PROSPECTING SAND OFFSHORE COLLIER COUNTY: LESSONS LEARNED FROM THE ANALYSIS OF HISTORICAL DATASETS IN A GEOSPATIAL FRAMEWORK AND APPLICATION OF GEOLOGICAL MODELS

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ABSTRACT

Many eroding beaches require periodic beach replenishment to maintain stable berms for coastal protection and recreation. This paper reports on sand search investigations offshore from Sanibel Island. The study area lies north of Cape Romano in Collier County and ranges from 1 to 35 miles offshore. Here, prominent seabed morphologies on the inner continental shelf include linear sand ridges up to 5 miles long. These ridges have asymmetrical profiles with steeper offshore gradients and are oriented from N-S to SW-NE. These ridges are interpreted as relict sand bodies that are associated with lower sea levels than those of today (Finkl *et al.*, 2003) but are constantly reworked by modern shelf-oceanographic processes.

Offshore sand search investigations in Collier County, which were initiated about three decades ago, targeted deposits that included ebb-tidal shoals and nearshore sands, deposits infilling karstic depressions (sink-holes), and paleo-channels; and offshore ridges. Although prior investigations characterized this shelf area as a zone depleted of suitable sand sources, recent comprehensive reviews and new analysis of sand search efforts suggest borrow potentials in offshore sand ridges.
Additional Index Words: *sand searches, sand ridges, sand banks, inner shelf deposits.*

INTRODUCTION

Offshore sand searches have become increasingly sophisticated and specialized over the last few years triggered by decreasing sand sources that are suitable for beach restoration. In phase with this 'new interest' in offshore sand searches is increased study of identification, genesis, classification, and modeling of offshore sand ridges and banks (*e.g.* Brunn, 2003; Dean, 2003; Finkl *et al.*, 2003; Dyer and Huntley, 1999, Davis *et al.* 1993). Shelf sand ridges have been appreciated as singularities for some time, but new studies emphasize the widespread occurrence of sand ridges as fields, the pressure of which greatly enhances the potential for locating multiple good-quality borrow sites. Multiple ridge fields occupy different parts of the continental shelf and although they are broadly similar, there are differences in orientation, morphology, and composition.

Review and re-investigation by Coastal Planning & Engineering Inc., of previous sand search efforts offshore Collier County indicate that previous focus on incised river channels and sinkhole depressions as possible sand sources was misleading and may have led to the conclusion that exploitable materials were not present in this shelf environment.

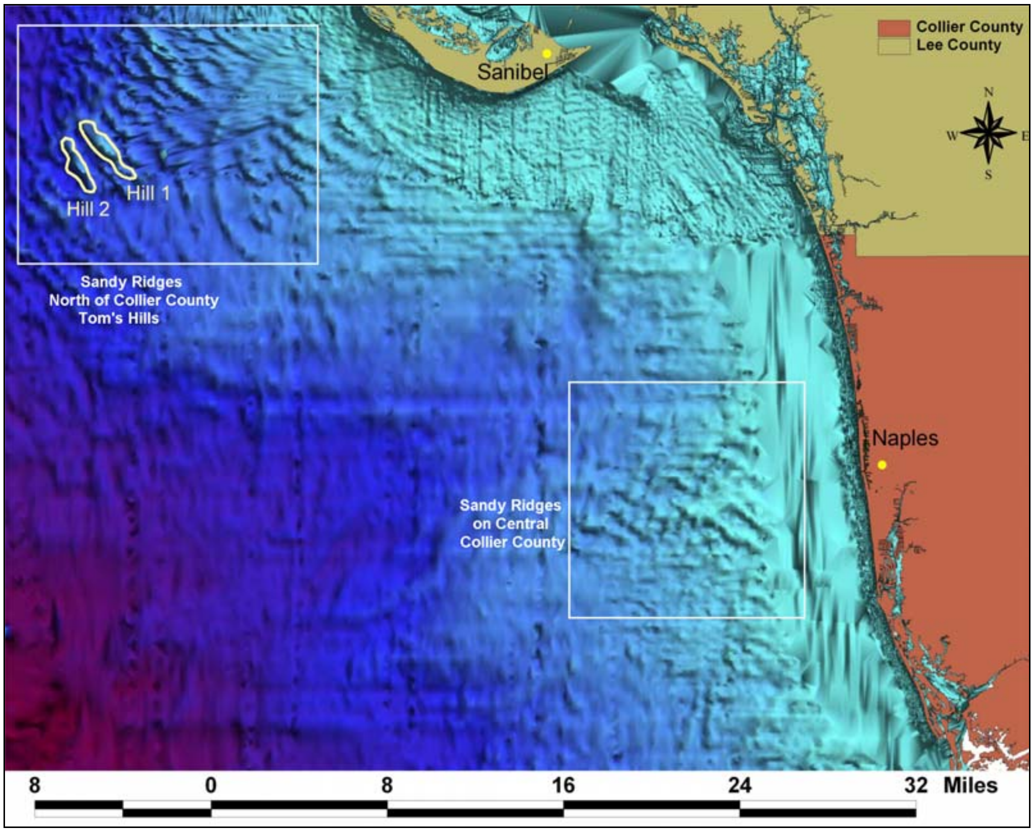

Figure 1. Sandy ridges offshore southwest Florida. Study areas on the continental shelf near Sanibel Island and Naples, Florida are indicated by rectangles for detailed study areas N5 (Naples 5) and T1 (Tom's Hills).

The primary purpose of this paper is to explore the suitability of these ridge systems as sand resources for beach restoration. A secondary purpose is to consider hypotheses that account for the formation and development of three sand ridges.

STUDY AREA AND GEOLOGICAL BACKGROUND

The study area occupies the coastal region from Sanibel Island to Big Marco Pass and extends 33 miles offshore (Figure 2) along portion of Collier County. The area displays many landform characteristics of a sedimentary shore and is broadly characterized by a range of coastal barriers, estuaries, lagoons, inlets, wetlands, swamps, and karst features. Hine e*t al.* (1986) collectively identify the various coastal landform units in geomorphological terms was the West-Central Barrier Chain.

