Natural Hazards and anthropogenic parameters affecting Milos island landscape, Greece

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Introduction

Milos is the western island of the Cyclades island complex (Figure 1), in the Aegean sea. It is the fifth largest island of this complex, with an area of about 159 km^2. Milos is generally a low altitude island; the eastern part being lower compared to the western. The two highest peaks, both situated at the western part, are 636m and 748m; all the other peaks are lower than 300m. One of the most impressive morphological characteristics of the island is Milos bay, a natural harbour at the north, one of the largest in the Mediterranean.

Geological, volcanological and tectonic characteristics

The island is composed of four type of rock units: a north-dipping Paleozoic crystalline basement, of para and metamorphic rocks (Figure 2) which are mostly outcropping in the south of the island. It consists mainly of metamorphic rocks of blueschists- or greenschist facies, dated 33 Ma and 64 Ma respectively. This strongly eroded basement, is covered by transgressive marine sediments mainly conglomerates, marly limestones, sandstones and marls, of Late Miocene-Early Pliocene age, which have been affected by a mild diagenesis. Follows a Late Pliocene to Quaternary volcanic cover, having a thickness of 300-400 m, which is primarily composed of rhyolitic tuffs and is extended in the whole island. The bulk of the volcanic rocks were erupted between 3 and 1 Ma ago, however activity as young as 80Ka has been documented. Finally, in discordance over all these formations recent alluvial deposits exist, that close the stratigraphic sequence.

Although Milos island is not currently volcanically active, it retains intense hydrothermal processes. This activity is expressed by the occurrence of many hot springs (30-85°C), fumaroles (98-102°C), hot grounds (100°C at a depth of 30-40cm) and submarine gas emissions, widespread on and

around the island. Fyriplaka volcano is the most recent volcanic activity on the island and includes fumaroles, solfataras and hot grounds.

The island is dissected by four main groups of faults (Figure 2). The major set includes faults that striking NW-SE, which are responsible for the formation of Milos bay, the extensive depression that dominates the central part of the island, and they have affected the metamorphic basement. The second one includes faults with E-W directions that are located mainly at the western and southern part of the island. The third group consists of N-S trending faults evidently seen at the eastern part of the island and finally faults with NE-SW direction

Seismicity

The seismic activity in the broader area of Milos island is relatively low, however its seismic hazard is not negligible. The earthquakes occurring in this area could be distinguished according to their focal depth (h), to intermediate ($h > 40$km) and to shallow ($h \leq 40$ Km) events.

Shallow depth earthquakes are of medium magnitude and are usually causing considerable damage, like those of 1738, July 20, M=6.5 and of 1992 March 20, M=5.3. The first one destroyed completely the village of Palaeochori and killed the majority of the citizens of the island. The epicenters of the main shock of 1992 event and the aftershocks were located along a narrow zone which extends through the central part of the island having a NW-SE trend and coincides with the Milos bay-Fyriplaka graben structure and its prolongations towards NW and SE. The focal mechanism of the main event is of normal fault, in accordance with the main faults of the area. Although this sequence did not followed by fatalities, it caused considerable damages to the structures of the villages of the central part of the island. About 16% of the constructions were to be demolished and 15% were considered temporarily inhabitable. This event followed by seismic fractures, liquefaction, landslides and rockfalls. Moreover changes in the water level and in the temperature of emitted gases were observed. These geodynamic phenomena, took place mainly on the neotectonic blocks of Milos bay-Fyriplaka volcano, and the SE coastal unit.

In addition to the shallow depth events, several intermediate earthquakes have shook the island, Although these are usually strong events, due to their great depth as they relating to the subducting African plate below the Aegean, they are only felt in the area without causing any damages.

In the island of Milos, earthquake swarms are very usual. Recent studies revealed that shallow events of low magnitude, appeared in groups of several events with a few hours duration. These events are mostly concentrated in the central and eastern part of the island and correlated with venting periodicity associated with the existing hydrothermal activity of the island.

