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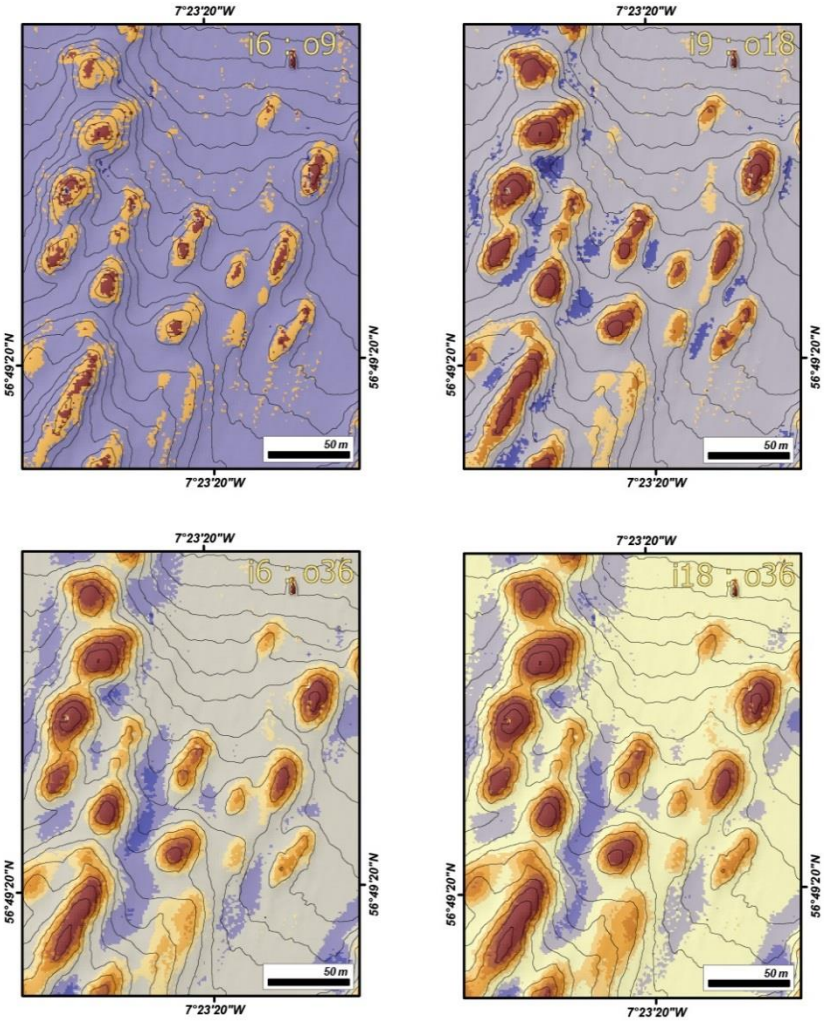
Semi-automated Mapping and Characterisation of Coral Reef Mounds: Mingulay Reef Proof of Concept

Marine Geosciences Programme

Internal Report IR/15/042



BRITISH GEOLOGICAL SURVEY

MARINE GEOSCIENCES PROGRAMME

INTERNAL REPORT IR/15/042

Semi-automated Mapping and Characterisation of Coral Reef Mounds: Mingulay Reef Proof of Concept

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Contributor

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Four different BPI maps of an area of the Mingulay Reef Complex, created using different analysis neighbourhood.

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Foreword

Over the last decades, we have been observing an exponential increase of the areas of seabed being surveyed with multibeam echosounder, providing the marine scientific community with vast volumes of data. However, our understanding of the seabed nature and processes will only follow this exponential growth if we are capable of study and distribute the information revealed by this datasets. That can require as much if not more resources than what needed to acquire the data since even the base mapping can be extremely time-consuming. Developing semi-automated mapping methods provide ways to reduce the effort invested to on production of maps. Additionally, interpretation of bathymetric data is implicitly subjective and any analysis of such data is vulnerable to errors by the interpreter, also minimise by the use of semi-automated methods.

After successfully develop a semi-automatic workflow and script to map pockmark (Gafeira *et al.*, 2012), it was decided to attempt to adapt that method or develop similar automated methods for other seabed bathymetric features. This report describes a new mapping approach developed to semi-automatically map coral reef mounds and to extract their attributes from multibeam datasets without interpreter bias.

Acknowledgements

This work has been carried out as part of the BGS Marine Geosciences Programme. We thank Laurence De Clippele and Prof Roberts Murray from the School of Life Sciences at Heriot-Watts University for providing the perspective of an end-user of a tool for semi-automated mapping of cold-water coral reefs.

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Summary

This report describes a new approach to map coral reef mounds. The study area used for this mapping exercise is located approximately 13 km east of the island of Mingulay (56°50′N, 7°30′W) and is known as the Mingulay Reef Complex. The approach adopted consists on the combination of the *Bathymetric Position Index* tool for habitat mapping and the semi-automated mapping method developed initially to map pockmarks at seabed. During this exercise, 354 coral reefs were successfully mapped. The results of this test-of-concept supported the creation of a customised tool for semi-automated mapping of cold-water coral reefs, to derive coral mound attributes from multibeam datasets without interpreter bias.

1 Introduction

Datasets such as sidescan sonar or multibeam echosounder give an indication of size and density of coral mounds at seabed. However, manual mapping of these features can be extremely time-consuming and it is implicitly subjective and any analysis of such data is vulnerable to interpretation errors. As such datasets have been acquired digitally over the last decade this provides an opportunity for the development of automated mapping methods to minimise interpretation errors.

After successfully developing a semi-automatic workflow and script to map pockmark (Gafeira *et al.*, 2012), it was decided to attempt to adapt that method or develop similar automated methods for other seabed features. Cold-water coral reefs can develop mound-like structures that can have comparable geometry to pockmarks but as a topographic high rather than a depression. Therefore, it was expected that would be possible to develop an approach to automatically map and describe the cold-water coral reefs. The Mingulay Reef was chosen as test site for this attempt, due to *1)* the high resolution of the dataset available and *2)* the possibility to collaborate with potential end-users.

2 Mingulay Reef Complex

The Mingulay Reef Complex is located in the Sea of the Hebrides, approximately 13 km east of the island of Mingulay (Figure 1). It comprises several cold-water coral reef areas constructed by the azooxanthellate *Lophelia pertusa* that provides 3D habit for many different species.

