

A New Approach to Mapping of the Continental Shelf

Olav Egeland

Manager of GeoCap AS , Norway .

Website: www.geocap.no

Email: olav.egeland@geocap.no

Abstract

New demands on the modeling of the continental shelf require the need for 3D graphics connected to seismic interpretation of seabed sediments.

A new module dedicated to the mapping of the continental shelf combines advances in seismic visualization with calculation of formal juridical concepts to determine the foot of slope and the outer edge of the continental margin.

The module has been tested on the Norwegian shelf and the results will be presented in a case study. The presentation will give a brief summary and display of relevant features connected to continental shelf interpretation and mapping. The main focus will be on the calculation of the maritime zones of jurisdiction of the continental shelf. Interpretation and selection alternatives will be demonstrated and classified.

The module applies the rules stated in UNCLOS Article 76 as guidance for the algorithms and working procedures.

Geodetic transformations are used when calculating distances in nautical miles and displaying geographical coordinates of various projections.

The software is an integrated part of the Geocap modeling and mapping system.

1. Presentation form

This paper contains text and images that were presented in an interactive demo at the ABLOS Conference in Monaco 2003 October 28-30. The images reflect the main steps in the live visualization using the new module in Geocap.

The presentation is about a test case study initiated by the Norwegian Petroleum Directory to investigate using an integrated 3D system for mapping and determination of territorial limits of the continental shelf. The emphasis is on the methods of the study and the integration of work within one package.

The result of the study is unofficial. The task was to utilize recent advances in a modern 3D system incorporating seismic interpretation with the technical specifications of UNCLOS Article 76 to determine the foot of slope and analyze the potential for the outer territorial limits on the continental shelf.

2. Arial overview and thematic picture.

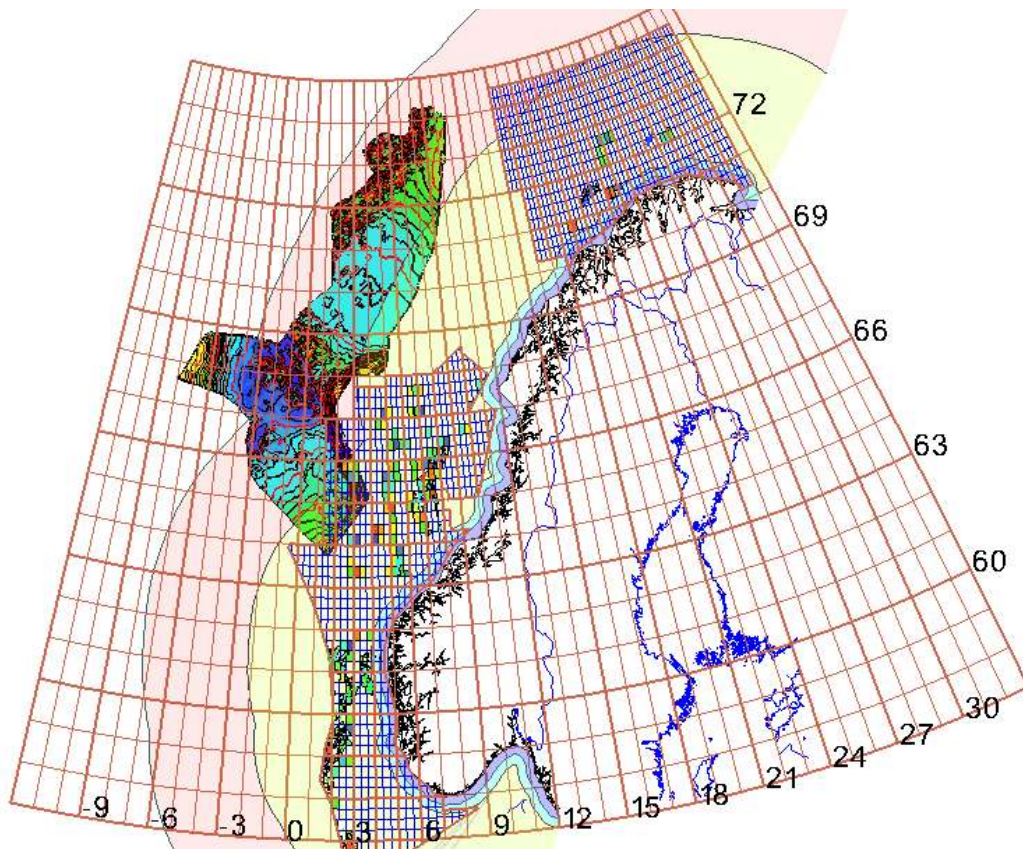


Figure 1 Thematic picture. Shows the Norwegian coast line and oil licenses together with the contiguous zones 12, 24, 200 and 350 M. The large displayed structure is subjected to a study to determine the outer territorial limits of the continental shelf.

The display in Figure 1 is viewed in 2D mode looking from above.

In Figure 2 the same structure is displayed in perspective mode.

One nice feature with the presented working methods is the ability to switch between 2D and 3D mode.

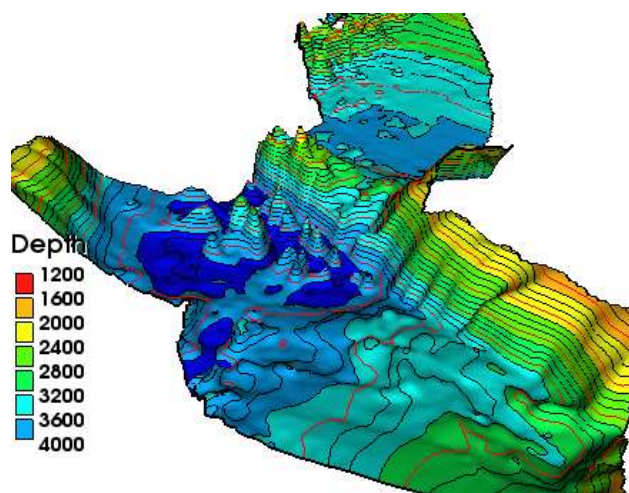


Figure 2 Seabed model.

3. Making a grid model from sonar data.

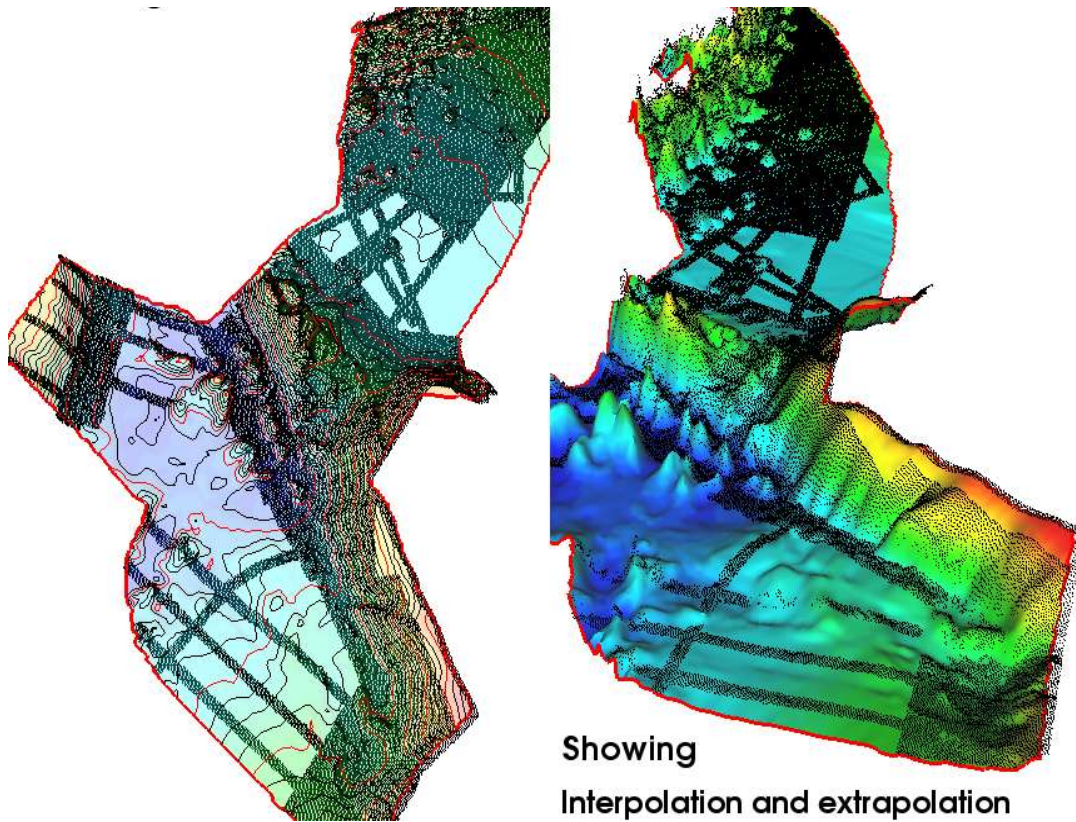


Figure 3 Gridding of input sonar data.

