Carbonate Eolianites in the Exumas - The Legacy of Vanishing Ebb Tidal Deltas During a Sea Level Rise*

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Abstract

The high-energy platform margin in the Exumas Islands portion of Great Bahama Bank is dominated by a tidal delta depositional motif, typified by islands (Pleistocene or Holocene) bounding open circulating tidal channels within which vigorous tidal flow leads to the formation of flood and ebb tidal lobes formed of ooid and other types of carbonate sands. As shown by the robust example of this motif associated with the tidal channel between Shroud and Hawksbill Cays, significant amounts of sediment form fully aggraded flood and ebb lobes and adjacent sand flats, and are reworked from the ebb tidal lobe by longshore currents and storms to nourish adjacent beaches and form back-beach sand ridges that quickly become cemented by meteoric cements. Isolated Early Holocene (~5,000 years old) eolianites on several islands in the Exumas, e.g. Gaulin Cay, Bitter Guana Cay, Cambridge Cay, O'Brien's Cay, and Warderick Wells Cay, are problematic, in that these significant relict deposits of ooid and peloid sands with large-scale foreset bedding clearly indicating sediment transport onto the platform are challenging to explain from the standpoint of the source of the carbonate sand. Age-related, coeval facies are lacking, and laterally adjacent shorelines generally lack appreciable Holocene sediment and commonly show signs of erosion and coastline retreat. We propose these eolianites are the result of ebb tidal lobe cannibalization by longshore currents and storms, and their apparent non-equilibrium state with the modern seaward coastline strongly suggests a major change in depositional conditions between time of deposition of the eolianites and present-day. It is likely that tidal delta lobe development occurred in these areas a few thousand years ago during a lower position of sea level when more vigorous tidal currents were concentrated in channels formed in deeper Pleistocene lows. Present sea level has resulted in less vigorous tidal currents in these areas and cannibalization through erosion (longshore currents and storms) of the ebb tidal delta lobe, beach sands, and the seaward portions of the eolianites themselves. The resultant, significant eolianite deposits at these localities are difficult to understand in the absence of their associated early Holocene facies belts, and would pose a very challenging dilemma to explain them in any ancient scenario. Associated facies are missing entirely or are severely truncated.

Introduction

Interest in modern analogs for carbonate sand reservoirs is warranted based on the substantial number of carbonate reservoirs that produce from grainstones and packstones, e.g., reservoirs described by Wilson (1975), Harris (1984), Roehl and Choquette (1985), Keith and Zuppann (1993),

and Harris and Weber (2006). The spatial variability of depositional environments and early diagenetic overprint that potentially creates reservoir heterogeneity within a carbonate sand system can be observed in the Exuma Islands portion of the Great Bahama Bank.

Tidal Delta Motif in the Exumas

The high-energy platform margin in the Exumas Islands portion of Great Bahama Bank (Figure 1) is dominated by a tidal delta depositional motif, typified by islands (Pleistocene or Holocene) bounding open circulating tidal channels within which vigorous tidal flow leads to the formation of flood and ebb tidal lobes formed of ooid and other types of carbonate sands.

As shown by the robust example of this motif associated with the tidal channel between Shroud and Hawksbill Cays (Figure 2), significant amounts of sediment form fully aggraded flood and ebb lobes and adjacent sand flats; the flood tidal lobe stretches approximately 3.4 km to the west and the ebb tidal lobe ~1 km to the east from the "center" of the delta (Petrie, 2010). Sediments are reworked from the ebb tidal lobe by longshore currents and storms to nourish adjacent beaches and form sand ridges that quickly become cemented by meteoric cements. Significant amounts of sand can be stored in these ridges; Harris and Ellis (2009) mapped 54 linear Holocene ridges on Hawksbill Cay. The ridges up to 12 m high totaled 17.6 km in length, averaged ~320 m in length, and collectively account for 62% of the islands 2.8 km^2 area. AMS radiocarbon dating by Petrie (2010) from a Cerion shell in a cemented, actively eroding beach ridge on the southernmost portion of Shroud cay indicate an age of ~580 +/- 40 years before present (BP). The age demonstrates that deposition, partial cementation, and erosion of the dunes occur on geologically instantaneous time scales.

An inventory of active tidal channels in the Exumas shows that examples like Shroud Cay where both the flood and ebb tidal lobes are well formed are not common. Fifty-two active tidal channels were identified from Landsat and off-shore DEM data between Highborne and Great Guana Cays in the Exumas by Harris and Ellis (2009) and Harris (2010); associated with these channels flood-tidal delta lobes are dominant (comprising 85% of the sand belt) and ebb tidal delta lobes are generally poorly developed (9% of the sand belt). We suggest that the dominant scenario in the Exumas is for the ebb lobe to eventually become less active, with the sands then extensively reworked by longshore currents (Figure 3).

