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Sedimentological Characteristics and Internal Architecture of Two Overwash Fans from Hurricanes Ivan and Jeanne

Horwitz, Mark[1] and Wang, Ping[2]

[1]BCI Engineers and Scientists, Inc., Lakeland, Florida 33803

[2]Department of Geology, University of South Florida, Tampa, Florida 33620

Abstract

Extensive overwash occurred along the Florida coast during the passage of four strong hurricanes in 2004, providing an excellent opportunity to study the spatial patterns and sedimentary architecture of washover deposits. Detailed 3D sedimentological characteristics of two of the overwash fans were studied through coring, trenching, and ground penetration radar surveys. The first washover-fan complex, deposited by hurricanes Frances and Jeanne is located on the Atlantic facing Hutchinson Island in southeastern Florida. The second fan, deposited by hurricane Ivan is located on the Gulf-facing Santa Rosa Island in northwestern Florida. Subsurface imaging using a 250 MHz Ground penetrating radar profiling system correlated well with bedding features observed in cores and trenches; while the Ground penetrating radar profiling provided greater spatial coverage. The internal architecture of the overwash lobes is generally characterized by: (1) planar horizontal to sub-horizontal stratification resulting from sheet flow regime overwashing a subaerial surface, and (2) steeply landward dipping tabular foresets, formed during landward progradation and subaqueous deposition, likely into a washover pond or lagoon. Associated local features such as truncated inclined bedding, scour holes, and truncated dunes are also common to washover sediment deposits.

Introduction

During the months of August and September 2004, four hurricanes ranging in strength from category 2 to 4 (Stafford Simpson scale) made landfall along the Florida coast (Fig. 1). On August 13, Charlie, a category 4 hurricane made landfall along the southern Florida Gulf coast. On September 5, Frances, a category 2 storm made landfall along the central Florida Atlantic coast. Hurricane Ivan, a massive category 3 hurricane made landfall along the northern Gulf coast near the Alabama-Florida border on September 16, and Jeanne, a category 3 hurricane made landfall on September 26, along the same stretch of Florida Atlantic coast that hosted Frances 21 days earlier. While overall storm impact to the coastal regions varied as a function of storm size, velocity and intensity, each storm generated various levels of overwash on the coastal barrier islands.

The Florida coastline is dominated by a nearly continuous chain of Holocene wave dominated and mixed-energy barrier islands which are dissected by numerous tidal inlets (Davis, 1994). Along the eastern Atlantic facing coast, the Holocene sediments rest unconformably on late-Pleistocene coquinoid limestone belonging to the Anastasia formation. The back-barrier environment is dominated by mangrove swamps and organic rich sediments. The Holocene sediment typically consists of medium to coarse-grained biogenic material reworked from the Anastasia formation, and detrital quartz with minor amounts of heavy minerals. In contrast, Holocene sediments of the northwestern Gulf coast barriers typically consist of homogeneous well-sorted medium quartz sand with variable amount of heavy minerals (Stone and Stapor, 1991). Florida's coastal regions are microtidal with tidal ranges on the order of 0.3 to 0.8 m. Topographic relief on the barrier islands rarely exceeds 10 m, making the barriers particularly vulnerable to inundation and overwash during extreme storm events.

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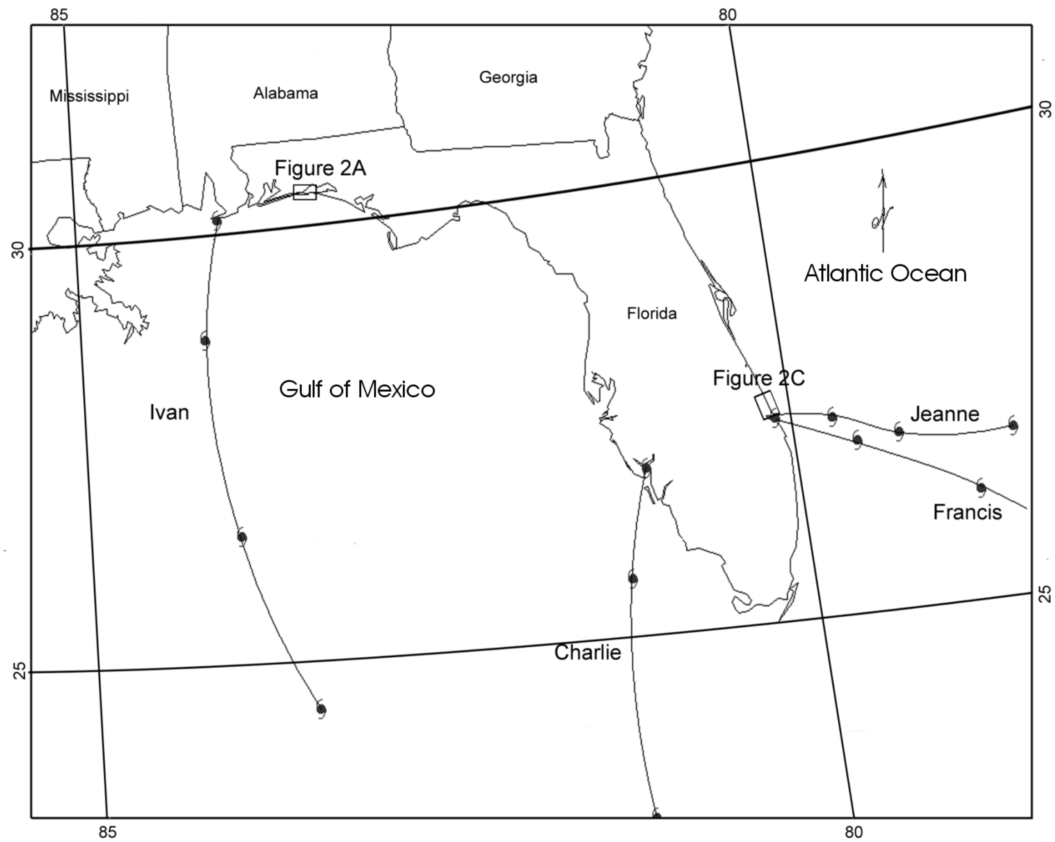

Figure 1. Study areas and the tracks of hurricanes that impacted the Florida coast in 2004.