Figure 1 – Location of Mingulay Reef Complex, (adapted from Roberts *et al.*, 2009).

The area of the Mingulay Reef Complex includes E-W orientated bedrock ridges that rise to less than 100 m water depth, within an area where water depths locally reach 260 m, causing disruption to the oceanographic currents flowing north-north-eastwards into the Minch (Figure 2). Upon the ridge, prominent mound-like structures are observed predominately in Mingulay Reef 1, Mingulay Reef 5 (North and South) and on the Banana Reef (Davies *et al.*, 2009). Those near-circular features are up to 5 m high and have a general diameter of 15 m (Long and Wilson, 2003).

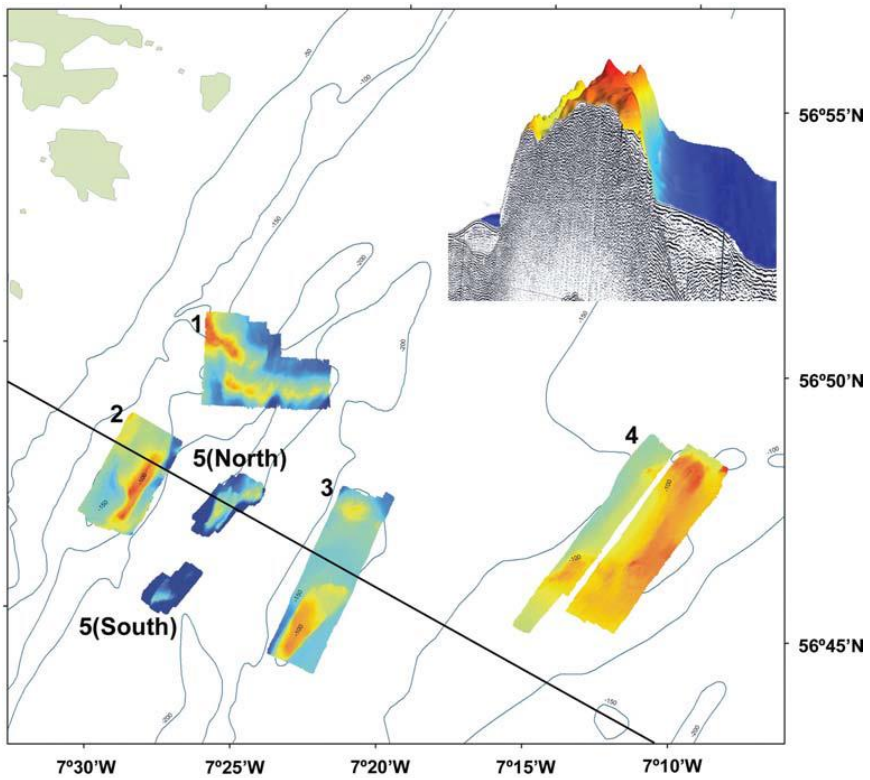

Figure 2 – Map extracted from (Roberts *et al.*, 2005).

Some of these reefs have been dated to over 4,000 years old, however, they are likely to be much older as the samples collected were from surficial sediments. Growth rates reached up to 12 mm a^{-1} which is the highest growth rate so far found in any cold-water coral reef (Douarin *et al.*, 2013). These figures have been derived from more than 50 dates (U/Th and ^{14}C) acquired from the Mingulay Reef, however, Douarin *et al.* (2013) did not find evidence of coral growth from 1.4 ka to modern times despite video and samples revealing live coral on the reef. She identified several collapses in the coral ecosystems during the Holocene (Douarin et al., 2015). Live coral samples seem preferentially distributed on the top and flank of the mounds from Mingulay Reef 1 and Mingulay Reef 5 (North and South).

Figure 3 shows the schematic model of cold-water coral reef build-up presented by Douarin *et al.* (2014). This model explains the systematic sedimentary sequence observed in vibrocores, suggesting cyclic depositional environments that can be subdivided into four major steps: reef initiation, framework expansion, collapse of the framework and coral rubble. Each step characterised by changes in the relative biodiversity, sedimentological regime and changes in erosional processes.

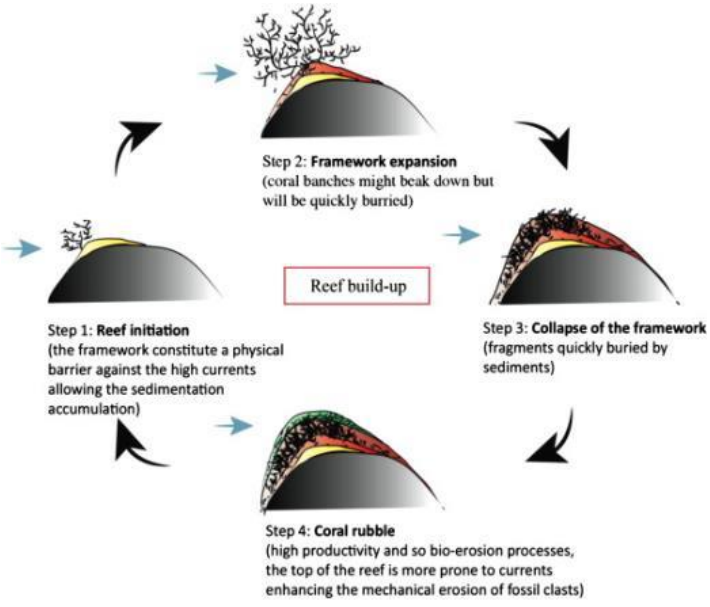

Figure 3 - Schematic model of cold-water coral reef build-up, extract from Douarin *et al.* (2014).

3 Data

In early summer 2003, multibeam surveys were carried out in four areas to the west of Scotland where the coral *Lophelia pertusa* had previously been recorded. The surveys used a 200 kHz Kongsberg EM2000 MBES with approximately 50% overlap between survey lines. East of the island of Mingulay a total of five areas between 2 and 21 km^2 were surveyed (Figure 2). A further survey in 2006, on board of the RV 'Pelagia' equipped with the 30 kHz Kongsberg EM300 MBES, covered some of the reefs and identified previously unknown reefs (Davies *et al.*, 2009). These are the elongate reef named "Banana Reef" and a series of mounds called "Four Mounds".

