The Pará-Maranhão and the Amapá Megaslide Complexes – Characteristics of giant submarine landslides in the Foz do Amazonas Basin – Brazilian Equatorial Margin

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Abstract

Recently, through 2D seismic analyses, great megaslide deposits were identified in SE and NW steeper slopes of the Foz do Amazonas Basin. Now in this work, previous acquired seismic data was reinterpreted and time correlated with well data to better investigate two mass transport complexes (MTCs). These two MTCs are developed at steep slope settings adjacent to the Amazon Fan: to SE the Pará-Maranhão Megaslide Complex and to NW the Amapá Megaslide Complex. Such deposits can mobilize thick siliciclastic series (up to 1,000 m thick) as a combination of debris flows, slided blocks and compressively-deformed allochtonous masses downslope over areas as large as thousands of km^2, leaving behind large scars (as high as ~700m) that strongly impact the sea-bottom morphology. In the context of megaslides, the instability is most likely induced by levels of weak overpressured shales revealed by previous studies on gravity tectonics across the Foz do Amazonas Basin.

Introduction

Mass transport complexes (MTCs) can compose up to 70% of the entire slope in continental margins all over the world (Hampton *et al.*, 1996). Such sedimentary complexes are also great elements in the architecture of submarine fans such as the Amazon Deep-Sea Fan, Foz do Amazonas Basin, Brazilian Equatorial Margin. The Amazon Fan is a Late Miocene (10,5 Ma - Figueiredo *et al.*, 2010), 10 km thick river-fed submarine fan which gave the basin a progradational smooth central portion bounded by narrow continental margins followed by steeper slopes (Fig. 1).

Scientific literature have greatly explored mass transport deposits in the Quaternary section of the Amazon Fan (ex: Damuth *et al.*, 1988; Piper *et al.*, 1997), however, Silva *et al.* (2009) identified large deposits along the steep NW and SE slope segments of the Foz do Amazonas margin. Recently, Araújo *et al.* (*in preparation*) used 2D regional seismic lines and well data to investigate two mass transport events in the basin (Fig. 1): (1) the Pará-Maranhão Megaslide Complex (PMMC), a huge frontally confined MTC located in the southeastern part of the margin, and (2) the Amapá Megaslide Complex (AMC), a very large set of slope failures to NW. These two MTCs will be briefly presented in this work.

Method

The 2D multi-channel seismic data include approximately 15,000 km of seismic-reflection profiles (Fig. 1). These data were provided by the geophysical survey companies FUGRO and GAIA, and the Brazilian Navy (LEPLAC data). For the seismic interpretation we used SMT (8.3) Kingdom Suite®. Regional bathymetric data are from the General Bathymetric Charts of the Oceans – GEBCO (www.gebco.net) and higher-resolution bathymetric data on the Upper to Middle Amazon Fan were compiled by the Brazilian Navy from different sources. Well data was supplied by Total – France.

Results

Pará-Maranhão Megaslide Complex (PMMC)

The PMMC is a large-scale MTC on the form of a huge drop of E-W direction and extends over the neighboring Pará-Maranhão Basin to SE. It is composed by four individual MTDs (SP1, SP2, SP3, and SP4 – from the oldest to the youngest – see Table 1) that started deposition during Pliocene (Araújo *et al.*, in preparation). It covers a total area of 110,000 km² and has a total volume of up to 130,000 km³. The main headscarp is located about 300 m of water depth with maximum vertical relief of 1,000 m along 180 km on the upper slope (Fig. 2). Downslope, detached from the headwall scarp, a great 1,000 m thick slided/rotational block extends over 12,500 km². The downslope limit of the displaced blocks is located at around 2,100 m deep, where there is another prominent scarp, with 700 m of vertical relief and extending laterally along 260 km. This secondary scarp is concave in plan and marks the boundaries of the source area of the disturbed mass distributed gradient below.

