Impacts of Hurricane Andrew on carbonate platform environments, northern Great Bahama Bank

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ABSTRACT

The northern (most energetic) quadrant of Hurricane Andrew (August 1992) passed over leeward-margin sand waves, bank-top sand shoals, reefs, and low islands of Great Bahama Bank for which an extensive prestorm data base exists. A reconnaissance survey seven weeks after Hurricane Andrew evaluated storm impacts on these bank-top settings. Resurveyed seismic profiles showed that positions, dimensions, and orientations of platform sand bodies were unchanged relative to fixed bedrock features. Surveys of reef communities indicated only minor storm-related disturbance. Coral bleaching may be due to storm-induced environmental stress. In addition, storm-wave plucking of boulders from emergent rocky cays resulted in localized crushing of reef biota. On low islands, beach erosion and storm surge were insignificant, and storm damage to *Casuarina* forests was minor and substrate-specific. Observed minimal hurricane impacts on northern Great Bahama Bank environments lying 10–75 km from the hurricane eye are reconciled by analysis of meteorological data, which show significant weakening of the storm (expressed as a rise in central barometric pressure of ~20 mbar) during passage across the bank-top. This study demonstrates the importance of specific dynamic aspects of hurricanes (e.g., varying intensity, strength, size, forward speed, duration) which influence their geologic potential, even over relatively short distances along the storm track of an individual hurricane.

INTRODUCTION

On Great Bahama Bank, the northern (most energetic) quadrant of Hurricane Andrew crossed environments assumed to be sensitive to impacts from major storms (leeward-margin sand wave complexes, bank-top sand shoals, 2–10-m-deep reefs and low-relief islands) and for which an extensive prestorm database (>1100 km of high-resolution seismic profiles, 56 core sites, 24 submarine excavation sites) exists. Seven weeks after Hurricane Andrew, a reconnaissance survey assessed possible changes in bank-top bathymetry and sand-body geometry, disturbance to reefs of the northern (windward) and western (leeward) bank margins, and storm impacts on low islands of the western bank margin (Fig. 1). Comparisons of pre- and poststorm data from Great Bahama Bank are reconciled with meteorological data to show that the varying intensity, size, strength, forward speed, and duration of Andrew were critical determinants of storm effects and should be considered when assessing the potential for widespread, long-term modification of landscapes or production of preservable storm deposits by hurricanes.

BANK-TOP BATHYMETRY AND SAND-BODY GEOMETRY

Northern Great Bahama Bank has several sand-wave complexes (Figs. 2, 3; similar to those described by Hine, 1982) and broad bank-top sand shoals (e.g., Mackie Bank; Fig. 4) that were believed to be susceptible to disturbance and modification by major hurricanes. To evaluate hurricane effects on bathymetry and geometry of these features, single-channel, high-resolution seismic profiles (0.15–0.20 m vertical resolution, <1 m horizontal resolution) obtained before and after Hurricane Andrew were compared. Repeated attempts were made to resurvey several profiles directly beneath the eye track of Andrew (Fig. 1), but poor weather prevented acquisition of interpretable seismic data. Seismic profiles were resurveyed using the Global Positioning System (GPS) for navigation. Calculated navigational accuracy was 100–200 m (Leick, 1990). However, relocation of sedimentary and bedrock features substantially smaller than 100–200 m indicated greater real navigational accuracy and suggested that calculated accuracy was dominated by uncompensated measurement errors.

