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Evolution of a Modern Ooid Sand Island (South Joulter Cay, Great Bahama Bank) and Implications for Subsurface Studies

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Summary

Islands play a critical role in focusing and shaping the filling of accommodation at the carbonate platform and EOD scale by influencing the local environment and exerting a clear control over distribution of potential reservoir and non-reservoir. Although islands are aerially restricted within the Joulters ooid sand body, there are profound implications of syndepositional island development including new facies, topography, meteoric diagenesis, and resultant localized heterogeneity. South Joulter Cay (SJC) provides one scenario for island growth highlighting complexity, illustrating important changes in sediment dynamics during sand body development, and suggesting an important control by periods of intense storms.

Introduction

In their study of the entirety of Great Bahama Bank (GBB), Purkis and Harris (2016) showed how islands play a critical role in focusing and shaping the filling of accommodation at the platform-scale by influencing the local environment and exerting a clear control over distribution of potential reservoir and non-reservoir facies. Islands are equally important at the local EOD-scale, so to provide an example of island development and its implications, we herein examine the nature and timing of syndepositional island growth within a broader ooid sand body, the Joulters ooid sand body covering some 400km^2 of GBB north of Andros Island (Figure 1a).

This sand body is famous as a site for the study of high-energy carbonate sediments and is an often-cited analog for understanding oolitic grainstone reservoirs due to the clearly observable interplay between vast stabilized and burrowed sand flats and active bedded ooid bars (Harris, 2019). The geological story of SJC which is one of the three Joulter Cays low-lying sand islands (Figure 1b), however, deserves equal attention given the critical role played by islands. Previous field mapping and local coring placed island formation within the overall development of the Joulters sand body and established that SJC is a very recent feature with radiocarbon dating showing ages from ~2000ybp to present (Harris, 1979).

SJC, while small in areal extent, acts to extensively modify the distribution of energy across the top of the sand body, blocking wave energy from the open ocean to the east, and confining tidal flow to the channels that lie to the south and north of the island (Figure 2). This aspect of an energy barrier introduces a sudden shift towards muddy facies in the immediate lee of the island and isolates ooid production to tidal channels and their associated ebb and flood lobes, as well as beach and shoreface settings fronting the island. The development of islands like SJC also introduces localized meteoric diagenetic modification to the underlying sediments (Halley and Harris, 1979), which along with the facies complexity adds to potential reservoir heterogeneity.

Methods and Preliminary Results

Our ongoing examination of SJC targets a better delineation of the processes and timing that formed the island. High resolution imagery, a DEM constructed from a drone survey (Figure 3), and field work improve on previous maps. The new data shows SJC is nearly 2.5 km long, has a maximum width >600 m and comprises a series of more than 40 elongate ridges and their intervening lows, primarily formed from oolitic sands. Major ridges diverge toward the southern end of the island, and bankward-dipping foresets indicate primarily seaward to bankward deposition. The ridges generally crest ~2 m above MSL and are closely spaced (tens of meters apart). An abandoned tidal channel cuts through the southern third of the island. The channel is filled with muddy sands (packstone equivalent) and floods from the bankward direction during very high tides through a mangrove-lined network of channels.

Historically, SJC records a period of higher ooid accumulation rate than occurs locally in the sand body today; ooid sand production was greater than the system's ability to hydrodynamically redistribute these sediments. Ridge topography on the island suggests that active sand bars locally built to beaches and back-beach dune ridges formed repeatedly. A scenario for island development based on existing data emphasizes growth stages reflecting variations in dispersal of ooid sands by tidal channels, wind and wave energy, and longshore and storm-related currents (Figure 4). Topographic profiles extracted from the DEM shows higher than average beach ridges are associated with the initiation of each of island growth stage, suggesting that the island's morphological evolution is closely integrated into the wider evolution of sediment generation and transport within the Joulters sand body.

We are testing the hypothesis that the initial ridges of the island, as well as the ridges associated with shifts between growth stages, are the results of storm deposition and resulting changes to the local hydrodynamic setting. Recent storms such as category 4 Hurricane Matthew which passed immediately east of Joulters on 10/6/2016 with maximum sustained winds of 225 km/hr (140 mph) moved sands across and to the back portion of the active shoal to the north of the islands but produced no pronounced subaerial ridge. The same storm locally eroded the beach on SJC to reopen the abandoned tidal channel, but this opening was short-lived. From observing the impacts of this storm as well as other recent ones, we believe that major storms proximal to Joulters and delivering east to west energy and sediment transport are most likely to have played a role in island development, but that a single storm by itself may be insufficient to cause change. Instead, it is more likely that multi-decadal periods of intense storm activity (Figure 5) as determined for the last 1100-1500 years by recent sediment coring and dating from several blue hole sites on GBB by Wallace et.al. (2019, 2021) provides the type of collective storm activity within the time frame that can relate to the initiation and growth change variability observed at SJC.

