Qualitative Slope Stability Evaluation for a Pipeline Route Off Espirito Santo State, SE Brazil

Pellizzari, P.O. – Petrobras
Ayres, A. – Tethys Geofisica Ambiental
Gallea, C.G. - Tethys Geofisica Ambiental
Castaños, G.X.O. – INTEC do Brasil
Piauilino, P.O.V - Petrobras

Abstract

In order to select a pipeline route a geophysical, geological and geotechnical survey has been conducted at the continental slope off Espirito Santo state. The survey comprised an area of approximately 470 km² between the 60 m and 1.380 m isobath with a total of more than 5.700 km of geophysical data and 70 geological and geotechnical piston-cores. An integrated interpretation of the data showed the presence of several obstacles that should be avoided allowing the selection of an optimal route to the planned 12" export gas pipeline determining areas associated to erosional and depositional events. Moreover, a qualitative stability analysis showed that the area is stable under the actual geological conditions and that the instability features observed were generated during the pleistocene when the area was dominated by a shelf-edge delta associated to the Doce river.

Introduction

The stability of the seafloor is a critical issue for the installation of offshore production facilities such as pipelines, manifolds and fixed platforms. At the same time, landslidings are important in shaping the morphology of the seafloor mobilizing large amounts of sediments downslope.

Between April and October, 2004, a large high-resolution geophysical, geological and geotechnical survey was conducted to determine the best route for a 12" export gas pipeline for the Golfinho field at the continental slope at the Espirito Santos Basin. The first results showed an area with an extreme complex near-surface geology characterized by the presence of canyons and gullies associated with gradients up to 60° at the shelf break. The correlation of geological and geophysical data indicated that during the late pleistocene the area was dominated by a shelf-margin delta with the Doce river carrying its sediments directly into the continental slope.

Shelf-edge (or shelf-margin) deltas are commom on features of quaternary shelves. Their main characteristics are, among others, a lobate to strike elongated shape, a length ranging from 25 to 60 km, the absence of a delta plain and the presence of slump-related canyon heads and gullies (Porebski and Steel 2003). They form during the falling and low stage of relative sea level on the shelf.

Results of the survey

- Bathymetry (figure 1):

In general the area is characterized a concave shaped slope with scarp between 130 m and 220 m water depth. Here the calculated gradients ranged from 49° to 11° at the SW the NE part of the scarp respectively. Two major canyons with troughs up to 350 m deep cross the area extending from the outer shelf to base of the slope. Extending downslope approximately 4 km from the end of the scarp there are several gullies 400 m wide and 35 m deep. In this part of the continental slope the average gradient is at the order of 6.5°. The gullies become progressively less prominent as less steep gradients are approached and disappear completely at 800 m water. The deepest part of the area (between 800 and 1,360 m water depth) the slope presents a smooth morphology without any significant bathymetric feature.

- Side scan sonar (figure 2):

The survey area is basically dominated by two different sonographic reflection patterns. The first is characterized by a high reflectivity and is observed in the shallow part (outer continental shelf) of the area. According to shallow geological samples taken within this domain it corresponds to medium to coarse sands with relative high amounts of shell fragments.

A second reflection pattern is a homogeneous, low reflectivity pattern, which dominates over 80 % of the survey area (continental slope). The gullies noted on the bathymetry appear as darker stripes oriented NW-SE.

The two major canyons are also clearly seen on the sonographic mosaic distinguished by a very low reflectivity reflection pattern. Localized occurrences of sand waves are seen within the canyons suggesting that sea currents are active in these areas. Rock outcrops (figure 3) are seen at the canyons head and, according to the samples taken, correspond to a siltstone.

- Seismic:

The interpretation of the seismic records allowed the individualization of three different sectors according to the type of echo-character and internal structure. The first echo is characterized by the absence or by the presence of discontinuous of sub-bottom reflections. This type of echo is observed exclusively in the southern part of the continental shelf. The northern sector of the continental shelf is dominated by an echo type characterized by a

sequence of continuous parallel sub-bottom reflections up to 7 m thick. This sequence overlies the first echo type.

