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Research paper

# Genesis and growth of a carbonate Holocene wedge on the northern Little Bahama Bank

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ABSTRACT

The study focuses on the sedimentary dynamics at the transition between the modern Bahamas carbonate platform and related adjacent slopes and deeper environments. A Holocene carbonate sedimentary wedge is developed at the edge of the carbonate platform extending along the northern Little Bahamas Bank (LBB; Bahamas). The transition area between the platform and the wedge shows superposed terraces. The Holocene wedge thickness varies from 0 to 35 m. Its surface is dominated by homogeneous, fine-grained, soft sediments. It lies on a Pleistocene substratum and fills depressions corresponding to lowstand erosional surfaces. On the uppermost slope, this wedge represents the main depocenter of fine-grained bank-derived sediments since the last bank flooding.

Twelve gravity cores were sampled from this wedge and allow the identification of both the processes that can supply this wedge and the wedge evolution based on content analyses and 19 radiocarbon ages.

At present, particle export from the LBB margins mostly occurs during episodes of winter cold fronts but also occurs during hurricanes. Evidence of hurricane impact in the sedimentary record is suggested by the recovery of two laminated sequences showing both decreasing sedimentation rates and varying velocities during platform export. The local morphology of the platform edge allows the better sorting and export of sediments according to the presence of tidal outlets and sediment sorting on the wedge. However, because no ooids from tidal deltas located on the platform edge were found in cores, tidal currents are probably not energetic enough to both mobilize and export sediment, even if tide–induced currents may help the export of fine-grained carbonate particles remobilized by either cold fronts or hurricanes on the platform and upper slope.

The formation of the wedge started at 13.6 ± 3.5 kyr cal BP following the meltwater pulse 1 A. It was supplied by shallow environment-derived particles produced on four narrow terraces between 60 and 20 mbsl after meltwater pulses. Since the LGM (Last Glacial Maximum), terrace formation seems to correspond to periods of sea-level stillstands and wedge formation, whilst escarpments correspond to periods of high rates of rising sea-level due to meltwater pulses. The main period of wedge growth started around 6.5 ± 0.9 kyr cal BP, when sea level finally reached the platform margins. The maximum flooding period around 4 kyr cal BP is characterized by the highest contents of aragonite needles exported from the platform.

## 1. Introduction

Modern carbonate sedimentary systems sourced by tropical factories represent good analogues of ancient carbonate environments and allow a connection between sediment facies and depositional processes. In modern carbonate environments, the tropical factory mainly involves shallow carbonate platforms and platform margins and is restricted to a narrow area on the Earth's surface. At a geological scale, it has been more widespread, especially during greenhouse Earth periods where it extends to middle-latitude areas. In ancient carbonate systems, very little is known about the sediment transfer zones from the shallow carbonate factory to the slope and deeper environments. Recently, Holocene wedges were recognized in carbonate systems (Glaser and Droxler, 1991; Zinke et al., 2003), especially on Bahamian uppermost slopes (Betzler et al., 2014; Mulder et al., 2017; Rankey and Doolittle, 2012; Wilber et al., 1990). Bahamian Holocene wedges are located just

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downslope from platform margins, can record many environment changes including platform flooding and have the potential to supply more distal slopes. Wilber et al. (1990) proposed the storm-related suspended mud and leeward drift of whiting events as major supply mechanisms for the sediment forming this Holocene wedge. Then, Wilson and Robert (1995) estimated the outsized larger effects of winter cold fronts on sediment suspension and off-bank transport. Cold fronts initiate a thermohaline circulation that exports sediment from the shelf to the slope. This hypothesis was validated by Betzler et al. (2014).

The deposition and distribution of sediment exported off the bank is controlled by the along-slope Florida current (Betzler et al., 2014); hence, the GBB Holocene wedge was interpreted as a "periplatform drift". On the northern Little Bahama Bank (LBB) windward margin, another Holocene wedge was recently recognized by Rankey and Doolittle (2012), who made a preliminary survey to describe the uppermost slope morphology and concluded that this wedge was not markedly impacted by the bottom current. Mulder et al. (2017) imaged the wedge at deeper water depths than Rankey and Doolittle (2012) and over a large part of the margin. Mulder et al. (2017) showed that the wedge was discontinuous in front of small submarine channels supplied by tidal passes (Fig. 2) and concluded that present-day off-bank export was the result of two processes: (1) tidal current acceleration (tidal flushing) following the resuspension of fine-grained carbonate on the lagoon after hurricanes or storms, and (2) export along the whole margin by density cascading supplying the Holocene wedge. Process (1) is a temporary source process and occurs over very short periods of time (hours to days), whilst process (2) occurs simultaneously over the whole platform margin and over longer periods of time (several days). Although the export through tidal passes and channels is beginning to be understood (Rankey and Reeder, 2011; Reeder and Rankey, 2009, 2008), the timing and processes of the formation of the Holocene wedge through density cascading are not accurately understood. In this paper, we propose providing more insight about the formation of this wedge using lithological and compositional descriptions and establish a significant Holocene stratigraphic framework using a set of cores.

