BRAZILIAN SOUTHERN MARGIN: AN EXAMPLE OF THE IDENTIFICATION OF THE BASE OF THE SLOPE ON A PASSIVE CONTINENTAL MARGIN

Author 1: Luiz Carlos, TORRES, BRAZILIAN, Brazilian Navy Hydrographic Center
torres.luizcarlos@gmail.com

Author 2: Izabel King, JECK, BRAZILIAN, Brazilian Navy Hydrographic Center
izabelkj@terra.com.br

Author 3: Ana Angélica Ligiéro, ALBERONI, BRAZILIAN, Brazilian Navy Hydrographic Center
anaangelica@urbi.com.br

Author 4: Hélio Heringer, VILLENA, BRAZILIAN, University of the State of Rio de Janeiro
heliovillena@gmail.com

Abstract

The establishment of the outer limit of the continental shelf beyond 200 Nautical Miles requires firstly the determination of the regions mentioned as base of the slope for then to determine the foot of slope (FOS) in order to apply the criteria in accordance to United Nations Convention on The Law of the Sea (UNCLOS). The foot of slope (FOS) is defined on UNCLOS, Article 76th "... in absence of the evidence to the contrary, the foot of the slope shall be determined as the point of maximum change in the gradient in its base." Based on the last part of the statement it is reasonable to interpret that first it is necessary to identify the base of slope to find out later the point of the maximum change in the gradient in this region (base of slope). Considering the first sentence of the statement it is comprehensible that there is another way to determine the FOS which is not based on gradient changing. The current study presents some discussions regarding the identification of the base of slope in passive margins using the Southern Brazilian Continental Margin as an example. In order to attend this approach the data carried out by the Brazilian Continental Shelf Project were employed. Furthermore this study considers an overview exercise of the determination of the FOS by means of "evidence to the contrary" with the use of public domain data basically. The results of this study imply that is more advantage to the Coastal State in using of gradient in this region instead of invoke prove to the contrary to the determination of the FOS.

1 - INTRODUCTION

The purpose of this paper is to demonstrate the developments which were implemented in the Brazilian Southern Continental Shelf regarding the identification of the base of slope since it presentations on UN headquarter Commission on Limits of the Continental Shelf in August 2004 until the moment and an exercise by the determination of foot of slope invoking evidence to the contrary. Additionally, the paper would emphasize the Brazilian Government efforts in order to contribute for the implementation of the UNCLOS Article 76 and testify that the changes performed in the Brazilian Continental Shelf Outer Limit were supported by means of scientific, ethical and legal aspects. The Brazilian Continental Shelf Project (LEPLAC) had, as a fundamental purpose, the delineation of the outer limits of the continental shelf beyond the 200M, by which Brazil, in the accordance with Article 76 of the United States Convention on The Law of the Sea (UNCLOS) will exercise sovereign rights for the exploration and exploitation of mineral resources of the seabed and its subsoil, as well as the living organisms belonging sedentary species. The planning coordination and control activities related to the LEPLAC were carried out under the supervision of the Inteministerial Commission for the Resources of the Sea (CIRM), principal advisory agency to the

Presidency of the Republic of Brazil for the execution of the National Policy for the Sea Resources. The Federal Budget was its main source of financial support.

2 - BRAZILIAN SOUTHERN CONTINENTAL MARGIN

The main geological features of the Brazilian Southern Continental Margin, which control the regional physiography, are the Rio Grande Fan, the Mostardas Low, the Marginal Plateau (comprising the Florianópolis High, the Florianópolis Platform and the Rio Grande Terrace) in the Pelotas Basin; and the transitional low to São Paulo Plateau, in the Santos Basin.

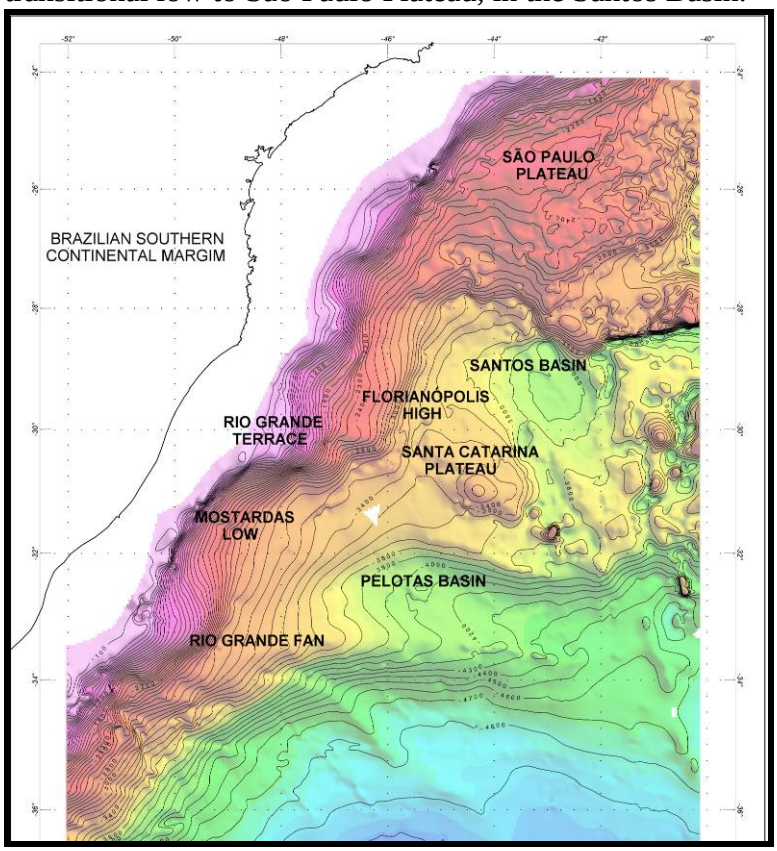

Figure 1 - Major features of the Brazilian Southern Margin.