Geomorphological characteristics

The relief of the island is intensely influenced by the lithological formations (Diagram 1), because of the differential erosion taking place in this area, as well as by the tectonic characteristics. The altitudinal analysis showed that the largest part of the island (65.59%) is presented by altitudes that vary from 0 to 100 m (Diagram 2). Most of the low altitude values exist at the eastern part of the island, mostly near Milos bay.

The island may be divided into two geomorphological units the east and the west (Figure 3). The east part is characterised by low altitudes (mean altitude is 120 m), smooth morphology and some plains. Only at the north and NNE part the morphology is hilly which is covered by volcanic rocks. In the western part the morphology is more intense with higher altitudes (mean altitude is 242 m). Quaternary formations are 18% less in the western than in the eastern part and the higher altitudes (Hondrovouno - 636m, Profitis Ilias - 748m) are found at lava formations. Finally, in the eastern part, which has been more eroded than the western one, erosional remnants are found mainly in the volcanic rocks.

The above two geomorphological units are further divided into five sub-units (Figure 4), as follows:

1. The eastern part of low hills and medium slopes, consisting of volcanic activity products which are prone to weathering
2. The western unit of high hills and high slopes, with formations of volcanic domes and lava flows, the mechanical characteristics of which result to the development of steep slopes.
3. The central-eastern unit of the phreatic explosion craters.
4. The unit of very low slopes, consisting of green lahar formations. Increased downcutting valleys, due to intense seasonal rainfall, are often found here.
5. Finally, there is a central unit of the alluvial plains.

The coastline of Milos has a total length of 131.4 Km and presents a large variety due to the different lithological formations and tectonic characteristics. The coasts of Milos could be divided into three units (Figure 4):

a) this with morphology that was affected by the tectonics of the area; they are found at the east, west and south parts of the island. These are coasts of high altitude alternating with low-altitude coasts that correspond to submerged valleys.
b) that of mean altitude, found at the north part of the island, owing their morphology to the lithological structure, as mostly are composed of soft pyroclastic formations.
c) The low coasts that found in large extend at Milos bay, along the pyroclastic and other loose formations.

Morphological slopes

The topographical slopes of the island were calculated with the use of GIS; a process that combined with photo-interpretation of the aerial photographs of the area and fieldwork, to confirm the quantitative analysis results.

Regarding the morphological slopes, the island may be divided into two geomorphological units. The first one corresponds to the eastern part of Milos and is characterized by low values of morphological slopes (lower than 5%) while dispersedly, mainly at the easternmost and at the Milos bay coasts, there are regions of larger values of morphological slopes. The second geomorphological unit concerns the western part of the island that is characterized by distinctly higher values of morphological slopes, extending to even 100%. The morphological coastal slopes are high in both the above units; at the western part costal morphological slopes are covering bigger area than at the eastern part. At the coastal zone of the eastern part, at the areas of Kerdari bay, Mitakas, Apollonia and Pilonissi, the coastal slope values are especially low, as is mentioned below at the part of this study focused on the coastal zone. Generally the island is characterized by morphological slopes that in few cases extend 40% (Diagram 3). The distribution of the morphological slopes often relates to the lithological formations (Diagram 4). At the eastern part where low values of slopes are present, alluvial deposits are covering relatively large areas. The above segregation may also take place according to the altitudinal distribution of the area. The difference observed at the altitudes of the eastern and western part of the study area is obvious and shown in figure 5.

In the frame of this study the morphological slope changes were mapped (Figure 5) through photo interpretation of aerial photos and fieldwork, which are often related to the lithological variations, the tectonic characteristics and geomorphological features.

The coastal zone of Milos is mostly characterized by high coastal slope values, as is presented at the map of figure 3. Specifically, the 15.67% of the coastal zone is of low morphological slope values (<10%), the 13.04% of medium values (10-40%) while 71.29% of high values (>40%). The largest part of the south coastal zone of the island is characterized by high morphological slopes values, and has been derived by marine erosional processes. The few small beaches created at the south part are due to limited extend of alluvial depositions. The low morphological slope values are mostly observed at the bay of Milos, where marine deposition coasts were observed at certain cases (Figure 3). A characteristic example of this case is the tombolo formation at the area of Rivari (Figure 3 & 8). Most of the low coastal slopes values are found at alluvial depositions.

