Origin of Late Pleistocene Instability Events at the Espírito Santo Basin, SE Brazil

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Abstract

A geophysical survey performed at the southeastern coast of Brazil, at the Espírito Santo basin, identified several instability features such as canyons, gullies and turbidite layers along the continental slope. The geological model suggested for the area is that of a shelf-edge delta, where a combination of high sediment input rates and elevated gradient at the upper continental slope would trigger the instabilities events.

Introduction

Submarine mass movements are the result of a combination between the geotechnical condition of the sediment and a triggering mechanism, mainly the tangential component of gravity, seismic and/or cyclic (i.e. storm) load, which is the external stimulus to initiates the slope instability process. The issues regulating the geotechnical condition of the sediments are: grain size distribution, sedimentation rate, bioturbation, the organic matter content, the presence of free gas and/or gas hydrates. The combination of these issues may lead to soft sediments, which under cyclic loading may disrupt and move downslope.

The study area is located at the Espirito Santo basin, southeastern Brazil. This basin is gaining importance on the brazilian oil scenario due to recent oil and gas findings, specially in deep water regions. The area is located approximately 80 km NE from the city of Vitória and 37 km SE from the Doce river mouth (Fig.1), extending for 20 km from the 70 m to the 1200 m water depth.

The continental margin offshore Espírito Santo state is characterized by a relatively narrow continental shelf (between 40 and 65 km width) with the shelf break located at an average water depth of 90 m (França, 1979).

The recent geological history of the east brazilian continental margin is dominated by the effects of the regression / transgression cycles that occurred in the last 120 ka. According to Willwock (1995), during the maximum transgression, the sea level was slightly above its actual position. The seafloor at the study area is cutted by a series of gullies and two major canyons suggesting the existence relatively recent of mass movements events.

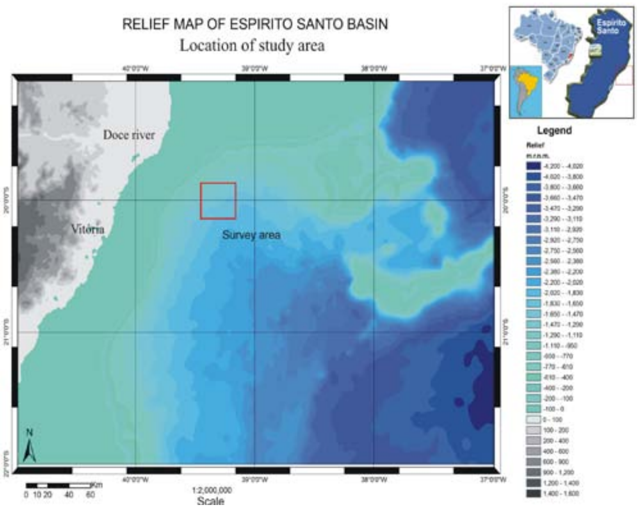

Figure 1: Location of the study area at Espírito Santo Basin.

Method

The survey comprised a total of 4,560 km of 12 kHz single-beam bathymetry, approximately 1,170 km sub-bottom data and 35 geological piston-cores (4” diameter) from which 44 sub-samples were taken for biostratrigraphic dating. Geophysical data and cores were processed at the Marine Geology Laboratory of the Fluminense Federal University. Biostratigraphic dating was conducted at Biostratigraphy, Paleoecology and Paleoclimate Laboratory of the Federal University of Rio de Janeiro using the Planktonic foraminifers biozones from Ericson and Wollin (1968) and Vicalvi (1997,1999).Bathymetric data was gridded to a final XYZ files (XY corresponding to UTM East and North coordinates and Z to the water depth) with Surfer 8.0 using interpolation method of linear Kriging. Data was then visualized with *Fledermaus*. Seismic data was interpreted using CODA software.

Results

General morphology

The water depth at the study area varies from 60 m to 1290 m with a series of gullies and two major canyons (Fig. 2). The shelf-break is delineated approximately by the 100 meters isobath and is characterized by a 90 m high and very steep scarp with gradients ranging from 3°

to 40°. The heads of the canyons have an amphitheatre shape. The sinuosity (distance along thalweg / straight line distance) as defined by Kastens & Shor, (1986) is 1.028 and 1.135 for the southern and northern canyon, respectively. The head of southern canyon indents the continental shelf for 1 km while the northern canyon does it for 2 km indicating different stages of maturity (Popescu *et al*. 2004). At 1,300 m deep the two canyons seems to converge in one single channel.

