Sea floor instabilities on the southeastern flank of the Amazon Fan and adjacent Area, Foz do Amazonas basin: preliminary results

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Abstract

The Foz do Amazonas basin is affected by gravitacional processes in two scales in time and space, at least: the gravity tectonics and the occurrence of mass transport deposits. Besides that the construction of the Amazon deep-sea fan involves alternation between the channel-levee systems and mass transport deposits (MTD`s). These MTD´s are represented by shallower masses and also by megaslides complexes mapped on deeper portions of SE and NW sectors of the basin. Reis *et al*. (2010) proposed a relationship between the local gravity tectonics and those remobilization processes and deposits, where fold belts could impact significantly sea floor – causing reliefs up to 500 m on the bottom - that could trigger mass movements. This paper presents an analysis of different resolution seismic data and multibeam bathymetry data along southeastern of the basin based on the recognition of main echofacies on the seismic profiles, focusing on the identification of shallow mass transport processes. Associated morphological features, such as faults and erosive scarps were also mapped. The echofacies were then interpreted in terms of *sedimentary domains*, showing areas where erosive or depositional processes predominate on southeastern of the basin.

Introduction

During the last decade, the occurrence of megaslides complexes (MTCs) has been reported in Foz do Amazonas basin (Araújo *et al*., 2009; Silva *et al*., 2010; Reis *et al*., 2010; Reis *et al*., 2016; Silva *et al*., 2016), as giants occurrences of late Neogene-Quaternary stacked siliciclastic slide masses revealed by 2D multichannel seismic data (Figs. 1 and 2): the Amapá Megalisde Complex (AMC); the Central Amazon Megaslide Complex (CAMC), and Para-Maranhão Megaslide Complex (PMMC). Unlike the Upper Quaternary MTDs previously mapped in the area as superficial submarine slides (e.g., Damuth & Embley, 1981; Piper *et al*., 1997), those megaslides comprise mostly siliciclastic-type allochthonous masses which affect the entire sedimentary succession since at least the Mid Pliocene (Reis *et al*., 2016) forming slides as thick as ~700 m, covering extensive areas as large as 118.000 km^2.

Reis *et al*. (2016) and Silva *et al*. (2016) evinced that across the NW and SE flanks of the Amazon fan, the siliciclastic-type megaslides are all sourced from large upslope slide and/or rotated blocks (AMC and PMMC). The *décollement* of these upslope blocks was triggered by structurally-induced movements since Mid Pliocene-Pleistocene, that gave rise to sedimentary blocks which have undergone long lasting deformation, having been variably folded and faulted by the sliding along an overpressured condensed section (H3 horizon). H3 horizon equally acts as the upper *décollement* level for the gravity tectonic system that operates on the regional scale of the Foz do Amazonas basin. As for the submarine slides, Reis *et al*. (2010) proposed that gravity tectonics has acted as a significant preconditioning parameter for slope failures.

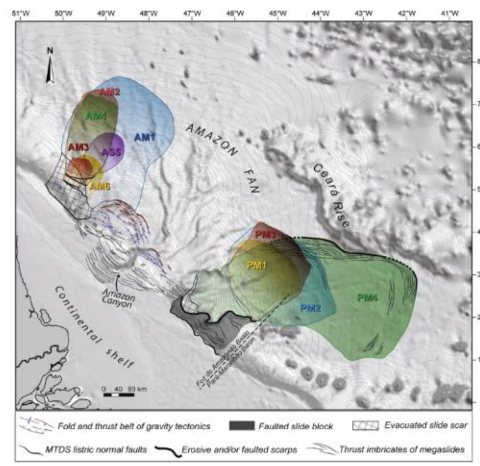

Figure 1: Simplified map illustrating Amapá Megaslide Complex and the Para-Maranhão Megaslide Complex areas and structural domains on the upper slope (after Reis *et al*., 2016).

