Local Seismicity and Seismic Velocity Structure in the Front of the Hellenic Arc˙ Preliminary Observations

VALLIANATOS PHILIPPOS[a] KOKINOU ELENI[a], SIRAGAKIS MANOLIS [a], MAKRIS JOHN [a]
[a] Laboratory of Geophysics and Seismology, Department of Natural Resources and Environment, Technological Educational Institut Crete, 3 Romanou Str. Chalepa, Chania, Crete, GR 73133,

Abstract: - The shallow seismogenic layer in the Front of the Hellenic Arc is considered responsible for a large number of earthquakes occurred in Southern Aegean and especially around Crete Island.
Information concerning the seismic velocity structure and local seismicity in the area around Crete Island are combined in order to trace the shallow seismogenic layer. In addition, the relation between the shallow seismogenic layer and the main sedimentary sequences as well as deeper structures is investigated.

Key-Words: - Front of the Hellenic arc, Crete, velocity structure, local seismicity, shallow seismogenic layer

1 Introduction

The Hellenic arc comprises the most seismically active area of Europe due to the interaction between Eurasia and Africa. An ocean-continent interaction occurs on a curved surface, which is defined by the shallow branch (20-100 Km) of the Wadati-Benioff zone, intersecting the outer side of the sedimentary arc (Western Peloponnesus-west of Kythira-south coast of Crete-east coast of Rhodes) and dips at low angle (~30^o) to the Aegean Sea (Papazachos et al., 2000). Additionally, the boundary between Aegean and African plate in the most western part of the Hellenic Arc (e.g Ionian Sea) is of continent-continent type now.
The island of Crete represents an emergent high in the fore-arc of the Hellenic Subduction Zone, indicating the transition between African and Eurasian plates. A variety of intensive studies in the last decades figured out the geodynamic attributes of the wide area of Southern Hellenic Arc (Le Pichon and Angelier, 1979; Angelier et al., 1982; Makris and Stobbe, 1984; Meulenkamp et al., 1988; Taymaz et al., 1990; De Chabalier et al. 1992; Hatzfeld et al., 1993; Delibassis et al., 1999; Ten Veen and Postma; 1999; Papazachos et al., 2000; Knapmeyer and Harjes, 2000; Bohnhoff et al., 2001; Jost et al., 2002; Makris and Jegorova, 2005).
The current work comprises the next step of that presented by Kokinou et al. (2006). In the context of the pre-mentioned study, information concerning onshore and offshore seismic reflection experiments data, topographic data (www. geomapapp.org) and previous results (Makris and Stobbe, 1984; Kissling et al., 1995; Bohnhoff et al., 2001; Makris and Yegorova, 2005) were used in order to construct detailed velocity models for the area around Crete Island. Thereinafter, the main sedimentary sequences as well as deeper structures were traced. Special emphasis was given in the velocity structure of the Cretan crust sedimentary cover in order to understand the intense shallow seismicity of the wide area around Crete. Main purpose of the previous and present work is to investigate the shallow crustal structure of the Southern Hellenic Arc and especially the wide area around Crete Island and to figure out the seismogenic structure up to 35 Km from earth surface.
The dataset (Geodynamic Institute of the National Observatory of Athens, GI-NOA) used in the present work includes moderate to strong earthquakes (M≥3.9) occurred in the period 1990 - 2005. The events of the period 2004-2005 from the pre-referred dataset were compared to the observations of the South Aegean Seismological Network (SASN) (Vallianatos et al., 2006). HYPO 71, as a standard processing tool, is used for the recorded earthquakes analysis. In the present study the data of about 290 earthquakes were used, exhibiting focal depth up to 35 Km. The number of shocks with focal depth greater than 35 Km was small.