In Figure 3 , the picture to the left shows the sonar data displayed together with the seabed in a transparent form. The seabed structure was gridded using the sonar data as input. The picture to the right shows the resulting surface. The sonar data is filtered from noise and honored in the gridding process. The areas of interpolation and extrapolation are visible in the map.

The gridding algorithm applies a sort step with a spiral search for input data at each grid node. A parabolic interpolator will then evaluate the collected points at the node. Three grids were worked out with different grid node spacing: 200 meter, 2000 meter and 4000 meter. All three grids are used in the presentation.

The spiral search for input data varies with the density of the input points. When the data density is high the search will soon pick up enough points while low density will require the spiral search to spin wider until the necessary and sufficient number of points are found. Thus the seabed modeling turns out rather satisfactory for the different areas of interpolation and extrapolation.

4. Displaying and interpreting seismic 2D sections.

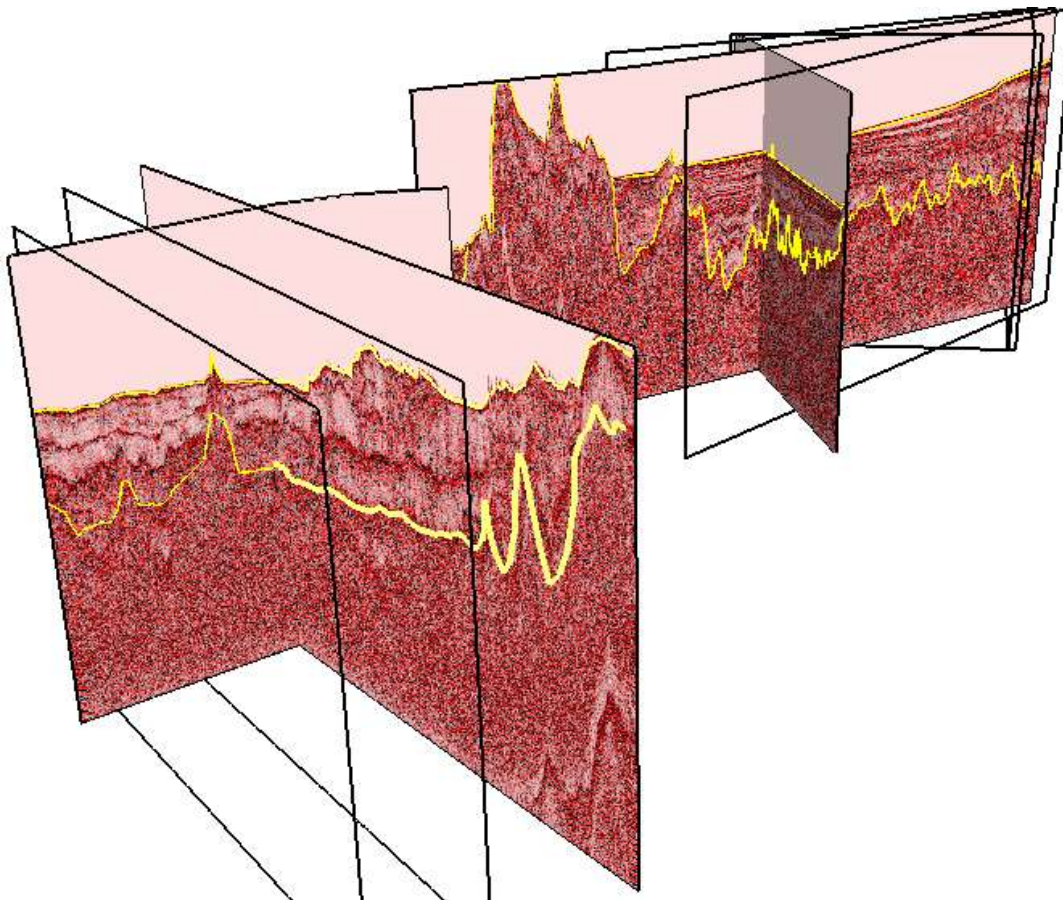


Figure 4 Seismic 2D sections.

After modeling the grids, 2D seismic lines were displayed and interpreted. Their importance is directly connected to the evaluation of the outer limit of the continental shelf in connection with the sediment thickness parameters as defined in UNCLOS Article 76.

The area to study has ten seismic 2D sections. Figure 4 shows the outlines and a few examples of the seismic sections. The yellow lines are digitized interpretations. The seabed reflector lines are quite obvious, but the lower sediment lines (base sediments) are more open to interpretations.

The seismic sections are all in the time domain. The interpreted lines must be converted to depth.

5. Studying a single seismic section.

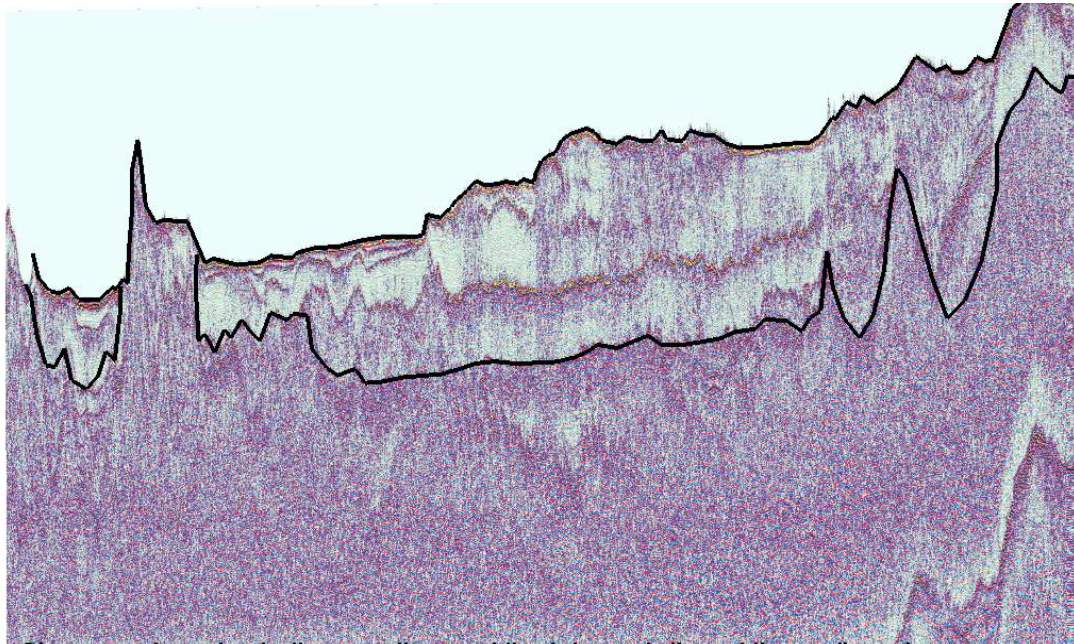


Figure 5 Close up of a single seismic section.

Each seismic section had to be interpreted by digitizing two reflectors: the seabed and the base sediment. These two reflectors together form the cross section of the sediment in the time domain.

When displaying a seismic section one can apply different color tables to highlight the seismic signals. Seismic color tables are developed for this purpose.