Washover deposits are common along the Florida coastline and play an important role in the evolution of the barrier islands (Davis, 1994; Sedgwick and Davis, 2003). When storm surge, combined with wave set-up and swash run-up (Wang et al., in press) exceed beach/dune elevations, overwash occurs. The morphological response of barrier islands and the spatial distribution of washover sediment deposits are controlled by various factors including, the geographic location relative to the storm center, duration of exposure, and flow confinement (Schwartz, 1982; Stone and Wang, 1999; Morton, 2002; Stone et al., 2004). In addition, morphological factors including island width, topography, and vegetation coverage also play significant roles in overwash and sedimentation. In areas close to the storm center, low lying barriers are often completely inundated resulting in continuous cross-island sediment transport with sediment deposition occurring in a progradational manner into the back-bay. In contrast, distal to the storm center, overwash and the resulting sediment transport and deposition may be intermittent; occurring during the run-up of larger waves (Schwartz, 1982). However, once overwash is initiated and effectively decoupled from the nearby marine environment, washover typically produces a characteristic set of sedimentary structures (Sedgwick and Davis, 2003; Schwartz, 1982). These can be subdivided into high flow regime structures dominated by subhorizontal to low angle landward dipping planar layers and laminae, and low to decelerating flow regime structures characterized by steeply inclined, landward dipping tabular foreset stratification or avalanche bedding.

The objective of this study was to examine and describe the detailed sedimentological characteristic and internal sedimentary architecture of two washover fans (Fig. 1). Previous studies have documented the sedimentological characteristics of washover deposits through trenching and coring (Schwartz, 1982; Leatherman, 1979; Sedgwick and Davis, 2003). This study integrates similar approaches with high resolution ground penetrating radar (GPR) survey data. GPR profiling has been used extensively over the last decade for imaging shallow stratigraphy (Bristow et al., 1996; Jol et al., 1996; Heteren et al., 1998; Moller and Anthony, 2003), and despite typical conductivity issues related to saline groundwater, GPR has proven to be particularly useful in studying barrier island stratigraphy where substantial freshwater aquifers are present (Jol et al., 1996; Buynevich et al., 2004; Dougherty et al., 2004).

Study Areas

The first of the two studied overwash fans, referred to as Little Lake fan, is located on the northern end of Hutchinson Island (Figs. 2C and 2D), approximately 25 km northwest from the point of landfall of hurricanes Frances and Jeanne (Fig. 1). Hutchinson Island is a 35 km long barrier island along the Florida Atlantic coast. The island, which is oriented 340, ranges in width from 0.2 to 2.0 km, and is bordered by Ft. Pierce inlet to the north and St. Lucie inlet to the south. The mean tidal range is 0.8 m (NOAA, 2005). Elevations at the site range from mean sea level to roughly 1.3 m. Much of the undeveloped portions of the island are covered by dense mangrove marsh. The study area lies along the eastern shoreline of a small lagoon (Fig. 2C). An examination of 2004 pre- and post-storm aerial photographs indicate that storm related washover sedimentation filled the eastern most portion of the lagoon in a progradational manner. Washover sedimentation occurring during hurricane Frances created a lower sediment terrace, the top of which currently lies at approximately 0.2 m above mean sea level. Overwash occurring during the passage of hurricane Jeanne, deposited a second sediment terrace or washover lobe, the top of which lies at an elevation of approximately 1 m.

The second studied overwash fan, referred to as Beasley Park fan, is located on the east end of Santa Rosa Island, a 75 km long, Gulf facing barrier island (Figs. 2A and 2B). The island is oriented roughly east-west, and ranges in width from 0.2 to 1.0 km. Tidal inlets border the island on the east and west, and the mean tidal range is 0.4 m (NOAA, 2005). The site is situated approximately 120 km east of the hurricane Ivan's landfall. Pre-storm relief at the site reached to 3.5 m above mean sea level (Wang et al., in press). The site is flanked on the east and west by vegetated dunes 7 to 10 m high. In contrast to the dense mangrove swamp which dominates the east coast site, vegetation at the Beasley Park site is limited to sparse patches of sea oats. As shown in Figure 2A, washover deposits from Ivan extended 300 m landward (north) from the Gulf shoreline.

Methodology

This study is based on core, trench, and GPR data collected during February and May 2005, five to eight months after the storm impact. Little bioturbation occurred during this pre-summer period. Some morphological changes caused by aeolian transport were measured by Wang et al. (in press). The two study areas were chosen based on the presence of characteristic washover fan shaped sediment bodies. Additional consideration was given to the possible effects of sediment composition, barrier morphology, and vegetation coverage. The Atlantic facing, Little Lake fan is characterized by dense mangrove swamp, while the Beasley Park fan, located along the Florida Panhandle, is generally devoid of dense vegetation. It is worth noting that the Beasley Park fan is located in the area that was significantly impacted by overwash occurring during the passages of hurricane Opal in 1995 and Georges in 1998.