2 South Aegean Seismological Network (SASN)

Prior the presentation of the results we give a brief summary of the new telemetric seismic network which has been installed since the end of 2003 on the island of Crete and the broader area of South Aegean and is continuously operated by the Laboratory of Geophysics and Seismology of the Technological Educational Institute of Crete in order

to provide modern instrumental coverage of seismicity in the southern Greece, as well as some more insight into the stress and deformation fields, tectonics, structure and dynamics of the Hellenic Arc. Network's geometry as well as site selection has been chosen carefully, since the primary goal is to locate seismic events, fact which assures the most accurate determination of seismic parameters. Furthermore, plenty of studies are conducted, concerning mainly the crust structure of the area which will lead to a representative velocity model, the stress-field and the focal depth distribution. The South Aegean Seismic Network (SASN) is now well established with a stable technical and financial position. The associated SASN database has increased in both quantity and quality during the period 2003-2006 and is being extensively used for research. Due to the technical development of the network, there has also been a good knowledge of software applications for seismic data acquisition, communication and processing. Today the network consists of 10 operational stations (nine short period and one broad-band station) which are equipped of three-component sensors, third generation high resolution 24-bits digitizers, Reftek type 130-1. The configuration of the network is shown on figure 1.
Telemetry is digital in terms of conventional TCP/IP networking using dedicated ADSL-VPN connections. Data are transmitted to the central processing unit, situated at the Laboratory of Geophysics and Seismology building in Chania, Crete, where the data packets stored in two data servers and one real time processing server running Seismic Network Data Processor (SNDP) software. In addition backup connections with satellite links are prepared for installation.

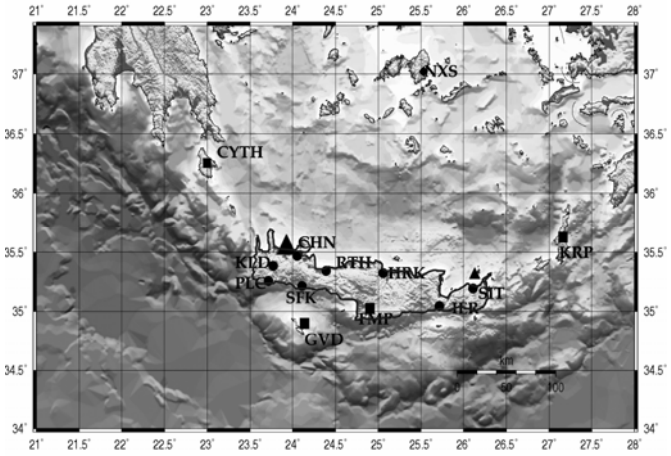

Figure 1 Geographic distribution of the Seismological Network of south Aegean (Laboratory of Geophysics and Seismology Technological Educational Institute of Crete). Black bullet denotes on-line stations, whereas black square sites where seismic stations are off-line. Black triangle denotes the broadband station in Chania (CHN) and the smaller one the accelometer installed in Sitia (SIT).

3 Velocity profiles and distribution of moderate to strong earthquakes in the area around Crete Island

In the context of the present study, three velocity profiles (see Kokinou et al., 2006 and fig. 2) were selected in order to study the geodynamic processes around Crete Island.

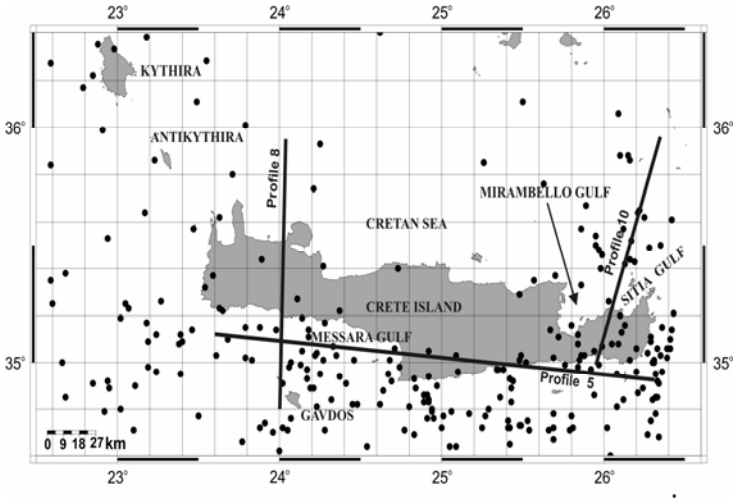

Figure 2 Map locating the velocity profiles and spatial distribution of earthquakes around Crete Island.

