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Location of geohards at Rhodes island, SE Greece

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ABSTRACT: The geomorphological, geological, neotectonic and geotechnical conditions of Rhodes island (Southeastern Greece) have been studied at a scale of 1: 100,000. During this survey a number of potential natural hazards were recognised. Namely, floods, liquefaction, tsunamis, high seismic acceleration along active faults, sea shore changes, landslides and subsidence. Natural hazard mapping and land zonation with respect to probability of occurence are the first steps towards natural hazard management. The most effective tools for minimisation of losses are long term land use and urban planning.

RÉSUMÉ: Les conditions géomorphologiques, géologiques, néotectoniques et géotechniques de l' île de Rhodes (SE Grèce) ont été étudiées (échele 1:100.000). Pendant cette étude un nombre des hasards naturels possibles ont été mis au point. C' est à dire, inondations, liquéfications, tsunamis, accélérations seismiques importantes au long des zones de failles, des changement des côtes de la mer, glissements gravitaires et subsidences. La cartographie des hasards naturels et la zonation de terrain rélative à ses apparitions constituent le premier pas pour la gestion des dommages. L' outil le plus important pour minimaliser les pertes de vie et les catastrophes est le planning urban à long terme.

1 INTRODUCTION

Rhodes Island is located in the South East of Aegean Sea (Fig. 1), essentially on the convergence margin between the African and the European lithospheric plates. This position is responsible for complex geomorphology, lithostratigraphy, neotectonic processes and variability of geotectonical properties. Devastating natural phenomena occurred many times during the long history of Rhodes causing significant damage. In addition the structure and fate of political and social systems has been highly influenced.

Based on detailed mapping, field reconnaissance, study of selected bibliography and experience gained from Rhodes Island, a first approach on terrain evaluation was attempted, in order to create geohazards inventory which will be used as a first step towards land use and urban planning.

The main scope of the project is to locate potential problematic areas and then proceed to detailed surveys at those critical areas. Analysis and evaluation of parameters affecting geohazards (morphology, geology, neotectonics, seismicity, geotectonical properties) helped identify hazardous sites and the results are presented on a 1:100.000 scale map.

2 GEOMORPHOLOGICAL CONDITIONS

Topography at Rhodes is extremely variable due to its geotectonic position and the resulting intense geodynamic processes (Fig. 1). High mountain areas are found at the central, north and south part of the island and extend from east to west even though the island is elongated along an northeast striking axis. The structure of mountainous areas is governed by fault tectonics. Topographic changes are so abrupt that large morphologic discontinuities are common along major fault zones.

Alpine orogeny rocks usually create high relief whereas Molasse and Post Alpine formations form the plains. River pattern is also complex i.e. catchment areas are variable in size, and most rivers flow towards the southeast part of the island.

3 GEOLOGICAL CONDITIONS

The main geological formations at Rhodes Island are Alpine, Molassic and Post Alpine (Fig. 2). Alpine formations, from a stratigraphic point of view, are at the bottom, but they form the mountainous parts of the island. Molasse and Post Alpine formations lie unconformably on top of the Alpine orogeny rocks. It is characteristic that Post Alpine formations occupy the plains, the seashores and the estuaries (Mutti et al. 1970, Lekkas et al. 1993, Papanikolaou et al. 1995).

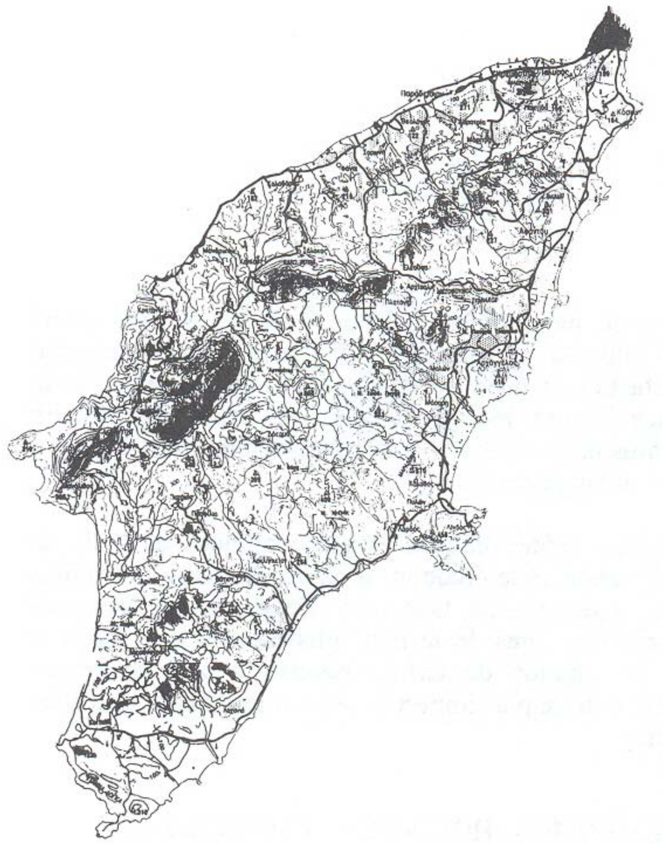

Figure 1. Map of Rhodes island.