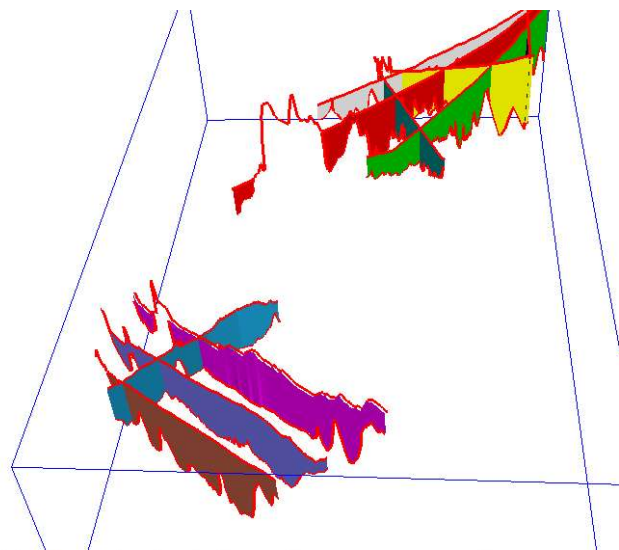
In the picture above, a faint white spot in the middle area can be seen. These reflections were not included in the interpretation because of their vague appearance.

The sharp reflection in the lower right is a false image; i.e. multiples of already recorded signals.

The seabed reflector is so distinct that one can apply the auto tracker which follows a sharp edge and produces a contour.

The interpretation of the base sediment is normally not so distinct and care has to be taken during the interpretation.

6. Converting digitized sediment lines in cross sections.



The seabed reflector and the interpreted base sediment for each seismic section are combined into a cross section model.

The interpretation should be consistent so that crossing sections match and have the same sediment thickness.

Consistency is maintained by the display of previous interpretations.

Figure 6 Interpreted seismic shown as cross sections at their locations.

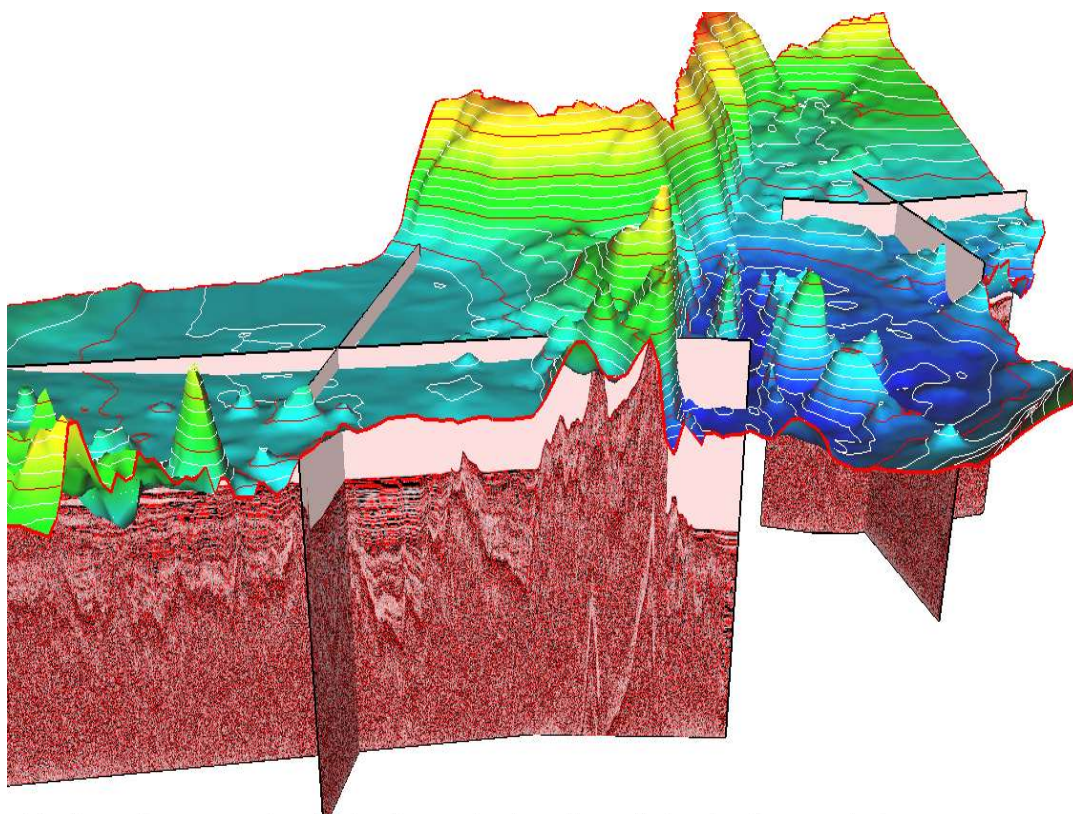


Figure 7 Seismic sections in time and seabed in depth.

The display shows the mismatch between the seismic sections in time and the seabed model which is in depth. The time values for the seabed lines are far below the real seabed. The seismic time values have to be converted to depth values.

7. Depth conversion of seismic time sections.

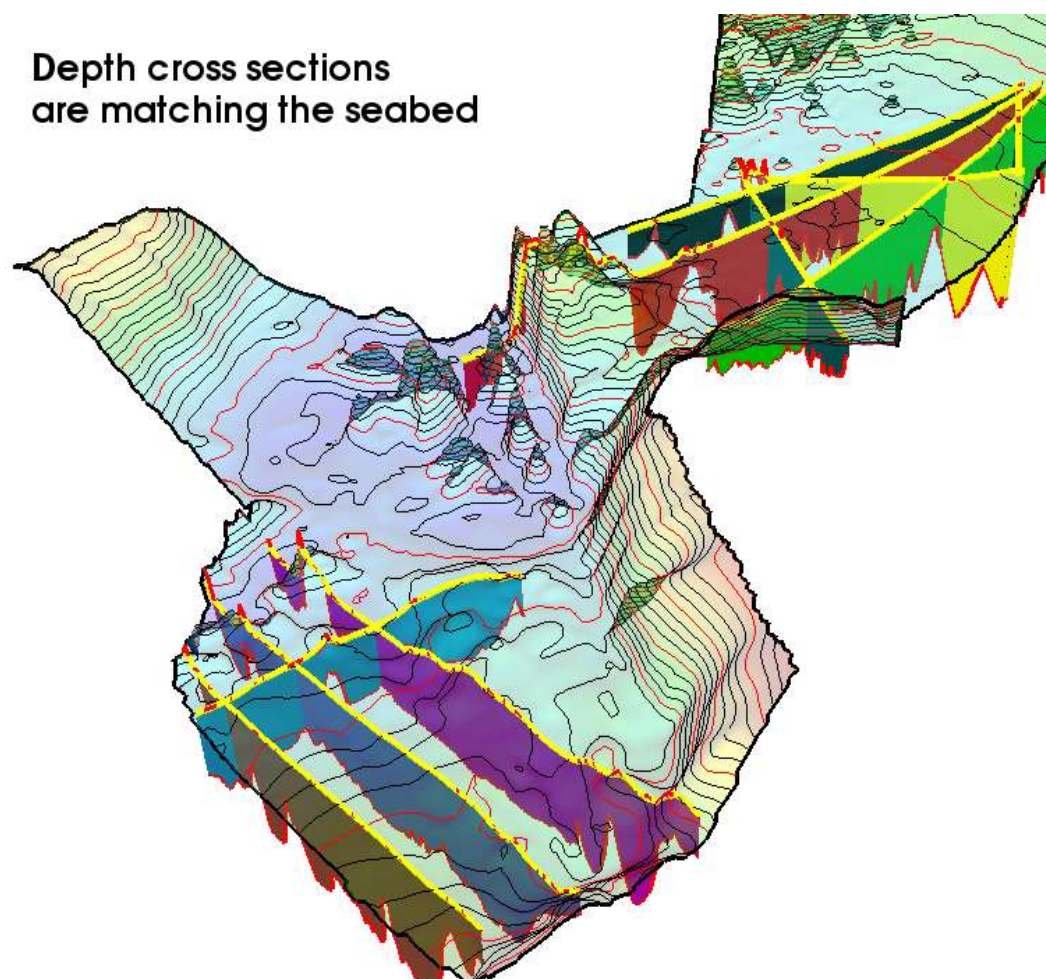


Figure 8 Depth converted seismic cross sections displaying sediment thickness in thru depth.