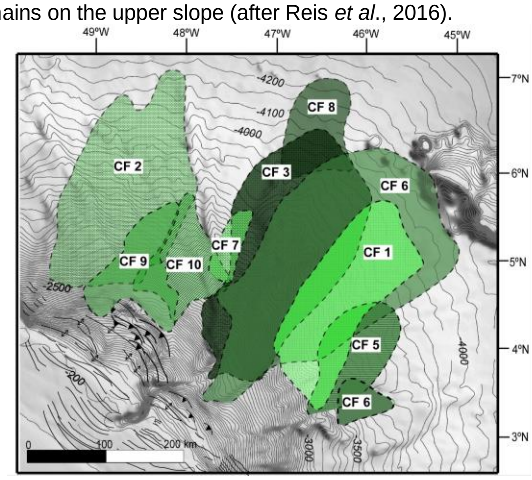

Figure 2: The Central Amazon Fan Megaslides Complex and structural domains localized on the upper slope (modified from Silva *et al*., 2016). CF1 to CF10 are stacks of megaslides in late Neogene-Quaternary sedimentary succession.

In such a context, a complex link between variable modes and scales of gravity-induced processes (gravity tectonics and MTCs emplacements) has been established in the Foz do Amazonas Basin.

However, the lack of available high-resolution seismic data or sub-bottom profiling had prevented until now the analysis of sea-floor instabilities and geological hazards across the Foz do Amazonas basin. In the present work, the coupling between a grid of regional-spaced 3.5 kHz profiles and along-track multibeam bathymetry (recently made available for this work) and the pre-existent seismic data of variable resolution allowed us to map shallow occurrences of sea-floor instabilities on the southeastern flank of the Amazon fan and adjacent area (domain of the Pará-Maranhão Megaslide Complex), based on echofacies analysis and on the recognition of shallow morphological features indicative of erosion and sea-floor instabilities (e.g., slides scars, erosive and/or faulted scarps, faulted and/or rotated blocks).

Data and Method

The dataset available for the present work comprises: a grid of 2D multichannel lines provided the Brazilian National Agency of Petroleum and Gas (ANP) and LEPLAC project; a grid of monochannel seismic; 3.5 kHz sub-bottom profiling and along-track multibeam bathymetry made available by LEPLAC (Figure 3)
The bathymetric maps were elaborated from a compilation of data from the General Bathymetric Charts of the Oceans (GEBCO – www.gebco.net) and higher resolution seismic data on upper to middle Amazon Fan provided by Directorate of Hydrography and Navigation - Brazilian Navy.

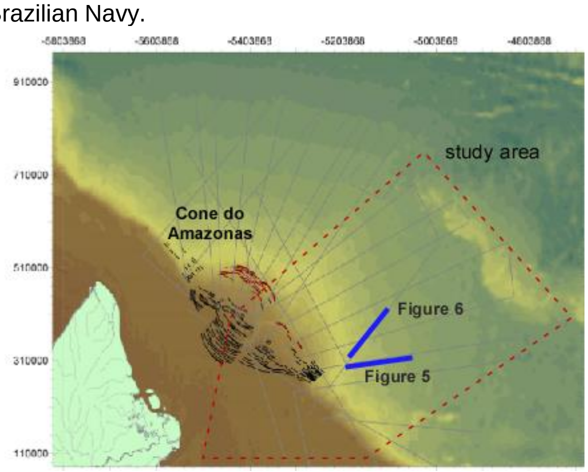

Figure 3: Bathymetric map of the Foz do Amazonas basin showing the location of the study area and the dataset (3.5 kHz profiles) used on this project.

