INFERENCES ON POTENTIAL SEAMOUNT LOCATIONS FROM MID-RESOLUTION BATHYMETRIC DATA

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ABSTRACT

Seamounts are underwater volcanoes that did not grow tall enough to break to the sea surface and turn into islands. Once formed, seamounts tend to gradually sink under their own weight and the subsidence of the lithosphere. The ocean floor is littered with these former seamounts, here called 'seamounds'. Seamounts occur throughout the world's oceans, but their number (which may surpass 50,000) is difficult to estimate, even roughly, because it depends on the resolution of the bathymetric map used and the specific definition of a seamount used, i.e., the limits used to distinguish between seamounts and seamounds. Here, the locations of a subset of the seamounts of the world were identified using two algorithms relying on the depth differences between adjacent cells of a digital global elevation map distributed by the U.S. National Oceanographic and Atmospheric Agency (NOAA). The overlap of both algorithms resulted in a set of about 14,000 seamounts, but a different number would have been found had we used different thresholds. Known seamount locations supplied by NOAA and SeamountsOnline (http://seamounts.sdsc.edu) were compared against the corresponding seamounts located by the study, which led to some degree of ground-truthing. The coordinates of the seamounts identified in this study are available on the CD-ROM attached to this report, and on http://www.seaaroundus.org.

INTRODUCTION

Seamounts are undersea mountains (usually of volcanic origin) rising from the seafloor and peaking below sea level (Duxbury and Duxbury, 1989; Kennish, 2000). Typically, seamounts are formed by volcanic activity over hotspots in the earth's crust (Epp and Smoot, 1989). Spreading of the sea floor away from these hotspots via plate tectonic movements means that seamounts often form long chains or elongated clusters. There are many opinions on what defines a seamount, but one widespread definition states that a seamount should be steep-sided and rise 1,000 m or more from the sea floor (Duxbury and Duxbury, 1989; Epp and Smoot, 1989). The shape of seamounts is also an important factor, often crucial in the identification of seamounts from sea floor data. Most are circular or elliptical (Epp and Smoot, 1989), although very elongated seamounts do occur (Wessel and Lyons, 1997).

Though most people may be unaware of it, underwater seamounts are fairly common. However, global seamount datasets containing information on seamount positions are rare and often only contain data for single oceans (e.g. Fornari et al., 1987; Smith and Jordan, 1988; Epp and Smoot, 1989; Smith and Cann, 1990; Wessel and Lyons, 1997). In fact, Wessel and Lyons (1997) state that despite the post-World War II increase in oceanographic exploration, only a small fraction of seamounts have actually been mapped bathymetrically. Any detailed global seamount datasets that exist are usually maintained by governmental departments and are not available to the public. The *Sea Around Us* Project (http://www.seaaroundus.org) has conducting a global analysis with the goal to generate a spatial dataset of points across the world's oceans that indicate large peaked bathymetric anomalies with a high probability of being seamounts, and we present its key results.

Obtaining data on seamounts has taken many forms over the years, ranging from visually scanning contour maps (Batzia, 1982) to extrapolating using remote sensing data (Wessel, 1997). The bathymetric data contained in the ETOPO2[1] raster dataset supplied by NOAA was chosen as the baseline data from which possible global seamount locations were inferred.

For the purpose of the *Sea Around Us* Project, a global database of seamount point locations was required. In this contribution, we attempt to infer potential seamount locations, and thus to generate, at least, a lower estimate of the number of seamount in the world's oceans.

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[1] ETOPO2 Global 2' Elevations CD-ROM. 2001. National Geophysical Data Center, NOAA/NGDC. USA.
<http://www.ngdc.noaa.gov/mgg/fliers/01mgg04.html>

METHODS

The criteria we used to study seafloor anomalies across the globe were more general than the vertical gravity gradients used by Wessel (1997) and the slope and length to width ratios used by Batzia (1982). We assumed that a possible seamount should have a rise of 1,000 m or more from the seabed and should be roughly circular or elliptical in shape. Moreover, since the ETOPO2 data was the source for all analyses, the occurrence of volcanic activity was not a defining parameter.

The ETOPO2 dataset was constructed from a variety of sources, but mainly consists of data from satellite altimetry. The dataset was supplied at a 2-minute cell resolution (13.7 km² at the equator), which allowed a generalized, global analysis, but certainly caused us to miss many seamounts.