The upper continental slope, where the morphology is dominated by gullies, is dominated by an echo-character defined by the presence of sharp, continuous, parallel sub-bottom reflectors. These are truncated by the surface of the seafloor (figure 4) indicating that erosive processes have dominated during a certain period of time.

On the other side, deposicional processes dominate the deeper part of the continental slope. This is evidenced in the seismic records by a echo-character defined by a the presence of a transparent layer averaging 2 m in thickness overlaying a sequence of well defined parallel sub-bottom reflectors (figure 5). This upper layer may locally assume a more hummocky internal structure.

- Geology:

A total of 35 geological shallow cores were taken to evaluate the geology of the area. The geological information together with biostratigraphic dating of selected samples were correlated to the geophysical data helping to understand the recent geological history of the area allowing a qualitative stability evaluation.

Very coarse sandy sediments with up to 82% of gravel and sand dominate the southern part of the continental shelf. These characteristics drastically change in the northern sector of the continental slope where the seafloor is composed of a light brown to orange silt with millimeter tick layers of organic matter (figure 6).

Deeper in the gullied upper slope the sediment maintains the same grain size characteristics grading to a gray color in upper part of the core (figure 7) indicating a change in the depositional environment. According to the biostratigraphic dating the section is of Pleistocene age on the base and Holocene in the top indicating a change of depositional environment with the sea level rise.

In the deepest part of the survey area the seafloor is essentially composed by a silty sand (64% of sand and 28% of silt) indicating changes in the sedimentary processes. Turbidite layers tens of centimeter tick are seen at the base of the slope. These turbidites are of Pleistocene age coverage by a 1 m tick Holocene marine silt (figure 8).

Conclusions

Today the survey area is located between the outer shelf and middle continental slope without major influences of the Doce river. However, geological and geophysical evidences showed that during the late Pleistocene the area was dominated by a shelf-edge delta. During that period the Doce river extended through the continental shelf empting its sedimentary load directly on the shelf-break and upper continental shelf.

The complex morphology with all its instabilities features observed at the present seafloor was generated during that period. The of high accumulation rates typical of deltaic environments associated to a existent steep continental slope were the main factors controlling stability. High accumulation rates do not allow sediments to dissipate internal pore pressure resulting in ”softer” sediment with low shear strengths. High slope gradients generate high shear stresses over the sediment mass. This combination of factors often results in downslope mass movements, which are major source for sand transport for deep sea. The turbidite layers shown on figure 8 indicate that these mass movements were restricted to the Pleistocene. With the Holocene transgression the Doce river delta stepped back to its present position while normal deep-sea sedimentation processes assumed a major hole in the area.

The presence of Holocene ooze layer in some cores shows that under present environmental conditions the area can be considered stable.

References

Porebski, S.J. & Steel, R.J. (2003) – Shelf-margin deltas: their stratigraphic importance and relation to deep water sands. Earth-Science Reviews (68). Pag: 283-326