3.1 *Alpine Formations*

Alpine formations fall within six different geotectonic units. These units are: Lindos Unit, Laermi Wild Flysch Unit, Ataviros-Akramitis Unit, Archagelos Unit, Profitis Ilias Unit and Ophiolitic Nappe (Lekkas et al. 1993, Papanikolaou et al. 1995).

3.2 *Molasse*

Molasse makes up most of central and south Rhodes and is of Lower Oligocene to Lower Miocene age. Conglomerates, containing sandstone at the base of the molasse are 160-200 m thick and are followed by grey marls, approximately 300 m thick, which contain fine sandstone, micritic limestone or ash at the top. Upwards the molassic sequence involves pelagic sandstone with conglomerate intercalations, 450-500 m thick, and river deposits.

3.3 *Post Alpine formations*

Post Alpine Formations can be grouped into five main categories which involve different facies at each basin of deposition.

- Clastic Pliocene has different characteristics from one locality to another including different deposition environment, lithology, thickness, grain size, and mechanical properties.
- Formation of Asgouros outcrops along the coasts of the island. It is composed of very weak sandstone and clays, and does not exceed 130 m thickness. It is of Upper Pliocene - Lower Pleistocene age.
- Formation of Rhodes is made up of Pleistocene bioclastic limestone which locally contains marly and clayey intercalations.

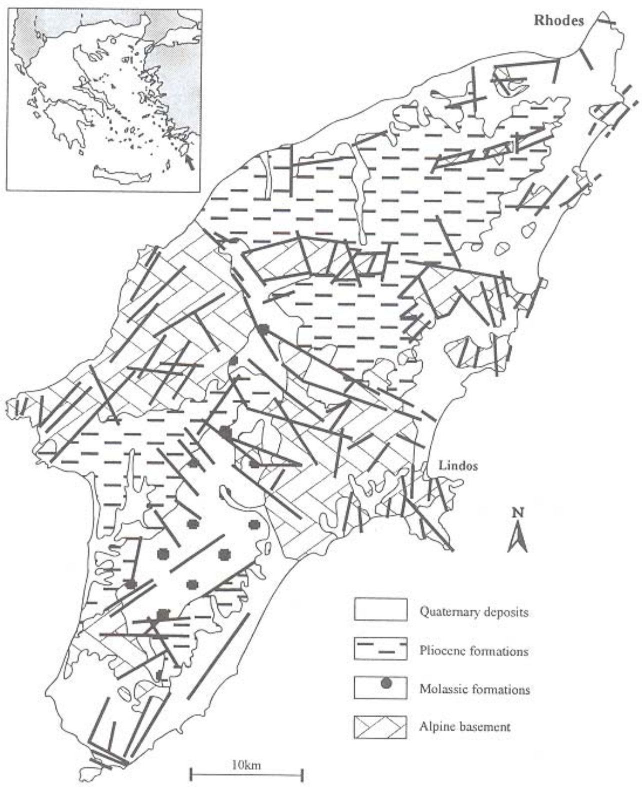

Figure 2. Geological sketch map of Rhodes island.

- Formation of Poros is a calcareous to dolomitic palaeosoil of Lower Pleistocene age, less than two metres thick (duricrust).
- Within Post Alpine formations there are also alluvium, scree-talus and coastral deposits which play the key role on slope stability and liquefaction.

