Selection of Algorithms to Determine Foot of the Continental Slope to Delineate the Extended of the Continental Shelf

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Key words: Geoinformation/GI; Hydrography; Legislation; Extended Continental Shelf; Foot of the Continental Slope (FOS); Article 76 of UNCLOS 1982

Foot of the continental slope (FOS) is a key feature to implement a provision under Article 76 of United Nations Conventions on the Law of the Sea (UNCLOS) 1982 in respect of the delineation of the outer limits of the continental shelf beyond 200 nautical miles (M) from the baseline from which the breadth of the territorial sea is measured. The coastal States are eligible to claims the outer limits of its continental shelf to the Commission on the Limits of the Continental Shelf (CLCS).

The FOS is defined in Article 76 in paragraph 4(b) as *"In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point in maximum change in the gradient at its base"* (UNCLOS, 1982). The general rule to determine the FOS is based on a geomorphologic evidence by identification of greatest change in the gradients at the base of continental slope. Nevertheless, evidence to the contrary by implements of the geological and geophysical evidence can be used if failed to prove the geomorphologic evidence.

There is a saying among seafarers that "the hardest part about captaining a ship is finding a ship to captain" (Carleton et al., 2000) and this relates to an implementation of Article 76, where the toughest part about mapping the foot of the continental slope is to find the foot of the continental slope (Carleton et al., 2000). The problematic on different interpretations to identify FOS about the aspect of quantification of gradients, depth, sea floor morphology and a question about the location of base of the slope (BOS) region were answered with developments of software packages come in a selection of an algorithm to determine foot of the continental slope. This papers will examines the selection of algorithms to determine the possible FOS and what is the benefits to the coastal Sates in solution of appropriate algorithms and methods to determine these so-called vital features to the outer limits of continental shelf claim among the coastal States.

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1. INTRODUCTION

On 10 December 1982 placed in Montego Bay, Jamaica a constitution for the oceans named as United Nations Conventions on the Law of the Sea 1982 (UNCLOS) was concluded and entered into force on 16 November 1994. The UNCLOS 1982 was signed by 159 countries provides customary international law comprises of 17 parts, 320 articles, nine annexes and a final act.

Key feature of the UNCLOS 1982 was to deals about a definition and a limit of various maritime zones, rules for a protection and conservation of an oceanic environment from pollution, a marine scientific research, method for dispute settlement to prevent war resolution between a claimant State and as an international equity of living resources for the other land-locked and geographically disadvantages States.

One of the important provision in UNCLOS 1982 is Article 76 described about a continental shelf. There are many areas of continental shelf beyond 200 nautical miles (M) are still disputed and have unresolved boundaries. The coastal State intending to establish the outer limits of the continental shelf beyond 200 M from the baseline from which the breadth of the territorial sea is measured, is obliged to submit an information regarding the limits of the continental shelf with supporting scientific and technical data to the Commission on the Limits of the Continental Shelf (CLCS) an established body set up under Annex II of UNCLOS 1982.

As to date of 7 of May 2018, there were 79 coastal States have made a submission. The CLCS will make a recommendation of the submission based upon the information of scientific, technical data and jurisprudence submitted by the coastal States. However, not all the submissions have yet been given recommendations by CLCS. It is because to examine the submission is not an easy process, and the delineation of the extended continental shelf is not a straightforward subject. It requires a combination of understanding and a knowledge of geodesic, hydrographic, geomorphologic, geological and geophysical on the characteristic of the continental margin. Moreover, the legal and jurisprudence also need to be consider by the CLCS before the recommendations can be granted.

This paper focused on the selection of algorithm to calculate the maximum change in the gradient at its base for the purpose of determination of foot of the continental slope (FOS) to delineate the extended of the continental shelf. How the selected of an algorithm give effects on the chosen of foot of the continental slope, and the analysis of the results will be beneficial to other coastal States to get the idea's behind of the selection of algorithm in the software packages.

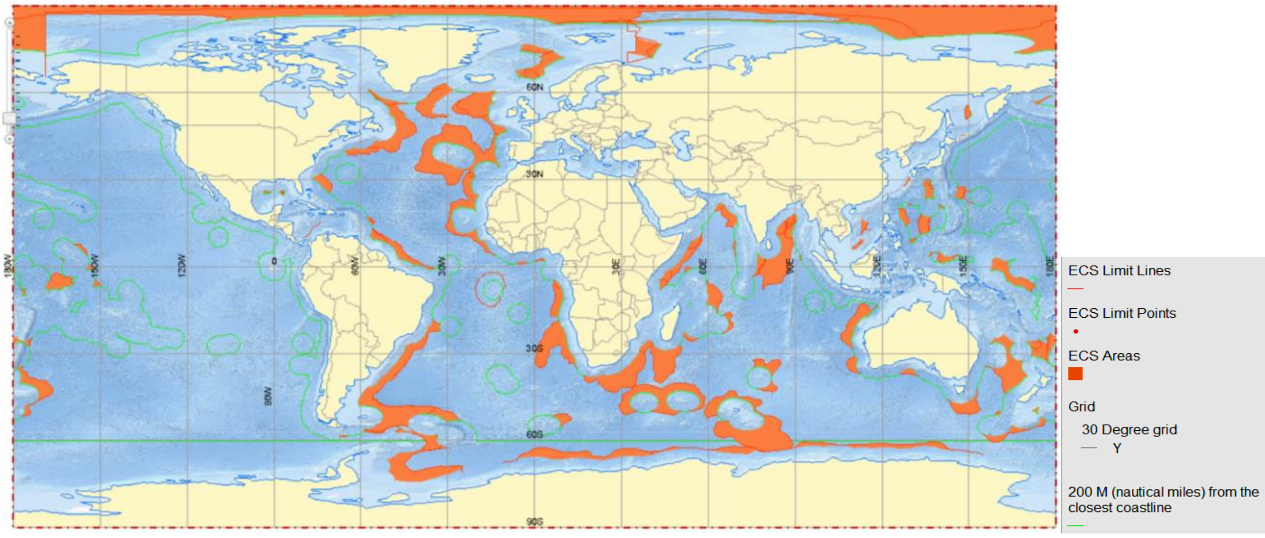

Figure 1: The Extended Continental Shelf Submission claimed around the world as at 7 May 2018 *(Source: http://maps.continentalshelf.org/)*

2. PROVISION OF ARTICLE 76 OF UNCLOS 1982

The provision of the Article 76 in paragraph 1 gives a legal definition of the continental shelf based on either natural prolongation or distance as follows:

> *"The continental shelf of a coastal State comprises the seabed and subsoil of the submarine areas that extent beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baseline from which the bread of the territorial sea is measured where the outer edge of the continental margin does not extend up to that distance."* (UNCLOS, 1982).

Therefore, it is mean the coastal States need to carry out a test of appurtenance to enable them a right to extend the continental shelf limits beyond 200 M distance. The desktop study runs by the coastal States should consist in the demonstration of the natural continuation of its land region to the outer edge of the continental margin extends beyond a line delineated at a distance of 200 M from the baselines from which the breadth of the territorial sea is measured.

According to the provision of Article 76 in paragraph 3, the continental margin can be described as a submerged prolongation of the landmass of the coastal State which consists of the seabed and subsoil of the shelf, the slope and the rise. It was agreed by Carleton et al. (2000) that the concept of continental margin was a prolongation of the landmass.