Additionally, during mid-July 2013, a surface-towed boomer shallow seismic survey (BGS cruise 2013/7) took place in the area, and its main objective was to determine the thickness and extent of the coral layers (Wallis, 2013). It showed that the mounds sit on a relatively smooth rock head (Figure 4).

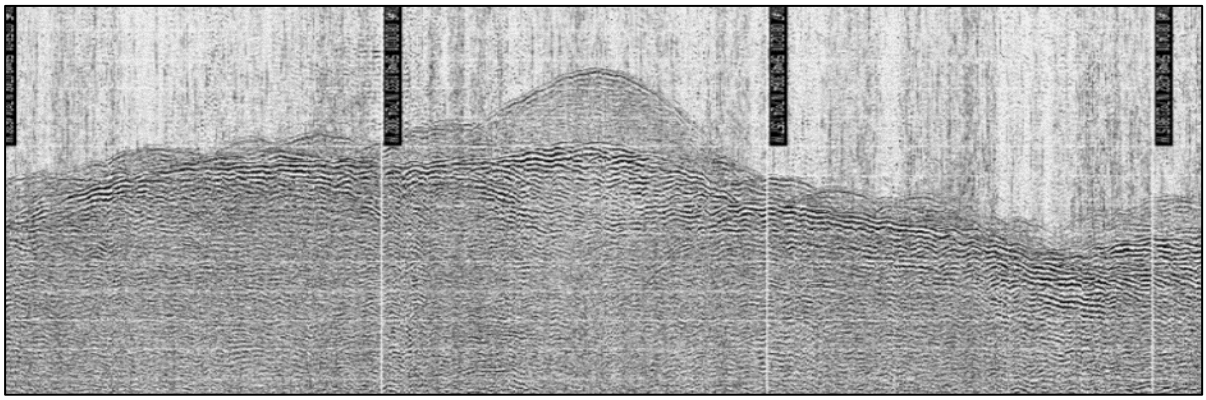

Figure 4 - Boomer line across one of the Mingulay's cold-water coral mound, showing its internal structure and how it sits on top of underlying rock head.

4 Semi-automated mapping

A semi-automated mapping tool was previously developed for mapping and attributing pockmarks from multibeam datasets (Gafeira *et al.*, 2012). This has since been adapted for mapping cold-water corals mounds, often termed 'mini-mounds', found on the Celtic Margin. However, due to the preferential development of cold-water coral mounds in areas of irregular topography, the application of the semi-automated mapping tool directly from the bathymetric data is not possible. Therefore, it was decided to attempt to map this features using a derived dataset, the Bathymetric Position Index (BPI) map.

4.1 BATHYMETRIC POSITION INDEX

The BPI was originally derived from topographic data to characterising watersheds and was called topographic position index (TPI) (Weiss, 2001). It is a measure of where a certain location is relative to its surrounding (*i.e.* compares the water depth of each cell in a DEM to the mean water depth of the neighbourhood cells). Positive BPI values represent locations that are shallower than the average of their surroundings, as defined by the neighbourhood (ridges). Negative BPI values represent locations that are deeper than their surroundings (depressions). BPI values near zero are either flat areas or areas of constant slope (Figure 5).

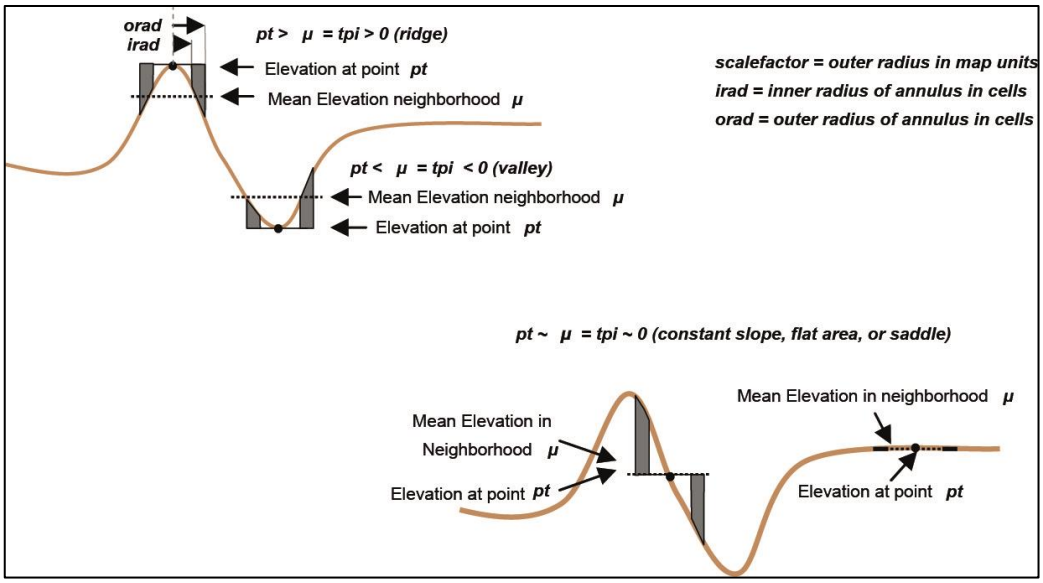

Figure 5 - Topographic Position Index (TPI) illustration taken from Weiss' poster (2001).

To develop and test the new method, a small area of the Mingulay Reef Complex was assessed (Figure 6). The use of a smaller area allows short processing time and faster rate of iterations during the process of writing the scripts.

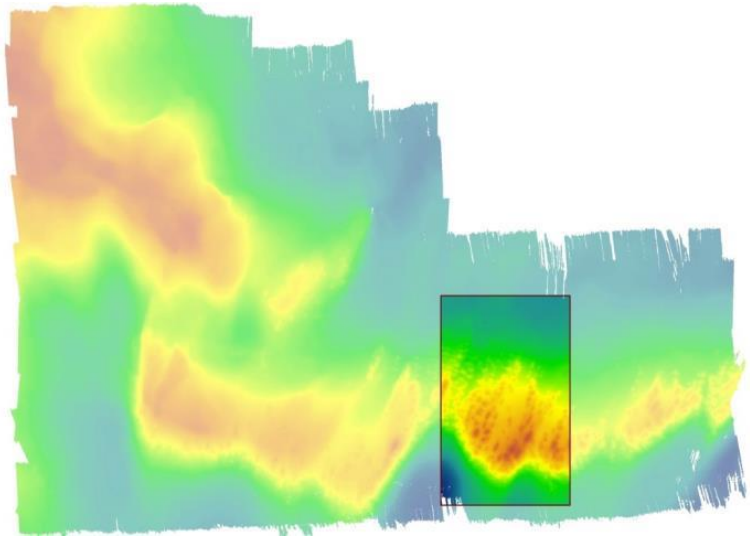

Figure 6 – Location of the clipped area used for this mapping exercise.