At the Beasley Park fan, a total of 2 km of GPR profiles were collected including 11 shore parallel and 5 shore perpendicular transects arranged in a grid over the washover fan (Fig. 2B). At the Little Lake fan, a total of 17 profiles were surveyed, including 8 shore normal and 9 shore parallel transects arranged in a grid (Fig. 2D). The GPR data were collected using a Sensors and Software Noggin SmartCart, equipped with a 250 MHz antenna. The antenna separation was fixed at 0.3 m, and a step size of 0.05 m was used. The theoretical vertical resolution of GPR at 250 MHz is on the order of 15 to 30 cm (Jol, 2003; Annon, 2003). Spatial data was obtained in the field with a wide area augmentation system (WAAS) enabled GPS receiver and the transects were surveyed with a Sokkia Total Station for topographic control. The GPR data were processed using Sensors and Software EKKO Mapper software. A standard processing recipe was used which included dewowing and scaling using automatic gain control (AGC) with a time window setting of one pulse width. An AGC time window of one pulse-width amplifies reflections equally, and is often used to enhance moderate to low amplitude reflections, those which typically define internal sedimentary structures. Based on field observations, cores and trenches, it was determined that the base of the recent washover sediment deposits lied coincident with (Little Lake fan)

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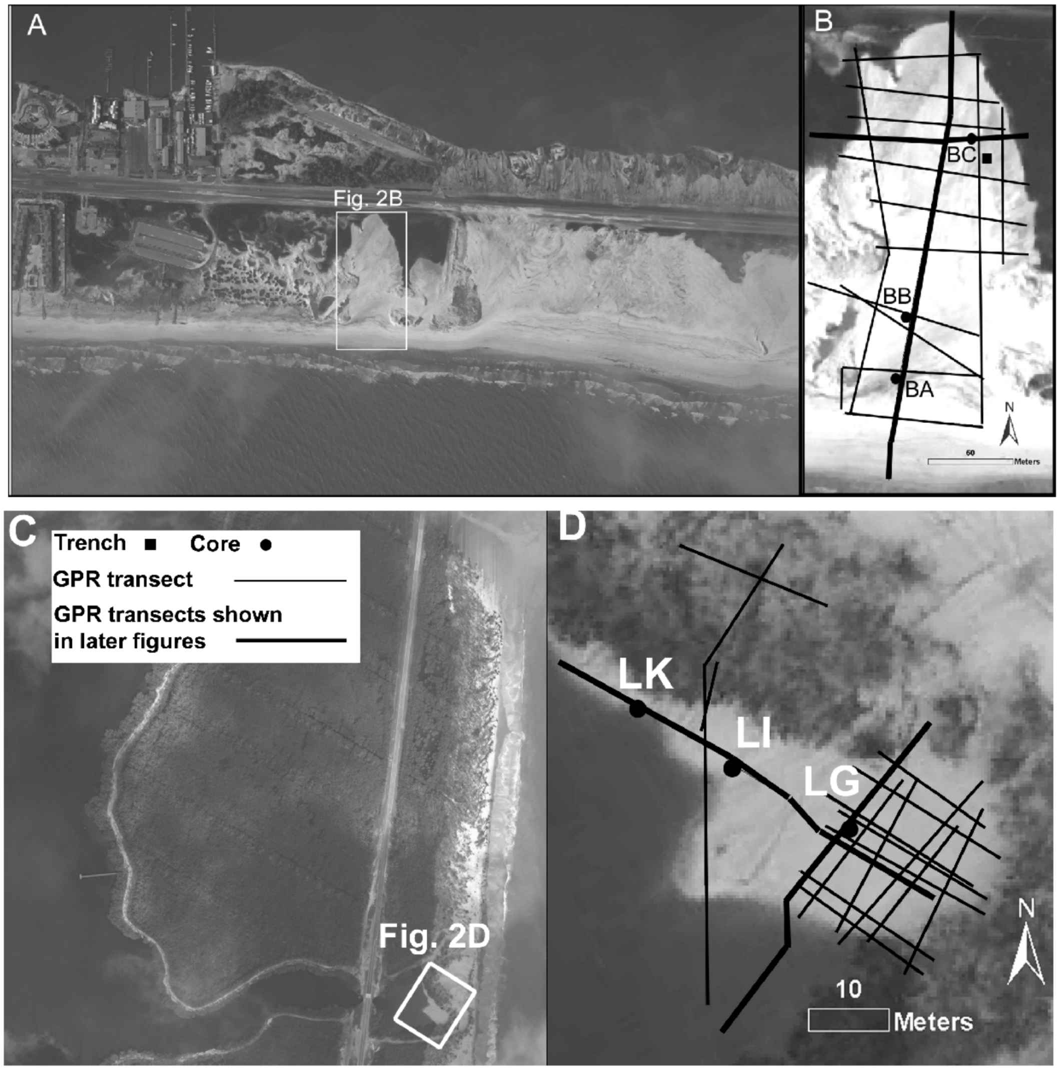

Figure 2. (A) Aerial photo of Santa Rosa Island and the Beasley Park study area (photo taken 10/2004). (B) Detail of the Beasley Park washover fan showing locations of cores, trench and GPR profiles. (C) Aerial Photo of Hutchinson Island showing the Little Lake fan and study area (photo taken 10/2004). (D). Detail of the Little Lake fan showing the location of cores and GPR transects.

or well above (Beasley Park fan) the water table. Thus, the typical signal travel velocity for dry sand, 0.15 m/ns was applied (Annon, 2003).