The Rio Grande Fan is a unique physiographic feature of the Southern portion of the Brazilian Continental Margin. Its geomorphic influence is shown by the protuberance of the continental shelf break line and the convex bathymetric curves that extend towards the deep sea in a continuous slope ending up into the Argentine Abyssal Plain. Its area of influence varies geographically specially to the North where the bathymetric contours extend towards the East, encircling an West-East depositional mound. The beginning of the infill of the Rio Grande Fan (Cone) is correlated to the bacinal evolution related to the rifting phase and ends up probably with deltaic Miocene deposits. Recent studies suggest that at least 2,000m of the South Rio Grande Shield were eroded to serve as source of up to 11,000m sediments in the post-rift section of the cone. During the Miocene the climax of the sedimentation reached a rate of 360m/m.y. The Mostardas Low has its origin in a graben filled by sediments since the rift phase to late Paleocene. In the present-day, this low represents an embayment of the margin. The Florianópolis High reflects a natural seaward continental projection of the basement which continues seaward in the form of a marginal plateau with a SE axis. Its transversal position to the coastline dates back to the beginning of the opening of the Gondwana super-continent, at about 125 m.y. ago. The eastern boundary of the Florianópolis High corresponds to a North-South aligned feature known as the Florianópolis Platform. The Rio Grande Terrace is a morphological feature built up by an intense deltaic sedimentation since the Paleocene up to the Pleistocene. These three

elements make up a plateau-like feature that underwent a terrigenous Cretaceous and Tertiary sedimentation similar to the São Paulo Plateau (Figures 1 and 2).

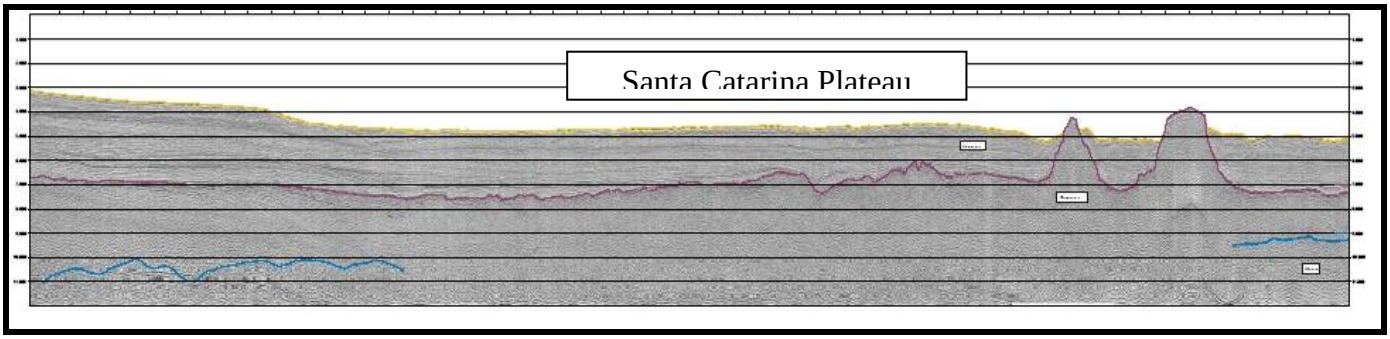

Figure 2 - Seismic profile 500047.

The São Paulo Plateau Transition corresponds to a structural low and an embayment of the bathymetric contours between the Marginal and the São Paulo plateaus (Figure 1).

3 – GEOPHYSICAL DATA

The Brazilian Government dedicates great efforts in order to contribute to the implementation of the UNCLOS. The first one may be translated by the mobilization of experts in order to conduct the Brazilian Continental Shelf Project. Professionals from Brazilian Navy, Petrobras and Brazilian Scientific Community joining them in order to plan the geophysical surveys, acquire geophysical data, process them, interpret them and prepare the technical and scientific support to the Brazilian Submission. The second one was to employ four hydrographic ships to carry out geophysical data in the Brazilian Continental Margin. The field works lasted around 10 years in order to cover almost 8,500km Brazilian coastline. All the data acquired by LEPLAC were acquired exclusively to meet UNCLOS Article 76 parameters. In the Brazilian submission some measured data from public domain were employed jointly with which carried out by LEPLC in order to compose the database which construct some grids (Figure 3). The table I summarize the geophysical data collected in whole Brazilian Continental margin.