Factors leading to this evolution can be some combination of (i) aggradation of sands in the tidal delta lobes and tidal channel itself to the point that current velocities are reduced, (ii) gradual or abrupt change to wave and wind-influenced longshore flow to the point that sand transport along the seaward side of the islands is modified, (iii) significant modification of the entire tidal channel and tidal delta system by a catastrophic storm, and (iv) a change in sea-level and associated changes in current velocities and patterns.

Eolianites in the Exumas

The first three factors mentioned above can be observed or conjectured for extant Holocene tidal channels in the Exumas, whereas the forth factor is believed to be the principal one related to the deposition of problematic eolianite deposits on several islands in the Exumas. Isolated Early Holocene (~5,000 years old; Table 1) eolianites on several islands, e.g. Gaulin Cay, Bitter Guana Cay, Cambridge Cay, O'Brien's Cay, and Warderick Wells Cay (Figure 4), are problematic, in that these significant relict deposits of ooid and peloid sands with large-scale foreset

bedding clearly indicating sediment transport onto the platform are challenging to explain from the standpoint of the source of the carbonate sand. Age related, coeval facies are lacking, and laterally adjacent shorelines generally lack appreciable Holocene sediment and commonly show signs of erosion and coastline retreat (Figure 5). We propose these eolianites are the result of ebb tidal lobe cannibalization by longshore currents and storms, and their apparent non-equilibrium state with the modern seaward coastline strongly suggests a major change in depositional conditions between time of deposition of the eolianites and present-day.

A long-standing general "problem" of having peloid-ooid eolianites exist along the windward margin of the platform, first expressed by Illing (1954), centers around the source, transport, and timing of the dune sediment. Peloids and perhaps the ooids in the eolianites are apparently derived from the interior of the platform though the prevailing wind directions are (and apparently have been) from off platform. This leads to the question of how sediment generated well back from the platform margin is transported to windward settings from which it is blown back in a bankward direction without at the same time mixing with the predominantly skeletal sediments typical of the platform margin. Various solutions to this problem have been proposed: a) Illing (1954) suggested that ooid-peloid sediment forms behind marginal cays, is swept into shallow bays and beaches during periods of submergence, and is blown bankward with subsequent sea level fall – a model implying that the dominant growth of cays would be in a bankward direction; b) Newell (1955) and Newell and Rigby (1957) suggested the greatest supply of ooid-rich sand lay in marginal submarine ooid ridges, areas that should be preferred sites of dune development during an ensuing period of exposure at which time these ooids would be blown into dunes - a model forming a series of margin parallel dunes, in which the inner ones would be older and the outer ones younger; and c) Beach (1982) proposed deposition of platform-margin eolianites at the end of a sea-level highstand, wherein small skeletal sand cays formed along the windward margin, restricted circulation and promulgated the formation of ooids in the adjacent tidal passages. Small cuspate tidal deltas likely formed around the bankward edge of these tidal channels, and tidal currents and longshore currents may have swept these sediment seaward to accumulate along the ocean- facing beaches where they could be blown by the predominant southeast trade winds into large dunes. Kindler (1992) proposed a model for Holocene deposits in the eastern Bahamas that invoked episodic sedimentation versus continuous sea level rise. He documented an older Holocene (~ 5000 year old) oolitic eolianite tied to a sea-level lower than today, and younger Holocene (300 to 500 year old) bioclastic beaches and dunes tied to present sea level. His model considers pre-Holocene topography and changes in the rate of the transgression as controls over local hydrodynamic conditions, which in turn control the onset and offset of sedimentary processes.

Evolving Holocene Depositional System in the Exumas

We propose that tidal deltas played a key role in the formation of prolific ooid and peloid eolianites earlier in the Holocene than today at certain localities in the Exumas, and a variation of the 'models" proposed by Beach (1982) and Kindler (1992) is the most logical explanation for the source of the sands. Modern examples like Shroud Cay demonstrate that tidal delta systems can indeed produce vast amounts of ooid and peloid sands, to the point where sands diminish the width of the tidal channels as sand flats are produced adjacent to the bounding islands, sands locally fill the channels diminishing their effectiveness, and sands are transported from the ebb tidal lobe to accumulate on adjacent beaches and 'dune' ridges.

Similar conditions must have occurred at the Gaulin Cay, Bitter Guana Cay, Cambridge Cay, O'Brien's Cay, and Warderick Wells Cay localities earlier in the Holocene based on the occurrences of relict eolianites, but not at the present time, implying a major change in conditions

influencing deposition. It is likely that tidal delta lobe development occurred in these areas a few thousand years ago during a lower position of sea level when more vigorous tidal currents were concentrated in channels formed in deeper Pleistocene lows (Figure 6). Present sea level has resulted in less vigorous tidal currents in these areas and cannibalization through erosion (longshore currents and storms) of the ebb tidal delta lobe, beach sands, and the seaward portions of the eolianites themselves (Figure 7).