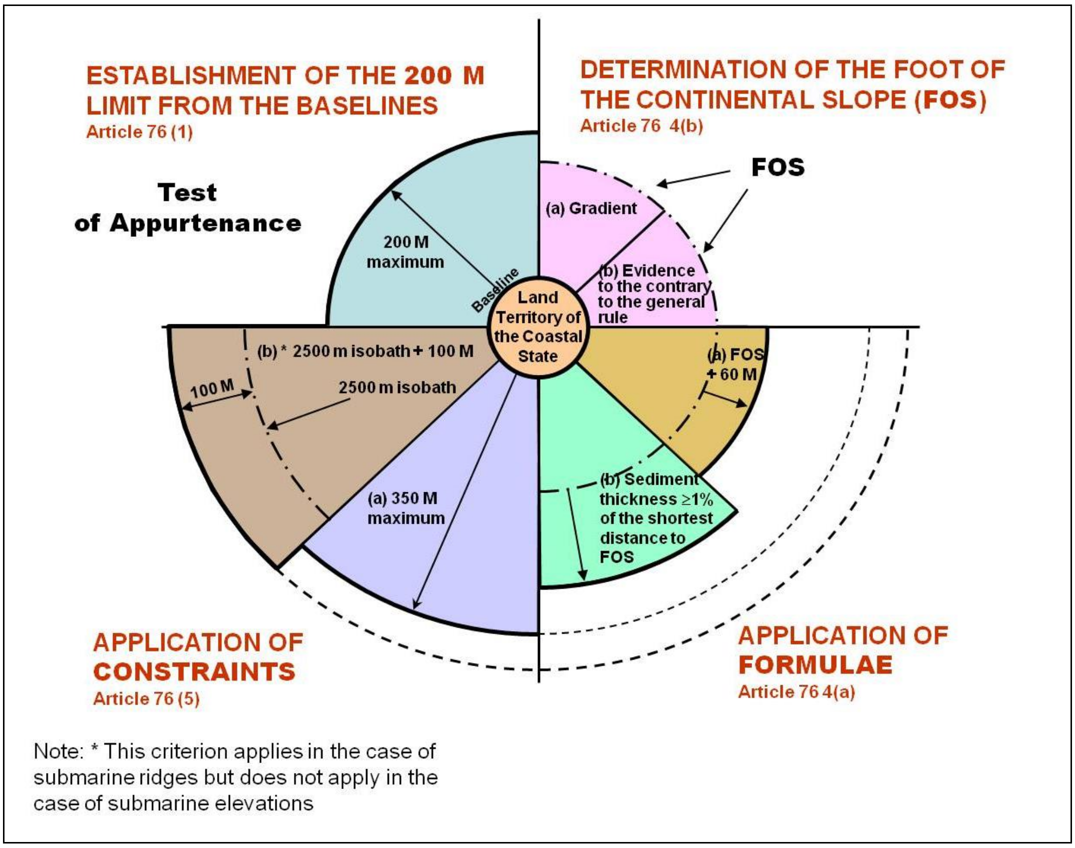

Figure 2: Illustration of application of Formulae and Constraints for establishing the Outer Limits of the Continental Shelf (after CLCS/11, 1999)

Moreover, the breadth of its outer limit provision can be determined based on a combination of complex blend of legal, geodesy, hydrography, geomorphology, geology and geophysics concepts, which can be confusing even to experts in the individual fields (Symonds et al., 2000).

2.1 Determination of Foot of the Continental Slope (FOS)

Foot of the continental slope is a key feature to determine the outer limits of continental shelf. Under paragraph 4(b) of Article 76 the determination of foot of the continental slope has describe generally as *"In the absence of evidence to the contrary, the foot of the continental slope shall be determined as the point in maximum change in the gradient at its base"* (UNCLOS, 1982).

It can be understood from above provision that the foot of the continental slope should be at the base or the deeper part of the slope. It is also can distinguish an identification of foot of the continental slope by means of computation of maximum change in the gradients at its base as the general rule. But, the process of determining foot of the continental slope using of evidence to the contrary has been called "the exception to the general rule" (Alcock et al., 2003). Additional understanding about the foot of the continental slope by Carleton et al. (2000) was, he believed, in principle that the foot of the continental slope represents an attempt to separate continent and ocean.

It can summarise here there are two essential requirements by means of maximum change in the gradients at its base that was needed to implement from the provision before location of foot of the continental slope can be identified. First requirement is to identify the region of base of the continental slope, and the second requirement is to determine the location of the steepest part of the slope within base of the slope (BOS) region.

2.1.1 Identification of Base of Slope (BOS) Region

The base of slope is defined in paragraph 6.2.2. of CLCS/11 (1999) as below:

> *"From a geomorphological perspective, the shelf in ideal cases is the part of the seabed adjacent to the continent, which forms a large submerged terrace that dips gently seaward. The breadth of the shelf depends on the geological evolution of the adjacent continent. The continental shelf extends seaward to the continental slope, which is characterized by a marked increase in gradient. The base of the slope is a zone where the lower part of the slope merges into the top of the continental rise or into the top of the deep ocean floor, in the case where no rise exists".*

The morphology of the continental margin around the world is multifaceted, but it is normally can be understood by a simple continental margin which comprises of continental shelf, slope, rise and abyssal plain. Alcock et al. (2003) states that base of the slope region can be identified at the lower part of the morphological margin, and this region generally occur between the point where the general gradient of the margin became less than 1º where it is the lower end of the range of slope gradients and above 0.5º where it is the generally quoted upper limit of rise gradient (see **Figure 3**).

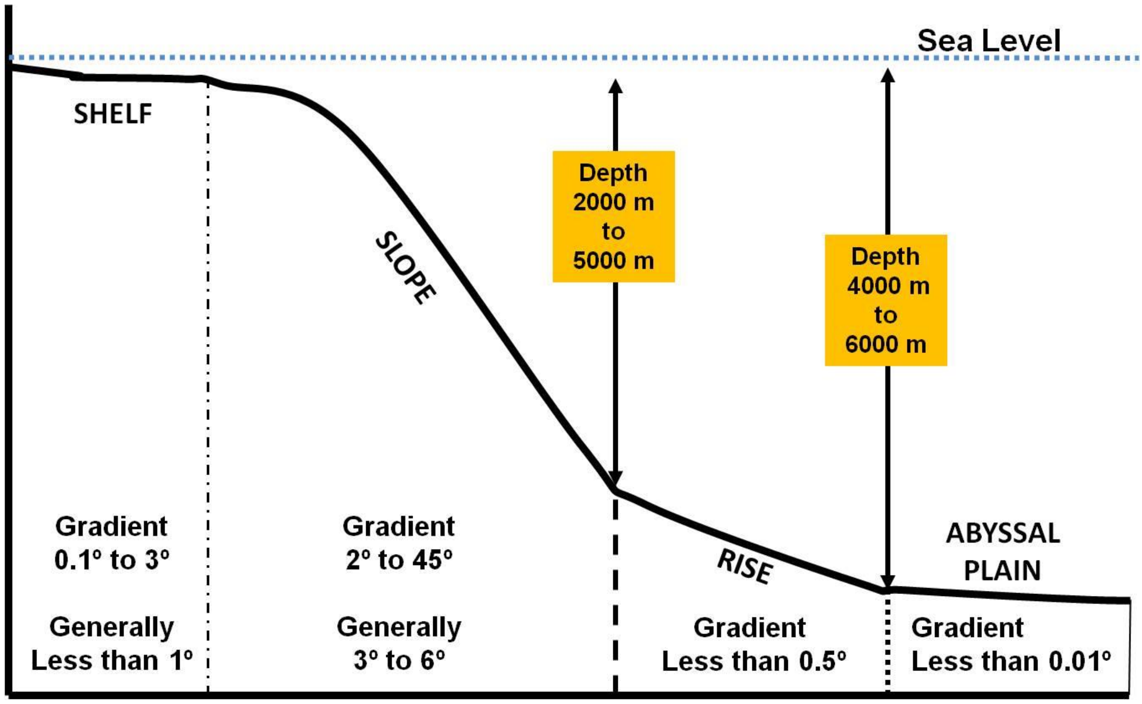

Figure 3: Show illustration cross section of simple seafloor morphology and gradients (after Symonds et al., 2000)

Moreover, the slope and rise zone as a base of slope region also can be distinguished by using geological and evolution characteristic, which was suggested by CLCS that the outer edge of the continent can be identify most appropriately within the continent oceanic transition (COT) or continent oceanic boundary (COB) zone. Alcock et. al. (2003) states that the outer edge of the COT or COB as the logical point equivalent to the foot of the continental slope. These view supported by the CLCS as mentioned in paragraph 6.2.3. of the CLCS/11 (1999) as below:

> "*….. The foot and the base of the continental slope are inseparable, and commonly lie close to the outer edge of the continent, that is, near the place where the crust changes from continental to oceanic.*"

2.1.2 Determination of Foot of the Continental Slope by means of Point of Maximum Change in the Gradients at its Base

After established the base of the slope region, the identification of the location of foot of the continental slope can be calculated by searching the maximum change in the gradients at its base. The gradient function of the seafloor is known by its first derivative, and the change to the gradient function is given by its second derivative.