The ESRI ArcGIS² software flow direction and sink algorithms (ArcGIS) were used in combination with the ETOPO2 data to obtain the locations of all detectable peaks on the sea floor. The ETOPO2 data was used in an ESRI grid format for a cell-by-cell analysis.

The ETOPO2 elevation data was prepared by first eliminating all land cells (any elevation above 0 m) and then converting negative elevation values to absolute numbers. This allowed using the ESRI algorithms (see below), designed to detect downhill flow direction and sinks, to identify uphill flow direction and peaks.

The ESRI flow direction algorithm was first applied to the ETOPO2 data. This algorithm produces a grid in which each cell is allocated a flow direction value determined by the steepest descent from the immediate surrounding cells. There are eight valid flow direction values indicated in Figure 1. For example, if a focus cell's direction of steepest slope is to the right, the focus cell's value is 1.

Cells determined to have an undefined flow direction were given a value equal to the sum of the possible flow direction values. Undefined flow directions occur when all surrounding cells are higher than the focus cell or when two adjacent cells flow into each other. The ESRI sink algorithm was used on the resulting flow direction grid to identify all flow direction cells that have undefined flow directions. The resulting sink (seafloor peak) grid could then be overlaid with the ETOPO2 depth grid to indicate all identifiable peaks on the sea floor.

Using the detected peaks, two methods were used to identify possible seamounts. The first involved isolating peaks found associated with a significant rise from the ocean floor. The second method isolated peaks with a circular or elliptical base in an effort to eliminate small peaks found along steep ridges. The overlapping seamounts found by using both of these methodologies were used as the project's seamount dataset. To determine the overlap in the datasets generated from the two methods, points had to be within 2 minutes of each other.

32	64	128
16	Focus Cell	1
8	4	2

Figure 1. Flow direction values indicate direction from focus cell.

Method 1

The initial part of the process involved producing a grid of standard deviation of depth across the ocean floor. The neighbourhood statistics function in ESRI's ArcGIS Spatial Analyst software was used to produce a grid giving a standard deviation in depth value for each ETOPO2 depth cell as compared to its immediate neighbourhood.

In order to enable the identification of possible seamounts, the standard deviation and seafloor peak grids were overlaid. Using ESRI's ArcGIS Spatial Analyst, each peak cell was then compared to a 5 x 5 kernel of its neighbourhood on the standard deviation grid. If any cells within the block were above a 300-metre standard deviation, the focal peak cell was considered a possible seamount (see Figure 2).

Method 2

The second method used the peak grid dataset in comparison to the ETOPO2 depth data. An algorithm was developed that scanned ETOPO2 depths around each peak, along 8 radii of 90 km each, at 45º intervals (see Figure 3). The lowest and highest depths over the radii (10 cells per radii near the equator, more at higher latitudes) were then recorded. A raw peak was considered a seamount when the following conditions were met:

1. Each and all of the 8 radii included depths differing by at least 300 m. This helped eliminate insignificant seamounds;

2. If 2 radii included depths between 300 m and 1,000 m, with the shallowest point being closer to the peak than to the deepest point, and if the radii formed an angle of less than 1350. This condition was used to help eliminate ridges from seamounts.

3. At least 5 of the 8 radii around a peak included depths with a difference of a least 1,000 m, with the shallowest point being closer to the peak than to the deepest point.
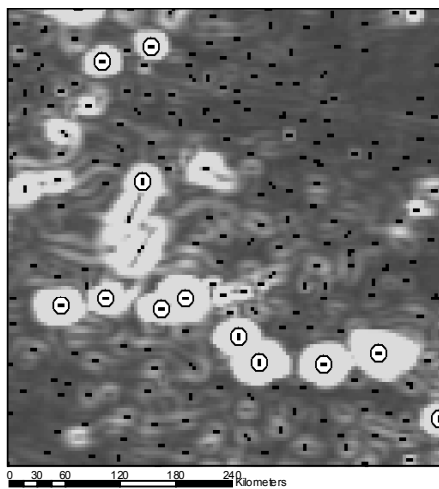