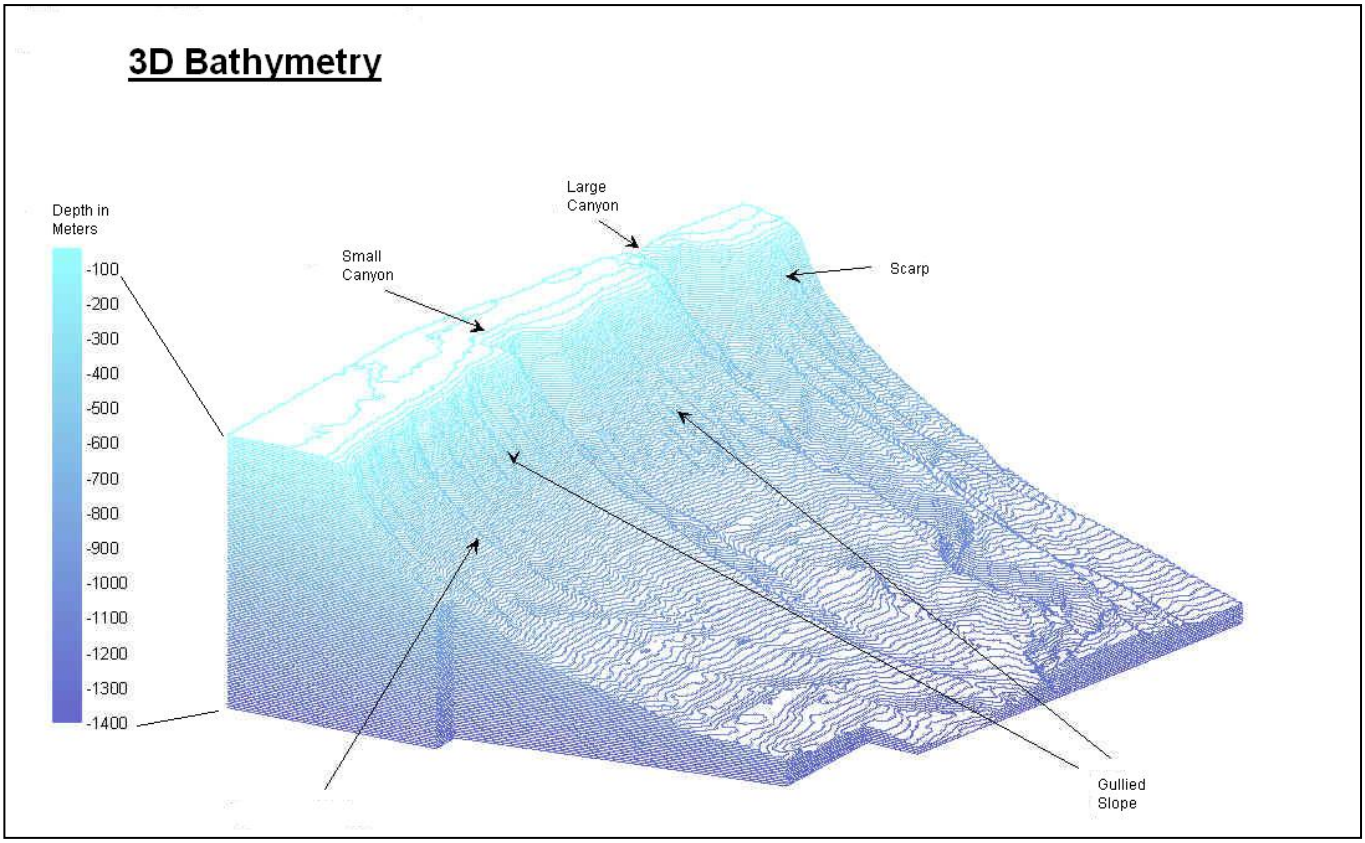

Figure 1

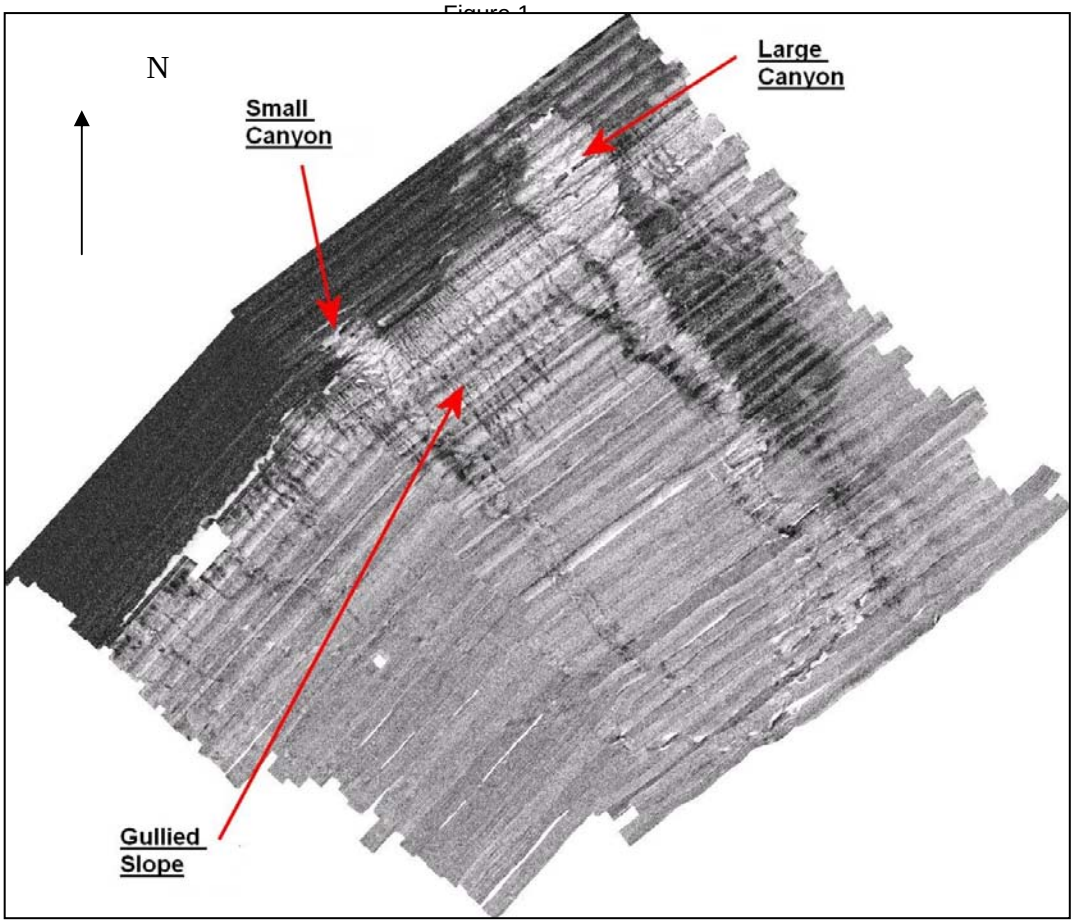

