surveys at a regional scale as stated in Heinrich et al. (2020). Interpretation of these archival data allows for creation of an initial geologic model for assessment of likely occurrence of restoration-compatible sediment resources. Successfully designed borrow sites are contextualized in a geologic framework, providing detailed examples of target facies. A summary of available and recovered data and borrow sites is presented in Figure 4, the full desktop survey data compilation is detailed in Appendix A.

Prior studies established the general architecture, stratigraphy, and location of key sedimentary systems within the coastal plain and offshore of western Louisiana (Howe et al. 1935; Fisk 1948a; Gould and McFarlan 1959; Suter et al. 1985; Suter and Berryhill 1985; Nichol et al. 1996; Wellner et al. 2004; Milliken et al. 2008; Milliken et al. 2008; Shen et al. 2012), although some uncertainty and ambiguity remains in regards to specific stratigraphic relationships and sequencing of coastal evolution (Heinrich et al. 2020). For a detailed overview of the geologic evolution of the western Louisiana coastal plain, see Heinrich et al. (2020) and ACRE (2022) and references therein.

Historically, sand resource investigations follow an iterative approach of increasing data density over smaller areas as regional/reconnaissance surveys locate promising features justifying detailed investigation (e.g., Khalil 2019). Engineering- or design-scale surveys provide the resolution and specific data types needed to constrain, design, and clear (of environmental, cultural, and hazards concerns) a borrow area for dredging. The engineering surveys are intentionally designed at various scales to identify and further characterize the suitability of sediment deposits but often do not include consideration for a broader regional geological framework context due to project-by-project level planning. LASMP is intended to expand findings from these valuable prior investigations, while identifying major sediment transport pathways and depocenters to efficiently locate additional resources at a regional scale for long-term restoration planning horizons. This reconnaissance-level investigation for LASMP Region 2A contextualizes five previously developed successful borrow areas in a geologic framework by integrating and refining findings from existing regional studies and borrow area assessments (Table 1). Due to the wealth of archival data within the investigation area, it also allows for testing resource distribution and occurrence predictions to further develop prospecting strategies cost effectively.

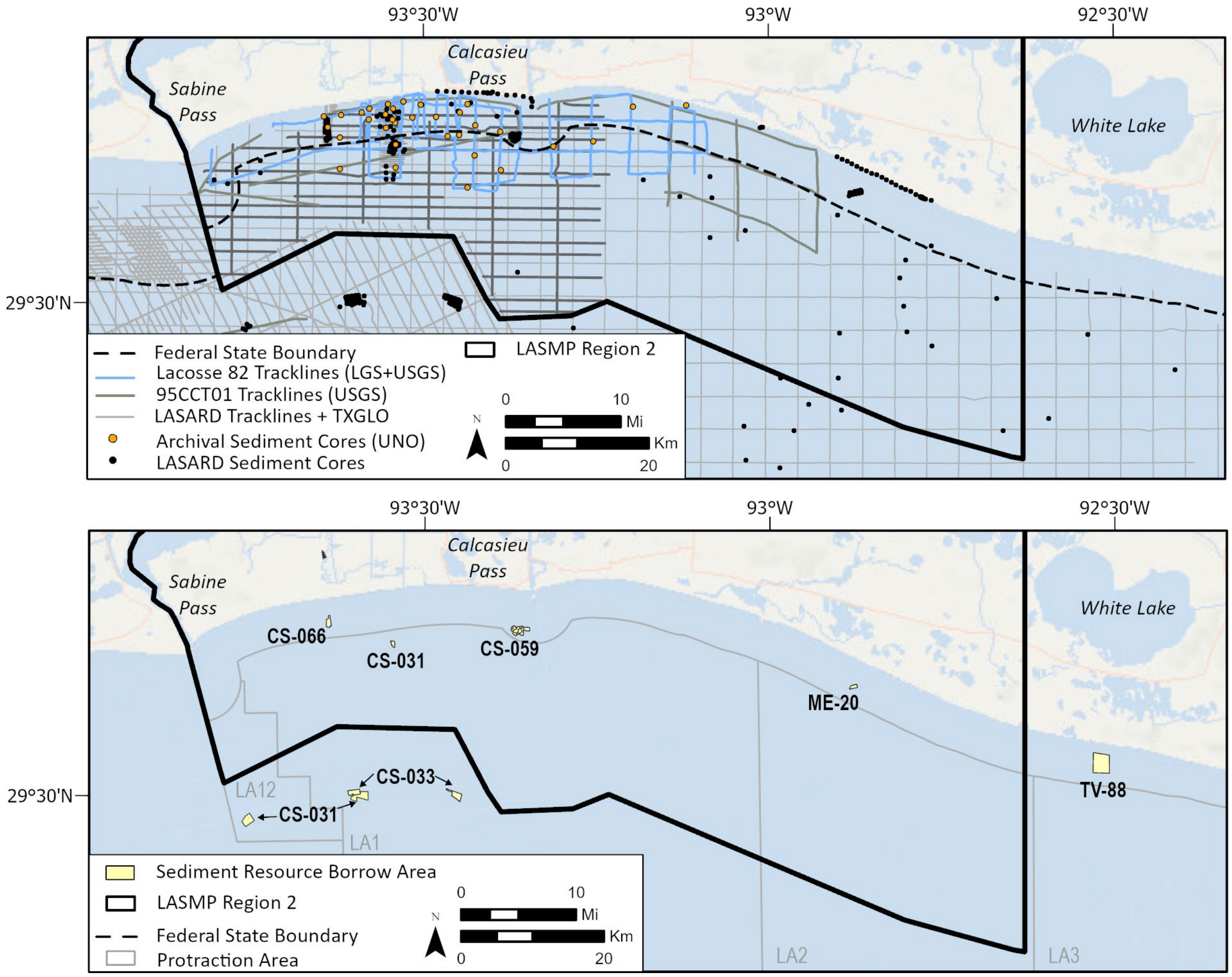

Figure 4. The upper panel shows archival data synthesized as part of LASMP initiative to build initial geologic framework and drive new data collection survey design plans. The lower panel shows successfully designed borrow areas cataloged in LASARD.

Table 1. Summary of previously designed or utilized offshore borrow pits/ areas in the vicinity of regional sediment resource targets mapped during this investigation.

CPRA Project ID	CPRA Project Name	Date	Borrow Site	Identified Sediment Volume MCM (MCY)	Dredged Sediment Volume MCM (MCY)	Source	Facies	Sediment Type*
CS-31	Holly Beach Sand Management Project	2003	Peveto Channel	Minimum of 1.5, maximum estimate not provided	2.1 (2.7)	CS-31 Completion Report, 2003	Paleo-channel belt	Sand
CS-33	Cameron Parish Shoreline Restoration Project	2014	HF, JF	6.6 (8.6)	1.5 (2.0)	CS-33 SF Completion Report, 2014	Sand bank/ Shoal	Sand
CS-59	Oyster Bayou Marsh Restoration Project	2019	Gulf of Mexico Marsh Borrow Area	Not Published in Completion Report	3.3 (4.3)**	CS-59 Completion Report, 2019	Incised Valley Fill	Fine Sediment*
CS-66	Cameron Meadows Marsh Creation and Terracing Projects	2022	NA	3.3 (4.3)	3.3 (4.3)	CPRA Infrastructure Polygon Database	Incised Valley Fill	Predominantly Fine with some Mixed-Sediment*
ME-20	South Grand Chenier Hydrologic Restoration Project	2016	Borrow Area, Alternative 2	5.0 (6.6)	Not published in Design Report	ME-20 Design Report, 2009	Incised Valley Fill	Predominantly Fine with some Mixed-Sediment*

* Marsh restoration sediment type was inferred from examining sediment cores within borrow areas, dredged sediment type was not specifically stated using new CPRA (2024) definitions. ** Does not include over dredged amount of 634 CM (533 CY) (634, 533 cy)

Previous sand searches and borrow area designs provide detailed seismic and core data to identify facies (types of sediment deposits with specific characteristics linked to formational geologic processes) that host suitable sediment resources (Table 1). These verified facies can be expanded and mapped along sediment pathways beyond the extent of the borrow design surveys using data from regional studies. Early investigation offshore of western Louisiana characterized sand deposits related to either fluvial-deltaic deposits associated with sea levels that were lower than present, or marine ridges, shoals, or banks representing reworked deposits during periods of rising or stable sea level (Suter et al. 1985; Suter 1986). The demand for compatible sediment along the rapidly eroding western Louisiana shoreline led to an assessment of the textural properties of the existing beaches as well as potential offshore borrow areas (Ramsey and Penland 1992). This led to a more detailed investigation of the identified Pleistocene Peveto Channel system which noted the complexity and variability of sand occurrence due to multiple cross-cutting channels (Figure 5; CPE 2002). The designed Peveto borrow area selection prioritized the thickest deposit of beach-compatible sand with the least amount of stiff overburden. The stiff, oxidized, Pleistocene floodplain clays were avoided in favor of softer clays to improve dredging efficiency and reduce risk and cost. An assessment of Sabine Bank demonstrated the utility of transgressive deposits as resources because most are exposed at the seafloor with no overburden and have high sand content. The investigation by CPE (2002) also analyzed transport distance from proposed borrow areas to the site of the restoration project as one of the first in Louisiana to provide coastal management planners the information needed to make informed decisions regarding resource compositional variability, level of risk, and dredge transport costs for offshore sediment resources.

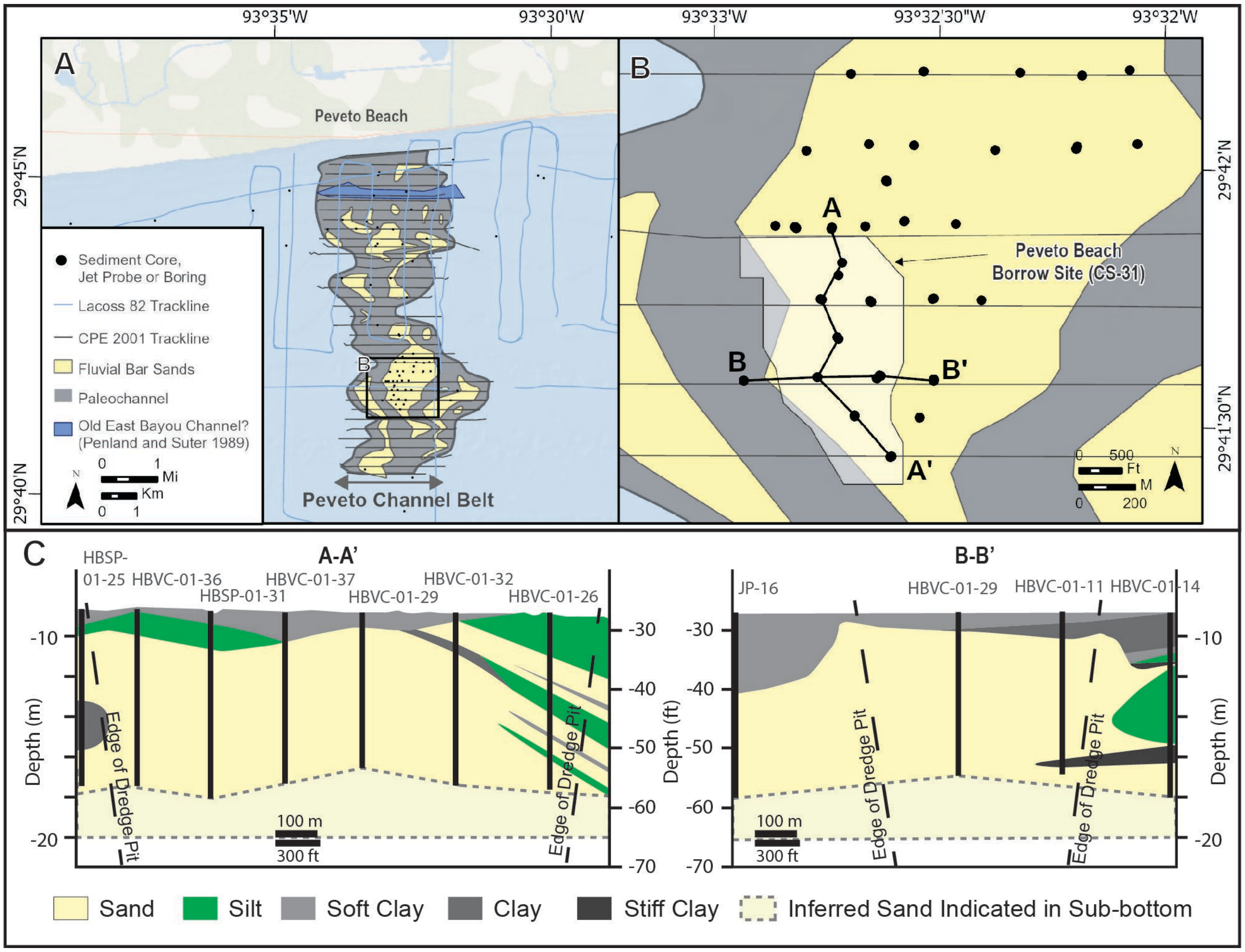

Figure 5. A) Peveto Channel Belt and B) developed borrow area CS-31 from previous investigations. C) Cross sections along the axis of the borrow area demonstrating the variability in geometry and thickness in channel belt deposit. The thickness of channel belt deposit were inferred from channel thalwegs according to (CPE 2002). Note fine-grained paleochannel fill. Figure modified from CPE (2002).

These investigations and others provided foundational information that led to detailed engineering-scale investigations for borrow area design and ultimate extraction for restoration projects. The iterative approach of locating and developing offshore borrow areas for beach and wetland restoration began in the early 1990s (Ramsey and Penland 1992) Currently, CPRA defines sand resources as sediment containing greater than 70% sand content and mixed-sediment resources as 30–70% sand (Khalil, Raynie, and Forrest 2023). Resources with minimal overburden are preferred. CPRA differentiates resources with less than or greater than 3 m (10 ft) in their classification scheme (CPRA 2024). Successfully developed borrow areas in Louisiana selected areas with less than 6 m (20 ft) of overburden or non-suitable sediment (CPE 2002; OSI 2019) and was the threshold criteria used in this reconnaissance investigation to consider a possible resource viable. A compilation of sand and mixed-sediment volumes of designed and extracted borrow areas for restoration projects are shown in (Figure 4) from the LASARD database, which provides documents and various geospatial data related to CPRA's restoration projects, monitoring programs, and large-scale data collection efforts. The utilized borrow areas or borrow pits were characterized in a geologic framework context as part of this investigation, which provided proven target facies that could be mapped elsewhere in the investigation area.

3.2 Geophysical and Geological Data Acquisition

A summary of geophysical and geological data acquired for the LASMP Region 2A reconnaissance investigation is presented here, which builds upon initial interpretations from the historical data review phase. During March 4–16, 2023, APTIM collected 562 km (349 mi) of full-suite geophysical data (Figure 6) aboard the M/V *Rachel K Goodwin*. The geophysical surveys simultaneously collected chirp sub-bottom, side scan sonar, magnetometer, and single-beam bathymetry. Equipment included Odom Teledyne E20 single-beam, Geometrics G882 Magnetometer, Edgetech 4200 side scan sonar, Edgetech 512i sub-bottom profiler and navigation was determined using Trimble SPS 461 differential global positioning system. See Appendix C and Appendix D for data collection methods and field notes. During geophysical and geological data collection, specific mitigation protocols were implemented to reduce potential impacts to marine mammals and endangered species as prescribed in the *Final Environmental Assessment on Sand Survey Activities for BOEM's Marine Mineral Program* (2019); specifically Appendix B of that document: *Survey Requirements and Mitigation Measures*. See Appendix E for mitigation Protected Species Observations during survey operations.