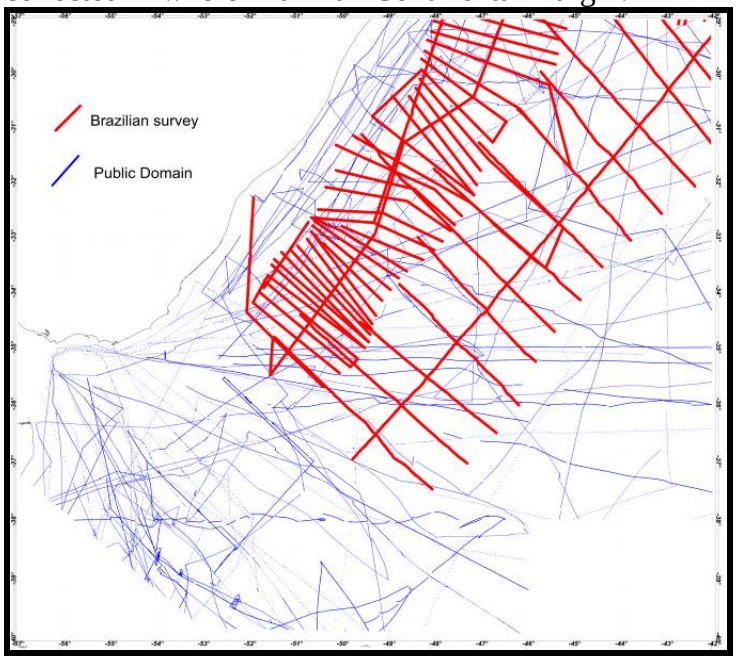

Figure 3 – Geophysical data lines acquired in the Southern Brazilian Margin by LEPLAC (red lines). The geophysical measured lines available on public domain are presented on blue color.

TABLE I – Geophysical data carried out on the whole Brazilian Continental Margin

Geophysical data	Length (km)
Seismic multichannel *	48.500
Bathymetry**	112.000
Gravity	96.000
Magnetometry	61.000

The third one may be demonstrated by the cooperative attitude of the Brazilian Representatives during the meetings with Commission on the Limits members. Additionally to the measured data, used preferentially in order to define the foot of slope and the 2500m isobath, in this paper were used data from public domain derived from satellite measurements (bathymetry and gravity). This data were used just in order to present a simulation regarding an exercise where was invoked evidence to the contrary.

4 - BASE OF THE SLOPE (BOS)

The most sensible and important feature for the implementation of the UNCLOS Article 76 is the identification of the region defined as the base of the slope. In the Scientific and Technical Guidelines, chapter 5, items 5.4.4 and 5.4.5 is described the method for the identification of the base of slope. Although it is not mentioned directly if the region where slope merge to the continental rise or to the deep ocean floor where the rise is not developed may be identified by means of the gradient, an analyze of regional distribution of gradient of the seabed presents itself as an important tool in order to provide this comprehension. The figure 4 presents a regional gradient analyze of the Brazilian Southern Margin. In the mentioned picture is possible to watch the trend of gradient distribution, and as consequence, to have a better idea of those obtained when a single profile is analyzed. Employing seabed gradient distribution is possible to identify in the bathymetric profile the region where will look for the point of maximum change the gradient. On the other hands, it is possible to identify or at least, have a good regional idea where is the base of slope by gradient analyze and mark it in the bathymetric measured profile the point of maximum change of the gradient in the regarding area, and this way, to determine the foot of slope (FOS).

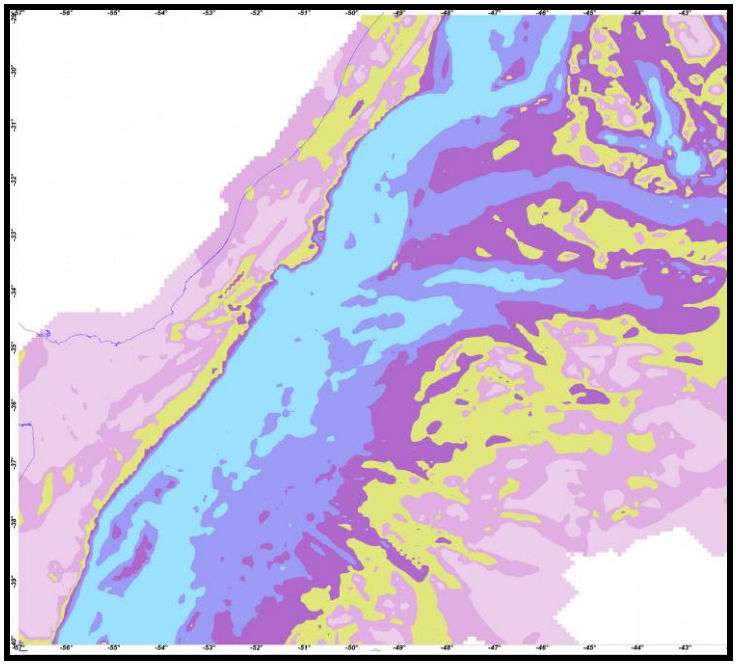

Figure 4 - Seabed gradient map. Analyzing the map is possible to visualize the provinces with common or similar gradient values. The area covered on this picture advances through Uruguayan waters too.

Physiographically the Brazilian Meridional Margin is divided into three regions, from South to North (figure 5),:

- Rio Grande Fan;
- Santa Catarina Plateau; and
- São Paulo Plateau Transition (embayment).

