The Geomorphological mapping of Keros island (Cyclades, Greece).

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Abstract

This study concerns the geomorphological mapping of Keros island in scale 1:10.000 . This island is located in "Small Cyclades" (Cyclades, Greece) and it is considered of major archaeological importance as it has been excavated since 1963 (since 1987 by the University of Cambridge). Keros is included in the topographic maps of the Hellenic Military Geographical Service scaled 1:5.000 and in the geological maps of the Institute of Geology and Mineral Exploration scaled 1:50.000 (map sheet "Schoinoussa"). This small island presents a complex terrain and a wide variety of landforms, due to its intense tectonism and the natural processes that shaped its morphology. The primary data that were used in the creation of the map mainly included geological and topographic maps. Decisive contribution in mapping was provided by the available Quickbird satellite imagery and Google Earth images, as well as the field work. Thematic layers of the topography, hydrography and geology were constructed through GIS software. A Digital Elevation Model was also constructed, from which the slope and aspect maps were created. The thematic maps of slope and lithology were classified into categories, which were combined to constitute detection criteria of landforms. Finally, with the appropriate combination of colors and symbols the geomorphological map of the study area was produced in order to pinpoint geoarchaeological issues concerning the human activities and occupation on the island during Holocene.

Key words: Keros, Small Cyclades GIS, multi-component analysis, semi-automated Geomorphological mapping

1. Introduction

Keros island is situated in Cyclades Island complex and specifically in a complex called "Small Cyclades" (consisted of the Islands Donousa, Schoinousa, Folegandros, Ano - Kato Koufonisi and Keros) (Figure 1). This complex is located south of Naxos Island. Keros is bigger than all the other islands in this complex. It is an important archaeological site of the Neolithic period (Renfrew et al., 2012, Renfrew .et al., 2013).

Figure 1: Location map

Steep landscape (unlike the other islands of "Small Cyclades") is observed, with minor exceptions, mainly in the northern part of the island, where there are areas with gentle slopes, mainly at Konakia and Gerania (Figure 2). Most areas with steep slopes are located in the southern, southeastern and southwestern part of the island.

Specifically Keros Isl. has a varied relief, with gentle to medium slopes mainly in the northern part, where Holocene and Pleistocene alluvial deposits are accommodated (sediment thickness up to 1,5m). In this area is located the biggest part of the arable land on the island, mostly in terraces of different ages. In the collapsed terraces, archaeological shells of different periods (Renfrew et al., 2012, Renfrew et al., 2013) and other archaeological remains are observed.

The southern part of the island is dominated by steep slopes which make the area inaccessible (Riedl et al., 1982). In this part of the island take place more livestock activities than rural. The fluviotorrential deposits end up in the sea without being deposited, due to steep slopes it is impossible to create large-scale alluvial fans, such as in the northern part. The areas with alluvial deposits are Glyfada (Figure 2) in the south-central part of the island and the Phiro bay in the southwestern part of the island. In the southern part of the island, most of the coastal cliffs are located. Furthermore eroded remnants of faulting can also be found. This evolution can be justified due to tectonic and erosional processes. There are landforms originated from these processes such as hanging valleys and knick points.

