Notes

Measured Gradients of the Sea Floor at Depths of 2,500m and Their Possible Influence on the Outer Limit of Juridical Continental Shelves

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Article 76 of the United Nations Convention on Law of the Sea (UNCLOS) defines the juridical Continental Shelf that a Coastal State may claim. (United Nations, 1982). One element of the formula provides an Outer Constraint beyond which a shelf cannot extend, either a line 350 M from the baselines or a line 100 M from the 2,500m isobath. How well a ,2500m isobath is located depends on a number of factors (see Monahan, 2000, and Monahan and Wells, 1999, for single beam-based contours, Hughes Clark, 2000 for multibeam), one of which is the gradient of the sea floor. In this note we measure and compare actual sea floor gradients at the 2500m isobath at many locations around the world. Determination of real gradients gives an indication of the magnitude of uncertainty inherent in the location of the 2,500m isobath.

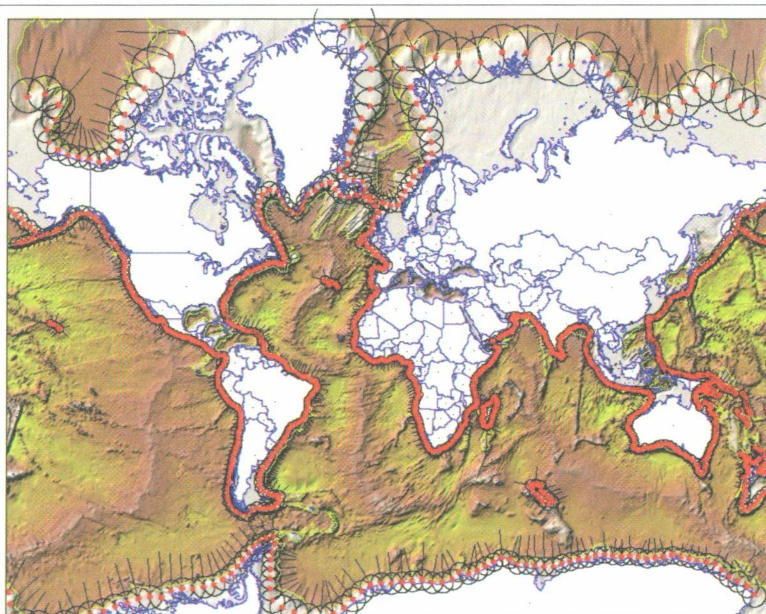

Figure 1: Locations of gradient measurements. 2,500 m isobath shown in yellow. Black circles were automatically generated at 100 M spacing. Profiles were drawn at centres of circles, shown by red dots. Gradients were measured at intersection of profile and 2,500 m isobath

Physical Setting

Generally, the 2,500m isobath will lie on the classical Continental Slope or, less frequently, on the Continental Rise. Textbooks used in the era when UNCLOS was being drafted, and no doubt influenced the wording of Article 76, generally stated that the gradients on these features were low, with values ranging from 1 to 4 degrees. For many years this was accepted and is still used as a 'rule of thumb' for planning and other calculations. For example, in adjacent chapters of a recent volume, Symonds et al (2000) report 'averaging about 4 degrees' while Prescott (2000) gives a value of 'about 2.5%' (1.43 degrees). The recent deployment of MBES(Multi beam echo sounding) surveys suggests that it may be time to revisit these values and determine whether they are still valid. Pratson and Haxby, 1996, probably began the modern era of measuring Continental Slope gradients when they compared both regional and local slopes as measured by MBES over five portions of the US Continental Slope and found a steepest regional gradient of 2.5 degrees and a steepest local gradient of 7.6 degrees. Although the observed regional gradient falls within the conventionally accepted value, the local gradient was almost twice the expected. In this note we report on measured gradients from the entire world.

Methodology

Unfortunately not many Continental Slopes have been surveyed by MBES, at least not with surveys that collected publicly-available data. Consequently, we used the ETOPO5 gridded data, realising that with a grid size of 10km we would only be able to measure regional gradients: it can be assumed that local gradients will be steeper. Using the CARIS LOTS software (http://www.caris.com/products/hydrography/lots), we began by automatically locating the points to be measured at a regular interval of 100 M (Figure 1), resulting in 920 locations to be measured. At each, we measured the gradient at the intersection of the 2,500m contour generated by CARIS LOTS from the ETOPO5 grid and a profile generated in LOTS. LOTS calculates gradient from the two nearest grid points to the profile.

We next assembled and numerically analysed the measurements, as shown in Figure 2 and Table 1.