Geological Framework and Background Studies

Description of the geologic setting is central to comprehension of bedrock seafloor surfaces and the sediments sitting on them. The nature of sedimentary deposits determines sand quality and its potential use for beach nourishment. It is thus helpful to understand the general shelf environments because the distribution of beach-quality sands on the seabed is not random, but spatially well defined in terms of stratigraphy, grain composition, age of materials, and erosional-depositional events. The study area is part of a larger continuum (extending southwards from Anclote Key to Cape Romano) that lies at the center of an ancient carbonate platform that faces an enormous ramp that forms the proximal portion of the west Florida shelf-slope system. This feature has exerted large-scale control on coastal geomorphology, the availability of sediments, and wave energy (Hine *et al.,* 2003). Although this region is relatively sediment-starved, ebb-tidal deltas and offshore sand ridges provide a significant sand source for beach nourishment.

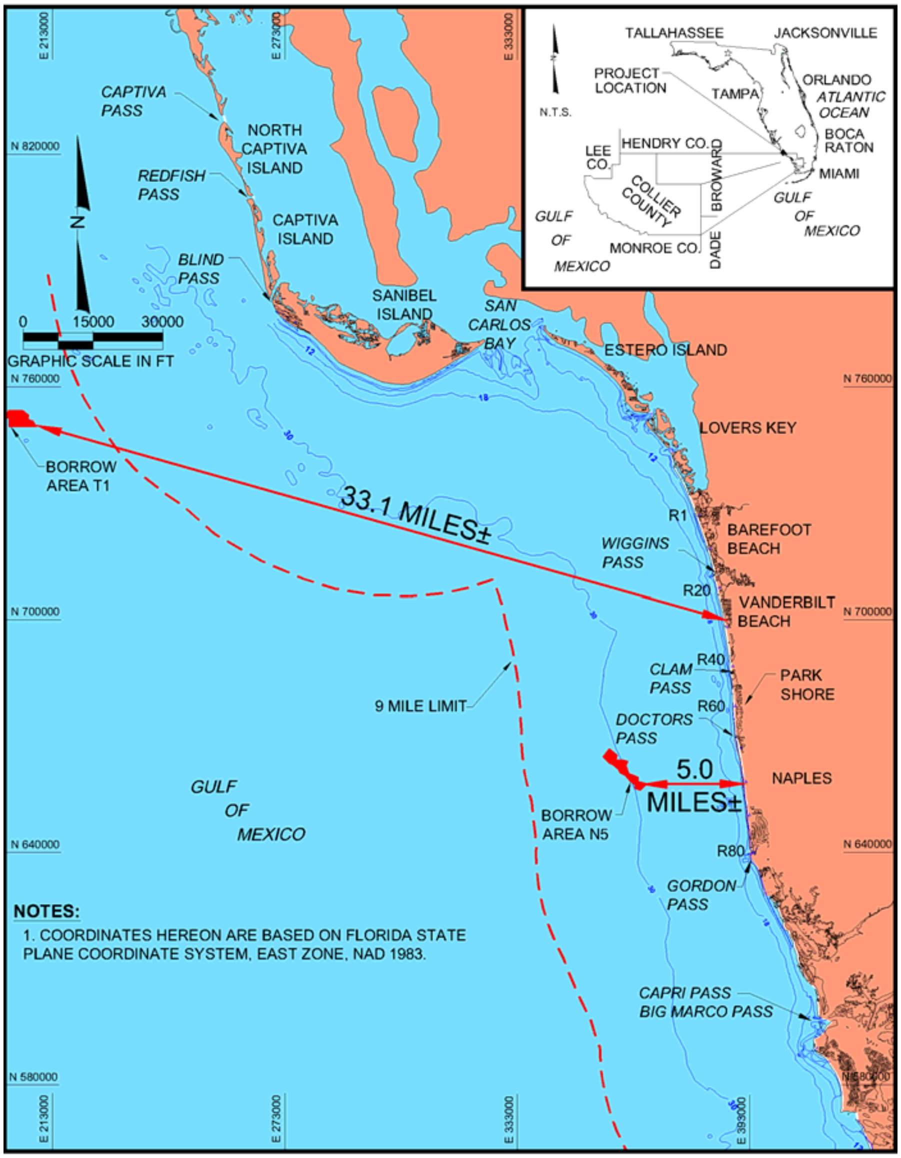

Figure 2. Map showing beaches, passes, geographic places names and two borrow areas defined by this study.

Cape Romano marks the southern end of the quartz sand dominated Gulf Barrier Island Chain where the siliciclastic to carbonate transition occurs rather abruptly (Sussko and Davis, 1992). The low wave energy regime allows for the construction of ebb-tidal deltas, which store large quantities of sand (Davis *et al.*, 1993; Hine *et al.,* 2003). Flood-tidal deltas along the west-central Florida coast are relatively inactive due to small tidal ranges, sheltered lagoons, and ebb dominated inlets (Davis *et al.* 1989; Finkl, 1994).

Various types of sand ridges (linear accumulations of sand bodies) occurring on the inner shelves are verified throughout the world, including the southwest coast of Florida (Figure 1). These topographically positive sandy accumulations on the seafloor are sometimes described as relict features (formed in response to lower sea levels) (*e.g.* McBride and Moslow, 1991) while others are recognized as active features that are in tune with large scale oceanographic processes (*e.g.* Dyer and Huntley, 1999). Prominent seabed morphologies in the study area include linear sand ridges, some of which extend continuously for distances greater than 4 miles. These deposits are geologically young, having formed during the post-glacial sea-level rise (Davis, 1997). Modern inner-shelf dynamic processes, such as the action of undertow currents, current refraction over bathymetric anomalies, eddy flows, and storm wave activity, reshaped and reworked the sedimentary architecture of these deposits to induce the morphologies presently seen. Other commonly occurring features in the area include various types of depressional (negative topographic) features that are incised into the karst surface and some surficial marls.

The wide continental shelf offshore off the "Paradise Coast", (described by Davis, 1997), which gently slopes seaward toward the central basin of the Gulf of Mexico, maintains shallow depths 5.5 miles offshore at the 30 ft isobath. Recent studies of shelf morphology and continental shelf depositional systems was summarized in *Marine Geology* (Volume 200, Numbers 1-4) (see Hine *et al.*, 2003), providing new insights and interpretations of the geologic framework and deposits of this coastal region.