The resultant, significant eolianite deposits at these localities are difficult to understand in the absence of their associated early Holocene facies belts, and would pose a very challenging dilemma to explain them in any ancient scenario. Associated facies are missing entirely or are severely truncated. The amalgamation of different age Pleistocene and Holocene deposits produces an exploration-scale linear grainstone thick that parallels the platform margin, and is inherently heterogeneous due to variation of depositional facies and diagenetic overprint (Figure 8). Marine Isotope Stage (MIS) 9/11 deposits, which form the backbone of the island chain, are complexly surrounded by younger Pleistocene MIS 5e deposits. These are in turn surrounded by older Holocene and modern MIS 1 grainstones.

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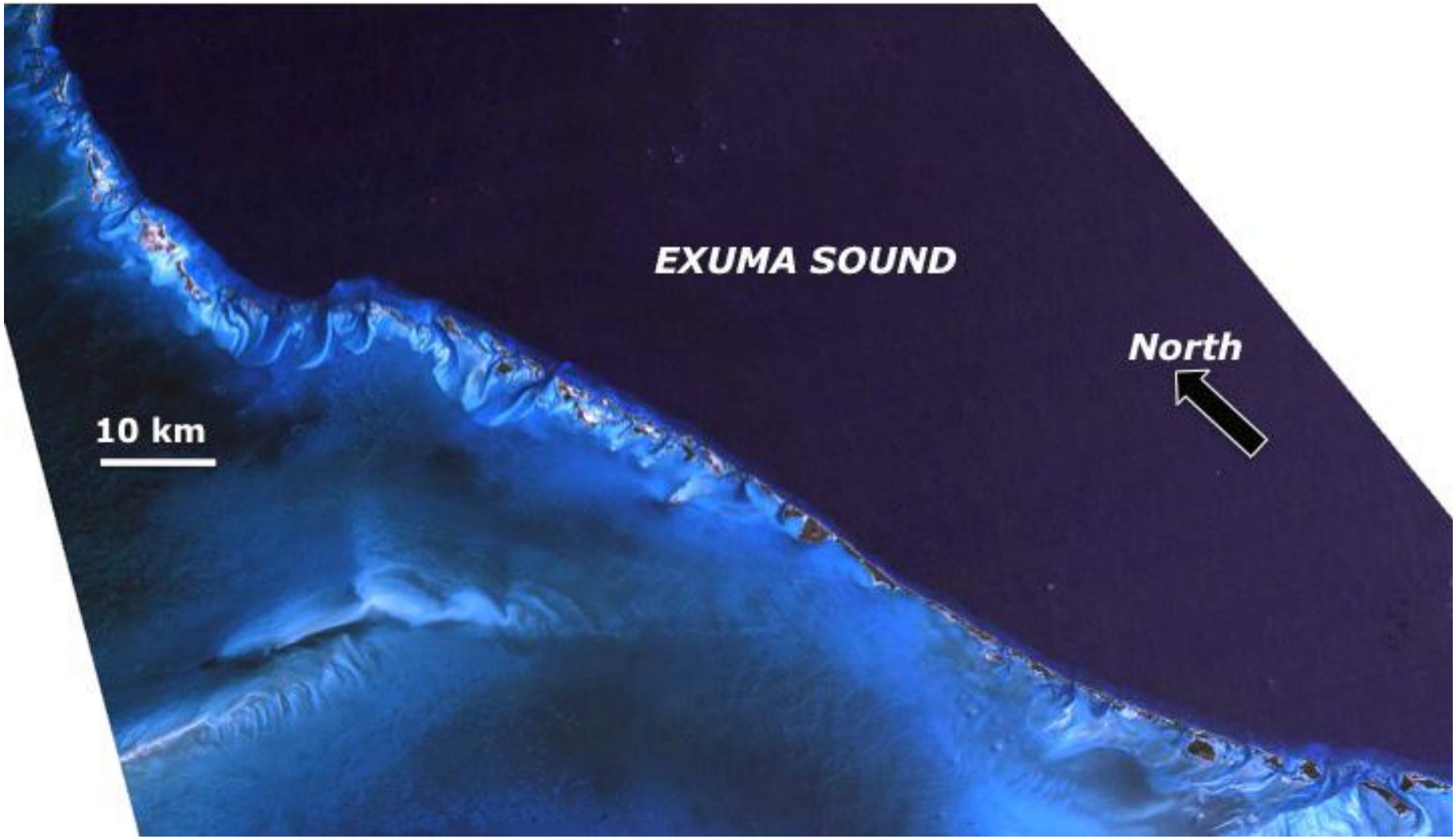


Figure 1. Landsat image from Harris and Ellis (2009) showing tidal deltas, channels, and islands of the Exumas, which form an exploration-scale linear belt of mostly ooid sand. This sand body is approximately 5–10 km wide, 170 km long, and parallels the platform margin but is set back from the platform edge.

