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Sedimentary processes determining the modern carbonate periplatform drift of Little Bahama Bank

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ABSTRACT

This paper presents an analysis of the combined influence of along-slope sediment transport and off-bank sediment export from the Little Bahama Bank (LBB) to the periplatform sediment wedge of the northwestern part of the slope over the last 424 ka. The LBB northwestern slope is divided in (i) a plateau-like structure (margin) at ~40 m water depth over at least 4 km parallel to the edge of the LBB; (ii) the uppermost slope with a mean slope angle of ~1.15° from 40 to 300 m water depth; (iii) the upper slope with slope angle of ~0.7 from 300 to 650 m water depth, (iv) the middle slope with slope angle of ~1.2, from 650 to 800 m water depth, and (v) the lower slope with slope angle of <~0.5, from 800 to 900 m water depth.

The uppermost slope, the upper slope, and the middle slope of the northwestern LBB were characterized by periplatform oozes that became more diluted with pelagic sediment toward the distal part of the slope. This sediment distribution of the northwestern LBB slope varied significantly over times according to the flooded surface of the LBB. The major flooding periods are related to the highest Relative Sea Level (RSL) (>−6 m) that occurred during interglacial periods, the highest sedimentation rates (10–30 cm/ka) and the finest sediment facies were found on the slope. During interglacial periods when RSL < −6 m, LBB was emerged but bank margins were still flooded and correspond to intermediate sedimentation rates (a few to 10 cm/ka) on the slope. Finally, during glacial periods (RSL < −90 m), LBB was emerged (including its margins), sedimentation rates on the slope dropped to a few mm/ka associated to coarser sediment facies.

Off-bank-transported sediment is the main sediment supply during sea-level highstands, occurring preferentially during three major periods of LBB flooding over the last 424 ka: marine isotopic stages 1, 5e and 11. During sea-level lowstands, shallow carbonate production was very low but could develop over a 4 km-wide plateau-like structure when RSL was above −40 m. The regional Antilles Current affected the sea floor along the northwestern LBB slope and influenced coral mound distribution as well as sediment facies and sequences along the upper and middle slopes (300–800 m). During glacial periods, the stronger influence of the Antilles Current upon the along-slope sedimentation promoted diagenesis via the development of indurated nodules in the upper slope (~400 m water depth). It also encouraged bi-gradational sequences showing a coarsening-up unit followed by a fining-up unit along the middle slope (~800 m water depth) that is thoroughly bioturbated. The characteristics of these contourite sequences were similar to those described in siliciclastic environments, but in contrast were condensed with low sedimentation rates over long (glacial) periods.

1. Introduction

Contourite drifts were first defined as large accumulations of sediment deposited at water depths exceeding 500 m by deep water bottom-currents circulating over the sea floor related to thermohaline circulation (Heezen et al., 1966; Heezen and Hollister, 1971; Hollister and Heezen, 1972; Faugères and Stow, 1993). Recently, the term "contourite drift" was also applied to deposits along continental margins built by intermediate (Van Rooij et al., 2010; Rebesco et al., 2013) or shallow (e.g. Vandorpe et al., 2011) water masses. Contourite drift morphology ranges from small patch drifts (<100 km^2) to giant elongate drifts (>100,000 km^2) (for a complete review see Faugères et al., 1999; Rebesco and Camerlenghi, 2008; Faugères and Mulder, 2011; Rebesco et al., 2014). The relatively continuous accumulation rates of contourite drifts (Knutz, 2008) provide a record of paleoenvironmental changes throughout time (Hernández-Molina et al., 2003; Llave et al.,

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2006; Voelker et al., 2006; Wilson, 2012, 2013; Toucanne et al., 2012; Mulder et al., 2013; Vandorpe et al., 2014).