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 potential sand or mixed-sediment deposits (e.g., grain size, percent sand, etc.) or could aid in the refinement of geologic framework understating. In total, 46 potential vibracore sites were selected for archeological and hazard clearance in coordination with BOEM and CPRA (Appendix F). APTIM's Qualified Marine Archeologist reviewed vibracore sites for clearance following BOEM's guidelines. APTIM geologists collected a total of 35 vibracores within the LASMP Region 2A investigation area aboard the M/V *Rachel K Goodwin* between September 8–13, 2023. Vibracores up to 5.9 m (19.5 ft) were collected using APTIM's SEAS VC-700 coring rig. APTIM geologists split each vibracore lengthwise and logged them in detail by describing sedimentary properties by layer in terms of layer thickness, wet Munsell color, texture (grain size), composition and presence of clay, silt, gravel, or any other identifying features. The sediment cores were photographed and subsampled for grain size and geotechnical analysis. A total of 83 subsamples were analyzed for Munsell color and grain size distribution. Grain size was determined through sieve analysis. Cohesive sediment consistency was determined from 137 samples analyzed for shear strength using a pocket vane shear tester. Both analyses followed ASTM Standards.

3.3 Development of Predictive Geologic Model for LASMP Region 2A

The predictive geologic model developed under LASMP is a simplified three-dimensional conceptual representation of surface and subsurface geology. It is developed through the interpretation of geophysical and geological data both historical and recently collected during this investigation, with a robust understanding of sedimentary and depositional processes in the Chenier Plain of southwest Louisiana (LASMP Region 2).

The model incorporates a source-to-sink approach, which evaluates the entire alluvial system from sediment delivery to redistribution and preservation, most importantly focusing on coarser-grained sedimentary environments suitable for coastal restoration in Louisiana. This approach enables identification of potential/compatible sediment resources and assessment of associated overburden.

The term "predictive" is intentionally used to convey the model's primary function: to support Louisiana's coastal restoration community including planners, project managers, and engineers for targeting potential depocenters of sand and mixed-sediment for future restoration projects.

The predictive geologic model is visualized as a block diagram created using computer drafting software (e.g., Adobe Illustrator). It is informed by spatial data (e.g., resource polygons, geomorphic features), interpretations of geophysical survey lines and sediment cores, and previously published geologic studies. These diagrams serve as generalized conceptual tools that synthesize subsurface interpretations, map-based products, and archival research from the recent investigation of LASMP Region 2A.

The main objective of this model is to communicate geologic and stratigraphic relationships at both regional and local scales, and as such these diagrams are not drawn to scale. Instead, artistic representation is used to depict the relative positions, extents, and stratigraphic relationships of key facies and features in a manner that enhances understanding and visualization. This illustrative approach helps convey to the targeted audience (restoration community of Louisiana) the linkages between surficial geomorphology and underlying sediment bodies such as the extent and thickness of a sand deposit associated with an abandoned channel belt or point bar.

Ultimately, the predictive geologic model is primarily a strategic communication and planning tool that translates complex geologic data into an accessible format to inform and advance sediment resource identification and coastal restoration planning in LASMP Region 2A (the Chenier Plain in southwest Louisiana).

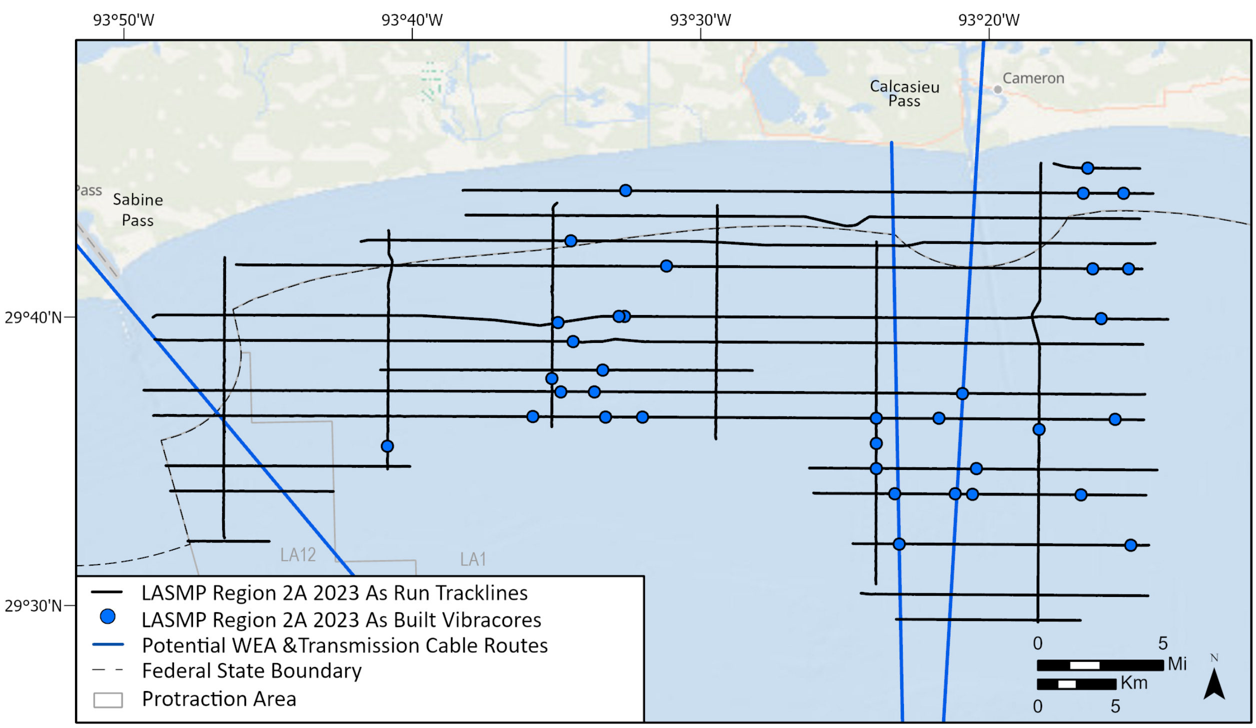

Figure 6. Vibracore sample locations and full-suite geophysics survey tracklines collected as part of this investigation. Potential WEA transmission cable routes from BOEM lease OCS-G37334 (https://www.boem.gov/renewable-energy/state-activities/gulf-mexico-activities).

4 Geophysical and Geological Results and Interpretations

In order to differentiate between landforms commonly grouped or used interchangeably by previous researchers (e.g., Suter and Berryhill, Jr. 1985; Wellner et al. 2004; Anderson et al. 2016), the nomenclature of Heinrich et al. (2020 and references therein) was adopted for this investigation. By differentiating generic "valley" or "channel" features mapped on the shelf, investigators can make more informed predictions of occurrence, preservation, sediment composition and possible sediment resources, as well as develop an accurate predictive geologic model for future resource exploration. The following presentation of terminology and definitions is paraphrased from Heinrich et al. (2020) and summarized in Figure 7.

LASMP Region 2A provides a reconnaissance level investigation of major geologic deposits and potential sediment resources that represent promising areas for future appraisal. The following landforms and associated sedimentary deposits have been commonly observed within offshore Louisiana (e.g. Heinrich et al., 2020), but it is important to note that there can be variability in the grain size and composition of deposits formed by similar processes (e.g., Sylvester et al. 2021). These variations may impact which level of resource classification a specific deposit falls within. Where possible, this report provides additional sedimentary interpretation and initial facies models to help describe the potential variability of a specific deposit where dense geologic sampling is not present.

A **channel**, existing as both subaerial and subaqueous landforms, is a conduit where fluid and sediment flow. The shape of a fluvial channel in cross section often appears as a "U" shape which often serves as the main diagnostic criteria. A **paleochannel** is an abandoned segment of a river that has been either partially or completely filled by younger deposits. For reference, modern fluvial channels range from single to hundreds of meters wide and a few meters in depth. Channel fills generally occur as sinuous ribbons of muddy sediment within a fluvial channel belt. A **channel belt** is a larger fluvial landform that consists of the floodplain area where a fluvial channel has migrated over time. These deposits of sand, silty sand, and gravelly sediment created by lateral migration of a channel interspersed with muds and fine sediment deposited as floodplain material. Channel belt thicknesses and extent can vary due to formational river conditions, length of activity, and other factors that lead to variability in sediment volumes and length of time recorded in preserved stratigraphy. **Incised valleys** are features often produced by falling stages of base level creating incision into existing surfaces. Many valley fill models exist but generally follow a succession of basal fluvial sands with overlying deltaic, estuarine, and marine sediment above. In rare cases coastal tidal deposits can be preserved within valley fills. The relative proportion of each is based on physical factors of sediment supply, valley geometry, sea level change rates, subsidence, and others. **Paleovalleys** are generally thousands of meters wide and several tens of meters deep. During stepped sea level fall and valley incision, channel belts and floodplains can become abandoned at higher elevations and a new floodplain forms deeper due to incision within the broader valley system, resulting in **fluvial terraces.** If lateral channel migration does not erode terrace deposits, they can be preserved as part of the paleovalley fill. **Floodplain** development in meandering streams is often a combination of lateral accretion of sandy point bar and channel deposits followed by vertical accretion of fine-grained sediment during floods. However, some portions of the floodplain are dominated by vertical accretion of fine-grained sediment.

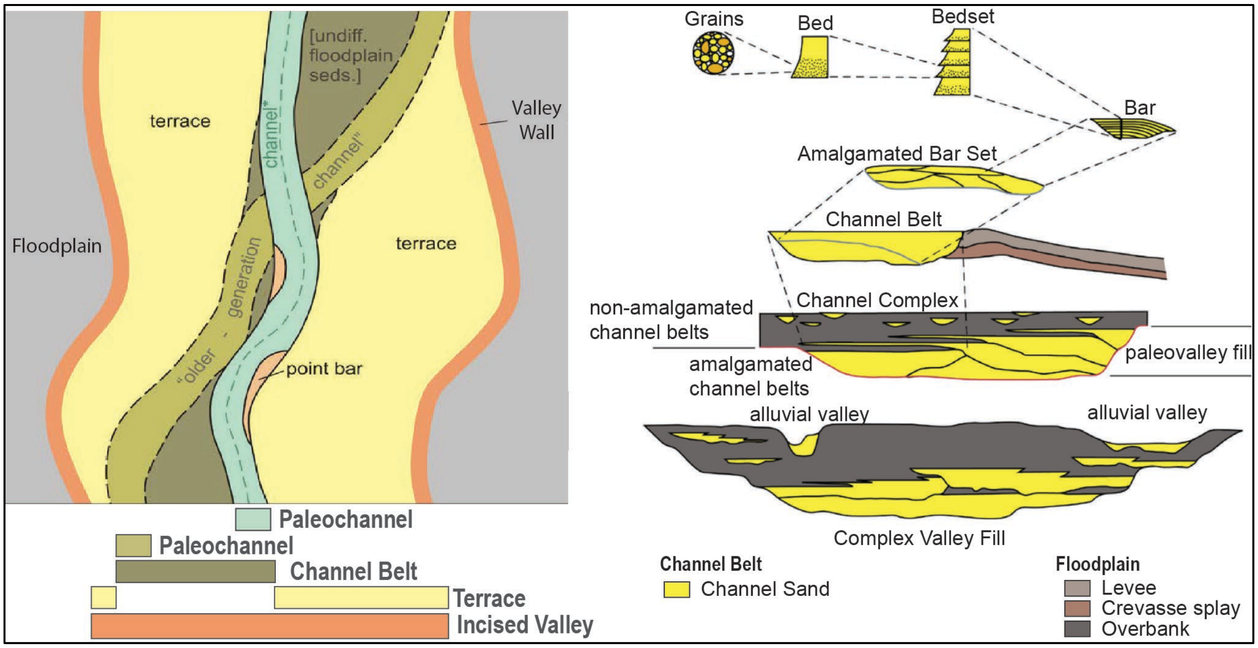

Figure 7. Conceptual landforms of fluvial valleys and associated hierarchy of fluvial deposits (modified from Heinrich et al. 2020).

In terms of sand and mixed-sediment resources, standalone channel belt deposits and those contained within fluvial terraces represent the highest likelihood for concentrated compatible sediment. These are the primary depositional environment targeted in this investigation's sediment resource prospecting strategy due to the previously successful borrow site CS-31 development (e.g., CPE 2002). Due to the type of environment and their response to sea level variations, it is inferred that fluvial environments, once identified, have a high likelihood of extending offshore. However, the amount and type of overburden must be considered to determine if each specific channel belt or terrace feature is a viable resource target.

4.1 Mapping Regional Subsurface Architecture and Key Geologic Features

The development of the predictive geologic model and delivery of an updated sediment resource inventory relies on accurate interpretations of the subsurface through sediment cores and geophysical data. However, the succession of sediments observed in Louisiana's Coastal Plain is not a continuous, complete record of all the sedimentary and sea level processes responsible for its creation. The slowly subsiding shelf consists of vastly different age deposits representative of the avulsed nature of the fluvial systems in the area occurring at similar positions in the subsurface. Without age constraint data, only relative positioning or timing of features can be determined. Entire stratigraphic intervals could be missing from the subsurface record depending on the degree of erosion or preservation. 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. Additionally, the following sections provide detailed observations of the distribution and characteristics of various deposits and interpretations on their depositional history, and sediment resource potential. Together the mapping and discrete characterization of these subsurface architectural elements provides the necessary scientific basis for assessing sediment resources and aiding in holistic system management. This investigation details the seaward expansion of the Peveto Channel Belt and channel belts contained within two fluvial terrace deposits as potential sediment resources (Figure 8). The Calcasieu and Sabine Incised Valleys identified by previous researchers (LeBlanc 1949; Suter and Berryhill 1985; Nichol et al. 1996; Milliken et al. 2008) are also mapped in detail. These incised valleys are significant to the geologic framework understanding, but do not represent viable sand and mixed-sediment resources due to the excessive amount of non-viable overburden overlying basal coarse-grained sediment.