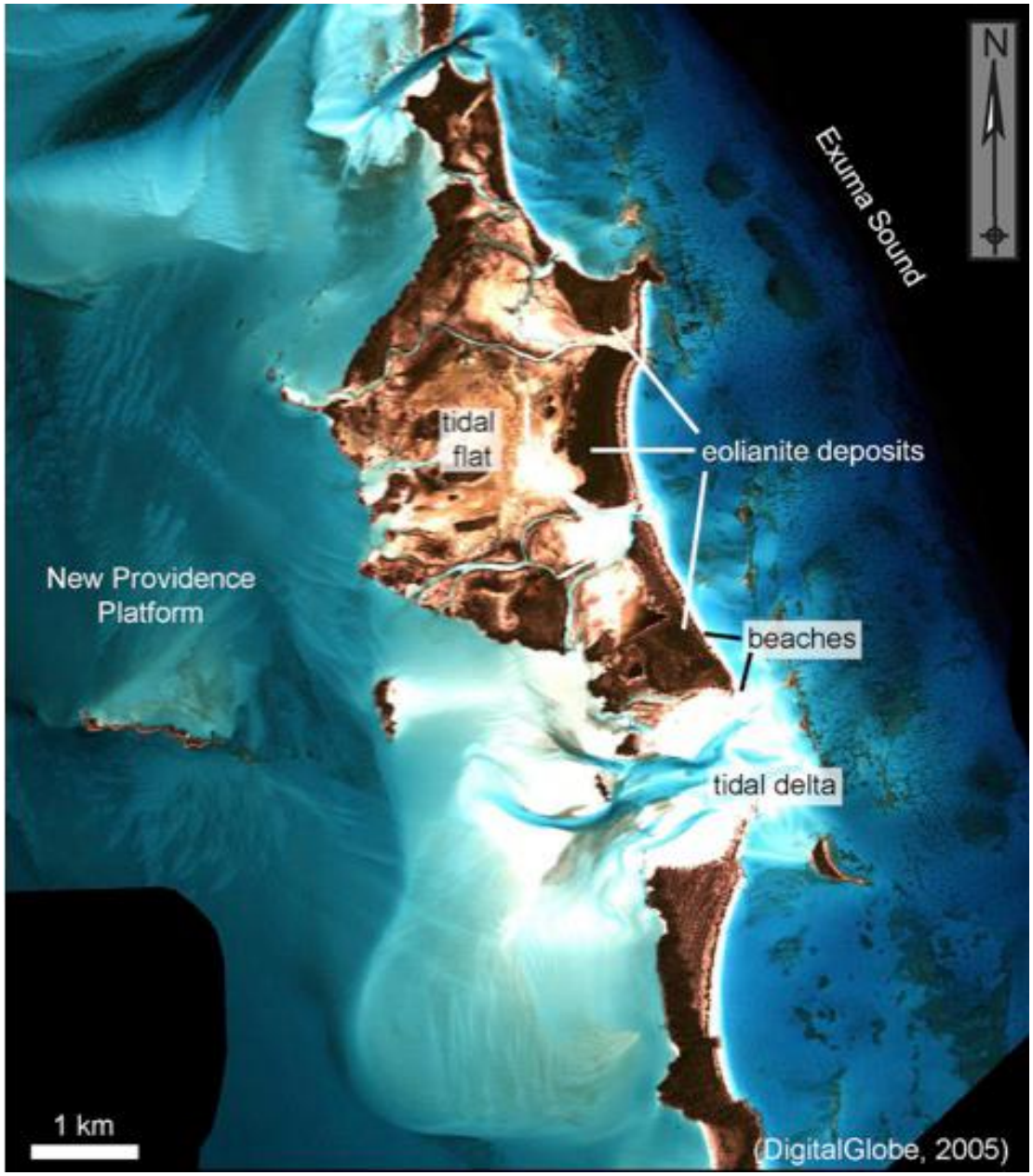


Figure 2. Well-formed tidal delta between Shroud Cay (north) and Hawksbill Cay (south) has fully aggraded flood and ebb lobes, as well as adjacent sand flats and well-nourished beach and dune ridges. Modified from Petrie (2010).