Results

The interpretation of 3.5 kHz profiles allowed the identification of 14 main echofacies in the study area that were grouped in a total of 5 main echotypes (Table 1; Figures 5-6). These echofacies were then interpreted in terms of sedimentary process, what allowed the identification of three major sea-floor domains on the southeastern Foz do Amazonas basin: 1. Continental Shelf Domain; 2. Mass-transport Deposits Domain and 3. Distal Debris Flow Domain. A map of the domains occurrence related to distinct sea-floor sedimentary processes is shown in figure 4. The main sea-floor domains can be summarized as following:

1. the **Continental Shelf Domain** groups three main echotypes (Table A). Flat sharp echos, with high reflectance and almost no penetration (*echotype S1;* Table 1); sharp echos with regular bed forms (*echotype S2;* Table 1) and sharp echos with an associated erosive morphology (*echotype S3;* Table 1). These echos are probably the result of a high rate sand/mud deposition, with a varying degree of bottom currents action, resulting in a predominantly terrigenous deposition, mainly on the continental shelf;

2. the **Mass-transport Deposits Domain** is largely concerned by echofacies related to gravitational instabilities and mass remobilization, such as the hyperbolic and transparent ones (Table 1). Hyperbolic echos can be represented by irregular hyperbolae that rise tens of meters above sea floor, with or whithout internal layering (*echotype H1;* Table 1). The H1 echotype is related to canyon and erosive channels and to *gravity-driven* processes, generally occurring on high gradient regions and representing mass-transport evacuated zones. The domain can also be represented by *echotype H2* (Table 1), characterized by irregular hyperbolae, but occurring as minor overlapping features, suggesting a higher degree of internal disorganization. The transparent echotype is represented by weak echos describing layers of different geometries and thicknesses. These echotypes generally reflect heterogeneous and poorly-sorted sediment slides. *Echotype T1* represents deposits generated by gravitacional flows, such as debris flows with a variyng range of fluidity. *Echotype T2* represents more localized and thick deposits, what probably comes from a minor water incorporation during the remobilization. Finally, echotypes BT represents bedded-transparent echos. *Echotype BT1* (Table 1) is linked to the occurrence of bedded parallel continuous layers interbedded with transparent deposits - probably representing the alternation between overbanking deposits or/and hemipelagites with debris flows. Because of this, it is commonly found in interchannel areas, sometimes showing *levees* remobilization. *Echotype BT2* (Table 1) is attributed to interlayered sediments with superficial truncated reflectors, with an erosive signature left by *gravity-driven* processes (slide scars). Echotypes BT are also found as uniformily-bedded echofacies being related to turbidite currents and/or hemipelagic sedimentation which can be associated predominantly to a constructive sedimentary process on the basin. It was recognized in very particular portions of the SE sector of the basin and it is not represented here. Major slide scars were also mapped and its distribution represents the evacuated zone associated to those mass transport deposits found on the basin;

3. the **Distal Debris Flow Domain** is mainly represented by an uppermost transparent echofacies (echotype *T1;* Table 1) which spread across the distal portion of the slided masses, recovering echofacies formed by interlayered plan-parallel transparent layers. They are interpreted as a distal and thin depositional fringe formed by debris flows.

Discussion and Conclusion

The results presented above show that the study area is widely dominated by widespread seafloor instabilities. The integration of all results lead to the following main points of discussion:

i. Morphological features indicative of seafloor disruption were identified across the shelf break area - with regional extensions up to 186 km in length - representing morphological steps which associated to erosive zones;
ii. Upslope slide scars are connected downslope with large occurrences of sediment slides coupled with debris flows, as shown to occur across the *Mass-Transport Deposits* and *Distal Debris Flow* domains;
iii. This study also reveals that the occurrence of shallow modern mass-wasting extends far beyond the area of the megaslides occurrence previously defined in the area (Silva *et al*., 2010; Reis *et al*., 2016; Silva *et al*., 2010; Figure 4) as submarine landslides induced by processes related to gravity tectonics.

As the main conclusion, considering the integration of all data of variable resolution level (2D mono and multichannel seismics; 3.5 kHz echosounding and alongtrack multibeam bathymetry), our preliminary results point out that the Foz do Amazonas basin presents a very high potential for widespread geohazards, even out of the areas affected by the late Neogene-Quaternary stacks of megaslides.