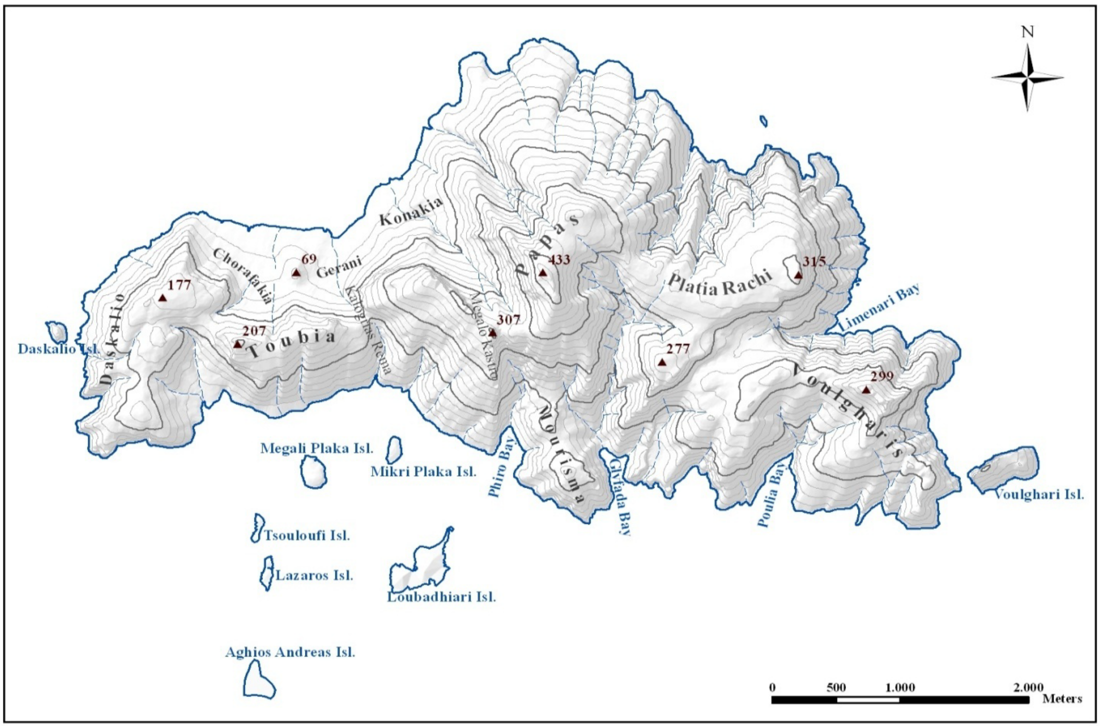

Figure 2: Place names of Keros Island.

For better understanding of the landscape evolution and the dominant physical processes shaping the relief of the island and consequently the activities of the habitants during archaeological periods, it is essential to carry out a geomorphological research and mapping. During this research the whole island will be mapped and the results will come through the description and the analysis of the landforms and the processes that created them. This analysis of the results will help to understand the archaeological importance of the island.

2. Methodology

2.1. Data Used

The first stage of the research was the collection of analogue maps (in raster format) and remote sensing data of the island. The analogue maps include the large scale (1/5000) topographic sheets of Keros Isl. by the Hellenic Military Geographical Service as well as the medium scale (1/50000) geological map from the Institute of Geology and Mineral Exploration. Remote sensing data include large scale aerial photos by the Greek Cadastre, Quickbird satellite images and Google Earth.

The second stage of the geomorphological mapping was the fieldwork. Over 60 stops of interest were investigated on the island during the Keros Isl. Field Survey Project in September and October of 2013. During the fieldwork many landforms were classified as well as a number of topographical and geological features which were not apparent in the maps and images of the study area. All these features of the landscape were listed in order to be included in the final results of the research.

2.2. Features

The topographic maps provided contours with a 20m interval, points of fixed altitude such as the triangulation points and the drainage network of the island. In the areas with slopes less than 15 ^{o} the regular and intermediate contours with 4 and 2 meters interval respectively where digitized from 1/5000 scale topographic maps in order to create a more detailed Digital Elevation Model for the next stages of the geomorphological mapping. The information about lithology and faulting were proved to be more difficult to be identified, since the scale of the geomorphological map was set to 1/10000 while the geological maps are scaled 1/50000. The geological formations and the faults were mainly identified and determined by the remote sensing data and the extensive fieldwork, in order to avoid errors and deviations in the final map.

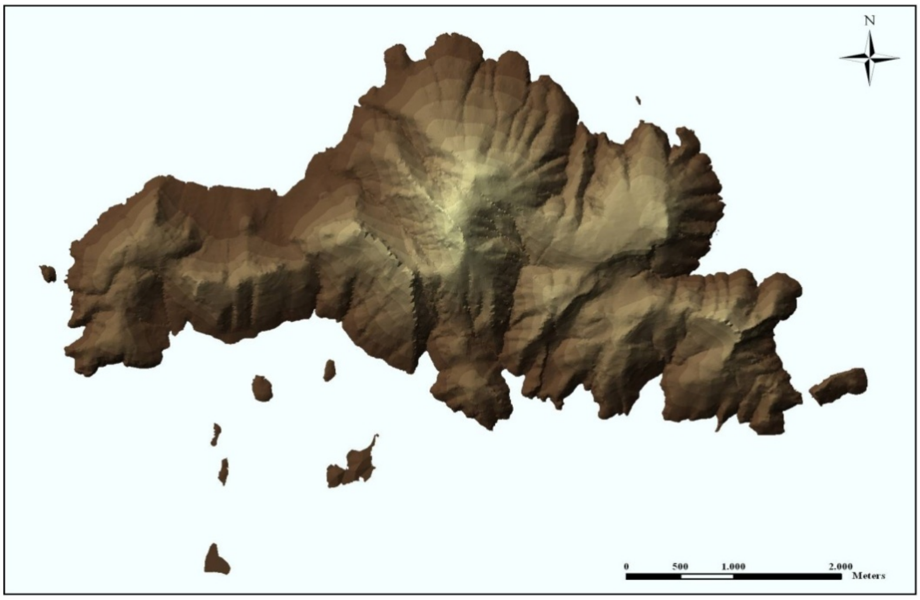

Figure 3. The Digital Elevation Model of Keros Island.