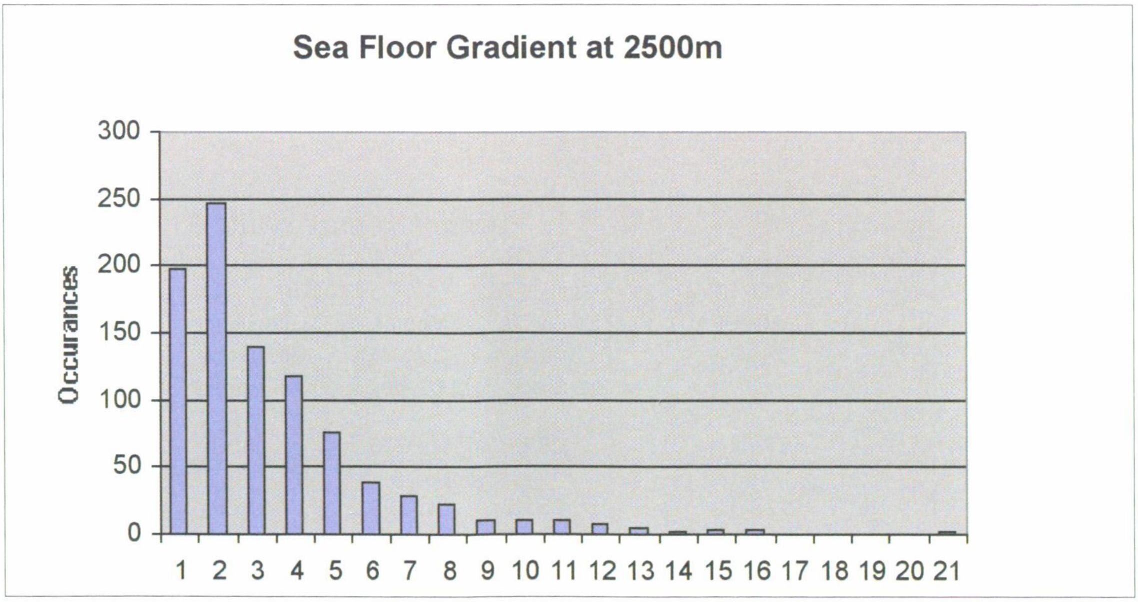

Figure 2: Histogram of the gradient points for the 2,500 m isobath, measured at points 100 M apart. X-axis is gradient in degrees, with "1" signifying gradients of 0 to1 degrees, 2 signifying gradients of 1.1 to 2 degrees, etc. Y –axis is number of occurrences of each measurement for each class

Mean	2.974472
Standard Error	0.092677
Median	2.091113
Mode	1.86
Standard Deviation	2.811044
Sample Variance	7.901969
Kurtosis	9.557922
Skewness	2.433783
Range	25.93
Minimum	0.05
Maximum	25.98
Count	920

Table 1: Statistical description of the gradients (in degrees) measured for the entire earth

The histogram shows a long-tailed distribution, with many values clustered towards zero, and ranging from 0.05 to 25.98 degrees. Under these circumstances, the mean does not give a particularly good indication of central tendency, since it can be unduly influenced by a few higher values. The median does not suffer from this malady, and we can immediately state that half the world's 2,500 m contour lies on sea floor with gradients less than 2.09 degrees. It also illustrates that the commonly-favoured value of 4 degrees gradient for the Continental Slope was a decent rule of thumb: 773 of 913 measured gradients (84.66%) were 4 degrees or less. The third quartile is 3.83 degrees, meaning that three quarters of the measured points have a gradient of less than 3.83 degrees.

This has immediate implications for the horizontal uncertainty of the 2,500 m isobath plus 100 M Outer Constraint defined by Article 76 of UNCLOS. Uncertainty in the horizontal location of an isobath is related to sea floor gradient via uncertainty in vertical (depth) measurement as (Horizontal uncertainty of isobath = ± uncertainty in depth measurement / tangent of bottom slope) (Monahan and Wells, 1999). Real depth measurements have a vertical uncertainty, and isosbaths derived from them have a higher uncertainty, with actual values varying with a particular data set, so that each would have to be evaluated individually. Nevertheless, the Guidelines published by the Commission on the Limits of the Continental Shelf (CLCS) (United Nations, 1999) recommend the use of IHO S44, Standards for Hydrographic Surveys. (IHO, 1998). S44 assigns depths of 2,500m to its Order 3 surveys, and specifies maximum allowable uncertainty for both individual measurements (depths) and isosbaths (bathymetric model). See Table 2.
The world-wide observations were broken into geographic areas, and statistics calculated for each area. For each area, the horizontal uncertainty of the median was calculated and is shown in Table 3.

		HORIZONTAL UNCERTAINTY			
	VERTICAL ACCURACY	1st Quartile Gradient	Median Gradient	3r Quartile Gradient	Max Observed Gradient
		1.1 deg	2.09 deg	3.83 deg	25.98 deg
SP 44 Table I Depth	57.51	2995	1576	859	118
SP 44 Table 3 Contour	125.10	6515	3428	1869	256.0

Table 2: The maximum uncertainty allowed under S44 for depth and isobath at 2,500m in the third column. Columns 4, 5 and 6 show the resulting maximum horizontal uncertainty for the first three quartiles of our measured gradient data. This can be read, for example, as meaning that one quarter of the 2,500m contours in the world could meet S44 specifications and yet have a horizontal uncertainty of more than +- 6,515m. Similarly, three quarters of the 2,500m depth measurements could have a horizontal uncertainty of more than +-859m

	Africa West	Europe	N Amer East	S Amer East	Africa East	Antarctic	Arctic West	Asia	Oceania	Islands	S Amer West	N Amer West	Asia East
Median	**1.26**	**1.38**	**1.47**	**1.58**	**1.68**	**1.69**	**1.75**	**1.75**	**2.20**	**2.22**	**3.4**	**3.57**	**4.03**
Horizl Uncerty Depth	2615	2387	2249	2085	1961	1949	1882	1882	1500	1484	968	922	817
Horizl Uncerty Contour	5688	5193	4892	4535	4265	4240	4095	4095	3264	3227	2106	2005	1778

Table 3: Horizontal uncertainty of depths and contours at 2,500m depth by geographic area. Values are calculated from the median gradient observed in each region, and from the maximum allowable uncertainty under IHO S44

Summary

The measurements presented here confirm that the general gradients on the Continental Slope around 2,500m depth are low, with a median of just over two degrees. Locally, gradients will probably be steeper. Soundings of 2,500m and isobaths derived from the soundings, even if they meet S44, can still have considerable horizontal uncertainty, as tabulated here by geographic area.

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