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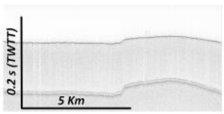
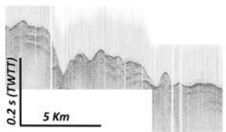
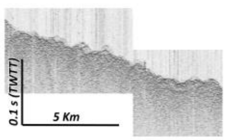
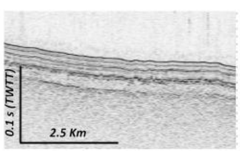
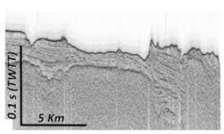
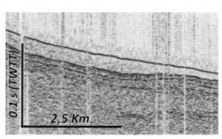
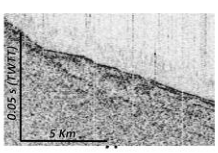
Reis, A.T., E. Araújo, C.G. Silva, A.M. Cruz, C. Gorini, L. Droz, S. Migeon, R. Perovano, I. King, F. Bache (2016). Effects of a regional décollement level for gravity tectonics on late Neogene to recent large-scale slope instabilities in the Foz do Amazonas Basin, Brazil. Marine and Petroleum Geology, V 75, 29–52.

Table 1: Main echofacies mapped on the study area and their associated sedimentary processes.

Echo type		**Echo facies**	**Interpretation**	**Sedimentary process/ setting**
Sharp (S)		S1 *Sharp*	*Continental shelf sediments*	*DEPOSITION BY NEAR-BED CURRENTS*
Hyperbolic (H)		H1 *Hummocky with irregular hyperbolae of variable elevations relative to sea floor*	*Erosional features coupled with generalized mass-transport deposits*	*SLOPE SLIDE SCARS and MASS WASTING (sediments slides/slumps)*
		H2 *Hummocky with small and irregular overlapping hyperbolae (tens of meters high)*	*Mass-transport deposits*	*MASS WASTING*
Bedded-transparent (Bt)		Bt1 *Interlayered uniformily-bedded and transparent*	*Succession of debrites and hemipelagites*	*INTERLAYERED MASS WASTING (debris flows) and HEMIPELAGIC SEDIMENT*
		Bt2 *Uniformily-bedded with truncated layers*	*Dip-slope layered deposits eroded by gravity-driven processes or currents*	*UPSLOPE SLIDE SCARS*
Transparent (T)		T1 *Transparent forming continuous layers (occasionally with internal intermittent reflectors)*	*Downslope widespread debrites*	*MASS WASTING (debris flow)*
		T2 *Transparent forming thickened masses*	*Downslope thickened debrite masses*	