PROJECT BACKGROUND & RATIONALE

The current work resulted from a three-phase comprehensive sand search investigation conducted for the Collier County Board of Commissioners. A methodological approach to marine sand searches, developed over the years by Coastal Planning & Engineering's Department of Geology and Geotechnical Services, was applied throughout this sand search investigation. The sequential procedures describe logical progressions and interactions between different data sources and indicate appropriate steps that are used during sand search investigations by CPE geologists and engineers. The method draws together local geological information and data to generate the final sand search deliverables.

The first phase included research, analysis, and mapping of historical reports and data plus construction of a regional GIS. Results of Phase I (historical review of existing data) indicated that prior sand searches during the last decade were only marginally successful because inappropriate depositional environments were targeted (CPE, 2002). After using a GIS database and analysis of existing data, it became evident that the most promising geomorphological features were offshore sand ridges. With this new model envisioned, reconnaissance bathymetric surveys, surface sampling and jet probes were conducted in order to identify promising sand ridges on the inner shelf. These preliminary field surveys (Phase II) consisted of 50 jet probes, 39 surface samples and reconnaissance bathymetry to identify primary, secondary and unsuitable deposits. Primary deposits identified in Phase II were sand ridges 5 to 7 miles offshore of Naples and Marco Island, the ebb shoal of Big Marco and Capri passes, and sand ridges southwest of Sanibel Island (Tom's Hills), in federal waters.

Phase III investigations included geophysical investigations (seismic and sidescan sonar) of the primary areas identified in Phase II investigation (CPE, 2003) and selection of two areas for detailed geotechnical (vibracores) and geophysical investigations. Phase III results identified two borrow areas located within offshore sand ridge complexes, namely N5 (Naples 5) and T1 (Tom's Hills) (Figure 2), that are detailed as follows.

RESULTS

Detailed seismic and sidescan sonar investigations and 50 vibracores were obtained for the definition of borrows N5 and T1. Borrow Area T1 is located in federal waters and required close coordination with the Mineral Management Service (MMS). Borrow Area N5, located in state waters, contains about 1.45 million cy of sand and T1 contains about 8.6 million cy of sand. The borrow areas are in ridge deposits that overlie the drowned west Florida 'peneplain' surface that is now a continental shelf (Hine *et al.*, 2003). Summarized textural information for these borrows is listed in Table 1.

Table 1. Final borrow area textural groin size information and volumes.

	Borrow Area N5	**Borrow Area T1**
Volume (cy)	1.45	8.6
Mean grain size (mm)	0.19	0.31
Percent silt (%)	5.8	2.45
Phi sorting	1.76	0.98
Munsell color	5Y 7/1	5Y 7/1
Distance from the Project Area	5 miles	30 miles

Borrow Area N5

This borrow is located at about 6 miles offshore Naples Beach (Figure 2) and consists of ridges bounded by subsurface depressions that are interpreted as solution holes (sinkholes) (Figure 3). The deposit contains 1.45 million cy of sandy sediments with highly variable shell and silt contents

Borrow Area N5 is a rectangular-shaped low-relief ridge that is angled about 45 degrees to the coastline. Water depths around the borrow range from 26 to 32 ft NGVD (Figure 4). High relief areas are located in the SE corner and along the center of the borrow dipping gradually to the North and to the West (Figure 4). Seaward of the borrow area (to the west) water depths decrease drastically over very short distances (Figure 4). The borrow area thus has an asymmetric shape with a gentler landward slope and a steeper seaward slope, possibly indicating offshore transport (*e.g.* Dyer and Huntley, 1999). The subsurface structure is complicated by karstic features on the underlying hardgrounds to produce complex deposit stratigraphy (Figure 3).

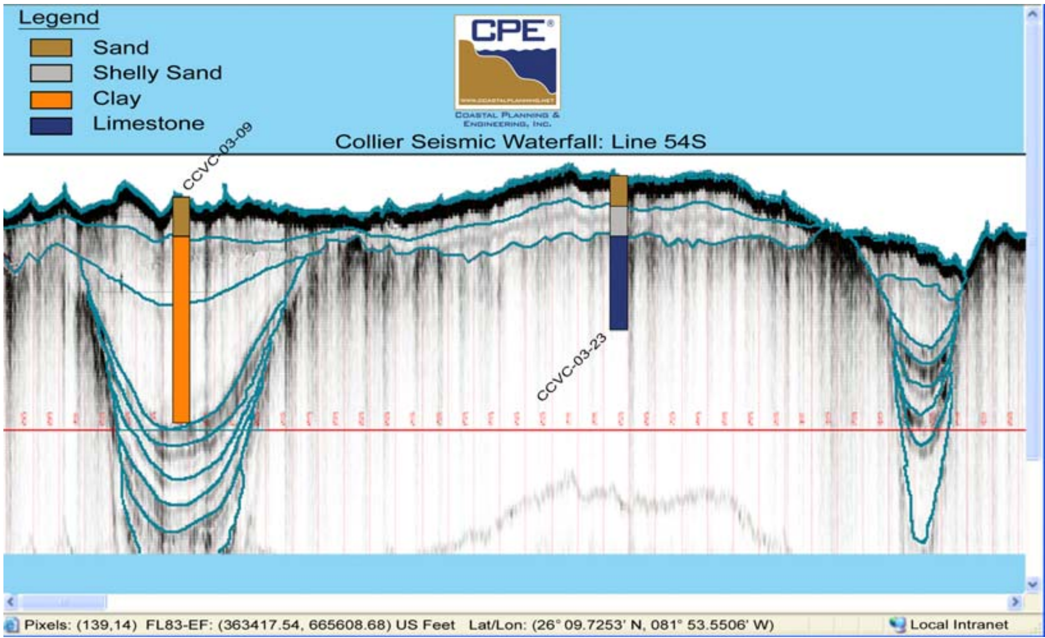

Figure 3. Seismic cross section of Borrow Area N5 showing sand ridge and sinkhole sedimentary sequences. The ridge area contains an upper sandy layer that grades downwards to shelly sand and limestone while the sinkhole is infilled with clayey sediments.

Greater sediment thickness is observed along the ridge crest, in the center of the borrow area (Figure 5). Isolated areas with greater deposit thickness (*e.g.* 10 ft 'mound' in Figure 5) are associated with infilled solution holes as shown in Figure 3. In general, surface sand thickness (excluding solution holes that are infilled with fines) range from 3 to 6 ft (Figure 5).