## 2. Geological settings

### 2.1. Environmental settings

The northern Little Bahama Bank (LBB) is an open ocean windward margin (Fig. 1; Hine et al., 1981; Hine and Neumann, 1977) settled in a high-wave-energy area. It is subject to easterly to northerly winds and waves (Fig. 1); (Hine and Neumann, 1977). Hine and Neumann (1977) demonstrated that two-thirds of all storms that affect the main ooid and coarse-grained shoals along the margin, such as the active Lily Bank, generate a net bankward flux. Shallow bank depressions (called "reentrants" or "cuts"; Hine and Neumann, 1977; Mulder et al., 2017) were formed between reef discontinuities during the Holocene due to a large bankward flow during the last acceleration of sea-level rise (Hine and Neumann, 1977), which stabilized approximately 4 kyr BP ago (Boardman, 1988). These discontinuities formed tidal passes directly connecting the platform to the uppermost slope (Mulder et al., 2017a). Flow acceleration induced by the reduced section in reentrants increases daily tidal velocities, which can then reach 1 m/s (Reeder and Rankey, 2009). The tidal accretionary bars along tidal channels formed shoals and small emerged banks. Coarse-grained (ooids or bioclasts) ebb and flood deltas were built at the landward and oceanward mouths of the tidal passes, where tidal velocity is reduced because of the increase of the flow section (Reeder and Rankey, 2008). Shoal morphologies created by sediments bypassing reentrants indicate a flood-dominated margin (Rankey et al., 2006). The combination of tides, swell, storm-induced waves and winds creates a net bankward energy flux (Mullins et al., 1979). Hence, off-bank sediment transport towards the slope is mainly reduced (Mullins et al., 1979). However, a minor portion of platform sediments manages to bypass the northern margins: series of canyons developed on the northern LBB slopes (Mulder et al., 2012; Tournadour et al., 2017) are lined by terraces that have recorded off-bank periplatform ooze export during the Quaternary. Chabaud et al. (2015) described the deposits related to this off-bank transport in sediment cores and demonstrated that the LBB northern slopes have been supplied by platform sediments since at least MIS 11. The main processes that are suggested to supply the periplatform area from the bank are density cascading (Wilson and Robert, 1995) and hurricanes. Hurricanes have been especially frequent along Bahamian coasts since 6 kyr BP according to Toomey et al. (2013). Those events are recorded along the GBB mid-slope as centimetric layers made of coarse-grained particles that increase local sedimentation rates. The role of hurricanes in off-bank transport is evidenced by satellite images (Rankey et al., 2004). More recently, a satellite image of hurricane Matthew shows that fine-grained particles can be exported further away from the platform margin, up to ~10 km (Fig. 1). Density cascading takes place during winter Bahamian cold fronts. Cold fronts bring dry cold air masses above the LBB. This refreshes shallow platform water masses. Moreover, when cold fronts overlie a water mass, the water mass temperature decreases, reducing evaporation, but the post-front conditions (increasing air temperature faster than water mass temperature) highly enhance water evaporation and increase salinity. Hence, increasing salinity and decreasing temperature increase the platform water mass density. Higher density initiates an off-bank thermohaline circulation that carries suspended sediments (Fig. 1). This way, shelf-derived sediments are deposited deeper on the slope. Currently, Florida experiences ~23 winter cold fronts (Hardy and Henderson, 2003). The Holocene wedge is the most important sediment accumulation extending along the uppermost slope at present. The LBB Holocene wedge on the uppermost slope was investigated by Rankey and Doolittle (2012) and Mulder et al. (2017). These authors described this formation as located below a terraced escarpment, highlighting past sea-level stillstands. It is made of periplatform-ooze that fills Pleistocene substratum depressions ranging from 0 m thick between depressions to 35 m thick on the central part of the wedge. It extends from 170 mbsl to 360 mbsl, forming a transition area between the platform margin and the upper slope (Tournadour et al., 2017).

### 2.2. Northern LBB sediments

Bahamian platforms are considered as almost pure carbonate systems (Traverse and Ginsburg, 1966). Only 0–3.4% of sediments comprise siliciclastic grains supplied by winds (Swart et al., 2014). At the platform located upstream of the study site, Enos (1974) described four sediment types (Fig. 2): (1) grainstones along the platform margin and (2) packstones on the back of the grainstone barrier. They are both formed by skeletal grains (coral debris, fragmented benthic foraminifera, *Halimeda* flakes, seagrass fragments, *Penicillus* fragments, and bivalve shells including conch and other gastropods; Rankey and Reeder, 2011; Reeder and Rankey, 2009). (3) Ooids are found in tidal deltas. Ooids are rare off the shoals and are stacked around the highest-energy environments, such as on decreasing current velocity areas (~0.6 m/s) surrounding reentrants (Reeder and Rankey, 2009). (4) Peloids are the most abundant type of particles in the lowest current-velocity areas (< 0.4 m/s), mainly on the edges of tidal deltas (Reeder and Rankey, 2009). They are found in the southwestern part of the study area, on the back of the grainstone barrier. Platform production induced large amounts of mud that are exported from Bahamian platforms (Wilson and Robert, 1995). In the < 4 μm grain-size fraction, the grains are mostly made of small aragonite needles, nano grains of calcite and coccoliths (Gischler et al., 2013).

At bathymetries of deeper than 400 mbsl, the slope sediments are rich in planktonic grains. Chabaud et al. (2015) defined the composition of the slope environment along the western part of the LBB. It is mainly made of skeletal grains (including planktonic foraminifera,