The first one (profile 5, fig. 3) comprises an almost E-W oriented profile in the southern part of Crete Island.
In the western most part of profile 5 the upper Alpine sequences are wedged out and the post-Alpine sediments rest directly on the lower series of the Alpine sequence or the upper Palaeozoic succession (6.3 – 6.5 Km/s). In the central part of profile 5 the layer corresponding to a velocity range between 5.3 and 6.2 km/s begins to dip in the offshore area between Gavdos and Messara Gulf. The dipping layer does not seem to influence the post-Alpine and Alpine sedimentary sequences but only the lower Palaeozoic succession and the basement. It is worth to note here that the pre-mentioned layer (6.1–6.5 Km/s) possibly corresponding to the Palaeozoic succession and/or the basement in the southern Cretan crust seems to

be influenced in its lower part by the geodynamic processes affecting the lower crust. It also corresponds to the same velocity layer of profiles 1, 2, 3 presented by Kokinou et al. (2006), possibly responsible for the shallow seismicity in the study area. The only difference between the seismogenic layer in northwestern Cretan crust and southern Cretan crust is indicated in the depth that this layer is traced. In southern Cretan crust the top of the pre-mentioned layer is traced approximately at 5-6 Km, while in northwestern offshore part of Crete Island at 8-13 Km (Kokinou et al., 2006).

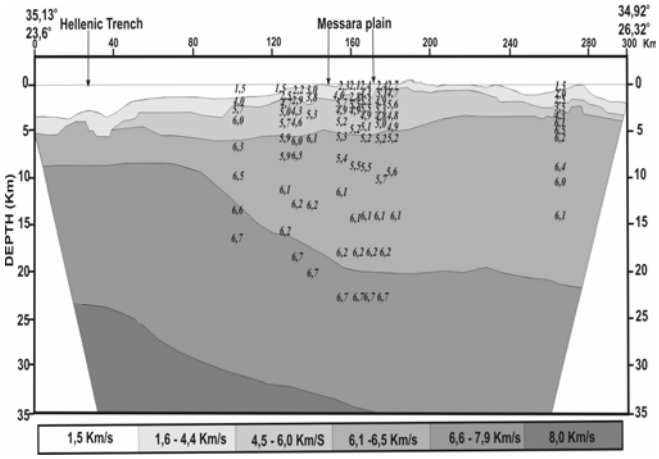

Figure 3 Velocity model for the E-W oriented profile 5 in the southern part of Crete Island.

Profiles 8 and 10 (figs. 4 and 5) provide images of the Cretan crust in N-S and NE-SW direction. A general remark is the gradual dipping of the Cretan crust to a NE direction. An uplift (profile 8, fig. 4) characterizes the onshore western part of Crete, showing a thickness of the sedimentary cover less than 10 Km. The deeper layers may image a progressive decoupling of the oceanic crust from the continental crust in a northwest – southeast front that is also referred by previous researchers [Makris and Jegorova, 2005].

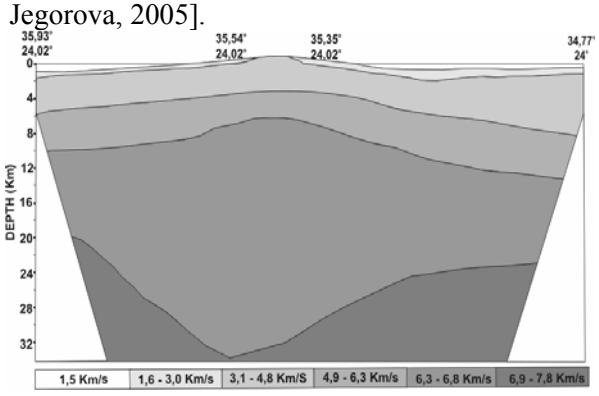

Figure 4 Velocity model for the N-S oriented profile 8 in the western part of Crete Island.

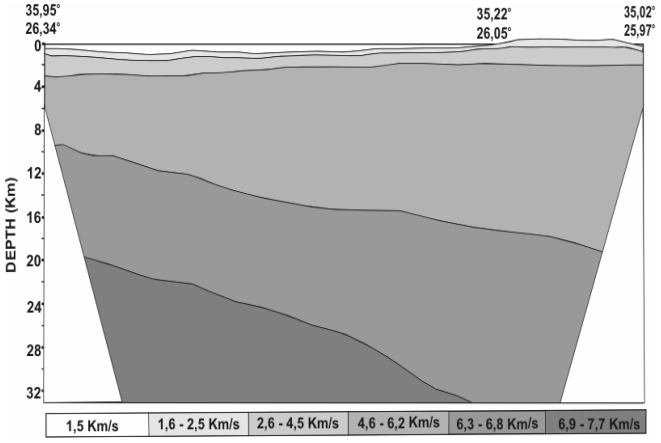

Figure 5 Velocity model for the NE-SW oriented profile 10 in the eastern part of Crete Island.