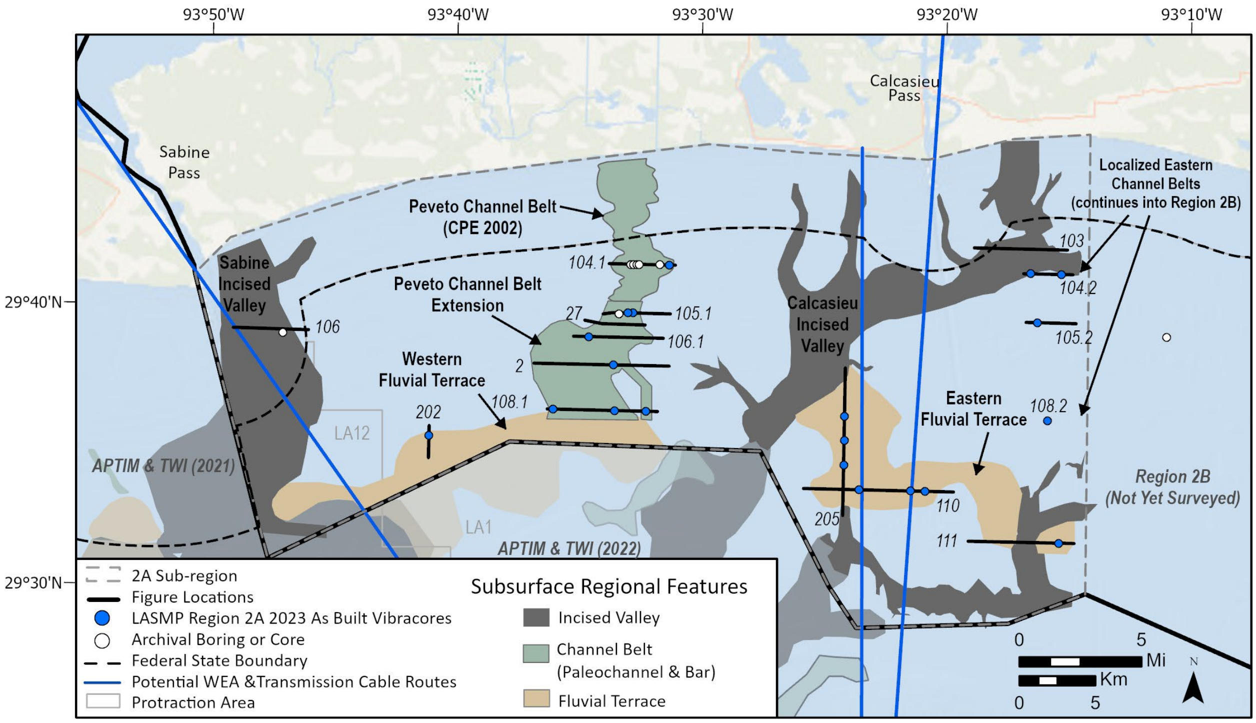

Figure 8. Mapped subsurface features within LASMP Region 2A. Sub-bottom profile figure locations are displayed in black with a trackline identifier, with selected newly collected and archival sediment cores or borings. Note sub-bottom profile locations contain archival and new geophysical data. Subsurface features identified are overlain with potential WEA transmission cable route for multi-use conflicts context. Interpretations from Texas state and outer continental shelf (OCS) investigations shown for reference (APTIM and The Water Institute 2021; APTIM and The Water Institute 2022). Potential WEA transmission cable routes from BOEM lease OCS-G37334 (https://www.boem.gov/renewable-energy/state-activities/gulf-america-activities).

4.1.1 Transgressive Ravinement Surface

The transgressive ravinement surface is mapped across Region 2A with the recently collected high-resolution chirp sub-bottom data (Figure 9). This surface is characterized by the truncation of underlying reflectors, separating variable packages below and laminated reflector packages above, where present. This surface coincides with the modern seafloor in some areas. Vibracore data exhibit a distinct contact between underlying oxidized sand or stiff fine-grained sediment and shelly muds above. This surface is interpreted as the resulting surface produced by marine and coastal processes reworking the subaerially exposed Pleistocene coastal plain deposits as sea levels rose, beginning ~22,000 years ago. Other studies have inferred a Pleistocene age for deposits outside the incised valleys and below the most recent transgressive ravinement (Fisk 1948b; Fisk 1948a; LeBlanc 1949; Suter and Berryhill 1985; Wellner et al. 2004; Milliken et al. 2008; Anderson et al. 2016; Heinrich et al. 2020). Marine sediment above the transgressive ravinement surface thickens landward and is greatest near the active tidal inlets, Sabine Pass and Calcasieu Pass. In areas of the inner shelf the Pleistocene surface is exposed at the seafloor and appears to be actively eroding. This has important implications for sediment resource development when characterizing the type of overburden overlying identified resources. Available core data verifies the fine-grained sediment existing between the top of an identified resource as stiff, indurated clay and silt that may require appropriate dredging strategies. This differs from LASMP Region 1 findings (CPRA and The Water Institute 2024) where any overburden was related to soft, Holocene deltaic-to-marine sediment.

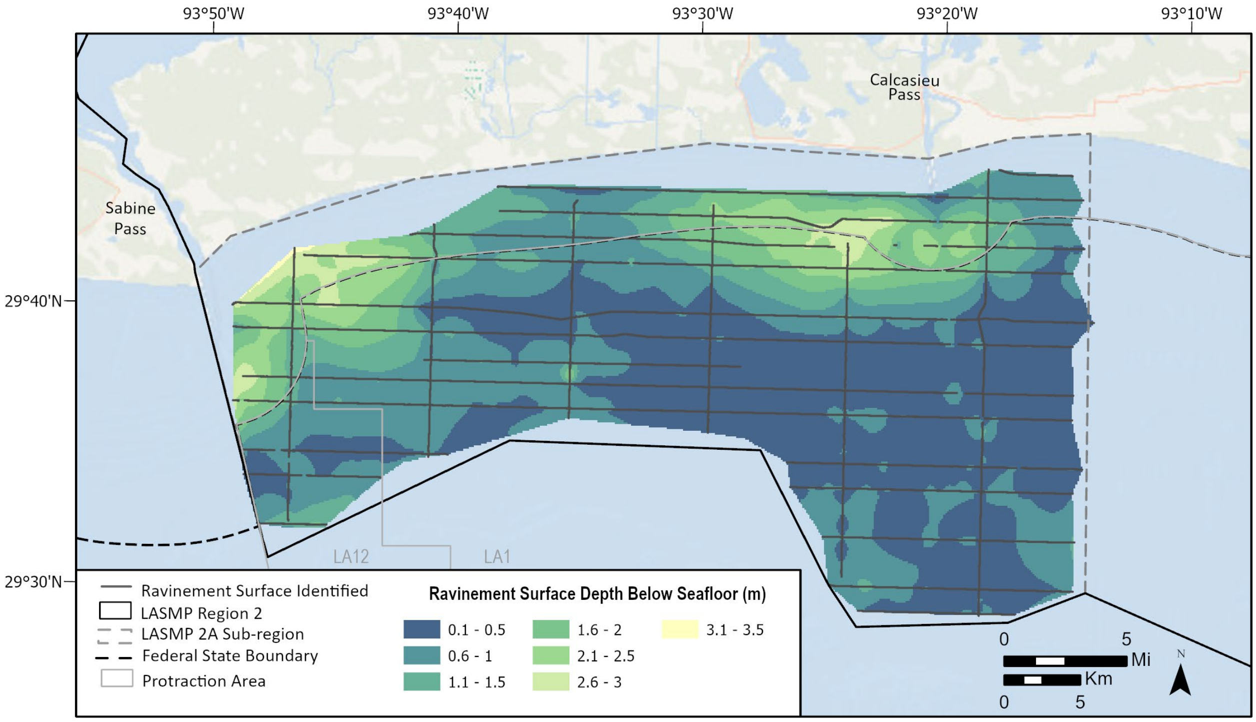

Figure 9. Depth below seafloor to the transgressive ravinement surface in LASMP Region 2A.

4.1.2 Calcasieu and Sabine Incised Valley Systems

The Calcasieu Incised Valley extends from east of Calcasieu Pass to the southwest where it joins the Trinity-Sabine Incised Valley System seaward of the investigation area. The valley is roughly 1.6–4.0 km (1.0–2.5 mi) across. The base of the valley is not constrained by chirp sub-bottom data in this investigation. Previous researchers note the valley incises to depths of 60 m (200 ft), consisting of fluvial braided and meandering sand deposits overlain by estuarine, bayhead delta, and marine fill (LeBlanc 1949; Nichol et al. 1996; Milliken et al. 2008). This fill succession is consistent with the underfilled valleys of Simms et al. (2006), where sediment supplied by the fluvial source could not fill the accommodation of the valley, leading to estuarine to marine deposition as the valleys were flooded during sea level rise.

In this investigation, the incised valley edges are delineated by a truncation of existing reflectors with valley fill facies consisting of laminated to draping, to gently dipping, reflectors (Figure 10). Minor cut and fill channels were observed, with more laminated reflector fill. The bottom of the valley was not observed and consistently displayed gas blanking, only imaging the upper portion of the valley fill. Sediment cores confirmed the fine-grained nature of the interpreted estuarine to marine fill. The upper portion of the Calcasieu Incised Valley fill is dominantly fine grained, with fluvial sand likely concentrated to the base of the valley. The clays and silty fill are much softer than the surrounding stiff, oxidized, indurated sediment; characteristic of Holocene valley fill compared to Pleistocene Prairie deposits noted by previous research (LeBlanc 1949; Nichol et al. 1996; Milliken et al. 2008).

A series of extensive incisional channel systems, smaller than the paleovalleys, are found throughout LASMP Region 2A investigation area. These incisional channels vary in complexity, size, and fill architecture and generally characterized by "V" shaped incisions, with transparent to faintly laminated fill, in which some of the more complex systems show basal chaotic to faintly dipping reflectors. The smaller systems demonstrate good acoustic imaging of laminated reflectors that characterize the underlying deposit incised by the channel (Figure 10). These incisional channels appear to coalesce into the main incised valley trunks and are interpreted as dendritic floodplain drainage channels with very rare indication of lateral migration characterized by clinoform sets indicating minimal sand content. Where sampled, the incisional channel fill consists of fine-grained sediment, with upper strong reflectors correlating to organic-rich sediments. The strong upper reflector overlying transparent channel fill sometimes indicates sand in other settings. Whether or not the chirp sub-bottom shows good acoustic imaging below transparent packages offers important insight to the deposit's composition. The signal from the chirp sub-bottom does not penetrate thick sand-rich deposits; this can be seen in the Peveto Channel Belt section where the signal produced a transparent or obscured seismic record below the sandy channel fill. Here, the laminated seismic facies of the underlying deposits is clear, indicating the absence of overlying coarser grained deposits that would attenuate the seismic signal.

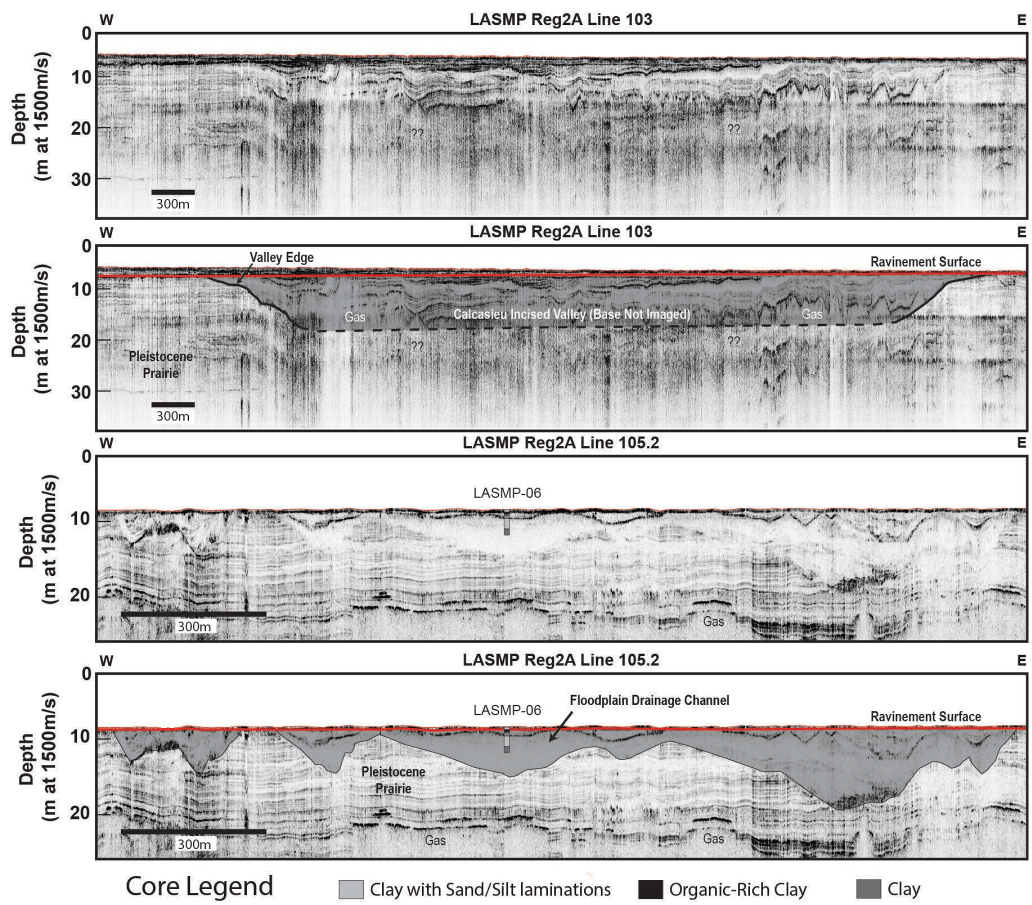

Figure 10. Sub-bottom profiles of the Calcasieu Incised Valley (upper panel) and mud filled (lower panel) drainage channels incising into likely Pleistocene Prairie deposits, capped by the transgressive ravinement surface shown in red. Note the valley base is not imaged in chirp sub-bottom represented by a dashed black line (upper panel). See Figure 8 for location.

Similar to the Calcasieu Incised Valley, the Sabine Incised Valley demonstrates the typical underfilled valley succession of Simms et al. (2006). The Sabine Incised Valley extends from the Sabine Pass area, where it joins Calcasieu and Trinity valley systems offshore of the investigation area. The Sabine Valley is roughly 6.4–9.6 km (4–6 mi) across and incises to depths of roughly 36 m (120 ft) below sea floor (bsfl). This is based on previous research (Milliken et al. 2008) since the valley base is not imaged in the chirp sub-bottom. Oil and gas platform foundation geotechnical boring, West Cameron 49 (Coleman et al. 1987), verifies laminated valley fill as fine-grained sediment, overlying sand at a depth of ~18 m (60 ft) below seafloor (Figure 11). Again, this is interpreted as the valley fill succession of basal fluvial sand with thick estuarine to marine fine-grained sediments.

Both paleovalleys contain thick overburden on the basal fluvial sand, making them non-viable sediment resources targets. Localized features may exist with higher sand content such as bayhead deltas that may classify as mixed-sediment resources instead of fine-grained sediment, but due to their limited spatial extent and current data coverage, were not identified in this investigation.