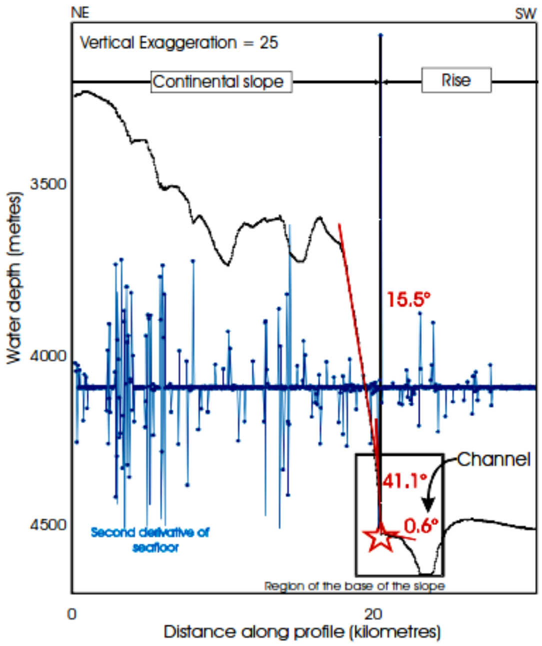

Figure 4: Show the illustration of the foot of the continental slope by using a method of maximum change in the gradient at its base. The bathymetric data (black line), second derivative (blue line) and seafloor gradients with the slope given in degrees (red line) (Stagpoole et al., 2005)

There are different problematic scenarios that incapability to determine foot of the continental slope by the general rule. One of the scenarios because of the irregular seabed topography, where numerous local maxima might be revealed in the change of the gradient at the base of the continental slope (Persand, 2005) and it is possible that the maximum *maximorum* may not be indicative of the location of its foot (paragraph 6.3.3. of the CLCS/11, 1999).

The CLCS also has indicated other scenarios might be happened when the curvature of the ocean floor along the base of the continental slope is continuous and in this scenario, it just not only the point but also a region that encompassed by the maximum change in the gradient.

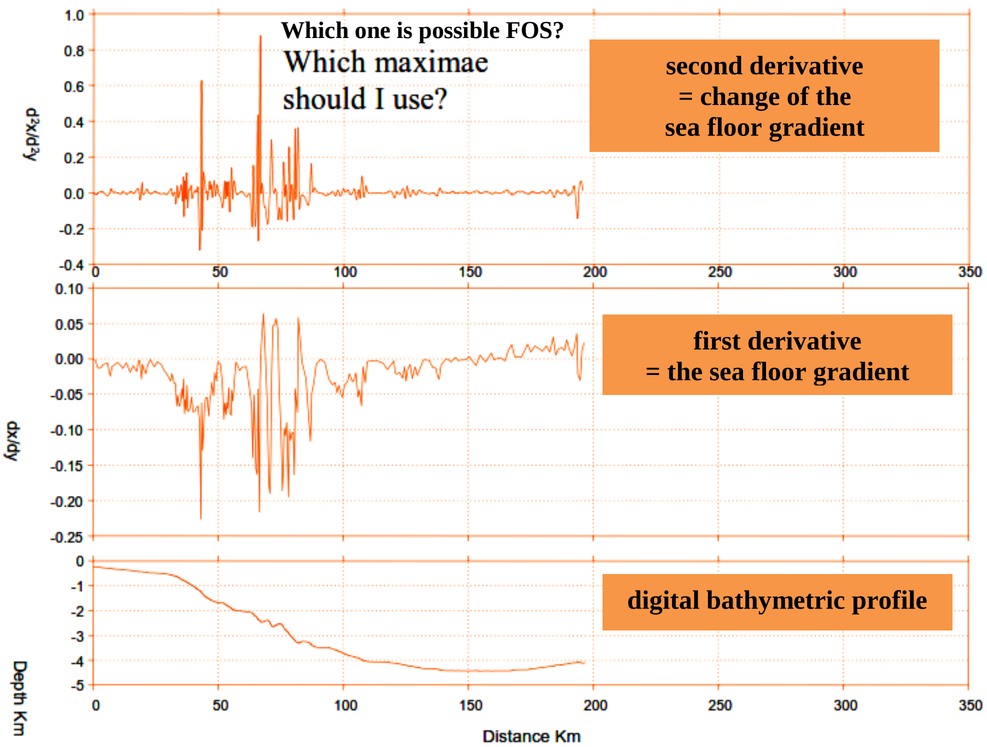

Figure 5: Instability of the solution (after Training Manual CLCS, 2006)

2D profiles and 3D models of bathymetric models can be classified as numerical and analytical representations. 2D profiles comprise of distance and depth. 3D models relate to digital evaluation models comprises of coordinates (latitude and longitude) and depth. Clearly that from bathymetric data, the foot of the continental slope can be identified where the depth, distance and coordinates relates each other to generate the 2D profile and 3D models.

There was a difference interpretation of the term "maximum change in the gradients" in Article 76 from the fundamental several 3D techniques to determine foot of the continental slope. According to the CLCS it was assumed that the "gradient" term in Article 76 is really meant to be a scalar quantity, the tangent of the slope angle, and "maximum" means in the direction of the gradient of this surface m (x, y) [and not the original seabed function f (x,y)] by means of maximum values of the absolute value of the gradient of the surface m (x, y).

However, a comparison analysis of both bathymetric models of 2D and 3D need to perform as the result of location foot of the continental slope by maximum change in the gradients using the same data set may be slightly different. The differences and the need to do a comparative analysis on the results obtained by the application of 2D, 3D or both was agreed by CLCS (paragraph 5.4.10. of the CLCS/11, 1999).

Several 3D methods have been developed and design over the past to determine a continuous trace of foot of the continental slope, among others designed by Vanicek et al. (1996) where the computation was based on the total surface of maximum curvature (SMC) using bathymetric data. This method also closely same interpretation to the provision of Article 76 where it can be considered that the total change in maximum curvature is equivalent to the maximum change in the gradient.

Another method to map the foot of the continental slope developed by Bennet (1998) by compute the second derivative surface in the gradient direction called the resulting surface of continental slope as "Surface of Second Derivative in the Gradient Direction" or "Surface of Directed Gradient" (SDG). The bathymetric data used by this method was pre-process by smoothing technique called bi-cubic spline smoothing.

Moreover, another method to determine the maximum change in the gradient was introduced by Clarke (2000) by calculated the surface of the second derivate using several thousand points (Persand, 2005). In this method, data filtering was applied because if not the maximum change in the gradient or the maximum curvature was not easily determined since the derivative maps are dominated by maxima with associated with much shorter wavelength, such as canyons, slump scars, diapirs, or small volcanic constructs (Clarke, 2000).

(a) Magnitude of the local slope, irrespective of orientation, is mapped out to highlight the location of high gradient;

(b) rate of change of gradient (the curvature) in the direction away from the margin is mapped out; and

(c) The topography is pre smoothed to remove topography with wavelengths less than a few kilometers and the curvature is again mapped (Clarke, 2000).

