

Final Technical Report for Award N00014-11-1-0061: Reconnaissance Marine Geophysical Survey for the Shallow Water Acoustics Program

John A. Goff

Institute for Geophysics, Jackson School of Geoscience, University of Texas at Austin
JJ Pickle Research Campus, 10100 Burnet Rd. (R2200), Austin, TX 78758
phone: 512-471-0476; fax: 512-471-0999; email: goff@ig.utexas.edu

LONG-TERM GOALS

Provide geophysical and geological environmental characterization in support of Office of Naval Research shallow water acoustics experiments.

OBJECTIVES

Conduct a reconnaissance CHIRP subbottom reflection and vibrocoring survey offshore Panama City, Florida, in advance of the ONR shallow water acoustics reverberation experiment that was conducted in 2013. Analyze data for a scientific study of shoreface ravinement and the formation of the Holocene sand sheet.

APPROACH

The transgressive ravinement surface is an important boundary within stratigraphic sequences, forming the base of transgressive systems tracts (Thorne and Swift, 1991). It forms by erosional back-stepping of the equilibrium shoreface profile during sea level rise, transferring eroded sediment from barrier, estuarine and relict sediments below the shoreface to the marine sand sheet overlying the ravinement (Bruun, 1962; Swift and Thorne, 1991). The classical schematic model for shoreface ravinement suggests that pre-Holocene substrate is exposed at the base of the shoreface (Swift and Thorne, 1991, their Figure 9; Thorne and Swift, 1991, their Figure 10). That model is complicated, however, where shoreface-attached sand ridges are present. Sand ridges are large, dune-like features that are oriented oblique to the shoreline, and commonly present on storm-dominated shelves where the sand supply is abundant (Goff et al., 1999, Schwab et al., 2013). Where present, they bridge the lower shoreface to connect shoreface sand with marine sands, and pre-Holocene substrate is only exposed in narrow windows at the base of swales (Schwab et al., 2013). How sand ridges form is a matter of spirited debate in the literature (see Goff et al., 1999 for review), but observationally we know these facts (e.g., Swift and Field, 1981): (1) sand ridges form as shore attached features, and become detached from the shoreline with continued shoreline transgression; (2) the acute angle with respect to the shoreline faces the along-shore current direction; and (3) sand ridges migrate in the direction of their obtuse angle, in dune-like fashion eroding on the upcurrent flank and depositing on the downcurrent flank. That sand ridges form and are most active in the shoreface zone where shoreface ravinement is required by geometric considerations is suggestive of a causal link between the two processes.

In this study I investigate possible linkages between shoreface ravinement and sand ridge formation using data collected during a recent near-shore to inner-shelf CHIRP and vibracore survey off of Panama City, Florida (Fig. 1). This portion of the Florida shelf is covered by the “MAFLA” (Mississippi, Alabama, FLoridA) sand sheet: marine sands up to 5.5 m thick underlain by the transgressive ravinement surface that separates it from Holocene estuarine muds and Pleistocene clayey sand (McBride et al., 2004). Much of the MAFLA sand sheet is formed into sand ridges (McBride et al., 1999; Richardson et al., 2001). The Holocene transgressive ravinement, associated with ongoing sea level rise since the Last Glacial Maximum (LGM), is often well-imaged in high-resolution acoustic reflection data, such as CHIRP (Nordfjord et al., 2009; Schwab et al., 2013). This surface is observed on the shelf either because of the physical contrast between Holocene sands above and Pleistocene or estuarine material below (often residing in buried river channels), and/or because of the presence of an erosional lag, which is often diagnostic of the ravinement (Richardson et al., 2001; McBride et al., 2004; Snedden et al., 2011). The Panama City survey was particularly chosen to span an important along-shore transition in both shoreface physiography and sand ridge morphology (described below). This provides a unique opportunity to investigate coincident changes in the seismically- and core-determined ravinement surface that might establish a causal relationship.