In order to examine the relationship between moderate to strong events and depth, the histogram of figure 6 was constructed. It is figured out that the majority of earthquakes with magnitude 3.9 ≤M≤ 5.1 evoke in depth less than 35 Km while the hypocenters of stronger than 5.1 earthquakes are located in depth ranging between 35 and 130 Km.
The earthquake foci distribution along profile 5 is presented in figure 7. The majority of the hypocenters are accumulated in depth ranging between 5 and 35 Km. The upper 10 Km of the most western part of the profile, in comparison to the eastern part, show very week earthquake foci distribution. Additionally, the first two layers of the velocity model, corresponding to Post-Alpine and the upper sequences of the Alpine sediments up to 5 Km below the surface, show almost no seismic activity.

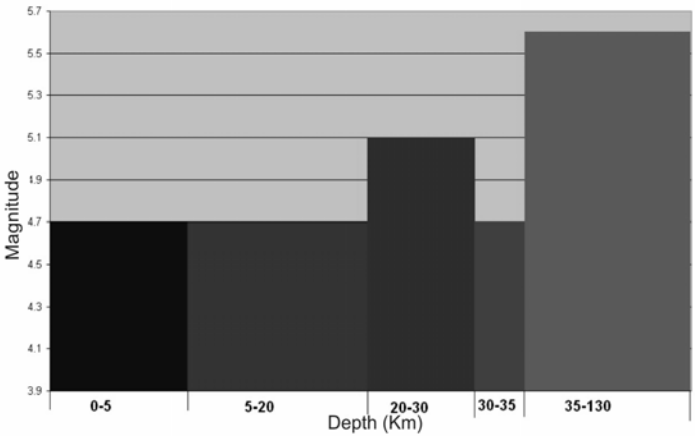

Figure 6 Histogram showing the relationship between magnitude and depth in the study area (data from GI-NOA catalogue).

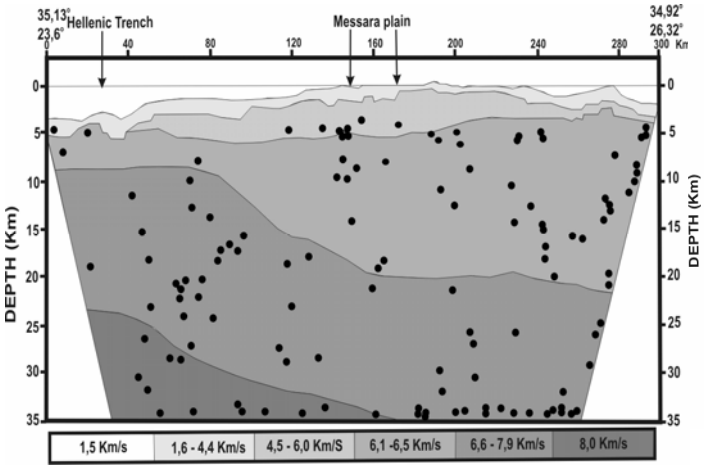

Figure 6 Distribution of the earthquake foci along velocity profile 5.

In the profile 8 (fig. 7), the local seismicity occurs in the southern part of the profile, corresponding to the offshore area between south coast of Eastern Crete Island and the wide region of Gavdos Island. The earthquake foci are observed at depth h>8 Km and especially between 15 and 30 Km.

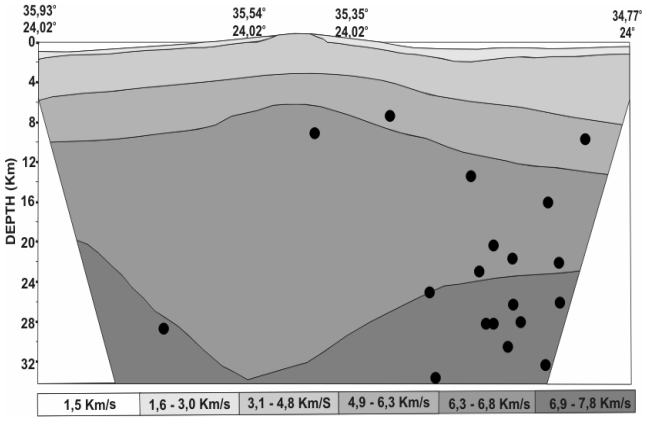

Figure 7 Distribution of the earthquake foci along velocity profile 8.