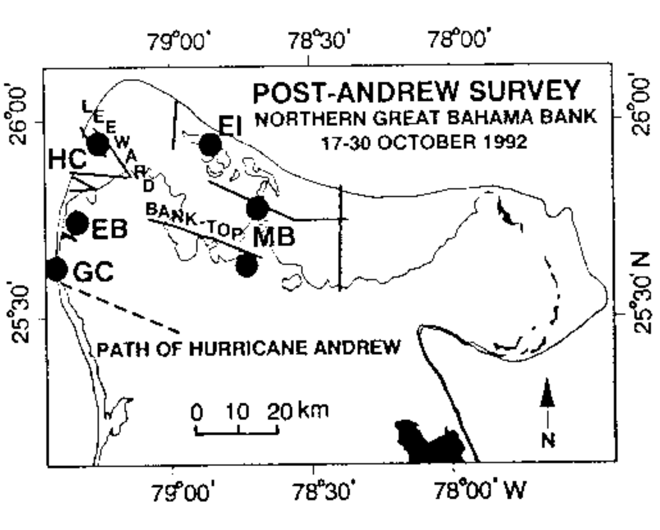

Figure 1. Locations of resurveyed seismic profiles (thick lines) and field sites (solid circles) on northern Great Bahama Bank. Named seismic profiles are illustrated in Figures 2–4. Field sites included low islands Gun Cay (GC), East Bimini (EB), Hens & Chickens Rocks (HC), and East Isaac (EI), reefs (HC, EI), and Mackie Bank (MB), a large sand shoal of central bank top. Dashed seismic profile near eye-track of Andrew had to be abandoned because of poor weather.

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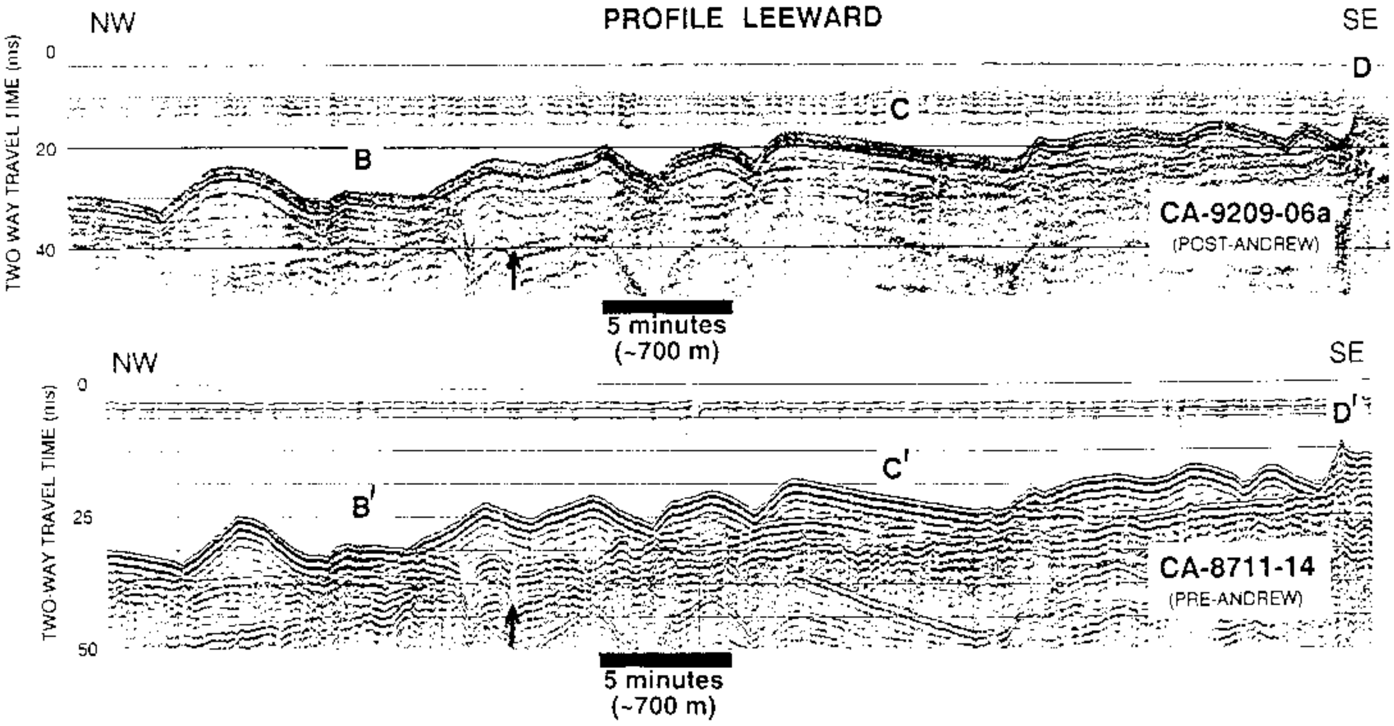

Figure 2. Parts of uncorrected post- and pre-Andrew analog seismic records from profile Leeward. Note position and orientation of Holocene sediment bodies (C, C') relative to fixed bedrock features (e.g., B, B', rocky outcrop and solution shafts; D, D', rock ridge). Lower arrow shows small solution shaft. Upper arrow indicates area where solution shaft should be on resurveyed profile. Also note apparent change in slope aspect of sand waves due to vertical and horizontal distortions (see Fig. 3 for more accurate view).