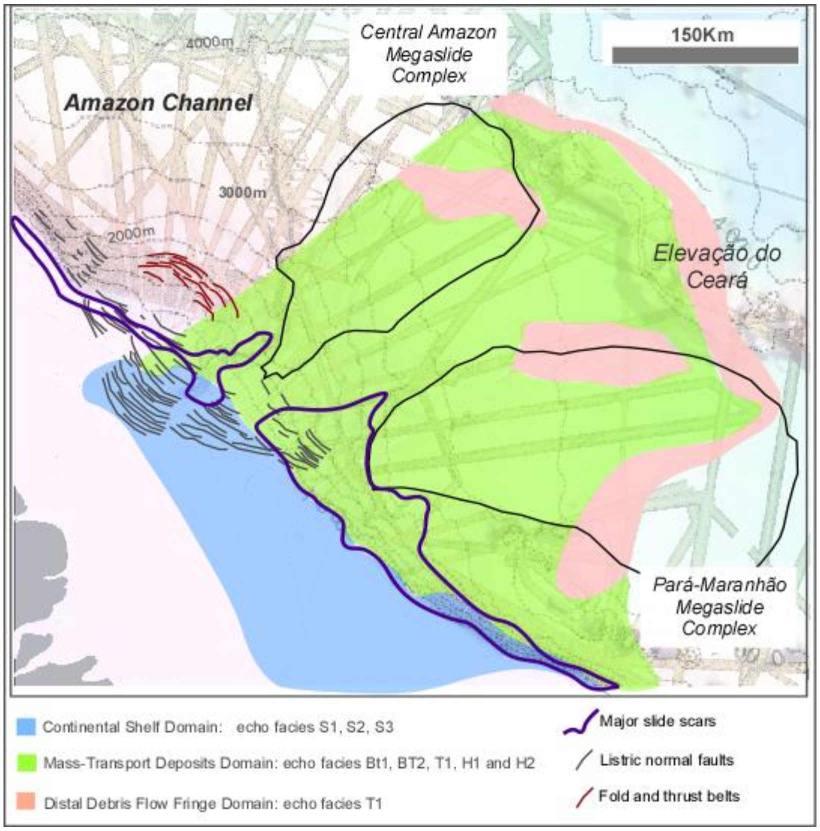


Figure 4: Simplified map of sedimentary processes domains based on echofacies identification across the southeastern Foz do Amazonas basin. Full black lines represent the outline of the superficial megaslides of the PMMC and CAMC shown in figure 1.

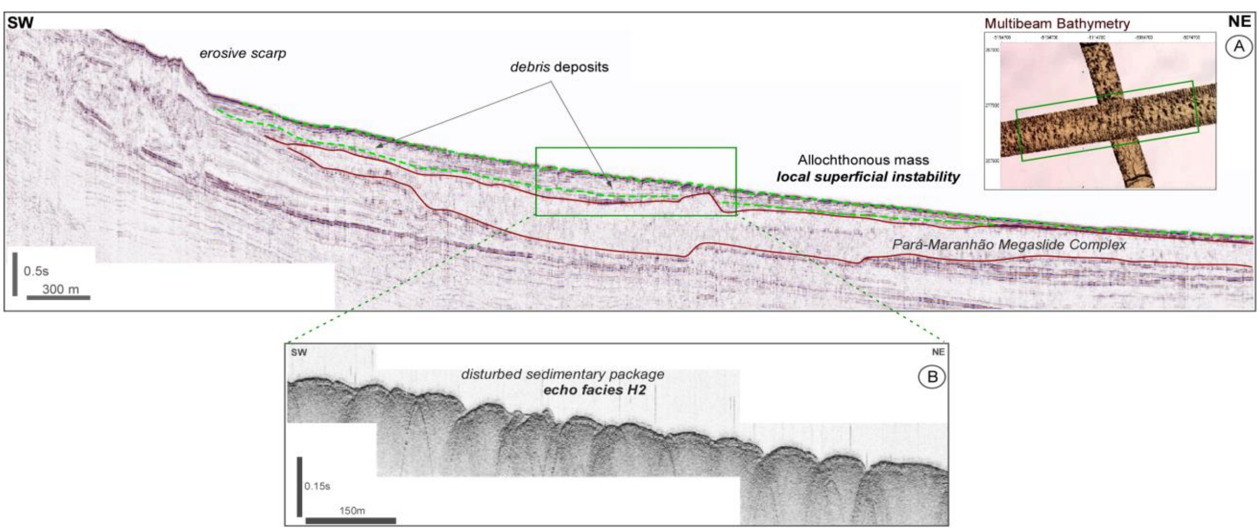


Figure 5: Seafloor instabilities seen on acoustic data of variable resolution level. **A**. 2D multichannel seismic line showing an allochtonous mass on top of the stratigraphic succession. **B**. An extract of a 3.5 kHz sub-bottom profile evidencing the seafloor occurrence of hyperbolic echofacies (echotype H2) indicative of ongoing modern instabilities. **C**. The roughness pattern on the multibeam profile illustrates the sea floor disturbance. See Figure 3 for profile location.

