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AN OBJECT BASED IMAGE ANALYSIS APPROACH FOR THE EXTRACTION OF THE KOLOUMBO VOLCANO AND ASSOCIATED DOMES-CONES FROM A DIGITAL SEABED ELEVATION MODEL

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Abstract

This paper concerns the study of the seafloor through digital seabed elevation models, using object based image analysis methods. The goal of this research was the automated extraction of geomorphological features from the seabed in regions presenting intense volcanic activity. The study area is located around the submarine volcano of the Koloumbo (in the submarine area northeast of the Santorini island, Greece). For this purpose, a Digital Elevation Model (DEM) of the seabed with a spatial resolution of 50m was used. Derivatives of the DEM, such us Slope, Topographic Position Index (TPI) and Terrain Ruggedness Index (TRI) were created in the open source software "QGIS 2.4". The implementation of the object based image analysis approach was performed in eCognition 8.7 software. Nine segmentation and classification levels were created in order to produce the final level segmentation "level 5", where the final geomorphological features were classified. The results of the method were evaluated using classification stability measures and qualitative and quantitative comparison of the results with existing map.
Keywords: *Geomorphology, Koloumbo, Greek volcanic arc.*

Περίληψη

Η παρούσα μελέτη, αφορά στη μελέτη του θαλάσσιου πυθμένα από ψηφιακά μοντέλα αναγλύφου, με την ανάπτυξη μεθοδολογίας αντικειμενοστρεφούς ανάλυσης εικόνας. Έχει ως στόχο την αυτοματοποιημένη εξαγωγή γεωμορφολογικών χαρακτηριστικών πυθμένα, στον οποίο εντοπίζεται έντονη ηφαιστειακή δραστηριότητα. Η περιοχή μελέτης βρίσκεται στη λεκάνη της Ανύδρου, όπου δεσπόζει το υποθαλάσσιο ηφαίστειο του Κολούμπο, καθώς και μικρότεροι υποθαλάσσιοι ηφαιστειακοί κώνοι, 7 χλμ βορειοανατολικά της Σαντορίνης. Για το σκοπό αυτό, έγινε χρήση ψηφιακού μοντέλου αναγλύφου πυθμένα χωρικής ανάλυσης 50m και των παραγώγων αυτού: Slope, Topographic Position Index (TPI) και Terrain Ruggedness Index (TRI). Δημιουργήθηκαν συνολικά εννέα επίπεδα κατάτμησης και ταξινόμησης με στόχο την παραγωγή του τελικού επιπέδου κατάτμησης "level 5", στο οποίο και ταξινομήθηκαν οι τελικές κατηγορίες γεωμορφολογικών χαρακτηριστικών. Τα αποτελέσματα της μεθόδου αξιολογήθηκαν με τη χρήση

αλγορίθμων που αφορούν την ευστάθεια της ταξινόμησης, αλλά και με ποιοτική και ποσοτική σύγκριση των αποτελεσμάτων με υπάρχων χαρτογραφικό υλικό.

Λέξεις κλειδιά: *Γεωμορφές, Κολούμπο, Ελληνικό ηφαιστειακό τόξο, Αντικειμενοστρεφής Ανάλυση Εικόνας.*

1. Introduction

The goal of this paper was to investigate the potential of the Object-based Image Analysis (OBIA) approach in mapping geomorphological features from a digital seabed elevation model (with a spatial resolution of 50m. The existing volcanic landforms were mapped and compared qualitatively and quantitatively with existing data.

The study area is located in the Koloumbo volcanic chain and it extends 20 km to the northeast of Santorini (Figure 1). It is composed of more than 19 volcanic cones of varying sizes, which are aligned along two distinct linear trends (N 29°E and N42ºE) that converge at the point of the Koloumbo volcano. Koloumbo is the largest of the submarine volcanic cones along the volcanic rift NE of Santorini. It has an ellipsoidal shape with the major axis trending NE-SW. The diameter of the Koloumbo volcanic cone is approximately 3 km, whereas the crater diameter is 1, 7 km. The average depth of the caldera rim lies at about 150 m depth forming a submarine circular cliff with the shallowest point at only 18 m below sea level. Within the cone there is a relatively flat-lying crater floor with an average depth of about 505 m (Nomikou, 2003; Nomikou, 2012, 2013a, b).

