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An Object Based Approach for Submarine Canyon Identification from Surface Networks

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Abstract

In this paper we propose using surface networks to identify submarine canyons from bathymetric data. Identification is done in two steps. First, thalweg lines that fit the canyon definition are extracted; second, the floor around each thalweg is measured to separate steep narrow canyons from broader channels. Results are validated against a classification provided by geomorphologists.

1. Introduction

Submarine canyons are relevant features for geomorphologists because they can explain the origin and evolution of marine landscape. Although there is a common understanding of what a canyon is, its description is often vague and its definition is not applicable for automatic classification. This issue leads to define parameters with arbitrary values that are difficult to establish.

Traditional methods require image segmentation and classification. These approaches compute discrete local descriptors such as the curvature and depend on threshold parameters chosen by the user. Furtermore, image classification can omit global photo-interpretative characteristics. In general, photo-interpreters identify canyons by their overall shape (narrow, elongated, steep slopes) and position (running across the continental slope in a straight line), observed around salient thalwegs.

This paper proposes an approach where thalwegs are extracted from a terrain surface network and canyons are built around them. We move away from pixel classification to an object-oriented approach built on a topological structure. The surface network is a graph where critical points such as pits and peaks are connected by ridges and thalwegs. Its extraction does not require any parameter. Relevant thalwegs are selected by simplifying the surface network. Simplification parameters are not set locally at pixel level but at the structure level. The valley floor is computed around each thalweg and used to classify canyons and other channels. The method is illustrated on a triangulated irregular network generated from multibeam sounding data from the St-Lawrence estuary (Canada). Results were validated against a manual classification performed by geomorphologists (Normandeau *et a.l* 2015).

2. Surface Network Construction

A surface network is a topological graph. Its nodes are pits (local minima), peaks (local maxima) and saddles (points being a local maximum in one direction and a local minimum in another direction). Saddles are connected to peaks by ridges and to pits by thalwegs (Figure 1). The integrity of the surface network is guaranteed by several topological constraints.

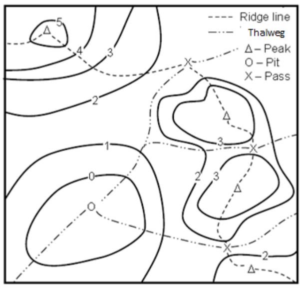

Figure 1. Surface Network Definition.

The surface network was extracted from the TIN following Takahashi *et al.*(1995). Robustness was ensured by setting the following rules: (1) saddles are counted with their multiplicity; (2) if two adjacent points are at the same elevation, their coordinates are compared to provide a total ordering of the points; (3) a virtual pit is added outside the domain and inside each hole corresponding to islands to avoid edge effects. The results are illustrated in figure 2A.

3. Surface Network Simplification

A canyon thalweg is identified by a series of connected thalwegs that cross the continental slope. As such, it starts with a saddle point located at the top of the slope and ends with a pit at its bottom. Extraction of the canyon thalweg is done by removing pits and joining thalwegs into longer lines. Point removal must preserve the topological integrity hence a peak or a pit is always removed with an adjacent saddle point (Rana, 2010). Figure 2 presents a sample of the surface network constructed from the TIN (A) and its simplification (B).

