The EARTHQUAKES OF CYPRUS

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Preface

The main goal of the present book is to give scientific information on the earthquakes of Cyprus. This information concerns: basic seismological knowledge, active tectonics in the easternmost part of Mediterranean where Cyprus is located, the space and time distribution of earthquakes in this area, the level of seismic activity there, the assessment of seismic hazard in Cyprus and the history of the strongest earthquakes which occurred in or close to the island. This information is described in the five chapters of the book. At the end of each chapter, the relative references (bibliography) are cited.

The **first chapter** is an Introduction that includes general seismological knowledge which is needed for the reader to get broader seismological knowledge and understand the following four chapters of the book. Its last section deals briefly with the history of the seismological knowledge in Cyprus.

The **second chapter** deals with active tectonics in Cyprus and surrounding area, which gives the geological and geophysical environment where earthquakes are generated there.

The **third chapter** concerns the seismicity of Cyprus and surrounding area, that is, the distribution in space, time and magnitude of earthquakes in the area of Cyprus.

The **fourth chapter** deals with the seismic hazard in Cyprus, that is, with the effects of strong seismic motion on the technical structures (buildings, etc.), which is of interest for engineers and important from social point of view.

In the **fifth chapter** of the book, the macroseismic effects (on technical structures, ground, water, etc.) of each of the known strong earthquakes which were strongly felt in Cyprus since antiquity are described.

We thank professors D. Mountrakis, G. Karakaisis and C. Papazachos for reading critically important parts of this book.We also thank Dr. S. Pilidou (Geological Survey Cyprus), Dr. K. Kyrou and F. Kyprianou (Water Development Cyprus) for information and data of the strong motion instruments in Cyprus.We appreciate the technical support (typing, etc.) of D. Vlachou and E. Konstantinidou.

The maps of the book have been created using the the GMT freely distributed software (Wessel and Smith, 1995).

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Chapter 1

Introduction

This first chapter is an introductory one of this book because it deals with basic seismological concepts which are needed for the reader to better understand the contents of the other chapters of the book. Thus, the present chapter deals briefly with: the seismic waves, the basic parameters of the source of an earthquake, the physical process of an earthquake generation, the theory of lithospheric plates, the seismicity and seismic hazard, the earthquake prediction and with the history of development of the seismological knowledge in Cyprus.

1.1. Seismic Waves

The instantaneous disturbances of the mechanical equilibrium of the earth's rocks in the focus of an earthquake travel in the earth and reach its surface where are felt by people and are recorded by seismographs. This transmitted disturbances form the **seismic waves**.The seismic waves are a kind of a more general category of waves which are called **elastic waves** and are generated and transmitted in any elastic medium.

Any quantitative description of the transmission of the seismic waves requires knowledge of the forces which act and the deformations which are caused by these forces in the earth's interior.The forces which act along

the different parts of a three dimensional body, like the earth, are defined by the **stress** and the **strain**. The stress and strain are not independent but coexist and are related with formulas which define the nature of the medium. To study the transmission of the seismic waves we make some assumptions for the nature of the medium and for the size of its deformation, so that the derived mathematical relations to be relatively simple and also to describe well the physical conditions. The most important of these assumptions are the assumptions of **continuity** of the medium, of the **elasticity** of the medium and of the **infinitesimal strain** (very small strain) of the medium during the transmission of the seismic waves. The periods of the seismic waves vary from a fraction of the second up to 54 minutes which is the period of the standing waves that are generated when the earth is triggered by big earthquakes (free oscillation of the earth).

Seismic waves are usually separated in **body waves** and **surface waves.** There are two kinds of body waves, the longitudinal or compressional or P waves and the transverse or shear or S waves, and two kinds of surface waves, the Rayleigh waves and the Love waves.

When a longitudinal wave is transmitted in an elastic medium the particles of the medium are vibrated in a direction parallel to the direction of the wave transmission, that is, parallel to the direction of the seismic ray, so that there are created successive spaces of high and low density. That is, during the transmission of the P waves there are changes of the density of the material. The direction of vibration of the material during the transmission of the longitudinal waves is called compression (C) when this direction coincides with the direction of transmission of the seismic wave, and dilatation (D) when is opposite to the direction of transmission of the wave. The velocity of transmission, α, of the longitudinal waves is given by the relation:

$$\alpha = \sqrt{\frac{\lambda + 2\mu}{\rho}} \tag{1.1}$$

where, ρ is the density of the material and μ, λ are called elasticity constants of Lamé. The constant μ is also called **rigidity** of the medium.