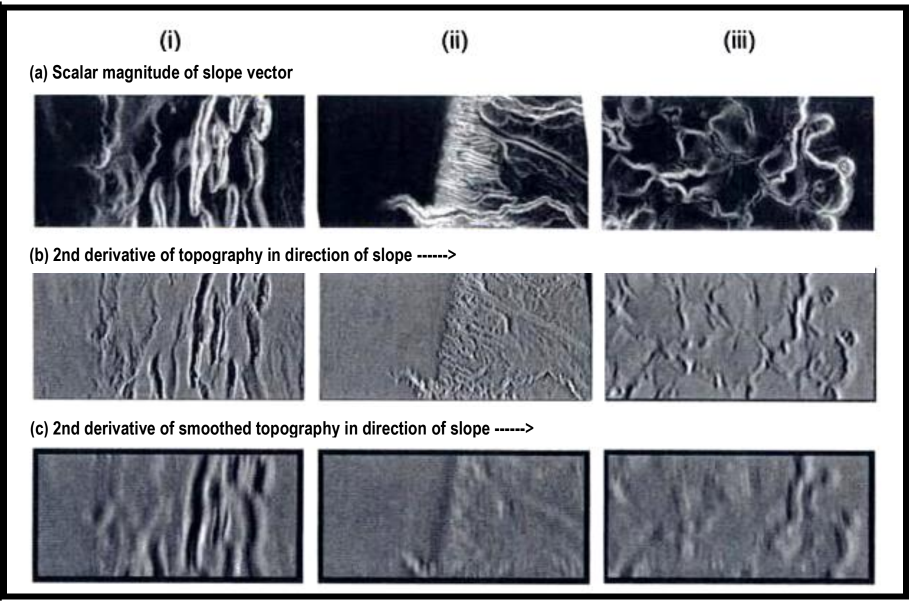

Figure 6: Multibeam data was used to infer the location of foot of the continental slope (after Clarke, 2000)

2.2 Filtering and Smoothing

Bathymetric data need to be used to determine the foot of the continental slope by means of maximum change in the gradient at its base. The second derivative obtained from the computation is normally an output based on the bathymetric data that have run through filtering and smoothing process.

The CLCS defines filtering in signal theory as the separation between signal and noise which is to be regarded as wanted or unwanted data. From perspective of Article 76, any data that obstructs the location of features along the continental margin comprise of shelf, slope and rise is considered as noise. There are various of filtering procedures, but the CLCS will only give more interest and pay close attention to the methodology such as the mathematical technique, and the output comprised of regularly space data set (CLCS/11, 1999).

The role of smoothing might have an important and useful application to use when the other bathymetric features might have similar wavelengths to those which define the location of the foot of the continental slope. Using the smoothing tool was allowed by CLCS but nonetheless, the CLCS will examine strictly the proper application for this, and the CLCS might request full disclosure of the original data, the mathematical details of smoothing algorithm and the output data.

3. DATA PROCESSING AND ANALYSIS

The area choose for this study is located in the southern most part of the South China Sea specifically in the area of the Dangerous Ground. South China Sea is a semi-enclosed sea area in dispute between the countries in the region due to the overlapping claims in whole or in part by Malaysia, Vietnam, Philippines, Brunei Darussalam and People Republic of China.

The data used is ETOPO1 grid provided by NGDC and can be downloaded at http://maps.ngdc.noaa.gov/viewers/wcs-client/. ETOPO1 is a one arc minute global relief model that connects the terrain between the land and sea. And, there are two types of software used for this study, which is Geocap (Shelf v6.4) and ArcGIS 10.1.

3.1 Gridding

By using Geocap, selection of gridding algorithm can be choose to set the parameter to generate the terrain modelling of the dataset. These gridding algorithm is Parabolic, Statistical Binning, Weighted Average and Single Beam. The Weighted Average algorithm is a default algorithm so it was choosen as it this algorithm will generate eight neighbouring grid cells to interpolate the grid to terrain modelling.

3.2 Map Derivative

From the gridded dataset, the surface of dataset can be generated from map derivative tools to produce a map with the gradient size, map in the direction of gradient or map the change of gradient in gradient direction. The algorithm to map the change of the gradient in gradient direction is same as the method developed by Bennet (1998). It is helpful to map the dataset using the map derivative tools to visualise the change along a gradient in along gradient direction or map of gradient size so that it can support the analysis on the placement of foot of the continental slope done through FOS analysis profile's tool to determine the maximum change in the gradient which further explained in next paragraph.

The texture map of change of gradient in gradient direction was generated rather than the scalar value and was overlaid with the critical foot of the continental slope point which derived from the bathymetric profile analysis tools to identify the maximum change of gradient of the seafloor at the base of slope region. The reason of the texture map was chosen because the scalar value was displayed for each grid node in the dataset. This gives more detailed information of the dataset.

3.3 Gradient Band Analysis

From the gradient band analysis , the base of slope region can be identified because it showed the gradient value for every region. It can be identified at the lower part of the morphological margin, and this region generally occured between the point where the general gradient of the margin became less than 1^{o} where it is the lower end of the range of slope gradients and above 0.5^{o} where it is the generally quoted upper limit of the rise gradient (Alcock et al., 2003).

3.4 Bathymetric Profile Analysis

14 bathymetric profiles were selected in a perpendicular direction to the depths estimates as a location at the point in maximum change in the gradient at the base of the slope region. From the gradient band analysis mentioned in above paragraph, the base of slope region can be estimate base on the steepness map derived. Hence, the 14 bathymetric profile was selected to start from the region between slope and rise only, which was identified as the base of slope region. This is to avoid an instability solution of the selected bathymetric profile cause by seabed roughness along profiles which might reveal many points of maximum change in the gradient, and the numerous of this possible points cause a confusing decision to locate the foot of the continental slope.

3.4.1 Filtering Algorithms

(i) Linear Re-sampling Filter

This algorithm is re-sample the bathymetric profiles with particular distance and interpolate linearly a new point. These new points are positioned on the straight line between the points of the original line. Several new points after sampling will be placed linearly in the same line if the sampling rate is denser than the original line and resulted the second derivative or the maximum change in the gradient equal to zero.

(ii) Spline Filter

Cubic spline algorithm gave a continuous first and second derivative to analyse the bathymetric profile which gave smooth lines approximately as the original input. The result derived from the spline filter than was resample with a specified interval that will give a better result instead of linear resampling.

(iii) Gliding Average Filter

This algorithm will calculate the value for each point along the bathymetric profiles and its neighbouring points with average value, and a specified paramater to the algorithm was set from the computation of the neighbouring points along the profile.

(iv) Median Filter

This filter function same as the gliding average filter where each point and its neighbouring points is set to the median value. Parameter specified in the algorithm is using the number of neighbouring points.

(v) Douglas Peucker

The Douglas Peucker algorithm generates a new line of points similar to the original input line, and it still preserve the basic shape of the original line. The tolerance was set between the original line to compare with the new line with the maximum deviance from the original line a lesser amount of than a given tolerance. By using this algorithm, it is useable to locate all essential points that characterize the profile including all extreme points. The output derived from the Douglas Peucker algorithm demonstrate a general representation of the seabed profiles without any true features represent significant physical spikes of the continental shelf sea floor.