An intense local seismicity occurs in the southwestern onshore part of profile 10 (figure 8) at depths between 5 and 22 Km, while week local seismicity in the most northern part of the profile. In addition, the Gulfs of Mirambello and Sitia in northeastern Crete Island show a relative local seismic activity, possibly corresponding to the NE-SW oriented fault zone located in the wide area of the Eastern Crete (Seismotectonic map of the major area of Crete Island).

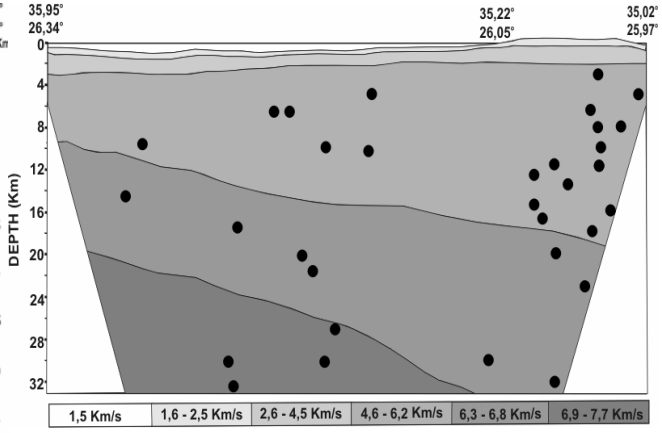

Figure 8 Distribution of the earthquake foci along velocity profile 10.

4 Discussion and Conclusions

In the context of the present work we attempted to investigate the relationship between seismic velocity structure and distribution of the local seismicity in the front of the Hellenic Arc. Our interest is focused in the sedimentary cover and a few kilometres below it, evoking the shallow seismicity in the study area.

An intense shallow seismicity occurs in the southern part of Crete Island across an E-W oriented velocity profile. The majority of the earthquake foci are indicated below the upper part of the Alpine sedimentary succession and show a regular distribution along the profile. The seismic basement of the southern part of Crete Island possibly involves in the geodynamic processes affecting the pre-referred region.

A progressive uplift of the onshore western part of Crete is defined in the profile that crosses the western Cretan crust in a N-S direction, while the thickness of the sedimentary cover decreases to less than 10Km (Kokinou et al., 2006). In contrast to the thinning of the sedimentary cover, the thickness of the lower crust increases up to 32.5km. Generally a west to east trending decrease of the sedimentary cover takes part in the offshore Northern Crete Island. The distribution of the hypocenters confirms the above result. The W-E thickness decrease of the sedimentary cover is possibly in agreement with the westward propagation of the Hellenic fold and thrust system.

Papazachos et al. (2000) used 961 shallow and intermediate earthquakes occurred in the period 1965 – 1995 to define the geometry of the Hellenic arc, by constructing three cross sections for its western, central and eastern part. A very intense shallow seismicity (h<20Km) is defined in the western part of Cretan crust. Based on this report we traced the shallow seismogenic layer in the profile of the

southern Cretan crust in depths between 5 and 22 Km, showing a velocity range between 5.3 and 6.7 Km/s. It could represent the lower part (carbonates) of the Alpine sedimentary succession, as well as the Palaeozoic succession and/or part of the basement.
Implication of the present includes relocation of past and earthquakes in the study area, accurate location of the currently recorded seismic activity either from permanent or temporary networks, as well as the detailed interpretation of the seismic stacked sections, especially for the upper crust sequences for the area around Crete.

Acknowledgments
This work is supported by the project ARCHIMEDES I: "Support of Research Teams of Technological Educational Institute of Crete", sub-project entitled "Multidisciplinary Seismic Hazard monitoring in the Front of the Hellenic Arc " **MIS 86384**, action **2.2.3.ζ**, in the framework of the Operational Programme for Education and Initial Vocational Training.

