Slope Instability on the French Guiana Transform Margin from Swath-Bathymetry and 3.5 kHz Echograms

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Abstract Although transform margins represent ~30% of rifted margins around the world, few studies have investigated mass-movement processes in such areas and their links with this specific structural context. The French Guiana transform margin and adjacent Demerara abyssal plain have been surveyed during the GUYAPLAC cruise, collecting multibeam bathymetric data, backscatter imagery, 3.5 kHz echograms and 6-channel seismic profiles. The study area is divided into three domains: the shallow Demerara plateau, the Guiana slope and rise, and the Demerara abyssal plain. The Demerara plateau displays multi-scale slope instabilities from huge deep-seated collapses of the whole margin to surficial creeping folds and recent slumps. Giant elongated pockmarks have been also observed for the first time in this area. Fluid escape is common everywhere on the plateau and probably enhances slope instability. On the Guiana slope and rise, large stacked lobate masses have been identified testifying to repetitive failure events. Fluid escape is

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also ubiquitous there, suggesting a dewatering of debris flows due to sediment loading. Two main types of sedimentary structures are observed on the Demerara Abyssal Plain: small meandering channels of the Amazon Fan at its eastern edge and sediment waves at its western edge, along the foot of Demerara continental slope.

Keywords Slope instabilities • debris flows • creeping • fluids • continental transform margin • structural inheritance • echo character • swath bathymetry

1 Introduction

Slope instability on continental margins needs further study to improve our understanding of the mechanisms that trigger it and the resulting natural hazards (e.g. damages to deep-water infrastructures, tsunamis and their impact on human population). A better understanding of the triggering mechanisms of slope instabilities that are capable of mobilizing up to several hundred cubic kilometers of sediments, represents an important scientific challenge because these events have a direct influence on the morphology and evolution of margins and oceans (Amblas et al. 2004; Canals et al. 2004; Leynaud et al. 2009; and references therein). Although shear margins represent ~30% of rifted margins around the world, yet few studies have been dedicated to the characterization of mass-movement processes along these margins that display specific structurally-controlled seafloor morphology (and especially a very steep ocean-continent transition). The aim of this study is to investigate slope instability along the transform portions of the French Guiana margin and, in the future, to try to highlight the impact of the structural inheritance on these mass movements.

2 Geological Setting

The study area is located in the western Equatorial Atlantic Ocean, on the French Guiana margin, which is characterized by a broad continental shelf and a steep continental slope that is interrupted at mid-depths along the northern part of the study area by the 1,000–2,000 m deep Demerara plateau (Fig. 1). The Guiana margin is fringed by the Demerara abyssal plain off the northern part of the study area and the distal part of the Amazon Fan to the south. The study area has been structured first by the opening of the Central Atlantic during Early Jurassic times, then by the opening of the Equatorial Atlantic at the end of Early Cretaceous, along a main transform zone (Gouyet 1988; Unternehr et al. 1988; Greenroyd et al. 2008). The studied margin therefore comprises transform and divergent segments