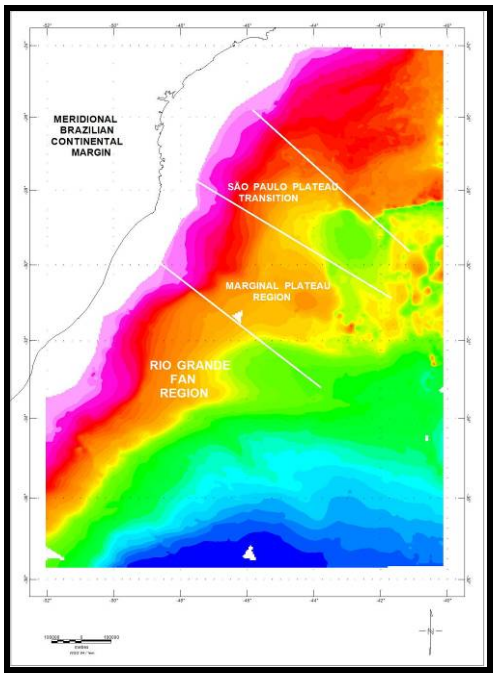

Figure 5 - The three regions of the Brazilian Southern Margin.

In these three regions, the base of the continental slope was identified and defined in accordance with the Scientific and Technical Guidelines section 5, specially in the following paragraphs:

5.4.5. – "The Commission defines the base of the continental slope as a region where the lower part of the slope merges into the top of the continental rise, or into the top of the deep ocean floor where a continental rise does not exist. ... First, the search for its seaward edge should start from the rise, or from the deep ocean floor where a rise is not developed, in a direction towards the continental slope. Secondly, the search for its landward edge should start from the lower part of the slope in the direction of the continental rise, or the deep ocean floor where a rise is not developed.

5.4.6 – As a general rule, whenever the base of the continental slope can be clearly determined on the basis of morphological and bathymetric evidence, the Commission recommends the application of that evidence. Geological and geophysical data can also be submitted by Coastal State to supplement proof that the base of the continental slope is found at that location".

Rio Grande Fan

The bathymetric profiles in the area of the Rio Grande Fan do not indicate major regional gradient variation from the continental shelf break to the deep sea floor. Because of that, a continuous slope is present. The first regional variation is observed exactly at the limit of the Rio Grande Fan; therefore, this region was defined as the base of the continental slope.

Some local channels and erosional surfaces were identified. They may be the cause of local gradient variations which, as consequence, may be disregarded. The bathymetric profile (black line in the adjacent map) exemplifies the geomorphologic characteristics of this region. The red box indicates the base of the continental slope.

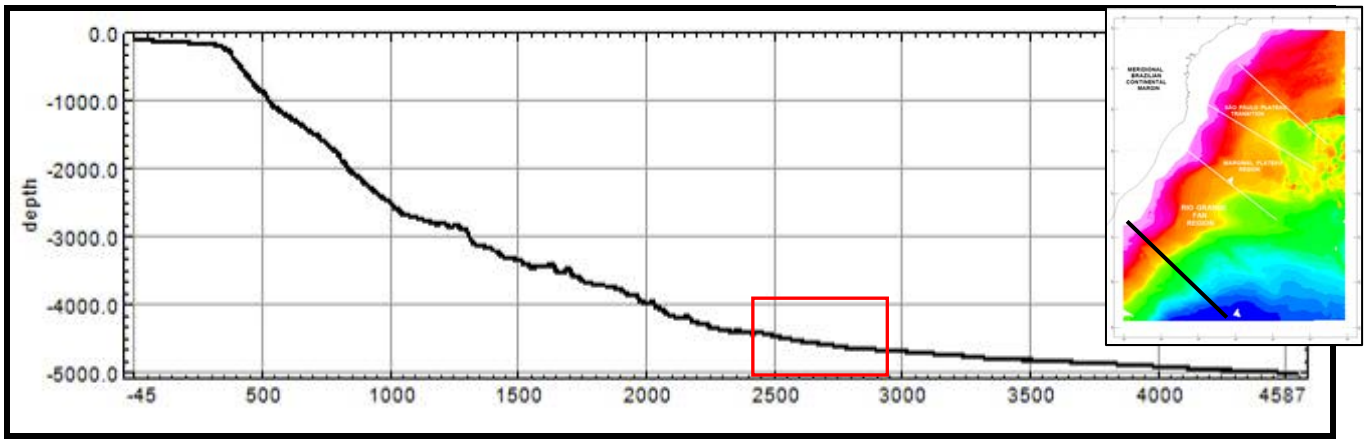

Figure 6 - Line 5000216 + 5000055, along the Rio Grande Fan.

Santa Catarina Plateau

Santa Catarina marginal plateau is considered to be a natural prolongation of the Brazilian margin. The base of the continental slope adjacent to this plateau is defined as an area around the eastern border of this geomorphological feature. The bathymetric profile (black line in the adjacent map) exemplifies the geomorphological characteristics of this region. The red box indicates the base of the continental slope.

