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Lower shoreface seismic stratigraphy and morphology off Fire Island, New York: Evidence for lobate progradation and linear erosion

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ABSTRACT

Under rising sea level conditions, barrier islands are largely ephemeral features, eroded on the seaward side by the transgressing shoreline and reformed by overwash to a more landward position. Locally, however, and over shorter time scales, shorelines can either advance or retreat, even in an overall transgressive environment, and the stratigraphy and morphology of the shoreface can be significantly impacted by the evolution of shoreface-attached bedforms. Fire Island, New York, is a well-studied example of such variability, with a stable-to-accreting shoreline at the western end and a retreating shoreline on the eastern end. In this study, we seek to better understand these differences by investigating the lower-shoreface stratigraphy at both stable/accreting (Fire Island West, or FIW) and retreating (Fire Island East, or FIE) shorefaces, using ultra-high resolution chirp seismic reflection data. Within the barrier/marine sands (the seismic unit between seafloor and shoreface ravinement), we identify six seismic units (WSUs 1–6 from bottom to top) in the FIW survey and two units (ESU1 and ESU2 from bottom to top) in the FIE survey; these units constitute the modern lower shoreface wedge. The barrier shoreface in the FIW survey is dominated by discrete and spatially-confined lobes. Isopach maps indicate that the lobe shifting was an episodic process with westward-migrating depocenters. The prograding shoreface was constructed by this lobate deposition; we speculate that these are related to ebb deposition from ephemeral barrier breaches/inlets. In the FIE survey, ESU2 accounts for the majority accumulation of the barrier shoreface and it is more linear than the lobate structure observed within the FIW survey, possibly derived from eroded shoreface sediments. Portions of this unit are absent however, exposing lower Pleistocene units to the erosive forces.

1. Introduction

Barrier island systems are common features that develop along many wave-dominated shorelines (Davis, 1994; Stutz and Pilkey, 2011; Fruergaard et al., 2015). Their low elevation and unconsolidated nature make their formation and evolution vulnerable to changing conditions like sea level, sediment flux and storminess (e.g. Rodriguez and Meyer, 2006; Wolinsky and Murray, 2009; Moore et al., 2010; Masselink and van Heteren, 2014; Fruergaard et al., 2015). Modern barrier islands encompass important economic and recreational areas, while ancient barrier deposits may produce high-quality petroleum reservoirs (Davis et al., 2003; Fruergaard et al., 2015). Although many attempts have been made to understand the evolution of both modern and ancient barrier system (e.g. Rodriguez et al., 2001a, 2001b; Cawthra et al., 2014; Brenner et al., 2015; Costas et al., 2016; Liu et al., 2017), the ways in which factors such as rates of sea-level rise, changes in sediment input, storms and geomorphologic process influence the long-term sedimentation process within barrier system are still important topics of investigation (e.g. Schwab et al., 2013; Fruergaard et al., 2015; Goff et al., 2015).

Fire Island, New York, is a narrow sandy barrier island within the Long Island barrier system (Fig. 1), experienced net erosion, accretion and stability in different coastal sections (Hapke et al., 2010, 2016; Schwab et al., 2013). It has been a long-standing natural laboratory for the US Geological Survey for studying coastal change, both onshore (e.g., Hapke et al., 2010; Lentz and Hapke, 2011; Lentz et al., 2013; Warner et al., 2017; Brenner et al., 2018) and offshore (Schwab et al., 2000, 2013, 2014a, 2017; Locker et al., 2017). This region was significantly impacted by Hurricane Sandy in October of 2012 (Hapke et al., 2013), providing the impetus for additional coastal change surveys (Goff et al., 2015; Hapke, 2016; Schwab et al., 2017). The survey by Goff et al. (2015) in particular included dense (∼ 50 m track spacing) chirp seismic reflection coverage of the lower shoreface and inner shelf offshore western and eastern ends of Fire Island. Although the

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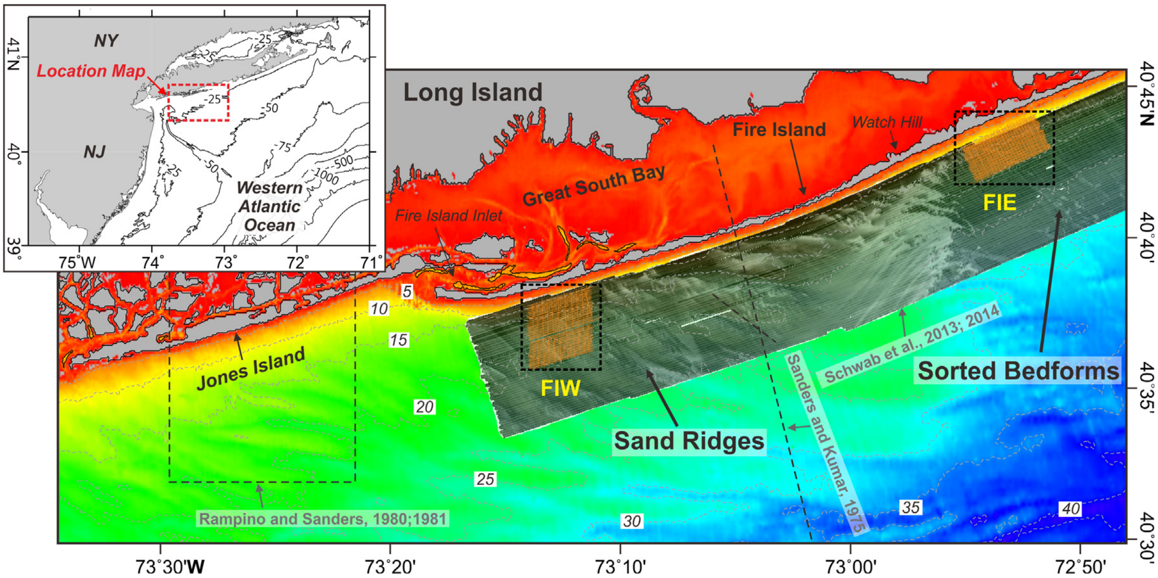