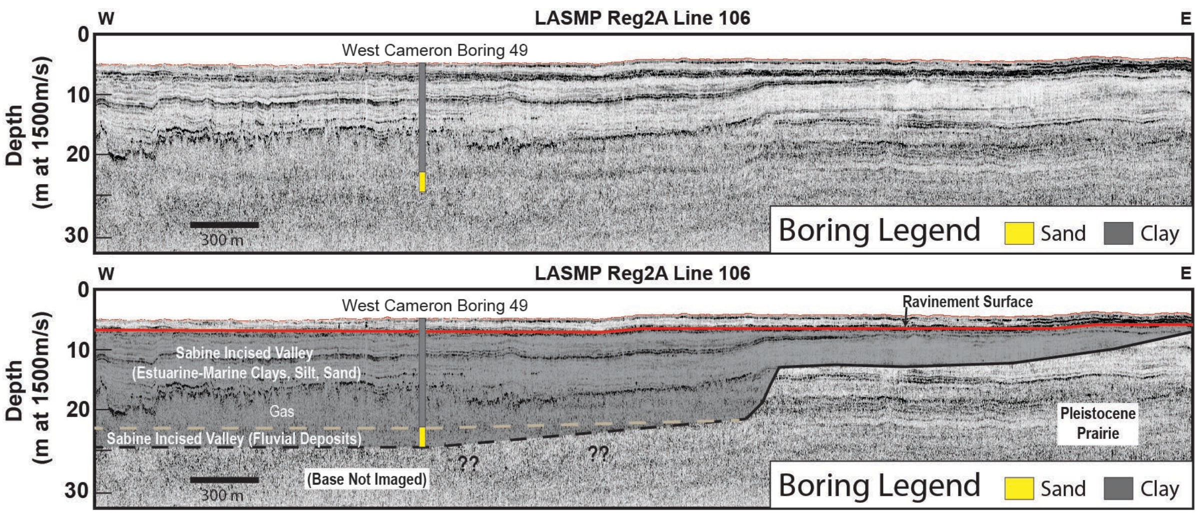

Figure 11. Sub-bottom profile of the Sabine Incised Valley and surrounding Pleistocene Prairie deposits, capped by the transgressive ravinement surface. Oil and gas platform foundation geotechnical boring 49 shows clay and silt overlying sand at roughly 20 m (65 ft) (bsfl); interpreted as fluvial sands with overlying estuarine to marine valley fill. Note the valley base is not imaged in chirp sub-bottom and is marked by a dashed black line, while the top of fluvial sand deposits are marked with a dashed tan line. See Figure 8 for location.

4.1.3 Peveto Channel Belt

Based on the recently collected geophysical and geological data, the Peveto Channel Belt was traced offshore an additional 5 miles from the extent identified by previous work (Suter et al. 1985; Ramsey and Penland 1992). This deposit contains a borrow pit which was dredged for the Holly Beach Restoration Project (CPE 2002). The channel belt extends south from Peveto Beach, which is roughly 16 km (10 mi) long by 4 km (2.5) mi wide, that truncates and incises existing laminated reflectors (Figure 12). The channel belts in seismic profile are characterized by transparent to faintly dipping reflector packages that grade into a “U” shaped channel form, which either contains transparent or faintly laminated reflector packages. In some instances, the dipping reflector sets transition vertically into more laminated reflector packages. In both cases, the channel belt reflectors are truncated at the top by a ravinement surface. The ravinement surface is either located directly at the seafloor or has a thin package of laminated reflectors above, interpreted as recent marine clay and silt. The complexity of the multi-generational stacked channel network increases in an offshore direction. Older, larger, first generational channels are crosscut by at least one more generation of younger, smaller channels in the Peveto Channel Belt Extension area creating inconsistent preservation, geometries, and amount of overburden of potential sand-rich channel belt deposits along the entire system. The deepest resolvable channel belt base is 18 m (60 ft) bsfl and is only resolved in archival boomer sub-bottom data.

Sediment cores verify a thin veneer of shelly marine clay overlying stiff, oxidized sand, and mud. The lower interval is interpreted as floodplain deposits subaerially exposed during times of lower sea level that underwent transgressive ravinement during sea level rise and subsequent modern marine deposition. Channel fill and floodplain fine-grained deposits are differentiated based on the degree of mottling or oxidation and are correlated to respective sub-bottom facies. Channel belt deposit units range from tan to reddish brown with variable fines content, interbedding, and display an overall fining upward sequence.

Channel belt deposits are ribbon-like deposits that are not spatially continuous and are punctuated by fine-grained abandoned channel fill. Similar to previous work, their thicknesses are inferred here from the base of the channel thalweg depth where acoustic imaging is better (Suter et al. 1985; CPE 2002). This offers a first order estimate of sand thickness where only chirp sub-bottom data are available or archival boomer sub-bottom data quality does not allow for interpretation. In future investigations it is recommended that both chirp and boomer be used so as to fully constrain the resource geometries of these thick sand deposits. Using both types of profilers, the internal reflector architecture and inferred sediment characteristics can be determined with chirp and the delineation of basal reflectors in thick sandy channel belt deposits from boomer seismic would greatly improve sediment resource characterization and identification (e.g., Sullivan and Miner 2019).

The larger channel belt is interpreted to contain local areas of both sand and mixed-sediment resources based on seismic facies and coring. Based on previously developed channel belt resources (borrow area CS-31) and analogous deposits, the size and specific geotechnical properties of individual resource deposits require dense appraisal surveying within the boundaries of the channel belt. The reconnaissance survey conducted during this study maps the channel belt for an additional five miles offshore, and chirp imaging combined with sediment coring identifies the presence of numerous pockets of sand within the larger channel belt (Figure 12). The previously constructed Peveto Channel Borrow Area (CS-31) targeted a sandy sub-deposit analogous to those identified within the channel belt extension. Similar to the appraisal approach successfully employed for CS-31 in CPE 2002, a closely spaced sub-bottom profiler survey centered on the interpreted sand deposits would help define specific sub-areas for borrow area construction within the complex geology of the channel belt, specifically Region 2A Line 106 and Line 2 (Figures 8, 12).

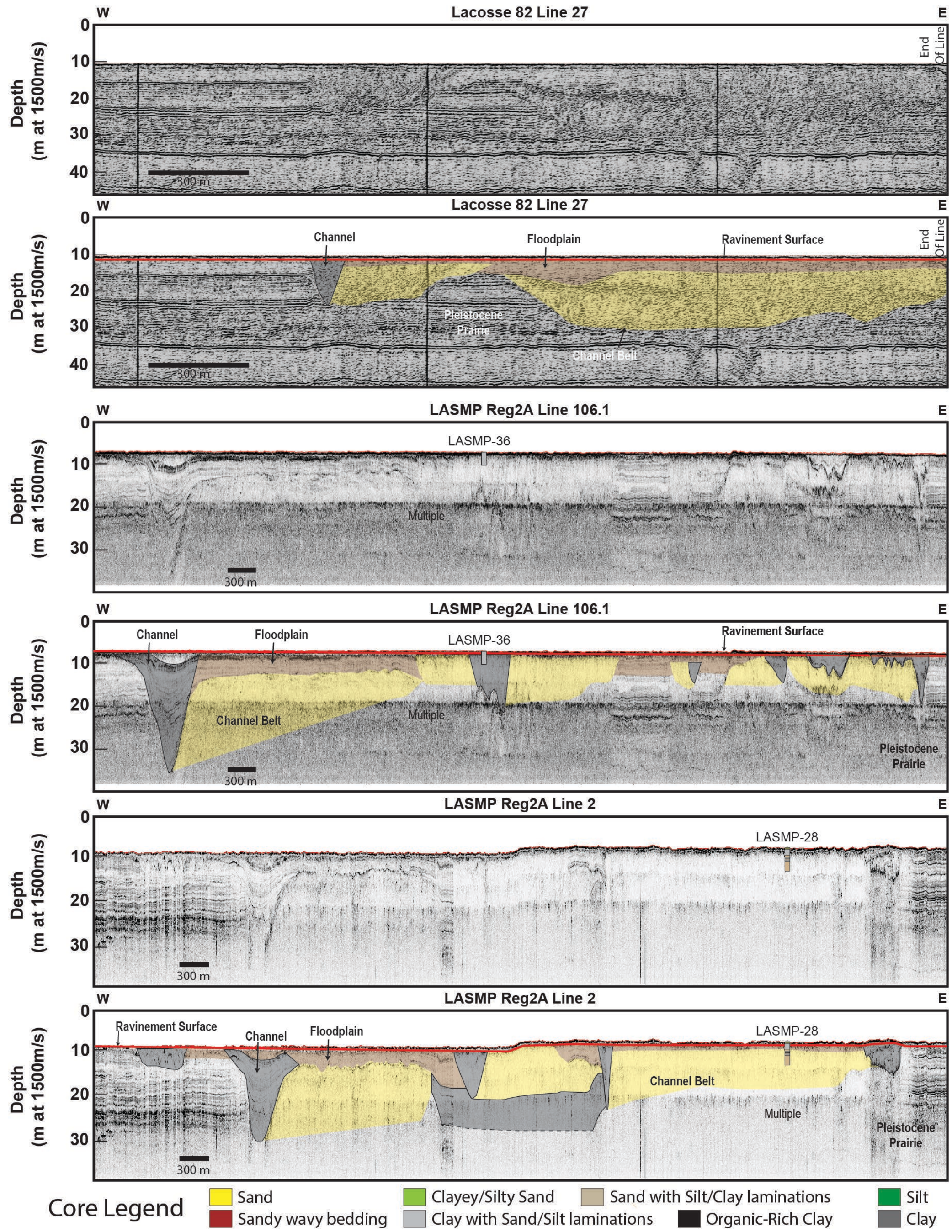

Figure 12. Sub-bottom profiles examples of the Peveto Channel Belt. Profiles progress from north to south across the channel belt and illustrate the complexity of the fluvial channel belt. Higher and lower frequency sub-bottom profiler data details internal reflector architecture and delineation of basal reflectors in thick sandy channel belt deposits that could not be accomplished without using both data sets. Note the archival Lacoss 82 line was collected using Loran-C so its positional accuracy has greater uncertainty compared to modern survey methods. The channel belt deposits are highlighted in yellow, channels or floodplain drainages in dark grey, floodplain in brown, and the ravinement surface is in red. Note some bases of channels or channel belts are inferred. See Figure 8 for location.

4.1.4 Fluvial Terraces

Fluvial terraces were identified in the LASMP Region 2A investigation area and linked to deposits mapped in areas investigated in Upper Texas State Waters and Sabine Bank (APTIM and The Water Institute 2021, 2022). The western fluvial terrace is perched above the Calcasieu-Sabine Incised Valley system and is generally oriented northeast to southwest. Within the LASMP Region 2A study area, the western fluvial terrace is roughly 20 km × 3.5 km (12 mi × 2 mi) and the larger interpreted deposit from a previous study of the eastern Texas shelf (APTIM and The Water Institute, 2021) is roughly 20 km × 6 km (12 mi × 4 mi). The largest and deepest fluvial terrace is roughly 365 m (1,200 ft) across and 22 m (72 ft) thick. In sub-bottom data, the terrace is characterized by three seismic facies. The first resembles a "U"-shaped channel form that truncates underlying reflectors and has faintly draping, laminated fill (Figure 13). The second seismic facies is characterized by transparent to faintly dipping reflectors grading into the first channel form seismic facies. Lastly, the third seismic facies is characterized by a transparent to laminated reflector package that grades into the dipping reflector facies or is separated by a hummocky reflector. These three sub-bottom facies are interpreted as paleochannel, fluvial or channel belt deposits, and floodplain deposits, respectively, making up the larger fluvial terrace feature. All of these seismic facies are truncated by an overlying transgressive ravinement surface and thin modern shelf deposits.

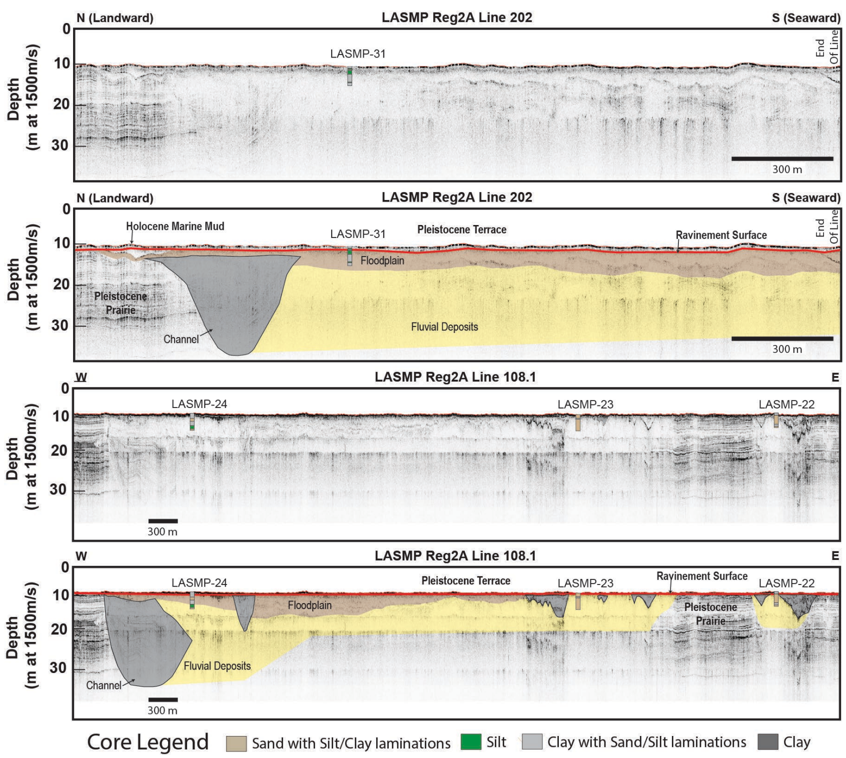

Figure 13. Sub-bottom profiles examples of the western potential terrace feature. Fluvial terraces form from reoccupation of fluvial courses and incisional processes. The western fluvial terrace correlates outside the study area and is linked to an extension of the Calcasieu-Sabine Incised Valley (APTIM and The Water Institute 2021; APTIM and The Water Institute 2022). They are composed of similar fluvial channel belts and floodplain deposits of varying preservation and geometries. Only partial sampling of the upper portions of the terraces was achieved through vibracoring efforts. The greatest sand potential is likely near the base of the fluvial deposit, some up to 22 m (72 ft) below seafloor. The fluvial deposits are highlighted in yellow, channels or floodplain drainages in dark grey, floodplain in brown, and the ravinement surface is in red. Note the base of fluvial deposits are inferred based on channel thalweg depth. See Figure 8 for location.

Similar to the previously mentioned western fluvial terrace, the eastern fluvial terrace is characterized by the same paleochannel, fluvial or channel belt deposits, and fine-grained floodplain deposits. The eastern terrace correlates outside the study area and is linked to an extension of the Calcasieu Incised Valley (APTIM and The Water Institute 2022). It trends to the southeast and is roughly 19 km (12 mi) along its axis and 3.2 km (2 mi) wide. Three vibracores sampled clean yellowish-brown sand and silty sand (Figure 14). Inferred sand thickness could be up to 20 m (85 ft) based on channel thalweg depths (similar to CPE 2002). Floodplain deposits appear to be more expansive but thinner, which could increase accessibility efficiency for sediment resource considerations. Accessing any potential sediment resources contained within the eastern fluvial terrace would be impacted by the proposed wind energy area transmission cable routes coming on land near Calcasieu Pass.