Conclusions and Implications

Islands like SJC localize high-energy grainy factories and shape their deposits around them, as well as providing a protected area in their lee for mud accumulation. This study focuses specifically on the process by which a key local facies transition occurs, namely the nucleation and growth of islands within an accommodation-restricted sand body.

The Joulter Cays, built of lightly cemented oolitic, skeletal and peloidal sediments, form along the eastern, windward-facing margin of the ooid sand body. The islands, especially SJC, introduce a new suite of Holocene facies (beach, back-beach storm ridges, tidal flats, ponds, abandoned channels) with their own unique bedding character and sedimentary structures into the dominantly subtidal record of the overall sand body. The positioning of the island also armors the sand body at its most energetic margin and the topography significantly influences the local water movement and thus depositional patterns. In addition, the islands introduce an element of spatially constrained meteoric diagenesis (cementation and dissolution) contemporaneous to deposition, thereby altering porosity-permeability patterns.

SJC provides one scenario for island growth highlighting complexity, illustrating important changes in sediment dynamics during sand body development, and suggesting an important control by major storms. Growth of the island impacts facies type and correlation along with the interpretation of sequence stratigraphic and diagenetic development within the modern sand body, and more importantly also in analogous subsurface grainstone reservoirs. Thus, at the EOD scale, islands like SJC add significantly to complexity and localized heterogeneity within a broader development of reservoir quality grainstone. Assessing the impact of storms in forming the island and changing ridge morphology will continue to help refine our understanding of the broad suite of controls over shallow carbonate platform facies patterns.

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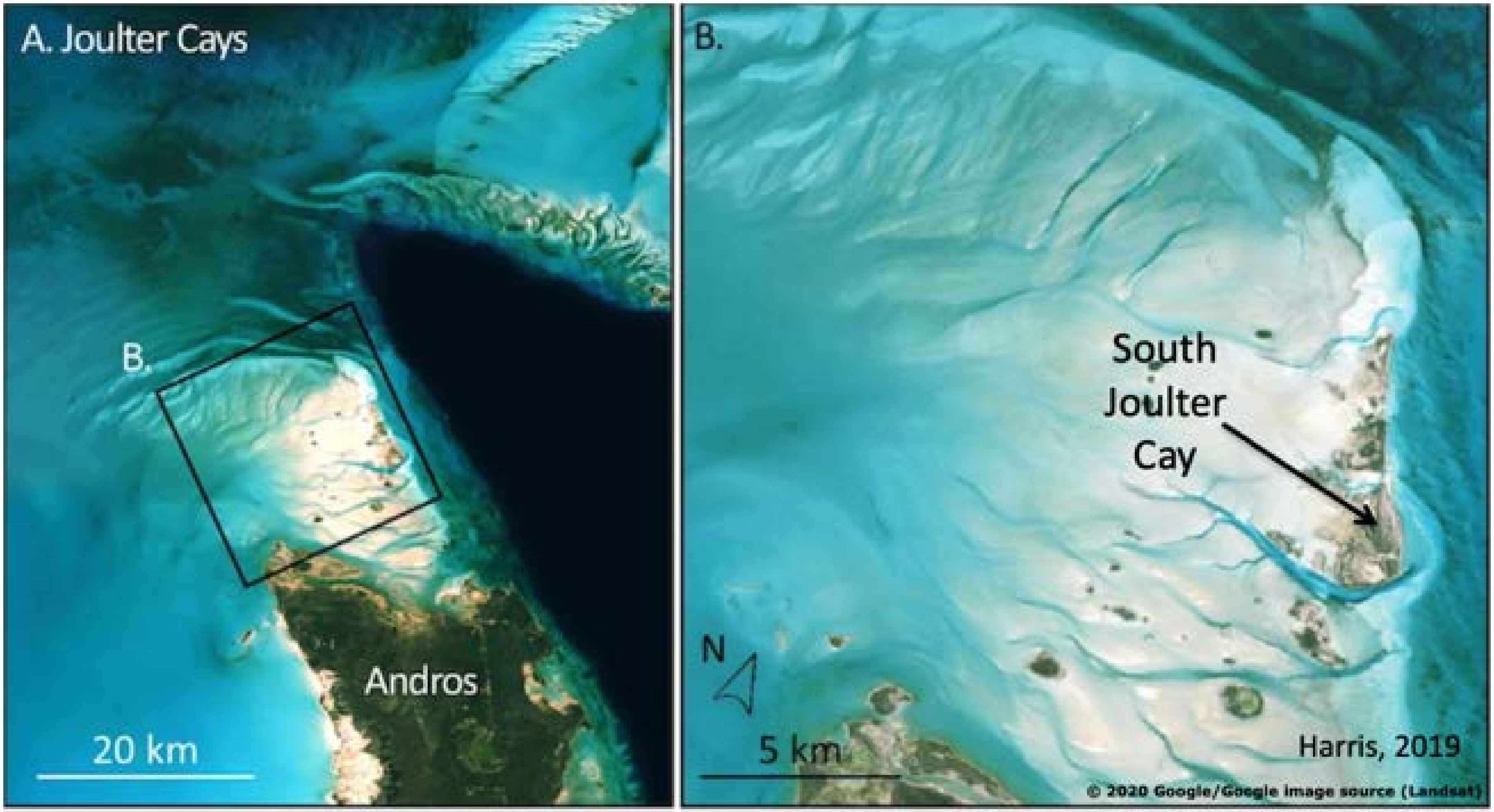