Further downslope, in an intermediate region, SP4 mean thickness is c. 750m with a chaotic to transparent internal seismic signature, with the presence of slipped blocks that exhibit features of original undeformed structures (Fig. 2). In this site, the SP4 thickens basinwards, while it clearly erodes the sedimentary package. The basal shear surface is a continuous and strong negative seismic amplitude reflection unconformable with the underlying strata. The toe region of SP4 is frontally confined due to the development of a thrust zone that eventually reach the seafloor forming pressure ridges (up to 50 m of relief – Fig. 3). The thickness of the sliding mass tends to decrease from about 1000 m to 600 m as the basal surface (detachment surface) migrates to higher stratigraphic levels. About 3400 m water depth, below SP4, there are SP3, SP2, and SP1 (Fig. 3). They are quite similar between each other, mostly compared to SP4. The three oldest MTDs are thinner (on average 140m) and occupy much smaller area (see Table 1 – Araújo *et al.*, in preparation). However, SP1 and SP2 internal seismic facies are more chaotic to transparent dominated by low amplitude reflections. Their toe region

is also difficult to define due to their subtle termination. SP3 has predominantly high amplitude chaotic facies. Furthermore, undeformed strata can be observed along its entire length.

Amapá Megaslide Complex (AMC)

The AMC is a huge MTC located between 2,700 m and 4,200 m water depth with total estimated area of about 80,000 km² to NW in the Foz do Amazonas Basin (Fig. 1). The AMC starts on a headwall scarp located on the upper continental slope, where a large displaced faulted block moves along a basal detachment surface. Six individual deposits were recognized composing the AMC (SA1, SA2, SA3, SA4, SA5, and SA6 – from the oldest to the youngest – see Table 2 – Fig. 4) and they are described by Araújo *et al.* (in preparation) as follows.

SA1 is characterized by highly chaotic to transparent seismic facies extending from 3,000 m to 4,200 m water depth, separated from the upper MTDs by a thick in situ non-deformed unit (900 m). It's landward and SE boundaries were reworked by a fold-and-thrust belt generated by gravity tectonics acting in the basin, which might disguised its source area. Above the non-deformed unit SA2 is the largest deposit of the upper complex. It's located about 2,000 m in the sedimentary column, sourced from the great displaced block. Its proximal seismic character is dominated by transparent facies, while its distal depositional units are extremely chaotic. SA3 is dominated by low amplitude chaotic to transparent facies, suffering substantial thickening close to its upslope limit, where traces of previous stratification were preserved. SA4 exhibits varying degrees of internal deformation from plane parallel to folded and highly deformed reflectors. Most significantly, this MTD is buttressed against the undisturbed slope strata in a downslope direction, producing thrust systems. SA4's basal shear ramps up and down the stratigraphy to create a series of staircase-like geometries, where it is possible to observe clear reflection terminations. SA5 and SA6 are the uppermost MTDs of the complex. They both display highly disrupted to transparent facies interspersed with preserved seismic horizons. Their upper surface is rather smooth in line with their small variation in thickness, which are likely inherited from their flat basal shear surface. SA6 extends beyond the limits of the seismic data set. However, like SA5 it was possible to identify its source as they were both generated by collapse of channel-levee.

Conclusions

The reinterpretation of 2D seismic data in this work promotes a new subject of study in the Brazilian equatorial margin – the Mass Transport Complexes.

(1) The Pará-Maranhão Megaslide Complex is composed by four individual mass-transport events that can be organized in two groups according to their morphological character: (i) SP1, SP2, and SP3 are small-scale MTDs compared to those mapped in the basin; (ii) they have similar distribution though lower slope – deep basin. SP4 is not only remarkable in size, but also in its downslope boundaries with prominent thrust systems.

(2) The Amapá Megaslide Complex, earlier presented by Silva *et al.* (2009), here was individualized in six mass-transport deposits, reinterpreted, and time correlated so was the PMMC. The SA1 represents the first mass-transport event composing the AMC, being underestimated due to reworking of its boundaries by regional gravity tectonics (the gravity tectonic structures acting in the basin). SA2 is the second largest event of the AMC, while SA3 is the smallest. For SA5 and SA6, it was possible to identify their source as they were both generated by collapse of channel-levee.

(3) In the adjacent slopes of the Amazon Fan, where the gradient is quite high (~5.5°) several concurring factors might have predispose the time correlated MTCs to failure. These include the presence of a décollement level above the MTCs acting as a common gliding layer (Fig. 2,3,4 – H1), rapid sediment accumulation (MTCs started in parallel with the Amazon Fan deposition), sea-level fluctuations affecting the location of sediment supply (most of the slope failures are Plio-Quaternary – see Tables 1 and 2), pore-fluid overpressure and consequently the gravitational collapse.