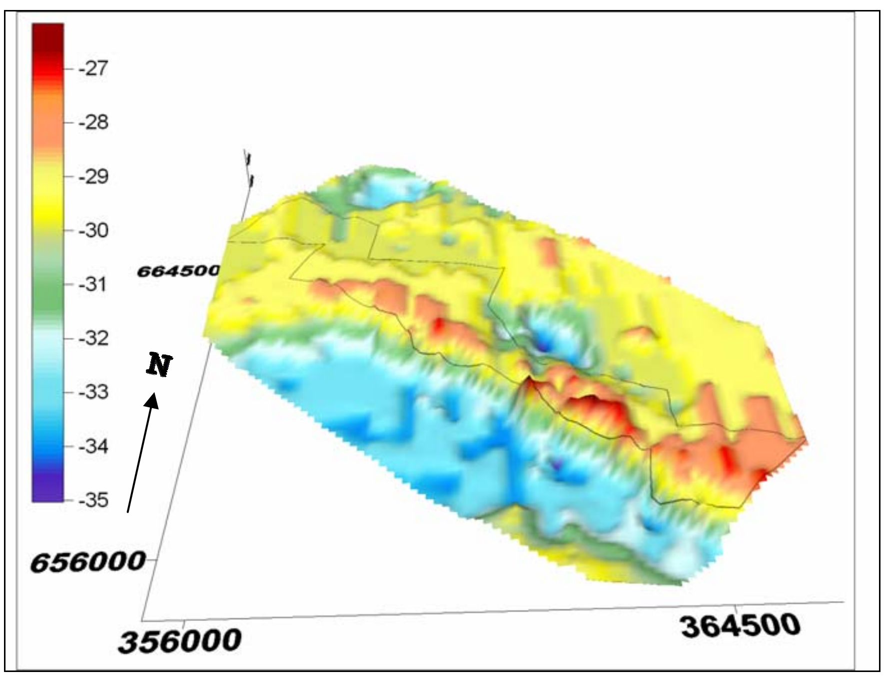

Figure 4. Digital terrain model of bathymetric data (in ft) for Borrow Area N5. The borrow area boundary is shown by the black line. Coordinates are in NAD83 Florida State Plane East.

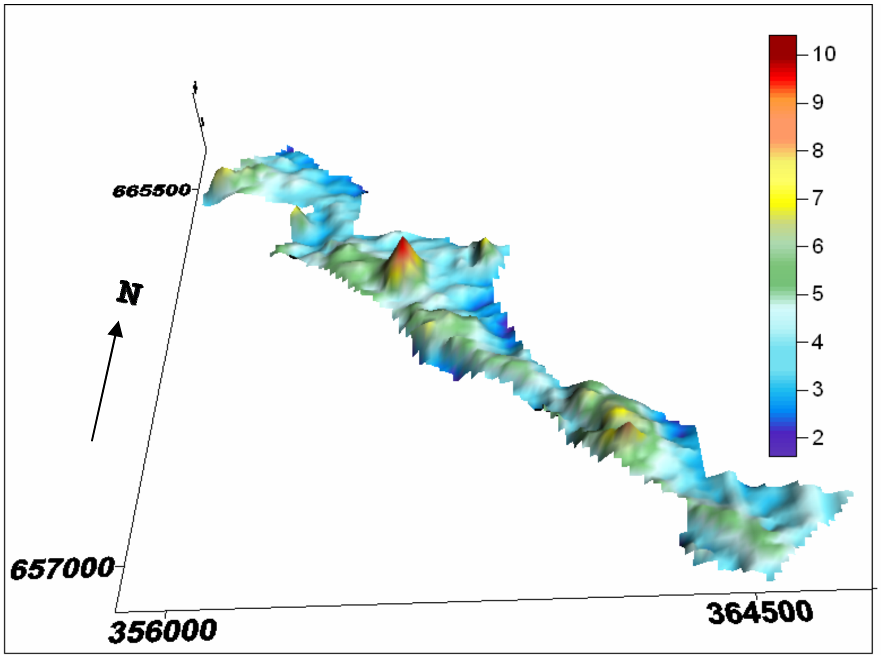

Figure 5. Digital terrain model of isopach data within Borrow Area N5 boundaries. Thickness is displayed in ft and coordinates are displayed in NAD 83 FL State Plane East.

Seventy-eight (78) samples were analyzed from 23 cores within Borrow Area N5 (vibracore locations and borrow area boundaries are shown in Figure 6). Summary results indicate a sediment mean grain size of 0.19 mm (fine-grained sand), with a phi sorting of 1.76 (poorly sorted) and 5.8 % silt. In terms of general trends, percent silt increases with depth as does shell content (hash, fragments & whole shells); carbonate clasts commonly occur at depths greater than 6 ft (Figure 6).

Analysis of the sidescan sonar data identified some hardground exposures adjacent to the borrow area. Limestone bedrock is commonly exposed on the sea floor of the west coast of Florida between subsequent sedimentary ridges (*e.g*. Locker *et al.,* 2003) and the data obtained here verifies this pattern.

Depths of cut in the borrow area range from 32 ft NGVD in the northwest section of the borrow area to 28.5 ft NGVD in the southern segment (Figure 6). The borrow area contains a total of 1.45 million cy of sand with depths of cut defined above discontinuities marked by rock rubble and shelly-silty layers.