(vi) Fourier Low Pass Filter

A Fourier Low Pass Filter relates with a signal theory where its filter noise or spikes along the bathymetric profiles line. The algorithm converts the original points along a selected profile approximately with a sum of sine and cosine functions with a different frequency. This filter will remove the unwanted frequencies and preserves the long wavelengths with low spatial frequency

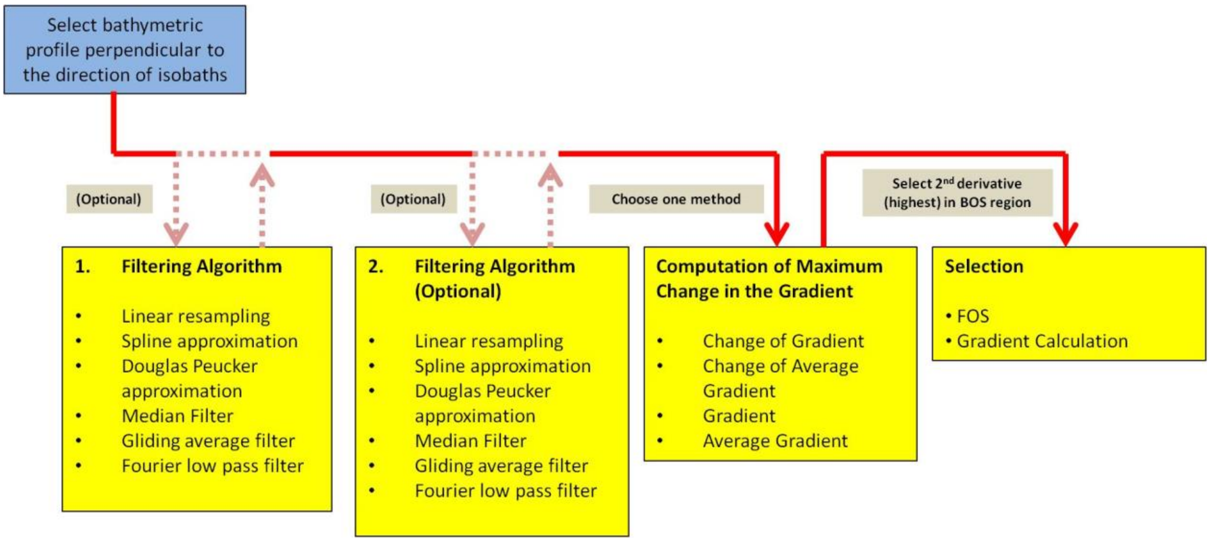

Figure 7: Geocap Bathymetric Profile Analysis Workflow to Determine FOS

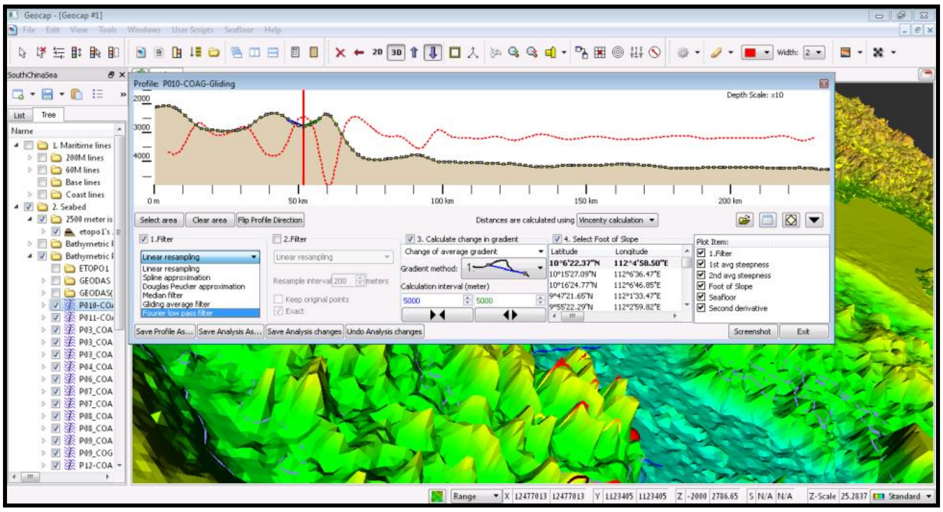

Figure 8: Screenshot from Geocap show the profile analysis tool with the selection of filtering algorithm

3.4.2 Computing the gradient and the change of gradient

(i) Finite Differences

Finite differences method used in Geocap to calculate the possible of derivative (approximately) is same as the definition of the derivative. But the function is not constant and the limit value which has a tendency near to zero will replace with finite differences.

$$f'(x) = \lim_{\Delta x \to 0} \left(\frac{\Delta y}{\Delta x} \right) \quad \text{is exchanged with} \quad f'(x_i) \approx \left(\frac{\Delta y_i}{\Delta x_i} \right)$$

where $\Delta x_i = x_{i+1} - x_i$ and $\Delta y_i = y_{i+1} - y_i$ ---------> Forward difference method

but if, $\Delta x_i = x_{i-1} - x_i$ and $\Delta y_i = y_{i-1} - y_i$ ----------> Backward difference method

The result from one of the methods is used to the other method to compute the second derivative. The derivative derived from point x only comprise the value at xi and another two neighbours points and its sensitive to local variations and noise along the data. This method not suitable to implement over a larger interval profile.

(ii) Computing Change of Gradient

Formula to calculate change of gradient as below (Mugass, 2005):

$$\Delta Gj = [f'(x_j)^+ - f'(x_j)^-] \div [\Delta X^+ + \Delta X^-]$$

where,

ΔX^+ = length of the interval after x_j and ΔX^- = length of the interval before x_j.

$[f'(x_j)^+$ = average gradient in x_j, $x_j + \Delta X^+$ and $f'(x_j)^- = x_j - \Delta X^-$, x_j.

(iii) Change of Average Gradient

This method was introduced by Geocap as a need to have a technique to examine a larger interval profile. Change of average gradient method computes the average of the gradient before and after the point, within given interval and these two values of steepness was compared to find the change of a gradient along the selected point.

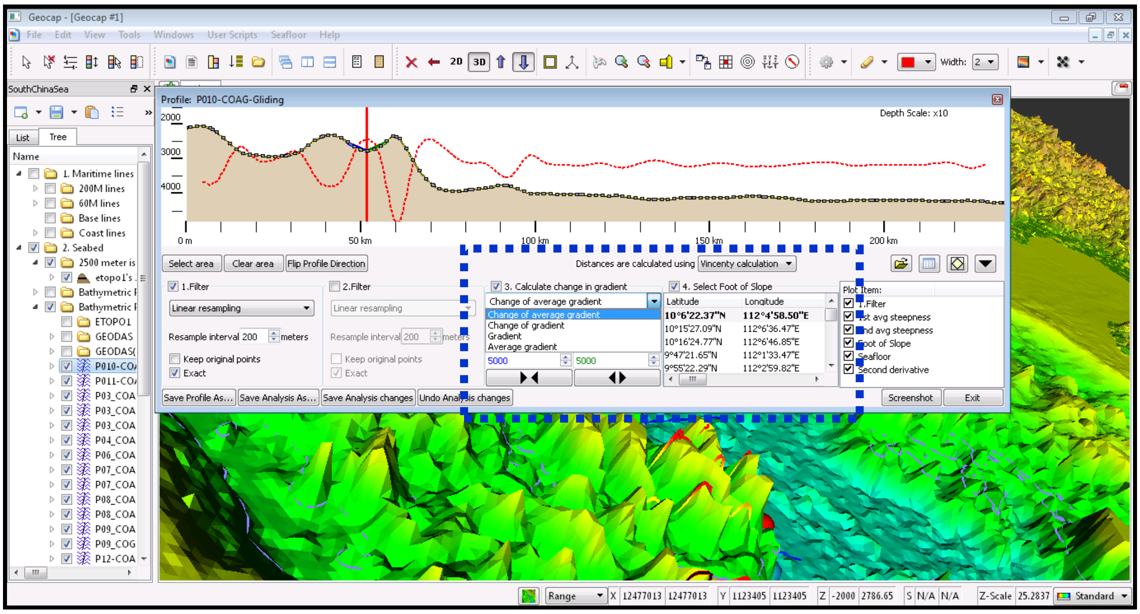

Figure 9: Screenshot from Geocap show the algorithms to calculate the 2nd derivative

3.4.3 Calculation of Slope and Curvature

The slope algorithm built in ArcGIS software apply the nearest neighbourhood method to calculate the slope. The neighbourhood technique calculates the slope at one grid point by comparing the elevations of the eight (8) grid points that surround it. For each cell, the maximum rates of change in value from the grid cell to its neighbours were calculated and the maximum change in elevation (rise) over the distance (base) connecting the cell and its neighbours identifies the steepest downhill descent from the hill. If there is a cell location in the neighborhoods with a No Data z-value, the z-value of the center cell will be assigned to the location.

