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published in

Geology

2018

DOI (link to publisher)

[10.1130/G39527.1](https://doi.org/10.1130/G39527.1)

document version

Publisher's PDF, also known as Version of record

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citation for published version (APA)

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Carbonate slope morphology revealing a giant submarine canyon (Little Bahama Bank, Bahamas)

T. Mulder¹, H. Gillet¹, V. Hanquiez¹, E. Ducassou¹, K. Fauquembergue¹, M. Principaud¹, G. Conesa², J. Le Goff³, J. Ragusa⁴, S. Bashah⁵, S. Bujan¹, J.J.G. Reijmer³, T. Cavailles¹, A.W. Droxler⁶, D.G. Blank⁶, L. Guiastronac¹, N. Fabregas⁷, A. Recouvreur², and C. Seibert⁸

¹Université de Bordeaux, UMR 5805 EPOC, 33615 Talence cedex, France

²Aix Marseille University, CNRS, IRD, Collège de France, CEREGE, 13545 Aix-en-Provence, France

³College of Petroleum Engineering and Geosciences, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia

⁴Section of Earth and Environmental Sciences, University of Geneva, 1205 Geneva, Switzerland

⁵Center for Carbonate Research, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida 33149, USA

⁶Department of Earth Sciences, Rice University, Baker Hall MS-40, Houston, Texas 77005, USA

⁷École Nationale Supérieure en Environnement, Géoressources et Ingénierie du Développement Durable, allée F. Daguin, 33605 Pessac cedex, France

⁸Institut de Physique du Globe de Paris, Sorbonne Paris Cité, Université Paris Diderot, CNRS, 75005 Paris, France

ABSTRACT

New high-quality multibeam data detail the morphology of the giant 135-km-long Great Abaco Canyon (GAC) located between Little Bahama Bank (LBB, Bahamas) and Blake Plateau. Knickpoints, chutes, and plunge pools mark the canyon main axis, which is parallel to the LBB margin. The canyon head covers a large area but does not represent the main source of the modern sediments. The material supplied through the LBB canyon systems originates below this head, which only shows erosive lineaments related to the pathway of currents running along the seafloor and restricted failure scars. Most of the sediment supply originates from the canyon sides. The northern canyon flank incises the Blake Plateau, which comprises contourites on top of a drowned Cretaceous carbonate platform. These deposits are susceptible to translational slides and form dissymmetric debris accumulations along the northern edge of the canyon. A large tributary drains the Blake Plateau. Two large tributaries connecting the southern flank of the GAC directly to the LBB upper slope form additional sources of sediments. Subbottom profiles suggest the presence of a sedimentary levee on the tributary canyon and of sediment gravity flow deposits. The GAC has been a permanent structure since the drowning of the Cretaceous platform, and its size and morphology are comparable to those of canyons in siliciclastic environments. The orientation of the GAC parallel to large-scale regional tectonic structures suggests a structural control. The size of the observed structures, especially plunge pools at the base of gigantic chutes, is unusual on Earth. The presence of deposits downflow of the pools suggests that the GAC results from or at least is maintained by persistent and sustained submarine gravity flows rather than by retrogressive erosion.

INTRODUCTION

Submarine canyons form the most impressive topographic reliefs shaping continental shelves and slopes (Shepard, 1981). They are usually narrow structures with depths reaching several kilometers for widths extending over a few kilometers. Most of them are laterally constrained by deep walls made of hard rock or indurated sediments. The deepest canyons in the world seem to be structurally controlled; e.g., the 2000-m-deep Capbreton Canyon (Bay of Biscay) is rooted on the north Pyrenean thrust deformation front (Cirac et al., 2001). Canyon flanks are shaped by gully networks, furrows, and slump scars indicating periods of active erosion. Four main processes directly related to canyon formation and persistence