Fig. 1. Location map for survey area (FIW and FIE focus areas) and previous stratigraphic and/or barrier evolutionary studies reported by Sanders and Kumar (1975), Rampino and Sanders (1980, 1981), and Schwab et al. (2013, 2014). Fine orange lines within FIW and FIE areas indicate chirp seismic survey track. Bathymetry is derived from NGDC Coastal Relief Model (http://www.ngdc.noaa.gov/mgg/coastal/startcrm.htm). Inset shows the location of the study area on the mid-western Atlantic coast. Modified after Goff et al. (2015) and Liu et al. (2017). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

primary intent of these surveys was to measure hurricane-driven changes in the major bedforms on the inner shelf, the coverage on the lower shoreface was substantial, and has not heretofore been interpreted. In this study, we define the transition between the lower shoreface wedge and inner shelf by the lowermost break in the slope; i.e., the "toe" of the shoreface (Swift et al., 1985; Goff et al., 2014). Our study has close parallels to a recent report by Locker et al. (2017), who collected chirp data covering the shoreface along nearly the full length of Fire Island. Our stratigraphic interpretations are broadly similar. However, our density of coverage enables us map the complex shoreface structures and heterogeneities in much greater detail.

The purpose of this study is to compare and contrast shoreface stratigraphy from stable/accreting (western) and retreating (eastern) settings, to seek clues to understand (1) why these differences exist in such proximal locations and (2) how are they may be related to migration of shoreface-attached bedforms. Shoreface-attached major bedforms (i.e. sand ridges and sorted bedform) are widely observed in the U.S. Atlantic coast (Swift and Field, 1981; McBride and Moslow, 1991; Thieler et al., 2001; Browder and McNinch, 2006) and other places (Backstrom et al., 2009). They form in response to the shelf process at the toe of the shoreface, and are influenced both by shoreface advance/retreat and by onshore or offshore sediment transportation (Calvete et al., 2001; Coco and Murray, 2007). Schwab et al. (2013) hypothesized in particular that the western end of Fire Island is prograding in response to onshore migration of sediments from inner shelf sand ridges, which are abundant along the western half but largely absent along the eastern half. However, the post-Sandy studies indicate that the sand ridges migrate to the SW, an offshore direction (Goff et al., 2015; Schwab et al., 2017). In contrast to the Schwab et al. (2013) hypothesis, Goff (2014) proposed that migrating sand ridges act as an erosive mechanism, transferring shoreface sediments to the inner shelf marine sand layer and contributing to the formation of the transgressive ravinement. A detailed stratigraphic analysis may help to resolve this apparent discrepancy by constraining the mechanism of accretion along the lower shoreface.

2. Study site

Fire Island first formed ~ 8000 years ago (Rampino and Sanders, 1980), and developed in a high-energy wave and wind environment. It presently experiences net erosion in the eastern regions, accretion in the middle and stability in the west (Hapke et al., 2010, 2016; Schwab et al., 2013). A detailed understanding of barrier stratigraphy and development of Fire Island was earlier developed by Sanders and Kumar (1975), Rampino (1978), and Rampino and Sanders (1980, 1981, 1982, 1983) (Fig. 1). They suggested the barrier evolution is associated with a contrasting two-phase process that comprises an "in-place drowning" (or overstep) process as well as a landward retreat (or rollover) process. This barrier drowning hypothesis has been applied to other settings as well (e.g. Salzmann et al., 2013; Green et al., 2014; Cooper et al., 2016), although how the overstepped barrier was formed and preserved has been subject to debate (e.g. Swift and Moslow, 1982; Leatherman, 1983).

A comprehensive understanding of the seismic stratigraphy off Fire Island was recently developed by Foster et al. (1999), Schwab et al. (2013, 2014a), Goff et al. (2015) and Locker et al. (2017). In these studies, they found the barrier shoreface off Fire Island is primarily consisted of marine sands that derived from reworked Pleistocene sediments since highstand period and defined it as marine sand unit through seismic profiles and outcrop. The modern marine sand unit and lower shoreface off Fire Island are bounded above by the seafloor and below by the transgressive (or shoreface) ravinement (T, e.g. Fig. 2), which originated from erosion of the upper shoreface and emplacement on the lower shoreface (LS)/inner shelf during the Pleistocene-Holocene transgressive period (after Bruun, 1962; Emery and Myers, 1996; Goff et al., 2015; Liu et al., 2017). It caps a cut-and-fill channel system in both areas (e.g. Fig. 2) as documented previously by Goff et al. (2015). Although the isopach maps (Figs. 3B and 4B) of the marine sand unit has been previously illustrated and described by Goff et al. (2015), the morphology of the bottom surface (i.e. T) and the morphological transition between LS and inner shelf have not yet been reported.

3. Methods

The stratigraphic analysis in this research represents a further interpretation of the chirp seismic reflection data first reported by Goff et al. (2015). These data were collected in January 2013, offshore of Fire Island, New York, aboard the R/V *Seawolf*. Two focus areas are