By comparing the elevation values of neighbouring grid cells using the neighbourhood algorithm the percents of slope in each cell Z_5 can be estimates. The percent slope at grid cell Z_5 was estimated the sum of the absolute values of east-west slope and north-south slope, and multiplying the sum by 100.

Another algorithm useful in ArcGIS to calculate the slope of the slope or the change of the gradient is a curvature tool. From the raster input surface, the second derivative was calculated on a cell by cell basis.

4. RESULT AND DISCUSSION

4.1 Continuity of continental margin

From the ETOPO1 bathymetric data, the contour map of South China Sea in 2D was generated (see **Figure 10**) and it demonstrated the continuity of the continental margin where it shows a natural prolongation of the continental margin from the landmass up to the ocean floor. The colour band from the map divides the margin between continental shelf, slope, rise and deep ocean floor. It is a requirement for a coastal State to carry out a test of appurtenance or a desktop study to show the prolongation from the landmass up to the deep of ocean floor. From the contour map, the water depth between rise and slope approximately between 2867 m to 5068 m. Hedberg (1981) proposed that the most suitable location of the foot of the continental slope was at about 4000 - 4500 m water depth, at the base of an upper rise.

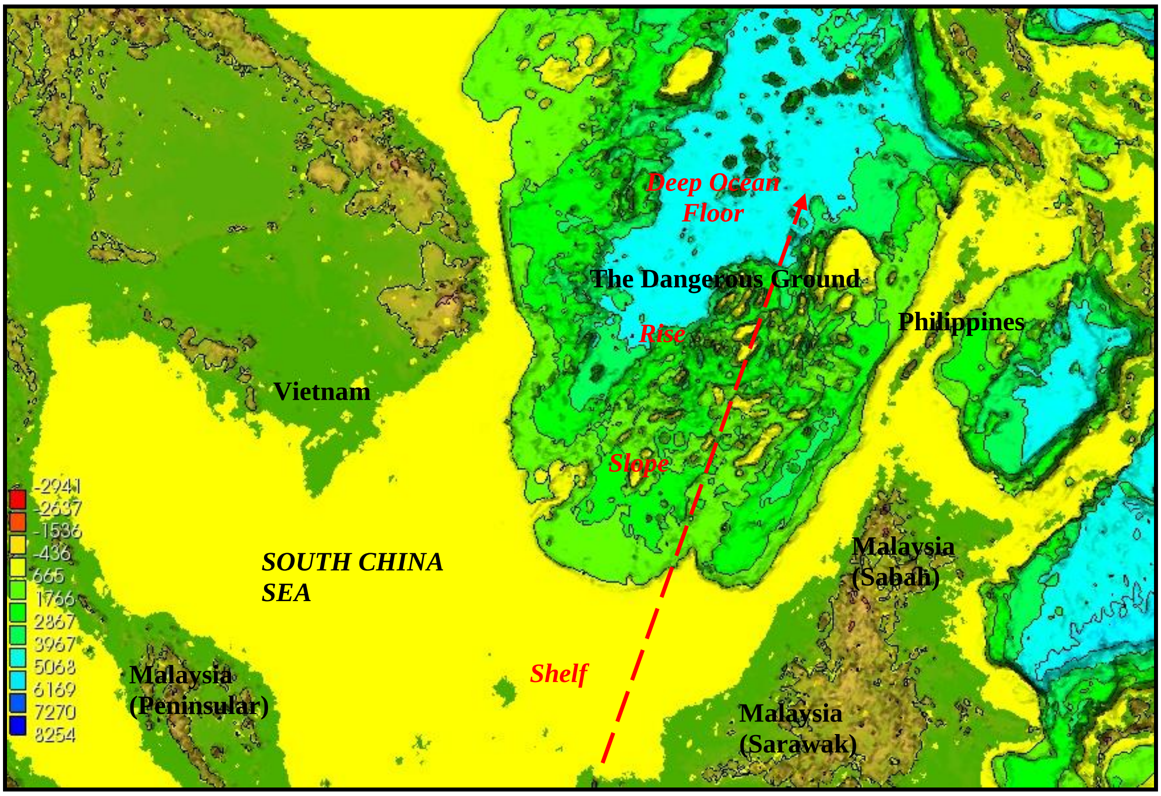

Figure 10: Continuity of continental margin of South China Sea

4.2 Change of Gradient in Gradient Direction's Map

The result of derivative map change of the gradient in gradient direction to determine the base of the slope region (Bennet, 1998) was generated. From the map, the yellow shaded area is the direction of gradient change and the possibility an area of base of the slope region close to the vicinity of The Dangerous Ground Area. From this derivative map, the coastal State can verify where is the BOS region so that location to select the bathymetric profile to analyses the location of maximum change in the gradient should be not confused. However, the orientation of selected bathymetric profiles must be perpendicular to the orientation of contour and follow the direction of the gradient.

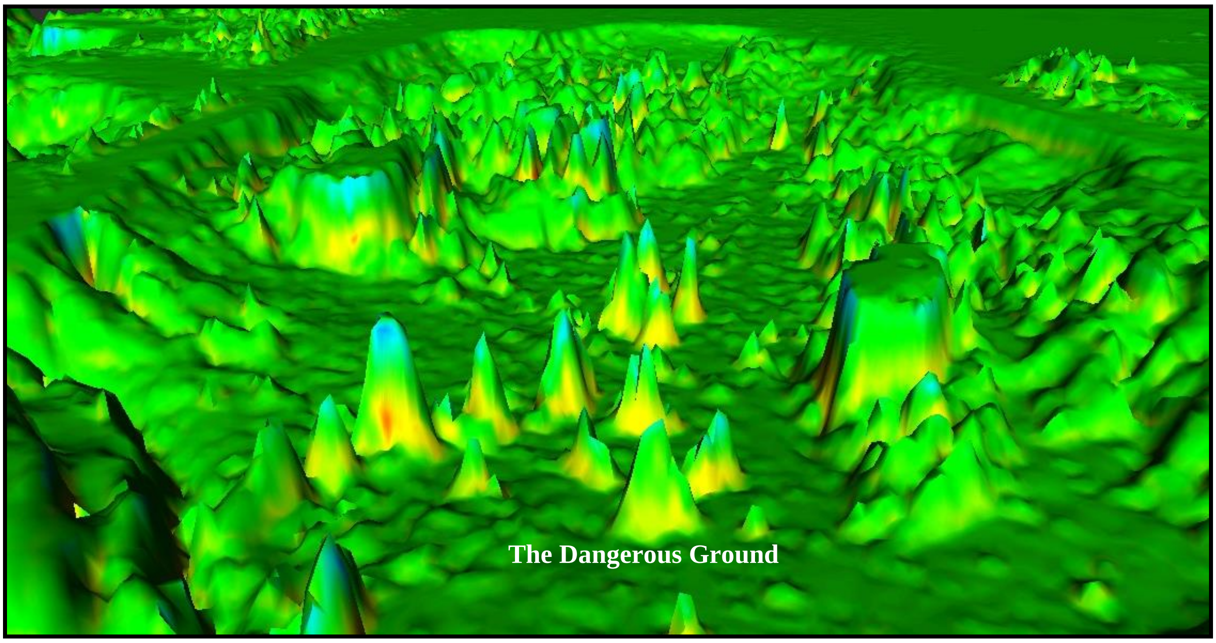

Figure 11: Change of Gradient in Gradient Direction's (shaded with yellow) in the vicinity of The Dangerous Ground

4.3 Gradient Band Analysis Map

Map showed the gradient band analysis illustrate the morphology of South China Sea based on the gradient analysis. From this map, base of the slope region can be identified at the lower part of the morphological margin where the general gradient of the margin became less than 1º where it is the lower end of the range of slope gradients and above 0.5º where it is the generally quoted upper limit of a rise gradient. From the map, it can be seen that the surface of a gradient between 1º (shaded with pink) to 0.5º (shaded with brown) could be the location of Continent Oceanic Transition (COT) or Continent Oceanic Boundaries (COB) where it is the logical point equivalent to the foot of the continental slope (Alcock et al., 2003).