Figure 1. (a) Landsat image showing the Joulters sand body immediately to the north of Pleistocene Andros Island. Box outlines the 20 sq.km area shown in (b) to more clearly show that the sand body is a vast sand flat rimmed on the east and north by relatively narrow active, mobile sands. The sand flat is partially penetrated by numerous tidal channels and dotted with several Holocene islands.

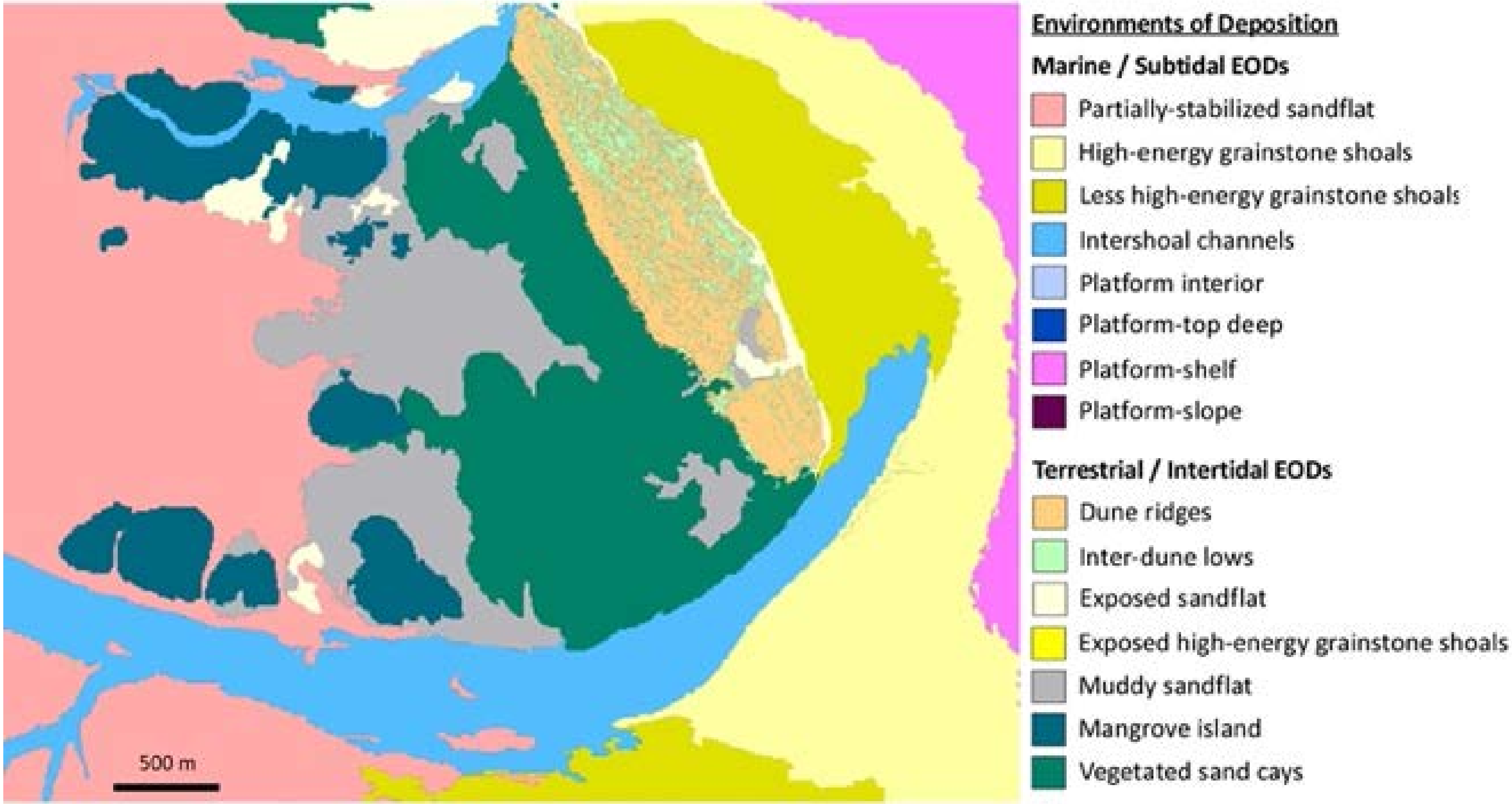

Figure 2. Environment of deposition map for SJC and surroundings. The island is bounded at the south by the largest and deepest tidal channel observed within the Joulters sand body and fronted by an active ooid sand shoal. Variably vegetated muddy sandflats develop on the lower energy, lee side of the island.