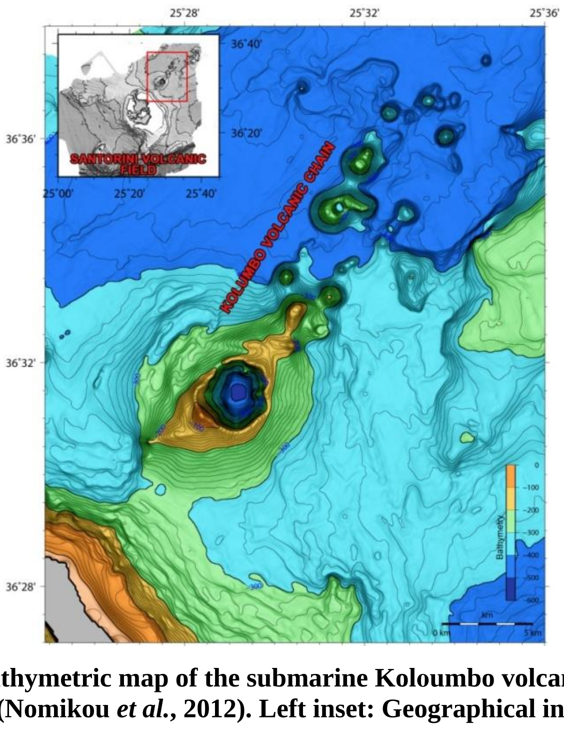

Figure 1 - Swath bathymetric map of the submarine Koloumbo volcanic chain using 10m isobaths (Nomikou *et al.*, 2012). Left inset: Geographical index map.

2. Object Based Image Analysis (OBIA)

Object based image analysis (OBIA) is a new approach for analysis and classification of digital images. According to Hay and Castilla (2006), OBIA is a special application of geographic information systems intended to introduce semantic objects in image analysis that incorporate spatial and quantitative features. With image segmentation and classification procedures, OBIA manages to consider and associate different image objects, towards deriving image semantics (Gercek, 2010). OBIA enables the creation of a hierarchy of multiple levels consisting of uniform in tone and shape image objects, that know both their neighbors at the same level as well as objects that are above or below them. At the same time, OBIA is employing statistical parameters relating to the color of objects (average tone, standard deviation, texture etc.) and properties that relate to the shape of objects (orientation, length, width, elongation, curvature, compactness, etc.). After each segmentation step, there is the possibility of restructuring the derived objects so that to refine them. The restructuring can be done with two different algorithms: "merge region" or "grow region". The algorithm "merge region" consists a basic tool used in this paper, for merging all neighboring object of a class in a large object. The classification results are not changing, but only the number of objects is being reduced by merging (Trimble, 2011).

3. Datasets and DEM derivatives

A digital elevation model (DEM) of the seabed, with a spatial resolution of 50m, was provided by the "Hellenic Centre for Marine Research". Its indices [Slope, Topographic Position Index (TPI) and Terrain Ruggedness Index (TRI)], were computed in the open software "QGIS 2.4" (Figure 2).

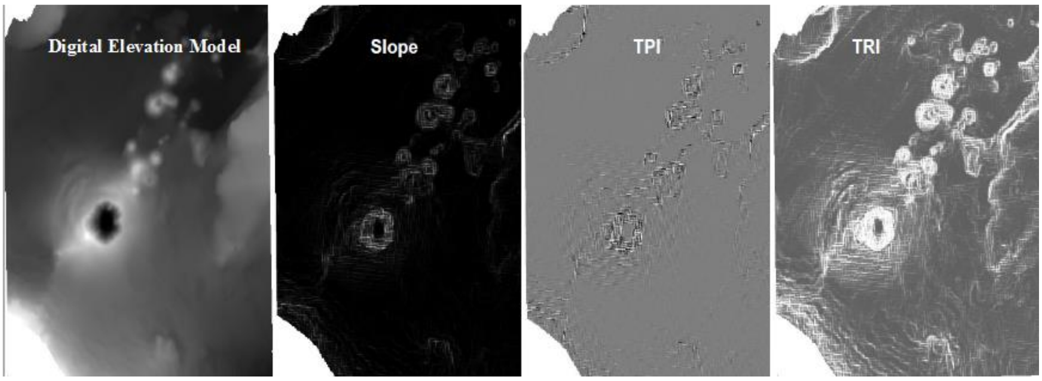

Figure 2 - Digital elevation model (DEM) of the seabed and its derivatives Slope, TPI and TRI.