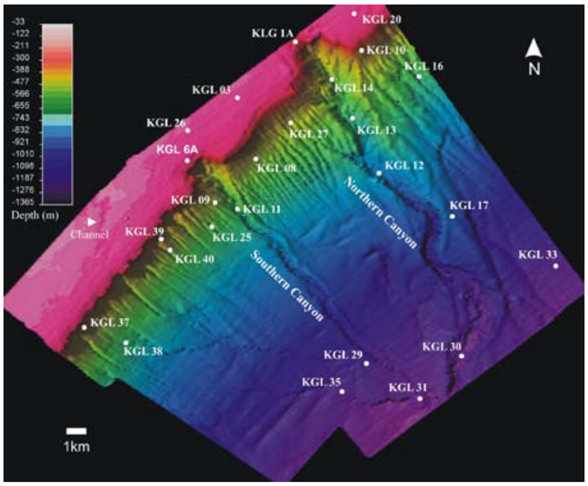

Figure 2: Location of the 25/ 35 cores onto bathymetry of the study area with the presence of the gullies and two main canyons. Sun-illuminated (45° azimuth).

The gradient of the area has higher values immediately after the break shelf up to the 150m isobath. These high gradients tend to decrease northeastward (Fig 3).

Sedimentation and seismic analysis

The seafloor along the outer continental shelf is dominated by brownish sandy sediments of which more than 50% is composed by very coarse sand with presence of mica.

This sediment occurs along a strike-elongated (NE-SW) stripe, parallel to the shelf break, approximately 900 meters wide. Sand-filled palaeo-channels are observed in the seismic records cutting this sedimentary sequence. At the outer continental shelf, the high-resolution seismic records. indicate different seafloor sedimentological composition for the southwestern and northeastern part of the area.

The sediment of upper slope has characteristics of fluvial / deltaic origin with very limited degree of bioturbation. The cores at the upper slope are mainly made up of muddy facies with more than 90% of clay. The first centimeters showed carbonate content characterized by presence of foraminifer, pteropods, gastropod and spicules. Organic matter is also found rather laminated in the cores.

The mud clasts (granule to cobble size) were identified in some intervals along the cores and are associated to debris flow deposits (Caddah et al., 1998). Truncated seismic reflectors observed in the high-resolution seismic records show that these gullies are erosional features and have developed over a relative thick sedimentary sequence with seismic characteristics very similar to the sequence observed at the outer shelf.

The sedimentation at lower slope showed cores with a turbiditic facies at core KGL 35 (Fig. 4) , with coarse sand (division A by Bouma) overlaid by fine sands (division B by Bouma), which in turn is overlaid by muds (division E by Bouma) (Posamentier and Walker, 2006).

Bioestratigraphic analysis on core KGL 35 showed that the Holocene is limited at 0,58 m with the presence of plexo *G. menardii*. Seismic data at this location shows a second strong reflector 1,5 m below the seafloor in average. This reflector blocks the seismic signal and is related to the turbidity layer. (Fig 4).

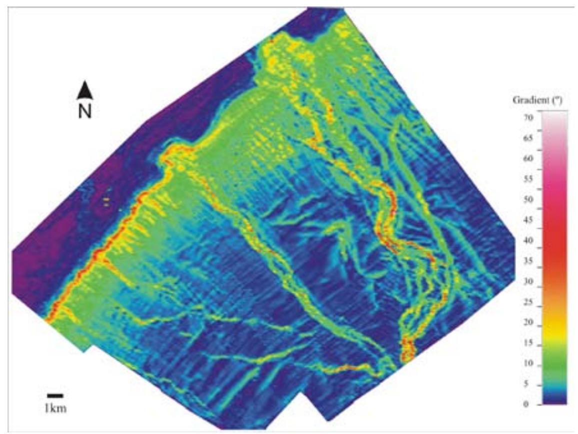

Figure 3: Map of the gradient.