References:
[1] Angelier, J., Lyberis, N., Le Pichon, X., Barrier, E., and Huchon, Ph., 1982, The tectonic development of the Hellenic arc and the sea of Crete: a synthesis, *Tectonophysics, 86, 159-196*.
[2] Bohnhoff, M., Makris, J., Papanikolaou, D. and Stavrakakis, G., 2001, Crustal investigation of the Hellenic subduction zone using wide aperture seismic data, *Tectonophysics, 343, 239-262*.
[3] De Chabalier, J.B., Lyon-Caen, H., Zollo, A., Deschamps, A., Bernard, P. and Hatzfeld, D., 1992, A detailed analysis of microearthquakes in Western Crete from digital three-component seismograms, *Geophys. J. Int., 110, 347-360.*
[4] Delibasis, N., Ziazia, M., Voulgaris, N., Papadopoulos, T., Stavrakakis, G., Papanastassiou, D., Drakatos, G., 1999, Microseimic activity and seismotectonics of Heraklion area (Central Crete Island, Greece), *Tectonophysics, 308(1-2), 237-248.*
[5] Geodynamic Institute of the National Observatory of Athens (GI-NOA), www.noa.gr.
[6] Hatzfeld, D., Besnard, M., Makropoulos, K. and Hatzidimitriou, P., 1993, Microearthquake seismicity and fault plane solutions in the southern Aegean and its geodynamic implications, *Geophys. J. Int., 115, 799-818.*
[7] Jost, M.L., Knabenbauer, O., Cheng, J. and Harjes, H.P., 2002, Fault plane solutions and small events in the Hellenic arc, *Tectonophysics, 356, 87-114.*
[8] Le Pichon, X. and Angelier, J., 1979, the Hellenic Arc and trench system: a key to the neotectonic evolution of the Eastern Mediterranean area, *Tectonophysics, 60, 1-42.*
[9] Knapmeyer, M. and Harjes, H.P., 2000, Imaging crustal discontinuities and the downgoing slab beneath Crete, *Geophysical Journal International, 143, 1-21.*
[10] Kokinou, E., Papadimitriou, E., Karakostas, Vallianatos, F., Crustal Velocity models for the wide area of Crete island in the southern Hellenic subduction zone, 2006, *First European Conference on Earthquake Engineering and Seismology (a joint event of the 13th ECEE & 30th General Assembly of the ESC), Geneva, Switzerland, paper number 577, accepted.*
[11] Makris, J., and Stobbe, C., 1984, Physical properties and state of the crust and upper mantle of the Eastern Mediterranean Sea deduced from geophysical data, *Mar. Geol., 55, 347-363*.
[12] Makris, J. and Yegorova, T., 2005, A 3-D density-velocity model between the Cretan Sea and Libya, *Tectonophysics, in press.*
[13] Meulenkamp, J.E., Wortel, M.J.R., van Wamel, W.A., and Hoogerduyn Strating, E., 1988, On the Hellenic subduction zone and the geodynamic evolution of Crete since the late Middle Miocene, *Tectonophysics, 146, 203-215*.
[14] Papachazos, B.C., Karakostas, V.G., Papazachos, C.B. and Scordilis, E.M., 2000, The geometry of the Wadati-Bennioff zone and lithospheric kinematics in the Hellenic arc, *Tectonophysics, 319, 275-300.*
[15] Vallianatos F., Makris J., Soupios P., Hloupis G., Nikolintaga I., Kokinou E., Moisidi M., Kalisperi D., 2006, A New Telemetry Seismological Network In The Front Part of the Hellenic Arc: its contribution to the study and understanding of the seismic behavior of the area, *presented in the European Geophysical Union Conference.*
[16] Seismotectonic map of the major area of Crete Island, 1982, *published by the Technical Chamber of Greece, Eastern and Western Crete branches.*
[17] Taymaz, T., Jackson, J. and Westway, R., 1990, Earthquake mechanisms in the Hellenic trench near Crete, *Geophys. J. Int., 102, 695-731.*
[18] Ten Veen, J.H. and Postma, G., 1999, Roll-back controlled vertical movements of outer-arc basins of the Hellenic suduction zone (Crete, Greece), *Basin Research, 11, 243-266.*