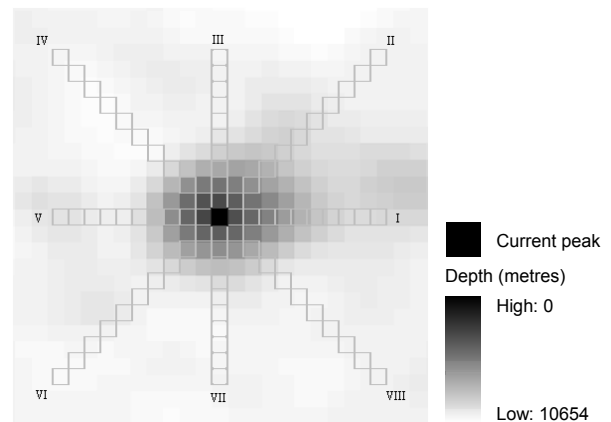**Figure 2**. Potential seamounts detected from standard deviation of depth around detected seafloor peaks.

Figure 3. Location of each radius relative to the current peak pixel (depth in metres).

RESULTS

The two methods produced different numbers of potential seamount, with the first method producing almost double the amount (30,314) of the second method (15,962). The overlapping points resulting from the two methodologies identified 14,287 possible seamounts (Figure 4). The 300-metre standard deviation threshold, used in the first method, produced seamounts that were within the broad seamount definition. As expected, many of the predicted seamounts occurred along mid-ocean ridges.

The range of seamount numbers varied differently for the two methods and their set thresholds. Smaller potential seamounts were identified by method 1 when the standard deviation threshold was lowered, thus increasing the seamount count (see Table 1). Method 2 remained relatively constant, with estimates between 15,000 and 20,000 seamounts depending on depth change threshold set between 100 m and 500 m. The non-linear variation in seamount counts as the threshold is increased for method 2 is attributed to the fact that the proximity to the nearest seafloor rise and the depth of the valley between is taken into account as well as the change in surrounding depth (see Table 1).
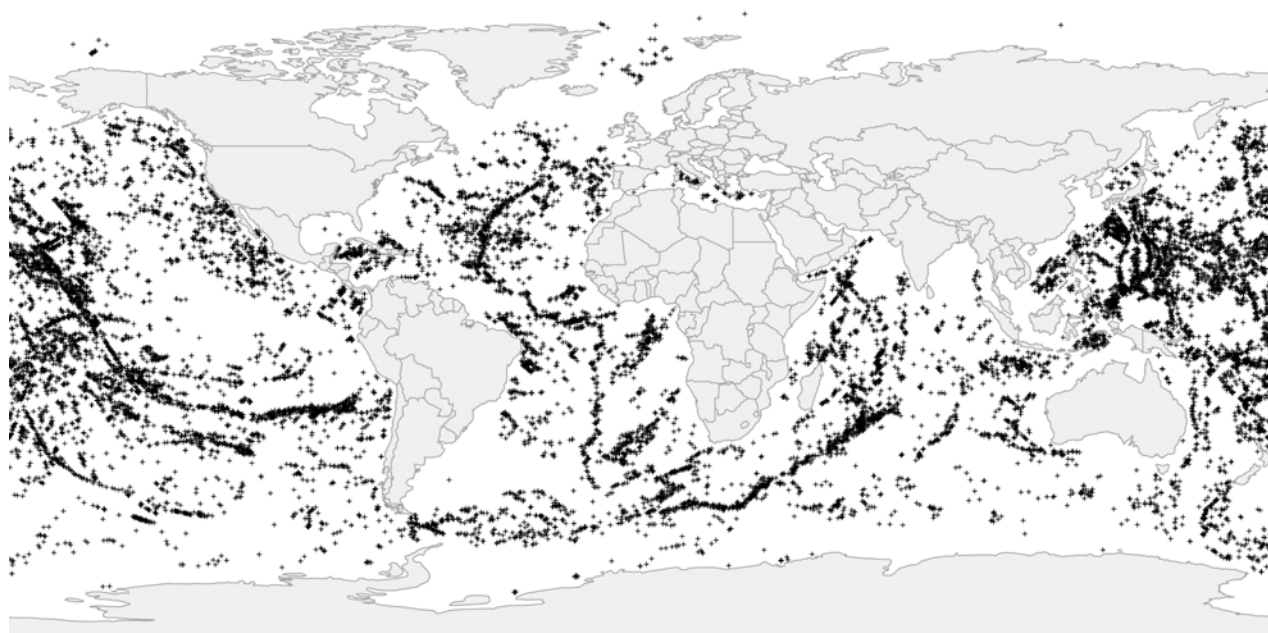
Figure 4. Global dataset of potential seamounts.