The seabed has been given a transparency in order to see the depth cross sections of the sediments. They are now correctly attached to the seabed as the yellow lines show.

Depth conversions were performed by multiplying the seismic seabed lines in time with the velocity of sound in salt water. That lifted the seabed lines up to the real seabed in depth. The signals making up the bottom sediment lines have also gone through the same water depth and consequently these lines were lifted the same amount at corresponding positions in the seabed lines.

In the interest of simplicity the sound velocity of the sediments was assumed to have a depth to time ratio of 1.

Depth conversion is an important and critical operation in order to find the correct sediment thickness. There are various formulae and procedures to deal with the different cases in the integrated system.

Often there is a different velocity for each sediment layer. A lookup formula will convert from time to depth. If the lookup curve varies laterally one can apply an algorithm called 'multiple lookup curves' which interpolates between adjacent lookup curves. Another popular technique is to model a 3D velocity cube. Any dataset with time values that is probed into that cube will come out in depth values. All these methods for depth conversion are implemented in the Geocap system.

8. Analyzing the seabed.

Much of the terrain analysis deals with the placement of the foot of slope line. This line should ideally be placed at the maximum gradient in the direction of slope.

An azimuth map is a color mapping of the direction of slope.

The orthogonal contours (in black) will always be orthogonal to the terrain contours (in white).

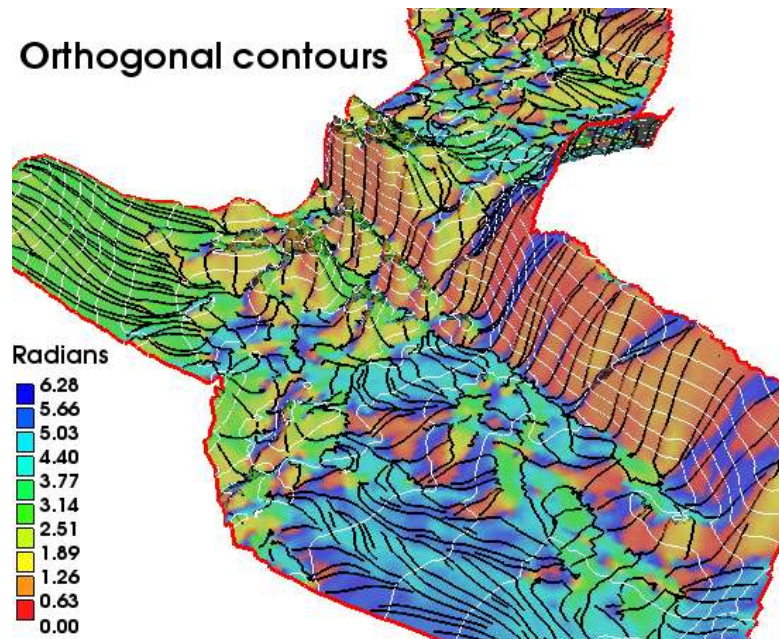


Figure 9 Seabed azimuth map.

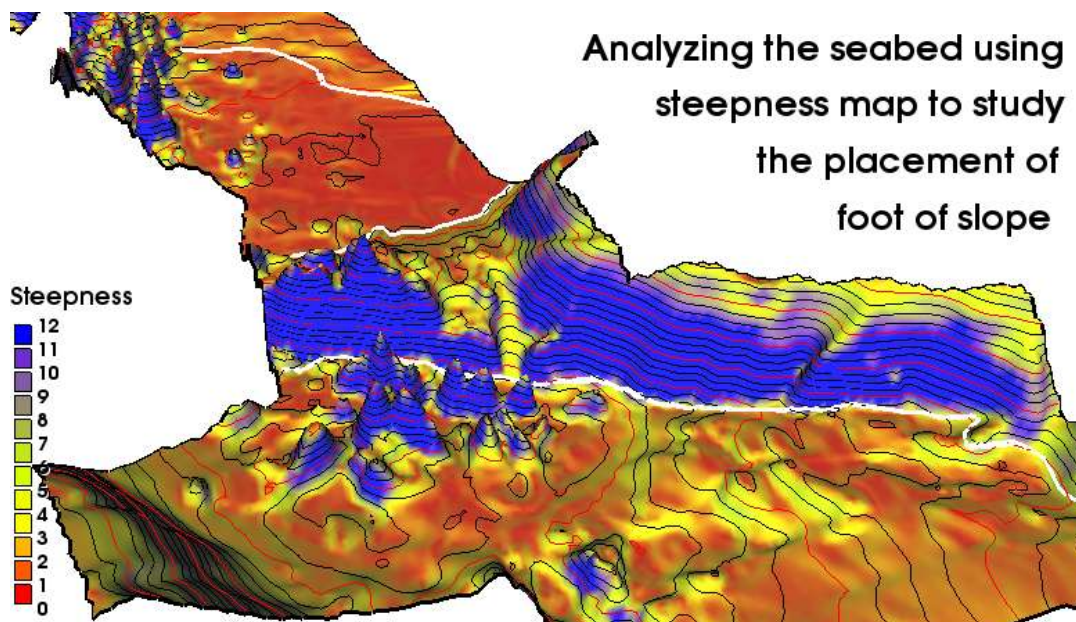


Figure 10 Steepness map.

The steepness map is achieved by calculating the first derivative. Using a suitable color table, one will normally get a good impression of the change in slope and seabed areas which are good candidates for the placement of foot of slope. In cases where the seabed shows a clear change in slope as in the southern part of the seabed in Figure 10, the placement of the foot of slope line can be digitized directly.