According to earlier studies (Heinrich et al. 2020), the terraces contain channel belts, channel forms, and floodplain deposits. The channel forms and vertical accretion floodplain deposits are characterized by oxidized and mottled fine-grained units. Where the channel belt fluvial sand are sampled within the terrace deposit, they consist of heavily oxidized, laminated to massive sand and silty sand, and generally exhibit a fining upwards sequence. These terraces, like most of the coastal plain stratigraphy, represent multiple generations of fluvial channelization with the possibility that deposits at similar stratigraphic positions may be of vastly different ages. The deposit is estimated to be of Pleistocene or older age based on its oxidation and stiff geotechnical properties; characteristics interpreted as oxidation and induration experienced due to subaerial exposure during a time of lower sea level.

Determining sediment composition at depth within the fluvial terraces proved difficult since sediment cores only sampled the upper portions of the unit and the generally transparent nature of the internal architecture in sub-bottom. The lower half (below ~10 m or ~35 ft) of the terrace are hypothesized to contain thick, sandy fluvial deposits based on landward, updip, equivalents of the Deweyville terrace deposits sampled in eastern Texas and western Louisiana (Heinrich et al. 2020; and references therein). One possible consideration that could be tested is the effect of thick, stiff, Pleistocene floodplain sediment on efficiency in accessing fluvial or channel belt deposits within these deposits during dredge operations. This terrace is up to 22 m (72 ft) thick and is sand-rich sediment making it a potential sediment resource, as noted by other investigators (Heinrich et al. 2020). Resource characterization would benefit from deeper geologic sampling and combination of chirp and boomer surveys.

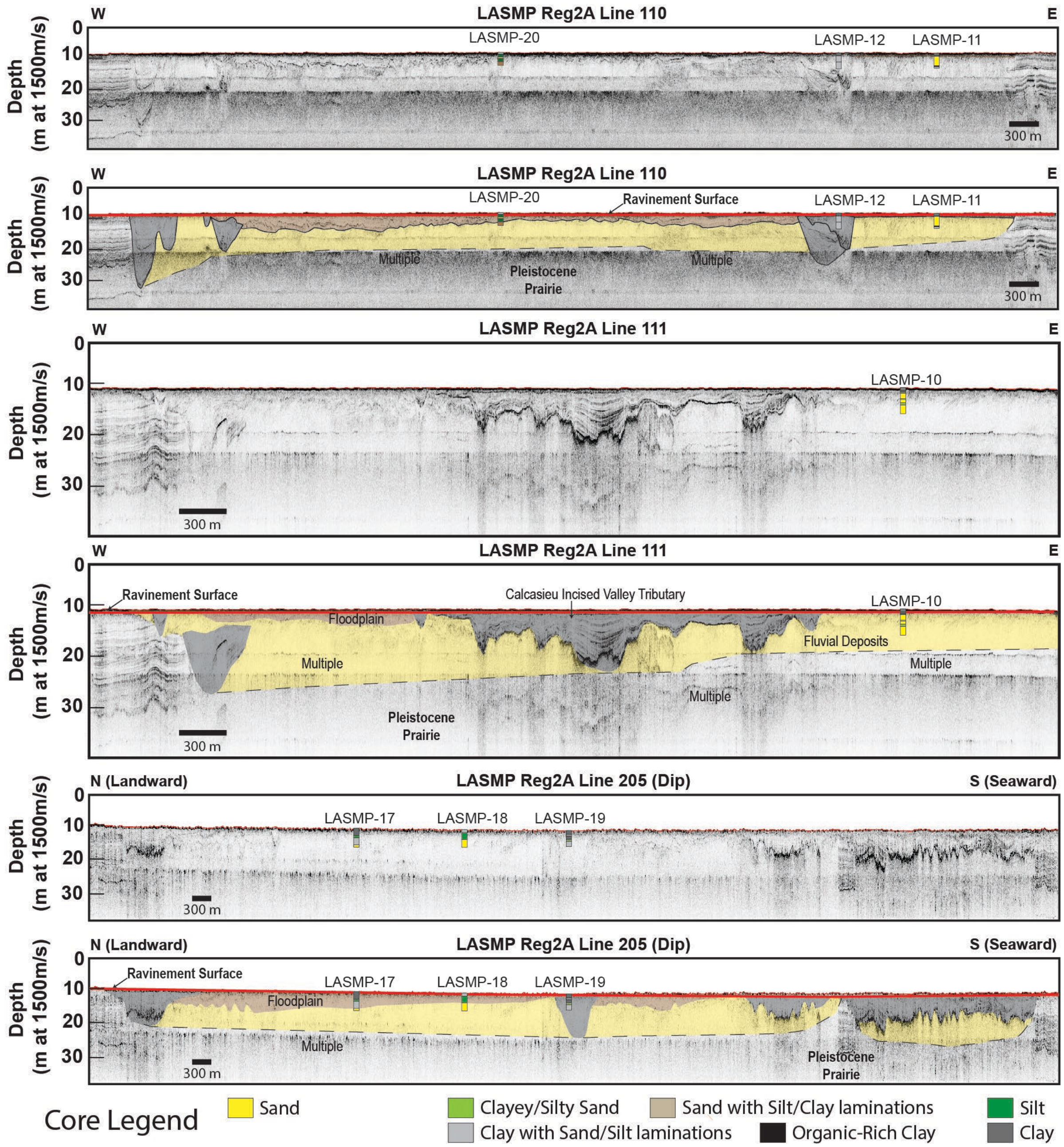

Figure 14. Sub-bottom profile examples of the eastern potential terrace feature. Fluvial terraces form from reoccupation of fluvial courses and incisional processes. The eastern terrace correlates outside the study area and is linked to an extension of the Calcasieu Incised Valley (APTIM and The Water Institute 2022). They are composed of similar fluvial channel belts and floodplain deposits of varying preservation and geometries. Only partial sampling of the upper portions of the terraces was achieved through vibracoring efforts and the greatest sand potential is likely near the base of the fluvial deposit, some up to 20 m (65 ft) bsfl. The fluvial deposits are highlighted in yellow, channels or floodplain drainages in dark grey, floodplain in brown, and the ravinement surface is in red. Note the base of fluvial deposits are inferred based on channel thalweg depth. See Figure 8 for location.

4.1.5 Localized Channel Belts along Region 2A Boundary

Two channel belts are identified at the eastern boundary of the Region 2A investigation area about 8.9 km (5.5 mi) and 18.5 km (11.5 mi) offshore, respectively. These features could not be correlated north or south with the existing data coverage, so estimating its spatial extent is not possible at this time. Along Line 104, the channel belt is characterized by transparent to faintly dipping reflectors that grade into "U" shaped channel forms that truncate underlying laminated reflectors, similar to those found in the Peveto Channel Belt (Figure 15). The two areas are roughly 610 m–1,220 m (2,000 ft–4,000 ft) across and 6 m (20 ft) thick. This feature is truncated by a ravinement surface and has little to no overburden. Chirp sub-bottom signal is lost below the transparent facies, which is verified as 5 m (17 ft) thick, olive-grey to yellowish-brown fine sand that is exposed at the seafloor. The offshore channel belt identified shows similar seismic facies (Figure 16) and extends into Region 2B based on geohazards survey derivative map products. The offshore channel belt thickness is 9 m (30 ft) estimated from channel thalweg depths, containing intervals of sand with fine-grained intervals. The acoustic penetration is much better beneath the interpreted offshore channel belt deposit indicating it could have higher contents of fines compared to the isolated channel belt found in the nearshore (Figure 15; Figure 16). The application of this interpretation is that the nearshore fluvial system contains higher sand content compared to the offshore feature to aid in delineating sand and mixed-sediment resources.

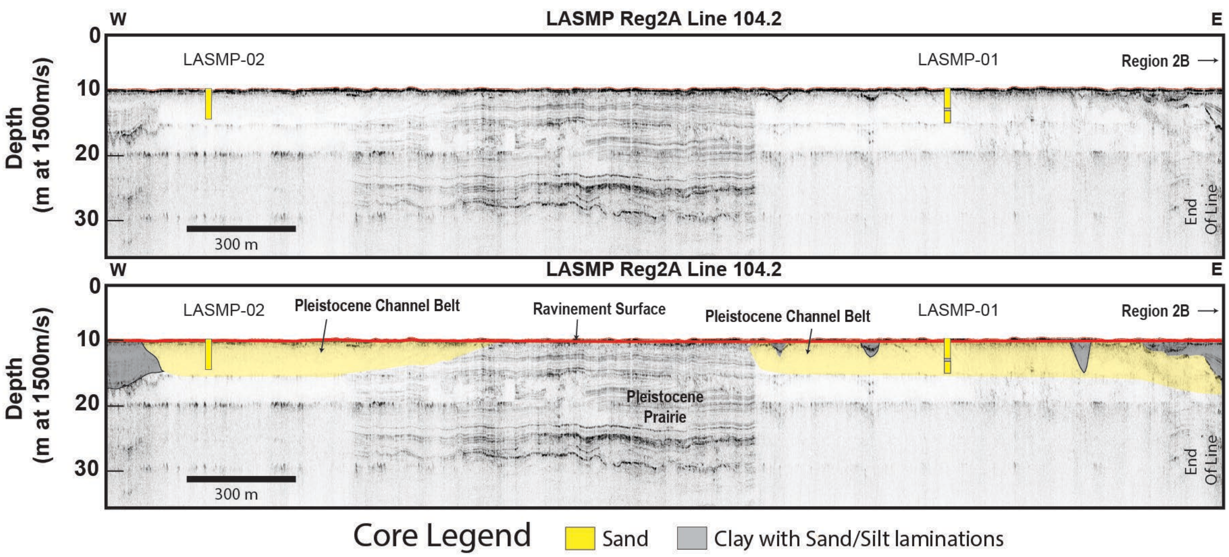

Figure 15. Sub-bottom profile example of a channel belt feature on the Region 2A boundary. The fluvial channel belt deposit are highlighted in yellow, channels, incised valley, or floodplain drainages in dark grey, and the ravinement surface is in red. Note the base of fluvial deposit are inferred based on channel depth and the loss of acoustic imaging below the channel belt package correlating to high sand content. This feature likely continues into LASMP Region 2B. See Figure 8 for location.

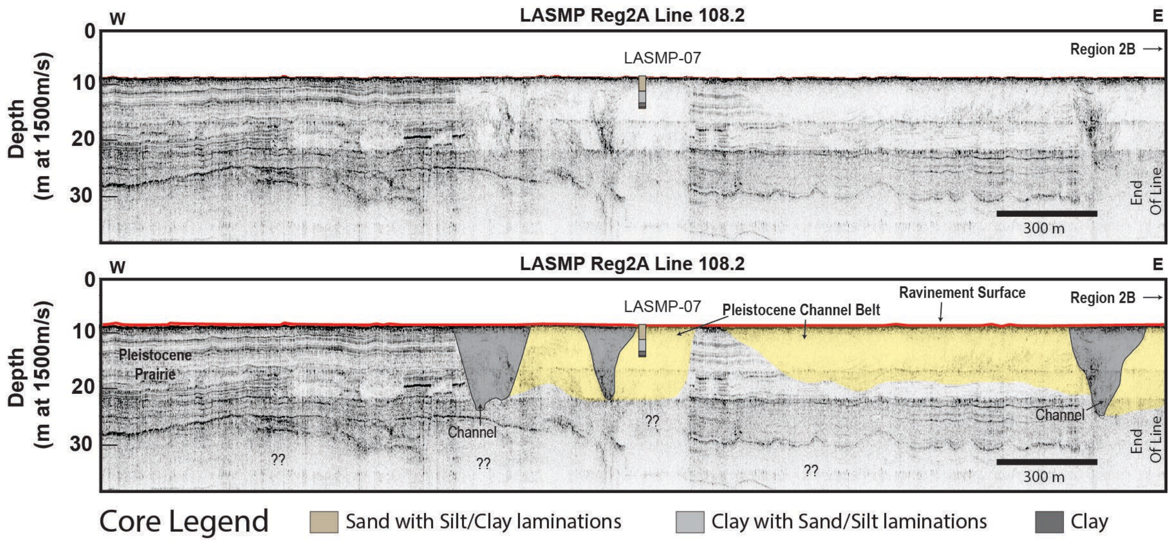

Figure 16. Sub-bottom profile example of an additional channel belt feature on the Region 2A boundary further offshore. The fluvial channel belt deposits are highlighted in yellow, channels, incised valley, or floodplain drainages in dark grey, and the ravinement surface is in red. Note continued acoustic imaging below the channel belt package, inferring lower sand content. This feature likely continues into LASMP Region 2B and could be a potential mixed-sediment resource. See Figure 8 for location.

These features continue east into Region 2B and were confirmed through archival geophysical data and derivative map products, which is explained in further detail in the following section. Only general locations of similar channel belt features can be determined from the lower spatial accuracy and variable data quality of the archival geophysical data in Region 2B. But if recently collected high resolution geophysical and geological data were available to verify the eastern channel belt's composition and extent, it may represent a promising sand resource considering the combination of clean fine sand, little to no overburden, and a relatively short distance to the coast and therefore future restoration projects.

5 LASMP Region 2A Predictive Geologic Model

As part of the holistic approach to sediment resource investigation, a data-driven predictive geologic model was developed on a regional spatial scale as a part of this study (Figure 17). This simplified three-dimensional representation of the surface/subsurface of the western Louisiana shelf was initially developed from archival geophysical and geological data, derivative map products from lease block hazard surveys, and data collected during the current investigation. The source-to-sink (S2S) approach considers the entire alluvial 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 channel belt point bar). Highlighting the preserved sand-rich environments of the broader geologic system can guide more localized and detailed investigations toward borrow area 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 approach comes from linking geologic and sedimentological processes to the needs of planners, engineers, ecosystem specialists, and broader stakeholders, and transforming complex technical concepts into clear, practical outcomes.

The western Louisiana shelf (LASMP Region 2) is composed of promising sediment resource targets related to several generations of alluvial depositional episodes that were periodically reworked as sea-levels fluctuated throughout the last 120,000 years. Without absolute age constraints, only relative timing of geological features can be assessed and placed in geologic frameworks from previous studies (Heinrich et al. 2020 and references therein). The main sediment resource target in this investigation is the fluvial meandering channel belt networks, likely Pleistocene in age. The previously identified Peveto Channel System (CPE 2002) is expanded offshore. These channel belt systems are cross-cut and truncated by the relatively younger Sabine and Calcasieu Incised Valleys. The valleys formed through fluvial incision of the shelf during the most recent lowstand roughly 20,000 years ago, and were later filled as sea levels rose during the transgression from roughly 20,000 years ago to modern day. The Sabine and Calcasieu Incised Valleys are filled by a sequence of basal fluvial sand overlain by deltaic and estuarine to marine fine-grained sediment according to previous studies (LeBlanc 1949; Nichol et al. 1996; Milliken et al. 2008). Only the upper fine-grained sediment fill package was imaged in the data collected during this investigation. Several discrete incisional networks are located across the shelf that could not be mapped in detail but are interpreted as drainage channels incising into a subaerially exposed floodplain similar to Speed et al. (2023). All features are truncated by the transgressive ravinement surface which is a result of coastal and marine processes reworking on the seafloor during sea-level rise. Fine-grained sediment underlying the transgressive ravinement surface, excluding the incised valleys, are stiff to very stiff, oxidized and of Pleistocene-age based on the available coring data. The stiffness of Pleistocene clay and silt overburden should be given special consideration when future investigators develop the sediment resources identified here. Previous successful borrow areas, such as CS-31 avoided areas of thicker Pleistocene overburden and employed specific dredge techniques (CPE 2002).