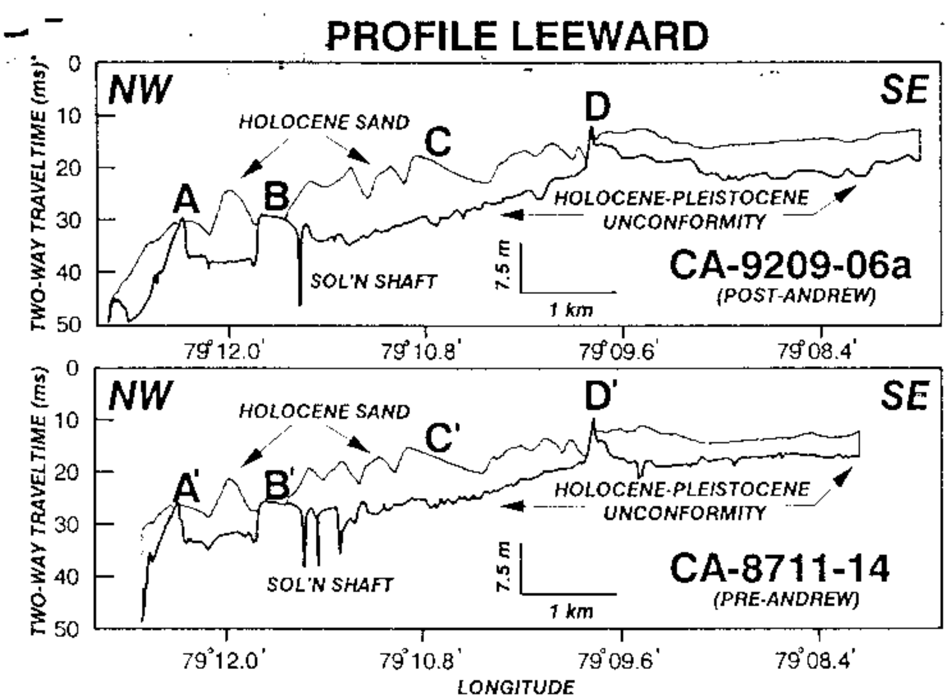

Figure 3. Simplified, digitized interpretations of profile Leeward showing relation of Holocene sediments (stippled) to Holocene-Pleistocene unconformity (irregular, heavy line) after and before Hurricane Andrew. Sediment body geometries have not changed appreciably over the six years separating these two profiles, indicating that Hurricane Andrew did not cause significant sediment transport or sand-body reorganization. A, A' is submerged, mostly buried Pleistocene rock ridge; B, B' is submarine outcrop of Holocene-Pleistocene unconformity and buried solution shafts; C, C' is Holocene sand-wave complex; D, D' is submerged Pleistocene ridge.

Pre- and Posthurricane Seismic Profile Comparisons

Digitizing pre- and posthurricane seismic profiles permits plotting of profiles at the same vertical scale and converts the horizontal time axis into spatial coordinates (latitude and longitude), thereby eliminating vertical and horizontal distortions on analog seismic records caused by variations in vertical scale, ship speed, and output speed of the paper recorder (Fig. 2). Much of any remaining distortion in the horizontal dimension was collapsed by projecting the digitized output on a common datum (parallels or meridians). Although this last procedure produced some residual distortion of its own, comparative trials demonstrated that such projection collapsed more distortion than it created, thus improving visual comparisons.

Profile Leeward

Profile Leeward (Fig. 1) was originally surveyed in 1987 (Figs. 2 and 3) and shows a sand-wave complex (C, C') overlying an irregular, karstic surface (Holocene-Pleistocene unconformity). Diver observations and coring of these sand waves (July 1991) showed that they were composed of unconsolidated Holocene sand and were not stabilized by sea-grass or submarine-cemented horizons. Several prominent rock ridges (A, B, D) and solution shafts (karst features developed during sea-level lowstands) imaged