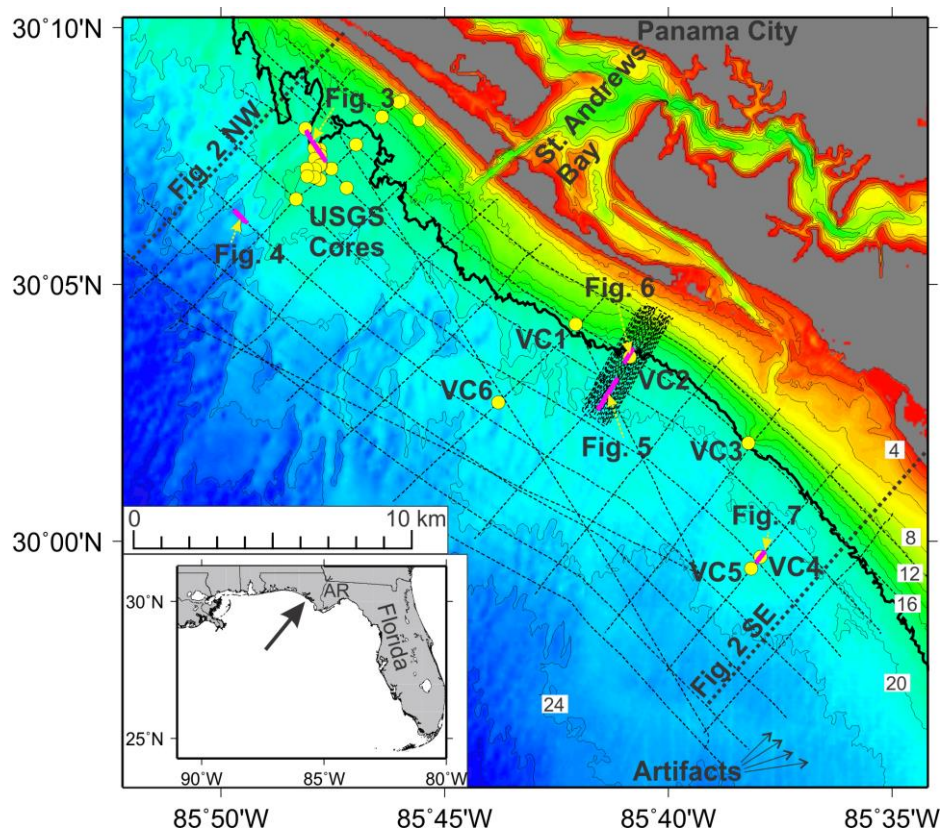


Figure 1. April, 2011 CHIRP track lines (dashed) overlain on regional bathymetry map offshore Panama City, Florida and St. Andrews Bay. April, 2011 vibracores (VC1-6) locations are also shown, as are prior cores collected by the USGS in the NW sector of the survey area.

WORK COMPLETED

The reconnaissance CHIRP and coring survey was completed successfully in April, 2011 aboard the R/V *Sharp* (Fig. 1). The CHIRP data have been processed for fish depth, heave and layback. The

CHIRP data have been fully interpreted. The vibracores have been split, photographed and sampled at 10-cm intervals for grain size analysis, which has also been completed.

RESULTS

The selected survey region lies offshore of Panama City and St. Andrews Bay, on the Florida panhandle (Fig. 1), in water depths ranging from ~8 m to ~24 m. Two important morphological transitions are observed in this region (Figs 1), and illustrated on profiles shown in Figure 2:

(1) The shoreface profile is narrower and steeper in the NW sector than the SE sector. Taking ~18 m water depth as the base of the shoreface (marking the primary inflection point that marks the sudden steepening of the profile above the regional trend), the shoreface in the NW sector extends ~2.1 km from shore, whereas the shoreface in the SE sector extends ~4.3 km from shore (Fig. 2). The steepest measured trend on the NW profile is 1.26° , whereas on the SE profile it is 0.28° (Fig. 2).

(2) Sand ridges are present in the NW sector but absent in the SE sector. Sand ridges are generally oriented ~N-S, oblique to the NW-SE trending shoreline (Fig. 2). The ridges form an acute, $\sim 45^\circ$ angle with the shoreline in relation to the northwestward longshore drift (Gorsline, 1966). Sand ridge heights are typically ~1-2 m (NW profile on Fig. 2), and the bedforms are present on the lower slope of the shoreface as well as the inner shelf. The SE profile only exhibits small-scale variations, much of which is likely artifacts associated with N-S-trending tracklines of the archival data used to construct the bathymetric grid (Fig. 2).

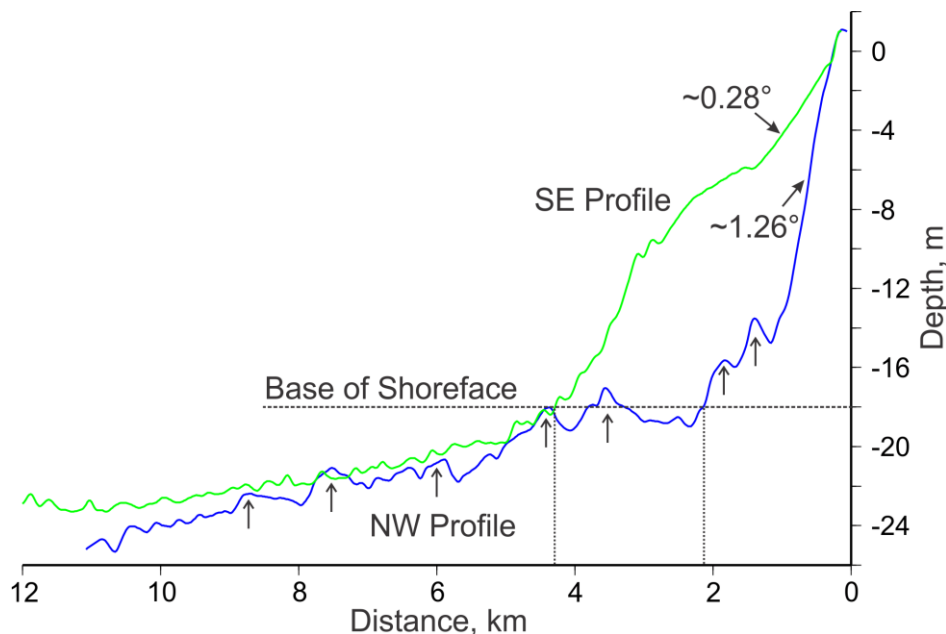


Figure 2. Shore-normal bathymetric profiles from NW and SE sectors of survey. Location shown on Figure 1

