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 stacked 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).

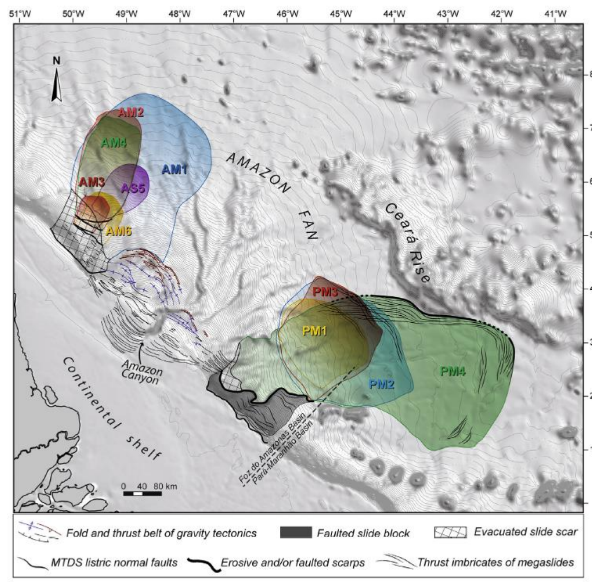

Figure 1: Simplified map illustrating Amapá Megaslide Complex and the Para-Maranhão Megaslide Complex areas and structural domains on the upper slope (after Reis *et al*., 2016).

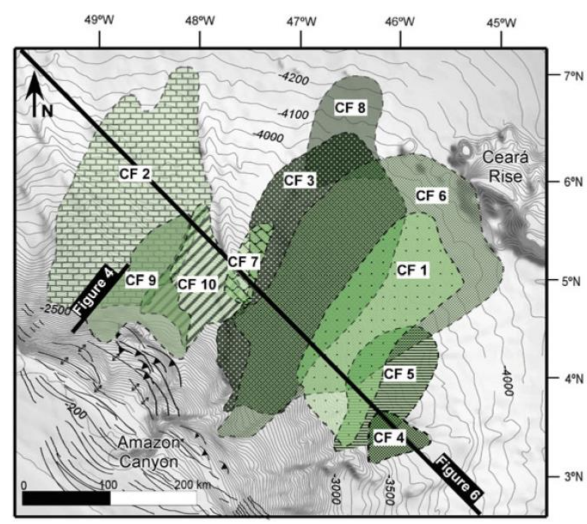

Figure 2: The Central Amazon Fan Megaslides Complex and structural domains localized on the upper slope (after Silva *et al*., 2016).

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: a link has been established between compressional deformation of fold-and thrust belts in the central Amazon fan and the onset of triggering conditions for sediment sliding processes during the late Quaternary. 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.

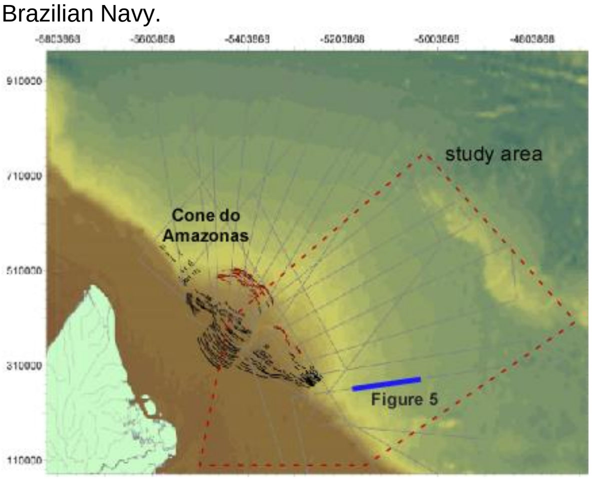

Figure 3: Bathymetric map of the Foz do Amazonas basin showing the location of the study area and the dataset (3.5 kHz profiles) used on this project.

The main methodology involved echofacies recognition on high-resolution profiles (3.5 kHz), as synthetized by Damuth (1980). The space and time relation between buried megaslides, superficial MTDs and sea-floor morphological features and deep structures (such as fault and erosive scarps, evacuated zones, ravines and channel-levee systems) was possible through the couple analyses of mono and multichannel seismic lines and sub-bottom profiling and multibeam bathymetric data (Hampton *et al*., 1996; Haflidason *et al*., 2004; Frey-Martinez *et al*., 2006).