In order to ground truth the GPR profiles, as well as to examine sedimentary features too fine to be resolved by the GPR, core (7.6-cm diameter) and trench data were collected along the GPR profiles (Fig. 3). Key sediment layers from the cores were sampled and analyzed to obtain grain size, and the heavy mineral content within discrete sieve fractions were estimated visually.

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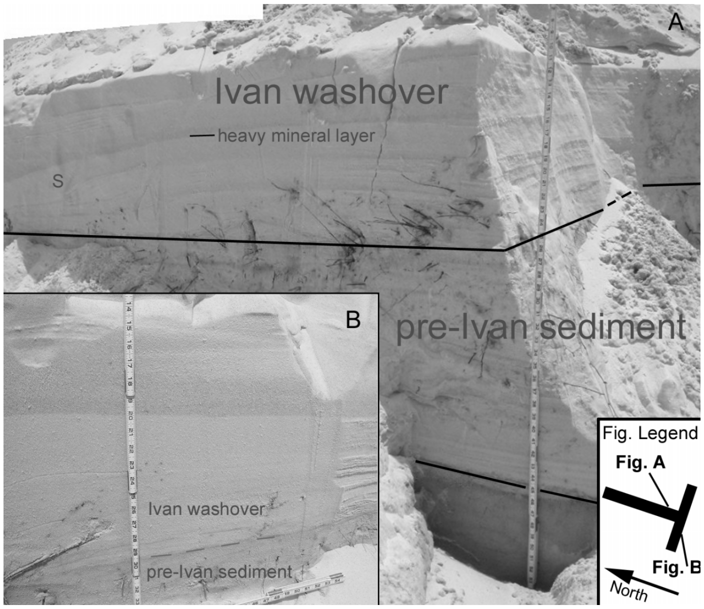

Figure 3. Photograph of the T-shaped trench at the Beasley Park fan. (A) West facing trench wall showing landward dipping sigmoidal (s) and tangential stratification. (B) North facing trench wall showing horizontal planar stratification (scale is in inches).

Results and Discussion

Beasley Park fan

The washover deposit at the Beasley Park fan is approximately 115 m wide and extends landward from the Gulf shoreline roughly 280 m (Fig. 2A). Since the washover sediment is largely comprised of reworked local material, the central and shoreward margins of the washover deposit are difficult to distinguish from the adjoining dunes, while the northern terminal margins are abrupt and easily recognized given the marsh area in which the washover terminated. These characteristics are consistent in the vertical dimension. The basal contact of the washover is distinct when sedimentation occurs over a vegetated and bioturbated substrate, and less distinct where deposition occurs on a non-vegetated sand substrate. The trench excavated in the northeastern portion of the washover lobe clearly exposed the basal contact of the washover evidenced by the burial of fresh upright vegetation (Fig. 3). Similarly, weakly bioturbated sediment containing sparse residual plant material or organic stain is found directly underlying the washover sediment layer in sediment cores B-1, B-2 and B-3 (Fig. 4). Core and trench data indicate the thickness of the washover layer ranges from 40 to 90 cm and is generally thickest along the central portion of the lobe thinning towards the margins.

Sediment is comprised dominantly of quartz grains with minor amounts of accessory dark heavy minerals. Grain size analysis shows that both the heavy mineral bearing and non heavy mineral bearing sediment are well sorted medium sand. The dark heavy mineral concentrations increase significantly in the 2.75 to 3.25 (phi) fractions. The absence of bioturbation, and an increase in the content of dark accessory heavy minerals, visible as rhythmically banded laminae (Fig. 4) and less distinct layers (Fig. 3B) are common features within the washover fan. Bedding features identified in the trench include landward dipping (down dip direction) sigmoidal and tangential clinoforms and horizontal planar stratification (strike direction). Horizontal as well as inclined planar and sigmoidal heavy mineral laminae are common within the upper 20 cm of the overwash sediment in cores B-1 and B-2.