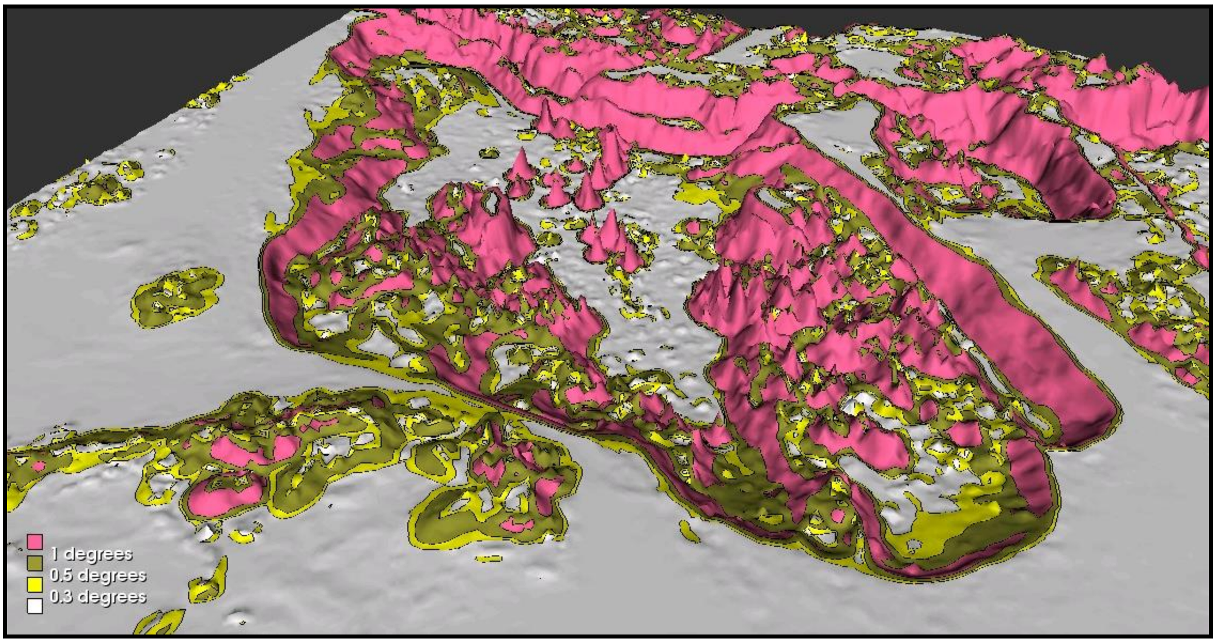

Figure 12: Gradient Band Analysis Map of The Dangerous Ground Area

4.4 Bathymetric Profile Analysis to Determine Foot of the Continental Slope

14 selected of bathymetric profiles from ETOPO1 data was generated and the result displays are 2D profiles comprise of analysis of depth and distance, and a 3D visualisation of the selected bathymetric profiles generates from the coordinates and depth. Based on the studies to the maps generates as discussed in paragraph of 4.1, 4.2 and 4.3, it is crystal clear and verify the correct location to select the bathymetric profile to analyse the location of foot of the continental slope which is in the vicinity of The Dangerous Ground Area between the slope and the rise margin, and the gradient of these margin is between 1º to 0.5º.

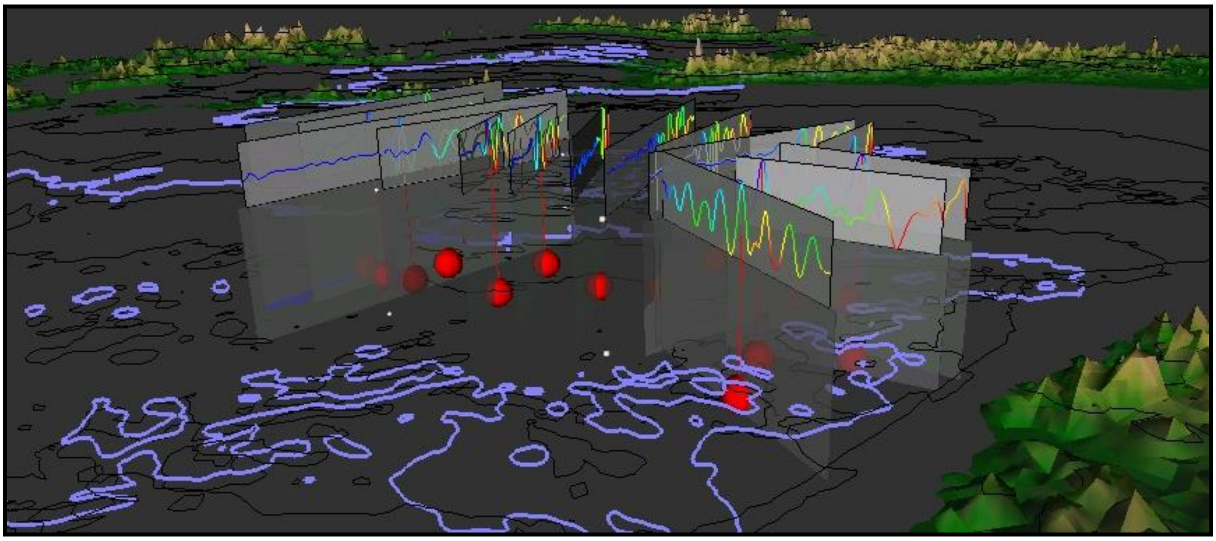

Figure 13: Combination of 14 selected profile in 2D profiles process in Geocaop Shelf to determine the 2nd derivative (maximum change in the gradient) which shown as red line.

14 selected critical foot of the continental slope were overlaid with the contour map of 2500 m isobaths derived from ETOPO1 to validate the selection of FOS. It was proven based that the critical FOS falls beyond the 2500 m isobath within the range of 2740 m to 4515 water depths.

Having a Geocap as one of the dedicated software to determine the foot of the continental slope assist the coastal State to make a decision related to the technical aspect on the law of the sea. The algorithms built in Geocap has proven from this study, it gives a satisfied result relates to the computation of the second derivative to define the maximum change in the gradient. The bathymetric profile was analyse mostly using the method proposed by Geocap known as Change of the Average Gradient. It gives a suitable location of FOS and this algorithm was useful to analyse the profile with long interval.

Moreover, the Geocap also come along with the algorithm to map derivative of map change of the gradient in the gradient direction and gradient band analysis. These maps can support on the identification of base of slope region and identification of the gradient of sea floor surface.