The transition between the two types of terrain is complicated by the artificially-constructed inlet channel for St. Andrews Bay (Fig. 1). Ebb-tidal sediments appear to be accumulating in this region, creating a bulge in the base of the shoreface as evidenced by the highlighted 18-m isobath shown in Figure 1. Sand ridge are obscured in this region, but are again in evidence to the SE as far as longitude $\sim 85^\circ 40' \text{W}$.

A CHIRP cross section along a strike line through a sand ridge in the NW sector of the survey area (Fig. 3) demonstrates two important subsurface horizons mapped in this analysis: Channel Base and Ridge Base. The Channel Base horizon underlies a buried river or channel. Such channels are very useful indicators in transgressive stratigraphy (Foyle and Ortel, 1997; Nordfjord et al., 2009): they erode into relict Pleistocene material, preserve estuarine fill sediments within them, and underlie the transgressive ravinement surface. Draped laminations within the channel (Fig. 3) are diagnostic of preserved estuarine fill (Nordfjord et al., 2006).

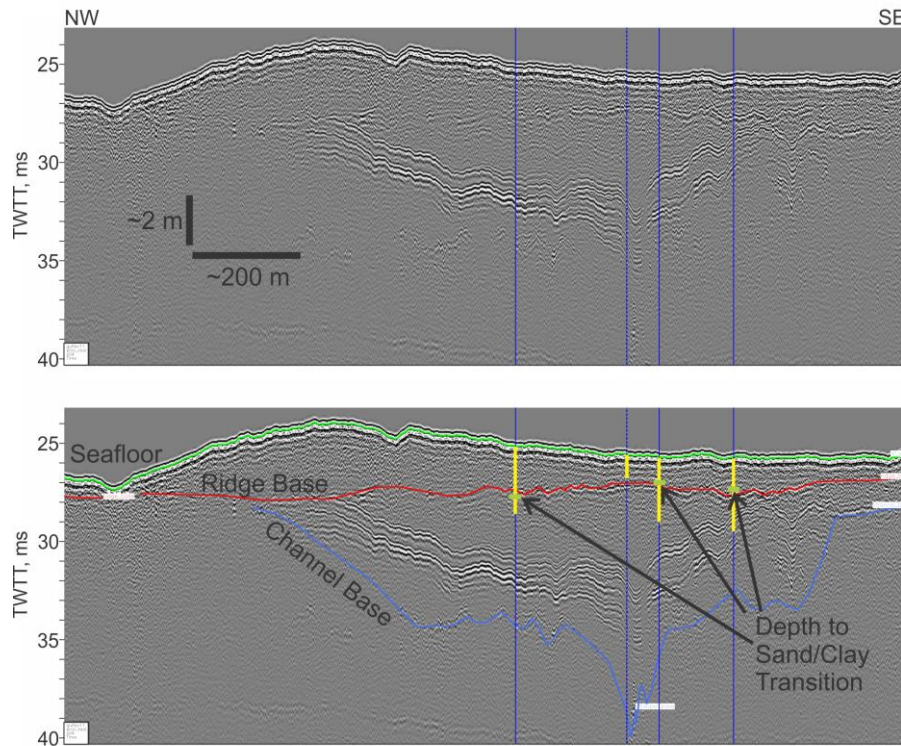


Figure 3. Uninterpreted (top) and interpreted CHIRP data from NW sector of survey. Location shown on Figure 1.

The Ridge Base horizon is a mostly flat-lying reflector that underlies the sand ridges, diagnostically either outcropping at or becoming very close to the seafloor in the deepest parts of the swales between the ridge crests (Fig. 3). The maximum thickness of the ridge overlying the Ridge Base is approximately 4 ms two-way travel time (twtt), or ~3.4 m (a sound velocity in sand of 1700 m/s is assumed here and elsewhere for converting two-way travel time to depth). In the cross section of Figure 3, the Ridge Base also serves to cap the channel horizon, truncating some of the channel fill laminations as well as the Channel Base horizon. Given that the sand ridges constitute the mobile marine sand sheet (reference), the Channel Base horizon in this example must be coincident with the transgressive ravinement surface. USGS cores penetrating this horizon indicate that reflector represents a transition from sand above to clay below (Fig. 3).

The reflection characteristics of the Ridge Base horizon change considerably where it is not underlain by a buried channel (Fig. 4). Rather than exhibiting a clear, continuous reflector as in the previous example, here the horizon is marked by a highly sporadic nature, and is often difficult to trace with confidence. A similar sporadic nature to this horizon was also seen in CHIRP data collected in during the SAX99 survey over a sand ridge offshore of Fort Walton Beach, Florida (Richardson et al., 2001).