Man Made Changes

Milos island has been subjected to many changes during the last decades, due to man activity, mostly mining and touristic. The recording of the changes was realized through photo interpretation of two series of aerial photographs (years 1960 and 1988, scale 1:30.000), as well as intense fieldwork and is presented in figure 6.

The most rapid alterations regard the increase of the area and number of quarries and mines on the one hand, and the spreading of the settlements and built-up areas on the other hand. The mining installations have been expanding rapidly in size and number, throughout the island. The change is very impressive at various sites, mines being ten times or more larger compared to their area in 1960, like for

example at the west part of the island, expanding from the eastern coast of the island to the east coast of Milos bay. The settlements have also been expanding in size, mostly at Milos (Plaka) and Adamantas villages, where the observed change is impressive as well.

Natural Disaster map

The geomorphological characteristics, the anthropogenic interference and the natural disaster factors are examined with the use of aerial photos, maps and fieldwork. The data were treated with GIS techniques in order to interpret the determinant factors that contributed to the present landscape evolution and to the future modification. For this purpose, from a series of maps that has been produced, the geological and geomorphological characteristics of the island, as volcanic and hydrothermal centers, seismic activity, rock collapse/sliding, lithology, morphological slopes and erosion risk are correlating together as well as with that of the human intervention. Final purpose is the understanding of the mechanisms that influenced and formed the present morphology of Milos island and based on them to access the future threats due to landscape changes provoked by natural hazards and anthropogenic interference.

CAPTION OF THE FIGURES

Figure 1. Location of Milos island in Aegean sea.

Figure 2. Simplified lithological map showing also the main faults.

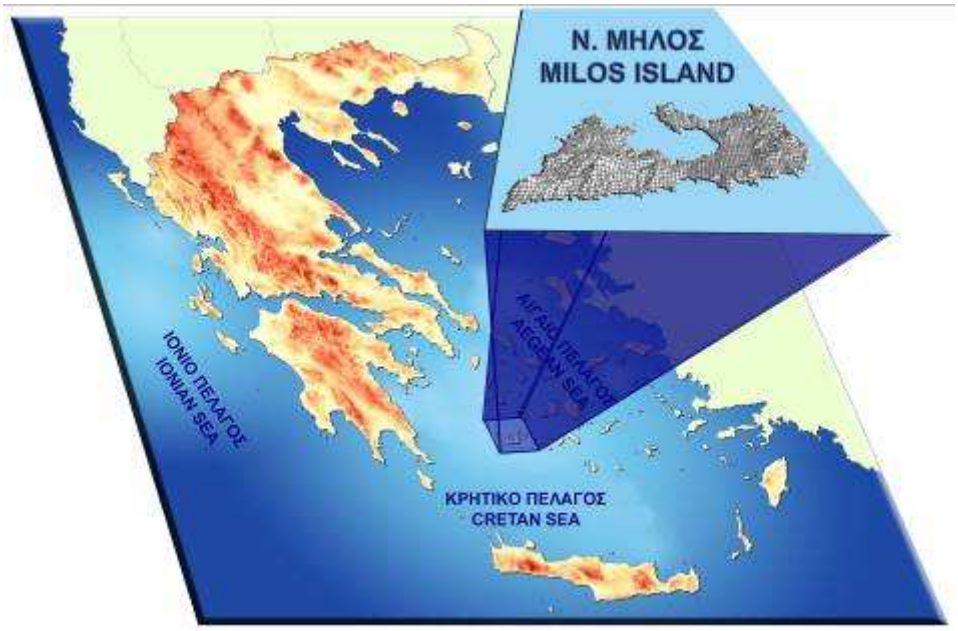
Figure 3. Hypsometric map of the island

Figure 4. Geomorphological map of Milos Island

Figure 5. Geographical distribution of morphological slopes

Figure 6. Map showing the main areas where man made changes are observed.