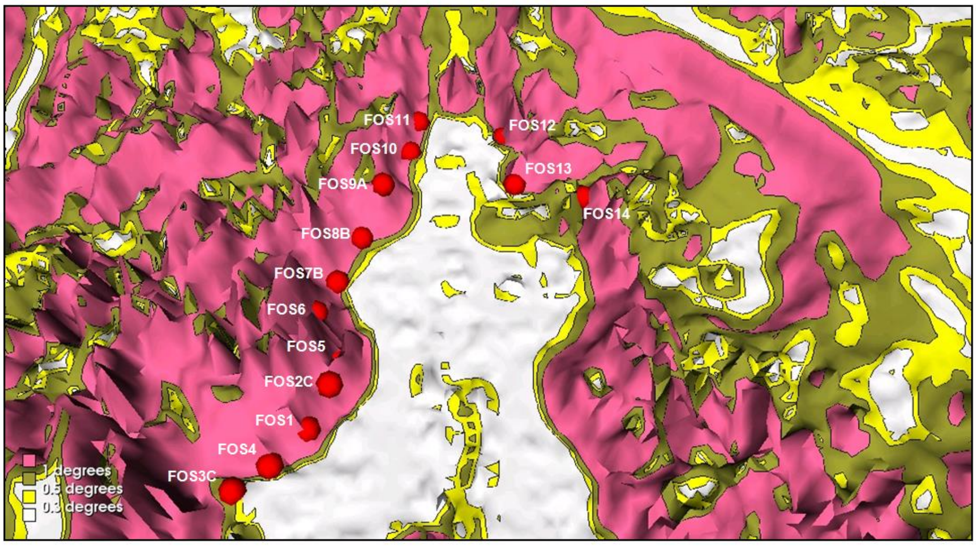

Figure 14: 3D Gradient Band Analysis Map overlay with 14 points of selected foot of the continental slope (FOS)

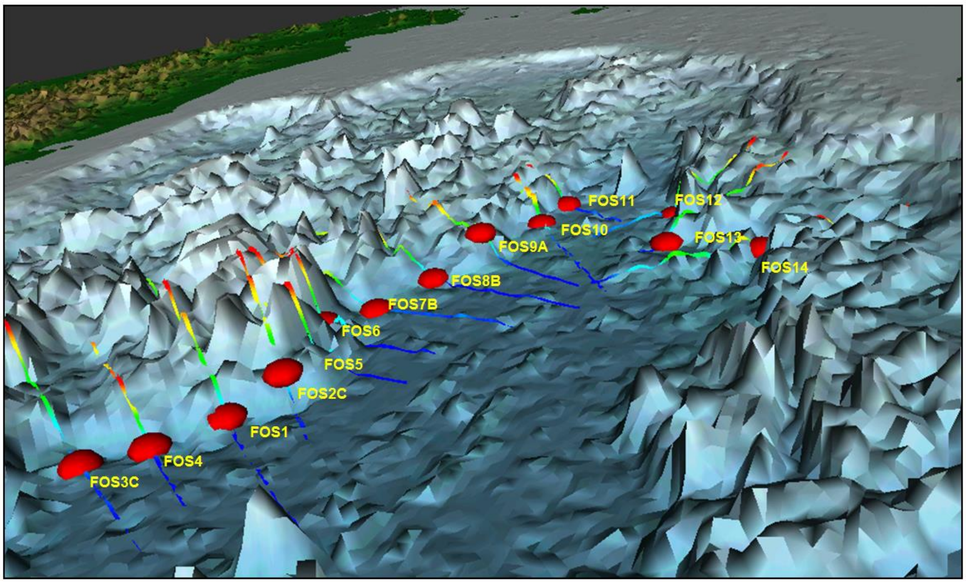

Figure 15: 3D bathymetric map (ETOPO1) overlay with 14 critical selected FOS points

4.5 Supporting Evidence from Geological and Geophysical Map

Justification on the location of base of the slope region where it is also a Continent Oceanic Boundaries (COB) or Continent Oceanic Transition (COT) was done by preliminary study to the map from W. Ding et al. (2003). From the map, it is clearly showing the morphological features and the COB or COT in the Dangerous Ground Area of the South China Sea.

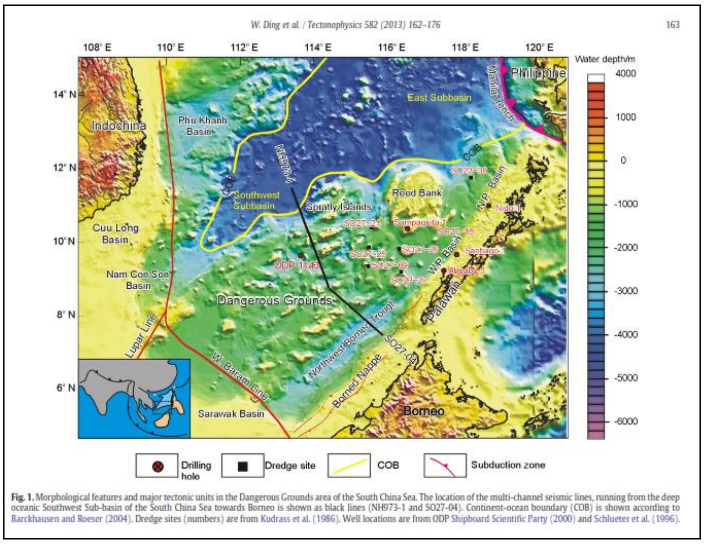

Figure 13: Show the morphological features and the COB in the Dangerous Ground Area of the South China Sea. (from W. Ding et al, 2013)

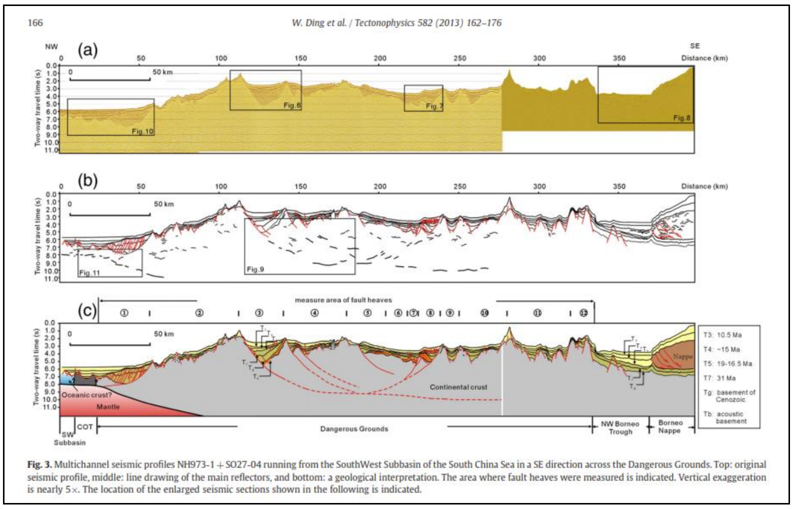

Figure 14: Show the multichannel seismic profiles NH973-1 + SO27-04 as shown in Figure 5.27 coloured in black line running from the SouthWest Subbasin of the South China Sea across The Dangerous Ground Area (from W. Ding et al, 2013)

5. CONCLUSSIONS AND RECOMMENDATIONS

Determination of foot of the continental slope at its base pursuant to the Article 76 of UNCLOS 1982 is a complicated subject that need to digest from every aspect comprises of geodetic, hydrographic, geomorphology, gelological and geophysical. Foot of the continental slope is a unique points that become as key elements to delineate the outer limit of the continental shelf beyond 200 M.

The data used in this study is a ETOPO1 gridded bathymetry which is only permissible to be use to demonstrate the continuity of continental margin, but for the real submission by coastal States the determination of foot of the continental slope have to used the actual single beam or multibeam data. This is the rule set by CLCS.

The recommendation from this study is, the coastal State should have a strong justification with regard to the determination of foot of the continental slope. Choice of software with sophisticated and robust algorithms can assist the submission with a confident information. This will give a clear information about the submission when it come to the CLCS to review of the submission.

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BIOGRAPHICAL NOTES

- Completed Bachelor of Geomatic Engineering at the Universiti Teknologi Malaysia in 2004 and Diploma on Law of the Sea at Yeosu Academy, South Korea in 2015
- Early career began as a data processor at the Fugro Geodetic (Malaysia) Sdn. Bhd and joint the Department of Survey and Mapping (JUPEM) in May 2005 since then has developed interest in boundaries affairs particularly geo-technical aspects of the law of the sea relates to maritime boundary delimitation, delineation of the extended continental shelf and marine jurisdictional issues.
- Desk Officer for Malaysia Continental Shelf Project since 2006 until 2015 and involved with the Joint Submission Malaysia and Vietnam (submitted on 6th May 2009 to Commission on the Limits of the Continental Shelf, United Nations).

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