Figure 2

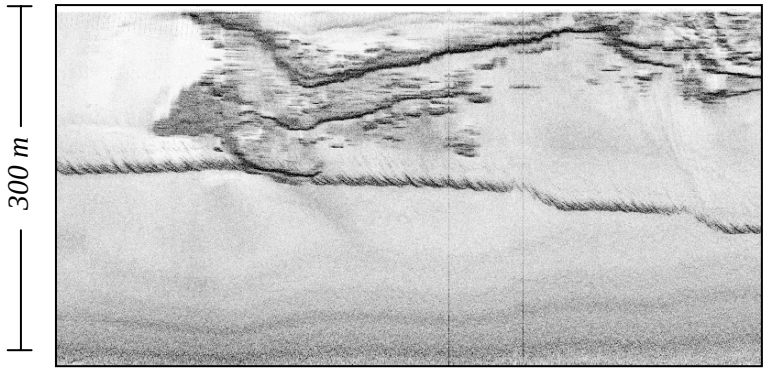

Figure 3

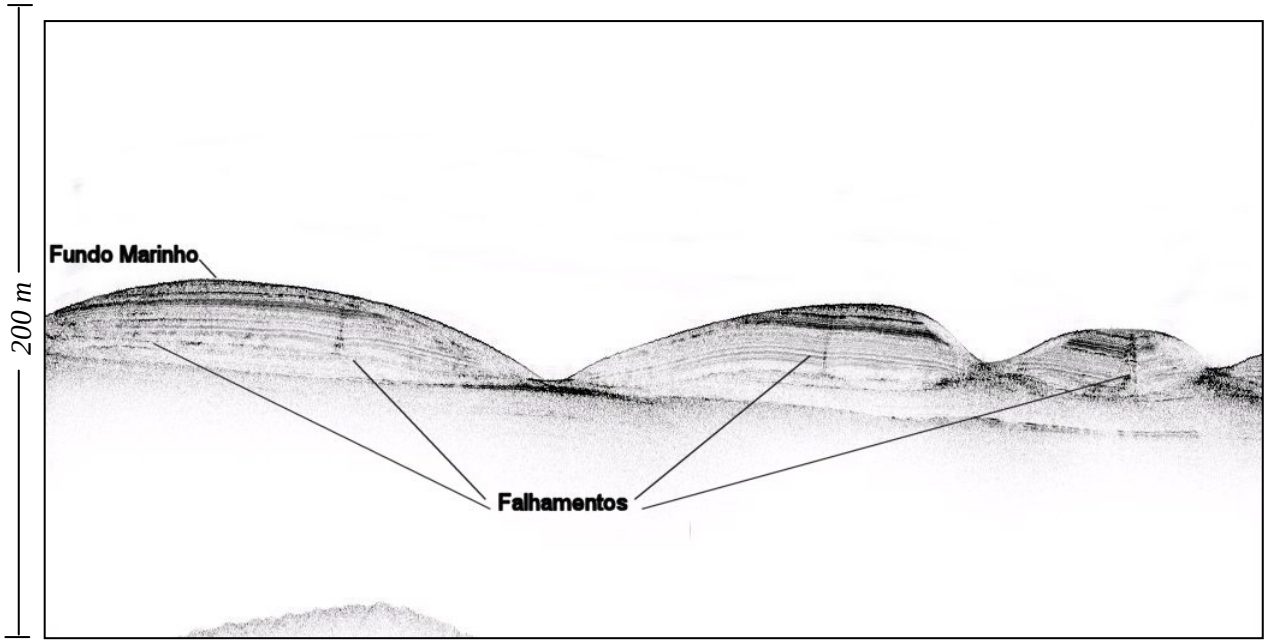