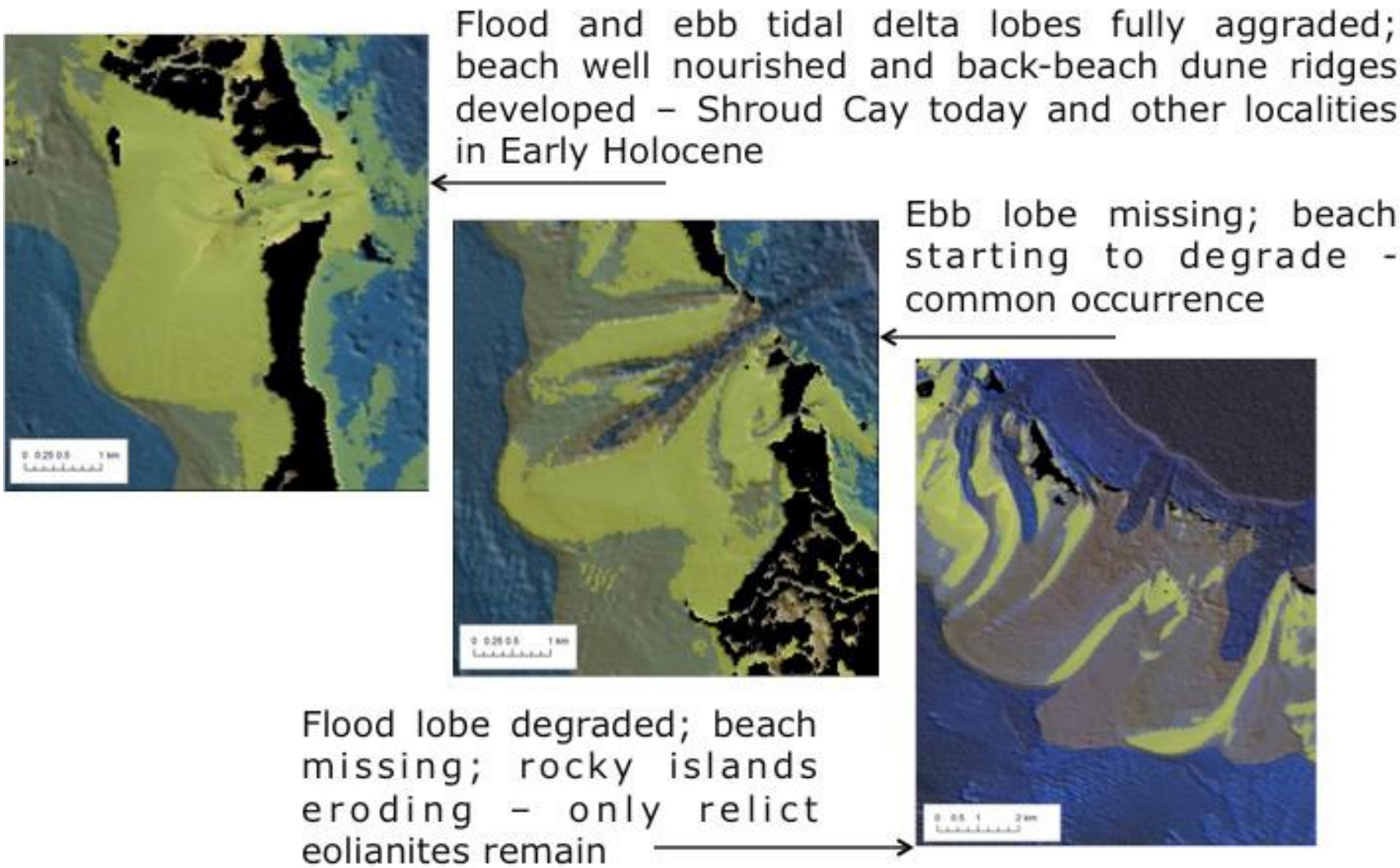


Figure 3. Interpreted Landsat images from Harris and Ellis (2009) showing sequential stages in a scenario of vanishing ebb tidal deltas. In each image, black is islands, gray shows the width of the sand body, and yellow indicates that portion of the sand body that is fully aggraded.