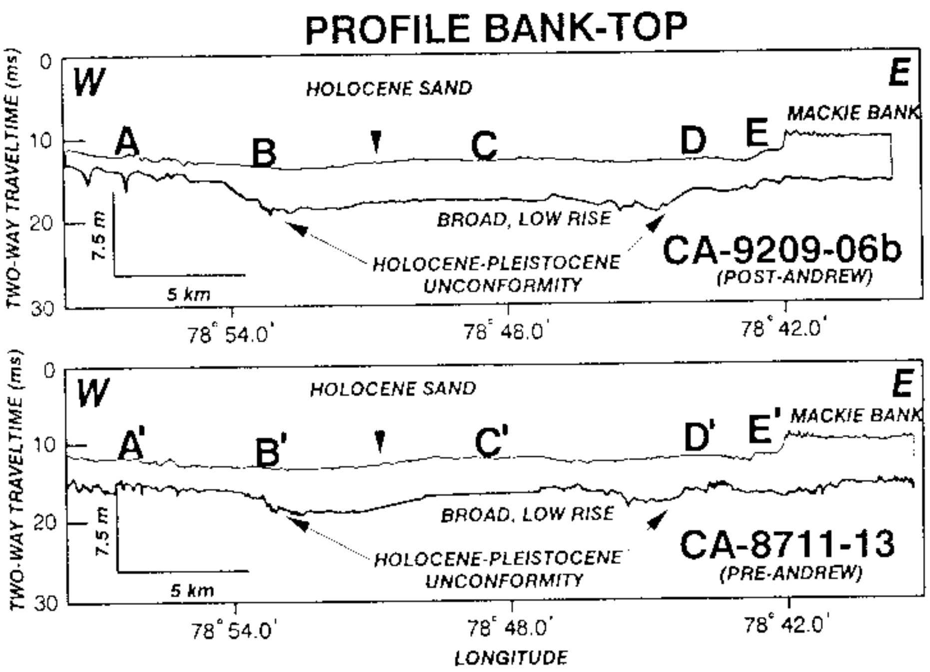

Figure 4. Simplified, digitized interpretations of profile Bank-top after and before Hurricane Andrew. Stippling indicates Holocene sediments; irregular, heavy line is Holocene-Pleistocene. Note similarity in sediment thickness across both profiles, indicating absence of significant storm-induced sediment scour and transport. Also, position and orientation of face of Mackie Bank (E, E') is unchanged on both profiles. A, A' is elevated, karstic Holocene-Pleistocene surface; B, B' is sloping Holocene-Pleistocene surface; C, C' is broad, low rise on Holocene-Pleistocene surface; D, D' is localized bedrock high; E, E' is depositional terrace and face of Mackie Bank, a bank-top sand shoal.

on this profile provided fixed references for evaluating posthurricane changes in bathymetry and sand-body orientations. The successful relocation of one of the solution shafts imaged in 1987 (measured diameter ~70 m) confirms the accuracy of navigation. While an adjacent solution shaft imaged in 1987 (Fig. 2, lower arrow) does not appear on the poststorm profile, careful inspection of the uncorrected analog data suggests a "near miss" (Fig. 2, upper arrow denotes apparent deformation of reflectors at the location where the solution shaft should be). The digitized versions of pre- and posthurricane profiles (Fig. 3) show that no significant changes in sand-body dimensions, slope aspects or orientations (relative to fixed bedrock features) have occurred in six years.

Profile Bank-top

Profile Bank-top (Fig. 1) included the western limit of a large bank-top sand shoal, Mackie Bank.[1] The western margin of Mackie Bank is a gently sloping surface approximately 2–2.5 m high (Fig. 4, E, E'). On seismic profiles, this drop-off appears very steeply inclined because of the extreme vertical exaggeration. The posthurricane profile showed that the position and slope of this drop-off (Fig. 4, E) are unchanged. In addition, sediment thickness across this region has not changed appreciably, indicating an absence of significant storm-induced bottom scour. Apparent sediment thinning at the western edge of the poststorm profile is caused by slight elevation of the Holocene-Pleistocene unconformity (~12 ms two-way traveltime) relative to the prehurricane profile (~15 ms two-way traveltime).

HURRICANE IMPACTS ON REEF ENVIRONMENTS

Posthurricane observations on windward- and leeward-margin reefs (originally surveyed in July 1991 and 1992) revealed negligible disturbance. Coral bleaching was commonly observed after Andrew and may relate to storm-induced environmental stress. In addition, highly localized damage to reef biota occurred in the immediate vicinity of rocky cays where boulders plucked from the cays by storm waves crushed sessile organisms.