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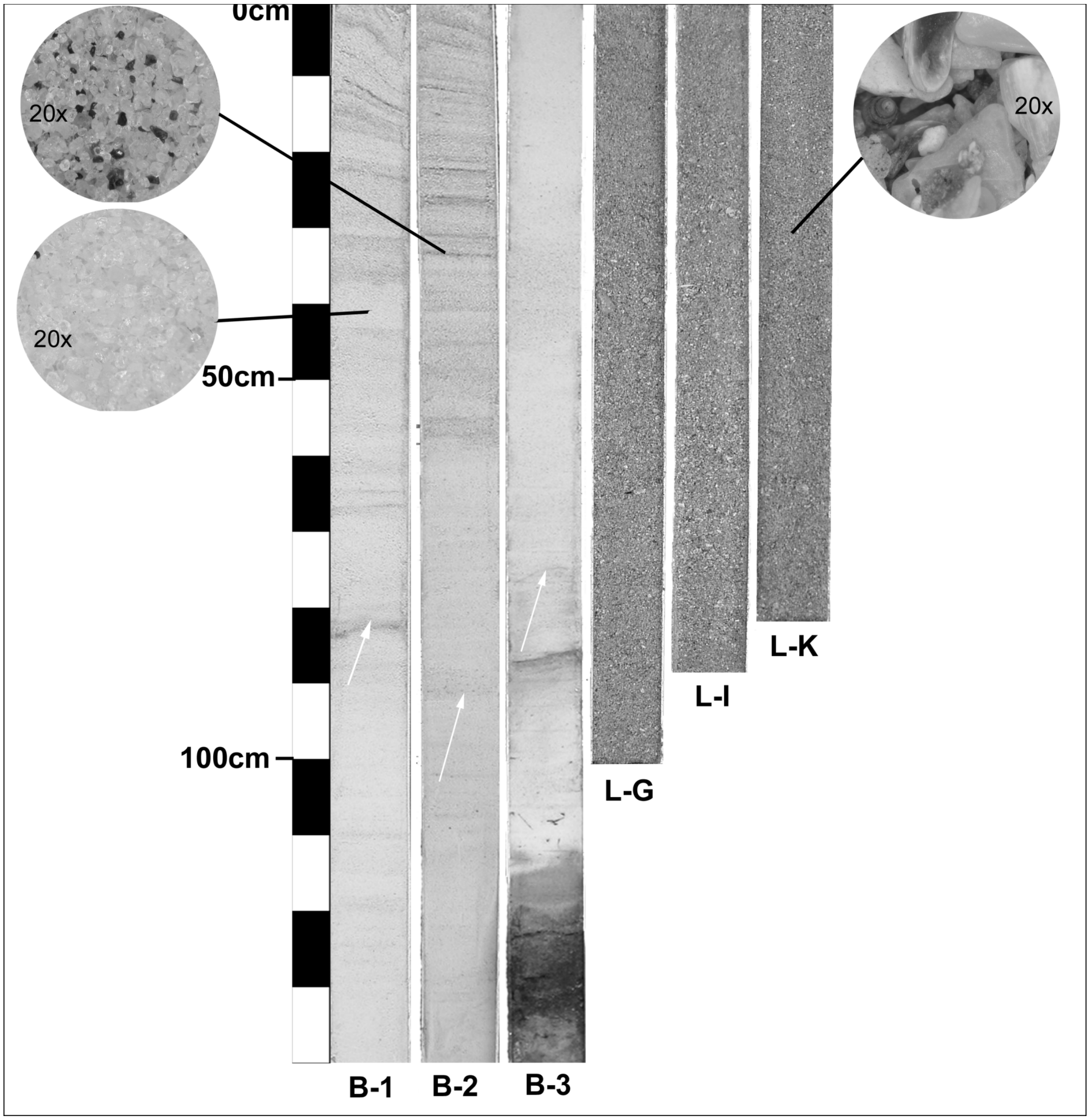

Figure 4. Photographs of sediment cores from the Beasley Park (B-1, B-2, B-3) and Little Lake (L-G, L-I, L-K) fans.

A total of 16 GPR transects were examined over the Beasley Park washover fan. Representative profiles are presented in this paper. Transect T5 (Fig. 5) was scanned in a north-south direction extending from the Gulf shoreline to the northern terminal end of the washover lobe (Fig. 2b). Transect T6 (Fig. 6) was scanned in an east-west direction extending across the width of the washover lobe (Fig. 2b). Core and trench data were used to ground truth the GPR interpretation. The depth of signal penetration was on the order of 2.5 to 3 m, and provided adequate coverage to image the internal structure within the recent washover sediment layer. High amplitude, discontinuous horizontal to subhorizontal and steeply inclined radar facies correlate with similar bedding features observed in the cores and trench. The horizontal to sub-horizontal bedding likely resulted from overwashing sheet flow regime over a wetted subaerial surface, while the steeply inclined or avalanche bedding would result from the progradation of the overwash lobe and decelerating flow associated with subaqueous deposition. A series of high amplitude, discontinuous bi-directional dipping reflections are evident on transect T5 (Fig.5B), centered between cores B-1 and B-2. These reflections are interpreted to represent older truncated dunes. The dune truncation apparently resulted from the overwash processes. In addition, a prominent

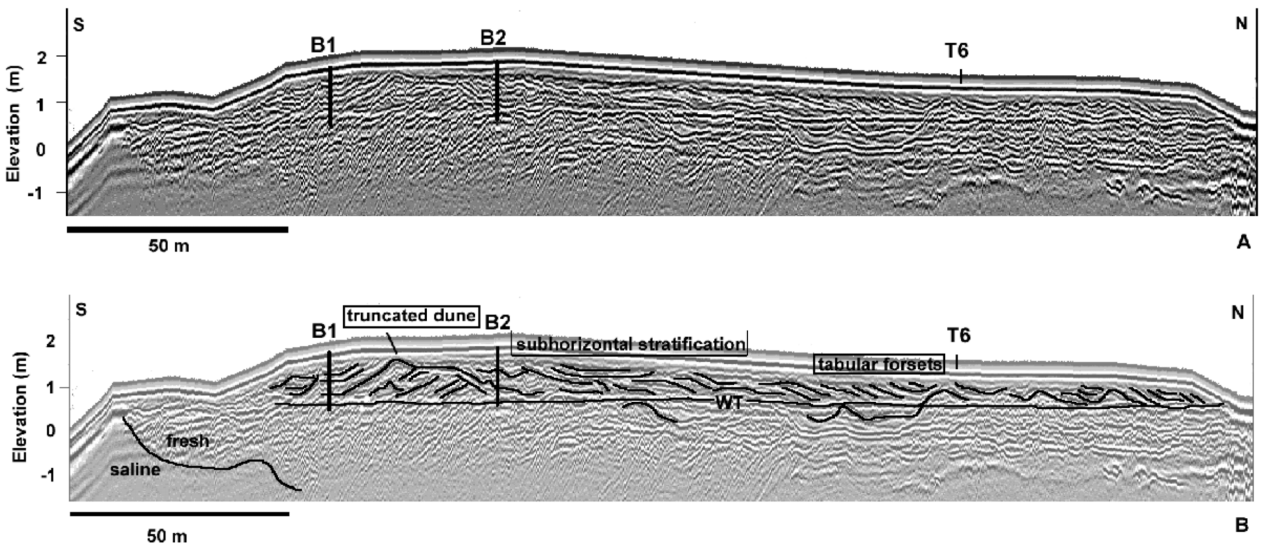

Figure 5. (A) Beasley Park fan GPR profile T5, note the intersection with GPR profile T6 and the positions of cores. (B) Interpreted GPR transect profile T5. The saline-freshwater interface is labeled, as well as the water table (WT). Bold lines outline prominent internal bedding features within the Ivan washover deposit and older truncated dunes.