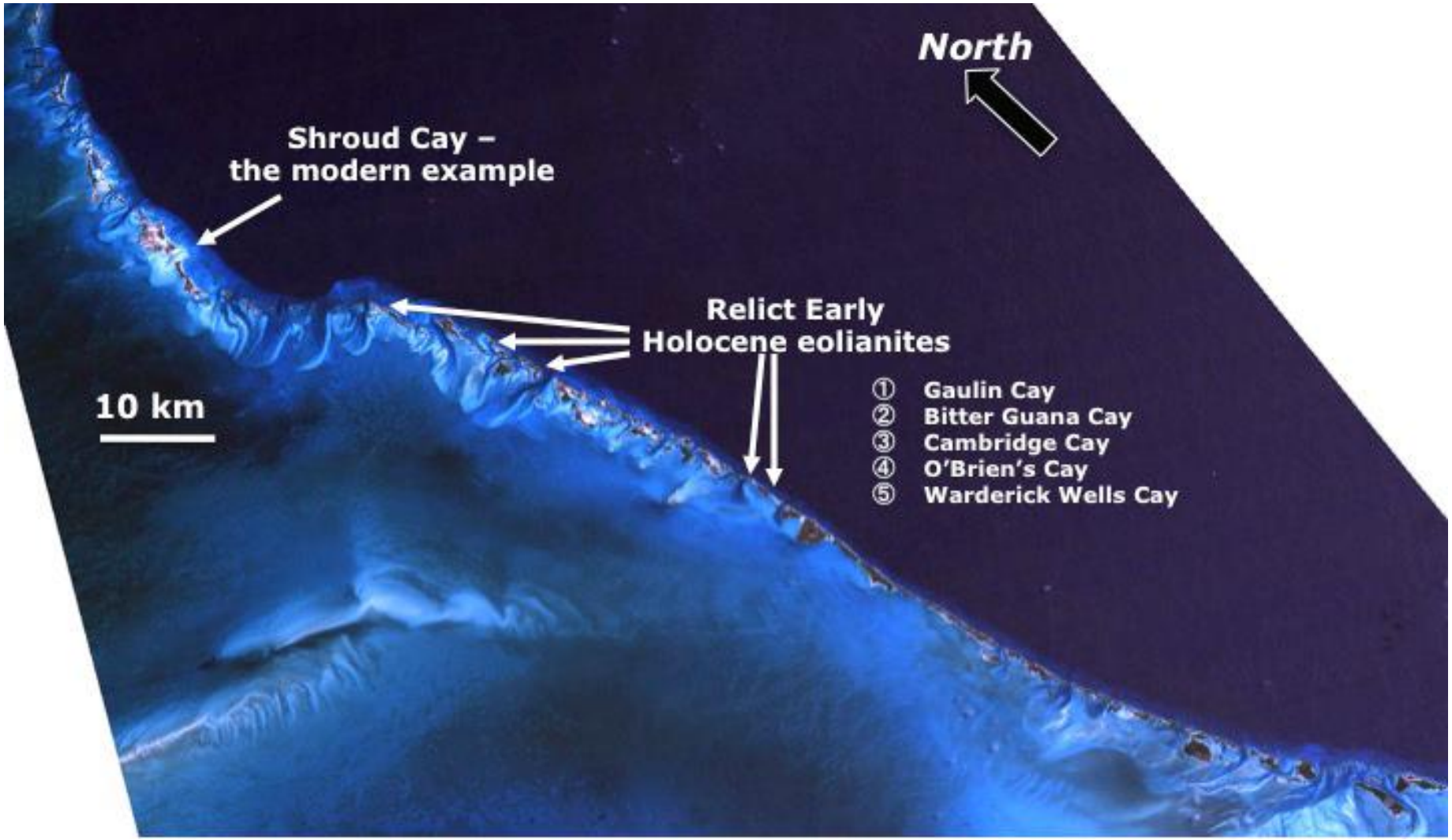


Figure 4. Landsat image from Harris and Ellis (2009) showing locations of key islands discussed in text.

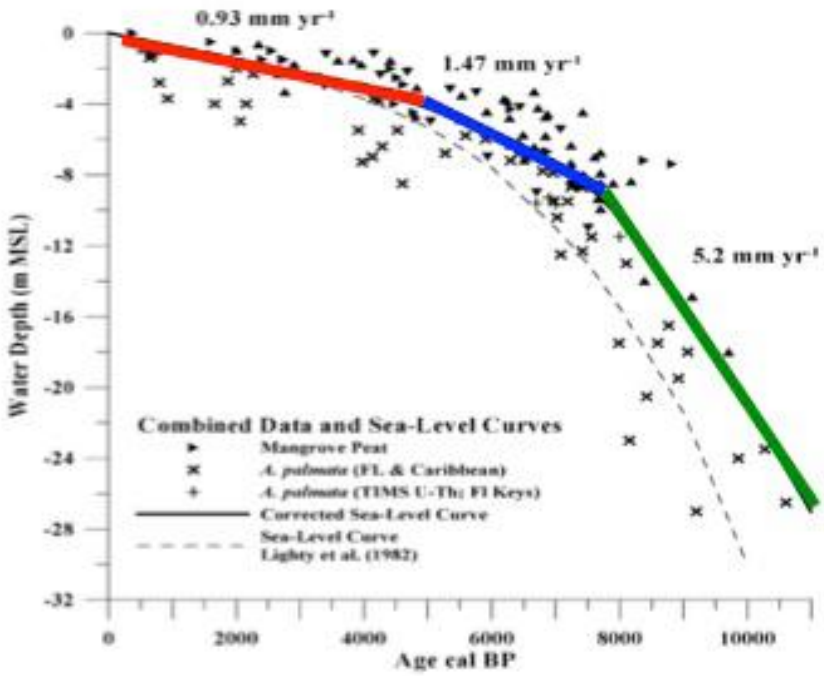
Figure 5. Oblique aerial photo looking south and toward the platform. White area is relict Holocene eolianite deposit; note ebb tidal delta, beaches, and a portion of the Pleistocene island itself are eroded.