2.3. DEM & Slope Map

The Digital Elevation Model (DEM) is a three-dimensional representation of the terrain, and it can generate other data useful in geomorphological mapping, such as slope maps, aspect maps, watersheds, river basins and drainage networks (approximately). It was created from the digitized contours and the elevation points of the 1/50,000 & 1/5,000 scale topographic maps for the study area. The primary format was a Triangular Irregular Network (TIN) that was transformed in raster format, with a cell size of 5X5 meters (Figure 3). The detail and the accuracy of the terrain representation is generally characterized as an element of major importance in geomorphological research.

The slope map is considered as one of the most important data generated by the DEM concerning geomorphological mapping (Gustavsson et al., 2009). It represents the relief inclination at every cell of the study area. It is one of the main features of geomorphological analysis, as different landforms occur in different inclinations (Figure 4).

The cell values were classified into 6 categories highlighting the different landforms in accordance with the uniform system of symbolism («Unified Key») which was established by the IGU Commission on Geomorphological Survey and Mapping during the 1960s – 1970s (Figure 5) (Gustavsson et al., 2006).

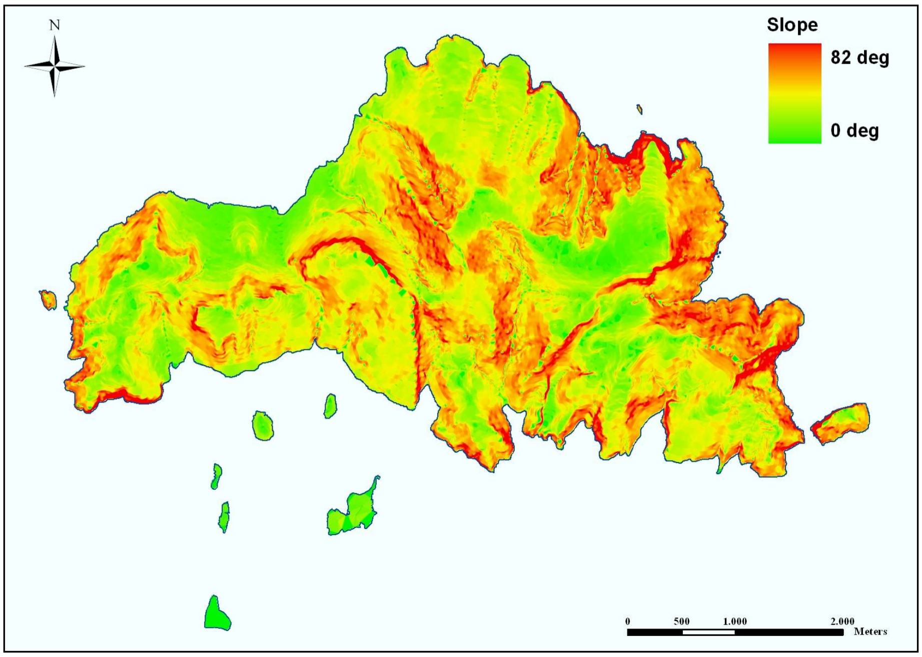

Figure 4. The Slope Map of Keros Island.

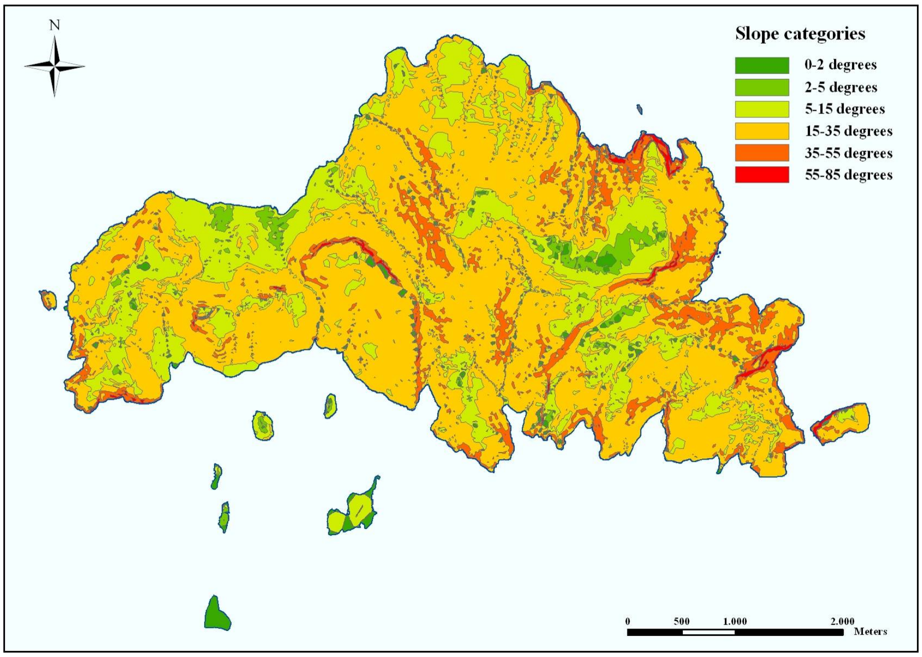

Figure 5. The Classified Slope Map of Keros.