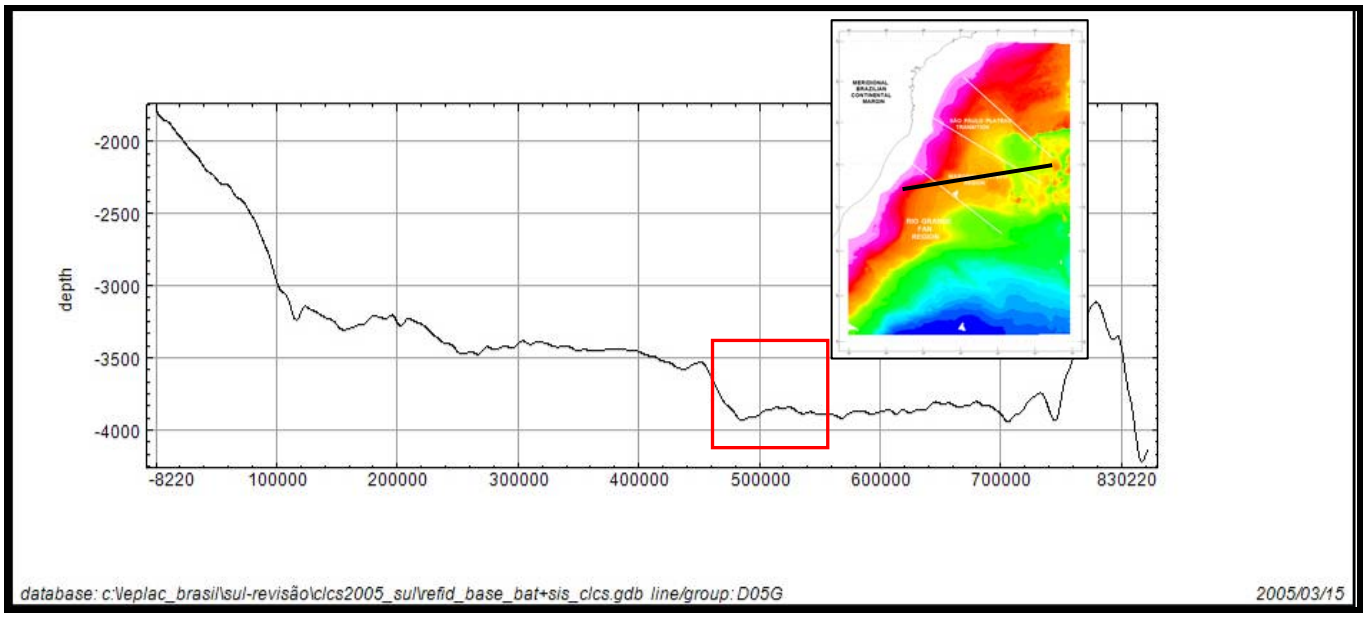

Figure 7 - Line 5080005, along the Marginal Plateau.

Transition to São Paulo Plateau

From the Marginal Plateau to the north, the base of the continental slope curves towards an embayment to the south of the São Paulo Plateau. In this confined area, the base of the continental slope was placed geomorphologically where the considered continental margin ends. The bathymetric profile (black line in the

adjacent map) exemplifies the geomorphological characteristics of this region. The red box indicates the base of the continental slope.

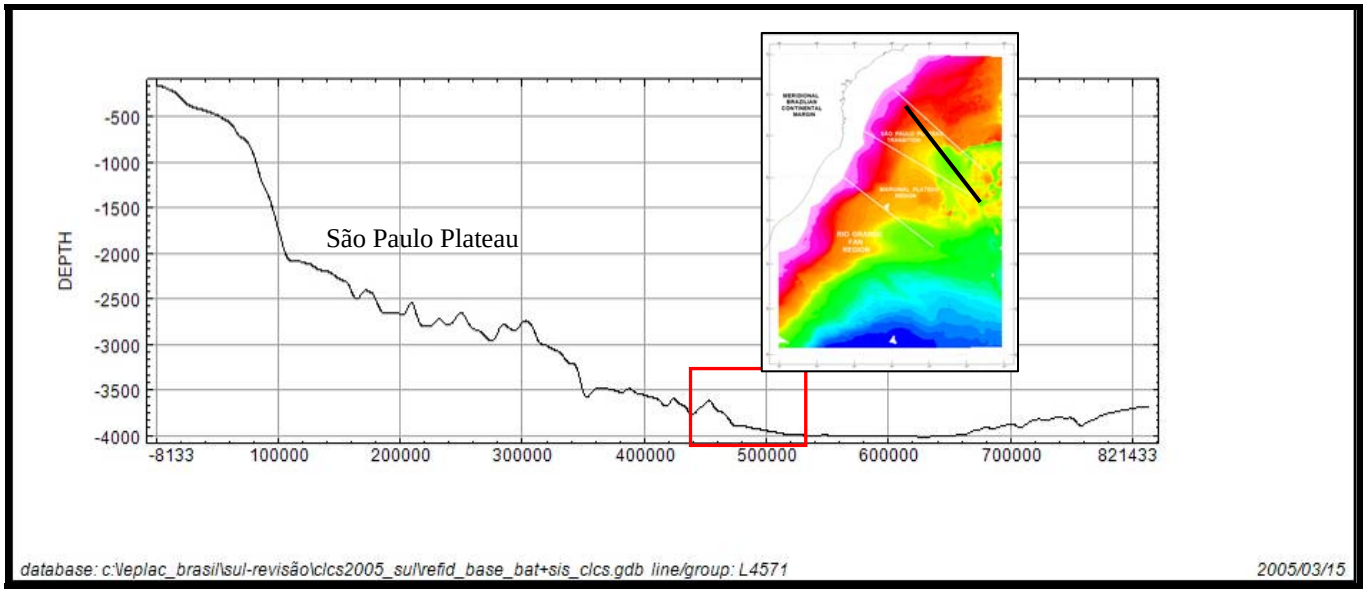

Figure 8 - Line 5000271 + 5000045.

The figure 9 presents the points of maximum change in the gradient determined over the bathymetric measured profile in the region identified in the analyze of seabed gradient distribution.