Different phases to flooding history; critical elements being (1) the nature of the sea-level curve and (2) local variation in Pleistocene topography:

~11-8 kybp - Skeletal outermost platform margin, possibly sourcing local dune ridges.

~5-8 kybp - Ooid/peloid delta and beach/ridge systems in certain localities (Bitter Guana, Gaulin, etc); mud on the platform top.

<5 kybp - Shroud Cay-like settings are robust, Phase 2 settings now eroding or already eroded, and platform interior deeper with grapestones.



From Toscano et al, 2003

Figure 6. Possible Holocene flooding history for platform top in the Exumas area; ages bracket time intervals potentially affecting eolianite formation and preservation.

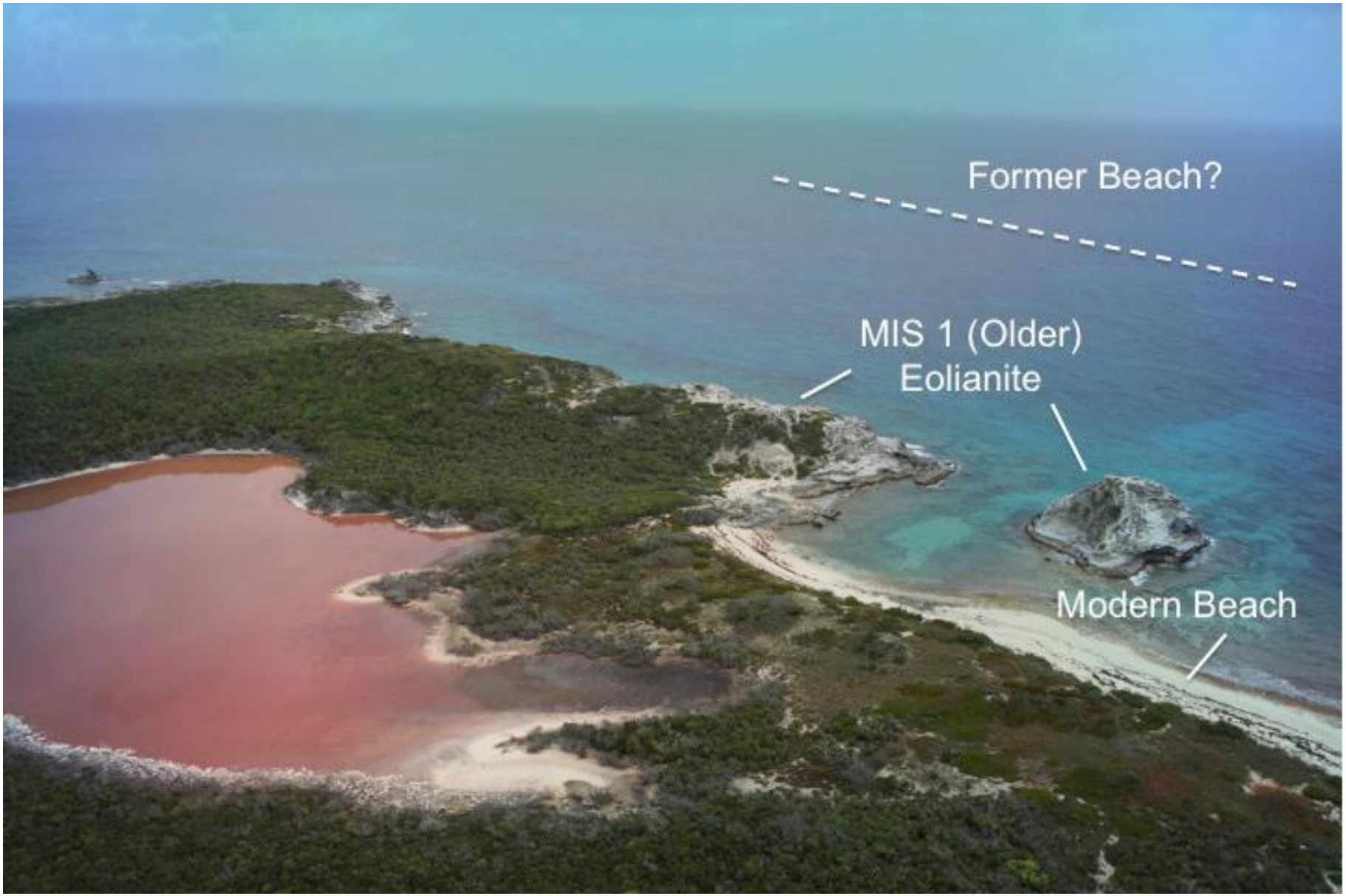


Figure 7. Oblique aerial photo looking seaward and showing erosional remnants of well-developed older Holocene eolianites. Dashed line suggests position of the beach that may have source the dune ridges; erosion has removed the older beach, laterally adjacent ebb tidal deltas, and a significant portion of the eolianites themselves.