Ground truthing was performed on a dataset of known seamounts set at a 30-minute resolution and produced from a combination of data from the US Department of Defence Gazetteer of Undersea Features (1989)[3] and SeamountsOnline (see Stocks, this vol.). It was found that approximately 60% of the known seamounts were within 30 minutes of predicted seamounts.

Since many studies are restricted to a particular ocean, an attempt to get an estimate of predicted seamounts per ocean was performed (see Table 2). The United Nations Food and Agriculture Organization (FAO; http://see www.fao.org) statistical areas were used to identify oceans.

The seamount count for the Pacific Ocean falls within the bounds of Wessel's (1997) estimate of 8,882. However, it is still below prediction of 12,000 by Batzia (1982), who also stated the probability of 22,000 to 55,000 seamounts in the Pacific Ocean.

Counts differ according to the boundary definitions of the Southern Ocean. The defining FAO areas would have underestimated the actual coverage of the Southern Ocean.

Table 1. Seamount prediction count at varied standard deviation (SD) thresholds.

	Potential seamount count	
S.D. threshold (m)	Method 1	Method 2
100	~ 142,000	~ 20,000
300	30,314	15,962
500	~ 8,500	~ 18,000

Table 2: Predicted seamount counts by ocean.

Ocean	FAO statistical areas	Number of potential seamounts
Pacific	61, 67, 71, 77, 81, 87	8952
Atlantic	21, 27, 31, 34, 41, 47	2763
Indian	51, 57	1651
Southern	48, 58, 88	883

[3] Included in the 5-Minute Gridded Global Relief Data on CD-ROM (ETOPO5). 1993. National Geophysical Data Center, NOAA/NGDC. USA. <http://www.ngdc.noaa.gov/mgg/fliers/93mgg01.html>

DISCUSSION

Our study has found a relatively simple way of extrapolating potential seamounts from mid-resolution bathymetric data. Although there is no reference to volcanism, the requirement for finding large undersea peaked features (potential seamounts) was fulfilled. The criteria for the extrapolation was only sensitive to a broad level, with the definition of seamounts still very generalized. This sensitivity is also directly influenced by the depth standard deviation threshold and the scope of the neighbourhood cells examined (method 1) or length of radii (method 2). The sensitivity of the extrapolation is also directly influenced by the resolution of the underlying bathymetry data. Any features smaller than the cell size of the bathymetry data will have their dimensions blurred with surrounding features, which could bring them outside the bounds of extrapolation criteria.

The ranges in the number of the potential seamounts predicted by both methods are caused by the actual task performed by each method. Method 1 detects the degree of change in depth surrounding a detected peak. The wider the degree of change permitted, the smaller the potential seamounts that can be located. Method 2 was used to identify the peaks that had surrounding depth profiles conforming to the general shape of a seamount (circular or elliptical). Although the depth change ranges could be altered for method 2, only a limited number of seamounts conformed to our criteria, regardless of the depth change threshold. Our attempt to eliminate peaks along ridges could also eliminate actual seamounts. This leads to the conclusion that the criteria used by method 2 are too restrictive. It was decided to keep the results conservative (i.e., find only very obvious seamounts) in order to reduce error.

The results were also restricted by both methods in the scope of the area around each peak was tested for seamount characteristics. The kernel used by method 1 equates to an area of approximately 342 km^2 at the equator. It was hoped that a kernel of this size would allow the detection of large seamounts while eliminating large peaked banks. This kernel size could be further looked into in order to optimize the analysis sensitivity. Likewise the radii lengths in method 2 have a similar effect and could also be optimized.

Our methodology has provided a relatively simple way of generating a global seamount dataset directly from elevation data (see Figure 4). Although the current output is suitable for a generalized global analysis, tighter seamount predictions should be possible with some refinements to the methods used.

The set of location data generated here (see Appendix 1 on the CD-ROM, or http://www.seaaroundus.org for details) should be considered a subset of a much larger global set of seamount locations, as 50,000 or more seamounts could probably be identified, using bathymetric maps of higher resolution that are presently classified, combined with a broader definition of seamounts, which would take into account the true extent of their variety in shape and groupings.

APPENDICES

1. Location of > 14,000 likely seamounts

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