9. Mapping the change in gradient.

Foot of slope determination
using maximum gradient
second derivative

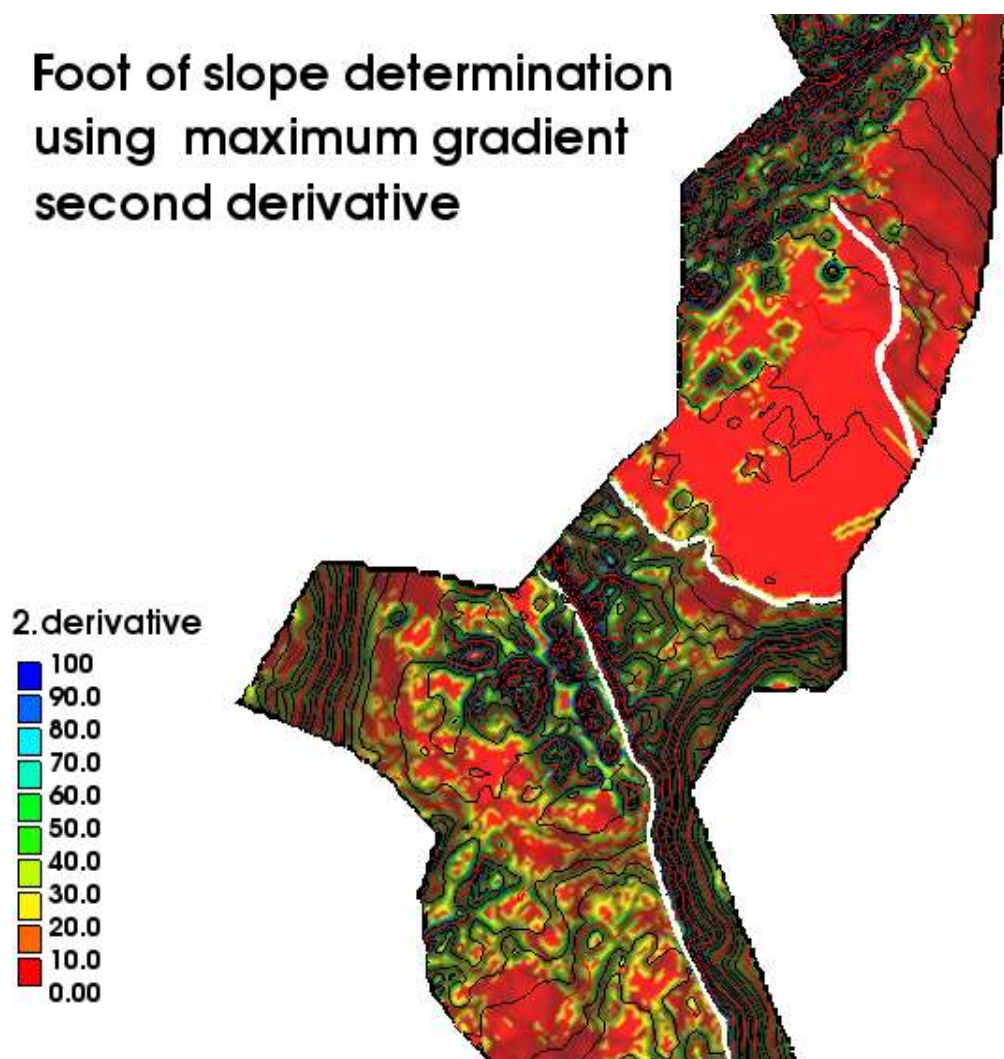


Figure 11 Color map of the second derivative showing change in gradient.

Another terrain study is to work out a color map for the second derivative. This is usually a more difficult map to interpret than the first derivative. However, using a suitable color table one normally can reveal the interesting area for the foot of slope line as the displayed picture shows. It is useful to study this map directly in the 3D model of the seabed and see the placement of the foot of slope line.

The foot of slope lines are drawn in white on the seabed.

10. Making several cross sections along the foot of slope line.

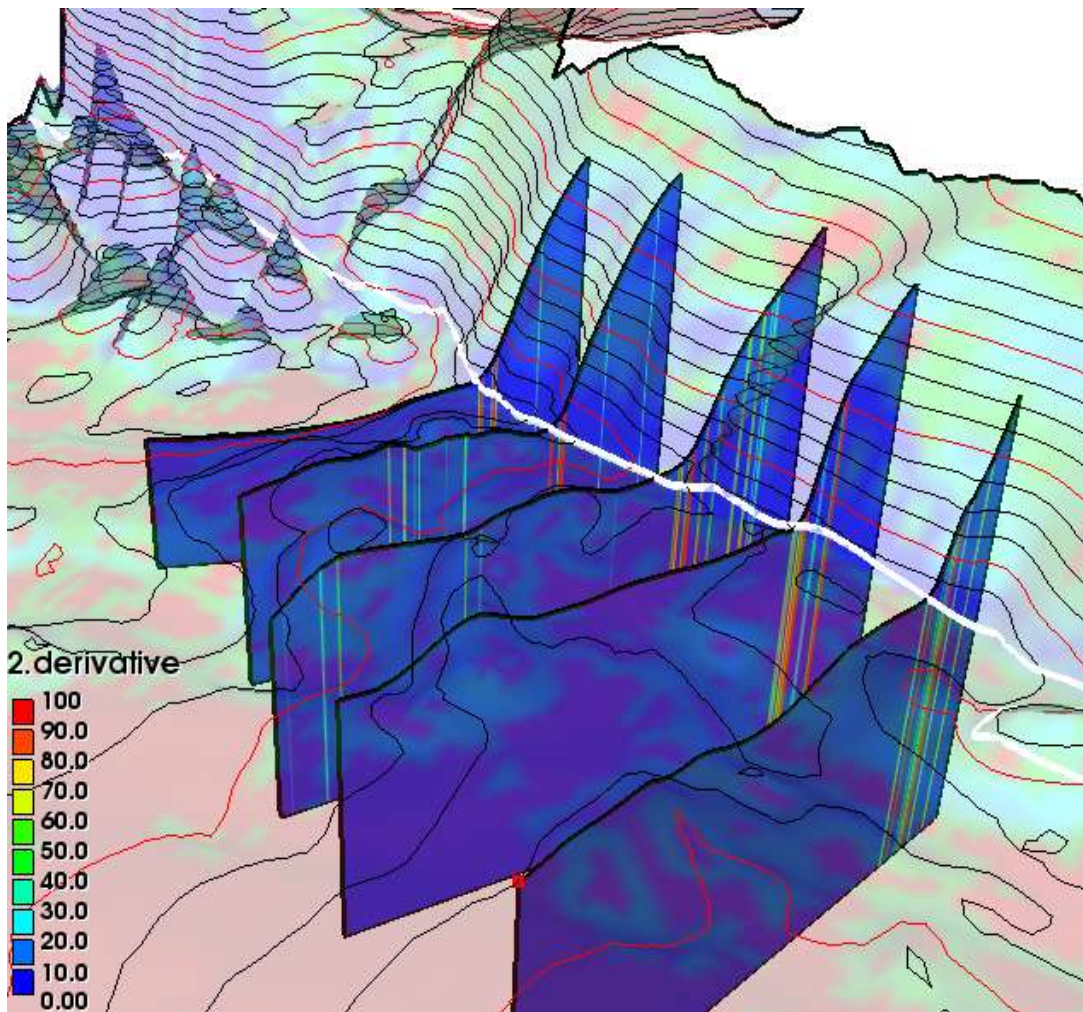


Figure 12 Cross sections of seabed model showing change in gradient as color bands.

The foot of slope line can also be analyzed by several cross sections at strategic places. The gradients are displayed as spectral lines in the cross section. The second derivatives are normalized to values between 0 and 100 to get a standardized range of values.

Any cross section can be displayed in the 3D model at its proper location thereby increasing the understanding of the foot of slope placement.

During a study one should operate in both 2D and 3D mode to achieve optimal insight into the nature of the seabed curvature from cross sections and surface maps using appropriate color tables.