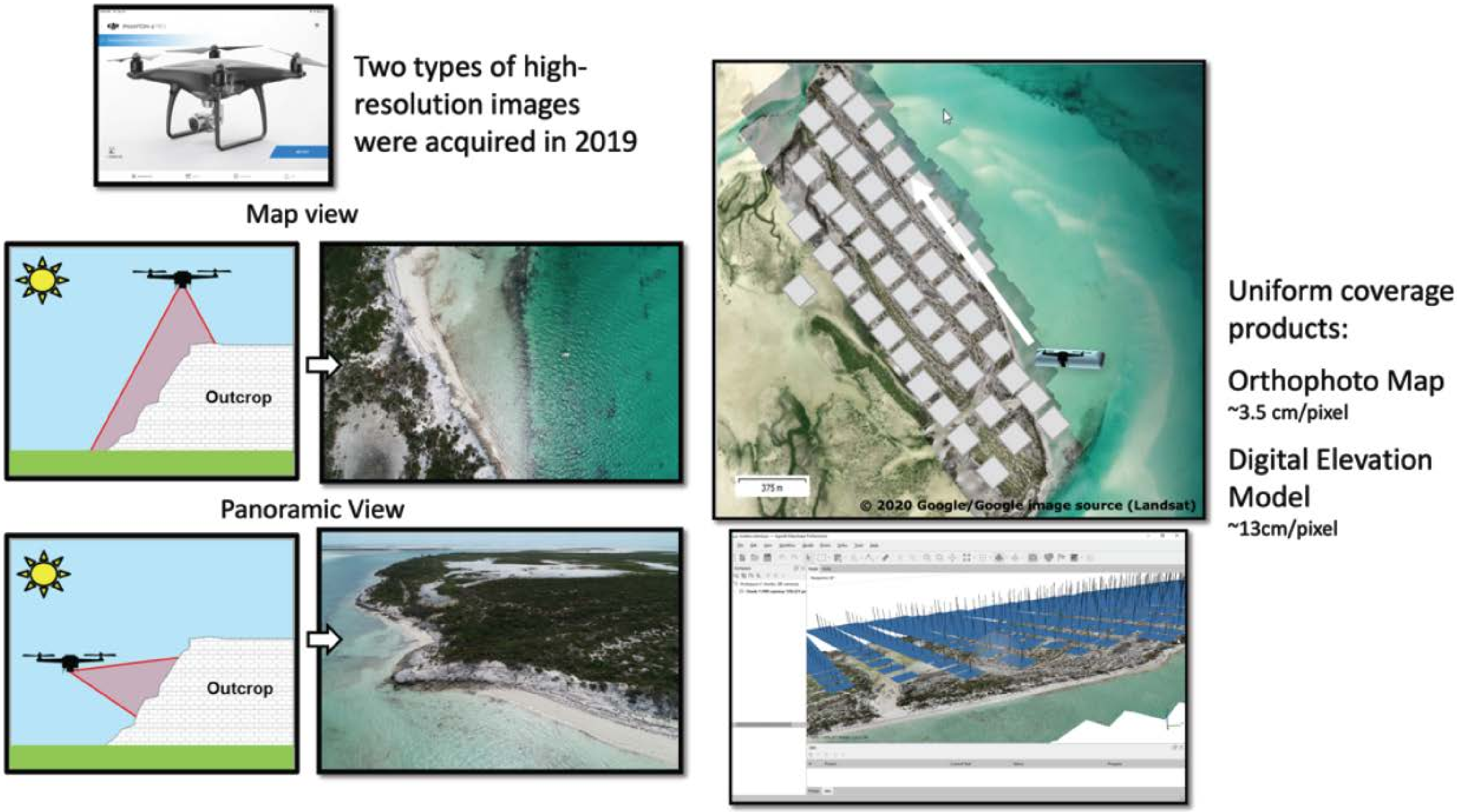

Figure 3. Summary of new data obtained for South Joulter Cay including a high-resolution drone survey and subsequent derivation of a DEM.

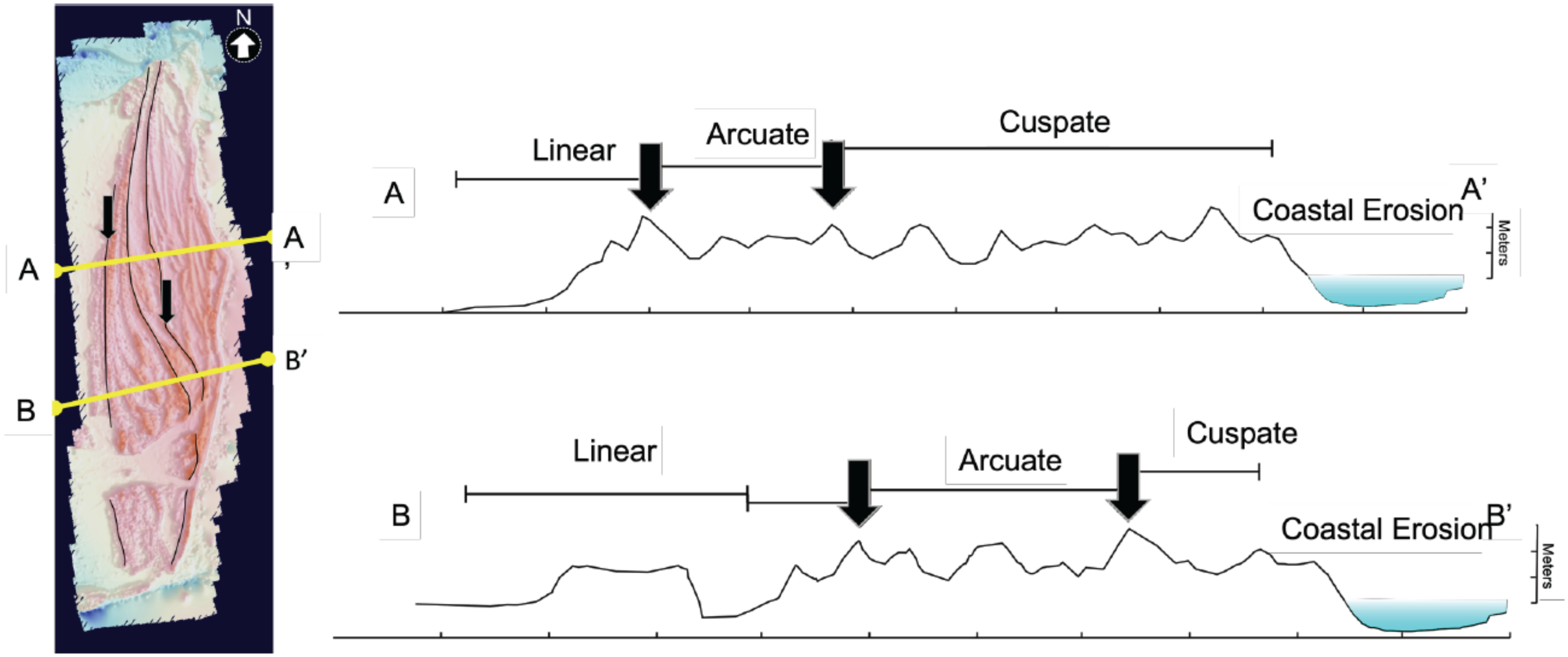

Figure 4. DEM from high-resolution drone imagery annotated to show interpreted morphological stages of island growth. Stage 1 Linear Ridges represent initial island formation; Stage 2 Arcuate Ridges formed as part of an ebb tidal delta lobe related to a channel cutting the island; and Stage 3 Cuspate Ridges were deposited as multiple prograding beach ridge sets driven by longshore currents. Note the boundaries between the growth stages shown by black arrows are consistently formed by higher ridges suggesting extraordinary depositional conditions.