The aspect map is generated by the DEM and it displays the orientation of the slopes of the study area in degrees (Figure 6).

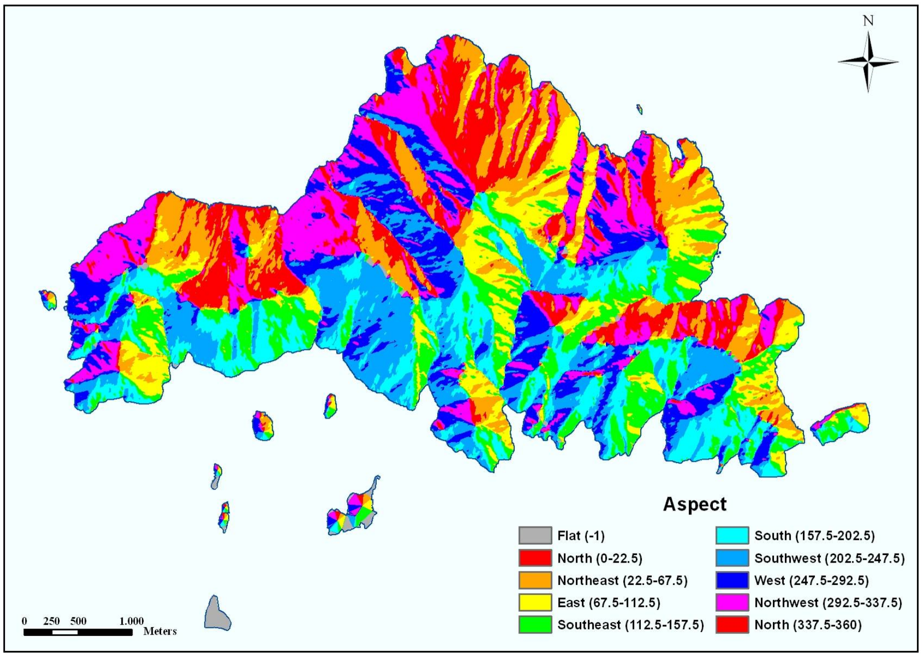

Figure 6. The Aspect Map of Keros.

2.4. Semi - Automated geomorphological mapping

Basic criteria for the identification of the landforms were slope and lithology. Various combinations of the specific criteria were used as shown in Table 1 (Van Asselen et al., 2006).

Table 1 - Criteria for multi-variable analysis

Landforms	Criteria
Cliffs	Slopes > 35^o Alpine formations
Planation surfaces	Slopes < 5^o Alpine formations
Deposit cones and debris	35^o > slopes > 5^o Post alpine deposits
Down cutting erosion	Slopes > 35^o Buffer 20 m. from streams

For the identification of the cliffs of the region were used as primary criteria high ground slope (> 35^o) in combination with the presence of alpine formations. The areas that were marked by the automated process were verified by aerial images and fieldwork (Pavlopoulos et al., 2009).

To determine the planation surfaces smooth relief slopes (<5^o) were used as criteria combined with the presence of alpine formations. Furthermore, classes of elevation of the DEM were used to classify surfaces levelling depending on the altitude, as well as the layer of the aspect map, in order to determine the direction in which these surfaces creep.

The multivariable analysis to identify alluvial and colluvial deposits, debris and screes had satisfactory results. For the identification of these landforms, qualitative interpretation of the available remote sensing data and the topographic and geological maps was also used in order to separate the alluvial from the colluvial deposits, as well as to determine the way these landforms occurred in specific areas. The fieldwork observations and notes played a major part in this procedure, since these features had to be verified.

The coastal landforms were determined by the combined study of topography, geological structure and remote sensing data. Many of the steep and medium slopes of the shores were already recognized during the multivariable analysis for the identification of the cliffs. Many stops were also made along the coast which verified the form of the coasts of the island.

The shapes of the valleys, down cutting erosion, gorges and knick points were identified by the combined study of the topographic maps, the slope map and fieldwork, while landforms like caves, rock falls and landslides were mainly identified through fieldwork.

2.5. Map Composition

The geographical entities were classified according their characteristics following the rules of cartographic generalization, abstraction and simplification (Gustavsson, 2005). Specifically, discrete levels of information were generated concerning topographic, hydrographic, geological, and geomorphological elements. For each geographical entity appropriate cartographic symbols were used. In individual cases new symbols were created for the accurate interpretation of the displayed information.