By using the BPI values it is possible to delineate the coral mounds, however, the delineation will depend dramatically on how the BPI map was calculated. The BPI is calculated from the bathymetrical digital elevation model (DEM) but if can be calculated at different scales. The BPI algorithm compares each cell's elevation to the mean elevation of the surrounding cells within a user-defined analysis neighbourhood. The analysis neighbourhood can have the shape of a rectangle, an annulus (doughnut shape) or a circle and any size defined by the interpreter. The BPI value for a given cell will depend on of the geometry and size of the analysis neighbourhood used in its calculation. Smaller analysis neighbourhood will allow the detection of smaller, localised variations in the terrain. BPI maps with different analysis neighbourhood were generated using Benthic Terrain Modeller (BTM) and compared (Figure 7 and Figure 8).

The BTM toolbox contains a set of customised scripts that allow users to create, from a multibeam bathymetry input grid, additional grids of slope, bathymetric position index or BPI and seafloor rugosity. It can be downloaded from the ArcGIS website:

http://www.arcgis.com/home/item.html?id=b0d0be66fd33440d97e8c83d220e7926

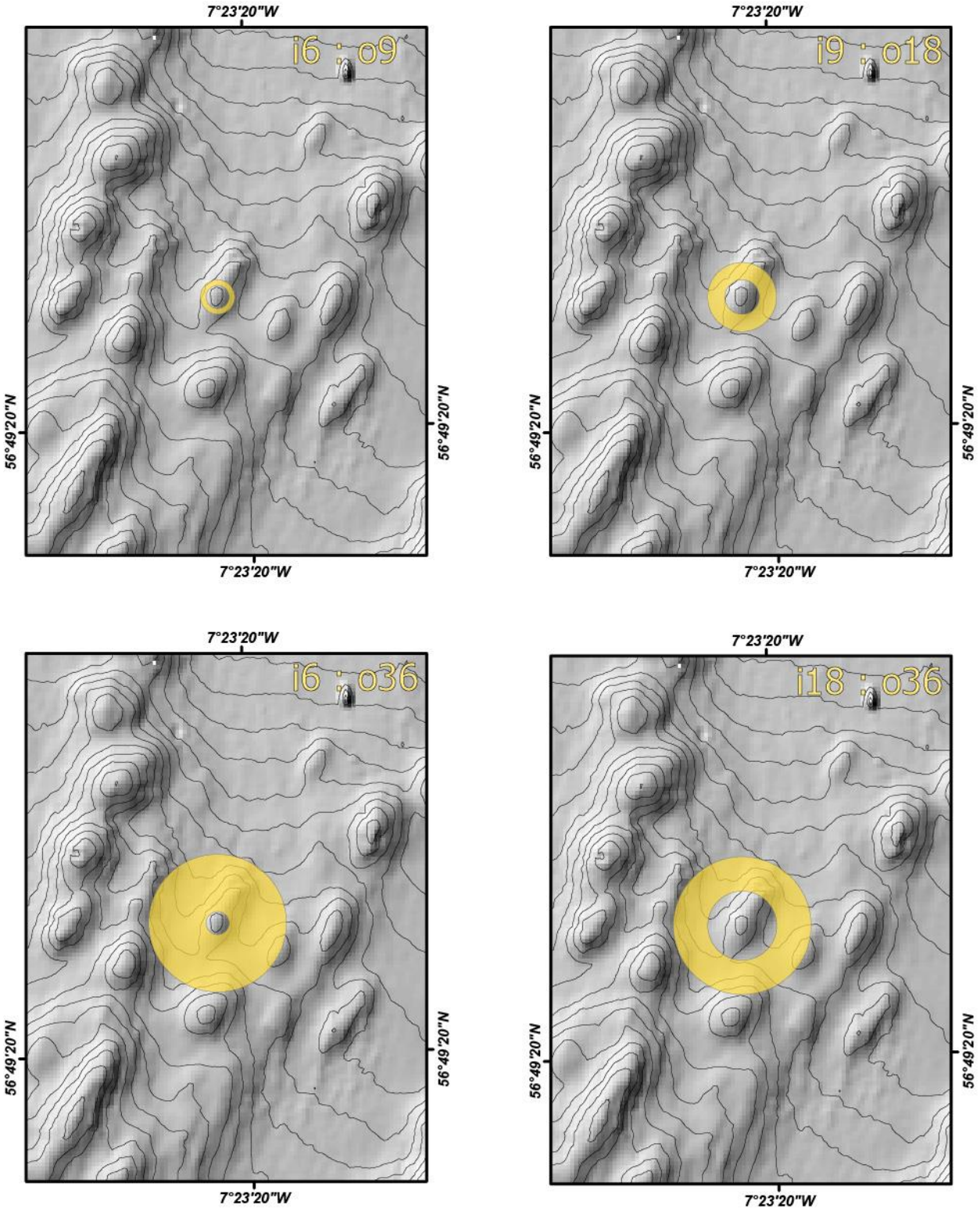

Figure 7 – Illustration of the analysis neighbourhood used to create the four different BPI maps. From with the finest scale map (i6:o9) with an inner radius of 6 cells and outer radius of 9 cells, and the broader scale (i18:o36) with an inner radius of 18 cells and outer radius of 36 cells.