References

Araújo, E. F. S., Silva, C. G., Reis, A. T., Gorini, C. Perovano, R. & Vendeville, B. In preparation. Characterization of the Pará-Maranhão and Amapá Megaslide Complexes, Foz do Amazonas Basin – Brazilian Equatorial Margin. To be submitted to Marine Geology.

Damuth, J. E., Flood, R. D., Kowsmann, R. O., Belderson, R. H. & Gorini M. A. 1988. Anatomy and growth pattern of Amazon deep-sea fan as revealed by long-range side-scan sonar (GLORIA) and high resolution seismic studies. American Association of Petroleum Geologists Bulletin. 72, 885-911.

Figueiredo, J., Hoorn, C., van der Ven, P. & Soares E. 2010. Late Miocene onset of the Amazon River and the Amazon deep-sea fan: Evidence from the Foz do Amazonas Basin: Reply. Geology Fórum. July 2010.

Hampton, M. A., Lee, H. J. & Locat, J. 1996. Submarine landslides. Reviews of Geophysics. 34 (1), 33-59.

Piper, D. J. W., Pirmez, P. L., Manley, P. L., Long, D., Flood, R. D., Normark, W. R. & Showers, W. 1997. Mass-transport deposits of the Amazon Fan. Proceedings of the Ocean Drilling Program, Scientific Results. Vol. 155.

Silva, C. G., Araújo, E. F. S., Reis, A. T., Perovano, R., Gorini, C., Vendeville, B. C. & Albuquerque, N. C. 2009. Megaslides in the Foz do Amazonas Basin, Brazilian Equatorial Margin. In: Mosher, D. C., Shipp, R. C., Moscardelli, L., Chaytor, J. D., Baxter, C. D. P., Lee, H. J., Urgeles, R. (Eds.), Submarine Mass Movements and Their Consequences. Springer-Verlag, New York, pp. 581-591.

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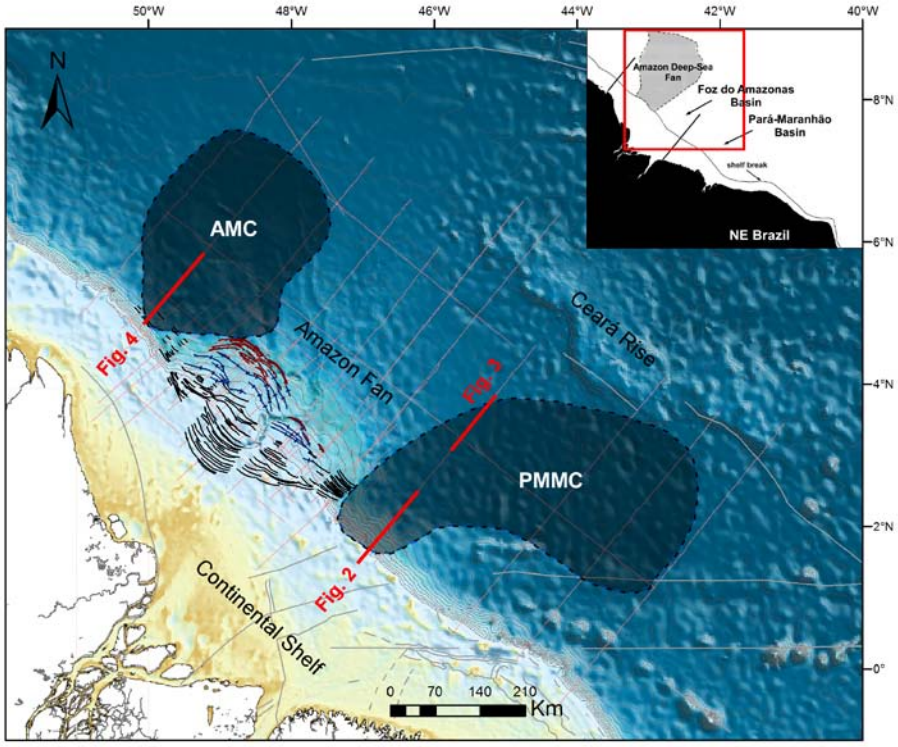