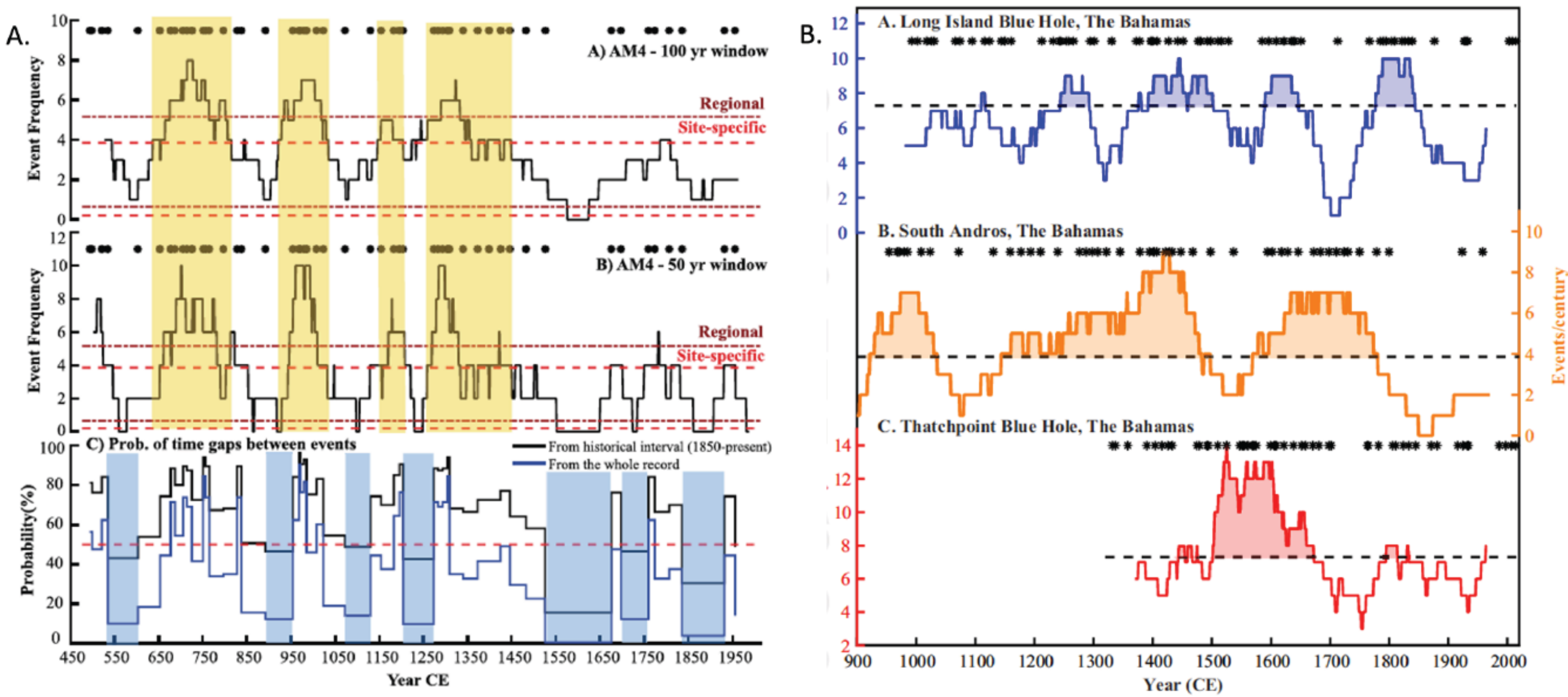

Figure 5. A) from Wallace et al., 2019, shows results from sediment coring in a blue hole on South Andros to assess timing of storm deposits and therefore storm frequency. Yellow highlighted portions of plot indicate four periods of intense hurricane activity. B) from Wallace et al., 2021, zooms in on the South Andros data as well as results from two other Bahamas sites to better delineate multi-decadal periods of intense storm activity.