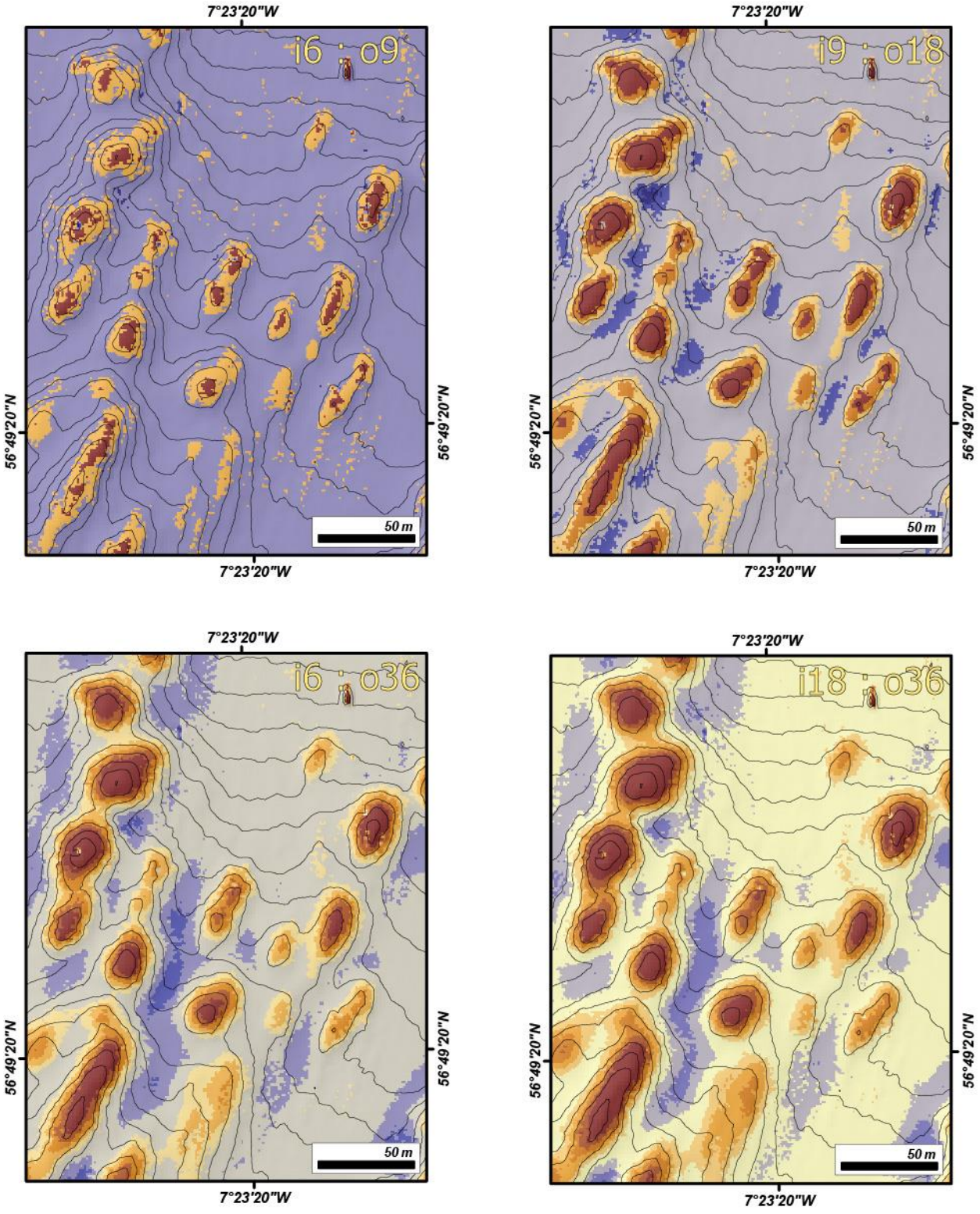

Figure 8 – Clip of the four different BPI maps created using different analysis neighbourhood. From with the finest scale map (i6:o9) with an inner radius of 6 cells and outer radius of 9 cells, and the broader scale (i18:o36) with an inner radius of 18 cells and outer radius of 36 cells. Note that the areas identify as topographic highs (in brown) change depending on the scale used.

Additionally to the visual assessment of the BPI map generated, profiles across some of the mounds assisted the selection of BPI map used as input dataset and also to define the threshold value for the automated method (Figure 9).

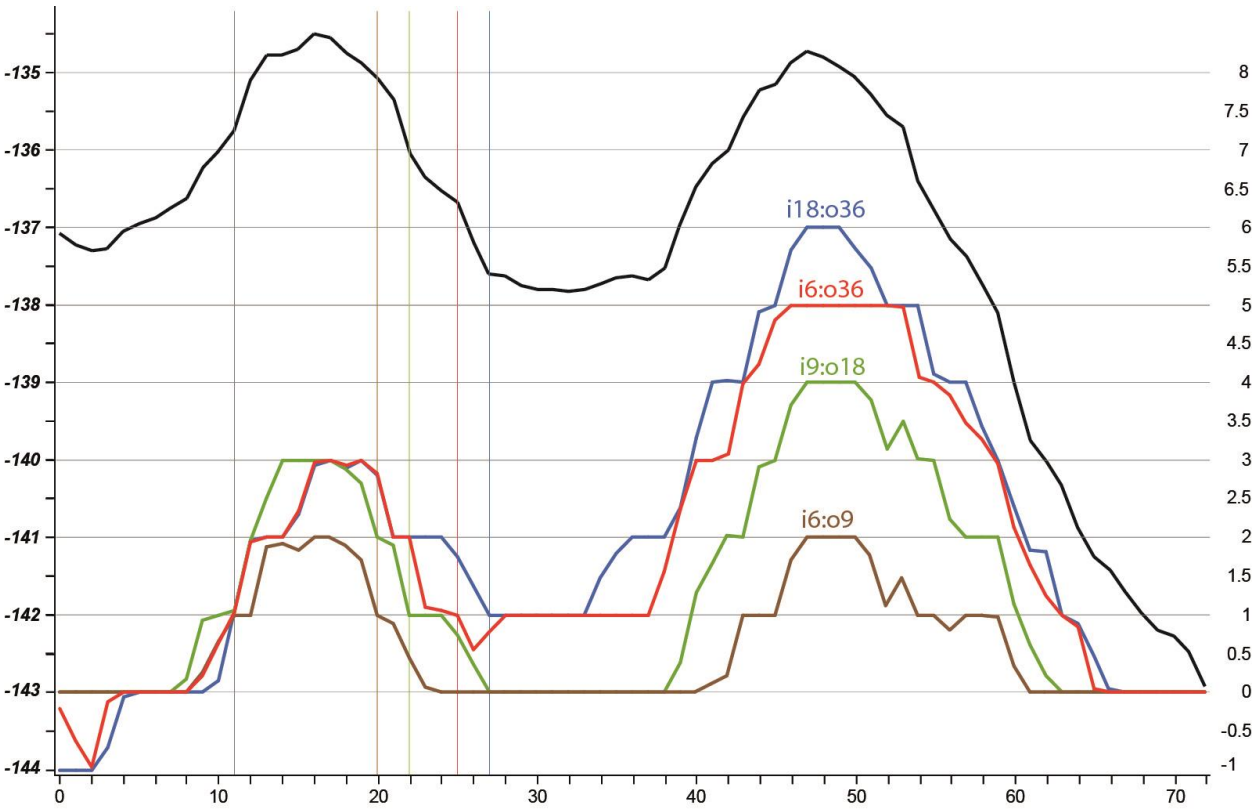

Figure 9 –The bathymetric profile (black) and four corresponding BPI profiles (in brown, green, red and blue).