Figure 4

1.000 m

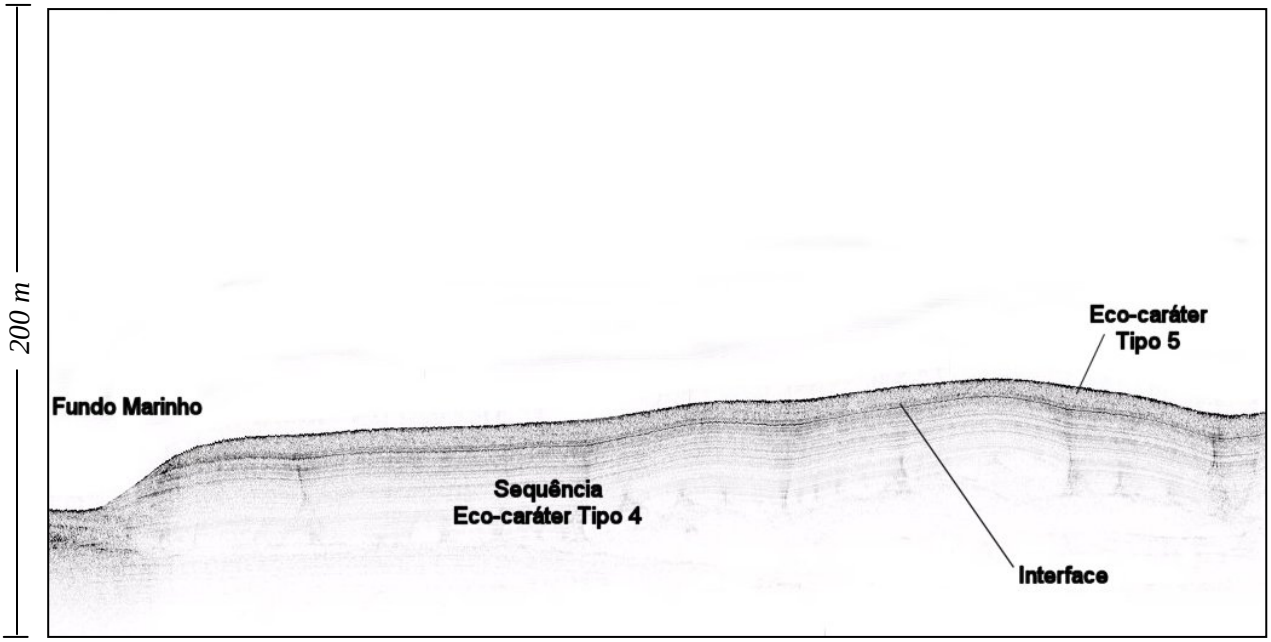

Figure 5

1.000 m