are (1) the subaerial phase of fluvial erosion such as for the Messinian Mediterranean canyons (Mulder et al., 2004); (2) retrogressive failures generating turbidity currents (Mulder et al., 2004); (3) frequent erosion by sediment-laden hyperpycnal flows generated by flooding rivers (Pratson et al., 1994); and (4) bypass with a lesser sedimentation rate in rapidly prograding margin environments (Pratson and Haxby, 1996). The majority of shelf-incised canyons are extensions of river mouths. During sea-level lowstands, the canyon head can directly connect to the river system, allowing a direct transfer of the river load to the submarine structure (Droz et al., 1996). Canyons also may be unconnected, with sediments supplied either by coastal drift, e.g., the Monterey canyon (California, USA; Klaucke et al., 2004) or Ogooue canyon (Gabonese margin; Shepard and Dill, 1966), or by other hydrodynamic processes including storms or lateral supply, both, however, remaining moderate when compared to supply from a canyon head (e.g., Normark and Piper, 1991). Canyons supplied by a pure carbonate tropical factory are rare and remain short (a few kilometers) and moderately deep (<100 m) and wide (<700 m), like on the northern slope of Little Bahama Bank, Bahamas (LBB; Tournadour, 2015) and on the Great Barrier Reef (Puga Bernabéu et al., 2011). The Baas Canyon (Australia) is an exception, however, developed in a cool-water carbonate environment (Mitchell et al., 2007). With a length of 135 km, a maximum width of ~15 km, and a maximum depth of ~3000 m, the Great Abaco Canyon (GAC; located between LBB and Blake Plateau) presented in this study compares with the largest submarine canyons in the world. Bahamian substrata shows tectonic activity since the Central Atlantic rifting (Kimmeridgian; Mountain and Tucholke, 1985). The archipelago shows Jurassic rift structures including the Blake-Bahama fracture zone. This tectonic heritage induced the Cenozoic subsidence of the Blake-Bahama Escarpment (BBE; Freeman-Lynde et al., 1981). Recent tectonic activity in the Bahamas has been reported in Walker's Cay by Mullins and van Buren (1981), in Santaren Channel (Masferro et al., 1999; Wunsch et al., 2016), and along Mayaguana island (Kindler et al., 2011).

The aim of this paper is to present a short overview of the sedimentary environments identified around the GAC, a major carbonate-fed canyon, to describe the canyon itself with its unusual and outsized morphological structures, and to evaluate the sources of the sediment supply.

METHODS AND ACQUIRED DATA

The Carambar 2 cruise (directed by the University of Bordeaux) was conducted from 30 November 2016 to 2 January 2017 on the R/V *L'Atalante*.

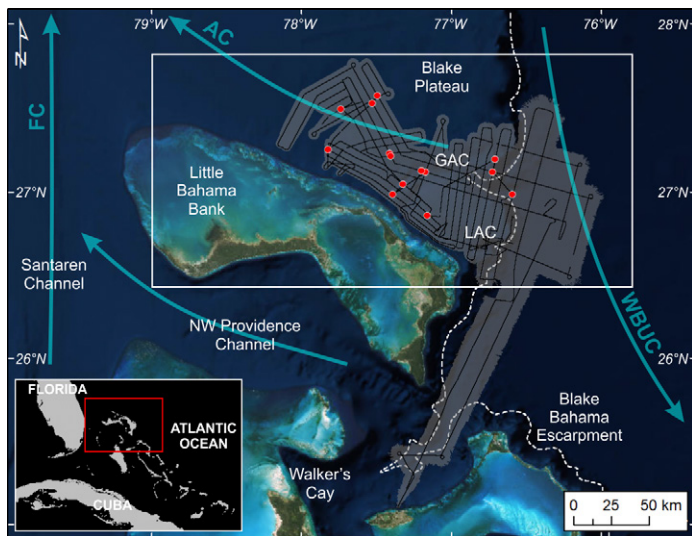


Figure 1. Geographical and oceanographical context of our study, including location of multibeam survey and sediment cores (red dots) collected during Leg 1 of Carambar 2 cruise (R/V *L'Atalante*), Bahamas. Blue arrows mark trajectories of main oceanic currents. AC—Antilles Current; FC—Florida Current; GAC—Great Abaco Canyon; LAC—Little Abaco Canyon; WBUC—Western Boundary Undercurrent. White dashed line is Blake Bahama escarpment.