Slope measures the rate of change of altitude in the direction with the largest slope (Wilson and Gallant, 2000). Areas with great slopes are displayed with light grey tones. The Topographic Position Index, compares the altitude of each pixel of the digital elevation model, with the average elevation of a particular region around the pixel. The Terrain Ruggedness Index, shows the heterogeneity present on the seabed by computing the total change in altitude between a pixel and its eight neighboring pixels (Riley *et.al.*, 1999).

4. Methodology – Implementation

In this study, OBIA was applied through the eCognition software and it includes segmentation and classification. Through segmentation, the DEM is segmented into objects through user-set parameters such as the desirable heterogeneity reflecting the size and the shape of the objects to be created. Different segmentation parameters can be applied creating different objects in various resolution levels of hierarchy in the same image. Objects in higher levels are referred to as super-objects, while in lower levels as sub-objects, creating a hierarchical objects network. The objects created have shape, spatial and spectral attributes such as size, area, position, relations to super- or sub-objects etc. Subsequently, the user defines the classes of interest assigning selected attributes and their values through fuzzy membership functions to each class. The objects of the image are then classified through fuzzy logic into the selected classes, each obtaining the proper membership value to each class (Baatz and Schape, 1999).

Multiresolution segmentation tests were performed, in which many combinations of scale parameters, homogeneity criteria and weights were used in each image layer. Nine different segmentation levels were finally selected through photo-interpretation. In the following, all landforms classes appear in italics while a number at the end of a class name indicates the segmentation level.

Level 1 was created for an initial separation of the areas where there are bathymetric data (*interesting area 1)*, from the areas where there are no bathymetric data (*background 1)*. For this purpose, segmentation was carried out with a very small scale parameter (=10) and returned very small objects. Class *interesting area 1*, included objects which had elevation values greater than -700m in the thematic level of the digital elevation model. By applying the algorithm "merge region", the class *interesting area 1*, was composed of a single object.

Level 2 and 3 were created in order to distinguish objects belonging to *volcano domes or cones with great slope (>10%)* (Figure 3).

Level 2 was created primarily to distinguish objects that are likely to belong to *volcano domes or cones with great slopes (>10%) or to inner crater walls*. A small scale parameter (=10) was employed and thus very small objects were created. Totally, five classes were created by employing only the slope parameter. Then, for each class the algorithm "merge region" was applied, for merging neighboring objects of the same class into one object.

In order to identify objects which eventually would be categorized as *volcanic dome or cones with great slope (>10%)*, level 3 was created. Segmentation took place with small scale parameter (=10) and only the slope feature was employed. In the initial classification of this level, the purpose was to distinguish objects that are likely to belong to *volcano domes or cones with great slopes (>10%) or to inner crater walls* (as classified in level 2) and then further normalization took place of the boundaries of these objects, using the function "Relative border to". In the second classification of this level (after "merge region"), the purpose was to distinguish the objects that eventually would be categorized as *volcano domes or cones with great slope (>10%)*. At first, "merge region" was applied for all classes of level 3. Then reclassification took place in order to employ the properties reflecting the integrated structure of a volcanic dome (area, compactness and positive values of TPI index).