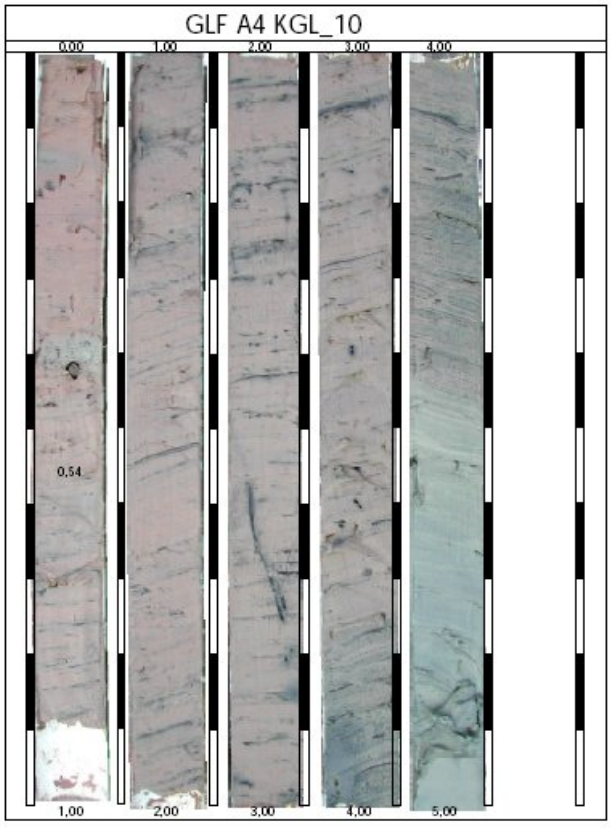

Figure 6

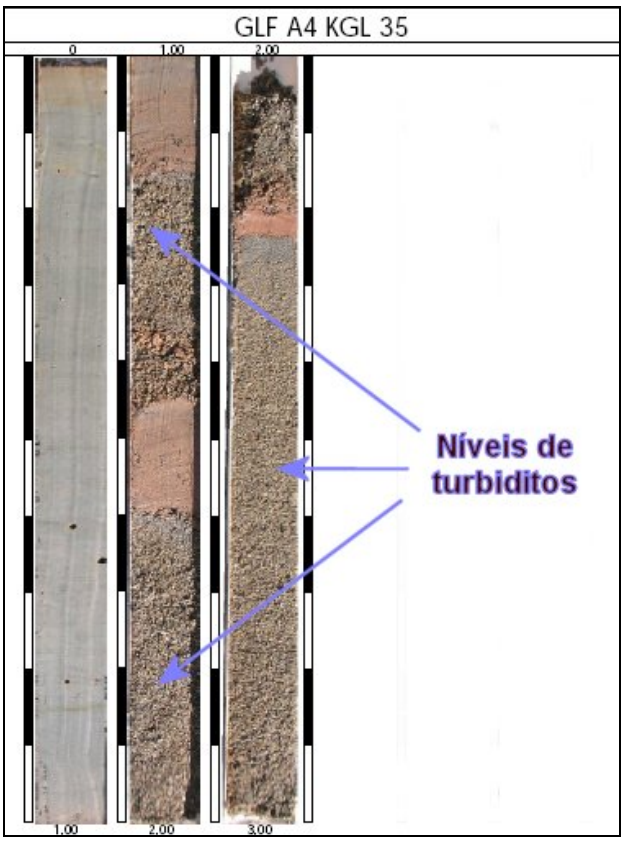

Figure 8

Figure 7