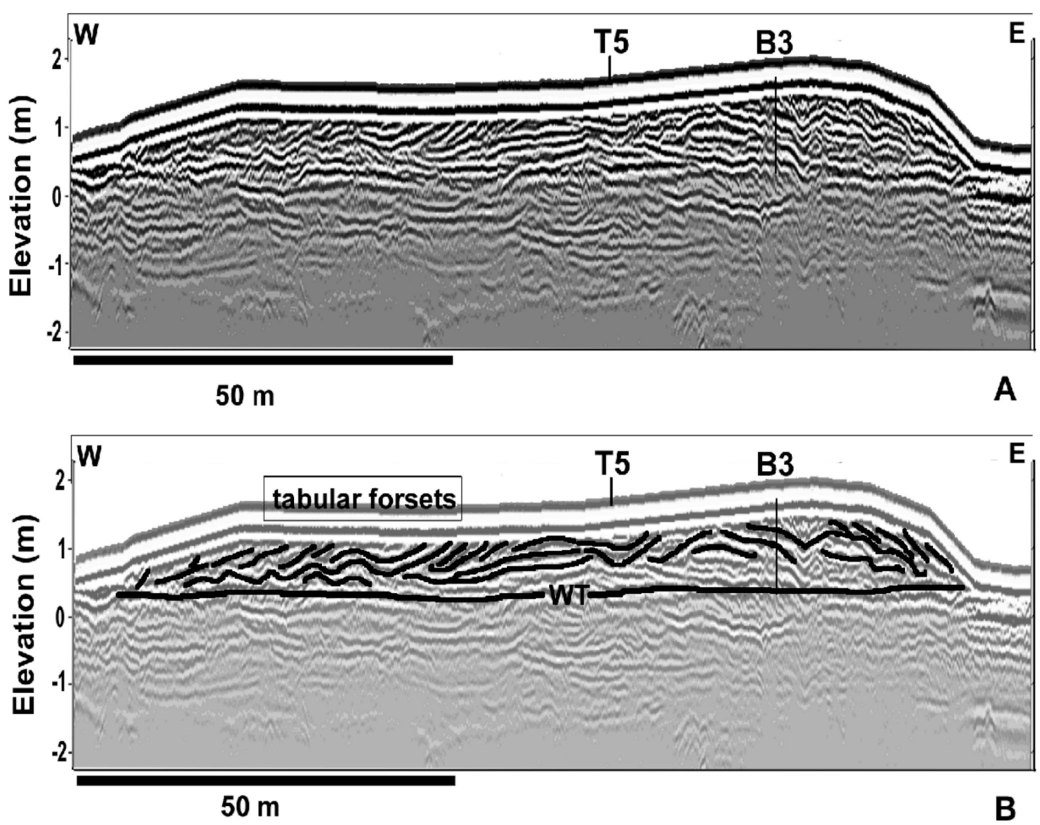

Figure 6. (A) Beasley Park site GPR profile T6. (B) Interpreted GPR profile T6, with bold lines outlining internal bedding features within the Ivan washover deposit.

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high amplitude continuous horizontal reflector was evident across most of the profiles (labeled WT in Figures 5 and 6), and correlates with the top of the water table, which was encountered in the trench at a depth 1.3 meters.

Little Lake fan

Overwash extent along the northern end of Hutchinson Island was limited by the dense mangrove marsh obscuring landward flow (Fig. 2D). However, in the Little Lake study area, the open space provided a less obscured path for the overwash, leading to the formation of the well-defined fan shape (Figs. 2C and 2D) washover deposit. Two discrete washover sediment terraces are present, the lower terrace was deposited during the passage of Frances, and the upper terrace, deposited by hurricane Jeanne, the latter being the focus of this study due to its higher elevation. The top of the lower washover terrace lies at approximately the mean sea level, and is overlain by the 1-m thick Jeanne washover. The two washover sediment deposits, although clear in plane view, cannot be distinguished in core or trenches. However, at a nearby location where the overwash fan extended into mangrove swamp, two distinctive layers separated by a coarse shell-debris layer are apparent, each representing discrete overwash events from Frances and Jeanne (Caldwell et al., in press). The sediment is comprised of coarse-grained poorly sorted biogenic fragments with lesser quartz grains. Three sediment cores, L-G, L-I and L-K were collected at the site (Fig. 2D), and while the homogeneity of the sediment provides little evidence of bedding features or stratification within the washover sediment, preferential orientation of shell material in the upper 40 cm of core L-G illustrates subtle inclined planar stratification (Fig. 4).