5 – DETERMINATION OF THE FOOT OF THE SLOPE

“As the point of maximum change in the gradient in its base”

In the Brazilian Southern Continental Margin the determination of the FOS was conducted by means of the existing bathymetric profile and bathymetry derived from seismic data. In addition, this determination was made in accordance with the methodology described in the Scientific and Technical Guidelines – section 5, specially in its paragraphs 5.4.1, 5.4.2, 5.4.7, 5.4.8 and 5.4.12. The following pictures exemplify the locations of used lines and the determination of foot of the continental slope in the region defined as the base of slope.

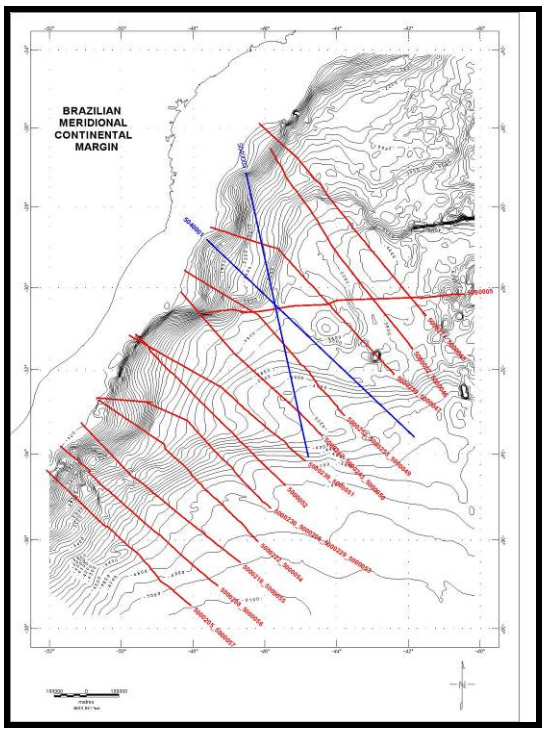

Figure 9 - Lines used in the determination of the foot of the Brazilian Southern Margin. The red lines represent the coupling lines (bathymetric profiles and bathymetry derived from the seismic lines). The blue lines represent synthetic profiles sampled from a grid constructed from measured bathymetric data.

Figures 10A and 10B present bathymetric profile showing the FOS in the region of the Rio Grande Fan and in vicinity of Brazil and Uruguay Maritime Lateral Limit, respectively. The second derivative was defined on the both bathymetric profile just in the region identified as the base of the slope and determine the FOS in each profile.

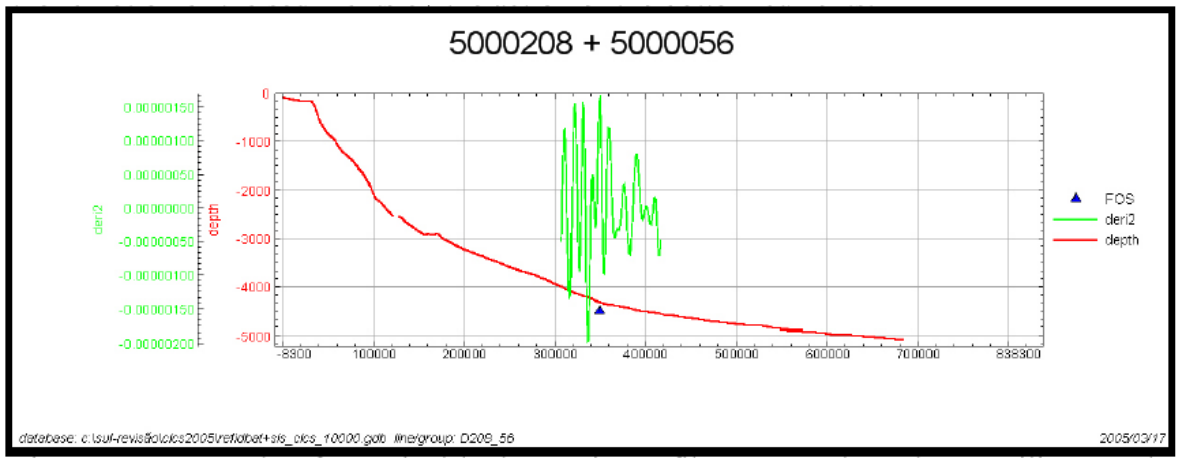

Figure 10A – Bathymetric profile in the region of the Rio Grande Fan. The blue triangle is placed at point which is identified the maximum change in the gradient.