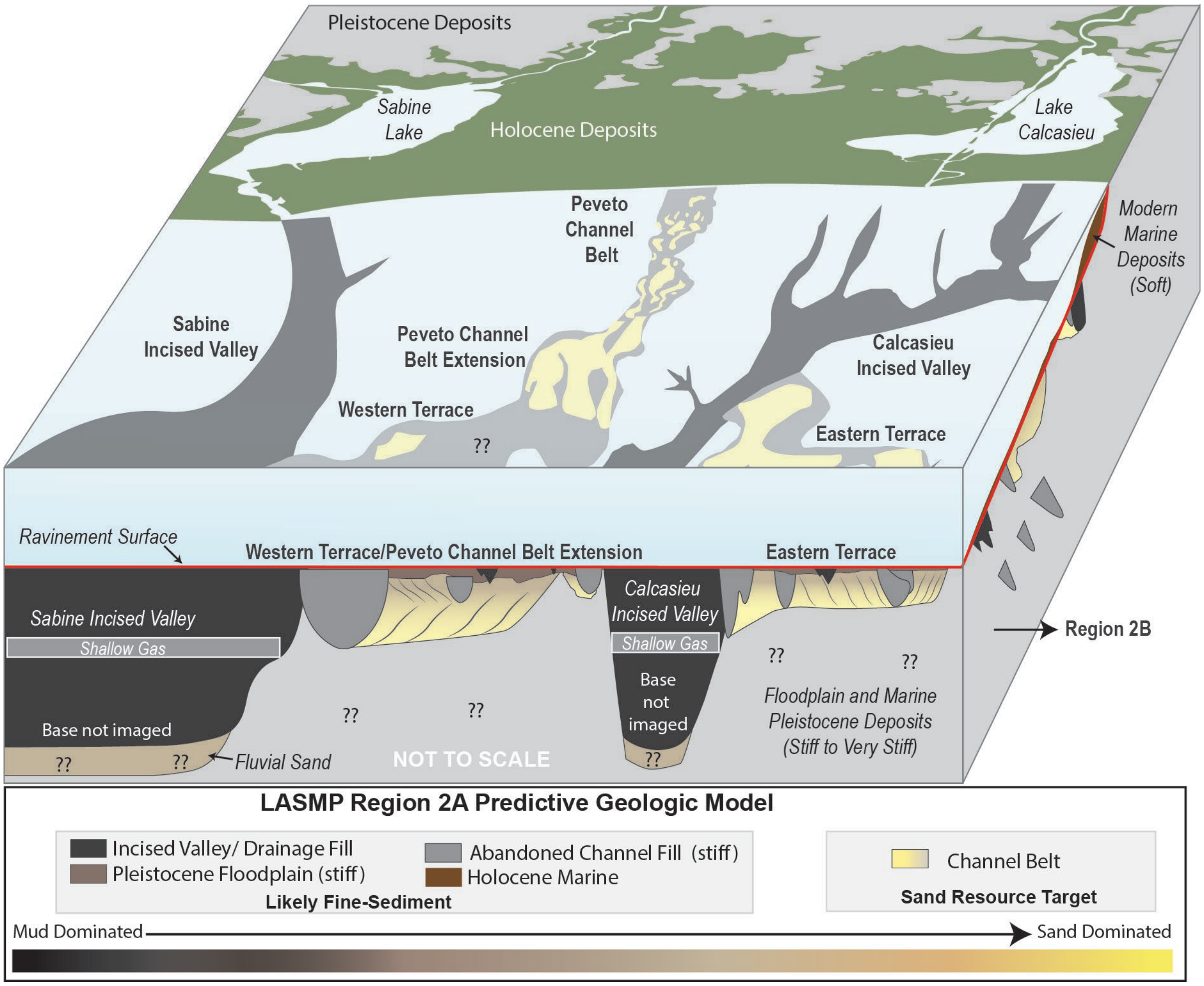

Figure 17. Three-dimensional predictive geologic model of the western Louisiana shelf, LASMP Region 2A, highlighting the distribution and relationships of sediment resources and non-viable fine-grained sediment. The Pleistocene meandering fluvial channel belts concentrate sand-rich sediment in fluvial bar and laterally accreting point bar deposits. The associated fluvial channel is filled with laminated to massive stiff clays as the channel was abandoned. In some cases, floodplains silt and clay overlie fluvial bars contained within the larger channel belt. The highly variable composition of the fluvial bars, both vertically and horizontally, contain both sand and mixed-sediment resources (CPRA 2024) but are interpreted as generally sand dominated. The Sabine and Calcasieu Incised Valleys and their associate tributaries contain Holocene to Pleistocene marine, estuarine, and deltaic fine-grained sediment in the upper subsurface within the study area.

6 Informing Future Investigations and Region 2B Development Plan

Maps, strategies, and recommendations related to the likely occurrence and distribution of sediment resources within each region enable 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. This study identifies and maps several sediment resources areas: the Peveto channel belt extension, the western fluvial terrace, and the eastern fluvial terrace (Figure 18). These resource areas represent the most promising sediment resources at a regional scale. Additional potential resources are likely present in the area, such as the channel deposits located in the east and continuing into Region 2B, but are likely smaller in volume than those presented here.

Indicated and inferred sediment resources related to fluvial channel belts containing localized areas of sand and mixed-sediment resources are identified in Region 2A. The inferred sand resources are those that had sediment cores confirm the presence of sand and acoustic imaging of likely sand-bearing deposits, but are contained within larger units with significant geologic heterogeneity due to their fluvial origin. Semi-verified inferred sediment resources related to smaller localized fluvial features are identified at the eastern boundary of Region 2A. A summary of mapped sediment resource areas for further investigation can be found in Figure 18. Both areas should be further evaluated to assess their viability as restoration borrow sources.

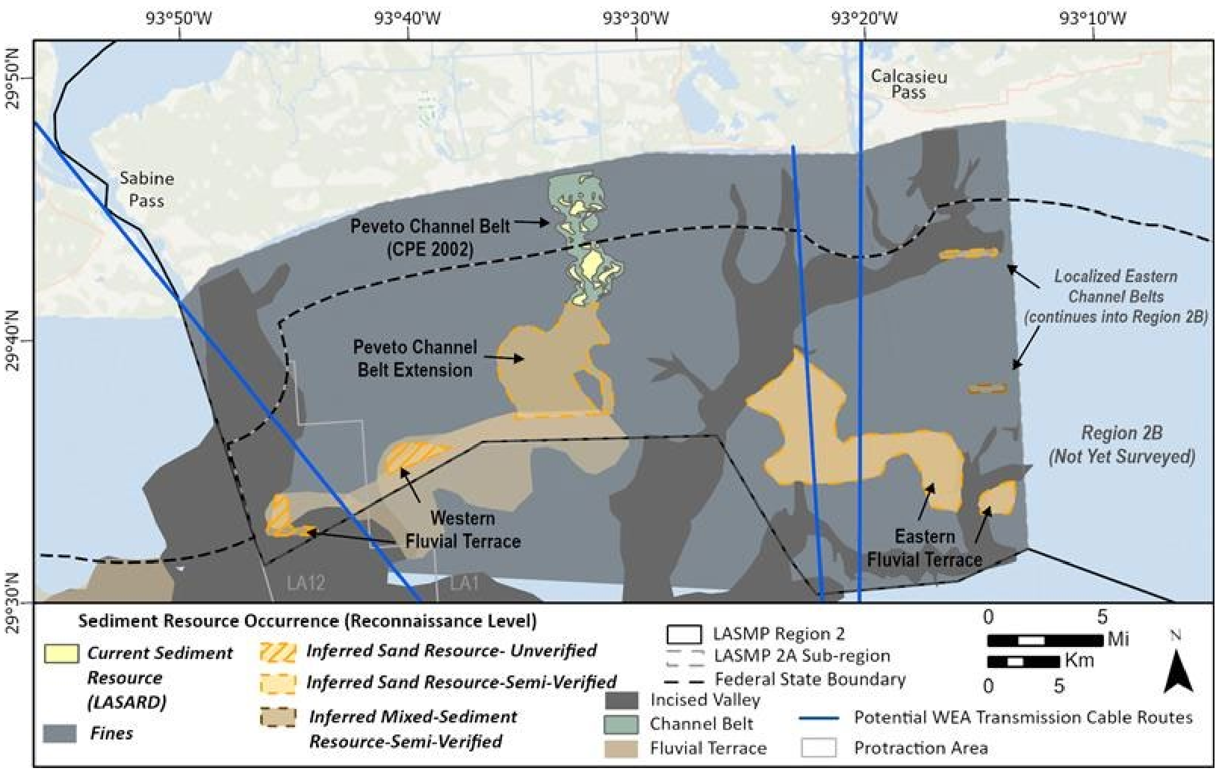

Figure 18. Summary of mapped sediment resource occurrence and classification. Sediment resources include both sand and mixed-sediment resources. Most are expanded from successful, previously designed and utilized borrow areas such as CS-31. Indicated sand resources are delineated in CPE (2002).

The use of higher density chirp and boomer seismic geologic sampling in future appraisal or design-level investigations would most efficiently characterize the identified resources' variability and geometries. Simultaneous data collection using low frequency boomer seismic (for deeper penetration) would allow for better seismic imaging of the base of these thick sand-rich deposits and higher frequency chirp sub-bottom (for higher resolution) would provide details of internal architecture (e.g., Sullivan and Miner 2019). Overall, the target fluvial channel belts display a transparent to faintly dipping seismic package. The loss of chirp acoustic imaging below the target package correlates to higher sand content, whereas more complete seismic records, even in dipping reflector packages, correlates to higher fine-grained sediment. The encountered textural variability when sampled was expected in fluvial deposits. It is recommended that future, more detailed appraisals and engineering investigations emphasize increased geologic sampling, both at greater depths and density of sediment cores to produce more confident net-to-gross volumes and decrease associated compatibility risks.

Integrating and repurposing derivative map products from OCS lease block hazard survey data supports interpretations of this regional scale investigation and refine identified deposit boundaries. An example of the hazard survey derivative products refining interpretations within the Peveto Channel Belt is presented in Figure 19. Line spacing during the Peveto Beach borrow site investigation was roughly 280 m and was interpreted as a anastomosing fluvial channel system that was overprinted with a series of subchannels (CPE 2002). Building on work from Heinrich et al. (2020) as well as APTIM and The Water Institute (2021, 2022), and with new data collected as part of this investigation, the sand deposits of the Peveto fluvial channel were interpreted as channel belt deposits related to laterally migrating point bar deposits. With the 30 m line spacing needed for OCS lease block hazards surveys, geologists mapped a meandering channel, with thalweg depths ranging from ~10–25 m deep within the previously mentioned Peveto Channel Belt. Sediment core data verifies the mud-filled channel with interbedded sand and fines related to a relict point bar deposit. The additional evidence provided from the repurposed hazard survey map products—integrated with available two-dimensional sub-bottom data—strengthens seismic facies interpretation, and depositional setting, and refines assumptions about sediment composition of these deposits. This strategy then informs areas with less data coverage, such as Region 2B.

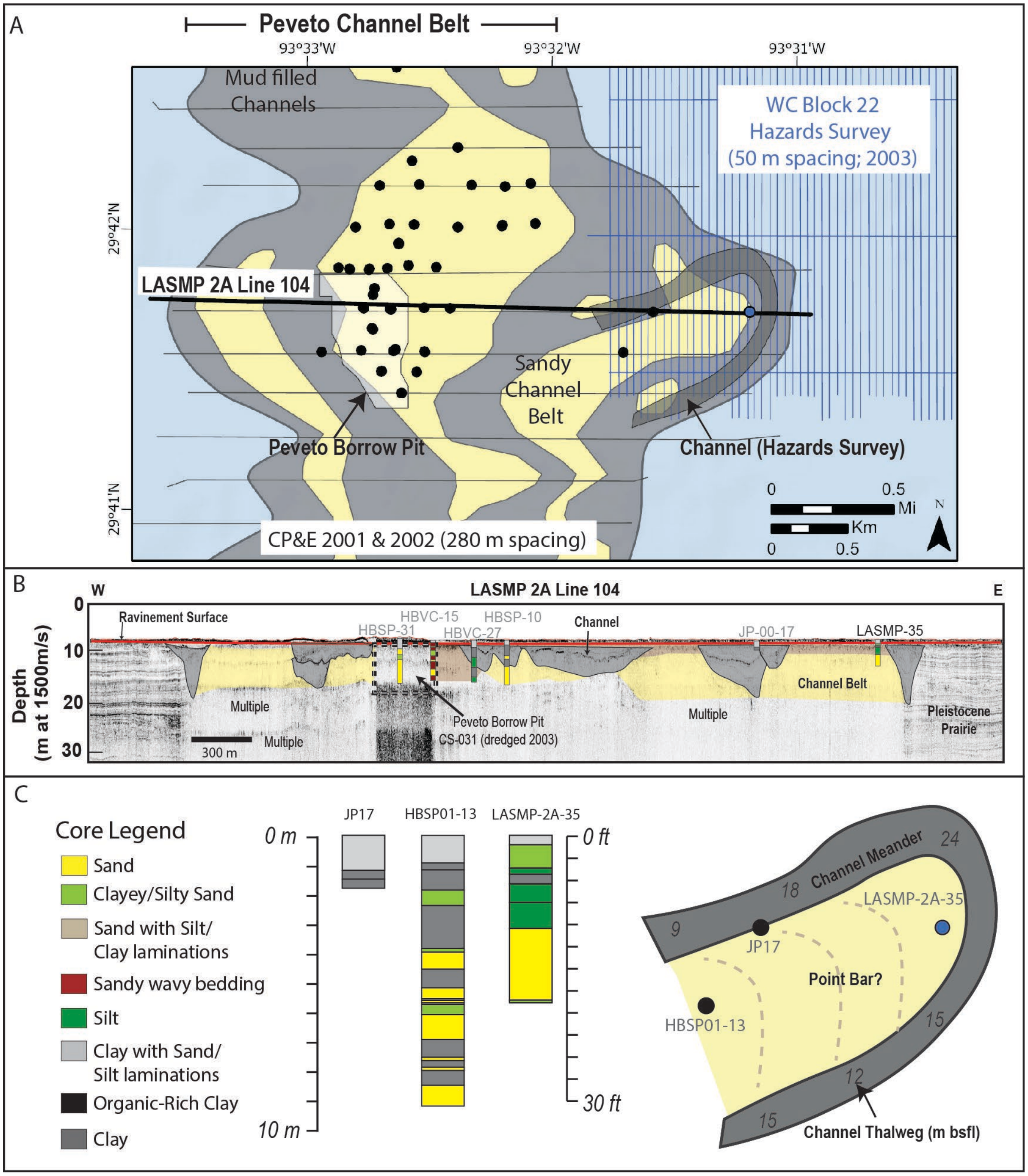

Figure 19. An example of the geospatial utility of hazard survey derivative map products improving interpretations of complex fluvial meandering systems using reconnaissance and design level investigations alone. A meandering channel and point bar system were interpreted and verified with archival and newly collected sediment core data. Chirp sub-bottom data collected as part of the LASMP Region 2A investigation cross cuts this meander. Core data verifies the fine-grained nature of the abandoned channel fill and the interbedded and variable nature of the point bar.