4.2 BGS CORAL MOUND TOOLS

Two scripts were written in Python during this work: "*BPI Feature Delineation"* and *"Feature Description"*. These were added to an ArcGIS Tool Box named BGS Coral Mound tools.

4.2.1 BPI Feature Delineation

If we consider a coral mound as a confined bathymetric high capable to be identified within a BPI map and invert the BPI map, it is possible to employ hydrological algorithms developed to identify sinks on digital elevation models. Sinks, in this context, are cells with an undefined drainage direction since no cells surrounding it are lower. BPI Feature Delineation script follows a similar logic to the script developed for mapping pockmarks and described by (Gafeira et al., 2012). By creating a script tool dialogue box (Figure 10) any user can run the script as a normal ArcGIS tool and read the description for the individual parameters (Table 1). The output of this script is a polygons shapefile delineating all the mounds respecting the dimensions and BPI values set by the thresholds defined by the used. The table of attributes of the output shapefile will capture varies characteristics of the mapped features (e.g. Area, Perimeter, Maximum BPI value, Minimum Bounding Geometry box's length, …).

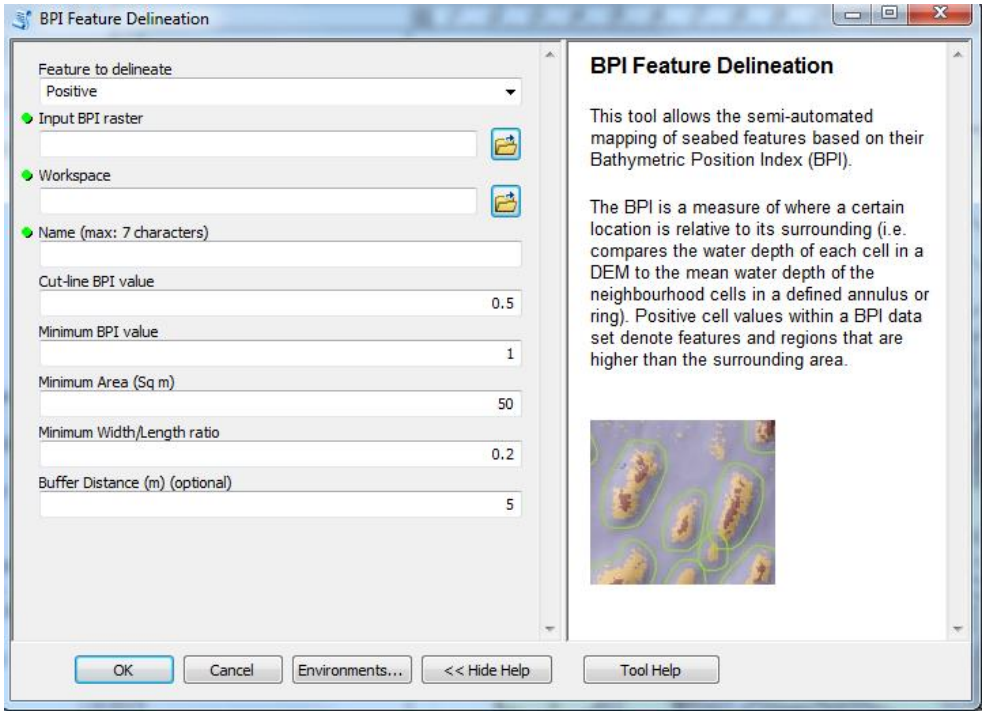

Figure 10 – "*BPI Feature Delineation"* script tool dialogue box.

Table 1- Parameter set for the *"BPI Feature Delineation"* script tool.

Parameter	Explanation	Data Type
Feature to delineate	Pockmarks (negative BPI values) or Mounds (positive BPI values).	String
Input BPI raster	File with the BPI map.	Raster Dataset
Workspace	Folder where the final shapefile and temporary files will be stored.	Workspace
Name	Shapefile name: without extension and should not be longer than 7 characters.	String
Cut-line BPI value	Threshold defined to delineate the features. Only areas with a BPI value higher than the Cut-line BPI value will be mapped.	Double
Minimum BPI value	Features with a maximum BPI value lower than this threshold will be excluded. The *Minimum BPI value* has to be the same or higher than the *Cut-line BPI value.*	Double
Minimum Area (Sq m)	*Minimum Area* threshold excludes features smaller than a given area.	Double
Minimum Width/Length ratio	*Minimum Width/Length Ratio* threshold allows excluding features based on their shape.	Double
Buffer Distance (m) (Optional)	A buffer is applied to the polygons created to compensate for the fact that the delineation process was based on the Minimum BPI threshold. The Buffer Distance should reflect approximately the distance, in plan view, from the initially delineated polygon to the actual rim of the feature.	Double

With the *"BPI Feature Delineation"* script tool and using the finest scale BPI map created (i6:o9) a total of 354 coral reefs were delineated within the study area. Figure 11 illustrate the results of this mapping exercise (polygons in light green) and also compare it to the automated mapping previous obtain by using directly the DEM dataset (purple). The application of the "*Feature Delineation*" tool with DTM dataset tends to underestimate the coral mounds' area.

A certain degree of manual editing would be recommended before proceeding to the extraction of further morphological attributes. However, for the aim of this exercise (test-of-concept) the second script "*Feature Description*" was run using the initially generated shapefile.