Its main objective was to understand the sediment transfer from the LBB slope to the ultra-deep basin (>4000 m) of this carbonate system (Fig. 1). The study area, explored during Leg 1 (30 November to 18 December 2016), comprises the northeastern slope of the LBB, including the southernmost extremity of the Blake Plateau and the abrupt (2000 m) north-south submarine cliff of the BBE. These areas extend from 700 to 5000 m water depth.

Onboard equipment included a Kongsberg EM122/EM710 multibeam echo-sounder (bathymetry and backscatter), a “chirp” subbottom profiler (1800–5300 Hz frequency modulation), high-resolution multichannel seismic instrumentation (four 35/35 in³ airguns and a 192-channel streamer), and a Kullenberg coring system. Data collected include >19,120 km² of multibeam bathymetry, 3776 km of subbottom profiles (penetrating 80 ms two-way traveltime), and 14 cores with a cumulative length of 89 m (Fig. 1). This new data set adds to the existing data of Ocean Drilling Program Leg 101 (Austin et al., 1988) and Leg 166 (Eberli et al., 1997) and the Bahamas Drilling Project (Ginsburg, 2001), as well as academic and industrial seismic lines.

RESULTS AND DISCUSSION

Canyon Morphology and Structure

The GAC runs for ~135 km parallel to the edge of LBB (Figs. 1 and 2). It is fairly straight, showing only three major, low-curvature bends (B1 to B3 in Fig. 2A) and has a U-shaped cross section (Fig. 2B). According to Jobe et al. (2011), this is typical of canyons controlled by depositional processes involving fine-grained sediment without significant erosion. The canyon head is located at ~1300 m water depth (Fig. 2A). The slope along the first 98 km of the downslope axis of the canyon (Figs. 2A and 2C) is moderate (0.6°), and then increases abruptly at a small knickpoint, i.e., a point of abrupt change in slope along the canyon longitudinal profile (K0 in Figs. 2A and 2C). Then, a major (1318-m-high) knickpoint (K1 in Figs. 2A and 2C) is encountered, followed by a 1.2-km-diameter and 200-m-deep depression (the western Pp in Figs. 2A and 2C). The third knickpoint (K2 in Figs. 2A and 2C) is 458 m high and followed by a 113-m-deep depression (the eastern Pp in Figs. 2A and 2C). Given the height of the knickpoints and the dip of >40° of the escarpment marking the knickpoint, they are called chutes. Downslope and along the last 37 km of

the GAC, the mean slope is steeper (2.2°), showing several knickpoints that in some cases are associated with a depression. Downslope, each depression is followed by a deposit forming a topographic high (Sbd in Fig. 2C). This suggests that each depression corresponds to a plunge pool formed by enhanced erosion related to flow expansion during a hydraulic jump generated by long-duration or frequent turbulent sediment-laden flows (Komar, 1971). The topographic high would thus correspond to slope-break deposits (Mulder and Alexander, 2001). The last knickpoint (K3 in Figs. 2A and 2C) is ~100 m high and marks the opening of the canyon to the deep basin at the toe of the BBE. Soulet et al. (2016), for the Polcevera Canyon (Ligurian margin), and Mitchell (2006), for southeast Australia, showed that large knickpoints and associated plunge pools could be related to faults. However, no evidence of faulting is observed at the location of the chutes in our study area. The size of the chutes and of the associated plunge pools strongly suggests that these structures have remained geographically stable for a very long time and that sediment-laden flow in the GAC occurs frequently. The location of chutes and plunge pools is possibly related to a change in rock lithology at the present-day edge of the Cretaceous carbonate platform. The flatness of the valley between chutes suggests that each chute corresponds to a particular stratigraphic level. A 50-km-long continuous tongue of deposits extends for >20 km away from the BBE and probably represents stacking of mass-wasting events originating from the submarine cliff (mwd in Fig. 2A). The most distal part of the GAC follows an ~N120° direction, i.e., parallel to the northern edge of Mayaguana island, and possibly relates to a fault (Kindler et al., 2011) with a direction consistent with that of the Blake Bahama fracture zone (Sheridan et al., 1981). The toe of the northern canyon wall is covered with a wedge showing a hummocky surface. It is interpreted as related to mass-wasting deposits initiated along the steep slope entrenching the plateaus located at the top of the walls (mwd in Fig. 2A).