During the transmission of **transverse waves** in an elastic medium the particles of the medium are vibrating perpendicular to the direction

of transmission of the wave in such a way so that the medium to be deformed only in a shear way. The transmission of this shear deformation in the earth forms the transverse waves which are also called shear waves or S waves. The velocity, β, of transmission of the shear waves is given by the relation:

$$\beta = \sqrt{\frac{\mu}{\rho}} \tag{1.2}$$

From relations (1.1) and (1.2) it comes out that the velocity, α, of the longitudinal waves is larger than the velocity, β, of the shear waves. For this reason, and because both waves are generated at the same time in the focus of an earthquake, the longitudinal waves arrive first in a seismological station and are called P (Primus) waves while the shear waves arrive second and are called S (Secondus) waves. Figure (1.1) shows a seismogram where the P and S waves and their arrival times at a seismological station are shown.

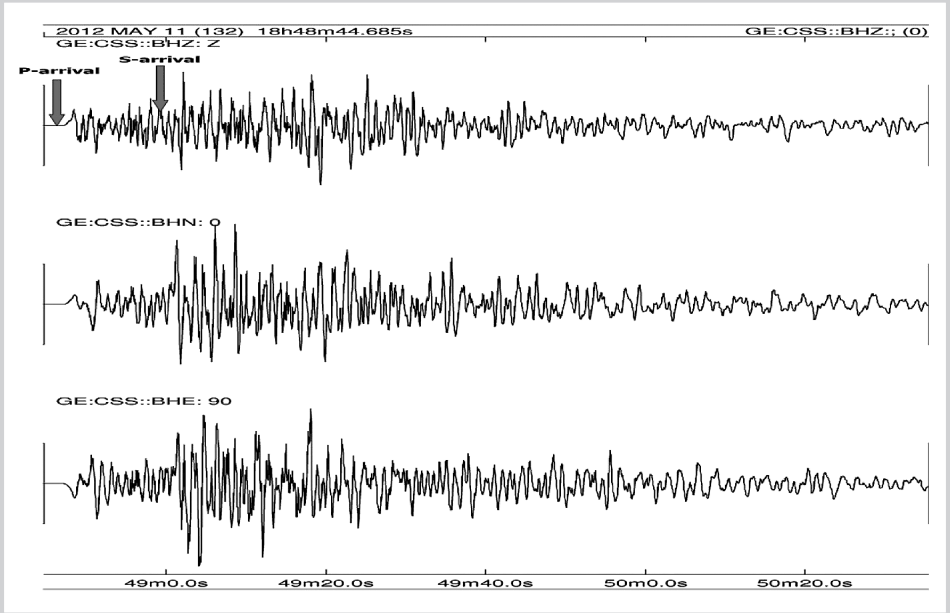

Fig. 1.1. A 3-component seismogram of an earthquake occurred off Cyprus on May 11, 2012 and recorded at the seismological station of Mathiatis (CSS) at Cyprus. The P-arrival (at 18:48:46.98) and S-arrival (at 18:49:00.87) are also shown.