Figure 7. Map showing the areas of Milos island which are in danger to rock-falls and slope failure



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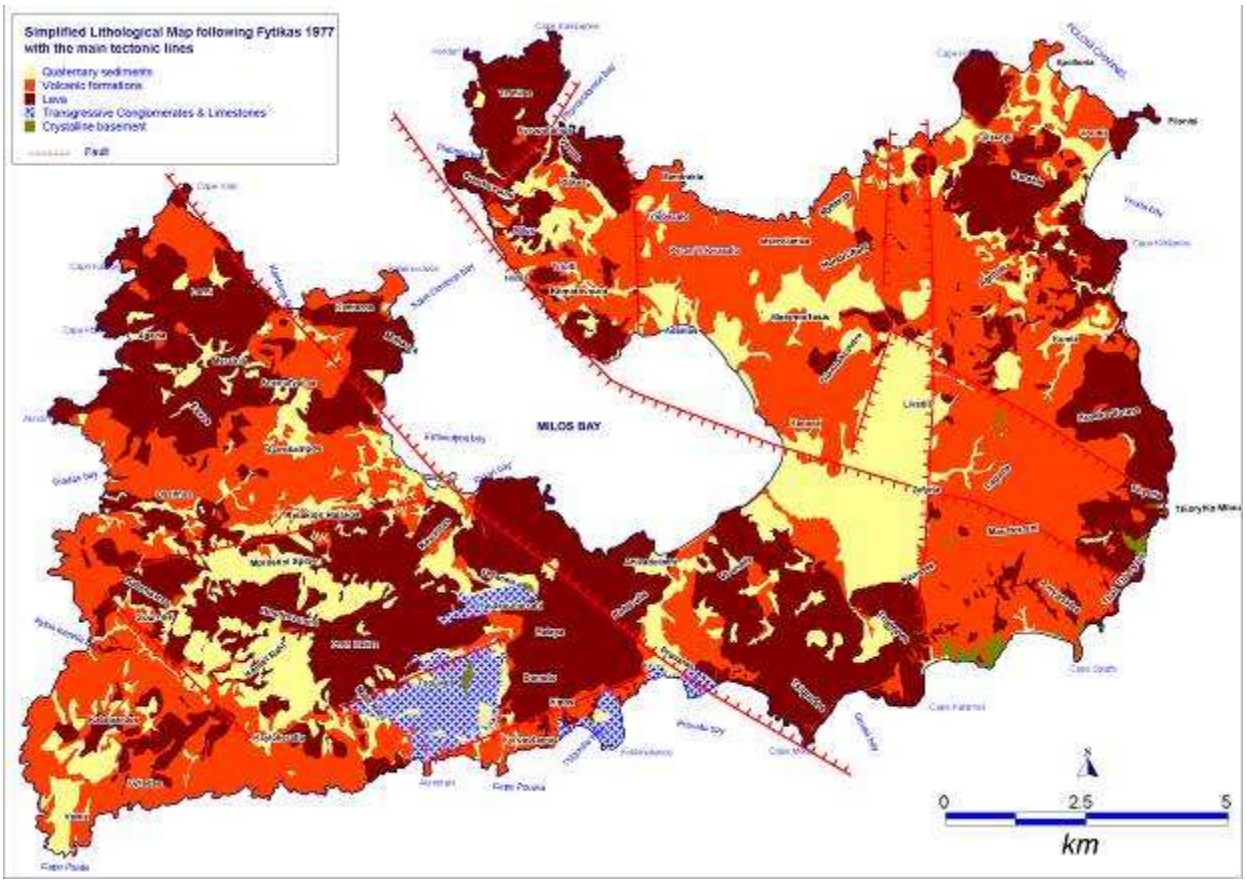


Figure 2. Simplified lithological map showing also the main faults.