NORTH AND SOUTH BIMINI

The low relief of North and South Bimini (~90% of the islands' area is <3 m above sea level) and their proximity to the northern eyewall (narrow region of intense cloud formation, rainfall, and maximum wind around the eye perimeter) of Andrew (16–20 km north) made them appropriate locations to examine storm impacts on beaches and terrestrial environments. Beaches along the eastern shore of North and South Bimini were unprotected from the easterly wind field during Andrew's passage. However, beach erosion was limited (0.3–0.5-m-high erosional scarp; Fig. 5). No sediment-overwash lobes or modification of narrow sand spits were noted.

In addition, there was evidence of only minor storm surge. A "storm strand" composed primarily of sponges transported from *Thalassia* meadows offshore was present landward of the erosional scarp. Also, a zone of grasses and shrubs ~1 m wide bordering the highest beach (1–1.5 m above mean sea level) was killed by salt-water incursion into the root zone. However, the thick carpet of *Casuarina* (Australian pine) needles on the forest floor landward of these grasses showed no evidence of disturbance or wave swash, and large (1–1.5 m tall) termite nests on the forest floor less than 25 m from the beach were intact and upright.

Wind damage to mature *Casuarina* forests was mostly restricted to trees bordering the beach and was substrate specific. *Casuarina* rooted in unconsolidated Holocene sand acquired a profound westward tilt, but few were toppled, whereas many *Casuarina* rooted on rocky substrates (lithified beach facies) were toppled, even in relatively protected settings near the interior of South Bimini.

DISCUSSION

Resurvey of seismic profiles parallel and perpendicular to the storm track, surveys of shallow reefs, and reconnaissance of low islands north of the hurricane's center reveal minimal storm-related damage on Great Bahama Bank. Seven weeks after the hurricane, observable effects are surficial phenomena (substrate-specific tree toppling, storm-wave plucking of boulders from rocky cays) with little geologic preservation potential. The superficial nature of these effects indicates that the varying intensity, size, strength, forward speed, and duration of Andrew were critical constraints on the storm's capacity to modify shallow-marine and terrestrial environments.

For example, reports of Andrew (Rappaport, 1992; Anonymous, 1992) emphasize the maximum intensity observed in the eastern Bahamas and south Florida, where minimum pressure (922 mbar) and maximum winds (250 km/h) were among the most extreme recorded for any Atlantic hurricane. However, Andrew weakened substantially as it traversed Great Bahama Bank. The central pressure rose ~20 mbar (to between

[1]GSA Data Repository Item 9333, analog seismic record of Profile Bank-top, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301.

