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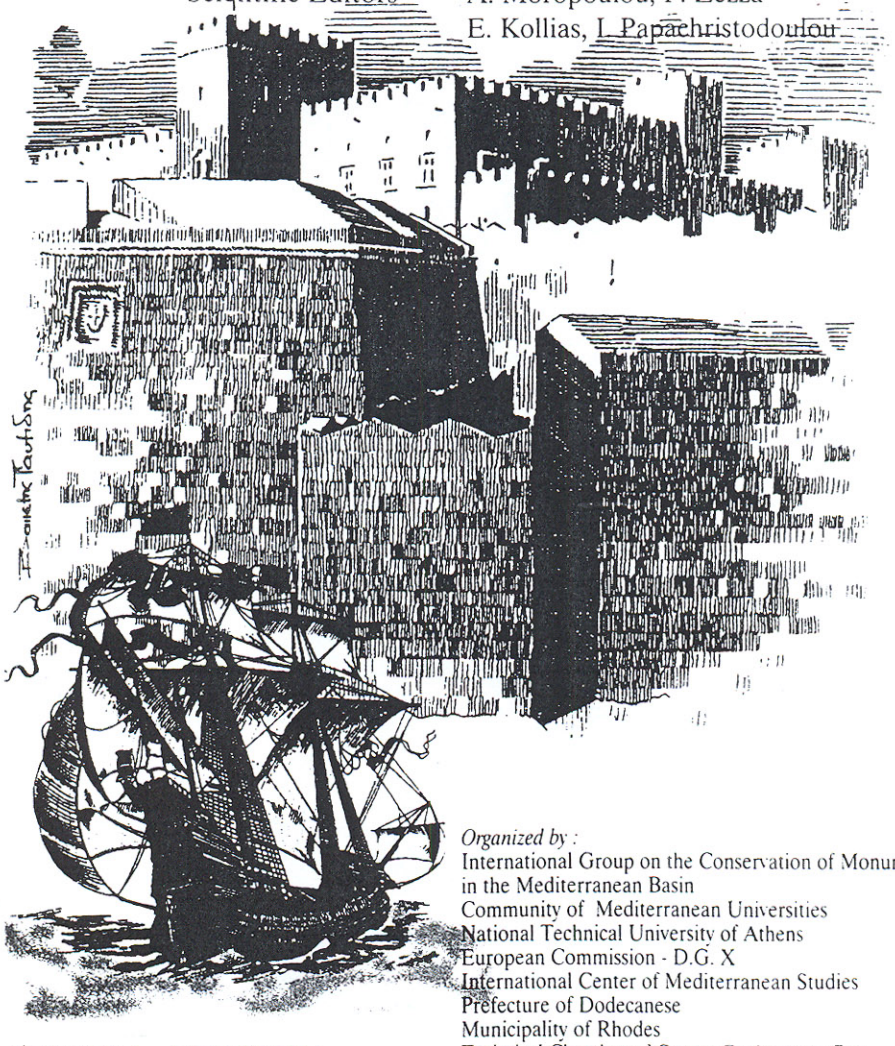

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OBSERVATIONS ON THE ACTION OF GEOLOGICALLY -INDUCED HAZARDS IN THE ANCIENT TOWN OF RHODES (GREECE)

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ABSTRACT: The town of Rhodes has been an important regional activity centre of the Aegean and Asia Minor. Inscriptions, written texts, and ruins show that Rhodes reached high levels of prosperity in the Classical, Roman, Byzantine and Medieval times. On the other hand, the geotectonic position of Rhodes is resulting in a large number of destructive geological phenomena. It has been confirmed that (since the prehistoric times) the following events have taken place and affected the city of Rhodes: (i) one meter subsidence of the eastern coast, which resulted in the destruction of quarries and possibly the abandoning of urban area, (ii) a series of serious earthquakes, in 227 BC, 197 BC, 183 BC, 344, 477, 516, 1481 AD that razed the city; the first of these destroyed the famous huge statue of Colossus, (iii) active faulting, expressed in the form of fault creep or fracturing, has deformed the old defensive walls; it is also held responsible for the of the statue of Colossus, in the 227 BC earthquake, (iv) damage and/or destruction, possibly from landslides, of the road network. The natural hazards have had direct or indirect consequences on the development of the City of Rhodes. In spite of the fact that natural disasters had severy impact, the advantageous geographical position of Rhodes made it again a primary centre of human activities.