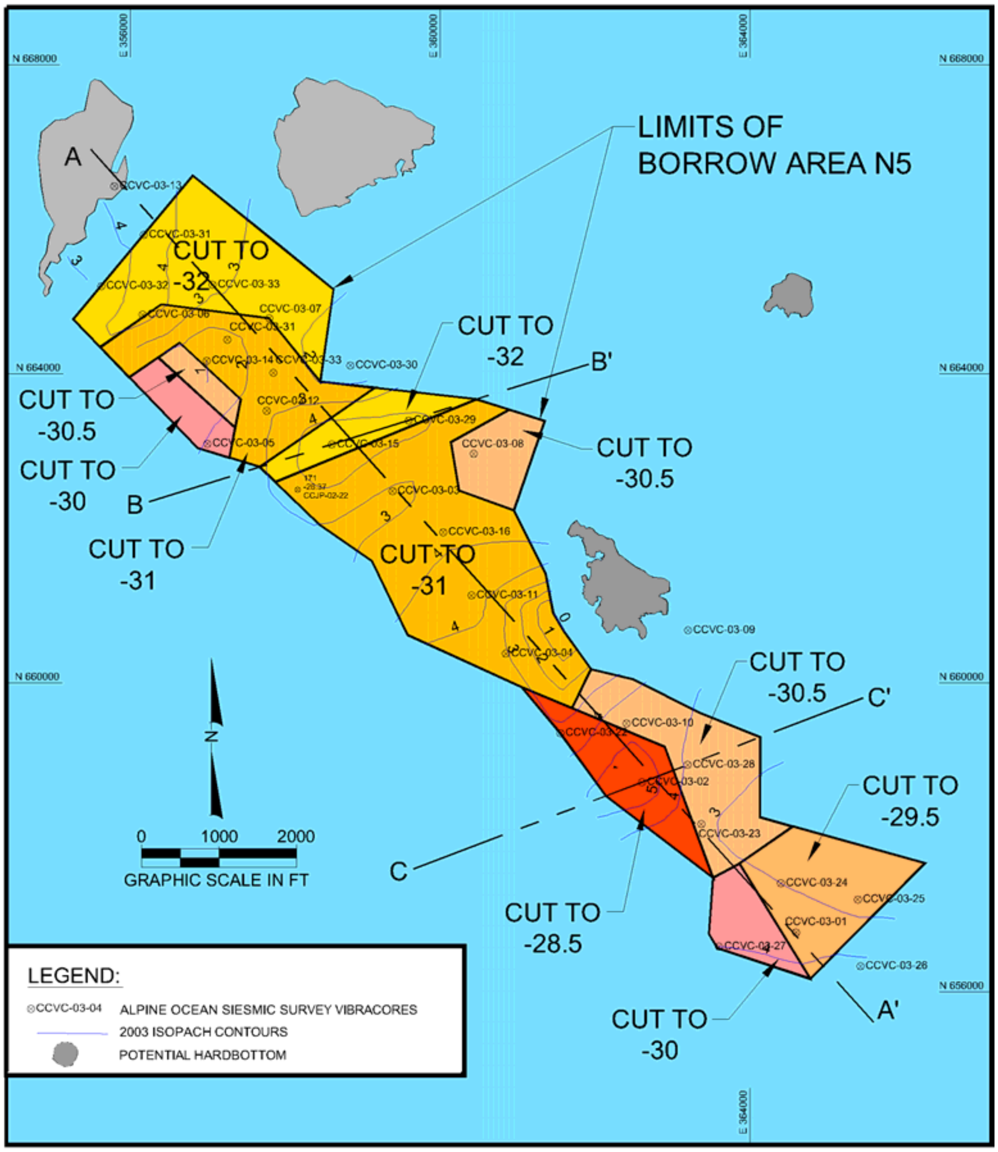

Figure 6. Final cuts and sediment isopachs for Borrow Area N5. Isopachs were generated by interpolation of vibracore and seismic data. Sediment thickness fluctuates from 1 to 5 ft but averages 3 ft.

Borrow Area T1

Borrow Area T1 is located in federal waters, about 33 miles northwest of Vanderbilt Beach and is part of an extensive ridge field that trends SE-NW (Figure 1). Seismic survey indicated that sand deposits are relatively high relief ridges (20 ft crest) that lie unconformably on top of pre-Holocene hardgrounds of irregular relief (drowned karstified surface) (Figure 7). These ridges show a typical asymmetry with a steeper seaward slope and a gentler landward-facing slope (Figure 8). Borrow Area T1 is located on the northwest corner of one of these ridges and contains about 8.6 million cy of relatively clean medium sand.

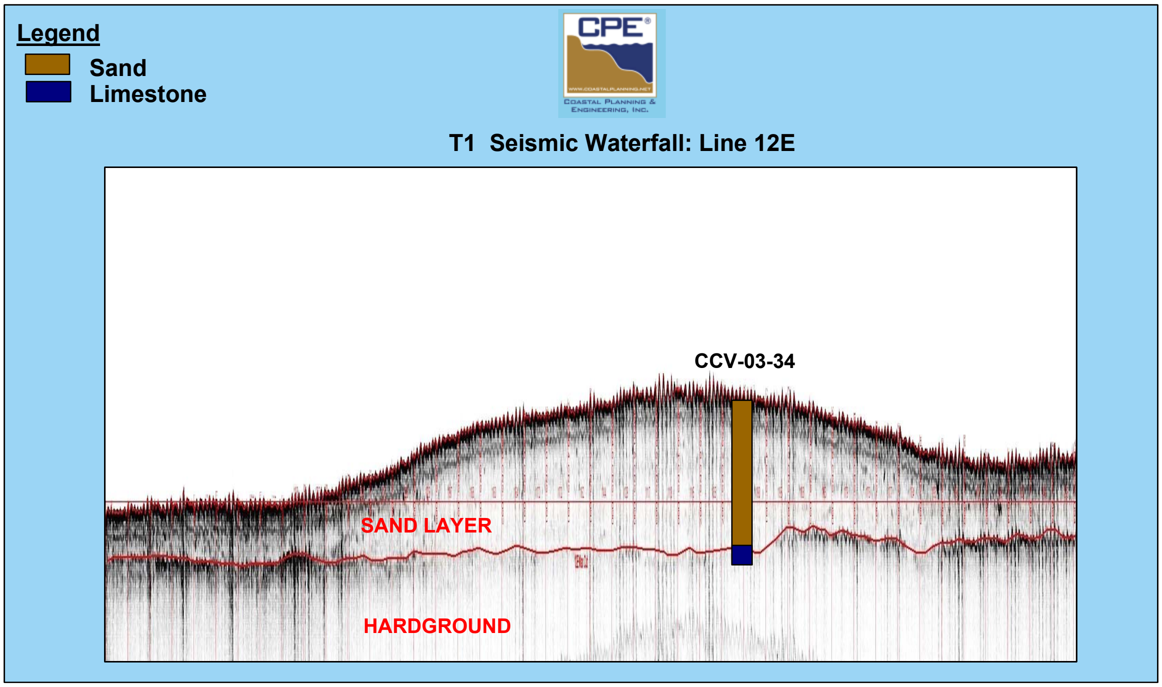

Figure 7. Cross-section across the sand ridge in Borrow Area T1.