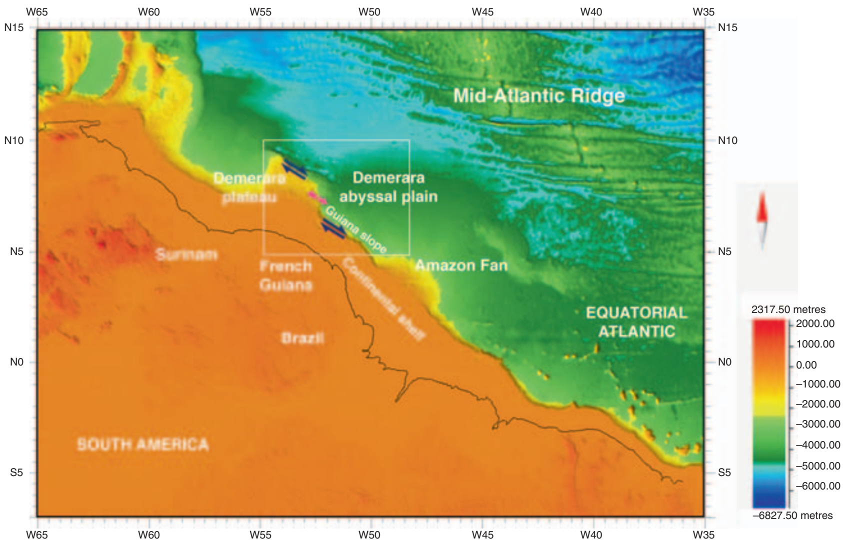

Fig. 1 Location of the study area (*white box*) situated in the western Equatorial Atlantic Ocean (Bathymetric map modified http://www.ngdc.noaa.gov, 2006). The blue and pink arrows indicate respectively the shear and divergent segments of the studied margin (Gouyet 1988; Greenroyd et al. 2008)

(Fig. 1). On the Demerara plateau, the post-rift sedimentation consists of successive wedges prograding from the continental shelf, with a maximum total thickness of 6 km at the foot of the upper continental slope. Presently, the Guiana margin is located between two major sedimentary sources, the Amazon and the Orinoco Rivers. In the abyssal plain, sedimentary thicknesses drastically increase south-eastwards (i.e. towards the Amazon turbidite system (Patriat et al. 2005).

3 Dataset and Methodology

The French Guiana margin and the adjacent Demerara abyssal plain were surveyed during the GUYAPLAC cruise onboard the R/V l'Atalante (2003; Fig. 2), as a part of the EXTRAPLAC French Program (Ifremer-IFP–SHOM-IPEV). The dataset comprises: (1) EM12-Simrad multibeam bathymetry and backscatter imagery; (2) 3.5 kHz echograms with an average penetration of 50 m below seafloor; and (3) 6-channel seismic profiles. All data were acquired at a speed of 8 knots.

Bathymetric data have been processed using CARAIBES software developed by IFREMER using a 250 m resolution grid. Additional processing has been performed on data from the Demerara plateau at a 125 m resolution grid. The 3.5 kHz data have been used to produce an echo-character classification on the basis of

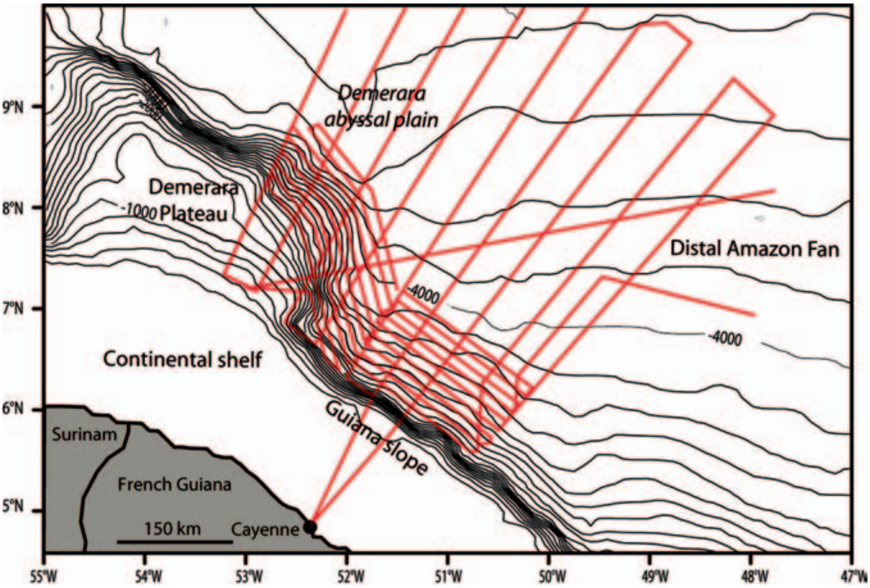

Fig. 2 Dataset of swath bathymetry, backscatter imagery, 3.5 kHz echograms and 6-channel seismic reflection profiles acquired during the GUYAPLAC cruise (2003, *red lines*)

(i) acoustic penetration and continuity of bottom and sub-bottom reflectors; (ii) micro-topography of the seafloor; and (iii) internal structures. The combination of the bathymetric and 3.5 kHz analyses allowed identification and characterization of the main sedimentary processes in the study area.