GAC Head

The main canyon morphologic head drains the southeastern extent of the Blake Plateau, forming an ~40-km-wide, roughly trapezoidal area extending upslope of the axis of the canyon at ~45 km from the shelf edge of LBB. The reflectivity map shows a few northwest-southeast-oriented erosion lineaments (li in Fig. 2D) bending from the distal part of the turbidite systems described by Mullins et al. (1984), with almost no recent sediment cover and only little evidence of sediment failure (s in Fig. 2D) or sedimentary structures (sediment waves of cyclic steps). The lineaments are aligned with those observed in the distal part of the LBB slope (Tournadour, 2015) and interpreted to result either from activity of the Antilles Current during periods corresponding to deepening of the core of the current (cold periods) or from the activity of the Labrador Sea Water that represents the upper part of the Western Boundary Undercurrent (WBUC; Evans et al., 2007).

On the southern flank of the GAC, two major tributaries (V1 and V2 in Fig. 2A) meet the canyon at a position ~11 km upslope of the K1 knickpoint. They originate on the upper LBB slope as other small canyons. The subbottom profiles (Fig. 2E) located between V1 and V2 show “moustache morphologies” made of layered sediment showing variations in acoustic impedance that suggest an alternation of carbonate turbidites and periplatform ooze deposited on a sedimentary levee. The presence of such confined levees suggests supply by turbidity currents and shows that tributaries may be the main sediment supply contributors to the GAC.

Contourite Plateaus

Two large, superposed plateaus at 1200 and 1140 m water depth, with a sedimentary cover as much as 60 m thick, occur north of the GAC (P1 and P2, respectively, in Fig. 2A). On the Blake Plateau, Neogene drifts were related to the interaction of the deepest part of the Gulf Stream with the WBUC (Pinet and Popenoe, 1985). These large flat areas are consequently interpreted as contourite plateaus. Near the canyon walls, the contourite