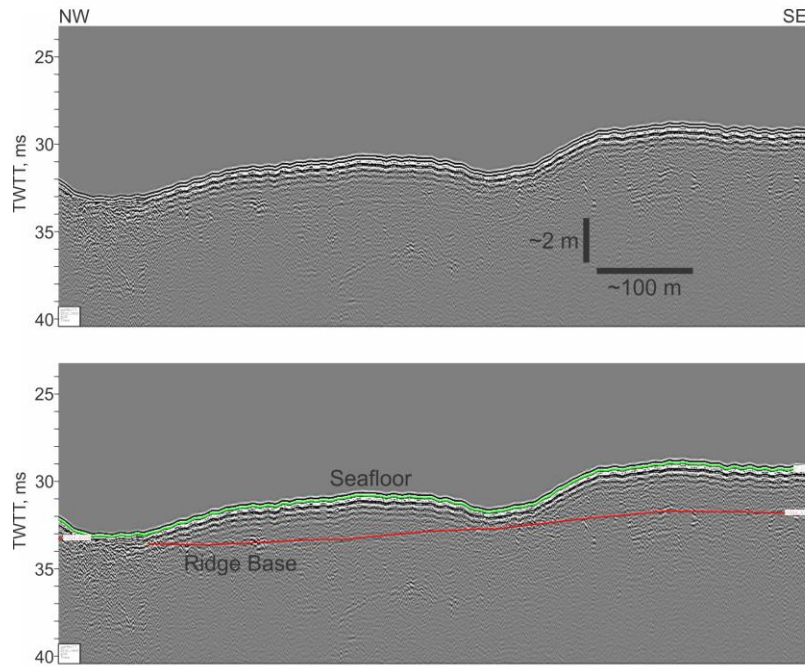


Figure 4. Uninterpreted (top) and interpreted CHIRP data from NW sector of survey. Location shown on Figure 1.

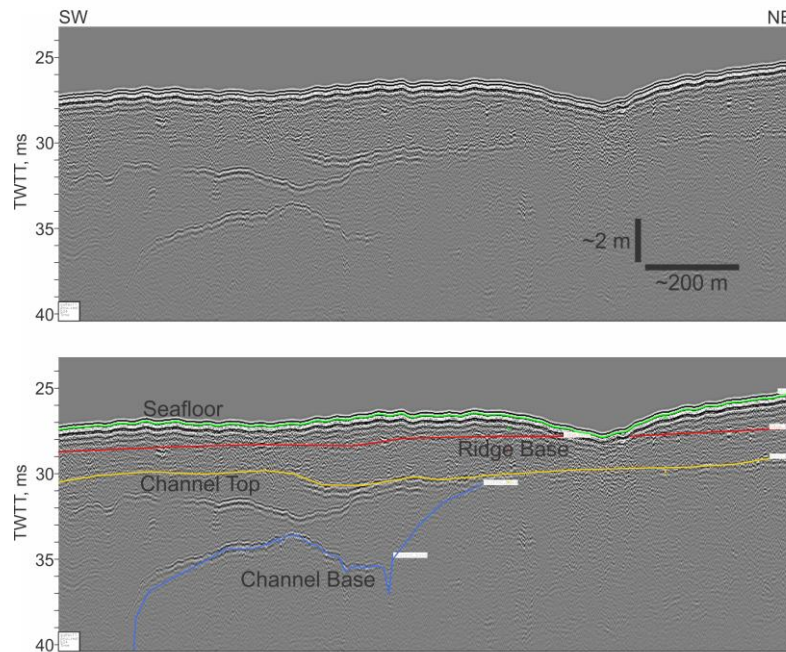


Figure 5. Uninterpreted (top) and interpreted CHIRP data from central sector of survey. Location shown on Figure 1.

Moving to the central portion of the survey area, in the area of the box survey (Fig. 1), we find that the stratigraphy exhibits added complexity (Figs. 5). Although Channel Base and Ridge Base reflectors are again observed, the Ridge Base reflector is not coincident with the top of the channel infill as

observed in the NW sector (Fig. 3). Instead we observe a third reflector capping the channel fill, which is referred to here as the Channel Top horizon. In this case, both the Channel Top and Ridge Base horizons are candidates for the transgressive ravinement surface. The channel imaged in Figure 5 is among the deepest observed in the survey, extending at least 50 ms twtt, or ~20 ms (~17 m) below the Channel Top horizon.