4 Results

The combined analyses of EM12-Simrad multibeam bathymetry and 3.5 kHz echograms revealed the detailed morphology of the French Guiana margin and the main sedimentary processes that have recently shaped this area (Loncke et al. 2009). Three main morphostructural domains have been identified: (1) the Demerara abyssal plain seaward; (2) the Guiana slope and rise to the South; and (3) the Demerara plateau in the western part of the study area (Fig. 3).

4.1 Demerara Abyssal Plain

This part of the study area, with water depths ranging from 4,000 to 4,800 m, is less well-imaged by our dataset than the slope domains but is characterized at its

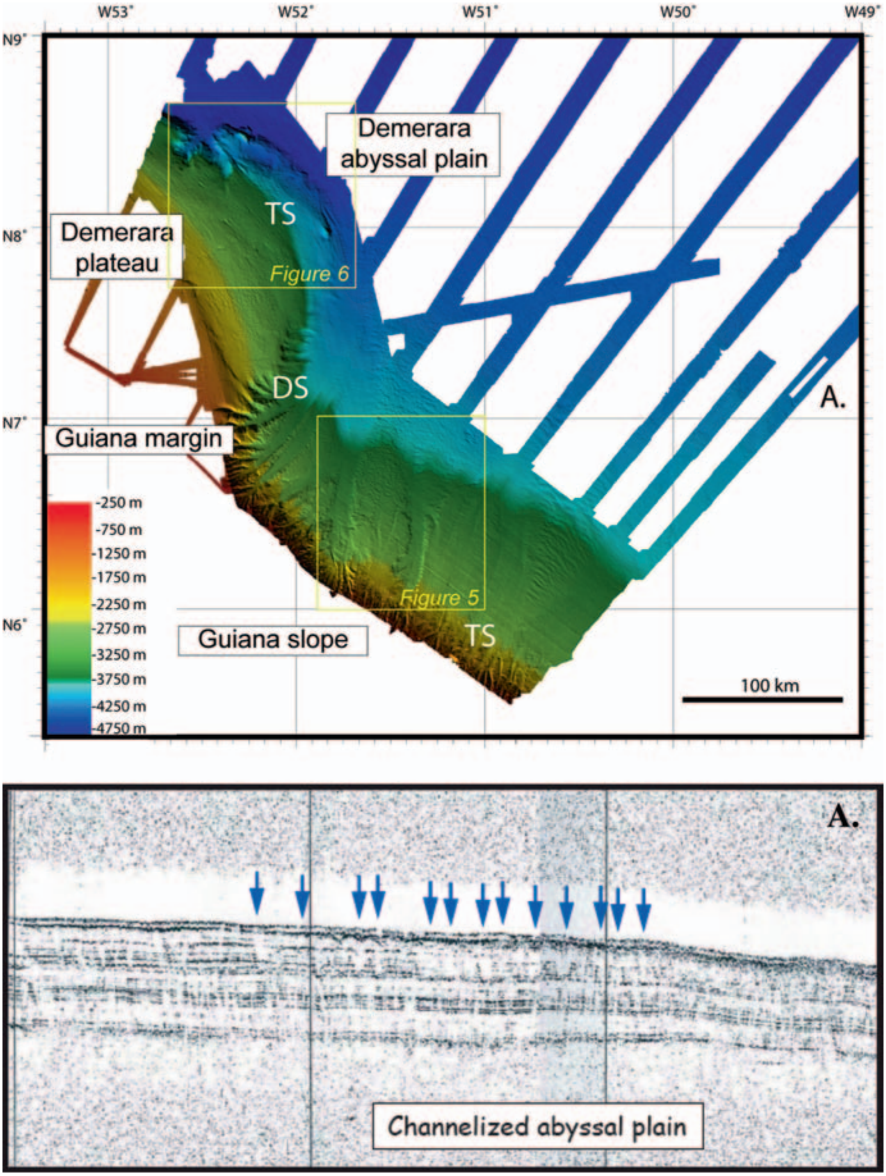

Fig. 3 EM12-Simrad color shaded bathymetric map of the French Guiana transform margin and adjacent Demerara abyssal plain (GUYAPLAC data). TS and DS correspond to transform and divergent segments of the study area. The 3.5 kHz excerpt (A) illustrates the fluid escape structures observed in the abyssal plain