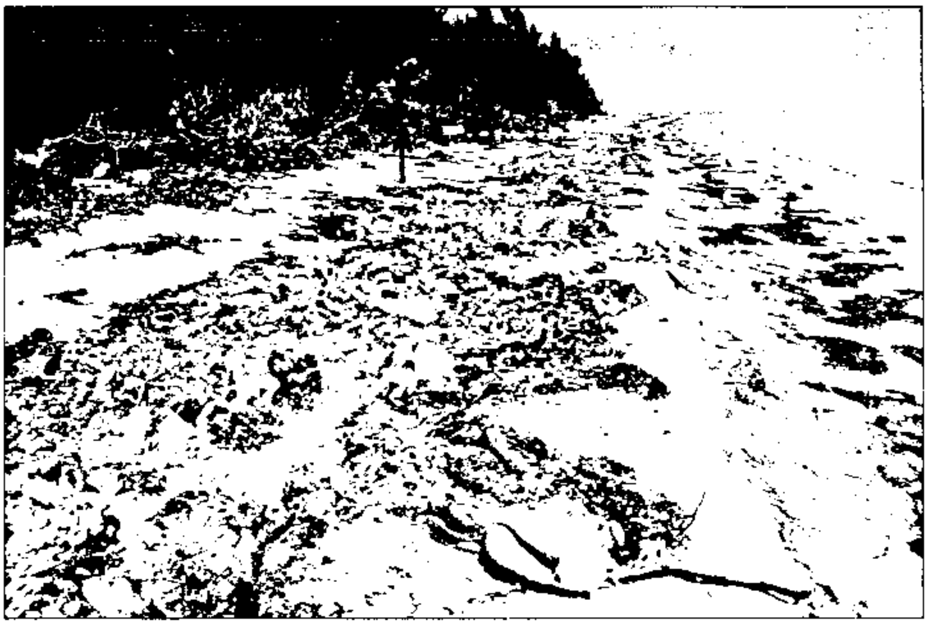

Figure 5. View northward along East Bimini beach. Note small erosional scarp (0.3–0.5 m) near normal high-tide level and storm strand (mostly sponges) on beach just shoreward of scarp. In situ grasses and shrubs of high beach (arrow) were killed by salt-water incursion into their root zone, indicating maximum level of storm surge (1–1.5 m). Note also that mature *Casuarina* immediately behind high beach appear unaffected.

941 and 948 mbar; Rappaport, 1992) near the western bank top. An estimate of the peak wind at this pressure was derived from the empirical relation $v_{max} = 6.3\ (p - p_o)^{0.5}$ (Pielke, 1990), where v_{max} is maximum wind speed (m/s), p is 1013 (standard sea-level pressure, mbar) or 1005 (typical tropical sea-level pressure, mbar); and p_o is observed surface pressure (mbar). This estimate yields v_{max} ~50 m/s (~180 km/h), a 28% reduction from wind maxima at peak hurricane intensity and a decline in Saffir-Simpson intensity from near category 5 to a minimal category 3 hurricane (Pielke, 1990). Dramatic reduction in wind velocity is consistent with observed minor tree and property damage on Bimini.

A similar calculation showing the effect of hurricane weakening on storm surge was obtained from $h_{max} = 0.867(1005 - p_o)^{0.618}$ (Conner et al., 1957), where h_{max} is surge height (ft) and p_o is central barometric pressure (mbar). At peak intensity (922 mbar), the predicted surge height in open water (ignoring effects of lunar tides and coastal geometry) is 13.3 ft (4.1 m), close to observed values of storm surge in south Florida of 16.9 ft (5.2 m) which occurred at high tide within the confines of Biscayne Bay (Rappaport, 1992). Increasing the central storm pressure to 948 mbar reduces the predicted maximum surge height to 10.5 ft (3.2 m). However, the predicted maximum surge may not have occurred on Great Bahama Bank because of the shallow water (~5 m) and rapid forward progress of Andrew along the storm track. On the bank top, the storm surge should behave as a shallow-water wave with velocity described by $v_s = (gd)^{0.5}$, where v_s is surge velocity, g is the acceleration due to gravity (9.8 m/s^2) and d is water depth (m) (Pond and Pickard, 1986). For bank-top water depths, the maximum calculated surge velocity is ~7 m/s. However, the forward speed of Hurricane Andrew across Great Bahama Bank was ~11 m/s. Thus, the storm surge would be unable to keep pace with the hurricane while crossing the shallow bank top, so the maximum estimated surge height would not be realized. Given these constraints, the observed storm surge of 1–1.5 m on East Bimini appears reasonable.

Impacts from any hurricane are proportional to the area and period over which hurricane conditions persist; more extensive surface damage and sediment redistribution are caused by larger, slower-moving hurricanes. Quick passage (Andrew crossed Great Bahama Bank in about 3 hours; Rappaport, 1992) of a weakened Hurricane Andrew across Great Bahama Bank probably prevented establishment of substantial unidirectional flow capable of modifying sediment bodies, whereas the limited radial extent of hurricane-strength winds (<50 km from the eye; Rappaport, 1992; Aberson et al., 1992) restricted potential changes in bathymetry to the area directly beneath the storm center. In contrast, Hurricane Betsy (1965) took about 9 hours to cross Great Bahama Bank (avg forward speed = 3.8 m/s; Sugg, 1966). Though roughly the same intensity as Andrew (sustained winds 190–225 km/h; Sugg, 1966), the slower moving Betsy appears to have generated substantial surge along its entire track and caused extensive sediment redistribution in shallow subtidal environments (Perkins and Enos, 1968).

Along its track, Hurricane Andrew twice reached sufficient intensity to rank among the most intense Atlantic hurricanes of this century. However, on Great Bahama Bank, Andrew's dynamic characteristics were remarkably different. Results of this study demonstrate the influence that dynamic storm parameters have on production of geologically preservable features (e.g., storm layer formation, sand-body redistribution, coral reef devastation), even over relatively short distances along the track of an individual hurricane.

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