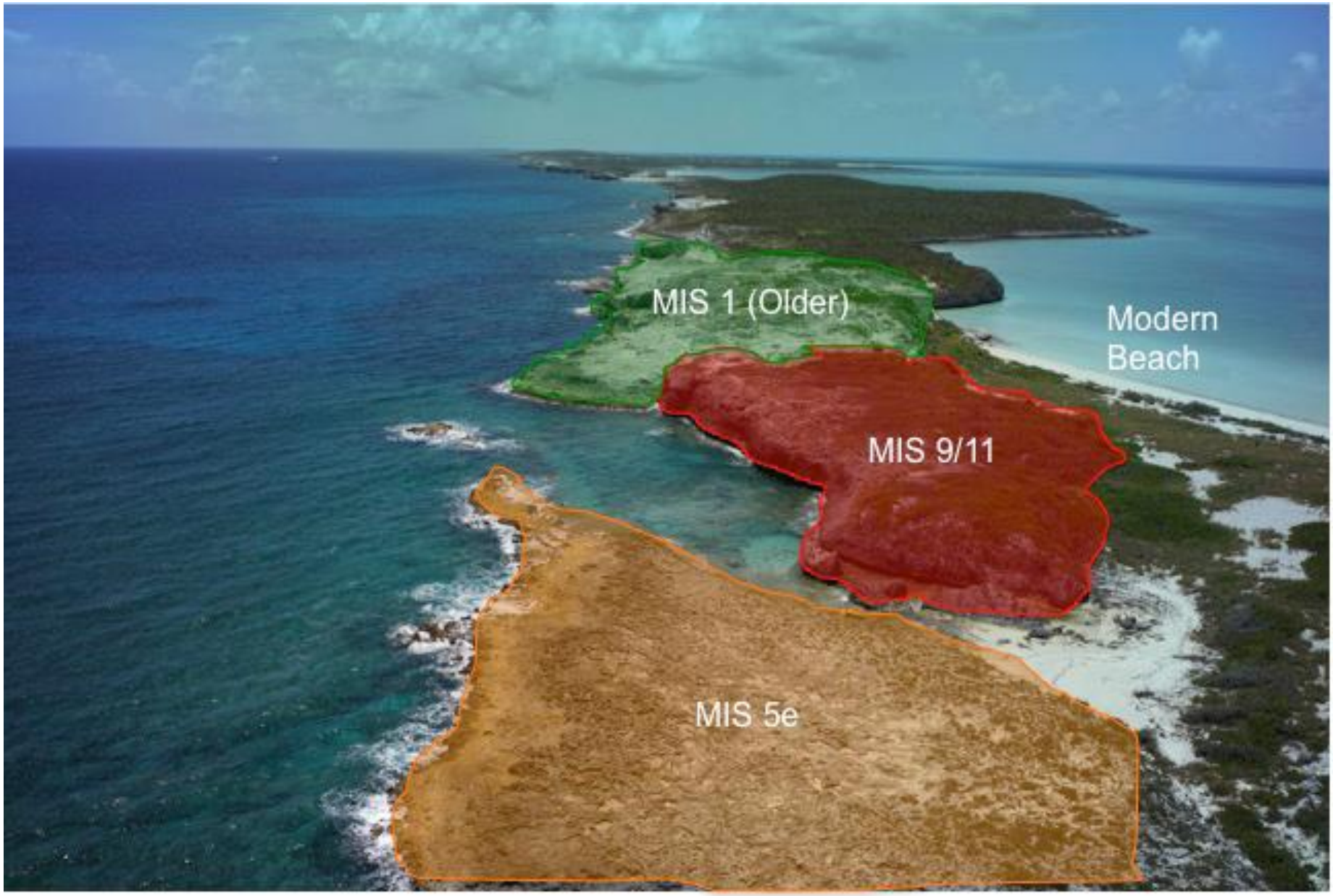


Figure 8. Oblique aerial photograph looking south to highlight that the Exumas Islands are an exploration-scale linear belt of amalgamated Pleistocene and Holocene primarily eolianite grainstones.

Radiocarbon YBP	Calendar YBP	Location	Description
7350 ± 50	8030-8310	Gaulin Cay, older Holocene eolianite	Cerion land snail
3970 ± 40	4300-4520	Little Wax Cay, hummocky storm ridge ~5 m above sea level on east side of island	Apple land snail
6020 ± 40	6750-6960	Bitter Guana Cay, upper eolianite	Cerion land snail
6170 ± 40	6950-7170	Bitter Guana Cay, upper eolianite	Cerion land snail
5170 ± 60	n/a	Lee Stocking Island, eolianite	Bulk sample

Table 1. Age control to support "older" Holocene interpretation of eolianite deposits.