Contourite deposits are widely documented in the literature (Stow and Holbrook, 1984; Faugères et al., 1999; Faugères and Stow, 2008; Stow et al., 2002, 2008). However, only few studies have highlighted the importance of contour-currents along carbonate slopes (Neumann and Ball, 1970; Correa et al., 2012; Betzler et al., 2013; Murdmaa et al., in this issue). Five modern carbonate contourite drifts can be found in the Bahamas: the Pourtales Drift, the Santaren Drift, the Cay Sal Drift, the Great Bahama Bank (GBB) Drift, and the Little Bahama Bank (LBB) Drift (Mullins et al., 1980; Anselmetti et al., 2000; Bergman, 2005; Bergman et al., 2010). The term "periplatform drift" was recently introduced (Betzler et al., 2014) to refer to a carbonate slope wedge that is under the influence of ocean currents. Such periplatform drifts are very specific compared to other drifts as the main sediment input result from off-bank transport of the carbonate platform located nearby. The classical contourite facies is characterized by a bioturbated coarsening-up unit ranging from the muddy facies to silty/sandy facies, followed by a bioturbated fining-up unit ending back with muddy facies. Such a facies succession described from the Faro Drift in the Gulf of Cádiz reflects the intensification and reduction of current velocities (Gonthier et al., 1984; Faugères et al., 1984). The term "contourite" represents one bigradational sedimentary sequence, and the term "contourite drift" refers to the staking of contourites forming the sedimentary body.

In carbonate environments, remarkable changes in sedimentation rates have been observed along slopes with a high (low) accumulation of sediment during interglacial (glacial) periods (firstly documented by Kier and Pilkey, 1971; Lynts et al., 1973; Mullins et al., 1980; Mullins, 1983; Droxler et al., 1983). During sea-level highstands, the complete submersion of the shallow-water carbonate bank, water depth <6 m, is allowed for the abundant production of fine-grained aragonite particles on the LBB (Neumann and Land, 1975). Production of sediment on the carbonate bank is sharply reduced when the bank top is partially or totally emerged during lowstands. Episodic sedimentation due to sea-level fluctuations between glacial and interglacial periods is explained by the "highstand shedding" model (Droxler and Schlager, 1985; Schlager et al., 1994), which is highlighted in numerous studies (Mullins et al., 1980; Boardman and Neumann, 1984; Boardman et al., 1986; Reijmer et al., 1988; Wilber et al., 1990; Rendle and Reijmer, 2002).

This study analyzed the spatial and temporal variability of sedimentation on the LBB Drift (~400 and ~800 m water depth). In addition, it aimed to highlight sedimentary processes at varying distances from the bank over the last 424 ka (highstand vs lowstand). A multi-proxy approach based on bio- and isotopic stratigraphy and sedimentary analyses of marine cores was combined with geometrical analyses of geophysical data. The aim of this paper is to explain the growth of this contourite drift and discuss the use of the term periplatform drift.