Fig. 1 - *Regional bathymetric map of the Foz do Amazonas basin and location of seismic dataset used in this study. The map also shows the MTCs mapped in this work, at the regional scale of the Foz do Amazonas basin and the gravity-related structures in the basin mapped by Perovano et al. (2009) (modified from Araújo et al., in preparation).*

Table 1 (Araújo *et al.*, in preparation)

Pará-Maranhão Megaslide Complex				
MTD	Área (km²)	Volume (km³)	Source area	Age
SP4	102.786	48.500	Shelf edge/upper slope	Quaternary
SP3	16.366	15.524	?	Quaternary
SP2	27.735	38.651	?	Pliocene
SP1	18.021	27.755	?	Pliocene

Table 2 (Araújo *et al.*, in preparation)

Amapá Megaslide Complex				
MTD	Área (km²)	Volume (km³)	Source area	Age
SA6	2.500	5.247	Levees	Quaternary
SA5	5.000	9.686	Levees	Quaternary
SA4	17.651	25.348	?	Quaternary
SA3	1.561	3.420	?	Pliocene
SA2	16.759	19.591	Lower slope	Pliocene
SA1	64	55.394	Amazon Fan	Late Miocene

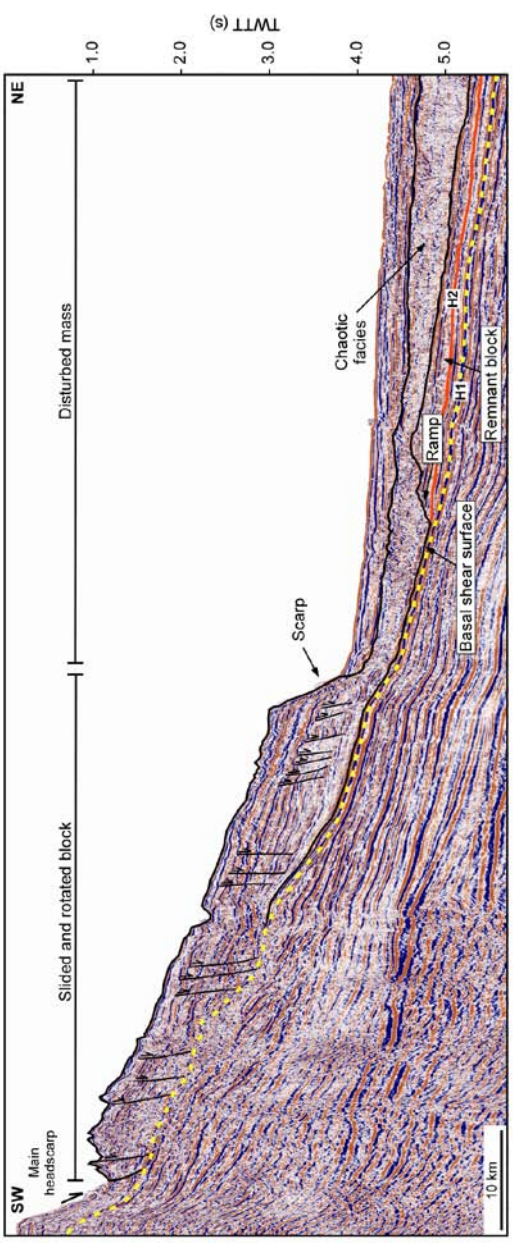

Fig.2 - Headwall scarp, displaced/rotated blocks and allochthonous mass in the upslope portion of the PMMC developed seaward of the SE continental slope of the Foz do Amazonas basin (modified from Araújo et al., in preparation). See figure 1 for location.