11. Studying a particular cross section with different color table.

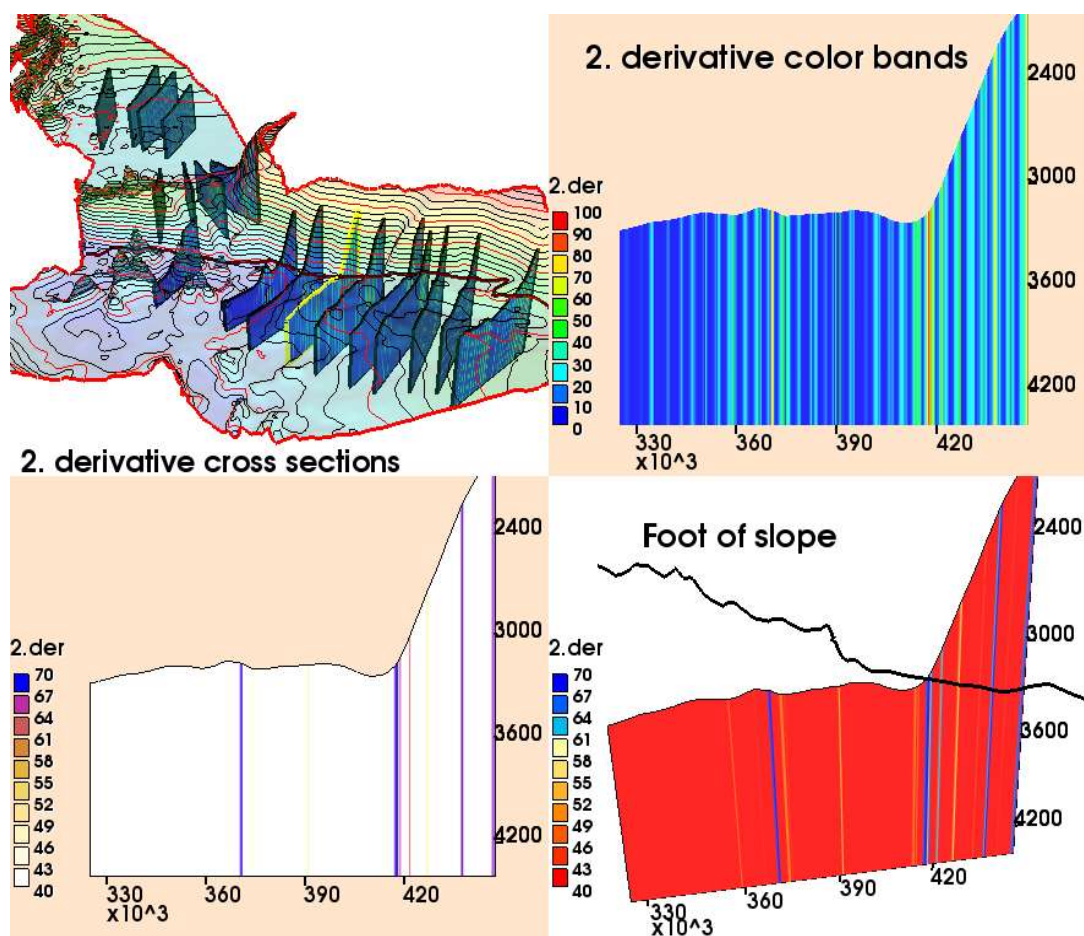


Figure 13 Display of cross sections to analyze foot of slope placement.

The above image montage shows a set of cross sections that were placed along the slope area. One particular cross section, highlighted in yellow, was studied in detail using various color tables.

To achieve a good cross section display one has to try several color tables and set up a mapping range properly to get the colored spectral lines as desired.

Any cross section can be mapped in a separate view port for clarity. It is still a full 3D model and can be displayed together with the foot of slope line when it is digitized.

The foot of slope line can be moved interactively by either using the line editor menu, or transferring the line to a spline widget which responds to immediate cursor actions as often seen in modern 3D visualization systems.

12. Further analysis of the northern part.

The northern part of the seabed terrain has a very flat area that makes it difficult to find a good place for the foot of slope line. Further analysis is necessary.

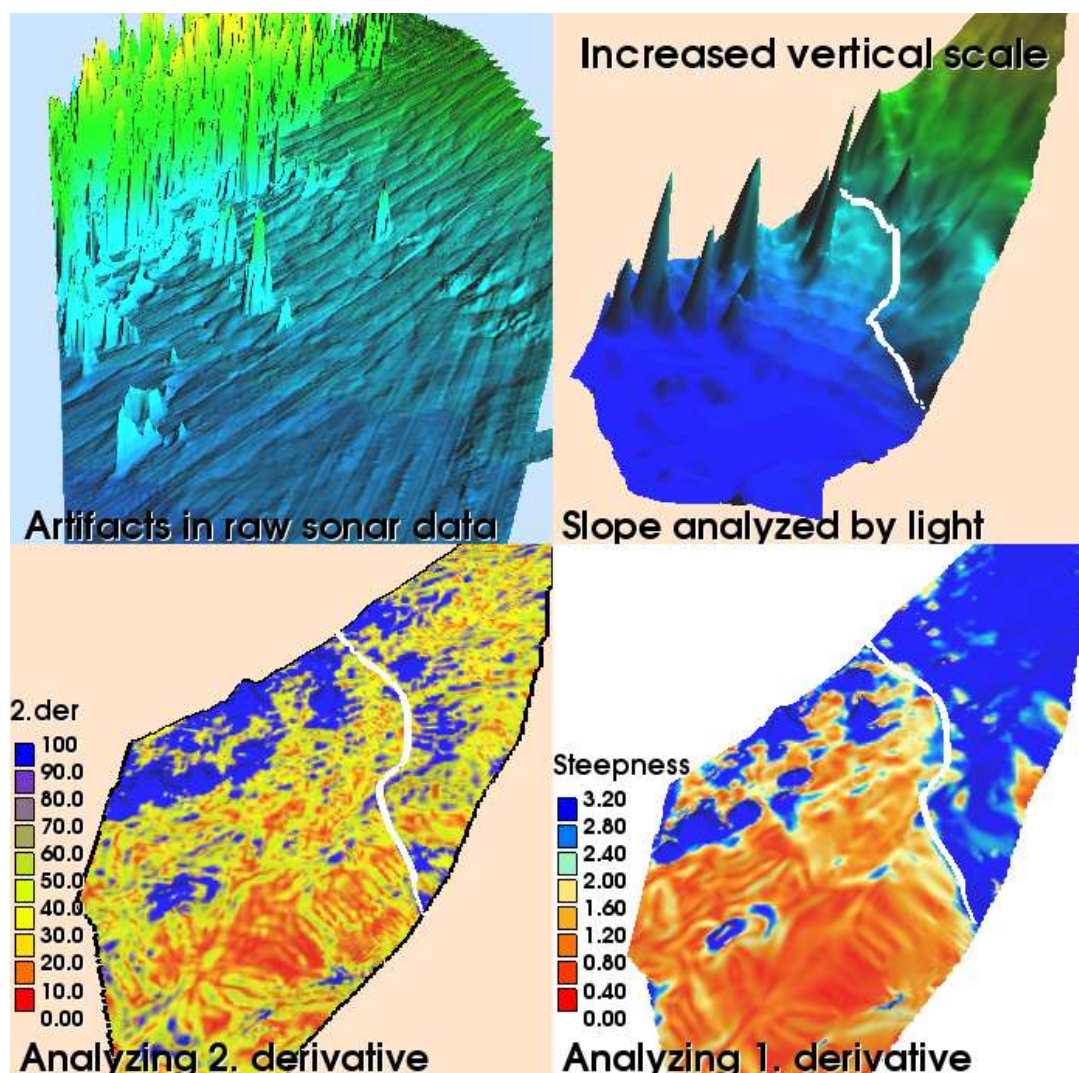


Figure 14 Detailed analysis of the northern part of the seabed.

The upper left image in Figure 14 shows unfiltered raw data displayed with the light coming in from the east. The artifacts of the ship collecting the sonar data are clearly visible. The swath width is rendered as broad bands.

The gridding process can smooth out errors that obviously are due to recording or collecting of data. This is done in the image in the upper right. In addition, the vertical scale has been increased more than 300 times to reveal the bend in the slope. In addition by using light coming from east, the foot of slope line can be adequately placed.

At lower left, a color map of the second derivative with a full range color table shows a kind of banded pattern across the seabed.

At lower right, the steepness of the slope is mapped and the foot of slope line displayed where the terrain has a clear bend. As can be seen from the color legend, the area below the blue color has steepness below 2 degrees.