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 Gravitational Flows 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*); sharp echos with regular bed forms (*echotype S2*) and sharp echos with an associated erosive morphology (*echotype S3*). 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 A). Hyperbolic echos can be represented by irregular hyperbolae that rise tens of meters above sea floor, with or whitout internal layering (*echotype H1*). 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*, 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* 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*

is attributed to sheet-like turbidites interlayered with hemipelagites, showing, however, superficial truncated reflectors, with an erosive signature left by *gravity-driven* processes and/or currents action. 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 Gravitational Flows Domain** presents mainly rough echofacies (echotype *R1*). These echofacies are recognized by high amplitude and reflectance and poor continuity seismic signature. They appear, in a general way, covered by transparent layers at a distal position on the basin, pointing out the existence of a thin distal mass wasting fringe, such as debris flows.

Conclusions

The 3.5 kHz profiles interpreted on the southeastern sector of Foz do Amazonas basin showed that 14 echofacies occur on the area; resulting in 5 main echotypes. Morphological features were also identified, where major slide scars occurring just after the shelf break - with regional extensions up to 186 km length - represent morphological steps which can be associated to erosive zones.

The echotypes were interpreted in terms of sedimentary processes, in order to achieve the comprehension about the spatial distribution of erosive features coupled with mass-transport deposits on the upper sedimentary column. Three sedimentary domains were identified: *the* ***Continental Shelf***, the ***Mass Transport Deposits*** and ***Distal Gravitational Flows*** domains, each one characterized by several echotypes. It is clear, in these preliminary results, that echofacies related to mass-transport and remobilization processes predominates on this sector, such as hyperbolic and transparent echos. This points out to the erosive potential of the area, largely dominated by erosive morphological structures and gravity-driven processes that may lead to wide spread seafloor instabilities and represent potential geohazard in the area.

Acknowledgments

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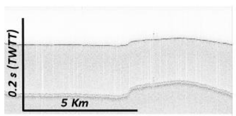
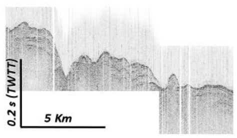
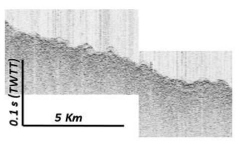
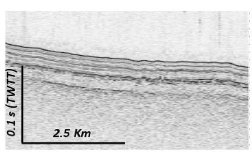
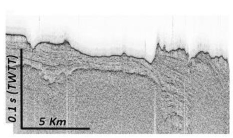
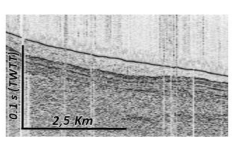
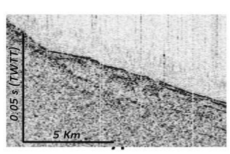
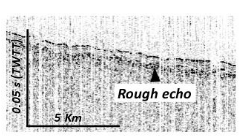
Table 1: Main echofacies mapped on the study area and their associated sedimentary processes.

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*	*SHEET TURBIDITES AND HEMIPELAGITES ERODED BY VARIABLE PROCESSES*
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*	
Rough (R)		R1 *Rough echos recovered by transparent layers*	*Widespread sands and/or gravels deposits (turbidite lobes) recovered by debrites*	*UNCONFINED TURBIDITE CURRENTS at the distal end of channel-levees (reflecting increasing occurrence of unconfined sands) recovered by MASS WASTING (debris flows)*