eastern edge by small meandering channels belonging to the Amazon Fan and at its western edge, along the foot of Demerara continental slope, by sediment waves probably created by contour currents (Fig. 4). The abyssal plain is also affected by

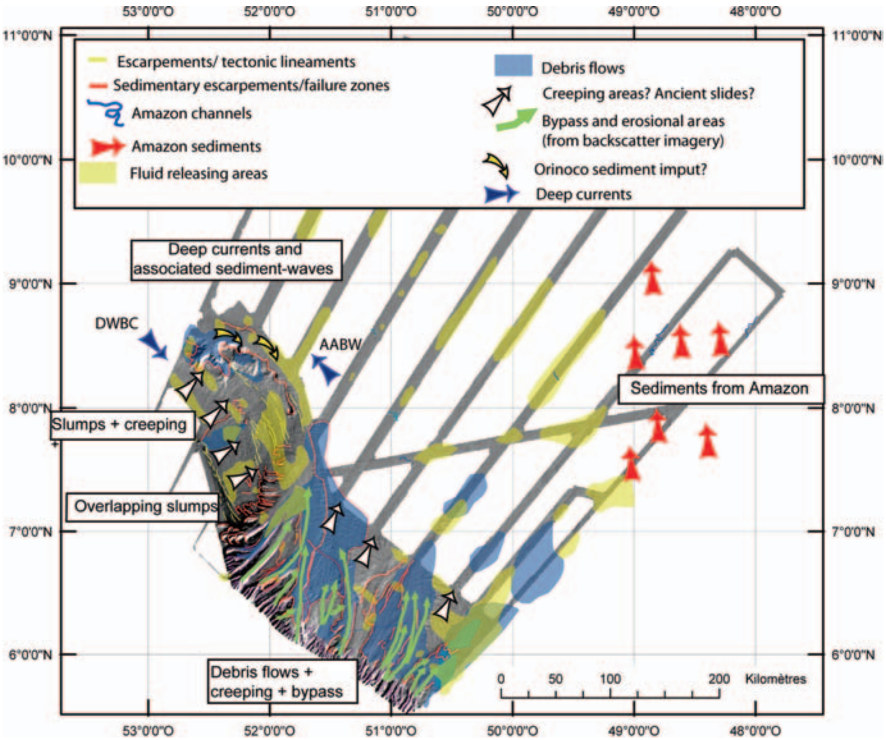

Fig. 4 Synthesis map of sedimentary processes and distribution of fluids (*in yellow*) deduced from the swath-bathymetry, backscatter imagery and 3.5 kHz echo-character mapping (Loncke et al. 2009)

numerous fluid escape structures (Fig. 3a, see also Loncke et al. 2009 for more details and examples of 3.5 kHz profiles).

4.2 *Guiana Slope and Rise (Transform Segment)*

The NW-SE oriented Guiana continental slope belongs to a transform margin segment (Figs. 1 and 3). The upper slope (down to 2,000 m water depth) is very steep and gullied by numerous sub-parallel canyons (Fig. 3). Downslope, the drainage network merges into a few wide (up to 5 km) U-shaped active valleys (Fig. 5). The continental rise shows several overlapping lobate masses with rough or folded surfaces that are interpreted to be mass-transport deposits (Figs. 3 through 5).