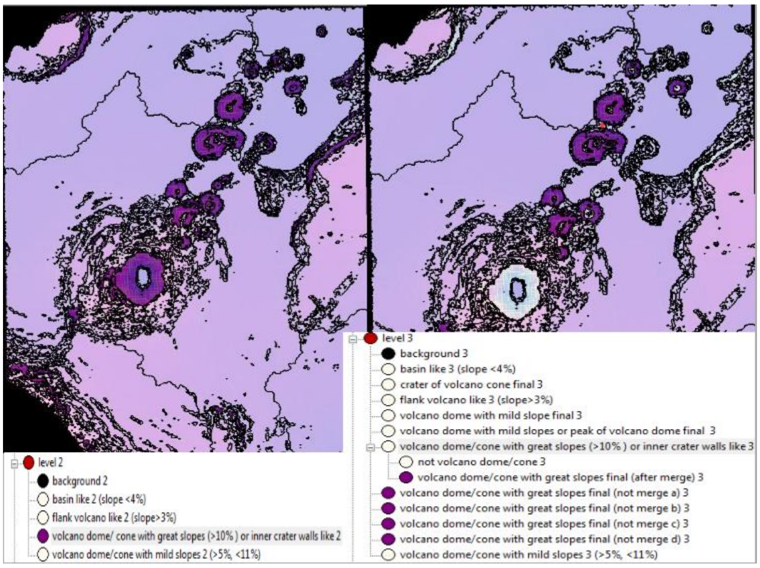

Figure 3 – OBIA classification results for levels 2 and 3.

Level 4 was then created in order to identify the *inner crater walls (with mild or great slope)*, and the *crater floor* (Figure 4). At first, segmentation took place with a small scale parameter (=10) and objects likely to belong to inner crater walls, were classified as *inner crater walls like 4*, based on large values of slope and by employing the function "Relative border to". Afterwards, the algorithm “merge region” was applied for all classes and 16 intermediate landforms classes were created. Finally, the desired landforms [*inner crater walls (mild slope), inner crater walls (great slope) and the crater floor*] were derived based on the features area, TRI, TPI, “Distance to” and “Relative Border to”. As an example, the category *inner crater walls*, was identified based on large values of slope and it’s almost circular shape, while the landform class *crater floor* was identified based on the relative proximity with the category *inner crater walls*.

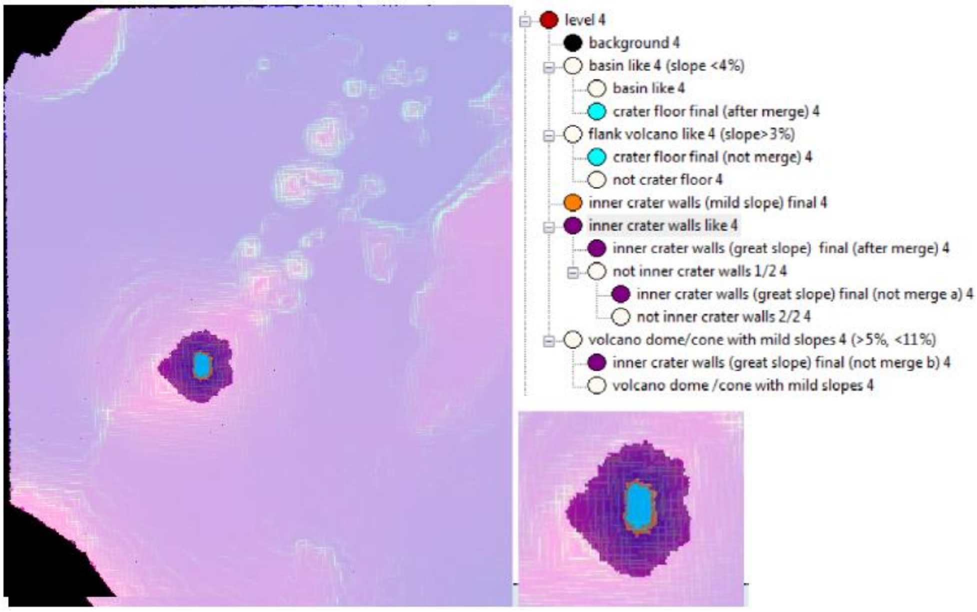

Figure 4 – OBIA classification results for level 4.