Introduction

The island of Rhodes and the town of Rhodes in particular have always been a significant center of development of human activity. From prehistoric until recent times in all periods, namely Classic, Roman, Byzantine and Medieval, the development of commercial, political and religious activities demonstrate that a series of important factors favoured the development of the town and the entire island in general. The most important parameter for the continuous crescent of the area is clearly its unique geographical location in southeastern Aegean but also its distinct natural-geographical conditions, such as the presence of fertile soils, natural harbors, mountainous areas, intense morphology, e.t.c.

On the other hand, from a geotectonic viewpoint the island of Rhodes lies on the boundary of the subduction zone of Eastern Mediterranean, where the Eurasian lithosphere plate overthrusts the African one, creating a geodynamic environment in the broader area of Dodecanese. The main manifestations of this activity are the intense geodynamic processes that take place which caused and keep giving rise to a series of natural hazards such erthquakes, active faults, displacements of the coastlines, landslides, tsunamis, e.t.c.

The activity of the aforementioned hazardous phenomena is recognised both from historical evidence and recent observations in the broader area of Rhodes and of the islands of Dodecanese. These recent observations were accomplished on the basis of extensive geological studies that are being carried out for many years at the town of Rhodes and in the broader area.

The objective of this study is to present some data on the action of natural hazards in the town of Rhodes, as they are investigated through the observation of some geological phenomena and processes that developed during the recent geological and historical times. Prior to presenting these data, it is worth making a short reference to the geological conditions that prevail in the surrounding area of the city of Rhodes so as to get a feel for the structure of the geoenvironment.

Geological conditions of the city of Rhodes

The city of Rhodes is located in the north end of the island and occupies the geographic triangle (Fig. 1) which is formed by the two coastlines on the one hand and by the hills of Monte Smith and Rodini on the other hand. In its northern extremity the area is plane but moving towards the south-southwest the morphological slopes become steeper, locally reaching values over 20%, while in some locations morphological discontinuities can be observed especially in the area north of the Monte Smith hill.

In the area of the city of Rhodes, earliest (MUTTI et al.[1]) and more recent studies (LEKKAS et al.[2], LEKKAS[3]) demonstrated that it is structured by the following geological formations:

- A lowermost geological formation, named the Asgouros formation, which consists of alternations of sands, silts, conglomerates, sandstones and marls which are alternated both laterally and in the vertical sense which has a total visible thickness of 70 metres. The age of this formation is Upper Pliocene-Lower Pleistocene. It is a formation liable to landslides, while, locally, it amplifies the seismic intensity.

Figure 1. View of the present city of Rhodes at the northern border of the island. The area crossed by the active fault which was probably reactivated within historical times (F), as well as the Korakoneri area which was subject to subsidence movements just after the Roman period (S), are noted.

- An upper formation, known as the Rhodes formation, which consists of thinly-bedded marly limestones and sandstone-marls at the base and massive bioclastic limestones of total thickness of 30 meters at the top. The formation is of Pleistocene age. It outcrops at the present location of the old city, in the area of the morphological rise of Monte-Smith and also in the area of Rodini. It is a rock formation with a good geotechnical behaviour which does not enfavour landslide phenomena, is not liable to subsidence and does not amplify the seismic intensity.
- Above these formations, the littoral deposits are developed, in a linear configuration along the coastline. A loose superficial mantle also of maximum thickness of about 4 meters produced by the erosion of the Asgouros formation. Moreover, man-made deposits are observed at places with a maximum thickness of about 5 meters. These outcrops are prone to liquefaction phenomena and landsliding movements, while they amplify the seismic intensity.