Although focused on LASMP Region 2A, this investigation has identified several areas of possible sediment resources in LASMP Region 2B. These findings inform and justify future survey design and strategic data collection efforts to establish a comprehensive sediment resource inventory at a reconnaissance level. Archived boomer data from 1982 and 1995 (Calderon et al. 2004; Bosse, Flocks, and Forde 2020; Bosse, Flocks, Forde, et al. 2020) extend from Region 2A into 2B, providing context to the subsurface at the current investigation boundary (Figure 4, upper panel). Several large channel belt features that have little to no overburden have been identified and could potentially be related to features hypothesized to continue from Region 2A to 2B (such as the localized channel belt shown in Figure 15 and Figure 16). Channel belts demonstrate both single and multi story arrangements, which adds to the complexity of correlation. The channel belts identified in Region 2B are 9–15 m thick (30–50 ft), 300–1,524 m (1,000–5,000 ft) wide, and are estimated to be of Pleistocene age due to their stratigraphic position below the ravinement surface (Figure 20). These features are located between 9.6–12.9 km (6–8 mi) offshore of the Mermentau River area and likely continue landward. Data quality decreases in the shallow water depths closer to shore, which is common in powerful lower frequency boomer seismic systems, and was not reinterpreted in this investigation. As demonstrated in the archived geophysical data the geometry, positioning, and cross-cutting nature of multiple generations of channels (Figure 20) leads to a complex stratigraphic architecture that is difficult to correlate across long distances. This can result in deposits of vastly different age at similar stratigraphic positions.

Previous researchers have detailed the complexity of correlating fluvial feeder systems, incised valleys, and channels that lead to major shelf edge delta depocenters along western Louisiana and eastern Texas (Suter and Berryhill 1985; Wellner et al. 2004; Anderson et al. 2016; Heinrich et al. 2020). There is strong evidence of components of fluvial systems controlling younger, smaller-scale drainage basins and the effect of these relationships on fluvial system preservation (Swartz et al. 2022; Cardenas et al. 2023). In an attempt to identify areas of potential archeological sites along paleo-river landscapes on what is now the modern shelf, Heinrich et al. (2020) compiled individual OCS lease block hazard survey data to map and differentiate fluvial systems and paleovalleys. No original geophysical data were available for reinterpretation, only interpreted maps created by geologists assessing individual lease blocks that were digitized and synthesized by Heinrich et al. (2020). However, the geophysical data compiled or collected for this investigation can be roughly correlated to channel systems identified in the Heinrich et al. synthesis based on the reported depth below seafloor of channel tops and bases. Cross referencing between data sets not only helps “untangle” the channels from lease block hazard surveys, but also allows for spatial expansion or refinement of interpretations from this investigation. This greatly strengthens the interpretations of channel presence (Figure 21A).

The frequent identification of potential channel belt features in both the archival boomer data and the OCS lease block hazard survey data from the eastern part of Region 2B is reinforced when placed within the broader, established geologic framework. This area contains multiple generations of paleochannels and channel belts that generally trend southwest as well as paleovalleys according to Heinrich et al. (2020). The Pleistocene Mississippi River course, located northeast of White Lake, contains several generations of channel belts up to 16 km (10 mi) across. The general trend of the Pleistocene Mississippi River course is in alignment with White Lake, a gap in subaerial Grand Chenier, and the numerous channel belt deposits identified offshore in Region 2B (Figure 21B). Compatible sediment are confirmed from a few archival platform borings, displaying sand in the upper 10–30 feet, with some borings showing over 80 feet of sand (Figure 21C). No clear trend in sand thickness can be observed by the limited boring data. This ancient Mississippi River course represents a major sediment transport pathway and, if it extends offshore, is important for sediment resource exploration and survey design for Region 2B to assess its viability.

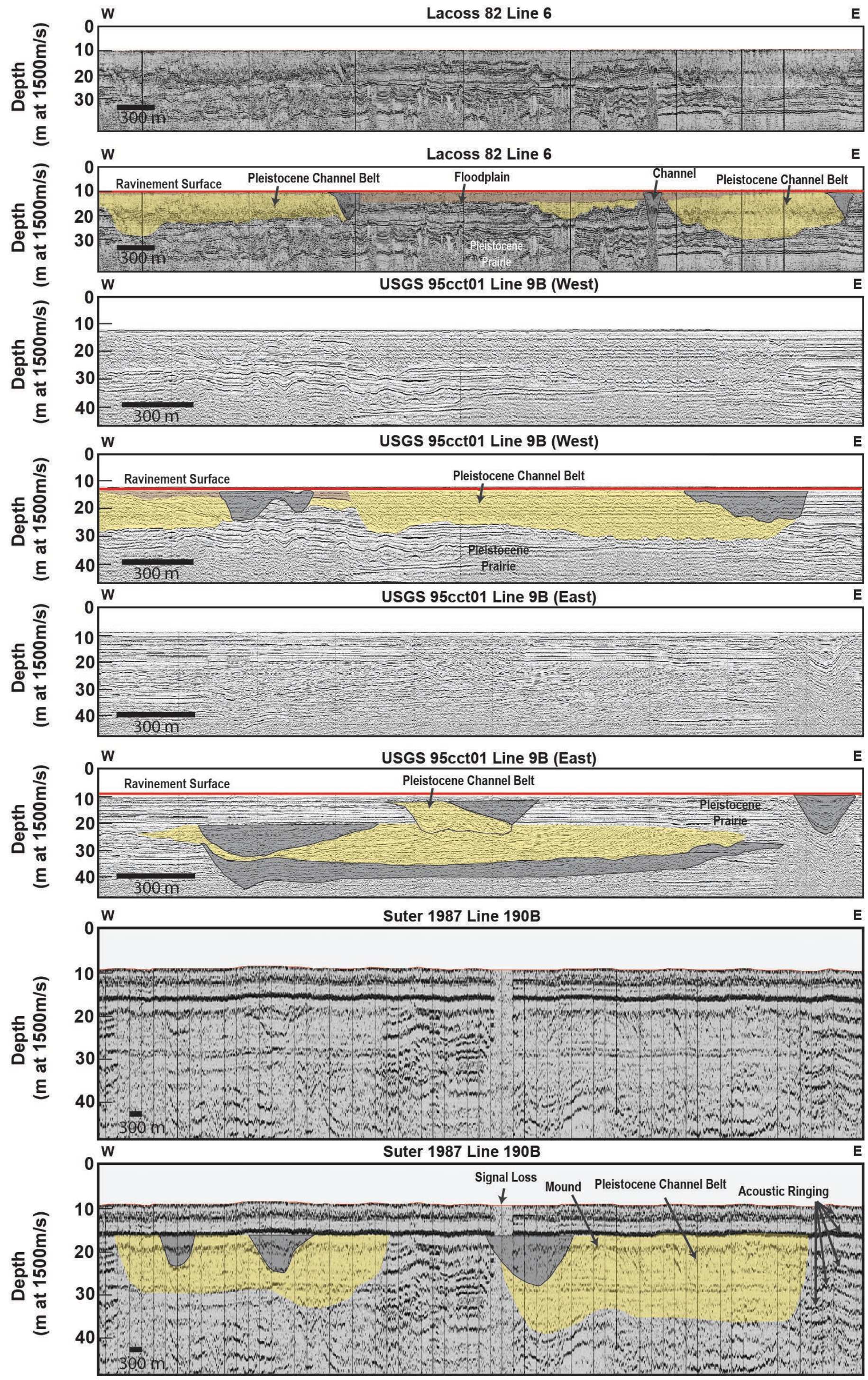

Figure 20**. Sub-bottom profiles examples of possible channel belt features in LASMP Region 2B. These features were identified through holistic compilation and reinterpretation of archived data sets and confirm the presence of potential sediment resources offshore of the eastern Chenier Plain. The channel belt deposits are highlighted in yellow, channels or floodplain drainages in dark grey, floodplain in brown, and the ravinement surface is in red. Note the base of fluvial deposits are inferred based on channel depth. Note these boomer seismic sub-bottom data were collected with Loran-C so its positional accuracy has greater uncertainty compared to modern survey methods. See Figure 21 for location.**

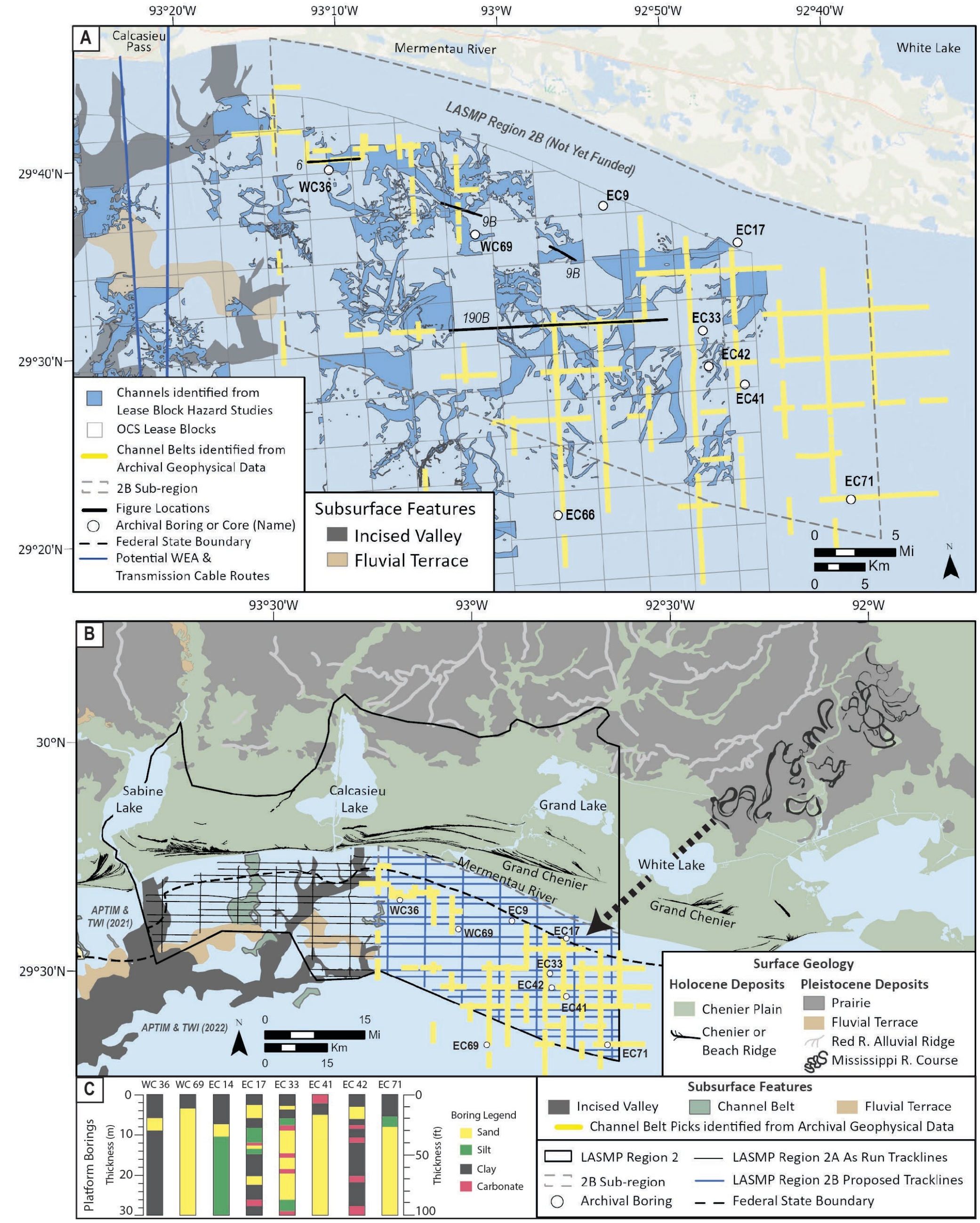

Figure 21 A) Map of channels identified from various archive efforts within the LASMP Region 2B area and interpretations from the Region 2A features to show continuation of features between sub-regions. Possible sediment resources in the form of channel belts were identified from archived boomer sub-bottom data (Calderon et al. 2004; Bosse, Flocks, Forde, et al. 2020; Bosse, Flocks, and Forde 2020). Channels from OCS lease block hazard surveys compiled by Heinrich et al., 2020 detail the complexity and overprinting nature of the coastal plain and allow for general correlation to channels identified in archived geophysical data. B) Regional geologic map demonstrating the probable continuation of the sand-rich Pleistocene Mississippi River course through White Lake and Grand Chenier into Region 2B offshore with the high presence of channel belt features identified in archived data. This map also shows the proposed survey tracklines for Region 2B once funded. C) Select archived platform borings near Region 2B demonstrating sand 3 m (10 ft) or greater, locations shown in panel A and B. Note Sub-bottom profile locations are displayed in black with a trackline identifier in panel A.

The synthesis of interpretations of Region 2A, along with the leveraging of archived geophysical and spatial data while contextualizing and linking into an established geologic framework, indicates several potential sediment resource deposits, including several that likely extend into Region 2B, such as ancient fluvial channels and associated point bar deposits. The ancient river channels responsible for the deposition of sand and mixed-sediment within Region 2A had to extend across Region 2B based on onshore geologic mapping with similar deposits and sediment resources likely to be present. Based on the findings presented, there is a high likelihood that Region 2B contains several potential sediment resources, specifically in the form of fluvial channel belts, among others.

7 Sediment Resource Estimates

Development of the sediment resource estimates follows the iterative approach outlined by LASMP and an initial resource inventory following the CPRA classification scheme (CPRA, 2024). CPRA classifies sediment resources based on sedimentary characteristics (e.g., grain size), engineering and accessibility factors (e.g., thickness of resource deposit and thickness of overburden), and level of confidence in the determination (e.g., spacing of geological and geophysical data, expected variability of different geologic deposits). Not all of these classifications are used within the current LASMP Region 2A investigation, but they are presented here to emphasize the relative hierarchy and degree of confidence conferred by these designations.

