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Margin collapse and slope failure along southwestern Great Bahama Bank

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ABSTRACT

Steep convex-bankward embayments into carbonate platform margins, often called "scalloped margins", have been observed in ancient examples and along modern platform of the Gulf of Mexico and the Caribbean region and are interpreted as erosional features produced by large-scale margin failures. Multibeam bathymetry data from the southwestern corner of Great Bahama Bank (GBB) image four margin failures and their associated erosional products. The bankward-convex embayments range in diameter from 3 to 23 km. The largest and southernmost collapse produces a scalloped margin while the other three are not changing the generally linear platform margin. The typical slope angle of the upper slope in this portion of GBB ranges from 20 to 40° with the margin break at ~60 to 65 m water depth. But in the four areas of platform margin collapse the slope angle increases and the margin break is shallower. The largest collapse eroded more than 350 m of the bank margin with an estimated ~15 km^3 of platform margin materials shed onto the adjacent slope. These margin collapses shed large debris blocks to the toe-of-slope and basin floor some tens of kilometers from the platform margin. In the southernmost segment margin collapse is followed by slope failures that produce mass transport complexes (MTC) that litter the lower slope and basin floor. The largest block in one MTC is 2000 × 800 m in dimension and is displaced by 1.2 km.

The margin collapses are more common along the southwestern GBB than the northern portions of GBB where large-scale slope failures are more common. This lateral distribution is attributed to the tectonic activity in the vicinity of the Cuban fold and thrust belt. Faults breaking the modern seafloor and Holocene growth strata on the Santaren Anticline document neo-tectonic activity within the belt. Thus, tectonic activity and associated seismic shock might be the primary trigger for the margin collapse and occurrence of the scalloped margin along the Old Bahama Channel.

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1. Introduction

Carbonate platforms can build steep, near vertical margins depending on the size and roughness of the slope material (Schlager and Camber, 1986; Kenter, 1990). In addition, outward and upward biological growth of the margin and slope, and rapid submarine cementation contribute to the steep slopes of carbonate platforms (Grammer et al., 1993). The modern margin and slope surrounding the Little and Great Bahama Banks, respectively, are testimony to this process. They all display a similar margin-slope morphology. A near vertical slope segment of approximately 100 m height develops around all Bahamian carbonate platforms on both the windward and the leeward sides (Palmer, 1979; Ginsburg et al., 1991; Grammer et al., 1993; Rankey and Doolittle, 2012). These near vertical well-cemented escarpment-like margins accrete during the Holocene due to rapid early-marine cementation of sediment combined with organic growth of sponges, coralline algae, and microbial communities. The steep slope (45°–70°) beneath the escarpment is also cemented but has a thin veneer of sediment and occasionally large boulders and talus debris (Ginsburg et al., 1991; Grammer et al., 1993, 1999). The cemented slope itself is onlapped by loose sediment. In the study area, the bank margin is generally at about ~60 m water where the gently inclined bank top (~3°) that changes abruptly into a steeply inclined wall with up to 70° inclination (Fig. 1). At ~100 m water depth the slope declivity decreases to ~25°. This slope profile extends to an average depth of 165–180 m, where it is onlapped by a sediment wedge. The wall and the cemented slope are here called the cemented upper slope. The slope angles in the onlapping un-cemented sediment wedge decrease rapidly and are generally 2–8° in the middle slope and less than 2° in the lower slope (Fig. 1). The onlapping wedge displays a 20–30 m deep moat at its top that is formed by plunging of sediment laden waters from the platform top (Betzler et al., 2014).

Many models place slope failures in the margin and upper slope where declivity is high. However, modern margins and uppermost slopes are generally intact. The steep cemented slope only shows

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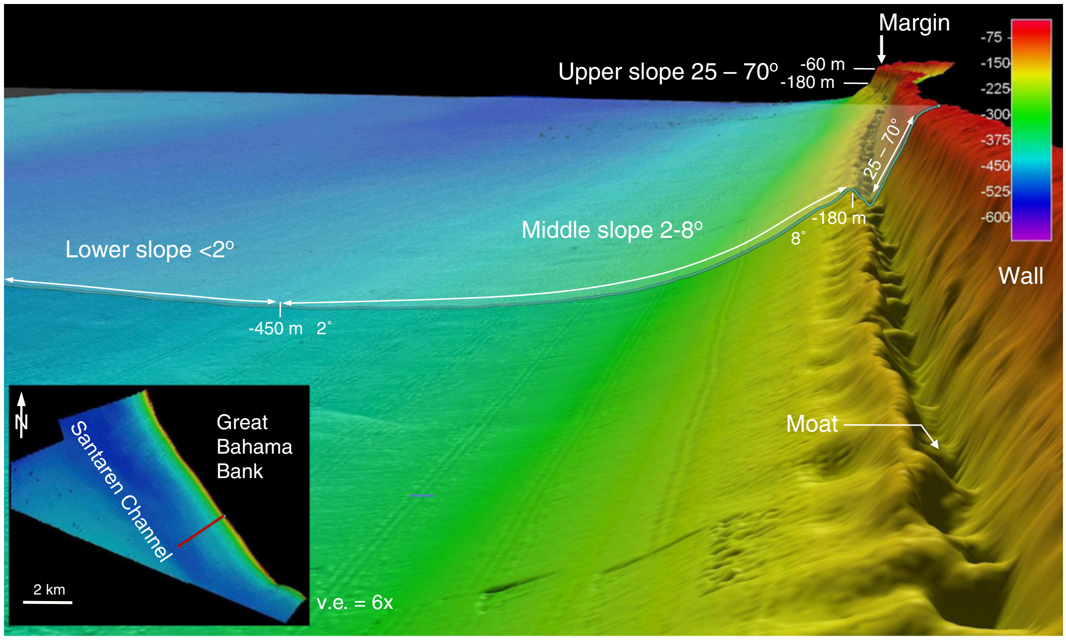