The symbolism of the lithology, the tectonic and the geomorphological features is generally in accordance with most geological and geomorphological maps, as part of an effort that was made in order the map and its legend to be self-explanatory (Figure 7).

Since the contours are displayed with light shades of grey, indication of the relief inclinations was essential as an additional feature of the morphology, in order to improve the map readability. The geological formations (except the volcanic) are symbolized with light colors and fills, so as to be distinguished from the other features of the map. All features relative to fluvial or maritime processes use blue color, as well as karstic landforms by the coast of the island. The notches showed in the map reflect only those which were observed and measured during the fieldwork in September of 2013.

The discrimination in the changes of slope and the height of the fronts of the cliffs originates from the fact that a large scale map must be accurate and detailed. The bases of cliffs with fronts less than 20 meters of height were not symbolized because this would make readability difficult, since they are very close to the edges. Bases of discontinues with gentle change of slope were considered not necessary to be displayed. The type of the symbols used to represent abrupt and gentle changes of slope corresponds to the type of coastal landforms symbols but in different colors.

The planation surfaces are displayed with gradient colors from green to orange, which indicate their elevation. The orientation of these surfaces is represented with a thick arrow. In the rockslides symbol the arrows show the direction in which these rocks slide. Debris and screes use a symbol with circles of gradually increasing radius, which indicates the direction in which they fall downhill (to the side where the radius increases).

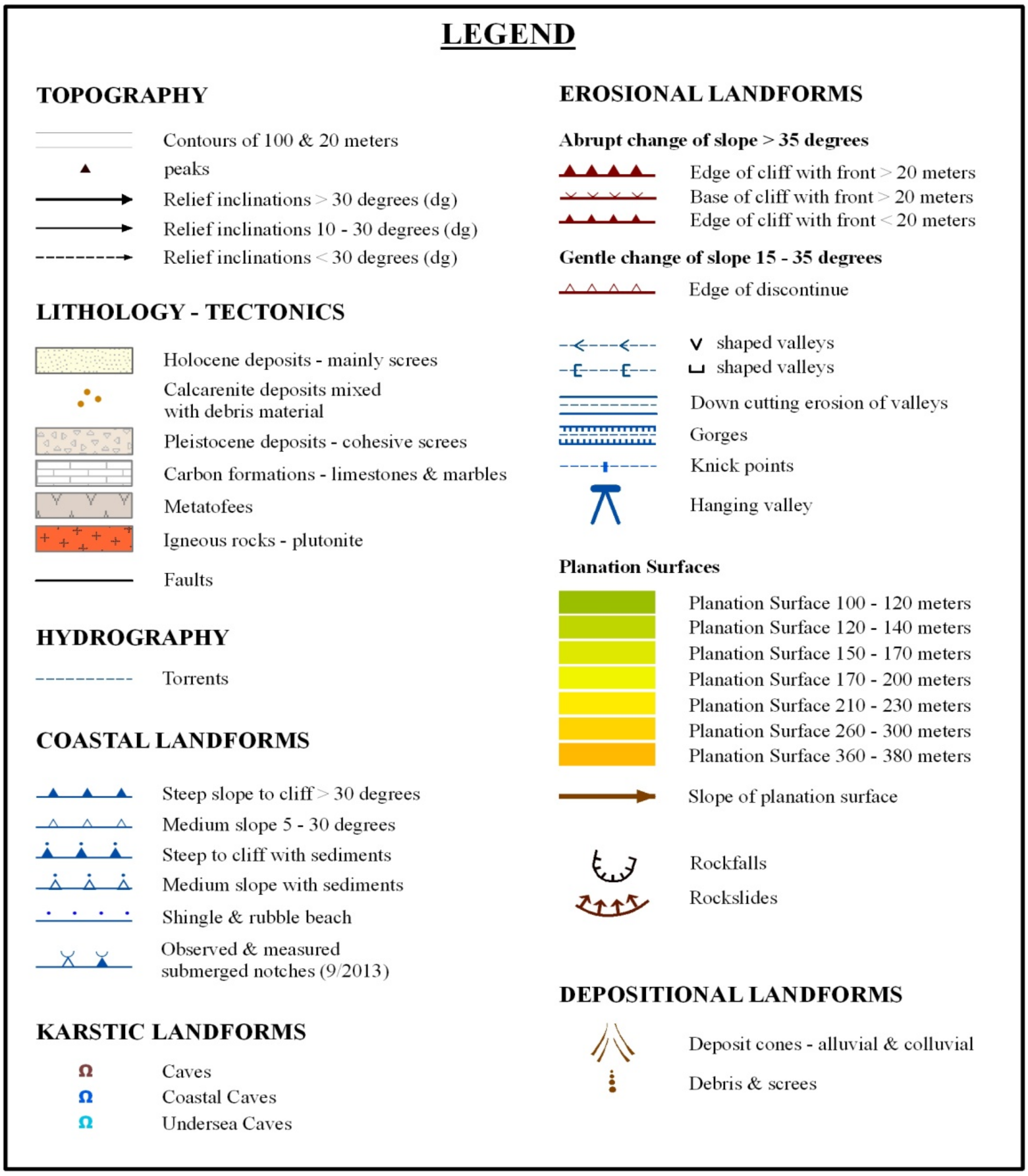

Figure 7. The legend of the geomorphological map.