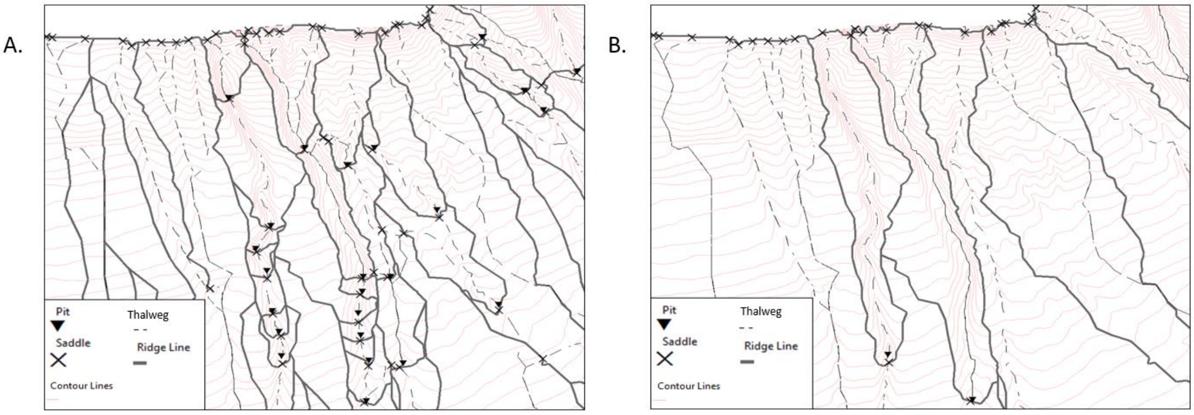

Figure 2. Surface network extracted from the model and its simplification.

Noting p_0, p_1 and p_2 three pits joined by consecutive thalweg lines, three criteria are applied to check if the lines p_0p_1, and p_1p_2 belong to a canyon and p_1 can be removed (figure 3). First, if the slope ratio between p_0p_1 and p_1p_2 is very small or large, there is a change of slope and p_1 must be preserved: pit p_1 can be located at the bottom of a slope. According to experiments, small values are lower than 0.3 and large values are greater than 3. If this value is close to one, slopes are homogeneous. Second, the Euclidian distance and the distance along the thalweg between two consecutive pits are computed. If their ratio is small, the thalweg is meandering and does not belong to a canyon. Finally, only thalwegs located on the estuary slopes are kept. Thalwegs located on the floor of the estuary, characterised by a small height difference, are removed.

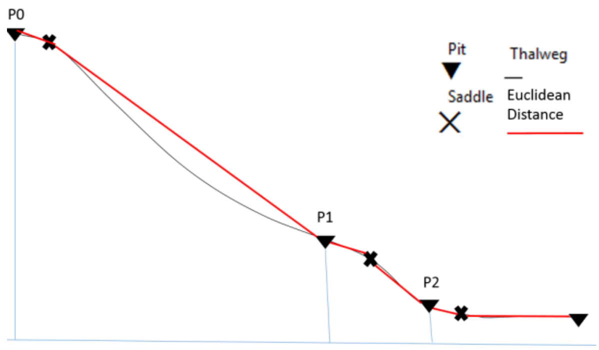

Figure 3. Criteria to identify the canyon thalweg.

4. Valley Floor Extraction

The St-Lawrence estuary contains different types of submarine valleys. Our canyon thalweg definition matches both channels and canyons. In comparison with channels, canyons are narrower with steeper sides. Hence two criteria were identified to separate both types of features: the floor width and the break of slope measured between the floor and the side.

The canyon thalweg is the line of lowest elevation that defines the axis of the canyon. The canyon floor is relatively flat along a direction orthogonal to the thalweg. Hence the floor can be delineated by a growing region approach from the thalweg (Straumann and Purves, 2008). Instead of setting an absolute slope threshold defining flatness, an average cross-sectional slope is measured along the thalweg in its close vicinity and used as a threshold value. A polygon containing the points satisfying the slope criterion is then built around the thalweg (figure 4). This approach allows defining the floor without fixing a parameter value. Thresholds in our study area were measured between 0.5 and 2 degrees. Overall, the average threshold was 1.5 degrees, which agreed with values proposed by Straumann and Purves (2008).

The width of a channel or canyon was measured by the average distance from the thalweg to the border of the floor. A threshold width was set according to geomorphologists' classification to 150 m.

For the second criterion, the angle between the floor and the slope was measured by taking a point on the slope. It was measured by the ratio between the height difference and the distance from the point to the thalweg. If the angle difference is important, there is a break of slope characterising a canyon. On the opposite, a small angle difference corresponds to a smooth change of slope. The maximum ratio for channels was measured at 0.029 while the minimum ratio for canyons was 0.049. The gap being quite significant, this criterion appears more robust than the width criterion.