Level 6 was created in order to identify the *volcano domes with mild slopes or peak of volcano domes with great slopes* and the *crater of volcano cones*. In the previous levels (3 and 4), it was not possible to identify those categories, due to their small size and their mild slope. In this level, the thematic level of DEM was employed with weight value 3 (producing objects resembling the depth contours), while the thematic level of slope was given weight value 1. With a large scale parameter (=100) and weight value 3 for the thematic level of DEM, each landform class consisted of one to three objects. The objects of class *crater of volcano cone like 6* have negative values of TPI, as they are at lower heights than their neighboring objects, contrary to the objects of class *volcano with mild slopes or peak of volcano dome with great slopes like 6 (a)* that have positive values of TPI, as they are at higher elevations than their neighboring objects. After the classification, the command “merge region” was applied for all classes. In Figure 5, 21 *volcano domes with mild slopes or peak of volcano dome with great slopes* and two *craters of volcano cones* were derived.

Objects on level 7 were created in order to identify the *volcano domes with mild slope*, which were not classified at level 6 (with a relative large size) (Figure 6). Segmentation took place by assigning weigh 1 to both DEM and slope thematic layers, while the shape criterion was set as 0,3 and the compactness criterion as 0,9. This segmentation of DEM resulted into objects resembling the depth contours. A large scale parameter (=260) was applied, and resulted to each landform class to be composed of a single object. For the classification of objects that belong to the class *volcano dome with mild slope like 7 (b)*, small values of compactness, positive values of TPI and mild values of slope were applied.

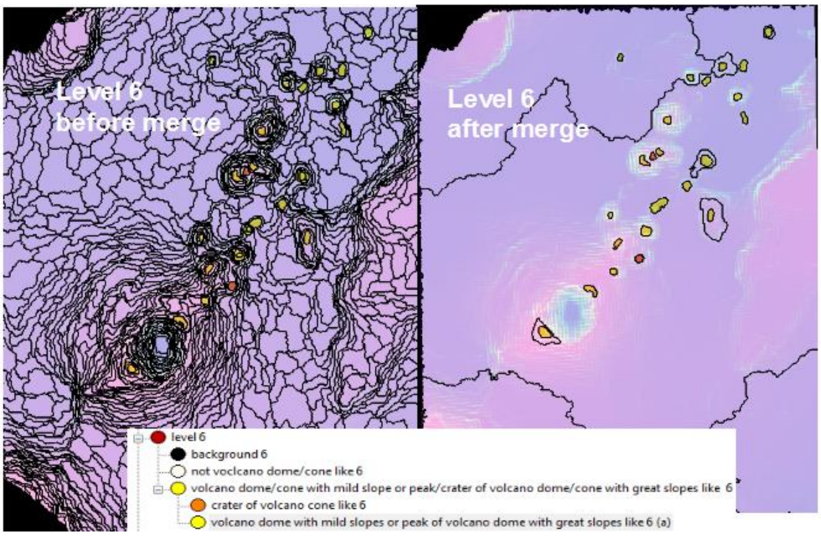

Figure 5 – OBIA classification results for level 6, before and after merging regions.

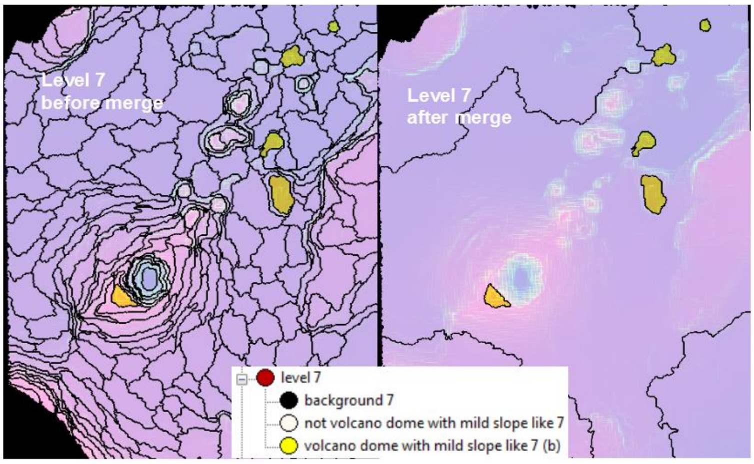

Figure 6 – OBIA classification results for level 7, before and after merging regions.