Water depths in the borrow area fluctuate from 36 ft to 54 ft and increase from minimum depths of around the 36-39 ft NGVD in the center (ridge crest), to 40-46 ft NGVD to the east (gentle slope) but depths increase abruptly to the west (offshore facing segment) reaching 54 ft depth on its NW corner (Figure 8).

Vibracores from the center of the ridge reached limestone rock fragments at a depth of about 20 feet (about -55 ft to -65 ft NGVD). The borrow area has a general sediment thickness that ranges from of 3 to 20 feet (Figure 9). Thickness follows the same general trend as surface bathymetry with greater thickness located in the center of the borrow area (ridge crest). To the east of the crest, sediment thickness generally ranges from 8 to 12 ft and in the western edge of the borrow area, there are thinner sections.

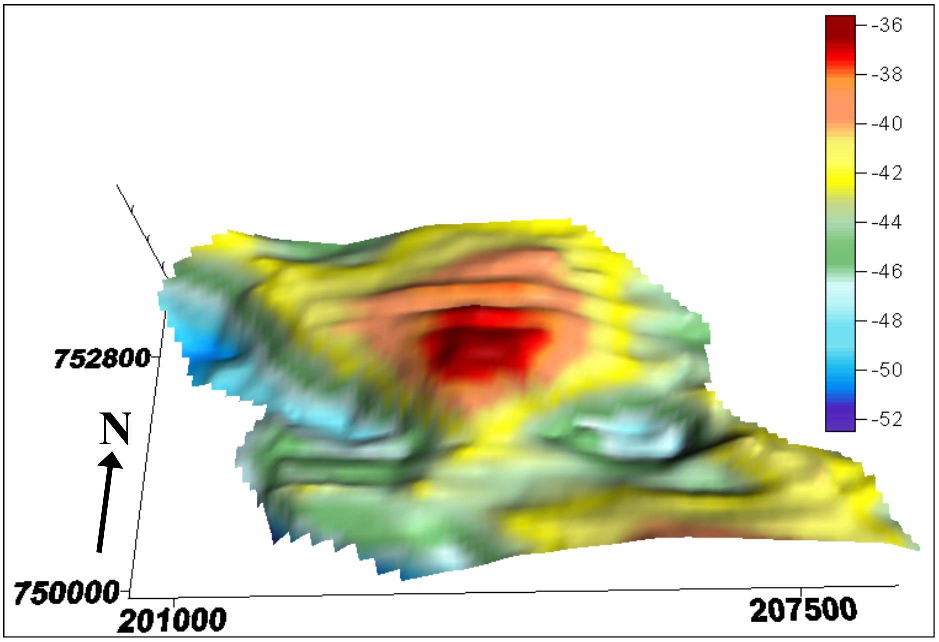

Figure 8. Three-dimensional display of bathymetric data for Borrow Area T1. Elevations are in ft NGVD and coordinates are in NAD83 FL State Plane West.

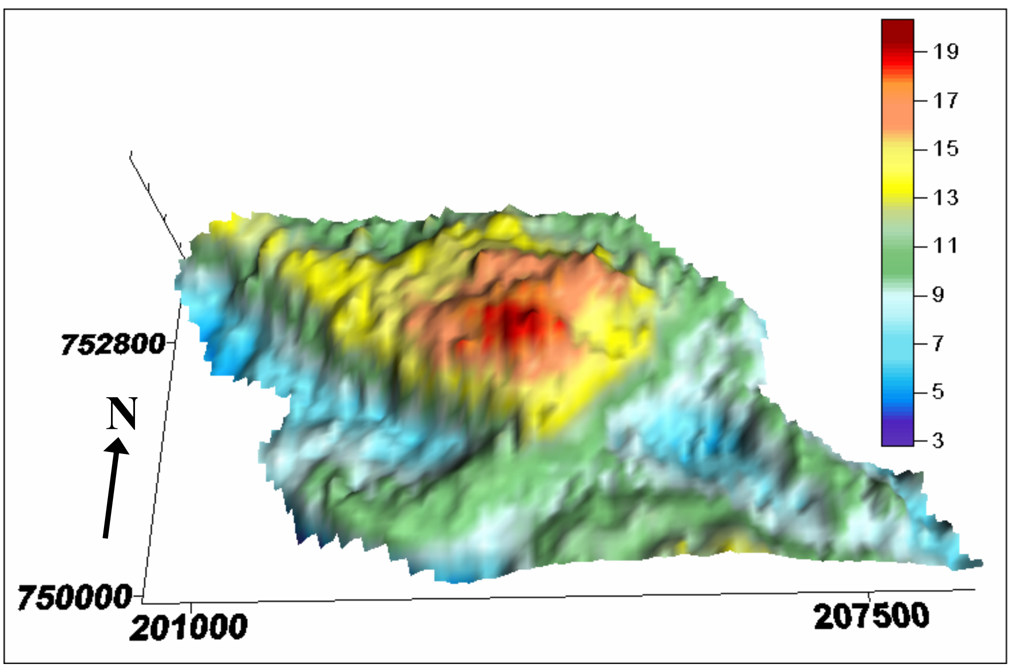

Figure 9. Sediment thickness dropped over seafloor topography for Borrow Area T1. Sediment thickness is displayed in feet and coordinates are in NAD 83 FL State Plane West.

The superimposition of bathymetry on top of the subsurface hardbottom surface (mapped from the seismic record) (Figure 10) shows the pattern of sedimentation as it relates to the uneven hardbottom subsurface. The northwest corner of the borrow area, sediments mapping up the ridge thin out almost to bedrock. (Figure 10).