Fig. 1. 3D view along southwestern Great Bahama Bank, displaying the undisturbed margin and slope morphology. The upper slope extends from the margin break to onlap of the sediment wedge at approximately −180 m and includes the wall and the cemented steep slope. In the onlapping sediment wedge the slope angle gradually decreases from 8° to 2° in the middle slope. The lower slope is less than 2° in declivity. The moat is a series of plunge pools at the base of the steep cemented upper slope. V.E. = vertical exaggeration.

small, localized slope failures with 10–100's of meters width (Grammer et al., 1993). Catastrophic large-scale slope failures, however, have been documented in the un-cemented slope (Harwood and Towers, 1988; Mulder et al., 2012a,2012b).

While failures occur mostly on the slope along northwestern GBB and LBB, in the study area that is further south and close to the Cuban fold and thrust belt, the platform margin is involved. These margin collapses are reminiscent of steep embayments that have been observed in many ancient examples and linked to catastrophic margin collapse based on the deposition of breccias and megabreccias on the slope and basin floor (Cook et al., 1972; Playford, 1980; Mullins et al., 1991; Hine et al., 1992; Eberli et al., 1993; Morsilli et al., 2002; Janson et al., 2007, 2009). Mullins and Hine (1989) used the term 'scalloped margin' to describe the largest (plurikilometer) of such convex-bankward embayments. They observed them in western Florida and the Caribbean region and interpreted them as caused by platform margin collapse. However, in the absence of multibeam bathymetry data, the connection between margin collapse and their depositional products is not well established. New multibeam data covering over 100 km of platform margin and the adjacent slope and basin along the southwestern GBB image four large margin failures. While only the largest one has the size of a scalloped margin, the process is similar in all of the four failures. This study focuses on assessing the distribution, geometry, and morphology of margin failures and their associated carbonate mass transport complexes (MTC).

2. Data sets and methods

The surface morphology of the margin and slope is imaged by multibeam bathymetry data and backscatter data acquired by Fugro Geoservices in 2011 and made available by the Bahamas Petroleum Company (BPC). These data cover an area of about 6500 km^2 along southwestern GBB (Fig. 2). The bathymetry data was collected using a Reson SeaBat 8160 59 kHz Multibeam Echosounder (MBES) system, which also recorded the backscatter data. The depth range of the study area is from 20 to 670 m water depth. The surface bin resolutions for multibeam bathymetry data are 15 m in the standard survey area and 10 m in selected high-resolution areas.

The high-resolution single-channel seismic survey was acquired concurrently with the multibeam bathymetry data using a GeoPulse 5430A sub-bottom profiler system that is able to transmit at frequencies from 2 to 12 kHz. The dominant frequency of the sub-bottom profile data is 3.5 kHz. The depth of penetration depends on the acoustic properties of the seabed, reaching up to 35 ms (TWT) in relatively fine-grained sediments. In addition, the top one second of nine multi-channel seismic lines within the study area was made available by BPC.

Fledermaus and ArcMap 10.1 software were used to analyze the multibeam bathymetry data. The slope is subdivided into 3 segments: the upper, middle and lower slopes, based on the measured declivities. Dimensions of different sedimentary features were quantified: length, width and thickness, together with the distance from platform margin and water depth. The interpretation from the multibeam bathymetry data is compared with subsurface data from Ocean Drilling Project (ODP) Leg 166, sub-bottom profile data and industrial 2D seismic lines. These data were analyzed using the Petrel (Schlumberger) interpretation software.

To capture the relation between the slope morphology and the basinal debris deposit, a semi-quantitative analysis was performed. Three different parameters were measured along the strike: the upper slope angle (steepness), the depth of the margin break, and the debris density. The 100-km long length of margin that was used for this analysis is shown in Fig. 2. The following methodology is used.

For the analysis, the upper slope angle (steepness) parameter is recorded at the uppermost slope in 500 m intervals along strike of the margin. The depth of margin break is the depth to the abrupt change from the platform top to the uppermost slope. The depth is measured along strike of the margin in 500 m intervals. The debris density parameter is used to quantify the debris on the toe-of-slope and basin floor. It measures the area of seafloor covered with blocks per unit area. First, the debris and blocks are identified based on slope angle cut-off criteria on the steepness map. Data points with a slope angle greater than 4° are treated as blocks. Afterwards a map containing the block distribution is generated and the debris density is calculated within a 1 × 1 km area (Fig. 3). With an average block size of more than 200 m across, a 1 × 1 km area is sufficient to capture the variability without losing significant details. The debris density is measured on the basin floor

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