A total of 17 GPR transects were scanned in a grid array over the upper washover sediment layer. All the profiles collected at the Little Lake fan were analyzed and interpreted but only selected representative profiles are presented and discussed here. Signal penetration was limited to approximately 1 m, a factor attributed to the sites proximity to the saline lagoon, and the absence of a substantial freshwater lens or aquifer along the northern part of the barrier island. However, given the thickness of the Jeanne washover sediment layer (~1 m), signal penetration was adequate to image internal sedimentary features within the targeted sediment layer.

Transect T10 was scanned in a shore normal direction over the washover lobe (Fig. 7), and transect T14 (Fig. 8) was scanned perpendicular to T10. Distinct radar facies are evident in the profiles. Moderate to high amplitude, horizontal to subhorizontal discontinuous reflections dominate the shoreward portion of transect T10, and merge landward into high angle planar and sigmoidal reflective patterns. There is a clear spatial transition in these reflections, consistent with landward progradational sedimentation. On most of the profiles, a high amplitude, continuous horizontal reflection is present at an elevation of approximately mean sea level, and is interpreted to represent the top of the water table. Numerous discrete hyperbolic reflections are evident on both transects T10 and T14 and interpreted to represent buried vegetation (mangrove or tree branches). While the trough shaped reflections evident on the southeast end of transect T14 (Fig. 8) are suggestive a washover channel, an examination of adjacent transect profiles indicate the reflections are not laterally persistent, and form a closed basin type feature. Given the limited lateral extent of those reflections, this feature is interpreted to represent a discrete scour hole within the washover sediment lobe. This scour hole is located close to the entrance to the lake and may be resulted from the eddy generated by the overwash flow entering the lake water body.

Several similarities and differences are identified when comparing the two studied overwash fans at the Atlantic and Gulf coasts. The sediment properties are significantly different in terms of grain size, sorting, and mineral composition. Fine-scale laminations illustrate by heavy mineral layers are ubiquitous within the sediment in the Beasley Park fan, while laminations within the sediment in the Little Lake fan are rarely evident due to the poorly sorted shell-debris rich sand. A major similarity identified from the GPR profiling is the combination of horizontal to sub-horizontal bedding and steeply inclined prograding foreset (or avalanche) bedding. Of particular interest is the widespread imaging of these features within the Little Lake fan where these bedding features were not visually clear from the cores and trenches, largely due to the poorly sorted nature of the sediment. Both fans show similar overall morphology. At Beasley Park fan, truncated dunes were identified and provide an additional indicator of severe overwash. At Little Lake fan, a scour hole at the entrance to the lake and numerous buried mangrove roots and trunks are characteristic features in addition to the horizontal and inclined bedding.

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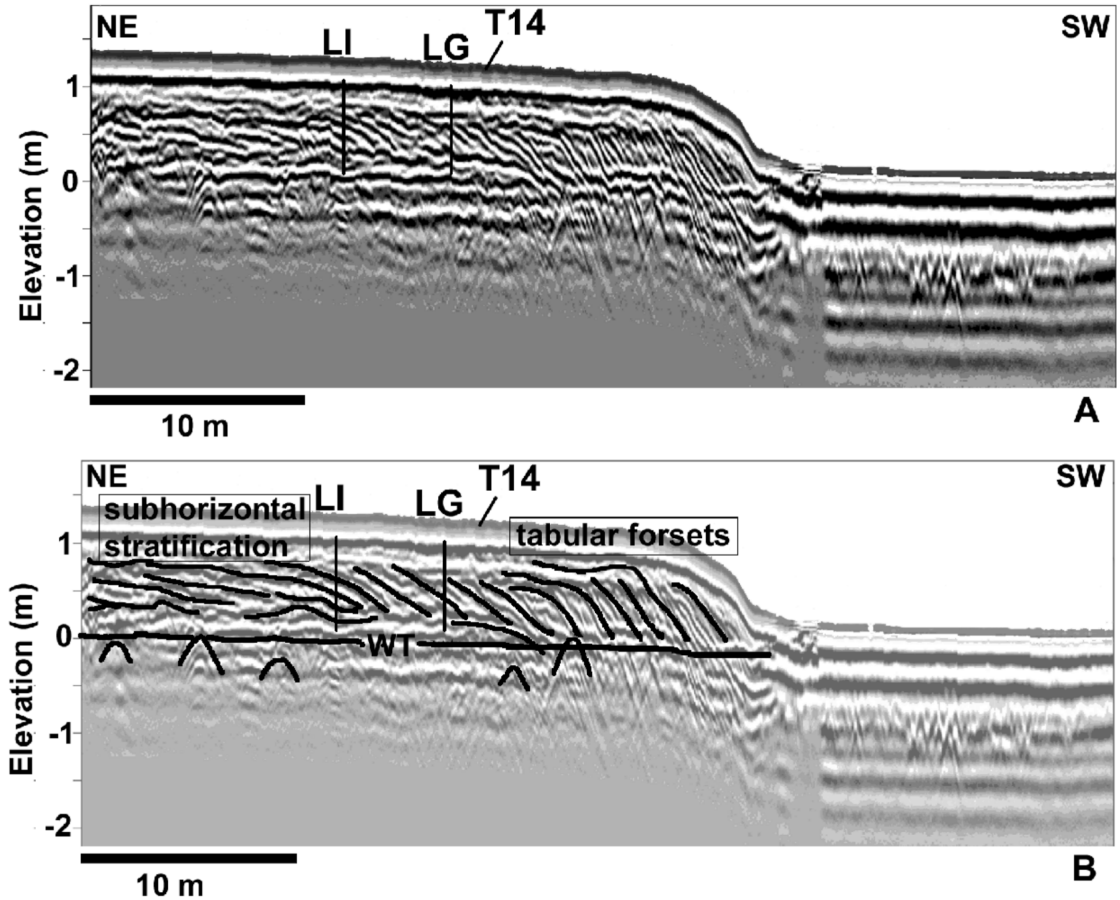

Figure 7. (A) Little Lake fan GPR profile T10 showing the positions of cores and intersection with profile T14. (B) Interpreted GPR profile T10. The continuous reflector labeled WT represents the water table. Highlighted subhorizontal reflectors are shown merging landward into steeply dipping sigmoidal and tangential reflections. Numerous discrete hyperbolic reflections at or below the water table are interpreted to represent buried mangroves or trees.