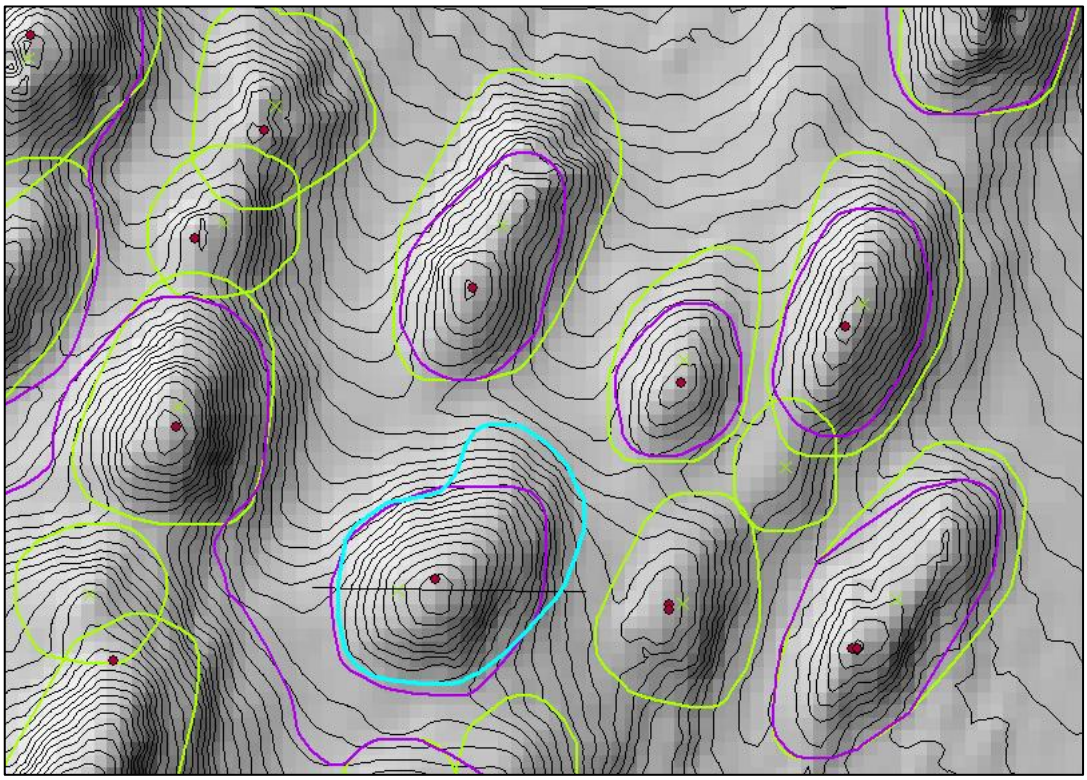

Figure 11 – Detail view of the differences between the mapping based on the BPI map (green) and the mapping based directly on the DEM (purple). Note that some degree of manual editing may be required (polygon highlighted in bright blue).

4.2.2 Feature Description

After manually editing the outline of some of the polygons generated by the first script, the geometry of some polygons may have changed but the attribute table will still be the same. Therefore, the information on it could be partially incorrect. The *"Feature Description*" script recalculates the attribute values for each feature and adds new attribute fields with additional information. After various conversations with members of the Coral Ecosystems Lab at Heriot-Watt University, it was decided to incorporate information from different datasets, when available. At this point, the "*Feature Description"* script tool (Figure 12) allows the extract information from the original DEM and from the BPI, Backscatter and Rugosity Map (Table 2). Plus, this tool can also calculate the original seabed slope before the development of the coral mound.

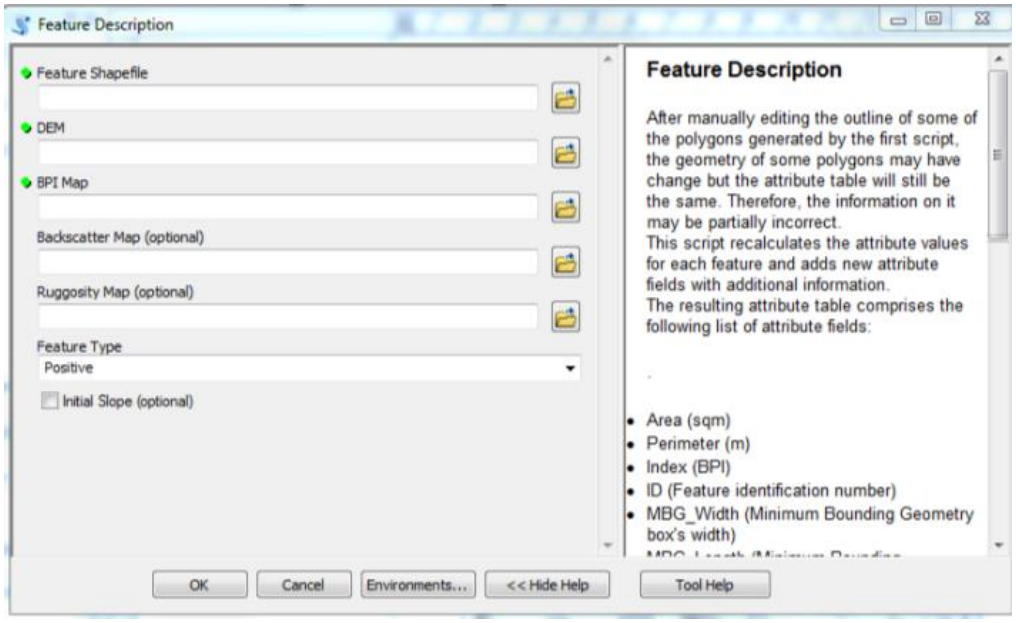

Figure 12 - "*Feature Description"* script tool dialogue box.

Table 2 - Parameter set for the *"Feature Description"* script tool.

Parameter	Explanation	Data Type
Feature Shapefile	Shapefile delineating the features	Shapefile
DEM	DEM from where the water depth will be extracted.	Raster Dataset
BPI Map	BPI Map previously used to delineate the features mapped.	Raster Dataset
Backscatter Map (Optional)	Backscatter data from where the backscatter values will be extracted.	Raster Dataset
Rugosity Map (Optional)	Rugosity maps from where the rugosity values will be extracted.	Raster Dataset
Feature Type	Positive features: features with a positive vertical relief, like mounds. Negative features: features with a negative vertical relief, like pockmarks.	String
Initial Slope (Optional)	The initial slope will be calculated by erasing the bathymetric data of the features mapped and recreating an initial surface.	Boolean

In addition to the polygon shapefile that delineates the mapped coral mounds, two other shapefiles are generated: *1)* a point shapefile that shows the centroid of the referred polygons ('shapefile'_C), and *2)* a point shapefile that marks the shallower point within each mound ('shapefile'_M). The table of attributes of both point shapefiles also includes the X and Y fields with the location of each point.