For example, the Fig. 5 shows an ancient N-S-elongated debris flow cut on both sides by two active submarine valleys and eroded on top by a network of furrows. The echo-character mapping confirms the presence of several large stacked recent mass-movement deposits (transparent, chaotic and undulating-bedded echo-types),

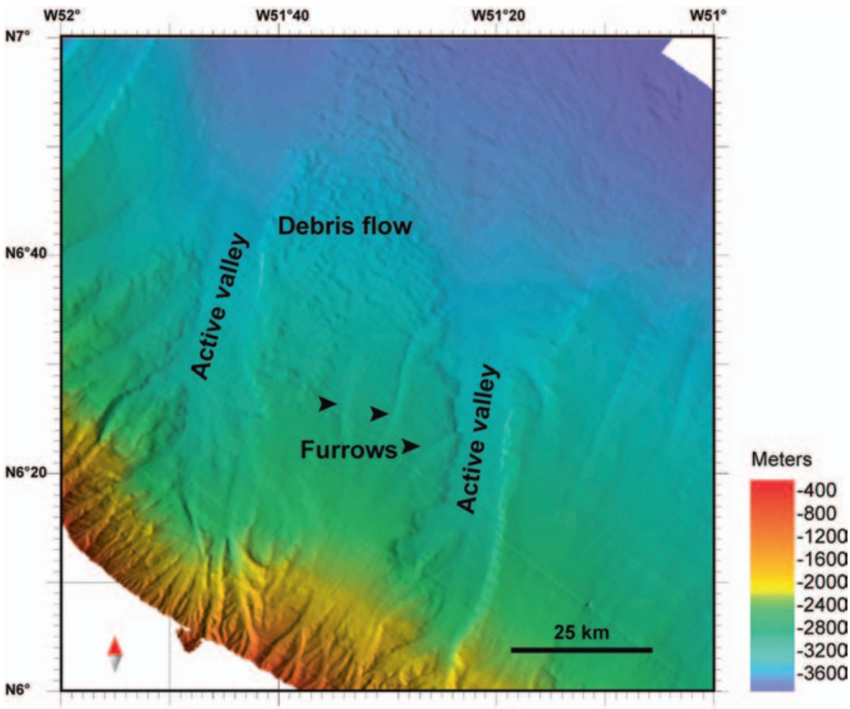

Fig. 5 Color shaded (260° azimuth, 44° elevation) bathymetric zoom focused on the Guiana slope showing large debris flow cut by active valleys (see location on Fig. 3)

testifying to repetitive destabilization events of this entire transform segment (Fig. 4). In this area, fluid or gas escape structures are frequently associated with buried transparent debris flow deposits, suggesting dewatering due to sediment loading. This dewatering process can later activate creeping of the sediments, as it has been observed on the Nile and Congo Fans (Bayon et al. 2009; Gay et al. 2004).

4.3 Demerara Plateau

The Demerara plateau is delineated by two NW-SE and N-S trending borders corresponding to the transform and divergent segments of this part of the Guiana margin (Fig. 3). The N-S divergent border is quite steep and deeply cut by canyons and failure scars, while the NW-SE transform segment is smoother and less dissected except at the northernmost end (Fig. 6). The Demerara plateau dips seaward and presents a segmented morphology with at least four “en échelon” NNW-SSE trending (i.e. parallel to the initial shear direction) slope breaks giving a “stair” aspect to the plateau (Figs. 3 and 6). These NNW-SSE structural steps seem to correspond to eastward collapses of wide blocks. On 3.5 kHz profiles (~100 km