13. Displaying various UNCLOS Article 76 lines.

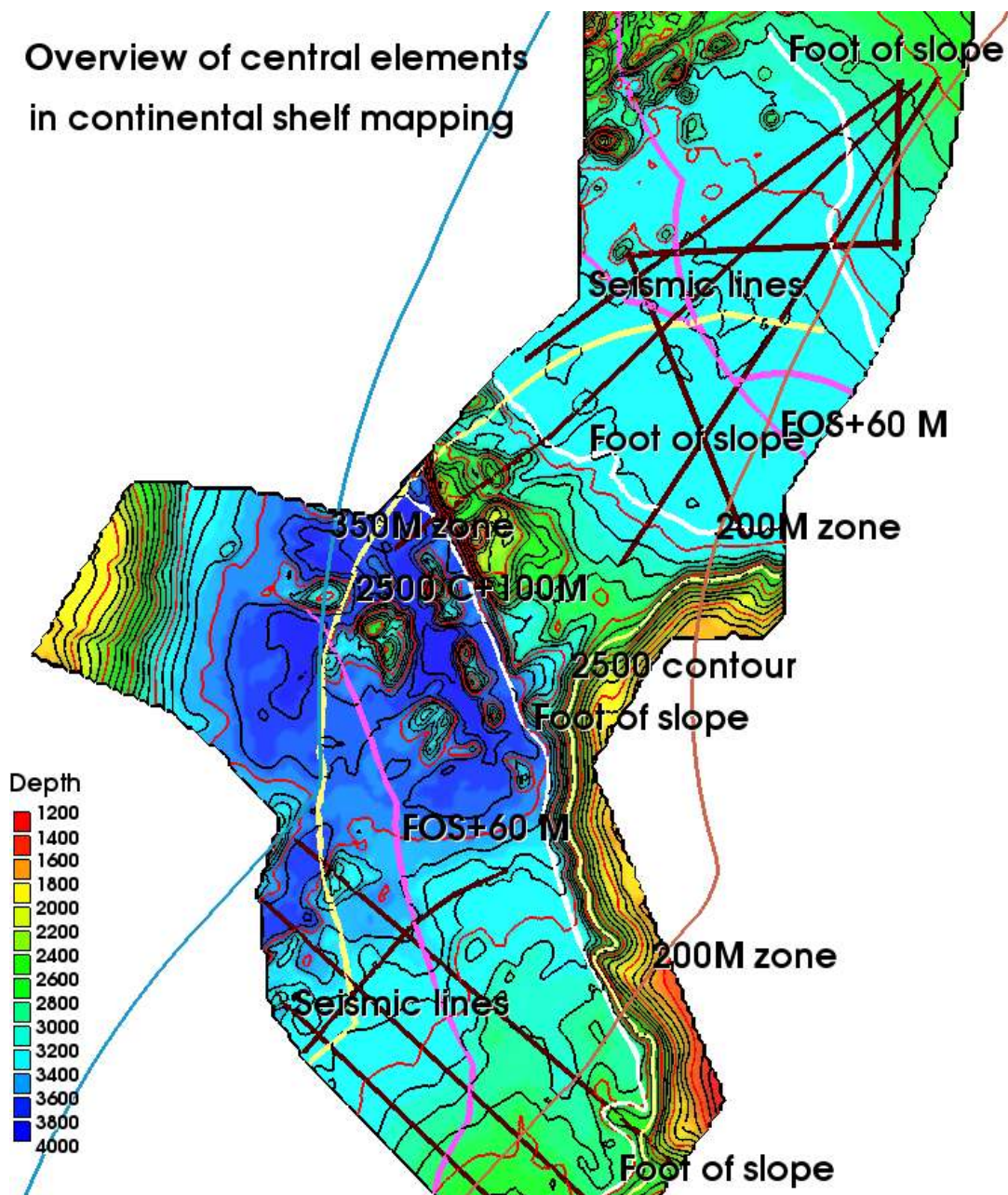


Figure 15 2D overview of some article 76 lines.

The display shows: Foot of slope, FOS plus 60 M, the seismic lines, 2500 m isobath, 2500 plus 100 M line, 200 M zone, 350 M zone.

If the continuous sediments have a thickness of more than 1 percent of the distance to the foot of slope positions, then the observation points at the sediments can be used for determining the outer territorial continental shelf.

14. Working out 1 percent sediment thickness from foot of slope.

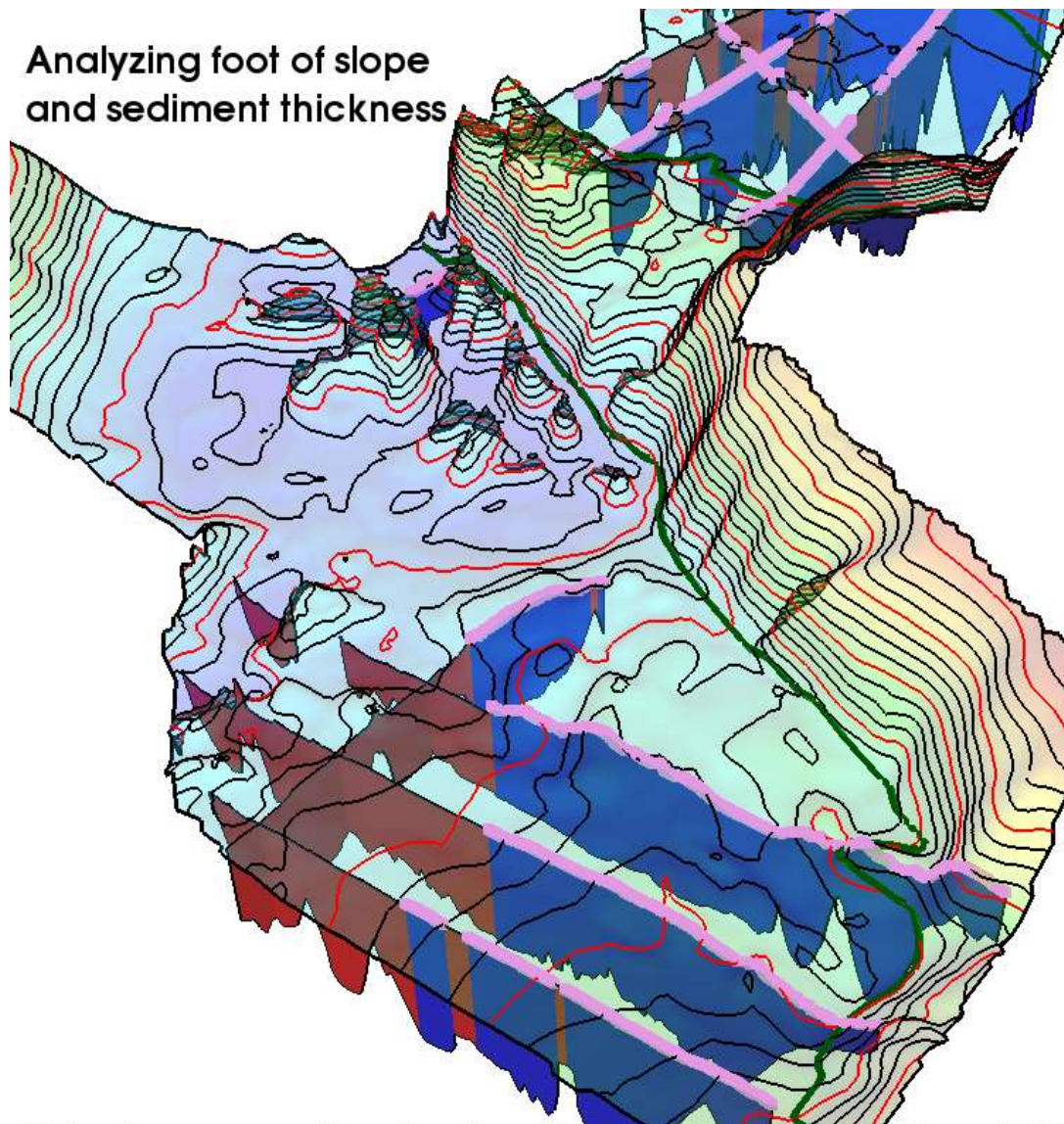
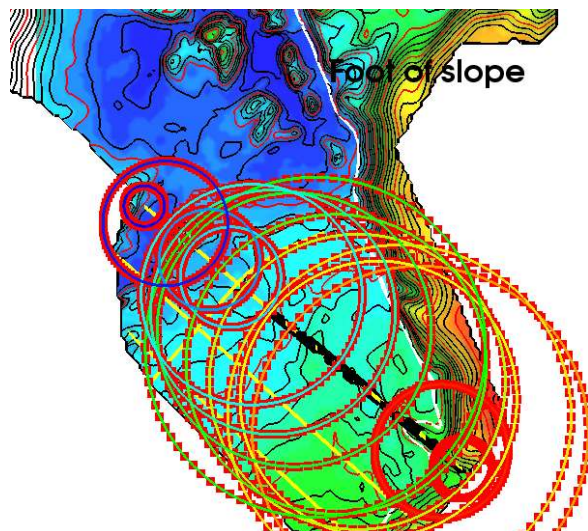


Figure 16 Sediment cross sections displaying 1 percent thickness.

The thickness of a sediment is compared with the distance to the foot of slope. In Figure 16 the parts of the sediments having more than 1 percent thickness are displayed in blue and highlighted with turquoise markers.



In order to study the 1 percent sediment thickness calculation, a set of circles can be worked out along a sediment line. The circles describe how far out the 1 percent thickness will extend from the center points at the sediments.