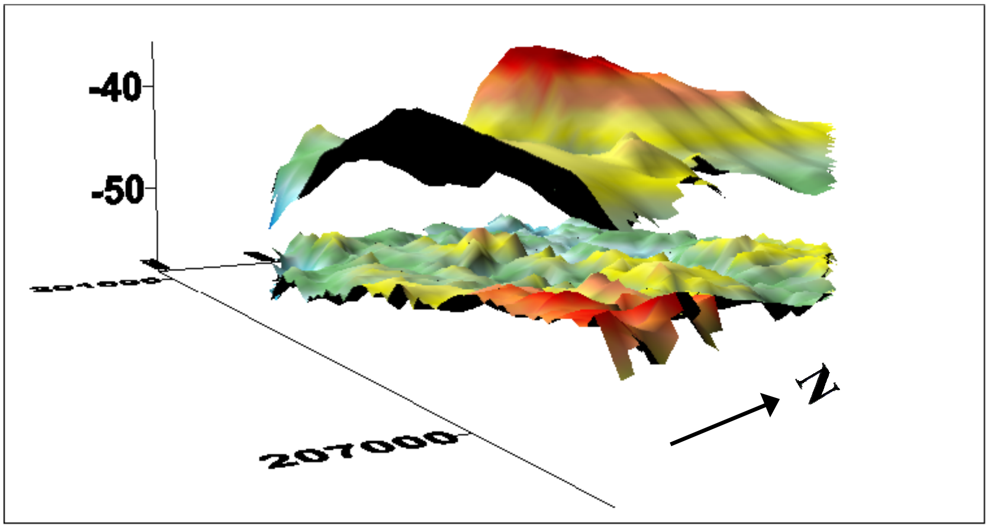

Figure 10. Overlay of T1 bathymetry and bedrock surface that facilitates visualization of sediment thickness. Elevations are in ft NGVD.

A total of 91 samples were analyzed from 17 cores within Borrow Area T1. Summary results (composites) indicate that T1 contains a mean grain size of 0.31 mm (fine to medium sand), with a phi sorting of 0.98 (moderately sorted), Munsell color 5Y 7/1 (light gray) and 2.45 % silt content (Table 1).

In terms of general trends, grain size decreases and percent silt increases with water depth. Sediments within the borrow area exhibit a coarsening upward sequence. Exceptions to the general trend include few basal layers where carbonate clasts of underlying bedrock occurres.

Depths of cut vary from -54 ft NGVD in the NW section of the borrow area, to -45 ft NGVD in SE section. The final borrow area design, location of vibracores and depths of cut is shown presented in Figure 11**.**

DISCUSSION ON ORIGIN OF SAND RIDGES, REWORKING AND MAINTENANCE

Evolution of Sand Ridges on the Southwest Florida Continental Shelf

Sand ridges on the inner shelf off west-central Florida form extensive fields that extend from 2 km off the beach to 25 km offshore. Stratigraphically, the sand ridges are separated from underlying Pleistocene and Tertiary carbonate strata by a Holocene ravinement surface (Twichell *et al.,* 2003). The top of the oldest unit, the present hard rock seafloor, is probably the late Oligocene to early Pliocene Hawthorn Formation, a phosphate-rich limestone and dolostone (Davis and Hine, 1989). Depressions in this unit, which are related to karst topography, contain Pleistocene and older strata immediately below the ravinement surface cut during the Holocene marine transgression. The youngest unit is the sediment that comprises the ridges themselves (Twichell *et al.,* 2003). The ravinement surface that separates the ridge deposits from older deposits is flat, and has only a thin discontinuous veneer of sediments in troughs between the ridges. The flatness of the surface suggests that there has been minimal erosion of trough floors during the Holocene rise in sea level.

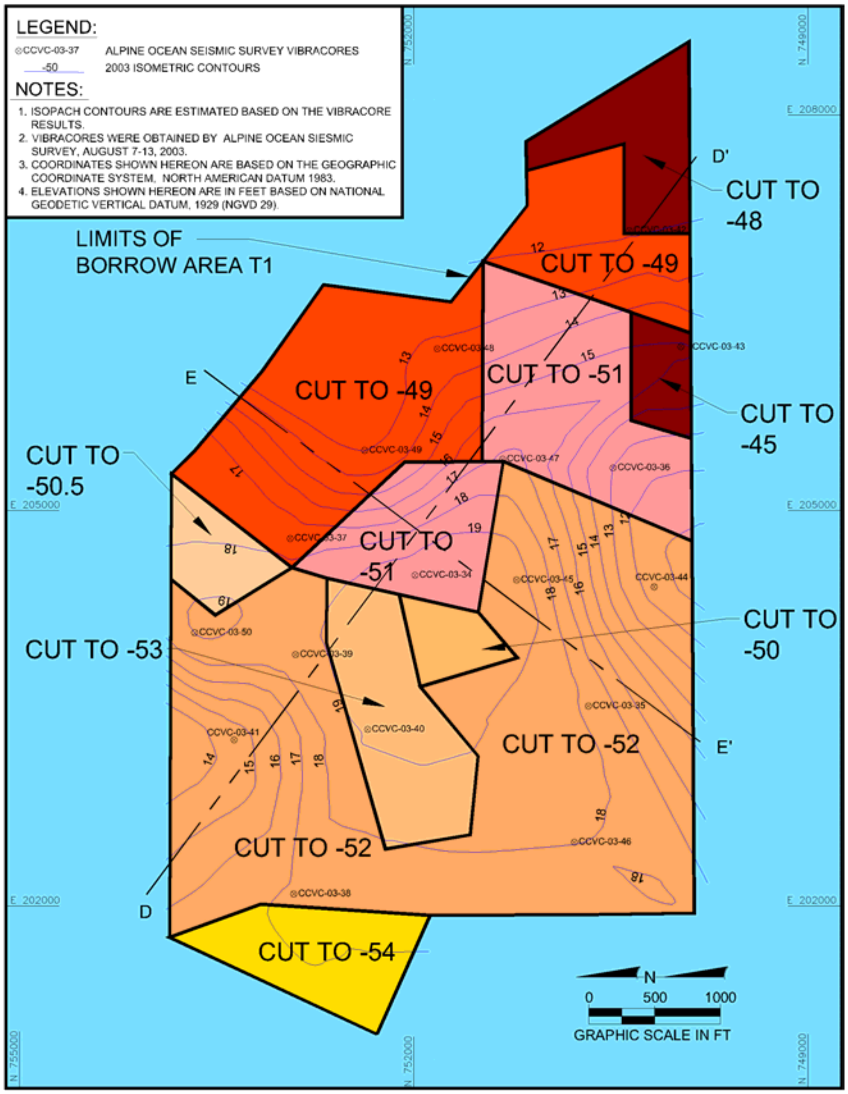

Figure 11 Borrow Area T1 final cut and isopach.