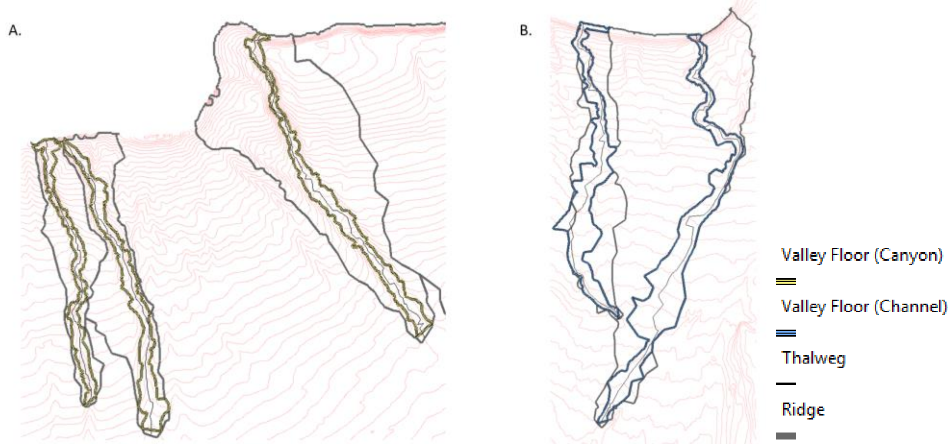

Figure 4. Left: canyons, right: channels.

5. Discussion and conclusions

Our results were compared with the classification obtained by Normandeau *et al.*(2015) who studied canyons in the St-Lawrence estuary based on their geomorphology and feeding sources. Threshold parameters were set through discussion with geomorphologists in order to match their classification. Our approach provides highly accurate landform locations (86%) compared to the manual approach. This measure considers similar results (same location but different length) by each work zone (table 1). As seen from figure 5, thalwegs were shorter because they stop at the bottom of the slope while canyons can extend in the estuary floor depending on how far sediments are transported.

Table 1. Accuracy of our approach

7 Work Zones	Manual Approach		Automatic Approach		Similar Results
	Canyons	Channels	Canyons	Channels	
TOTAL	12	9	11	5	6 of 7 zones
Accuracy			92%	56%	86%

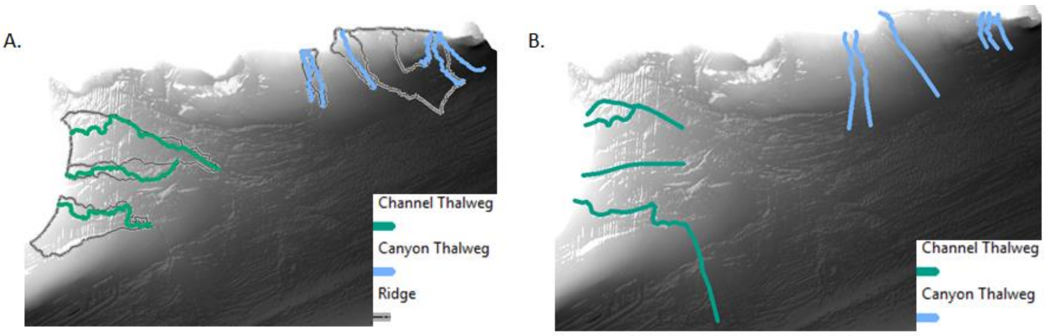

Figure 5. A)our approach, B)manual classification.

While a correct classification was obtained, it relies on the definition of threshold parameters, which were obtained through testing and comparison. In order to extend the model to other domains, further work is required to analyse threshold values and give a contextual definition which may depend on the area considered (including geometrical parameters such as the average slope and size of the continental slope or the shelf) and on geomorphological parameters such as the floor composition or some dynamic process observed over geomorphological scales. On a shorter term, the model shall be extended to describe other features that can be observed in the estuary, not only valleys but also the floor, slopes and shelf in order to provide a description of the morphological structure of the estuary at different levels.

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