3. Geomorphology of Keros Isl.

Initially the geomorphological map can be distinguished in 5 different parts (figure 8) (concerning the geomorphology and the processes of each area). These parts are:

1. The southwestern part of Keros
2. The West-Northwest part
3. The Northern-Central part
4. The Eastern part
5. The Southern-Central part

During the geomorphological mapping landforms can be identified, which indicate the composition of a steep landscape. Generally, the relief of Keros Isl. presents steep slopes, high altitudes (up to 433m) and V shaped valleys. The steepest relief is found in the southern part of the island. In this area located the steepest slopes and many coastal cliffs.

In the southwestern part of Keros Isl. (Figure 9) are situated coastal cliffs of medium to steep inclinations, V-shaped valleys, slope inclinations ranging from 5 to 25 degrees. The absence of alluvial fans is evident. The erosional and depositional processes are influenced mainly by intense climatic phenomena, since rainfall in the Cyclades is intense and occur only between November and March (Dazy et al., 1996, Varias et al., 2014), they do not favor the deposition of sediments, thus the creation of alluvial fans is very difficult.

Also the deep seabed observed in the southern part of the island coupled with the limited supply of sediments, intensify the difficulty of forming coastal deposition areas. The phenomenon of partial absence of deposition and specifically, alluvial fans observed throughout Keros, with few exceptions.

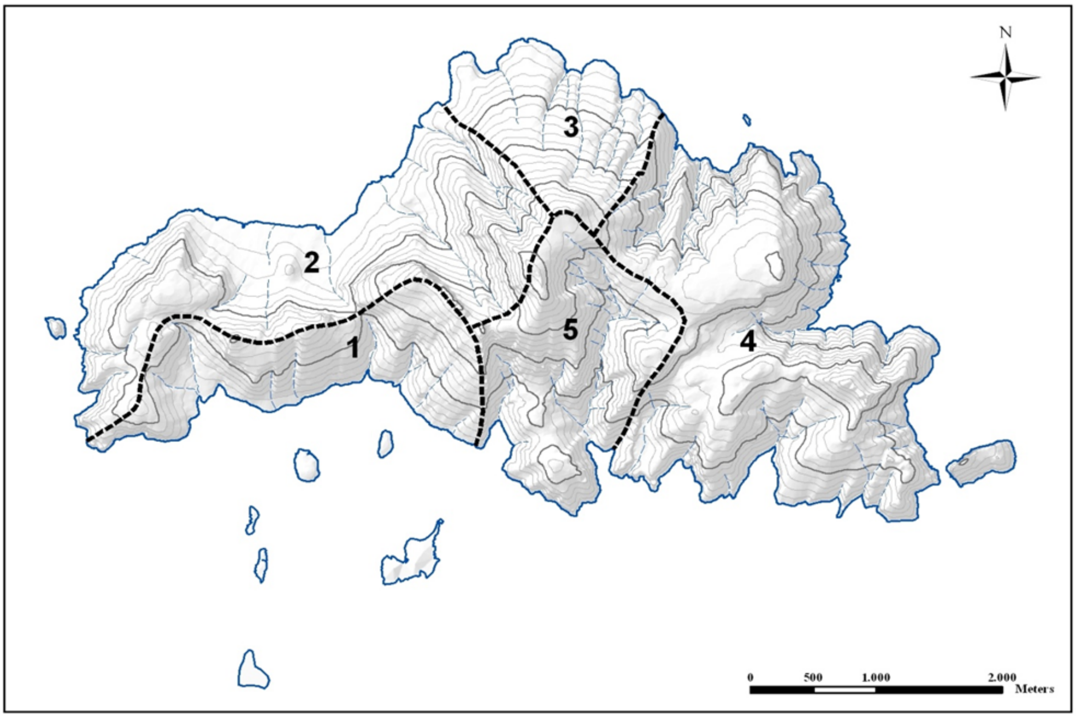

Figure 8: Five different geomorphological areas (Area 1, Area 2, Area 3, Area 4, Area5).

Finally notches appear at various depths in the southern area. The depths range from 45cm to 1.70m below present sea level.