4 NEOTECTONICS - SEISMICITY

In Rhodes a large number of faults crosses or borders geologic strata. Recent tectonic analysis studies (Lekkas et al. 1993) showed that known faults can be distinguished in three categories: active, probably active and inactive (Fig. 3). Faults were also grouped with respect to their throw, length and their kinimatic and dynamic characteristics. Active faults usually create one or more of the following characteristics:

- Significant morphologic discontinuities
- Sea shore changes (upthrown or downthrown fault blocks near the sea)
- Rotation and displacement of flat areas
- Large throw and length
- Recent geologic formations adjacent to older strata
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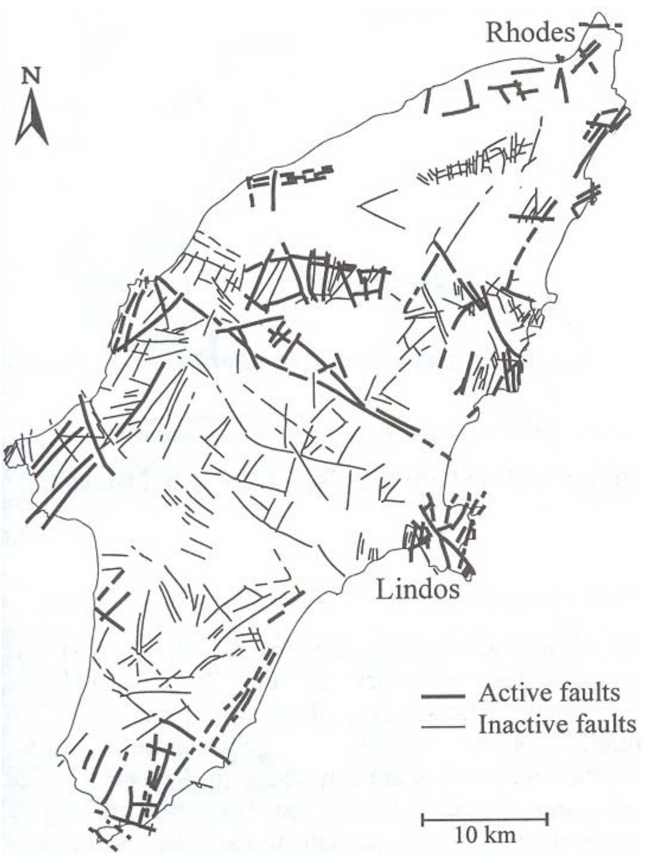

Figure 3. Fault grain map of Rhodes island.

These faults can either generate earthquakes (i.e. seismic faults) or be reactivated by them. In any case, maximum intensity is anticipated along fault zones and therefore they point out areas for special treatment in the contents of a land use planning project.

Based on historic seismic data and data of recent earthquakes Lekkas et al. (1995c) calculated very high maximum seismic parameters (with 90% probability not to be exceeded in the next 100 years). The calculated values are:

- Seismic acceletarion 350 cm/sec^2
- Seismic velocity 29 cm/sec
- Seismic displacement 11 cm

5 NATURAL HAZARDS

5.1 *Landslides – Toppling*

Landslides and overtoppling pose significant hazard in Rhodes. They have repeatedly struck in the past causing damage at residences, roads and other structures. It cannot be overemphasised that landslides, as most natural hazards, also caused major economic and social impact. The main causes of landslides and overtoppling are the following:

- High slope angles and morphological discontinuities.
- Lateral and vertical variability of geologic strata.
- Extenssive jointing that is observed preferably along fault zones.
- Poor geotechnical properties of young sediments
- High seismic acceleration
- Human indluence.

Recently Lekkas et al. (1995a) proposed a methodology that takes into account the presence or not of the above landslide causing mechanisms and identifies hazardous areas i.e. areas with high probability of occurence of landslides. Such landslide prone areas are presented in figure 4. The slopes of Profitis Ilias, Archipoli and Archagelos are such high risk.

5.2 *Floods*

Floods have caused severe impact at Rhodes island during the 90's, mainly due to human influence. The last few years frequency and intensity of floods seems largely increased as floods of 1994 and 1996 point out.

Recent research (Lekkas et al. 1995b) showed that apart from climatological parameters the occurence of floods is governed by:

- The size of catchment area.
- Permeability of the materials on the earth surface.
- Topography.
- Vegetation.
- Human influence (i.e. structures in the catchment area and changes of the river bed).

The analysis carried out according to those criteria revealed that attention should be drawn at Afadou, Charaki, Massari, Malona etc. (Fig. 4).