Shoreward of Figure 5, Figure 6 displays CHIRP reflection data that includes the location of core VC2. Channel Base, Channel Top and Ridge Base reflection horizons are again observed. The channel imaged in this section is much smaller, however, with a high-amplitude, chaotic basal reflector extending only 4 ms (~3.4 m) below the Channel Top. The interior of the channel does not exhibit any laminated reflectors, and the Channel Top reflection is only sporadically in evidence. Nevertheless, the horizon itself can be inferred from the position of the highest point of the Channel Base reflector, which is, furthermore, contiguous with the well-imaged Channel Top reflector observed to the SW in Figure 5. In both Figures 5 and 6, the Ridge Base horizon is above the Channel Top horizon by 1.5-2.5 ms (~1.2-2.0 m). The sand ridges imaged in both these plots are smaller than observed in the NW sector, with peak thicknesses above the sand base of ~2 ms (~1.7 m). Core VC2, which penetrated the Ridge Base horizon but not the Channel Top horizon, is discussed below.

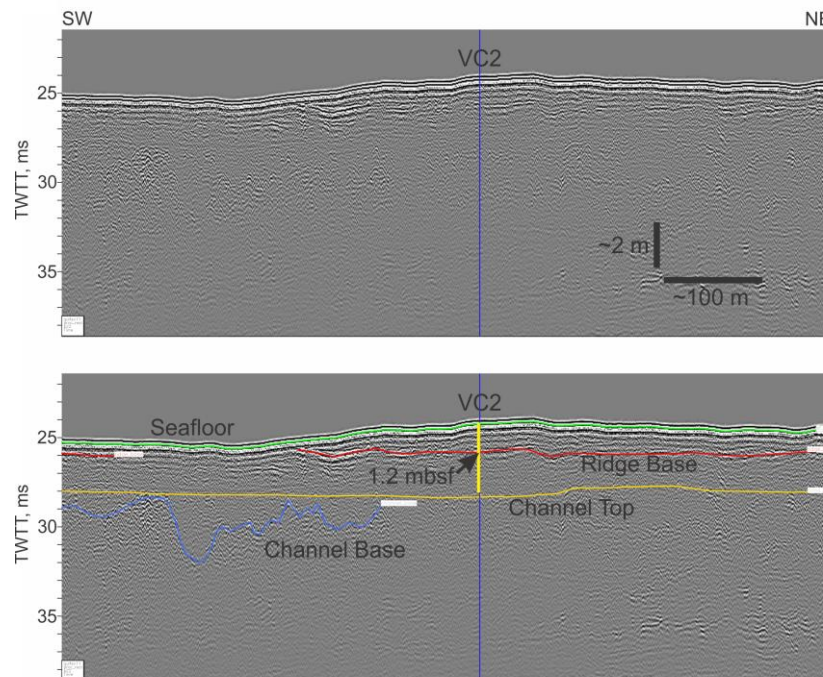


Figure 6. Uninterpreted (top) and interpreted CHIRP data from central sector of survey. Location shown on Figure 1.

Figure 7 displays CHIRP reflection data in the SE sector of the survey area, crossing core VC4. Another deep channel is imaged in this example, with a Channel Top horizon that truncates laminations in the channel fill section, and is therefore interpreted as a ravinement. The channel imaged in Figure 7 is also among the deepest observed in the survey, with a Channel Base horizon extending up to 22 ms below the Channel Top horizon (well below the bottom of the image). No sand ridges are observed in this region, and likewise no Sand Ridge Base reflector. Core VC4, which penetrated ~1 m below the seafloor, did not penetrate the Channel Top horizon; this core is discussed below.

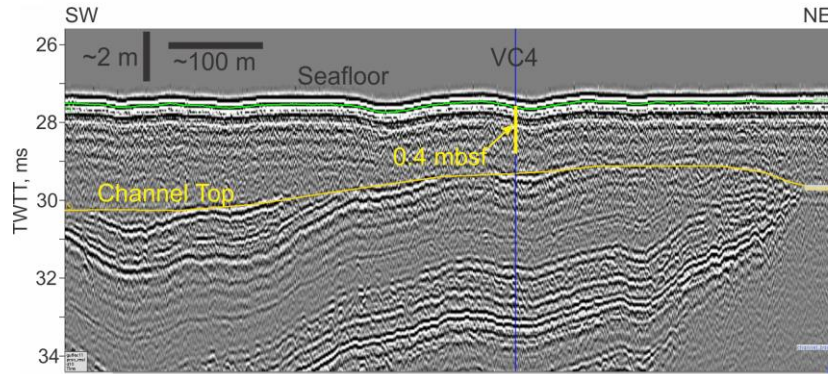


Figure 7. Interpreted CHIRP data from SE sector of survey. Location shown on Figure 1.

Interpreted Channel Base depths are presented in map view in Figure 8, along with an interpretive tracing of the possible thalweg traces. The channels are both sinuous and dendritic, and are interpreted here as paleo-river valleys. The grid survey (Fig 8, insert) provides enough density of coverage to make out greater details of what appear to be small tributaries (observed in Figure 6) trending southeast toward intersection of a much larger channel (observed in Figure 5).