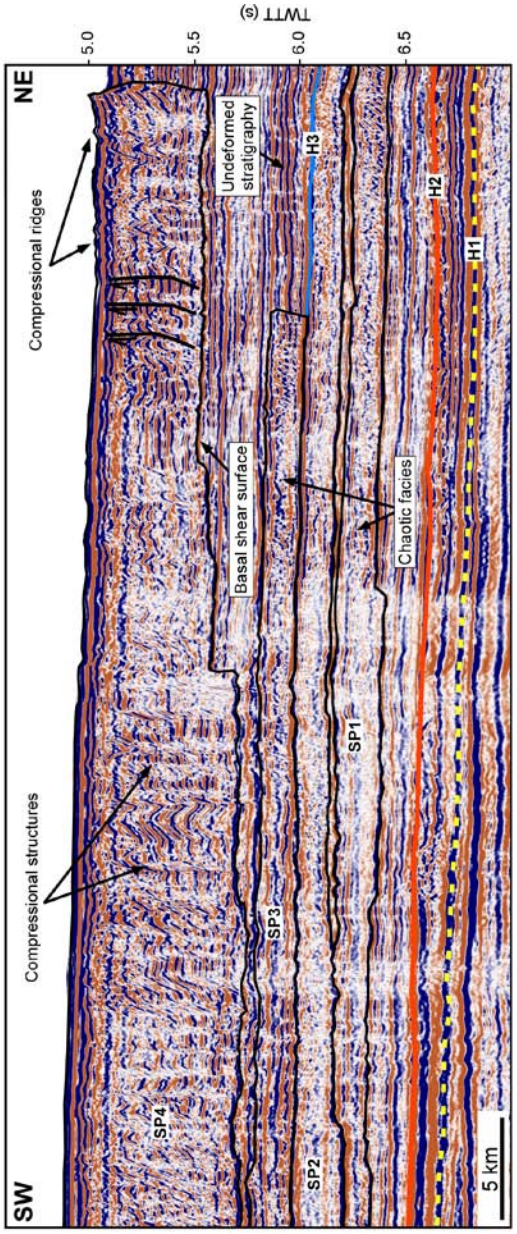

Fig. 3 - Time seismic line across the PMMC illustrating the lateral confinement of the allochthounous mass, evidenced by thrust imbricates and the formation of a pressure ridge with morphological impact (modified from Araújo et al., in preparation). See figure 1 for location.

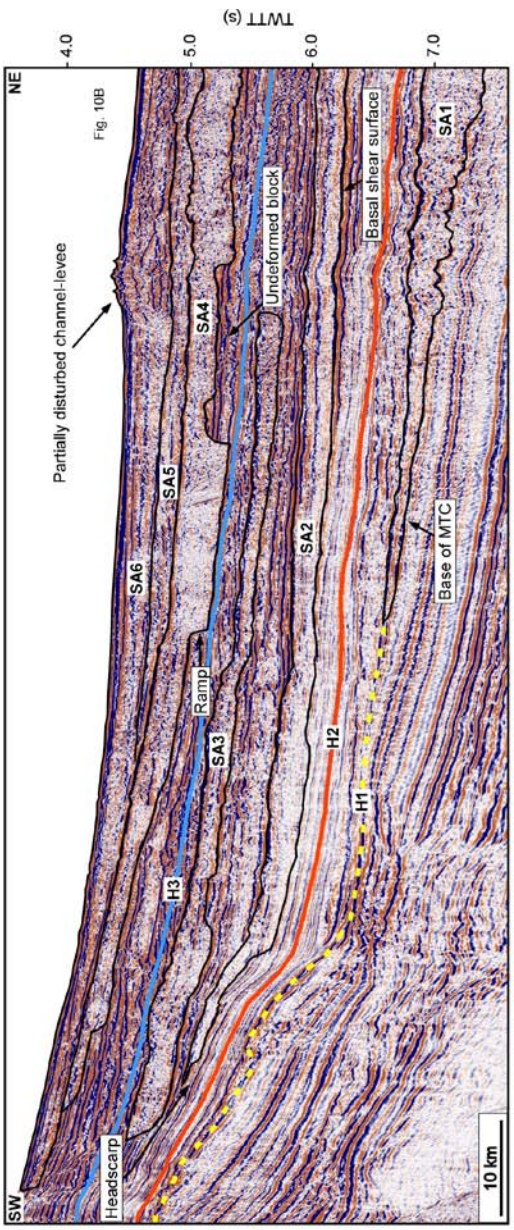

***Fig. 4** - Headwall scarp and allochthonous masses in the upslope portion of the AMC, developed seaward of the NW continental slope of the Foz do Amazonas Basin. The megaslide complex is composed by a succession of vertically-stacked individual allochthounous masses (modified from Araújo et al., in preparation). See figure 1 for location.*