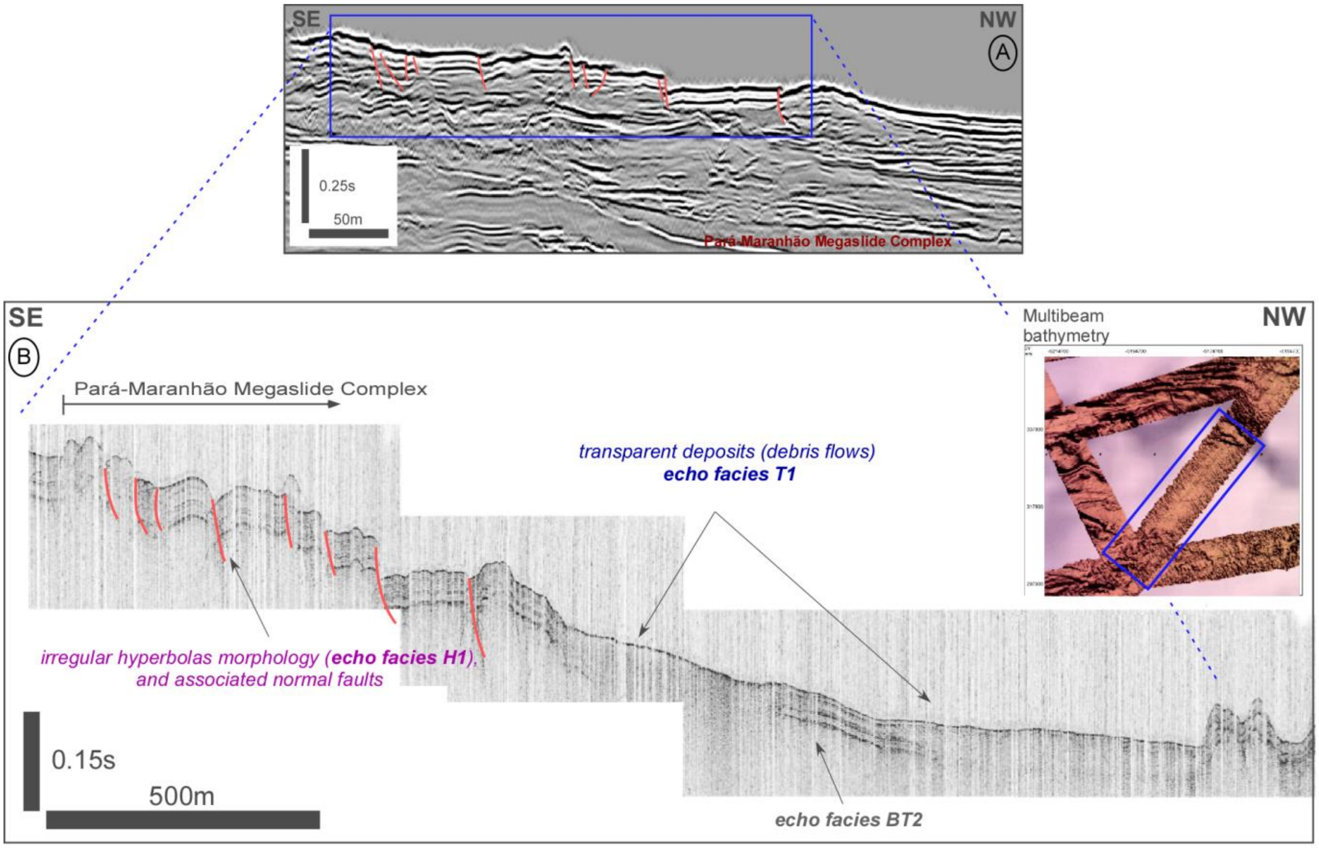


Figure 6: **A**. The multichannel seismic profile shows a faulted seafloor morphology affected by gravity tectonic-related faulting. The high-resolution profile in **B** also evidences that proximal faulting is related to downward transparent masses (debris flows). See Figure 3 for location.