Level 8 was created in order to identify objects that belong to *not flank volcano like 8* on the south side of the Koloumbo. Because in the southern area of Koloumbo, slopes are large and continue to be intense even outside of the volcano area (according to photo-interpretation), it was necessary to create a large segmentation level (the creation of which took into account the homogeneity of the wider area), so by creating large objects to determine the south boundaries of the flank of Koloumbo (Figure 7). For such a segmentation, the thematic layer of slope was used and a large scale parameter (=300) (for the creation of large objects) was assigned. Shape was set to 0,1 and compactness to 0,9 (so as to create compact shapes). Objects with large values of area (where there are not intense changes of slope), were classified as *not flank volcano like 8.* After the classification, the command "merge region" was applied for all classes.

Level 9 was created in order to identify the *flanks of volcano* (Figure 8). Level 9 was created after the creation of all higher levels and the application of command "merge region" to them. For this segmentation the following parameters were selected: scale 1, shape 0,1 and compactness 0,5. The class *flank volcano like (a) 9* was determined based on the relative proximity to the class *crater floor*, which was determined at level 4.

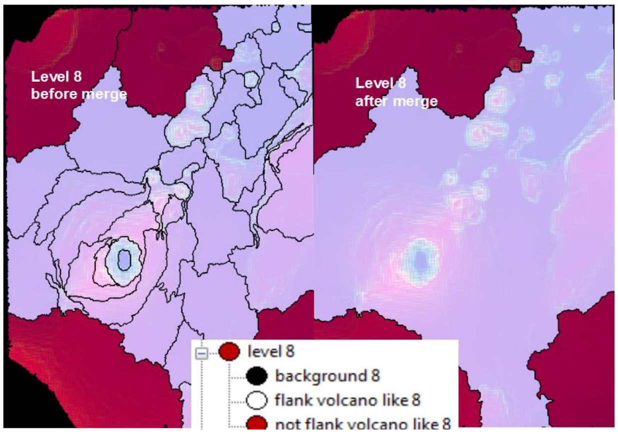

Figure 7 – OBIA classification results for level 8, before and after merging regions.

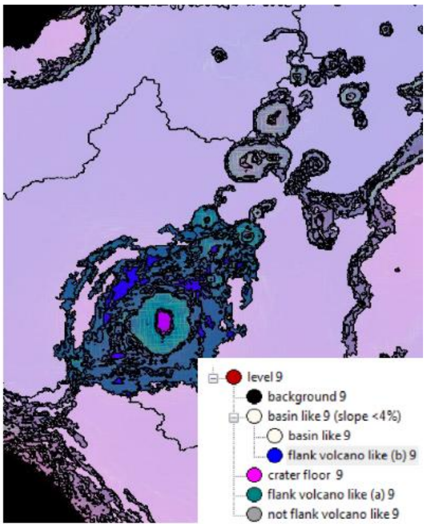

Figure 8 – Classification of objects in level 9.

Level 5 consisted the final map (Figure 9), in which the total number of landform classes were identified. The final categories identified in previous levels, were introduced with the function "Existence of", while the class *inner crater walls (great slope) 2/2 5*, was created in order to classify an object as *inner crater walls* (based on its proximity to crater floor). Basins, for reasons of cartographic representation, were divided into four categories depending on the range of depth values.

5. Evaluation

For the quantitative evaluation of extracted objects, the established indices Completeness, Correctness και Overall Quality (Mariano *et al.*, 2002) were employed. For computing these indices, it was necessary to digitize the boundaries of all extracted objects and those derived by photo-interpretation. Digitization was applied in the ArcGIS software. The computation of the above indices, took place by comparing the results of digitized photo-interpretation boundaries to the extracted feature boundaries (Figure 10).