5.3 *Seashore changes*

Rhodes island is near the convergence boundary of two lithospheric plates and the resulting tectonic forces are particularly strong. Seashore changes are characteristic of intense geodynamic processes and are observed along the east coast. Even though uplift

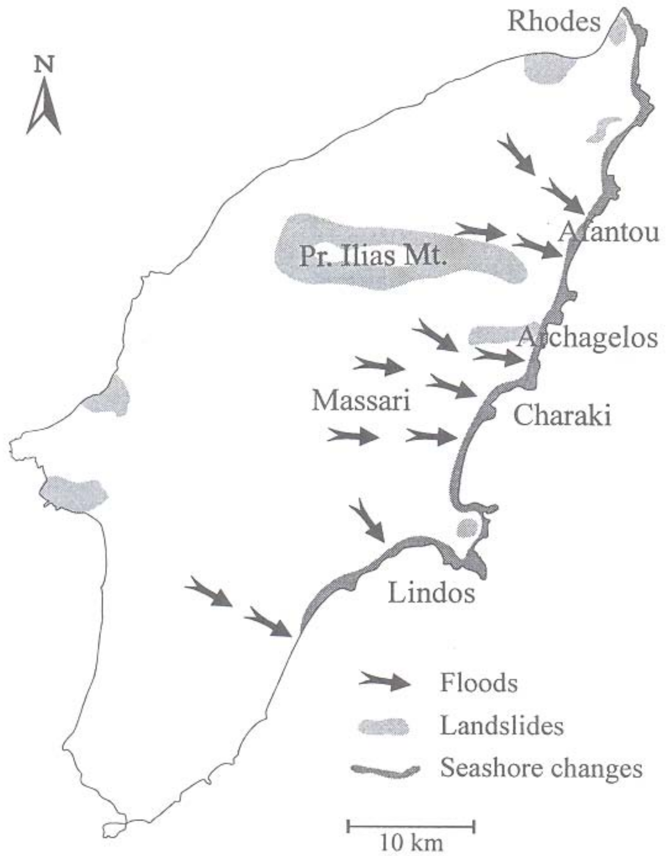

Figure 4. Areas prone to floods, landslides and seashore changes.

is more often, downthrow of land is also observed. Lindos, Tsabika and Karakonero are some representative cases of seashore changes (Fig. 5). Maximum displacement exceeds 4 m during the last few thousand years (Pirazzoli et al. 1989). At Karakonero Roman time ruins are found approximately 1 m below sea level (Lekkas et al. 1997a,b)

Seashore changes are definately a geologic hazard and can be very slow or violent (during earthquakes). In either case seashore changes should be identified especially where large engineering works are programmed or touristic development is on the way.

5.4 *Liquefaction*

Liquefaction takes place during earthquakes in sandy or silty ground with high groundwater table. It consists in rapid loss of shear strength that makes sands and silts behave like viscous fluids. Structures built on liquefaction sites will inevitably suffer severe damage. Broad liquefaction prone areas were first identified based on a number of criteria such as:

- Presence of coast formations, alluvium and river deposits.
- Presence of high ground water table.
- Geotechnical data.
- High expected ground acceleration during earthquakes

Broad liquefaction prone areas were subsequently narrowed to a few sites: Afadou, Kallithea, Charaki-Theotokos, etc. (Fig. 5).

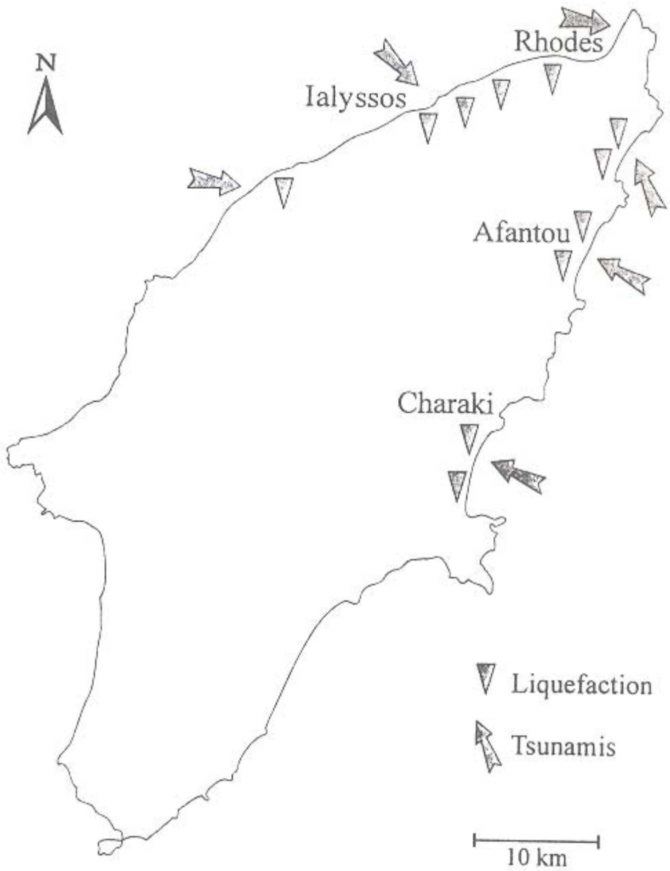

Figure 5. Areas prone to liquefaction and tsunamis.