Conclusion

Extensive overwash occurred along the Florida coast during the passage of four strong hurricanes in 2004. Along a 120 km stretch of Florida panhandle coast, hurricane Ivan induced washover sediment deposits on the order of 1-meter thick, and contributed to cross-island overwash and inundation at numerous places. Along the Atlantic coast, hurricanes Frances and Jeanne produced washover sediment deposits of limited aerial extent, with the majority of sedimentation confined to 30 km from the storm centers. Rarely did overwash associated with these two storms extend across the entire barrier island.

Detailed sedimentological characteristics of two overwash fans were examined in this study based on cores, trenches, and GPR profiling. Despite the significant regional differences in barrier-island morphology and sediment characteristics, substantial similarities in the internal architecture were identified in the two overwash fans. Both fans demonstrate horizontal to sub-horizontal bedding features induced by sheet flow overwash regime occurring over a subaerial surface. These bedding features are characteristic of the shoreward and central portions of the overwash platforms, and merge landward into steeply inclined sigmoidal and tangential foreset (or avalanche) bedding. The steeply inclined foreset bedding likely resulted from subaqueous deposition during flow deceleration as the as the lobe prograded into the low-lying flooded back-barrier environment. At the Beasley Park fan, heavy mineral laminations and truncated dunes are additional characteristics associated with the overwash deposits,

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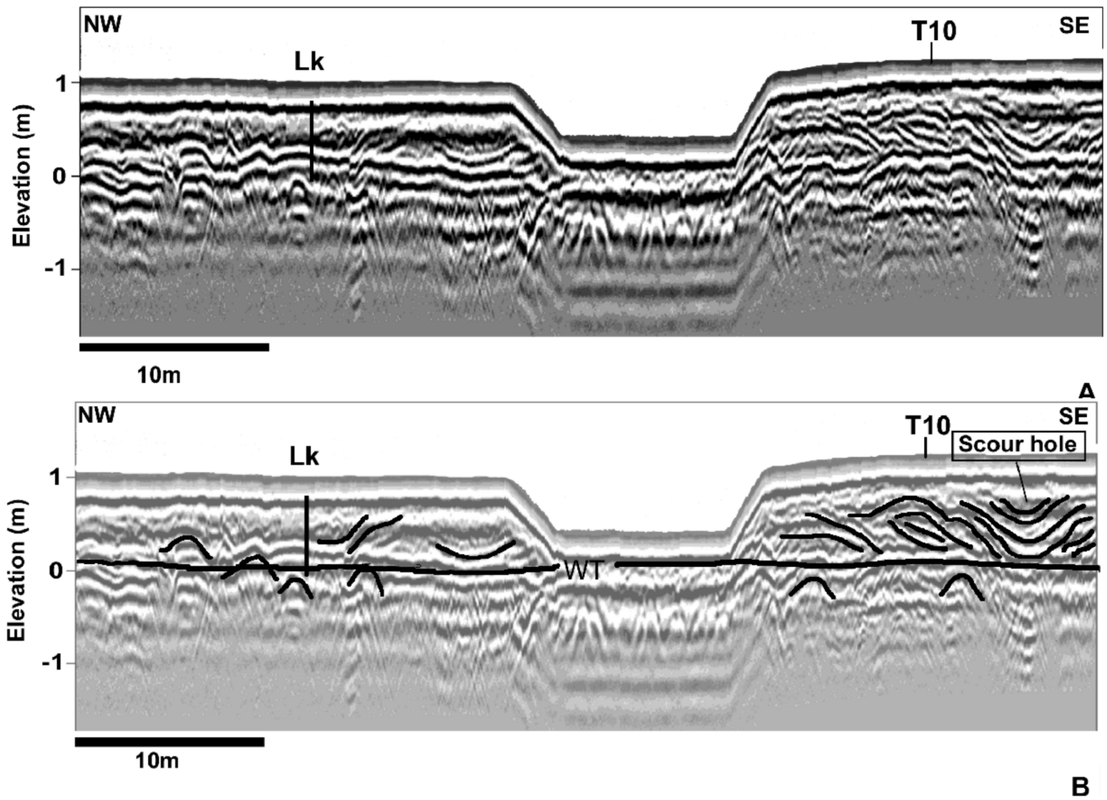

Figure 8. (A) Little lake fan GPR profile T14 showing the cores and intersection with T10. (B) Interpreted GPR profile T14 showing trough shaped reflections interpreted to represent a scour hole. The scattered discrete hyperbolic reflections are interpreted to represent buried mangroves or trees.

and are features clearly identifiable within ground penetrating radar records. At the Little Lake fan, bedding features are rarely visible in the sediment cores, in large part due to the poorly sorted nature of the sediment; however, the GPR records present clear evidence of fine-scale internal stratification. Similarly, the GPR profiles illustrate additional features characteristic of the washover sediment body including a scour hole near the entrance to the lagoon and numerous buried mangrove roots and trunks.

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