Figure 17 Studying 1 percent thickness from sediments.

15. Determining the outer territorial limit.

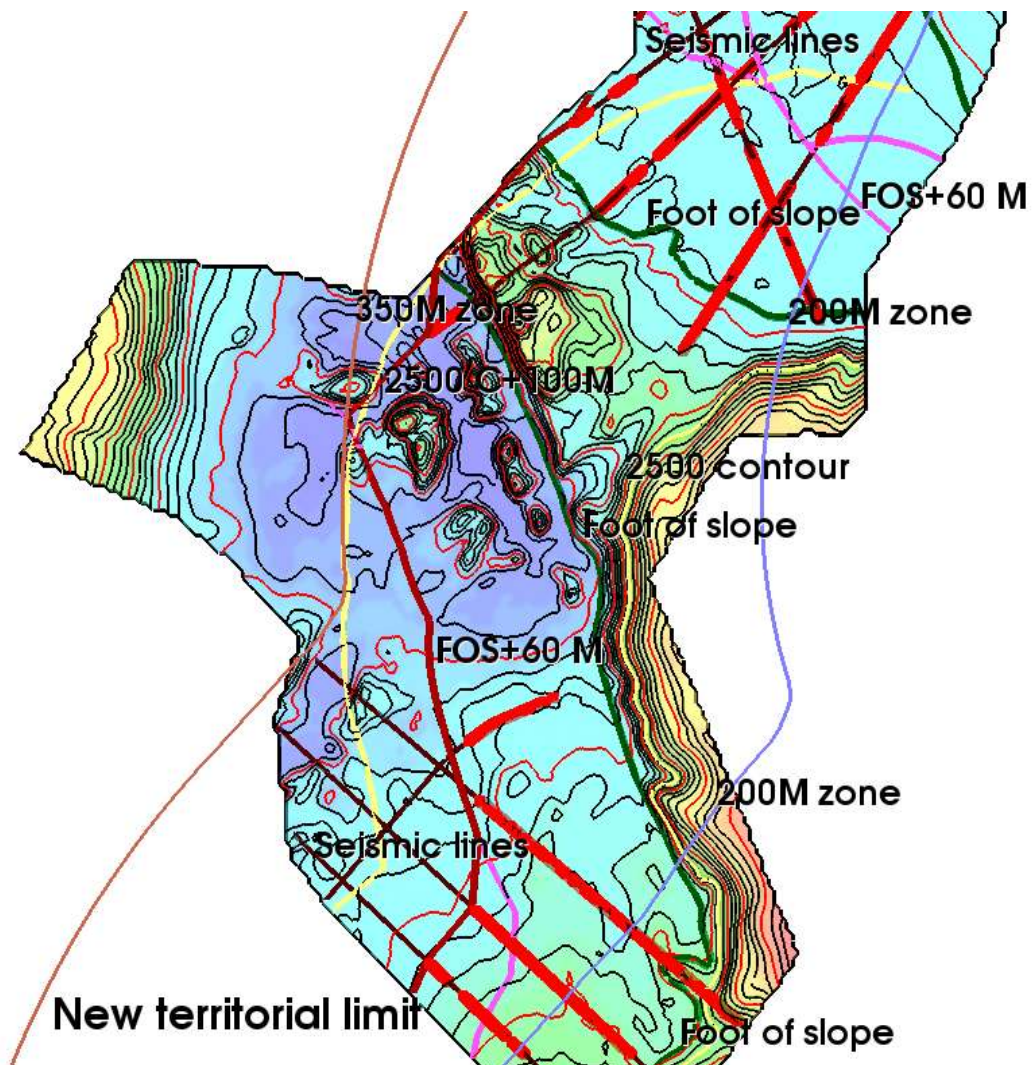


Figure 18 Map showing lines of interest and hypothetical new territorial limit.

It is clearly shown that the 1 percent sediment thickness rule extend the territorial limit at the lower left of the seabed. Otherwise the limit would have followed the 'FOS plus 60 M' line. Instead the new line is made up by the outermost '1 percent sediment' points and reaches the 'FOS plus 60 M' line higher up.

The territorial limit then follows the 'FOS plus 60 M' line until it meets the maximum extent of the 350 mile line and the '2500 m isobath plus 100 M' line, which in this case is the 350 M line.

16. Perspective view of assumed new territorial line.

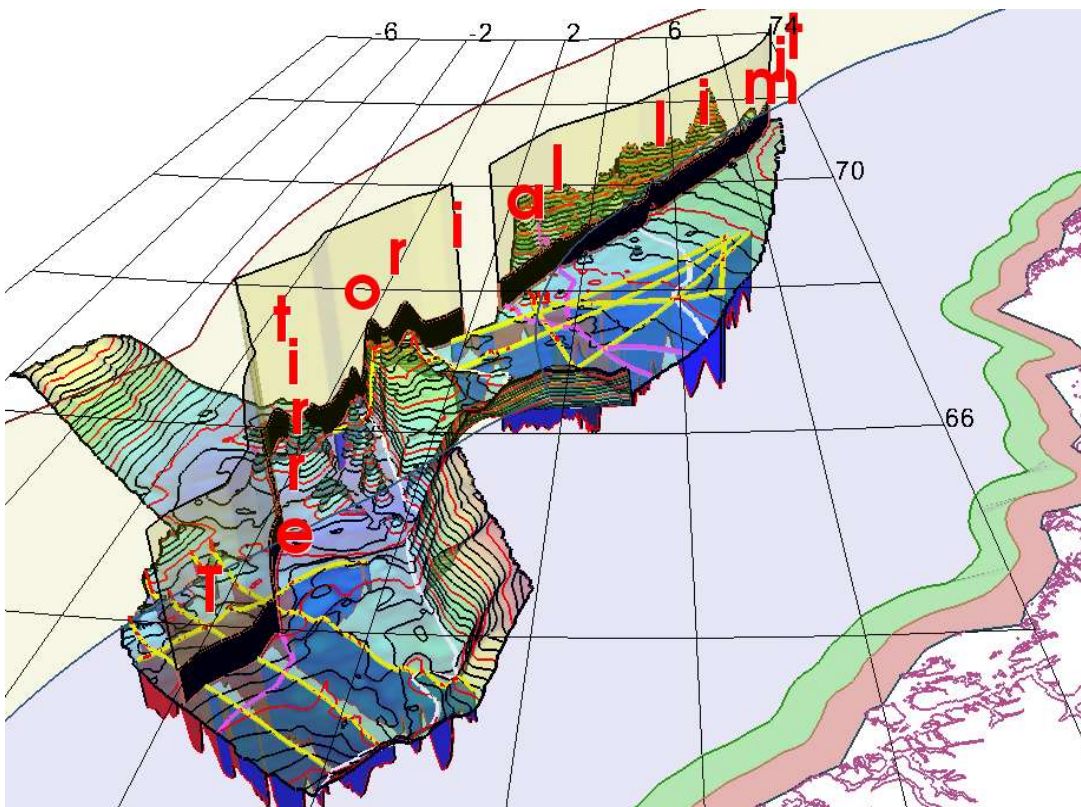


Figure 19 Artistic view of interpreted new territorial line.

Figure 19 shows some of the basic data for calculating a new territorial outer limit.

The 1 percent sediment thickness calculation from foot of slope is displayed through a transparent seabed.

Geographical coordinates and the coast line with its zones of jurisdiction are drawn to visualize the area.

The territorial limit is shown as a wall, partly with low opacity, to give an artistic impression to finish a live presentation.

17. Biography.

Olav Egeland (58) has MSc in mathematics from University of Oslo. He has previously worked with the Institute of Energy at Kjeller outside Oslo, then worked in the oil division in Norsk Hydro, was the founder of the former Geomatic company, and started the GeoCap company in 1998. GeoCaps main activities are towards the oil industry and seabed agencies.

18. Acknowledgments.

I would like to thank Harald Brekke and Morten Sand at NPD of Norway and Øvind Lønne of Geo-42 for briefing me on UNCLOS terminology and valuable hints in general.

I would also like to thank my colleagues in GeoCap for assistance in programming.