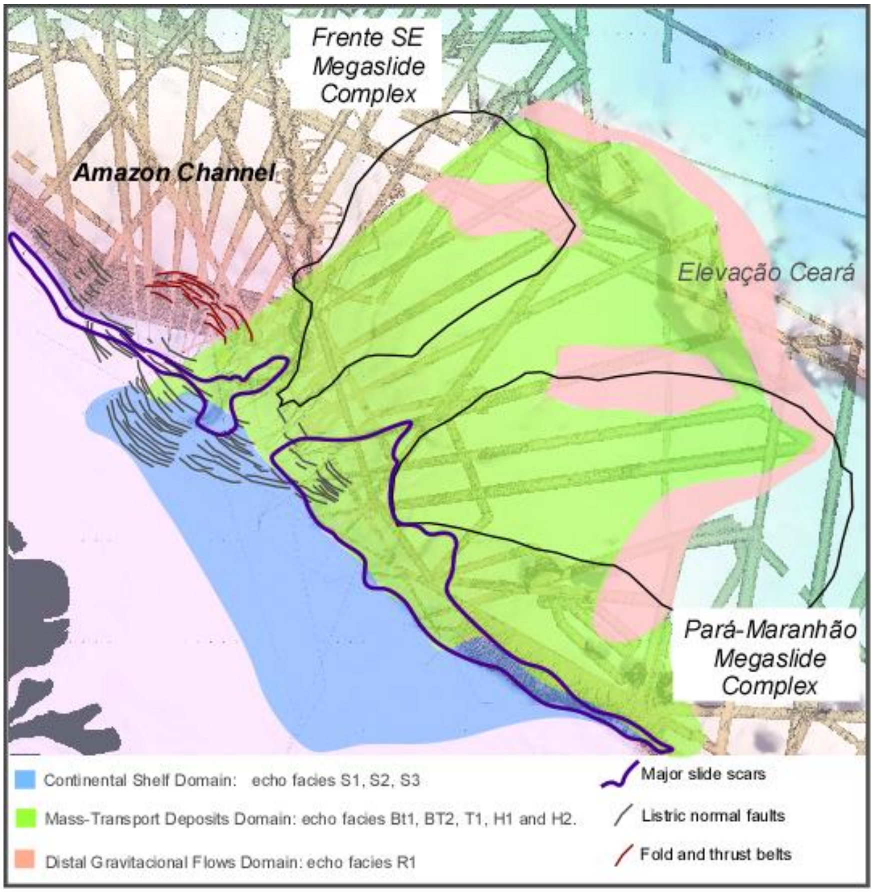


Figure 4: Map of sedimentary processes domains based on echofacies identification along the southeastern flank of Foz do Amazonas basin.