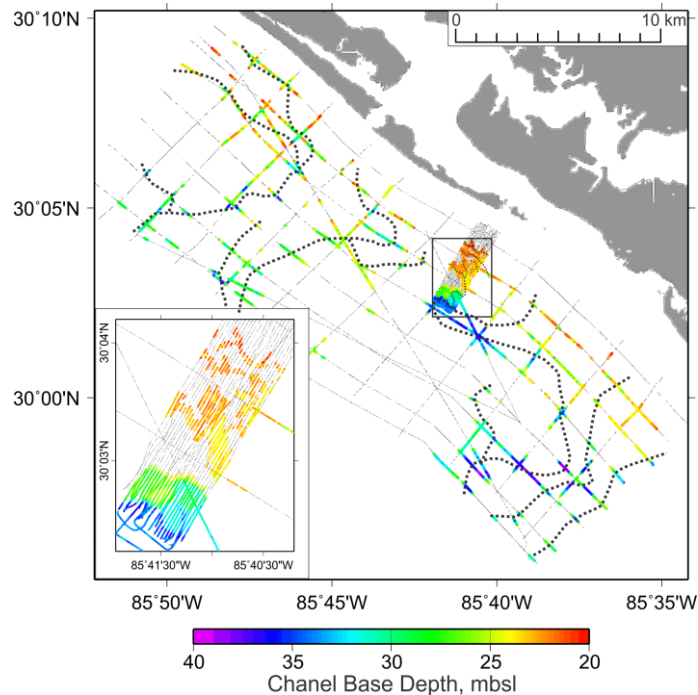


Figure 8. Channel Base horizon depths with interpreted thalweg traces. Inset enlarges focused survey region.

The depth to the Ridge Base horizon is presented in Figure 9. Other than the overall seaward dip, there is very little structure to this horizon. The key observation here is that the horizon cannot be traced seismically through most of the SE sector of the survey area, where no sand ridges are present.

The Channel Top horizon, or the Ridge Base where it caps the estuarine channel fill, is interpreted here to form the base of the Holocene sand sheet. Holocene sand could include barrier sand underlying the transgressive ravinement as well as marine sands above it. Under this interpretation, the thickness of

the Holocene sand sheet is displayed in map view in Figure 10. Other than a thickening offshore of the inlet channel, presumably associated with ebb deposits, it can be observed that there is a preponderance of thicker values (tending toward green colors, or ~4 m on the color scale) in the SE sector of the survey area. A number of areas show no measurements of Holocene sand thickness.

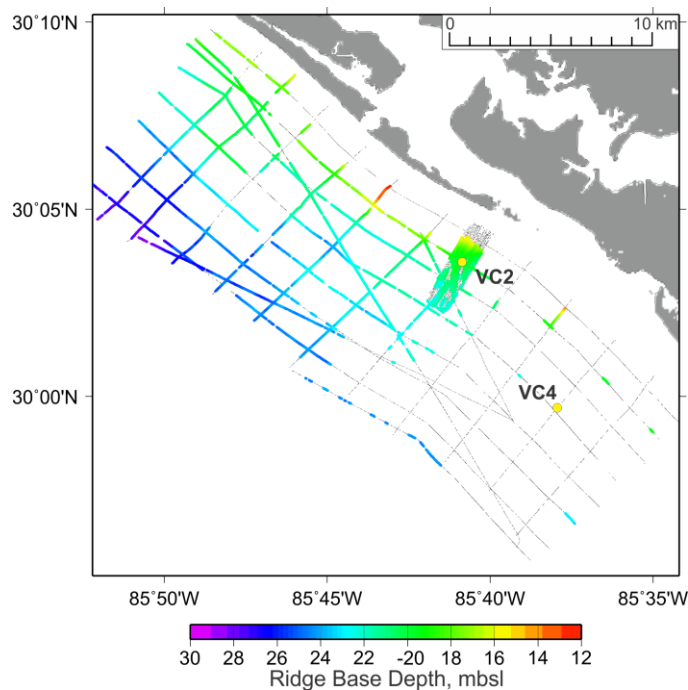


Figure 9. Ridge base horizon depths.

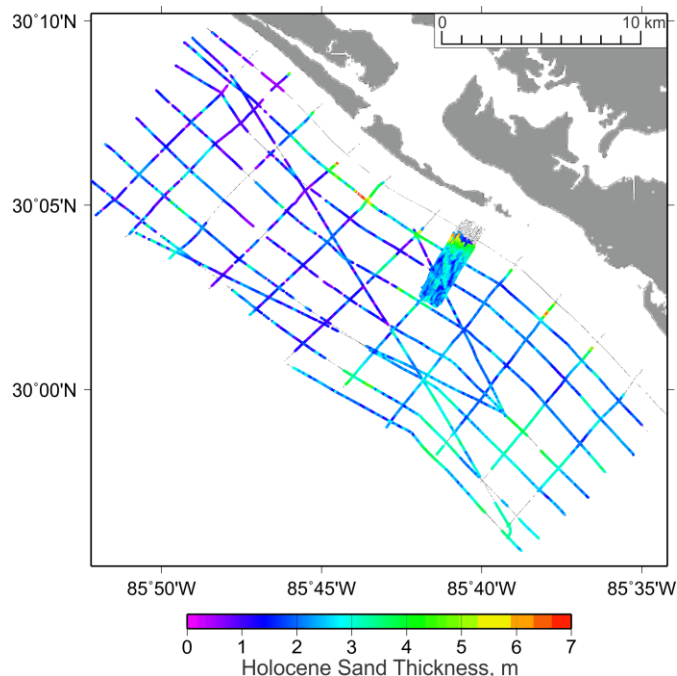


Figure 10. Holocene sand thickness.