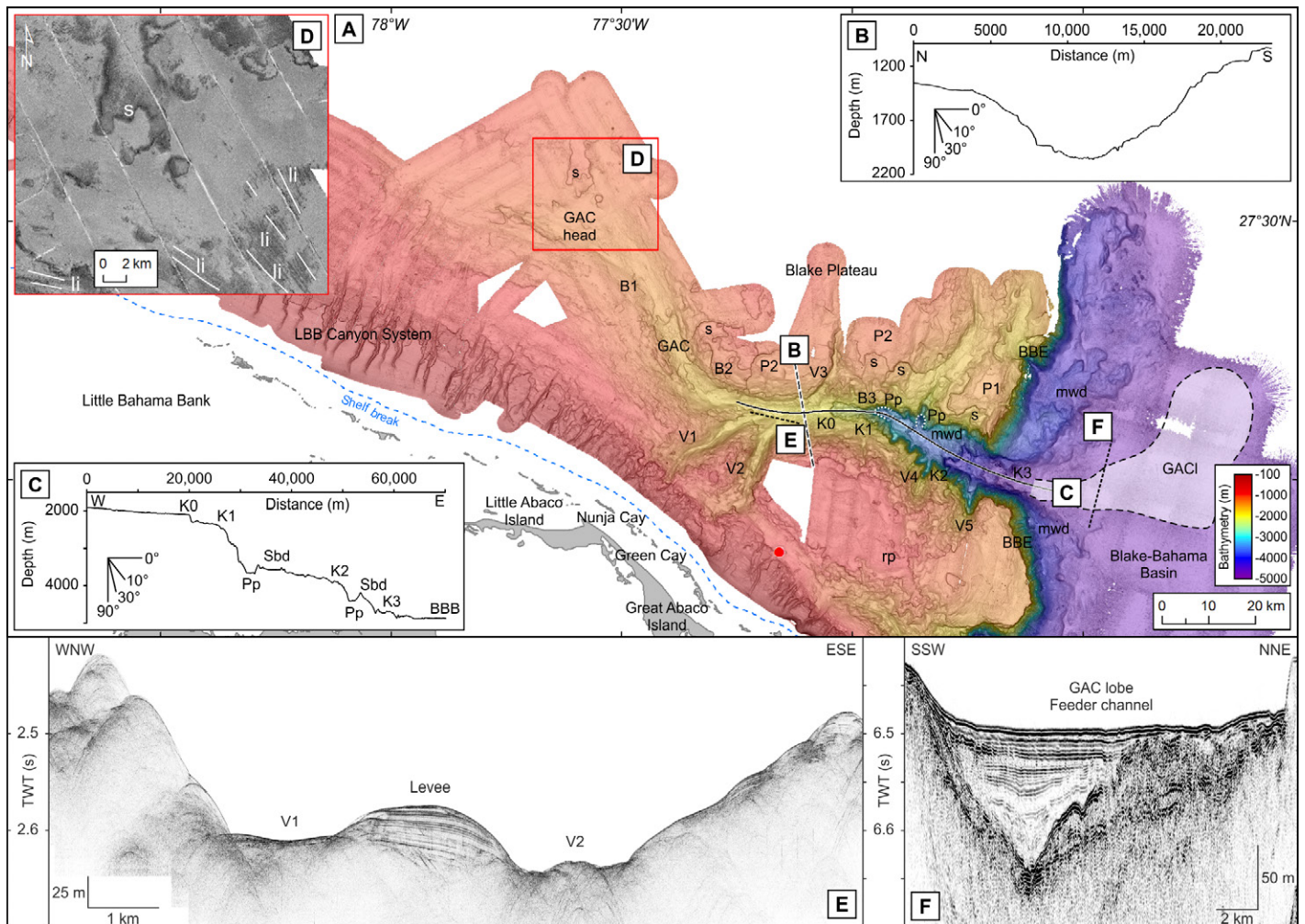


Figure 2. A: Bathymetric map of northeastern slope of Little Bahama Bank (LBB) including Great Abaco Canyon (GAC). B1–B3—main bends; BBE—Blake Bahama escarpment; GACI—lobe of GAC; K0–K3—major knickpoints; mwd—mass-wasting deposits; P1, P2—superposed contourite plateaus; Pp—plunge pool; rp—relict plateau; s—slide; V1–V5—tributary valleys. B: Bathymetric transversal cross section showing U shape of GAC. C: Bathymetric longitudinal cross section along distal part of GAC showing successive knickpoints K0 to K3, associated plunge pools (Pp), and slope-break deposits (Sbd). BBB—Blake-Bahama Basin. D: Enlargement of backscatter map showing head of GAC, erosive lineaments, and rare slide scars (high reflectivity in dark tones). li—lineament; s—slide. Lineaments have been overlain with fine white lines. E: Very high-resolution seismic profile showing sedimentary levee and the two main tributary valleys (V1 and V2). F: High-resolution seismic profile showing feeder channel of GAC lobe in abyssal plain. TWT—two-way traveltime.