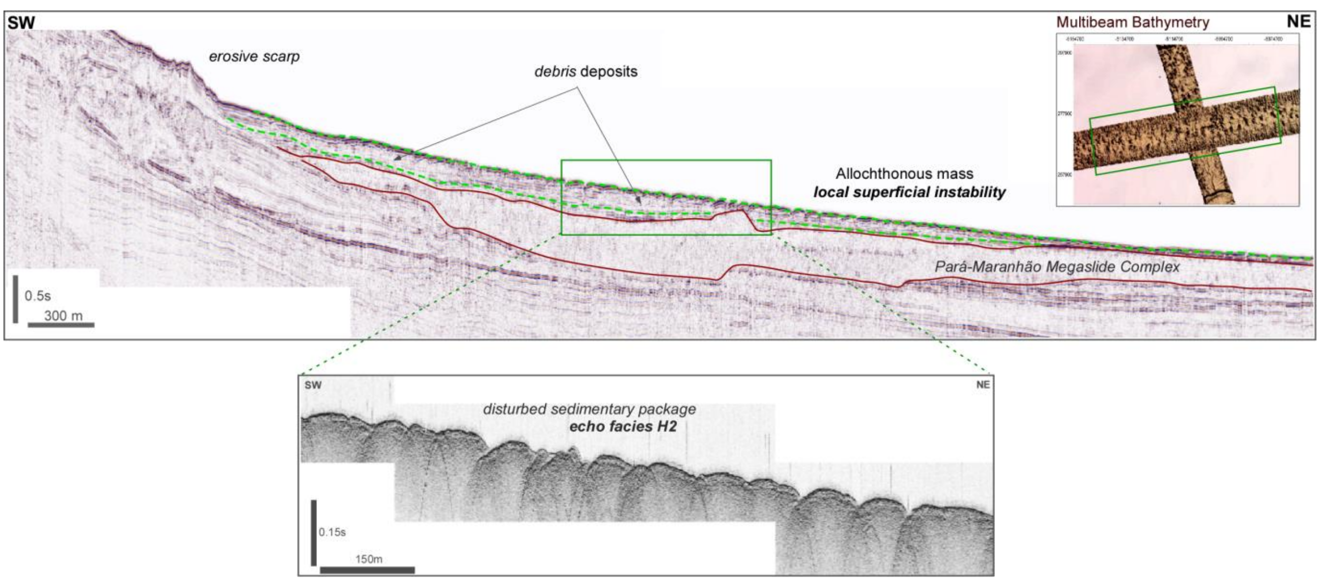


Figure 5: Local superficial instabilities of sea-floor on three different resolution data. **A**. The movement of an allochtonous mass near the bottom causes the shallow deformation showed on multichannel seismic profile; **B**. the hyperbolic signature (echotype H2) on 3.5 kHz sub-bottom profile. The roughness pattern on the multibeam profile illustrates the sea floor disturbance.

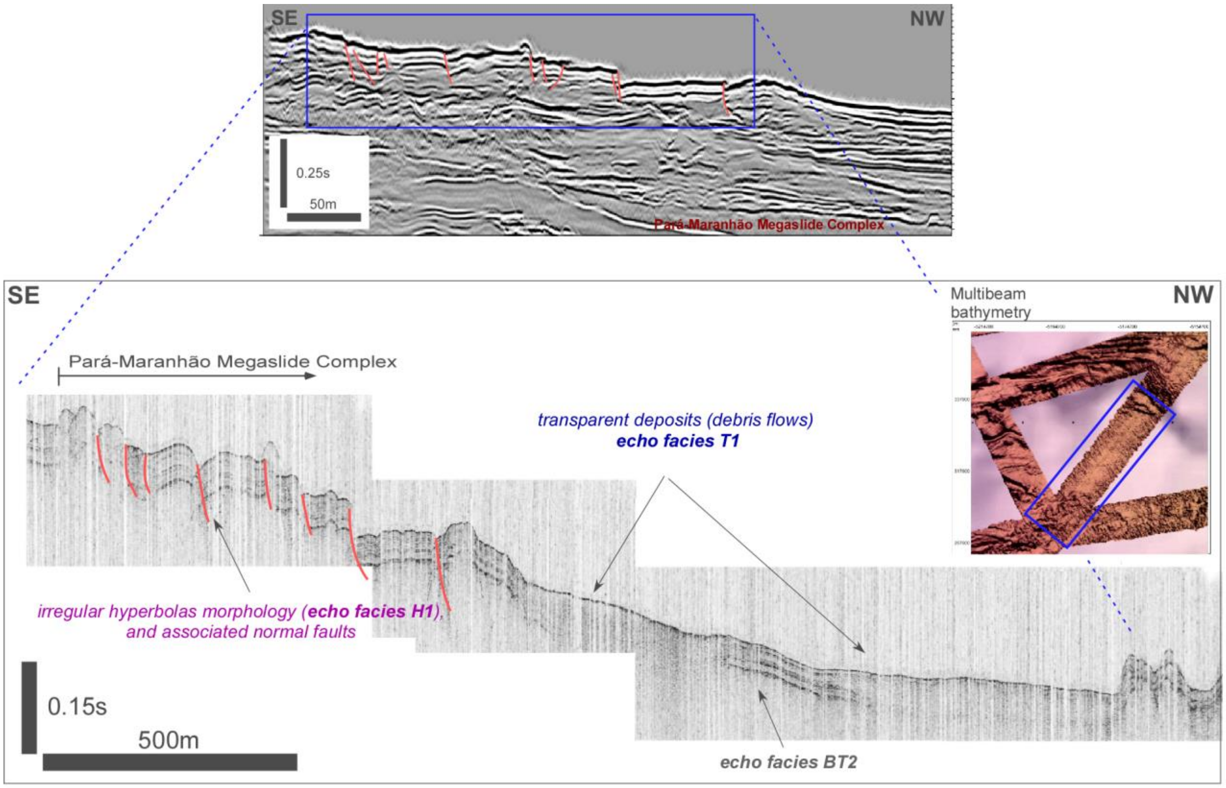


Figure 6: The multichannel seismic profile shows disturbed sea floor by faulting. The high resolution profile also shows the faults in the proximal portion of the profile, while transparent masses (probably debris flows) can be easily identified on the distal portion of the line.