5.5 *Tsunami*

As described earlier, Rhodes island is near the convergence boundary of the African and the European lithospheric plates that generates an intense seismotectonic - geodynamic regime. Earthquakes can occur anywhere in Aegean Sea that surrounds Rhodes Island, so tsunamis are highly probable. According to historic data and preliminary calculations (Papazachos & Papazachou 1989) tsunamis can reach uo to a few tens of metres. Taking into account that height, the seashore topography and the geographical distribution of economic, social and touristic activity it is possible to locate high risk areas: Rhodes city - Ialyssos, Kallithea, Afadou, Faliraki, etc. (Fig. 5).

5.6 *Earthquakes*

Devastating earthquakes struck Rhodes island many times during its history. Known historic earthquakes are those of 227 BC, 183 BC, 142, 344, 477, 516, 1303, 1481 (Papazachos & Papazachou 1989). On 26 June 1926 a XI intensity earthquake at Archagelos caused significant damage and killed many people.

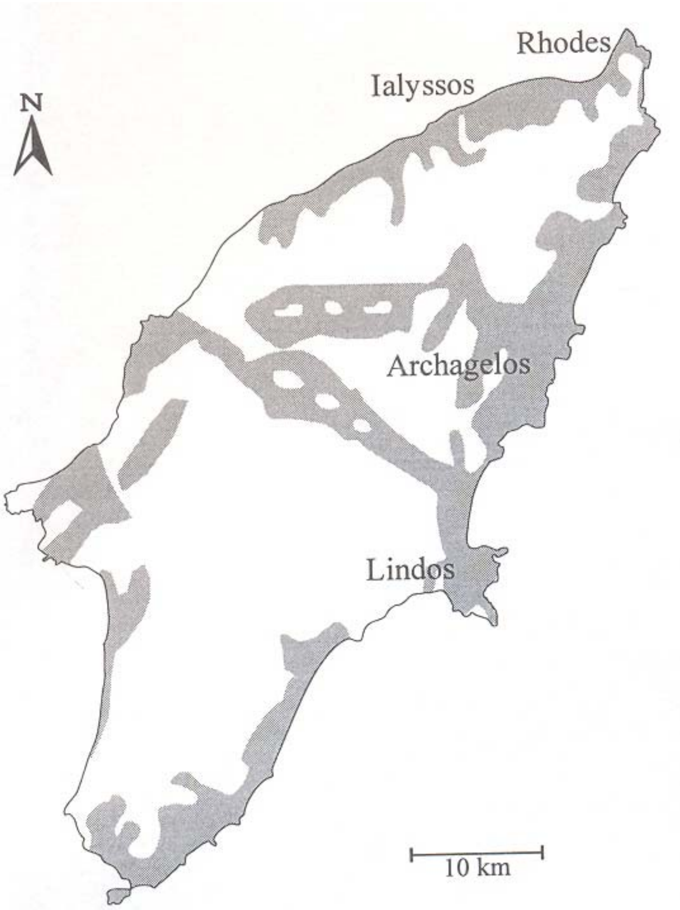

Figure 6. Areas of high expected seismic intensity.

Recent research that followed major earthquakes (Lekkas 1996) showed that the points below are critical for the geographical distribution of seismic intensity:

- Presence of active faults (i.e. faults that can generate earthquakes or be reactivated by them). Such faults are found at Rhodes city, Tsabika and Lindos.
- Presence of geologic formations with poor mechanical properties (Asgouros formations, Alluvium, Seashore deposits).

Areas of high expected seismic intensity were mapped (Fig. 6) based on existing geotechnical data and a study of neotetonic features. The map can be improved by taking into account other parameters that control distribution of damages and generation of earthquakes.

6 CONCLUSIONS - DISCUSSION

At Rhodes island natural hazards are due to active geodynamic processes (earthquakes, seashore changes) and geologic - environmental processes (landslides, liquefaction, floods).

Recognition of the kind of potential natural hazards and mapping are essential at a preliminary stage of a natural hazard management system. The main objective of that system should be the minimisation of social and economic repercussions. The natural hazard management scheme is twofold: Short term involving emergency actions and long term involving land use planning (including urban planning).

Large and expenssive engineering constructions are common for the prevention of floods and landslides. However, in some cases, those constructions are not effective in the long term because they are carried out without taking into account natural environmental processes. Smaller and environmental friendly engineering projects are well suited for high risk sites but land use planning and urban planning are even more effective.

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