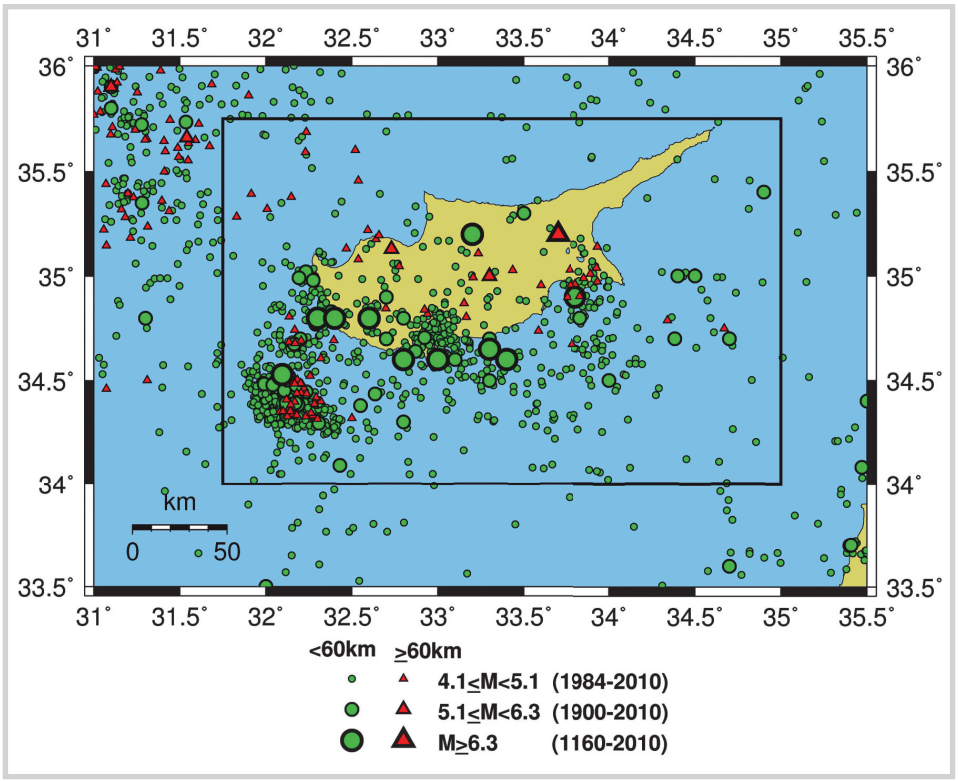

Fig. 3.4. Location of epicenters of three complete samples of earthquakes ($M \geq 6.3$ since 1160, $M \geq 5.1$ since 1900, $M \geq 4.1$ since 1984). Circles and triangles show epicenters of shallow ($h < 60$ km) and intermediate ($h \geq 60$ km) depth shocks, respectively. Three sizes of symbols are used to show corresponding three magnitude ranges.

3.2. Time Independent Seismicity of Cyprus

Study of time independent seismicity means investigation of the distribution of the frequency of earthquakes in respect to their size (magnitude, seismic moment, etc.) and to the space distribution of seismicity measures, but random distribution of seismicity in time.

The cumulative frequency-magnitude distribution of earthquakes is given by the Gutenberg-Richter (1944) relation (1.15). The parameter a_t can be reduced to a period of one year ($t = 1$year) by the relation:

$$a = a_t - \log t \tag{3.2}$$

► 76 AD, 34.6°N, 33.3°E, *h*=n, *M*=6.9, Paphos (IX)

In the Hieron Chronicon of Eusebius it is written that three towns of Cyprus were reduced to ruins by this earthquake. According to the allusion of Sirylline Oracles the two places are Paphos and Salamis. The shock was felt on the coasts of Phoenicia and the interior of Syria (Oberhummer, 1903; Sieberg, 1932a; Ambraseys, 1963, 2009; Guidoboni et al., 1994).

► 300c, 35.1°N, 33.8°E, *h*=n, *M*=6.8, Salamis (X)

Malalas writes that the greater part of Salamis in Cyprus plunged into the sea by an earthquake and the remainder was leveled to the ground. Constantius Chlorus gave money to rebuild the city, exempted the surviving citizens from taxes for four years and gave the name Constantia to the rebuilt city (Guidoboni et al., 1994; Ambraseys, 2009).

► 332c, 35.1°N, 33.8°E, *h*=n, *M*=6.6, Salamis (IX)

Theophanis writes that Salamis of Cyprus was destroyed by an earthquake and a large proportion of its inhabitants was lost (Ambraseys, 1963, 2009; Guidoboni et al., 1994).

► 341, 35.0°N, 34.0°E, *h*=n, *M*=6.5, Salamis (VIII)

According to Theophanes a violent earthquake struck Cyprus and much of Salamis was destroyed (Guidoboni et al., 1994; Ambraseys, 2009).

► 375c, 34.7°N, 32.5°E, *h*=n, *M*=6.8, Paphos (IX)

Information for destructions by this earthquake in Cyprus is given by Libanius and in Paphos by Jerome (Guidoboni et al., 1994; Ambraseys, 2009). Destructions in Kourion have been also observed by archeological excavations (Soren, 1981; Soren et al., 1986).