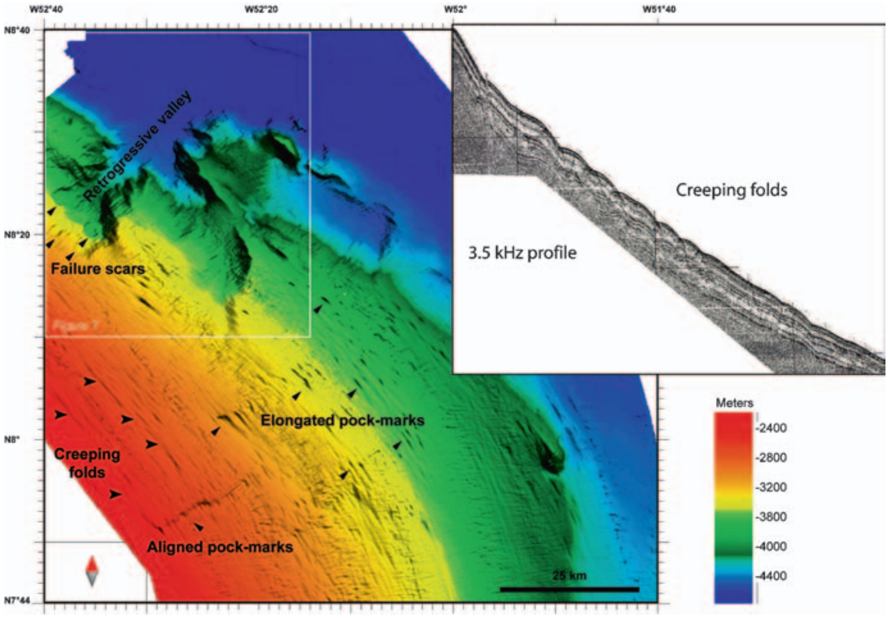

Fig. 6 Color shaded (50° azimuth, 56° elevation) bathymetric zoom focused on the Demerara plateau illustrating the rough seafloor morphology and the pock-mark field described in the text. The 3.5 kHz profile illustrates in section the creeping folds observed on the Demerara plateau

long, Loncke et al. 2009), slumps initiate upslope along the uppermost NNW-SSE slope break. Downslope, these slumps evolve to folded sediments that can correspond to compressive toe of slumps or creeping features. The sediments then thin distally into a rough to transparent mass sometimes showing seismic wipe-outs. At a deeper scale, seismic data show that this part of the margin has undergone repeated slope failure creating deep massive collapses (numerous overlapping transparent masses rooted at about 0.5 s two-way travel time below seafloor, Loncke et al. 2009). The plateau also displays a very rough surface with folds perpendicular to the slope direction probably related to creeping processes as testified by 3.5 kHz data (Fig. 6 insert).

More surprisingly, very numerous circular, elongated and/or aligned depressions have been observed on the Demerara plateau. We attribute these features, which are correlated to high reflectivity patches, to pockmarks. Some of them reach 2 km in diameter and 100 m in depth. The elongation of these features may be due to a reshaping by the DWDC (Deep Western Boundary Current, Dengler et al. 2004). Seismic wipe-outs are also identified on the 3.5 kHz echograms all over the plateau and underline the importance of the fluid and gas discharge in this area. At the northern end of the study area, the edge of the Demerara plateau is incised by a system of canyons, that have arcuate scarps at their heads and along their flanks (Figs. 6 and 7). Downslope of these scarps the canyon floors are covered by debris flow deposits (Fig. 4).