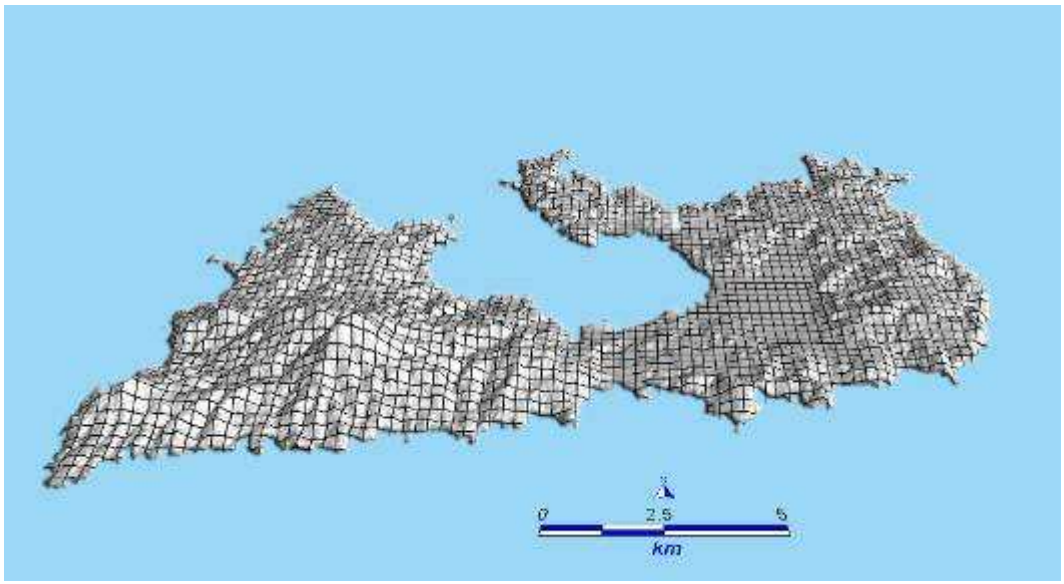


Figure 3. Hypsometric map of the island

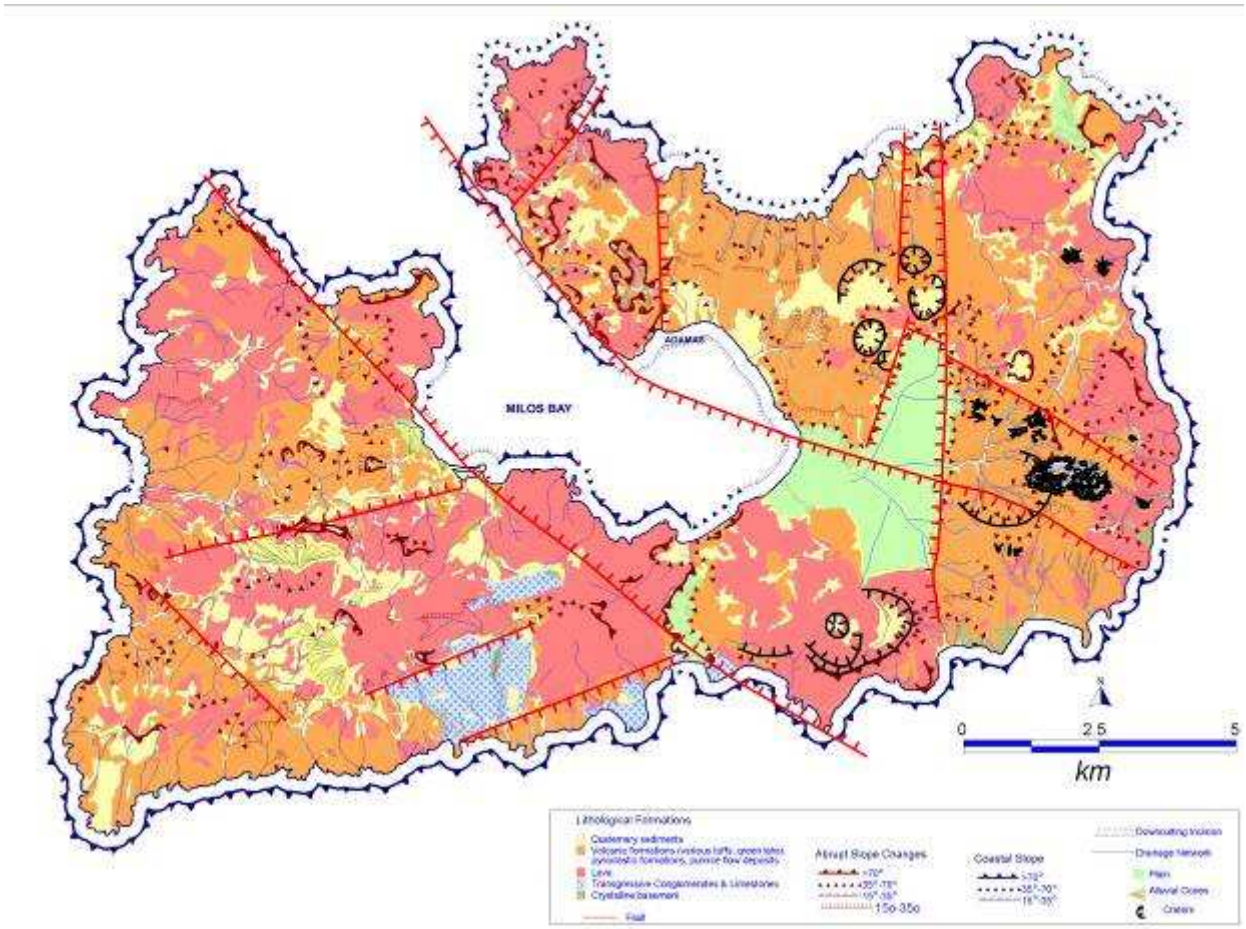