The continuity of the formations is locally interrupted by a number of faults which are characterised as active faults (LEKKAS[3]). These faults are easily recognised either by the displacement of the geological horizons at either side of the fault or by the morphological discontinuities that they have created. The

most significant fault has an east-west direction and it is the one which starts from the northern border of the morphological rise of Monte Smith and ends at the northern section of the Medieval wall, right where it displaces the Rhodes formation on which the Medieval wall is founded (Fig. 1). According to the existing data (LEKKAS et al.[2] LEKKAS[3]) this particular fault is considered to be an active fault which has been activated within the Pleistocene period but also within the Holocene period with a throw of at least 100m.

Observations on the action of geologically induced hazards - Comments

In the area of the city of Rhodes during the study the following observations concerning the action of geologically induced hazards were made:

- In the littoral area of Korakoneri on the eastern coast of the city quarried areas were observed, intended for the production of flagstones from the Rhodes formation. This particular formation, by nature, is suitable for quarring of flagstones, which presumably were used for the construction of major important buildings and for the walls. The important fact is that these quarries are found today below the sea level reaching even a depth of 1 meter (Fig. 2). This fact indicates that from the age of the works in the Roman period (PIRAZZOLI et al.[4]) up to present times, a subsidence movement took place which was of the order of 1-2 meters approximately. This movement of the land either occurred suddenly due to an earthquake or progressed gradually in order to attain an equilibrium. Due to these phenomena and to the concurrent change of the coastline, this field stoped being used, while inhabited areas at either side were also probably abandoned. According to historical evidence (PIRAZZOLI et al.[4]) the area under discussion was submerged during the first Byzantine period. If this subsidence was due to a seismic event it could be inferred that it probably corresponds to the earthquakes of 477 and 516 AC.
- Seismic movements. The island of Rhodes and Dodekanese in general are characterised by a high seismicity due to the neighbouring of this area with the convergence boundary between the two lithospheric plates. According to historical sources it is concluded that destructive seismic events took place in 227BC, 197BC, 183BC, 344AC, 477AC, 516AC, 1481AC (PAPAZACHOS & PAPAZACHOU[5]). In order to reduce the seismic hazard in the city of Rhodes, the locations where rock formations where outcroping were selected for construction activities (e.g. Rhodes formation) while other areas where the formations with a negative response to the seismic events were prevailing, were avoided. This is deduced by the fact that in all historical times, from Classical times up to Middle Age the important buildings and the fortification walls were founded solely on the Rhodes formation. Typical examples are the Stadium, the Temple in Monte Smith (Fig. 3) and the Medieval town (Fig. 4), which are entirely founded

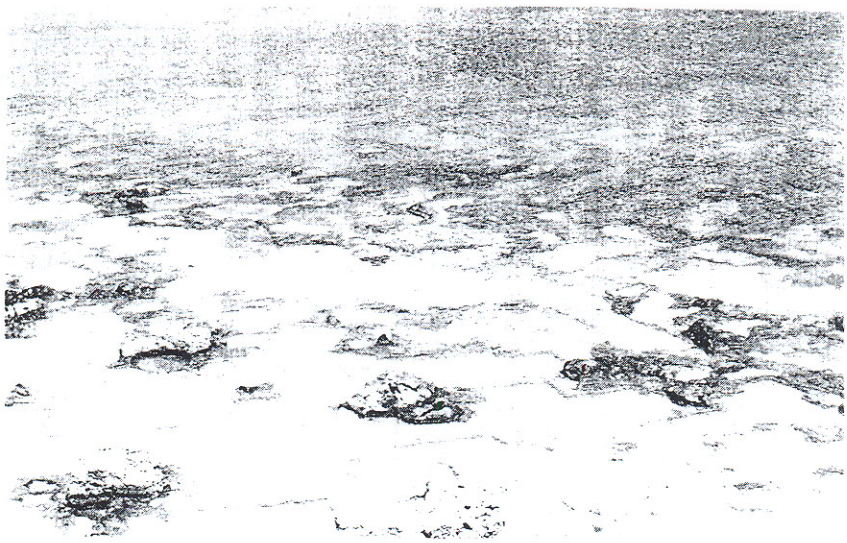

Figure 2. Quarried areas on the Rhodes formation which are found today at a depth up to 1 meter below sea level, due to subsidence movements of the land.