Vibracore VC2 (Figs. 1, 9) penetrated almost 3 m into the seafloor, through the Ridge Base horizon but short of the Channel Top horizon (Fig. 6). At the core location, the Ridge Base horizon lies ~1.4 ms (~1.2 m) below the seafloor (Fig. 6). A composite photograph of the split core (Fig. 11) reveals a

dense shell layer from ~1.1-1.6 mbsf, with a medium sand both above and below. The shell layer therefore provides the only likely candidate for generating the impedance contrast necessary to produce the Ridge Base reflector. The sand above and below the shell layer is not without some contrasts, however. More shell hash is observed in the upper sand, and the lower sand contains small fragments of woody debris that were observed to float during wet sieving. The grain size analysis (Fig. 12) also indicates that the sand up to ~1 m below the shell layer contains a larger fraction, up to ~10 %, of fine grained ($< 64 \mu$) sediment. Both the woody debris and the higher fine grain content imply that the lower sands have not been subject to reworking and remobilization, and therefore should be classified as relict barrier sand rather than as part of the marine sand sheet. Consequently, the Ridge Base reflector is interpreted here as the transgressive ravinement surface.

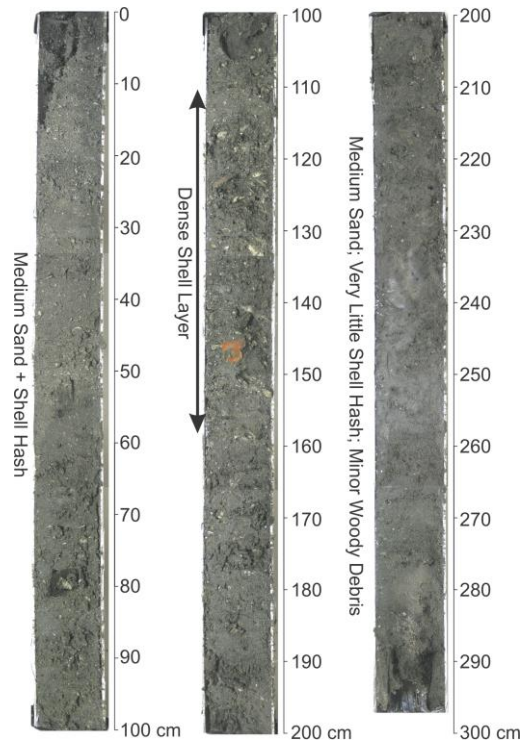


Figure 11. Composite photo for core VC2.

Core VC4 (Fig. 1) was collected in a region where the Ridge Base reflector is not observed seismically (Figs. 7, 9). It was intended to sample through the Channel Top horizon and into the channel fill sediments beneath. Although it only penetrated ~1 m and failed to reach that goal (Fig. 7), it nevertheless provided very valuable observations. The composite photograph (Fig. 13) and grain size analysis (Fig. 14) for VC4 display a nearly identical stratigraphic succession as observed in VC2: a dense shell layer (in this case also including a large amount of coral fragments), above which lie medium sand with shell hash, and below which lie medium sand with woody fragments and up to ~10% fine fraction. (VC5, which is nearby (Fig. 1), also exhibits this same stratigraphy.) The shell layer is therefore also interpreted here as the transgressive ravinement surface. However, unlike VC2, where shell layer begins ~1.1 mbsf, this shell layer is only ~0.4 mbsf. Furthermore, there is no seismic expression of this layer (Fig. 7). This could be a result of the reflector being overpowered by the seafloor reflection and/or the impedance contrast for the shell layer being too low to produce a reflection.

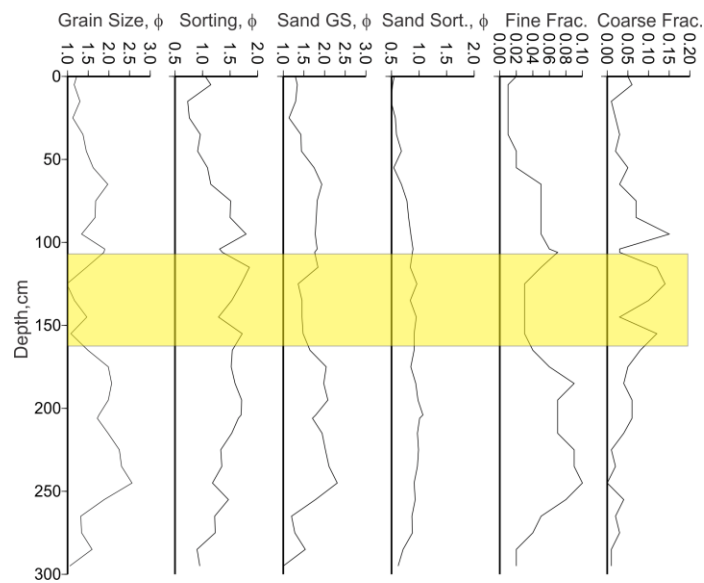


Figure 12. Grain size analysis results for core VC2. Yellow bar indicates location of shell layer.