2. Present-day environmental setting

2.1. Geological, climatic and oceanographic contexts

The Bahamian archipelago is composed by several shallow-water carbonate banks (Fig. 1) and has been considered tectonically stable since the middle Tertiary (Masaferro and Eberli, 1999). It forms an isolated platform with limited wind-derived siliciclastic supply and represents (in maximum) less than 3.4% of the platform sedimentation (Traverse and Ginsburg, 1966; Swart et al., 2014). The Bahamas is nowadays considered as a fairly pure carbonate sedimentation environment. The climate of the northern Bahamas is subtropical to temperate (Roth and Reijmer, 2004) with easterly trade winds (from NE, E, and SE) most of the year and cold northwesterly winds occurring during winter (Sealey, 1994). Wave energy flux is higher on the northern margin of the LBB (windward) than the southern and western margins of LBB (leeward) (Hine and Neumann, 1977; Hine et al., 1981a, 1981b). Oceanic circulation patterns in the northern Bahamas are complex. However, it is broadly accepted that the Antilles Current flows to the Northeast along the Bahama Escarpment and to the North of LBB (Rowe et al., 2015), where it merges with the Florida Current to form the Gulf Stream (Neumann and Pierson, 1966; Rowe et al., 2015). The only known current pattern described north of Little Bahama Bank suggests stronger currents at 400 m water depth than 50 m water depth (Fig. 2, Johns, 2011), which is in agreement with highest velocities located in 400 m water depth to the east of LBB (Lee et al., 1990). Measurements of the Antilles Current taken on the eastern part of the LBB northern slope recorded flow velocities at 750 m water depth ranging from 0.2 to 0.8 m/s directed northwest (Costin, 1968). In the same area, a reversal of bottom current across the east–west axis was recorded at 1040 m water depth but without quantification of the velocities (Gallagher, 1968). It has been suggested that the Antilles Current is not a steady flow but behaves as an eddy field along the Bahamian Archipelago (Gallagher, 1968; Ingham, 1974; Gunn and Watt, 1982; Lee et al., 1996). The Florida Current stretches northward from the Straits of Florida to Cape Hatteras (Rowe et al., 2015) with a discharge of 32.1 ± 3.3 Sv (Baringer and Larsen, 2001; Rousset and Beal, 2014). The surface currents are strongest on the western side of the straits, above the continental slope off Miami, with maximum velocities exceeding 1.5 to 2 m/s (Brooks and Niiler, 1977). Under this surface current (457 to 825 m water depth), southward-flowing countercurrents are found with average velocities of 0.18 m/s, and maximum velocities of 0.6 m/s (Neumann and Ball, 1970; Correa et al., 2012). Bottom currents along the eastern side of the Bahamas flow to the north at velocities reaching 0.5 m/s at 305 m water depth (Neumann and Ball, 1970; Neumann et al., 1977).

2.2. Geometry of the LBB Drift

In the Bahamas, the LBB Drift is a modern carbonate contourite drift that settled along the western side of the northern LBB slope (Mullins et al., 1980). The LBB Drift extends over 100 km (with a slope inclination around 1°) and a maximum width of 60 km (Mullins et al., 1980). According to the classification of Faugères et al. (1999), the LBB Drift corresponds to a plastered drift influenced by down-slope processes (Tournadour et al., 2015). The LBB Drift began approximately during the Miocene or Pliocene (Unit F in Fig. 3, Tournadour et al., 2015). A huge mass transport complex (Tournadour et al., 2015) affected the upper slope of the LBB Drift and the mass transport deposits formed a compressional area on the frontal edge (light blue of Unit F in Fig. 3) which may have been affected by a major erosional event (top of Unit F in Fig. 3). A major growth phase occurred during the entire Quaternary (Unit G, in Fig. 3), which is the main focus of this study.

LBB Drift deposits consist of a mixture of planktonic and pelagic microfauna living in the water column and sediments derived from the adjacent LBB (Mullins et al., 1980; Lantzsch et al., 2007), hence a typical "periplatform ooze" (Schlager and James, 1978). Lantzsch et al. (2007) showed, from sediment cores MD99-2202 (Figs. 1, 4A), fine-grained sediment with a high aragonite content during interglacial periods, and cemented coarser sediment with a high-Mg calcite content during glacial periods. Hardgrounds are present on the sea floor at approximately 600 to 700 m water depth in the Straits of Florida and, along the base of LBB (Neumann and Ball, 1970; Neumann et al., 1977; Mullins and Neumann, 1979). These can be explained by winnowing related to currents affecting the sea floor (Wilber, 1976), and the diagenetic potential of periplatform oozes (Heath and Mullins, 1984). Both mechanisms vary in intensity with distance from the edge of the bank (Mullins et al., 1985). Additionally, elongated carbonate mounds (lithoherms) have been observed on the western margin of LBB in the Straits of Florida (Neumann et al., 1977; Messing et al., 1990). These mounds were thought to be mainly controlled by currents providing nutrients, and by sea floor topography (Correa et al., 2012). ROV observations revealed that they were occasionally just carbonate blocks with a coral cover (Hebbeln et al., 2012). However, east of the study area deep carbonate coral mounds (bioherms) have been reported at depths