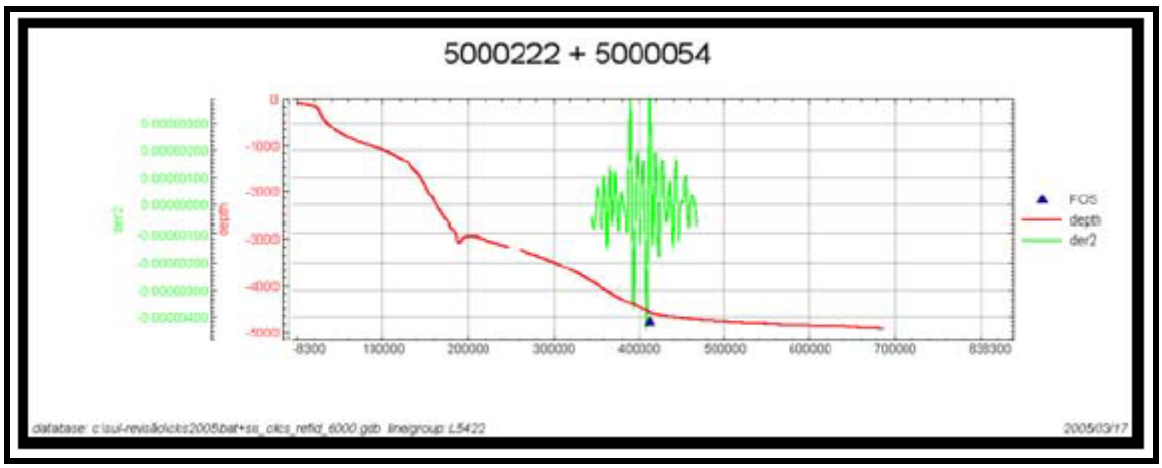

Figure 10B – Bathymetric profile in the region of the Rio Grande Fan Brazil and in vicinity of Uruguay and Brazil maritime lateral limit, respectively. The second derivative was defined on the both bathymetric profile just in the region identified as the base of the continental slope.

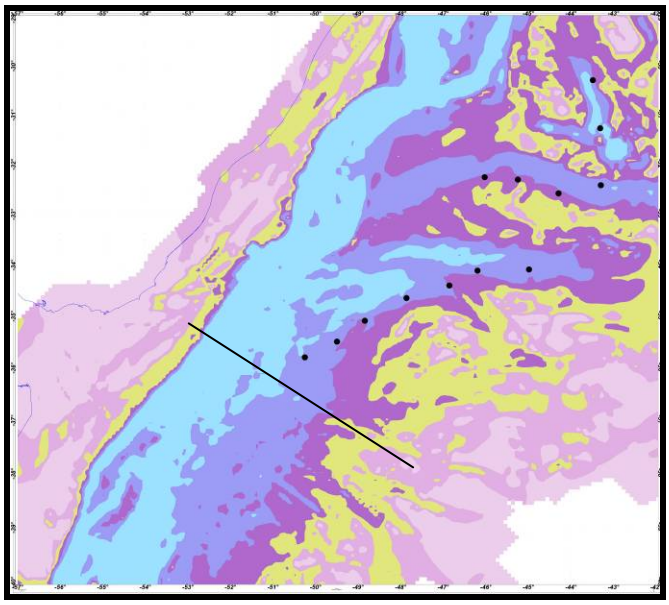

Figure 11 - Location of the FOS points determined over measured bathymetric profile, as showed in the pictures 10A and 10B, in the region identified as the base of the slope on the seabed gradient distribution map. Black line represents the vicinity of the Brazil-Uruguay lateral maritime limit.

"... in absence of the evidence to the contrary, …"

The definition of the FOS in the Article 76 of UNCLOS establishes: "... in absence of the evidence to the contrary, the foot of the slope shall be determined as the point of maximum change in the gradient in its base." In the statement is possible to think that beyond of gradient, there are other ways to obtain the foot of slope, although it is not point out the ways which may be done. In order to find out possible methodology to determine de foot of slope invoking the evidence to the contrary, Torres et al 2001, proposed in this region one methodology supported by stratigraphyc sequences evidences. Employing pieces of information derived from sediment core samples was possible to identify its source and stratigraphy (turbidity). Them, the place where were possible identify the source of sediment and record associated to slope process would be interpreted as FOS if invoking evidence to the contrary, as showed in the figure 12.

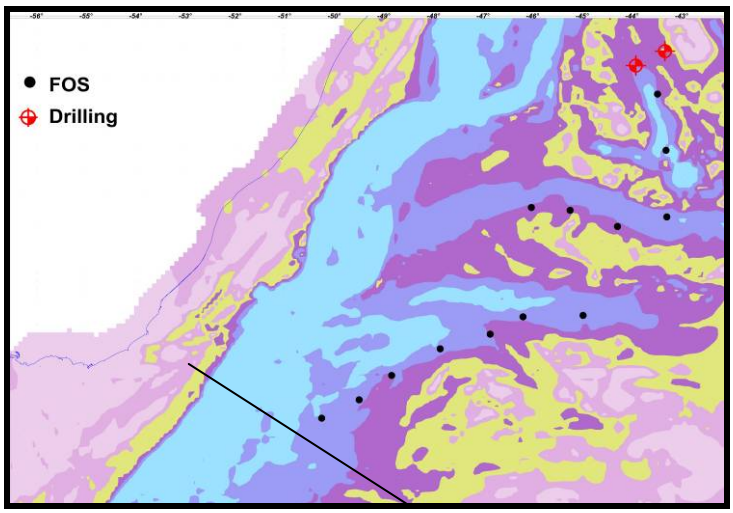

Figure 12 – The red points represent the place where was collected sediment samples of continental origin and in a place which there was a concentration of turbidity. Black line represents the vicinity of the Brazil-Uruguay lateral maritime limit.

The chapter 6 of Scientific and technical Guidelines details the way of using the evidence to the contrary and the principal highlight occur in the boundary of type of crust. In order to have an idea of crust boundary in this region it was proposed an exercise employing free air gravity data from public domain. Combining with bathymetry either of public domain it was possible to calculate de Bouguer slab gravity, which was derived in order to measure its variation and have an idea of the zone of transition crust from continental to oceanic, as showed in the pictures 13 and 14.