All of the shapefiles are completed with the full attribute table that comprises the following list of attribute fields:

Area (sq m)
Perimeter (m)
Index (BPI)
ID (Feature identification number)
MBG_Width (Minimum Bounding Geometry box's width)
MBG_Length (Minimum Bounding Geometry box's length)
MBG_Orient (Minimum Bounding Geometry box's orientation)
MBG_W_L (MBG_Width / MBG_Lenght)
MinWD (Minimum Water Depth)
MaxWD (Maximum Water Depth)
MeanWD (Mean Water Depth)
MaxVRelief (Maximum Vertical Relief)
MinVRelief (Minimum Vertical Relief)
ConfCL_WD (Water Depth of 1stConfined Contour Line)
MaxSlope (Maximum Slope)
MeanSlope (Mean Slope)
Min_Rug (Minimum Rugosity Value)
Max_Rug (Maximum Rugosity Value)
Mean_Rug (Mean Rugosity Value)
Min_BS (Minimum Backscatter Value)
Max_BS (Maximum Backscatter Value)
Mean_BS (Mean Backscatter Value)
InitialSlp (Mean Slope of the assumed initial seabed surface)

5 Conclusions

This work demonstrates that there is significant potential to support expert data analysis through the application of a range of automated steps, which accelerate mapping and feature characterization process as well as bring more rigour and consistency to the process.

The mapping based on the BPI values is better adjusted to the morphology of cold-water coral mounds whereas the direct application of the "*Feature Delineation*" tool, that use DTM as input data, tends to underestimate the coral mounds area.

The collaboration with potential external end-users during this work led to the expansion of the type of attributes extract automatically (Figure 13).

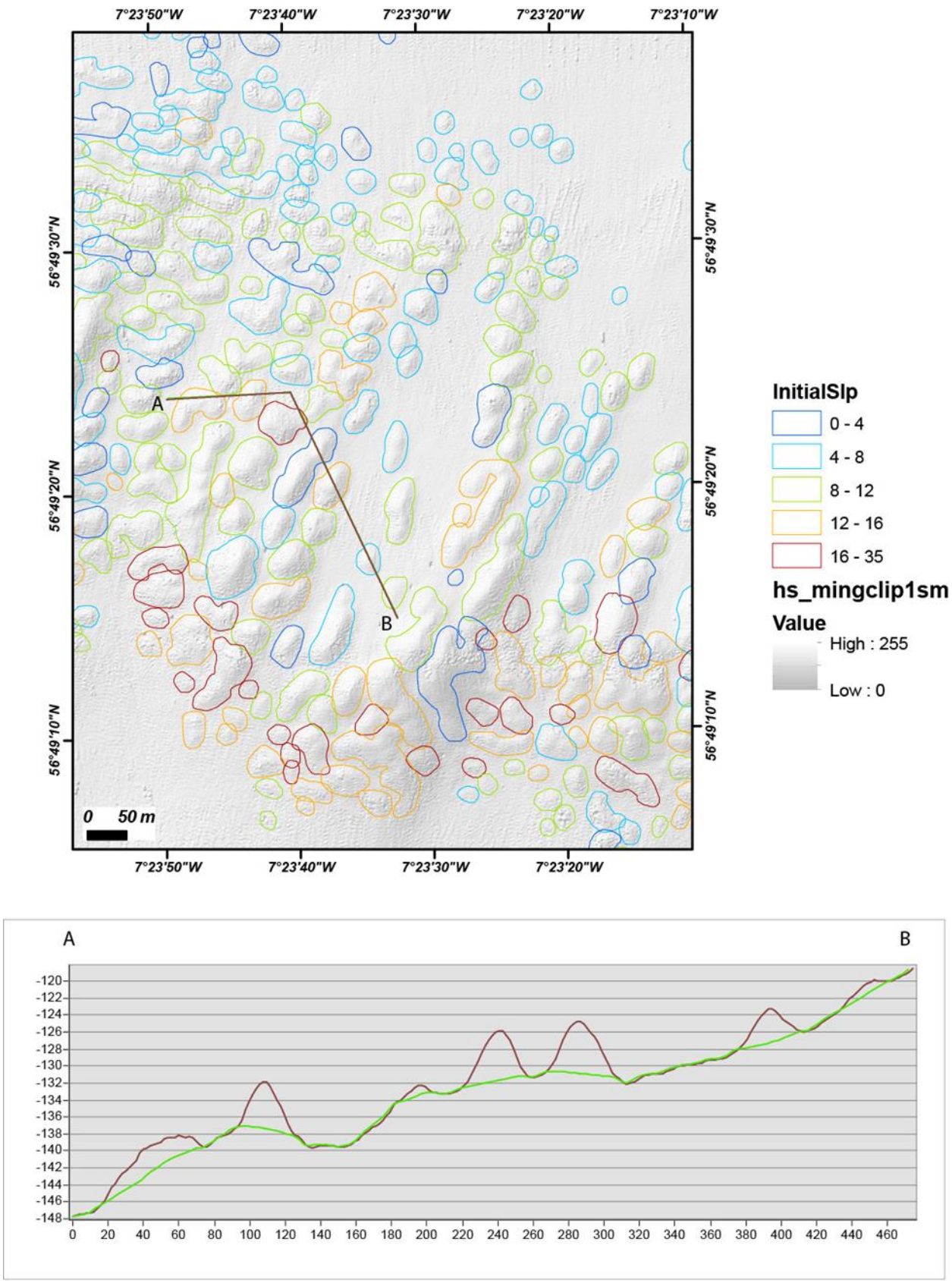

Figure 13 –*Top:* Map showing the coral mounds mapped within the study area, classified according to the steepness of the calculated original seabed. *Bottom*: Profile showing the present day bathymetry (in brown) and the assumed seabed morphology previous to the development of the cold-water coral mounds.

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British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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