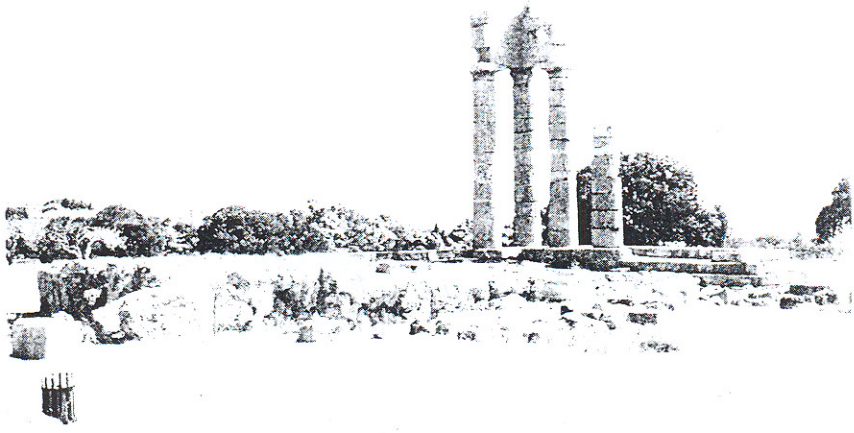

Figure 3. The temple at Monte Smith which is founded on the Rhodes formation.

on outcrops of the Rhodes formation. On the other hand, nowadays this measure was not always followed and thus the present city of Rhodes was quickly expanded on some not so favourable areas resulting in increasing the seismic hazard. The case of the foundation of large structures on loose soil formations which had covered ancient ruins that were founded on the Rhodes formation is quite characteristic (Fig. 5).

- Active faults. As it was metnioned, a number of faults occur in the populated area of the present city of Rhodes, which are intersecting the geological formations. The most important fault is the fault that originates from the norhtern border of the hill of Monte Smith and ends at the northern section of the Medieval wall (Fig. 1). In the area of the foot of Monte Smith no evidence of activity of the fault within historical times were observed owing mainly to the existing landslide phenomena and to the instability of the Asgouros formation members. On the other hand, at the other end of the fault close to the old city, the fault is intersecting both the walls and older monuments and has caused deformations in their structural elements either of plastic or of brittle nature. Moreover it has noticeably displaced carved monuments on the geological Rhodes formation.
  This fact proves the reactivation of the fault surface within historical times, however the time period of this activation cannot be determined with greater accuracy. This reactivation took place either at a slow rate, in the form of creep, or suddenly during a seismic event. Taking into account that the statue of "Kolossos" is founded in this area (KONSTANDOPOULOS[6], MASTRAPAS[7]) it is quite probable that the collapse of the statue and the reactivation of the fault surface at the earthquake of 227 BC, are interrelated. As it is known significant phenomena of amplification of the seismic motion occur at either side of the seismic fault which result in the occurrence of high intensities (LEKKAS[8]). The consideration of the reactivation of the fault is also supported by the fact that during this earthquake a displacement of the coastline took place in the western side of the city (PIRAZZOLI et al.[4]) which in turn was possibly caused by the displacement of the fault blocks.
- Landslide phenomena. Landslide phenomena must have taken place repeatedly in the western part of the city of Rhodes along the steep foot of Monte Smith hill, where the Asgouros formation appears. According to historical studies (PIRAZZOLI et al.[4]) the road network that connected the city of Rhodes with the western side of the island and other cities there (Ialissos, Kamiros, e.t.c.) was many times under restoration. The repeated restoration works seemed to follow the successive destructions from the landslides which were enfavoured both by the steep slopes and by the nature of the Asgouros formation which is prone to these phenomena.