The West-Northwestern part of the island presents steeper relief than the southwestern part (the inclination of slopes ranging from 5-35 degrees). In this part, a coastal cliff is located with medium to steep inclinations. This part also has also the apparition of landslides, especially in the coastal area. Planation surfaces at altitudes from 130 to 180m, were also discovered. This area is delimited by the fault which passes between the planation surfaces, and appears between 130m and 180m. Perhaps is the reason for the difference of the elevation between the two planation surfaces. The tectonism was the process which contributed to the creation of the two planation surfaces or splitting the same planation surface into two parts, due to the tectonic movement of this part.

The biggest alluvial fans appear in that part, in Konakia and Gerani where the most known settlements of the island were developed. This proves the dominant fluvial control of a torrent large enough to erode Pleistocene depositional formations(screes), that are the most erosive formations on the island. Thus the sediments are deposited downstream and this deposition forms the alluvial fans.

In this area the largest spread of terraces of all ages can be observed. In the northern part of the island, the terraces have more than 45cm sediments and consist mainly of coarse sand which has been derived from the erosion of the formation of Aiolianites that is found extensively in Gerani (in the northern part of the island). Around these collapsed terraces many archaeological findings are visible on the soil surface. The sediments which occur on terraces are coarse sands that comes from the erosion of the Aiolianites formation also situated in higher elevations. Aiolianites were found west of the Kavos Daskaliou teachers (Figure 9). In this part, a natural sediment trap was discovered. Probably the sediments were trapped due to the tectonic activity since the eastern side of the Gerani the rift from the eastern part of the area raises and essentially creates a natural sediment trap.

In the coastal area of Gerani, where the alluvial fan ends up in the sea and substantially eroded by marine processes, a natural stratigraphic profile (approximate thickness 20cm) of Holocene deposits is discovered (color grayish-brown). In this, archaeological remains were observed, which enable relative chronology of the layers of the profile. From bottom to top there were sherds of different archaeological periods from Early Cycladic years (20cm) to Archaic period (5cm).

In the Northern-Central part of the island a smooth relief can be observed, with medium inclinations of slopes (mainly in the north-coastal part) from 5-15 degrees. Greater inclinations were encountered in the western part of this section in the area of the torrent. This can be explained by the erosional processes of the torrent itself. At the summit of Papa, a planation surface appears with southeastern orientation at an altitude of 380m. The cliffs have also medium inclination. In the northern coastal cliffs medium inclination were also detected. Finally in this part of the island the alluvial fans are absent.

In the Eastern part of the island most of the coastal cliffs and most of the sharp V shaped valleys can be found. Steep slopes from 10 to 65 degrees can be detected. In coastal and continental areas many cliffs can be found. The absence of the alluvial fans is obvious, since the slopes are too steep to hold the sediments. The two main hydrographic networks in the region are located in Limenari bay (figure 9) in the north and Poulia bay (figure 9) in the south. In these areas can be seen sharp V shaped valleys like in all the hydrographic networks on the island. Knick points and gorges are detected in all the torrents of this part. The dominant processes are weathering, erosion from the precipitation. Finally gravity plays a very important role in the transportation and deposition of the sediments since the slopes are very steep.

At the top of the hill Platia Rachi, in the north, a planation surface was discovered orientated Northeast-southwest at an altitude of 260m. In the south two planation surfaces were detected with similar orientation at 182m and 222m.

In the underwater areas in the southern area of this part of the island, notches have been discovered at different depths. The depths range from 10cm to 3m below the present sea level. This indicator testifies the sea level rise, which limits the continental area with direct effects on humans of different archaeological periods.

Finally in this part, an area of particular geomorphological and not only importance has been discovered. From the north to the south part of this area extends a tectonic depression, which is a natural trap of Pleistocenic and Holocenic sediments. The depression was formed due to tectonic processes, trapping in sediments which have been deposited in this area. In the south part of this depression a hanging valley was observed.

The last part of the island is the southern and central part which presents smoother landforms in contrast of the southeastern neighboring part. In this area, the inclinations are smoother, two alluvial fans in Glyfada (Figure 9) and the largest number of cliffs can be found. Even in this part a planation surface was identified at an altitude of approximately 110m.

In the coastal area of this part, notches appear below the current sea level. The depths of their appearence range from 10cm to 2.9m. Finding notches is important for the geomorphological evolution of the island and for resolving questions about the human activities of relevant archaeological periods lived on the island.

Finally remnants of Karstic landforms were observed in all the surface of the island. Most of these remnants were Karstic caves or pipes which were uplifted by the tectonic activity and they were eroded and weathered. For this reason, the high altitude of these landforms can be explained.