plateau edges are affected by intense mass-movement features and large scars, extending 10 km away from the plateau edge, indicating generalized downslope sediment motion and sediment sliding toward the canyon edges (s in Fig. 2A). In places where the plateaus are dissected by the gully network, contourites in some locations form perched isolated relict structures detached from the main plateau. A large valley drains the contourite plateaus toward the GAC (V3 in Fig. 2). A smaller-sized relict plateau is located in the southern part of the GAC (rp in Fig. 2A). This area is very flat with a main plateau located at 1000 m water depth. It could be affected by the deepest low-energy part of the Antilles Current. Two small valleys connected to the GAC (V4 and V5 in Fig. 2A) drain this relict plateau. These two valleys constitute minor lateral sediment supply to the canyon. Downslope, the presence of a sedimentary bulge suggests sediment accumulation (a lobe) extending down to 5000 m water depth that is supplied by a feeder channel (Fig. 2F). This lobe seems to have occupied a stable position through time and is the only accumulation related to the canyon. The sediment accumulation is <200 m thick, has an ovoid shape (30 km long and 30 km wide in its widest part), and does not conform to the gigantic incision of the canyon. A 3-m-long core was collected in the upper deposits of the mid-lobe area and shows clay-rich

fine-grained grayish brown mud that was probably partly supplied by the WBUC. Because most of the supply from the LBB canyon system is carbonate mud, a large proportion of the particles arriving at canyon mouth could have been pirated by the energetic WBUC, either by direct transport by turbulent processes, or by erosion of the material sliding from the canyon sides. This would explain the apparent lack of sediment in the canyon at present. Our results are consistent with hypotheses of Hurd et al. (2016), who suggested that the drowned Cretaceous platform contributed to the development of a large-scale inflection in slope angle that itself acted as a first-order control on processes of sustained erosion, channelization, and sediment bypass.

CONCLUSIONS

The newly established bathymetric maps reveal the detailed and complex morphology of a giant valley with a vast canyon head. This kind of large seafloor sediment transfer system is unexpected in a pure carbonate-supplied deep-sea environment. The GAC represents the distal part of a large carbonate redeposition system draining the carbonate platform of LBB in the southwest and the contouritic Blake Plateau in the northeast. The contourite deposits on the plateau were eroded progressively

and drained to the canyons by tributaries or through erosion with mass sliding of the canyon sides. Although the sediment is not supplied as a point source in this carbonate environment, the canyon is comparable in size to the largest submarine canyons in the world. Sediment accumulation at the mouth of the GAC is not consistent with the size of its incision. The supply to the canyon from the morphologic head is small, with only restricted slope failures and lineaments probably related to bottom currents. Most of the sediment supply originates from the GAC canyon flanks. The sediments are sourced through erosion and mass wasting of the contouritic Blake Plateau and direct supply from the eastern LBB upper slope through small slope gullies and secondary tributary canyons draining the slopes of various parts of the adjacent LBB platform. Sedimentary processes flowing downcanyon seem to interact with contour currents especially when arriving to the abyssal plain. This study shows the importance of canyons in carbonate sediment transfer to the abyssal plain of the western North Atlantic. The large size of the GAC shows that it funnels long-duration sustained gravity flow processes, allowing the sorting of carbonate particles in a similar way as known from siliciclastic deep-sea turbidite systems. The nature and the size of the transported particles greatly impact the nature and the volume of deposits in the deep parts of the system, therefore leading to new guidelines for carbonate-hosted hydrocarbon reservoir exploration.

ACKNOWLEDGMENTS

We thank the captain and crew of the R/V *L'Atalante* for the quality of the acquired data, and Ifremer-Genavir (France) for cruise organization and technical support. This work has been supported by the French Institut National des Sciences de l'Univers program "Actions Marges." K. Fauquembergue's Ph.D. is funded by TOTAL. We thank Á. Puga Bernabéu and G. Hurd for their constructive comments on this manuscript.

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Manuscript received 15 July 2017

Revised manuscript received 5 October 2017

Manuscript accepted 6 October 2017

Printed in USA