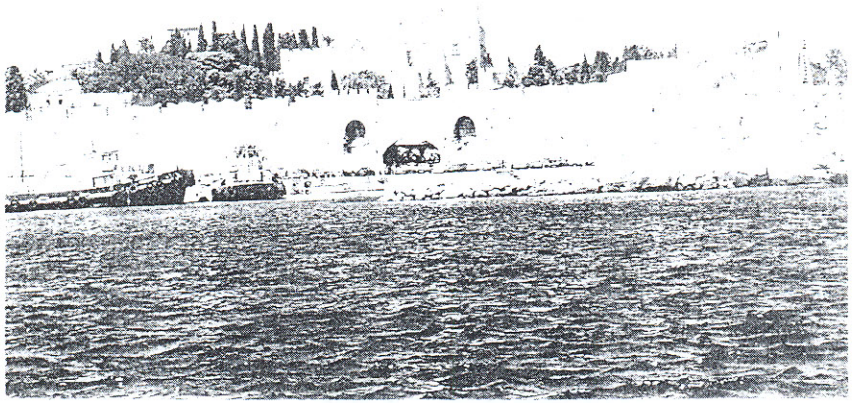

Figure 4. Foundation of the preserved part of the Medieval wall and of the old city on the Rhodes formation so as to reduce the seismic hazard.

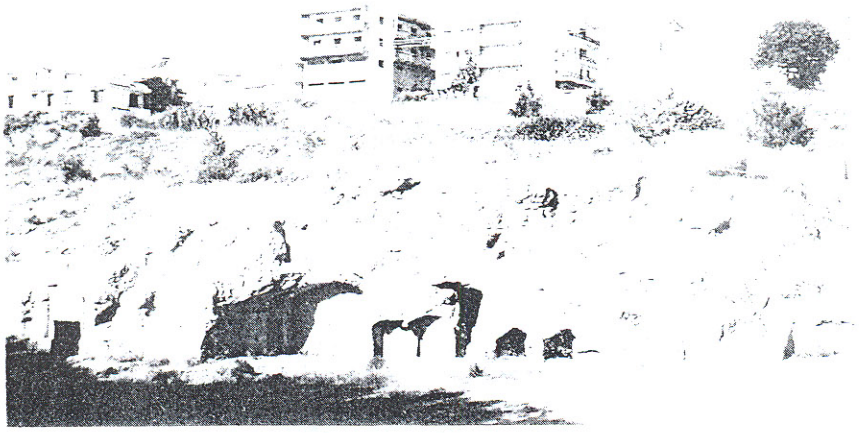

Figure 5. Carved monuments on the Rhodes formation as opposed to the recent constructions which are founded on recent loose deposits and are in great danger by the seismic movements.

Conclusions-Discussion

The island of Rhodes and the city of Rhodes in particular, have constituted a pole of attraction of human activities and an important center in the area of the Aegean and the Asia Minor, owing to their geographical location and to their natural-geomorphological advantages. These advantages are mainly owed to the intense geodynamic processes which in turn are induced by the convergence of the two lithospheric plates, the African and Eurasian, taking place south of the island. The result of those intense geodynamic processes is the occurrence of geological hazards. These hazards, which for the city of Rhodes, are the earthquakes, the displacement of the coastline and the landslides, can be investigated through their influence on the monuments and can be confirmed through the study of recent geological events that took place at historical times. The correlation of historical-archaeological information with geological knowledge can provide reliable evidence concerning the historical course and evolution of a city or of a broader area. It is clear that the onset of decadence periods can be related to the occurrence of big natural hazards, apart from other human causes, such as economical, military or social reasons, while on the other hand periods of prosperity can be corresponded with periods in which those natural-geological phenomena were in recession.

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