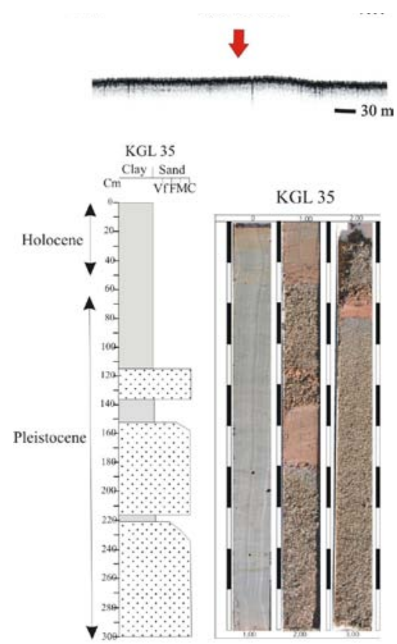

Figure 4: Reflector indicated the turbidite with a second strong reflector.

Discussion

The geophysical and geological data acquired at the study area suggest that the region was dominated by a shelf-edge delta during the Pleistocene. The sedimentation is typically deltaic, with the presence of preserved organic matter layers denoting river-dominated delta fronts (Bhattacharya & Walker, 1992). Furthermore, large amounts of brownish siliciclastic muds denote a higher terrestrial influence. Biostratigraphic dating using planktonic foraminifers showed sediments of Holocene and Pleistocene age, according to the post-glacial sea-level curve of Fairbanks (1989). The sea level reoccupied the 100 m isobath at the time at the Campos basin (Caddah et al., 1998). At that time, the Doce River crossed the narrow continental shelf carrying its sediment load direct into the continental slope excavating the channels identified both in the bathymetry (Fig. 2) and in the high-resolution seismic records. One the causes of deltaic progradation out across a shelf to its margin can be normal sediment flux with forced regression during relative sea-level fall (Porebsky and Steel, 2003). These authors have also described several characteristic features of Holocene and Pleistocene shelf-edge deltas that can be identified in the study area like: depth of shelf break between 75 and 135 m (Fig. 2), continental shelf gradient between 1º and 3º, delta top seaward shallowing channels up to 40 m deep and U-shape troughs and incisions of delta edge as gullies.

High deposition rates are typical in front of major river deltas and at the shelf edge under glacial maxima. If the clay content is sufficiently high, the compressibility-permeability properties would prevent full drainage, and a gradual excess of pore pressure will develop (Kvalstad et al., 2001).

The gullies and the turbidites seen in core KGL 35 (Fig. 4) are the expression of these mass movements and erosional events at the study area. One of the four ways to initiate turbidite flows is from the transformation of slumps or debris flows by mixing with seawater (Stow, 1994). Other possible ways (described by the same author) are directly from suspended sediments delivered to the sea by river during floods and from sand-spillover, grain flows or rip-currents feeding sediments into the heads of submarine canyons.

The eco-character this deposits is mainly observed at the southwestern part of the study area where the gullies are more prominent and the gradients is major. The difference in relation the size between the canyons indicates that direction of the river can have changed. The lateral movement of the river along the shelf during both sea-level lowstands and highstands can have contributed to the formation of the canyons in the same area (Pratson et al., 1994). This direct input at the southwestern area could be also linkage the events in this region, but the data used in this study does not allow to determine if the major canyons seen in the area were generated prior to the installation of the delta or are related to main channels of the delta.

In our case, the river would bring sediments up to the outer continental shelf and upper slope. Along the continental shelf the safety factors are extremely high and it is very unlikely that any kind of mass movement can occur. However, as the deposits build up at the upper continental slope, the high tangential component of gravity generated by the high gradients would make them more unstable, forcing them to slide downslope due to its own weight (Mulder & Cochonat, 1996).

Conclusions

The results indicate towards the presence of an active shelf-edge delta during the Pleistocene. During this period sea level was in a position close to what is today the shelf-break. (100 m water depth). The combination of high input of sediment and the elevated gradient at the upper slope was the main factor controlling the instability events at this region bringing to debris flow events and turbidites currents. As the sea level rose, the delta retreated to up to its actual position, ceasing all processes of instability.

Acknowledgments

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