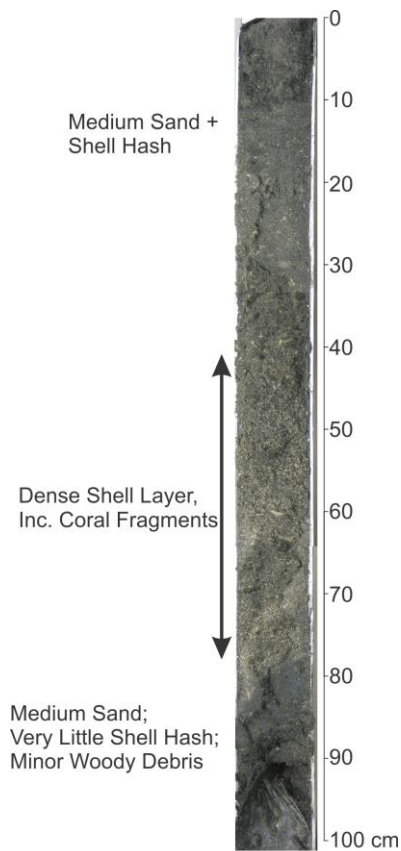


Figure 13. Composite photo for core VC4.

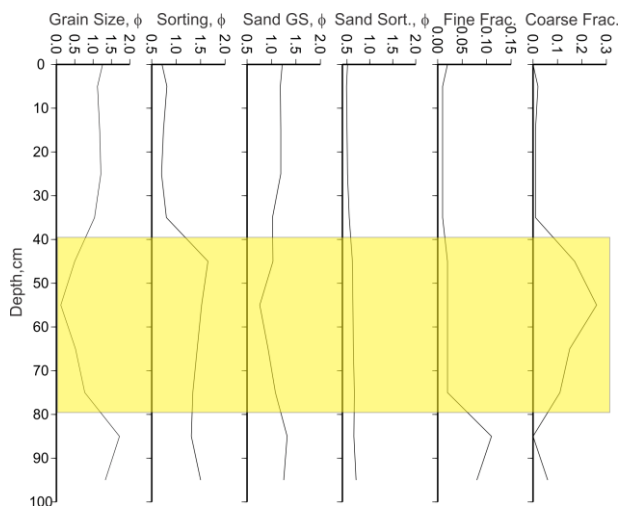


Figure 14. Grain size analysis results for core VC4. Yellow bar indicates location of shell layer.

The transgressive ravinement surface is found in this analysis to be coincident with the Ridge Base horizon. This surface undergoes a marked change across the survey region that can be correlated to the observations of changes in shoreface profile and sand ridge morphology. In the NW sector of the survey, the transgressive ravinement underlies large (up to ~4 m tall) sand ridges, and overlies and truncates the Channel Base horizon as well as laminated reflections associated with the estuarine fill within the channels (Fig. 3). In the middle sector of the survey, the transgressive ravinement underlies smaller (up to ~2 m tall) sand ridges, but no longer caps the buried river channels (Figs. 5 and 6). The ~2 m interval between the transgressive ravinement and the Channel Top horizon (which is also a ravinement surface) is interpreted to consist of relict barrier sands that were not reworked by a shoreface ravinement process. In the SE sector of the survey, where there are no sand ridges, there is also scant seismic evidence for the transgressive ravinement. Core evidence (Figs. 13, 14), however, places the transgressive ravinement at a very shallow depth of 0.4 mbsf. Most of the up to ~4 m of Holocene sand in this sector is interpreted to be relict barrier sand rather than marine sand. Therefore, the shoreface ravinement process can be seen to be most vigorous, in terms of removal of barrier sand and production of marine sand, where sand ridges are largest and the shoreface is narrowest and steepest, and becomes less vigorous as sand ridge heights lessen and the shoreface widens and becomes more gradual. These correlations could be explained with an hypothesis contending that sand ridges play a significant role in the shoreface ravinement process.

IMPACT/APPLICATIONS

The results of this work was instrumental in choosing a location for the TREX13 ONR shallow water acoustic reverberation experiment, and will be important for applications of acoustic modeling efforts to the experimental data.

The scientific results from this study provide the basis for a new model for understanding the transgressive ravinement, one that places migrating, shoreface-attached sand ridges in a central role both for eroding the shoreface and transferring that material to the marine sand sheet.

RELATED PROJECTS

This work is closely related to the ONR Shallow Water '06 program, where geological and geophysical site characterization were utilized in numerous efforts to model results of various acoustic experiments.

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