Borrow Area N5

One interesting textural parameter of the ridge field in Borrow Area N5 is the general coarsening downward trend. Other ridges, *e.g.* Longboat Key (CPE, 2003) and Captiva Island (CPE, 2002) on the west coast of Florida, show a general coarsening upward trend. This stratigraphic trend and particle size differentiation (coarsening upward) is characteristic of drowned shorelines that can be explained in terms of accelerated sea-level rise where barrier-beach environments advance on top of backbarrier lagoon sediments prior to submergence (*e.g.* Penland *et al.*, 1988). The N5 ridges do not, however, contain this characteristic morphostratigraphic signature. Rather, they are either relatively low-relief ridges sitting on top of shallow-water where there was perhaps no accommodation space for deposition and preservation of the full stratigraphic sequence or were originated by mechanisms other than being drowned shorelines. Amos and King (1984), while investigating European ridges, suggested that ridges are remnants of paleo-barrier islands and have thicknesses on the order of 60 to 90 ft. Because the west coast of Florida is sediment starved, coastal segments with bedrock exposures are not expected to contain such thick deposits. Some consideration, however, must be given to the fact that submerged barrier islands exhibit thicker deposits than remnants of ebb-tidal deltas or eddy flows around headlands. Because the ridges of N5 are relatively thin and characterized by coarsening downward trends (with high shell and silt contents), it is hypothesized that they are byproducts of paleo ebb-shoals and abandoned as described by McBride and Moslow (1991) and reworked by modern shelf process as described by Huthnance (1982) and Dyer and Huntley (1999). Because coarse-grained sediments offer more resistance to transport (sands and shells), they were deposited and preserved on top of underlying bedrock. As energy flow through the tidal channel decreased and the deposit became abandoned (shoreline retreat), finer sediments were deposited on top of the sequence as it was gradually reworked and re-oriented by modern shelf processes (wave and current refraction).

Borrow Area T1

The stratigraphic succession of T1 from top to bottom is generally characterized by: (1) relatively clean sands in top layers (*e.g.* upper 10 to 15 ft) representing beach-barrier depositional environments, (2) slightly fining downward (coarsening upward) trend to the underlying hardground surface.

The ridge is composed of clean, sandy sediments that resemble surf zones and beaches on the Gulf coast. The ridge fields in Borrow Area T1 ressemble in morphological and textural characteristics to the *en-echelon* banks described by Dyer and Huntley (1999). This similarity is verified by: (1) steeper seaward slopes that indicate offshore movement, (2) complex patterns with S-shaped ridges, and (3) location offshore from a retreating sand headland. En-enchelon banks occur where there is active retreat of sedimentary headlands formed by the convergence of littoral drift (*e.g.* Sanibel Island). A complicating factor landward of the Captiva-Sanibel ridge field involves the presence of Blind Pass that episodically closes and may have contributed sediments to ridge formation during flooding events. Evidence of small tidal channel occurrence in Borrow Area T1 is shown in the seismic record along its southeastern corner. The sedimentary features in the southeast part of T1 average about 6 ft thick and range from 90 to 150 ft in width. The sinuosity of the thalweg and channel dimensions identified in the seismic record indicates the presence of tidal channels. The retreat path of the inlet-tidal channel complex and the adjacent curved shoreline of Captiva-Sanibel ('sand headland') contributed to the formation of successive banks or ridges on the inner shelf in a stepwise manner forming a regressive sequence, part of which became abandoned on the inner shelf and re-worked by modern shelf/oceanographic processes. The seafloor morphology see today is referred as ‘sand ridges’ on the seafloor, or 'en-enchelon sand ridges' as defined by Dyer and Huntley (1999).

RIDGE REWORKING BY MODERN SHELF PROCESSES

The shoreline-oblique (30º-50º), inner shelf sand ridges offshore southwest Florida occur in an environment that is underlain by limestone and covered by a thin veneer of mixed carbonate and siliciclastic sands and gravels (Edwards *et al.*, 2003; Locker *et al.*, 2003). The ridges tend to be thicker and more widely spaced with increasing water depth, as observed along the New Jersey coast (*e.g.* Stubblefield *et al.*, 1984; Rine *et al.*, 1991).

Theories for seabed features consider the interacting system of water and sand and the feedbacks between both (termed morphodynamics). A common observation of large-scale bed features (ridges) is that they are generally inclined at an angle to the coast, or inclined in relation to the main axis of flow. Huthnance (1982) explained the growth and realignment of ridges by combining effects of cross-bank and along bank flows (current refraction). In his theory, Huthnance described that the along crest component of currents will be reduced by influence of friction turning the current vectors toward the ridge crest. In a cross-bank scheme, the flow speed is reduced on the downstream side of the bank due to friction over the ridge, thus inducing sediment transport toward the ridge area. For the Florida western shelf ridges recent current meter data indicates that the critical threshold velocity of sediment transport is frequently exceeded (Harrison et al., 2004), so that these sand ridges and bedforms are influenced by modern storm-induced bottom flows.

CONCLUSIONS

Re-interpretation of seafloor sediments on the continental shelf of southwest Florida near Naples indicates that: (a) nearshore seabed (within 3 km of the shore) typically does not constitute an appropriate source of beach material because bedrock lies at a shallow depth below a thin layer of inner shoreface sand (exceptions occur in ebb-tidal shoals); (b) infilled collapsed karst features or eroded surfaces in drowned paleo-channels and infilled sinkholes are now recognized as unsuitable sources of beach-compatible sands because they contain silt and clay; and (c) potential deposits containing beach-compatible sands are likely to be associated with specific morphostructures such as offshore linear sand ridges oriented oblique to the shore.

Sandy ridges along this stretch of coast are related to the migration of active inlets (*e.g.* N5), eddy flows and shoreline retreat adjacent to shoreline re-orientations (*e.g.* T1). These ridges are reworked by storm induced flows and evolutionary sequences based on morphodynamic-seabed stability may adequately describe ridge growth and development after abandonment on the inner shelf.

Two Borrow areas identified in this study are feasible to exploitation contain sufficient volumes of beach-quality sediments.

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