Three major subsurface sedimentary deposits related to paleo channel belts and fluvial terraces offshore of LASMP Region 2A were identified in this study: the Peveto Channel Belt Extension, the Eastern Terrace, and the Western Terrace (Figure 18). Due to the poorly sorted nature of the channel belt sand-rich deposits, the sinuous ribbon-like geometries, and current sediment core and geophysical coverage, the sediment resources were generally classified as both semi-verified and unverified inferred sand resources according to CPRA (2024) classifications. This is a conservative assumption, as the dominantly sand to silty-sand composition of the channel belt deposits likely contains both discrete areas of sand (or >70% sand) and mixed-sediment (30–70% sand) resources (e.g., Khalil, Raynie, and Forrest 2023) that will be refined and further constrained with subsequent appraisal and design level investigations. Historically, initial reconnaissance investigations of the Peveto Channel Belt found sand-rich channel belt deposits composed of 54% poorly sorted sand (Ramsey and Penland 1992), while sequential appraisal and design level surveys constrained and highlighted discrete channel belt deposits ranging from 8–35% sand (CPE 2002). The channel belt sand-rich deposits generally exhibit a fining upward sequence, implying a single deposit may contain sand resources near its base and mixed-sediment resources in its upper section. The textural quality is highly variable, even from similar seismic facies of the same feature, and should be appropriately refined with further detailed geological and geophysical investigations. This reconnaissance investigation did not update volumes of sand resources identified within the Peveto Channel Belt by the CPE (2002) design-level investigation. 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, and have less than 6.1 m (20 ft) of overburden (the overlying non-compatible sediment between the sandy deposit and the seafloor). Interpolating isopachs of highly variable fluvial deposits from sub-bottom data with such irregular spacing 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 Northern Gulf Sediment Availability & Allocation Program (NGSAAP) tool (Di Leonardo et al. 2022). The sand volumes are presented as both available and accessible sediment volume estimates.

This study attempts to quantify the volumes and associated overburden of the Peveto Channel Belt Extension, eastern terrace, and western terrace fluvial channel belt deposits. They represent logical target facies due to their continuity and potentially thick geometries. Fluvial channel belt deposits are characterized by transparent to faintly dipping reflector sub-bottom packages that grade into a "U" shaped channel form. The channel form is filled with laminated to transparent reflector packages and represents channel abandonment. The base of the channel belt package was not imaged in chirp sub-bottom data in most places. It contains high sand content as verified by the cores. The total thickness of channel belt deposit was estimated by the base of the channel form or channel thalweg. The channel belts or channel belt complexes usually exhibit similar thicknesses and geometries along the length of the deposit and can occur as single or stacked packages. The channel belt facies consists of clean to poorly sorted, very fine to medium tan-brown sand near its base, with more interbedded silty sand and silty clay facies in the upper portions. Channel belt deposits are expected to be variable in their composition and require sufficient geologic sampling to constrain. Channel belt deposits were previously dredged for the Peveto Beach restoration project (CS-31) suggesting the sediment resources of similar geological setting mapped in this investigation will be compatible for projects requiring sand resources.

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 obstructed 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. In-place pipelines include infrastructure that remains—either active or abandoned—that has not been physically removed from the seabed. Oil and gas pipeline infrastructure data were compiled from U.S. Bureau of Safety and Environmental Enforcement and Louisiana Department of Natural Resources databases. The Peveto Channel Belt Extension deposit saw the greatest reduction to available sand volumes due to the high concentration of in-place pipelines in the OCS West Cameron Area. LASMP Region 2A sand resources accessibility, especially those contained within the eastern Terrace, could be impacted by potential WEA transmission cable routes.

To estimate the known available sediment resources within Region 2A compared to the previously designed and dredged borrow areas in the area, the volumes of prior dredging were subtracted from the new resource volumes identified (e.g., APTIM 2023). Extracted sediment used for the CS-31 restoration project (CPE 2002) totaling 2.7 MCM (3.5 MCY) were subtracted from the total reported volumes within the larger Peveto Channel Belt identified by the CPE (2002). CPRA borrow areas for projects CS-33, CS-59, CS-66, ME-20 were either outside the LASMP Region 2A investigation area, did not overlap with major sediment resources identified here, or contained fine-grained sediment.

Initial first order estimates of the Peveto Channel Belt and channel belts contained within two fluvial terraces contain **703 MCM (920 MCY) of available sand resources and 505 MCM (662 MCY) of accessible sand resources (**Figure 22**)**. These represent indicated and inferred sand volumes, excluding overburden, and will be significantly reduced with further detailed investigation. The inferred sand volumes may contain localized mixed-sediment resources but are regionally classified as a sand resource with the current sediment core sampling based on the dominant geologic evidence. See Table 2 for feature thicknesses, overburden, and volume estimates for each feature. A summary of available and accessible sand resource targets with and without pipeline buffer exclusions can be found in (Figure 22; Table 2**).**

Table 2. Summary of quantified 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. Note the Peveto Channel Belt volumetrics come from the CPE 2002 design level survey and were not updated in this reconnaissance level investigation. * Denotes accessible volumes that could not be calculated with pipeline safety buffers.

Feature	Example Data Figure #	Facies	Area m² (ft²) (10⁶)	Average Unit Thickness m (ft)	Average Overburden Thickness m (ft)	Classification (CPRA 2024)	Available Sand Volume MCM (MCY)	Accessible Sand Volume MCM (MCY)
Peveto Channel Belt (CPE 2002)	**Figure 12**	Fluvial Channel Belt	7.7 (82.9)	20 (65)	2 (7)	N/A: Resources identified under prior scheme	15 (20) *	15 (20) *
Peveto Channel Belt Extension	**Figure 12**	Fluvial Channel Belt	43.9 (472.5)	6 (20)	4 (14)	Inferred-Semi Verified	263 (344)	102 (134)
Western Fluvial Terrace	**Figure 13**	Fluvial Channel Belt	49.7 (535.0)	4 (12)	3 (11)	Inferred-Unverified	32 (42)	26 (34)
Eastern Fluvial Terrace	**Figure 14**	Fluvial Channel Belt	70.6 (760.0)	6 (20)	3 (12)	Inferred-Semi Verified	393 (514)	362 (474)
Total							**703 (920)**	**505 (662)**

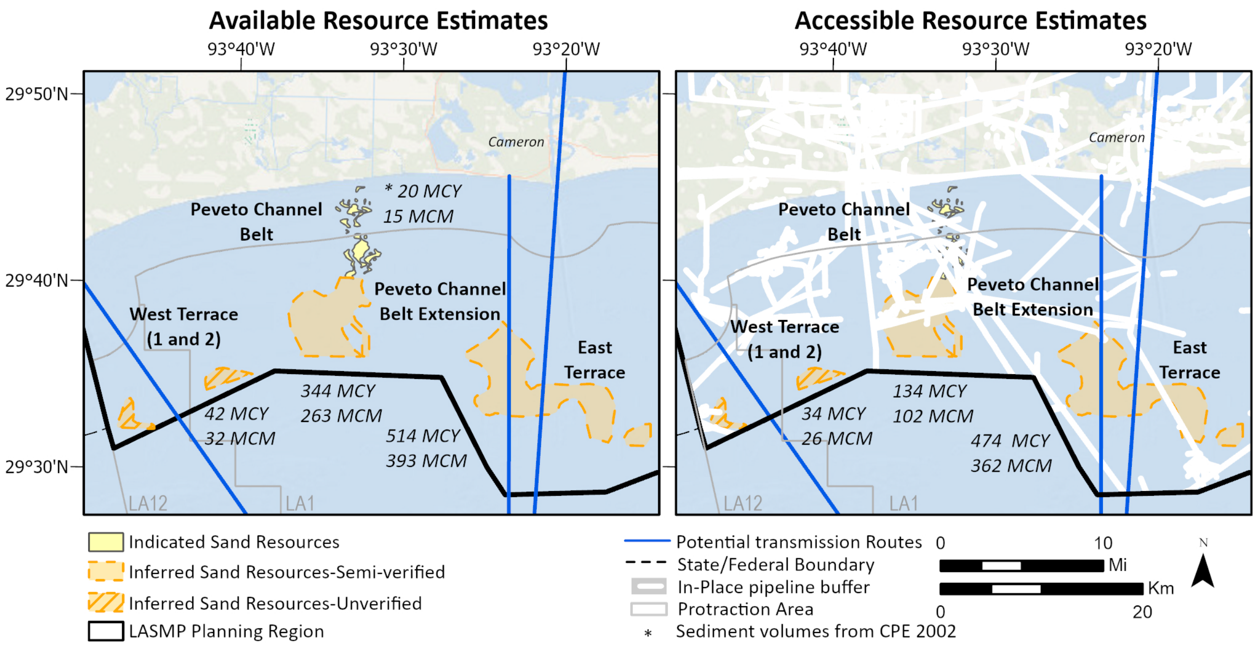

Figure 22. Map of available and accessible subsurface sand resources of LASMP Region 2A. Volume calculations are first order estimates of the sand-rich sediment identified at the reconnaissance level and will be refined with future resource investigations. Accessible resources exclude pipeline safety buffer of 610 m (2000 ft). In place pipelines compiled from Bureau of Safety and Environmental Enforcement and Louisiana Department of Natural Resources databases.

8 Conclusions and Recommendations

The Chenier Plain of Louisiana, which encompasses LASMP Region 2, has experienced high rates of wetland loss, which is creating a need for compatible sediment to help mitigate land loss. One of the important components of LASMP is to develop a holistic and comprehensive sediment resource inventory supported by visual communication tools to aid coastal managers, planners, and engineers to address the sediment deficit in the in the coastal area. Potential offshore sediment resources could be impacted or become inaccessible due to recently proposed WEA transmission cable routing, if implemented. The objective is to more efficiently allocate sediment resources for restoration projects, reduce multi-use conflicts (WEA transmission cable routing), and strategically inform future resource prospecting investigations using a systems approach.

The first phase of the Region 2 investigation included a comprehensive historical data and literature review and synthesis. Archival geophysical, geological, and lease block derivative spatial data were compiled and holistically reinterpreted. Proven borrow sites were contextualized in a geologic framework acting as verified examples to inform interpretation in undeveloped areas. Sediment core data were recovered from UNO archives to supplement the known existing data and formatted for LASARD where they will be publicly available. The interpretations from the data synthesis phase led to the creation of a preliminary geologic model to inform a strategic survey design of Region 2A, where 562 km (349 mi) of full-suite geophysical data and 35 vibracores were collected in 2023 by APTIM. APTIM geologist performed grain size analysis on 83 sediment samples to characterize the deposits textural properties. Geophysical and geological data interpretations led to the development of a predictive geologic model for the LASMP Region 2A. This simplified visual communication of the complex source-to-sink processes highlights the distribution and composition of sediment resource areas expanded within LASMP Region 2A. Comparison to the predictive geologic model developed for LASMP Region 1 highlights the key differences in geology between regions, 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 such as the Delta Sand Search Model, LASARD, and SSD map. The implementation of LASMP Region 2A provides a streamlined sediment resource identification workflow for further development and can be applied to other regions building upon previous work in the delta plain (CPRA and The Water Institute 2024).

A holistic assessment of sediment resource composition, distribution, and inventory of first-order volumes was provided for LASMP Region 2A. This investigation mapped three major sediment resource areas: the Peveto channel belt extension, the western fluvial terrace, and the eastern fluvial terrace (Figure 18). The resources are related to subsurface, paleo-channel belts located offshore of western Louisiana likely related to Pleistocene age river courses.

The Peveto Channel Belt of CPE (2002) and its seaward extension, eastern terrace, and western terrace fluvial channel belt deposits mapped in this investigation contain an estimated **703 MCM (920 MCY) of sand resources**. These are first-order estimates composed of indicated and inferred sand resources, which should be refined with further development through iterative, detailed resource surveys. 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. Excluding infrastructure safety buffers, the western Louisiana region is estimated to contain **505 MCM (662 MCY) of accessible sand resources**. These sand resource estimates, constrained by geophysical and geologic sampling, are further de-risked by linking to previously dredged or designed borrow areas.

Two localized eastern channel belts containing inferred sediment resources were identified on the eastern boundary of Region 2A (Figure 8) but could not be regionally correlated between geophysical data and therefore were excluded from resource quantification. The two identified localized channel belts have similar seismic signatures compared to other identified channel belts. The limited sediment core data show that the northern localized channel belt contains 5 m (17 ft) thick sand, while the southern channel belt contains 9 m (30 ft) of mixed-sediment. Both localized channel belts have no overburden and warrant further investigation. Archived derivative map products from the OCS lease block hazard surveys suggest these channel belts extend into Region 2B.

The previously identified Calcasieu and Sabine Incised Valleys were mapped in high resolution and are significant to the geologic framework, but do not represent sand and mixed-sediment resources at this time. These “underfilled” valleys contain expected valley fill successions of basal fluvial sand with >20 m (>60 ft) thick, of soft, fine-grained, estuarine-to-marine overburden making them economically unfeasible to extract.

In collaboration with BOEM and building upon previous synthesis efforts by Heinrich et al. (2020), derivative map products from OCS lease block hazard surveys were integrated into the interpretations of this investigation. The repurposing of detailed interpreted maps created from surveys with 30 m (100 ft) line spacing, supports the regional scale framework interpretation, constrains channel geomorphology and boundaries that can supplement areas of lesser data coverage in this investigation. Archived digital sub-bottom, complemented with the hazard survey derivative map products, were used to identify preliminary target deposits and channel belts systems in Region 2B. This example of repurposing open-source hazard survey data to cost-efficiently strengthen resource interpretations and de-risk areas of future investment shows the importance of interagency collaboration and creative problem-solving.

A series of recommendations to improve the efficiency of future sediment resource investigations in the area are part of the LASMP initiative.

1. Further development of the indicated and inferred channel belt sediment resources identified in this investigation would benefit from increased geological sampling and the use of lower and higher frequency seismic survey methods to constrain sediment variability and geometries. Longer sediment cores would help constrain the composition of the channel belt deposit with depth and should generally target areas of transparent facies with loss of acoustic chirp imaging below.
2. The two localized channel belts found along the Region 2A boundary could be promising potential sand and mixed-sediment resources due to their little to no overburden and proximity to restoration projects. Further geological and geophysical surveying is needed to constrain its extent in Region 2B and quantify resource volume estimates.
3. The fluvial terrace deposits could represent thick, up to 20m (60ft), fluvial sand-rich deposits and should be further characterized with the use of deeper geologic sampling methods and high quality, lower frequency sub-bottom profilers such as boomer seismic. Although the overburden may be greater, if sand resources are verified throughout the base of the deposit they could represent significant resources.
4. Special dredging technique and efficiency considerations should be given to areas of Pleistocene stiff clays overlying the Peveto Channel Belt Extension and Fluvial Terrace deposits.
5. Utilization of publicly OCS lease block hazard survey derivative map products should be integrated into resource prospecting efforts where possible to maximize investment of data collection.
6. Correlations of sediment composition and acoustic signatures, such as the loss of acoustic signal below transparent facies correlating to higher sand content, should be continually refined and shared when more information is available. Although this provided the best correlation to higher sand content, there was still variability in the sampled sediment composition across deposits.
7. The strategies and findings presented in this resource investigation are portable and could be adapted to areas of similar geologic settings.

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Appendix A. Desktop Report

Appendix B. Geophysical and Geological Data Collection and Processing

Appendix C. Geophysical Data Collection Field Notes

Appendix D. Geophysical Data Collection Mitigation Efforts

Appendix E. Protected Species Observer Notes

Appendix F. Archeological and Hazard Clearance for Vibracore Site Selection

U.S. Department of the Interior (DOI)
DOI protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)
BOEM's mission is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.

BOEM Environmental Studies Program
The mission of the Environmental Studies Program is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments. The proposal, selection, research, review, collaboration, production, and dissemination of each of BOEM's Environmental Studies follows the DOI Code of Scientific and Scholarly Conduct, in support of a culture of scientific and professional integrity, as set out in the DOI Departmental Manual (305 DM 3).