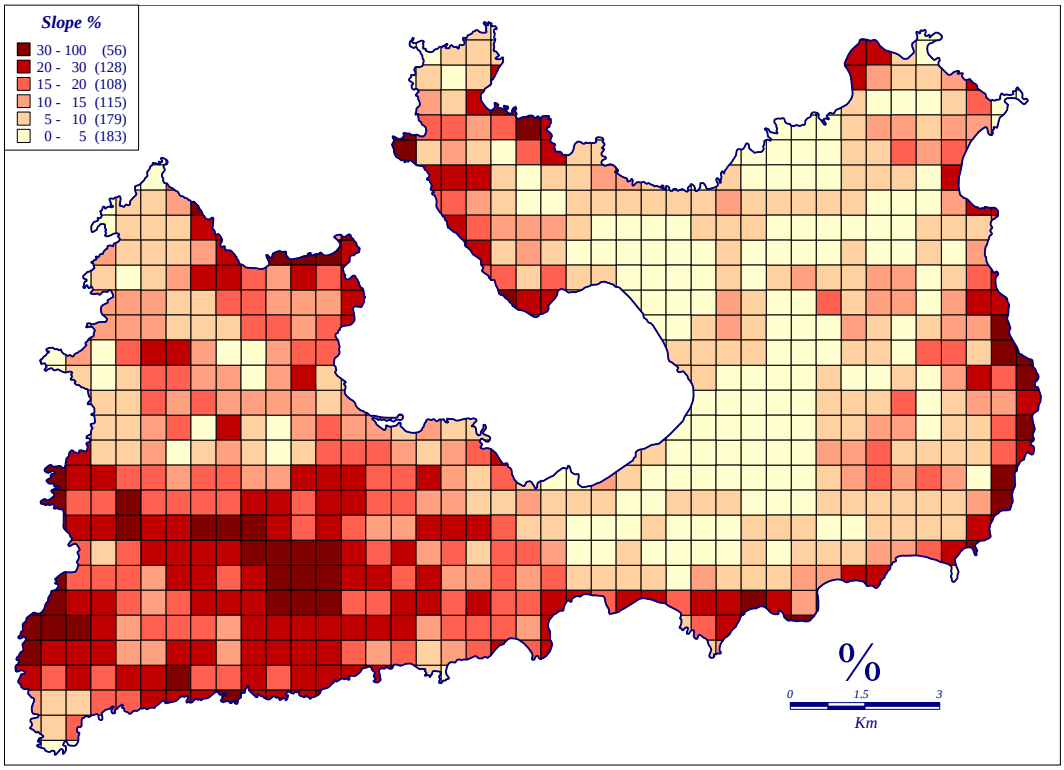


Figure 4. Geomorphological map of Milos Island



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