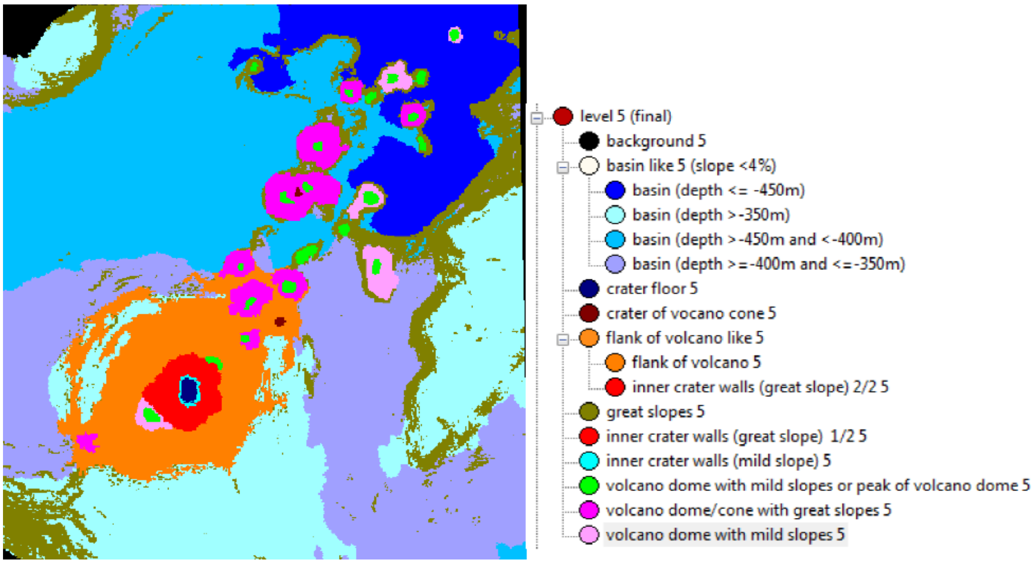

Figure 9 –The final map containing all derived final landform classes.

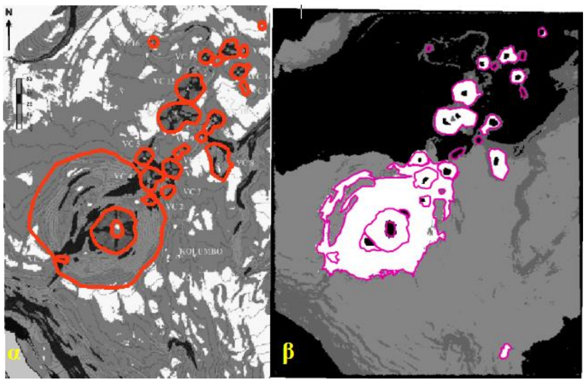

Figure 10 - Digitization of boundaries, a) as determined by photo-interpretation, and b) as produced by object based image analysis.

The lowest accuracy was observed in the *flanks of Koloumbo* (Table 1). This is expected as the assessment of the boundaries of the *flanks of Koloumbo* (by photo-interpretation), contain a high degree of uncertainty. The *crater floor* presents the second best overall quality, while the overall quality of *inner crater walls* was the best. The correctness of *inner crater walls* is approaching the unit. Finally, the *volcano domes-cones*, present the third best overall quality. Generally, the results of the quantitative evaluation have shown that all developed object based analysis rules, gave satisfactory results for the extraction of landforms classes in the region.

Table 1 - Classification Accuracy.

Class	Completeness	Correctness	Quality
Volcano domes-cones	78.30%	84.75%	68.63%
Flanks of Koloumbo	66.23%	87.53%	60.52%
Inner crater walls	88.04%	98.90%	87.19%
Crater floor	74.59%	93.81%	71.09%

6. Conclusion

This work has shown that the developed OBIA approach through a digital elevation model is a useful tool for the automated extraction of geomorphological features of seabed.

Finer segmentation was employed to distinguish volcanic landforms with great slopes, while coarser segmentation was employed for the recognition of volcanic domes-cones with small slopes (that are not easily distinguished from the surrounding environment).

It ıs worth noting that the inner crater walls, as determined by quantitative evaluation of the results, was the landform class detected with the highest accuracy. This seems reasonable, given the very specific form of this feature, which is easily distinguishable from the neighboring environment (great slope with almost circular shape).

By using higher resolution DEM, it is expected greater accuracy to be achieved.

7. Acknowledgments

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