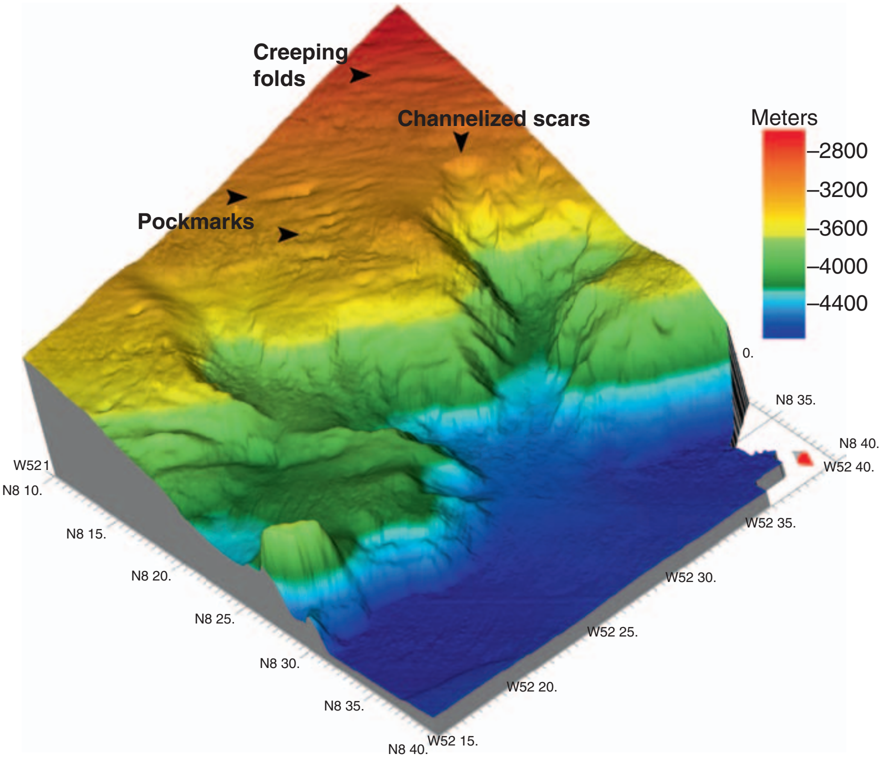

Fig. 7 3D view of the northern flank of the Demerara plateau showing the canyon network. Note the channelized scars, the creeping features and pockmarks described in the text (45° azimuth, 35° elevation, vertical exaggeration: 10)

5 Discussion and Conclusions

The dataset emphasizes the importance of slope instability in shaping the French Guiana transform margin. Sizes and styles of these mass-movements differ between the studied sectors:

- The Guiana slope and rise (transform segment), south of the Demerara Plateau, are mainly affected by huge and successive mass-movements, with slope failures generating large debris flows, sometimes buried and reworked by creeping processes.
- The whole Demerara plateau is affected by multi-scale mass-movement processes. The rough surface of the plateau is mainly deformed by creeping folds perpendicular to the slope and pockmarks. At a deeper scale, study in progress (Basile et al. 2009) shows repetitive slumping creating seaward collapse of the upper 500 m of sediments. The driving mechanism seems to be the tilting of the plateau in relation with increasing subsidence northeastward (Loncke et al. 2009). This tilting may allow the upper part of the sedimentary section to glide on décollements

sub-parallel to the bedding. The northern part of the Demerara plateau is mainly affected by small valley networks and debris flows. The lack of massive failure deposits probably indicates that the slow sliding on the plateau did not evolve, at least recently, in huge catastrophic events. Another remarkable characteristic of the study area is the abundance of circular and elongated bathymetric depressions corresponding to pockmarks, on the margin and in the abyssal plain.

Fluid escape features are also documented on 3.5 kHz echograms. Our dataset does not allow any speculation concerning the origin of the fluids, but good candidates could be the Black Shales or Cretaceous organic-rich layers on the Demerara Plateau, as suggested by Erbacher et al. (2004). In any case, these fluid escape structures seem to be closely related with slope instabilities, either along bounding faults acting as drains, or by surficial dewatering of debris flows. Whether the deformation observed at the surface is the imprint of ancient events or active features is still unclear. Given the freshness of deformations and the abundance of pockmarks, we believe that the seaward creeping processes experienced by the whole Demerara plateau are active today. Future work will be dedicated to a better understanding of the relations between structural inheritance (i.e. transform context), slope instability and fluid escape.

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