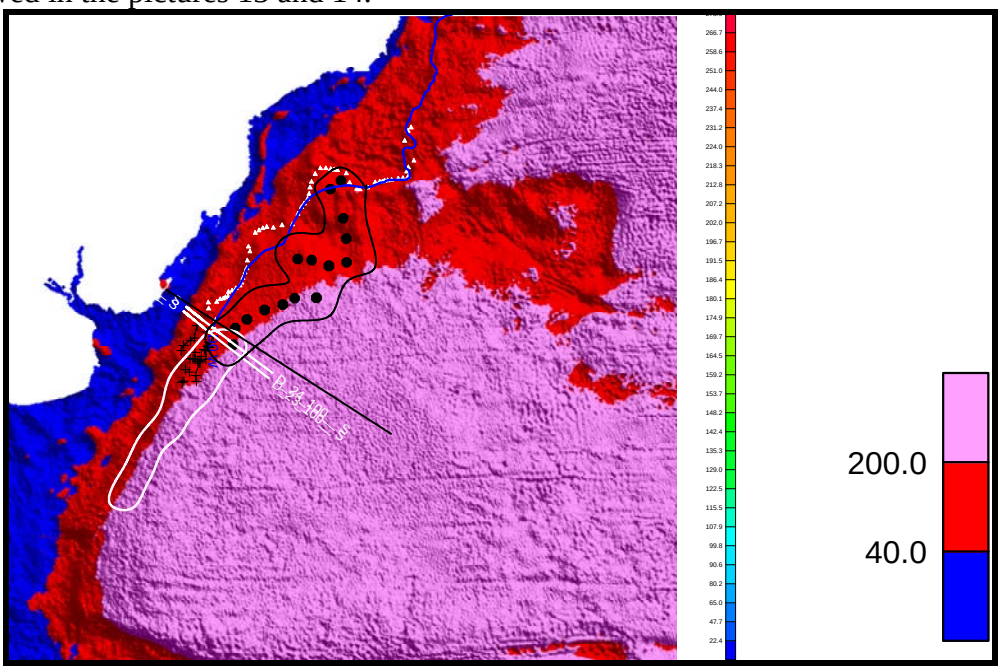

Figure 13 – Gravity Bouguer Map. In the red region the Bouguer gravity range from 40 mGal (blue) to 200 (purple) mGal and was interpreted as the COT (continental-oceanic transition zone). Black line represents the vicinity of the Brazil-Uruguay lateral maritime limit.

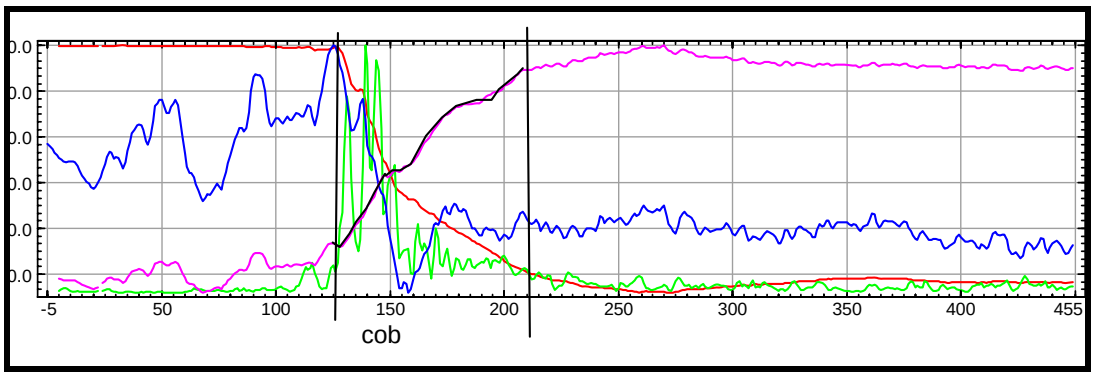

Figure 14 – Profile derived from the grid. Red line - bathymetry, green line - gradient of bathymetry, blue line - free air gravity and purple line - Bouguer gravity. The current profile is in the vicinity of Brazil and Uruguay Lateral Maritime Boundary.

On the figure 14 it is showed which the COT (black vertical lines) is over the geomorphologic slope and a possible foot of slope would be placed near of the right vertical black line, an indicative that consider the geomorphologic criteria may be most advantageous in this margin if compared with the evidence to the contrary on the same margin.

6 - FINAL REMARKS

The most sensible interpretation for the implementation of the UNCLOS Article 76 is the identification of the region defined as the base of the slope.
On the regarding area of study the application of the analyze seabed regional gradient tool points out as a useful aids in terms of identification of the base of the slope.
This geomorphologic approach employed to the identification of the base of the slope, in this paper based on gradient seabed analyze, usually would be improved if integrated with additional geological and geophysical evidences.
The application of tools which measures seabed gradient have to take in consideration that the characteristics of process and aspects which contributed for the development of the studied margin. Usually margin developed under huge continental sedimentation presents smooth gradient if compared with “hungry” continental sedimentation margin, where, usually, presents sharp variations on seabed gradient. Then, it is recommended, firstly a regional analyze of whole margin and after, if necessary, an analyze of portions of margin in order to assure that conspicuous features may have representative presentation. On the other hand, typical parameters (break of geological shelf, slope and continental elevation) adjusted for a specific margin, not necessarily, will present the same adjustment when applicable on another margin.
Although the exercise proposed to the determination of foot of slope invoking evidence to the contrary count on some simplifications, in this region, the determination of the foot of slope by means of maximum change of gradient in its base points out as the most advantageous method for the Coastal State.

7 - ACKNOWLEDGEMENTS

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