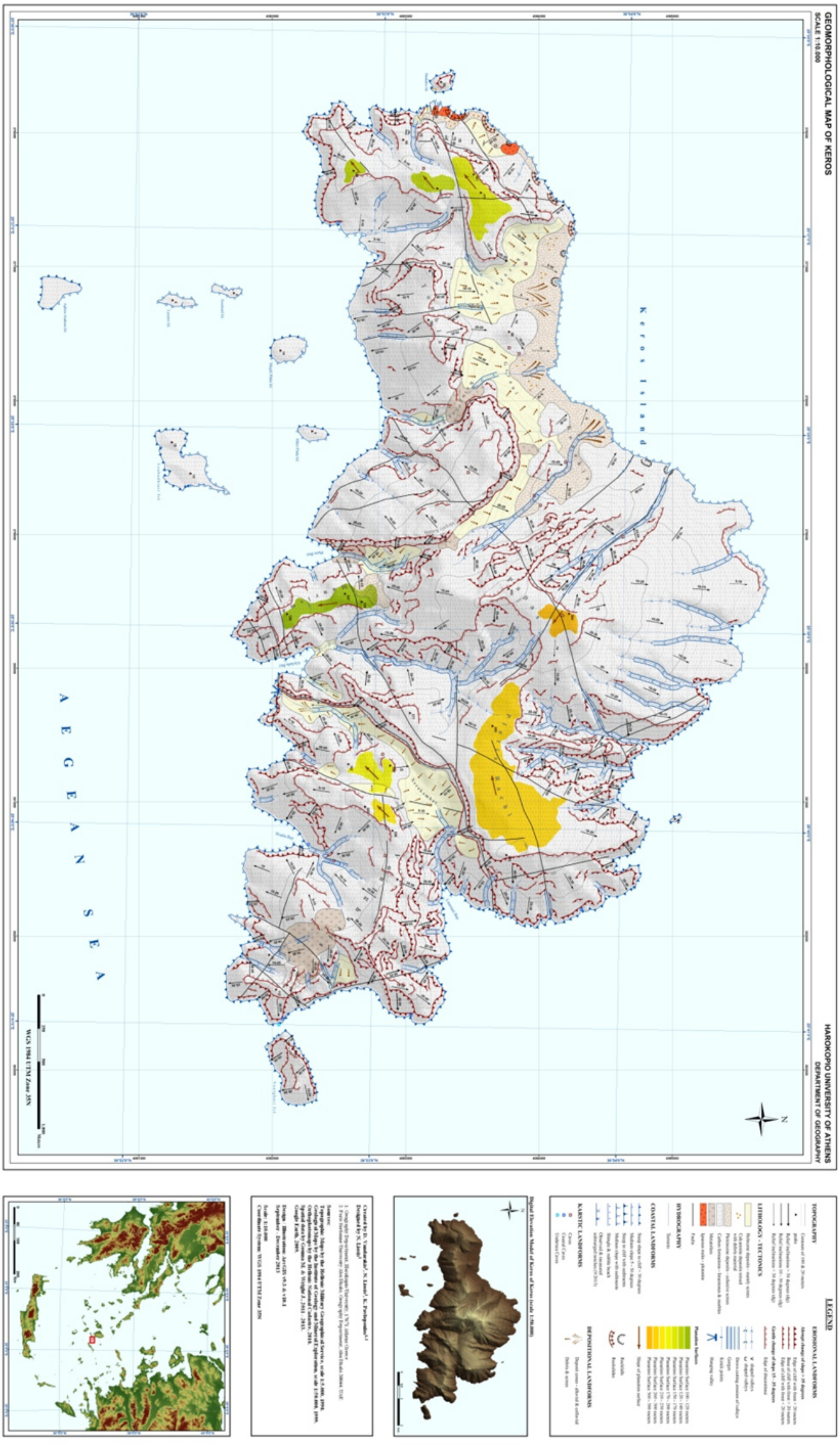

Figure 9: The geomorphological map of Keros Island.

4. Discussion-Conclusion

In the geomorphological mapping of Keros Island, there were identified, mapped, described and analyzed landforms, representatives of the evolution of the relief and the sequence of events that contributed to their creation.

These landforms as described in the chapter of the geomorphological mapping, are mentioning an environment with dynamic processes, that concerning the formation of the relief of this island. The processes that are testified by the landforms are specific and occur throughout the study area. The largest number of the landforms on the island is the result of erosion and deposition (V shaped valleys, gorges , alluvial fans , etc.) with a few exceptions where landforms encountered derived from sea level rise (notches), from tectonism, or as result of all the processes described.

During the geomorphological mapping manmade terraces were identified which were infilled with sediment from erosion of the overlying formations. In Gerania (Figure 2) this sediment had come from the erosion of Aiolianites, formations which have been identified in other parts of the Aegean Archipelago and they are paleoclimatic indicators (Cayeux, 1907, Pavlopoulos, 1992, Mataranga, 2004). Further study and analysis of these formations will provide important information, many of those concerning paleoclimatic conditions in the region and the processes that dominated the different archeological periods.

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