Seismology in Greece: a report

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"..severest of the earthquakes take place where the sea is full of currents or the earth spongy and cavernous: so they occur near the Hellispond and in Achaia and Sicily" (Aristotle, 384-323 BC)

Abstract

This report summarizes the recent developments of the science of Seismology and Physics of the Earth's Interior in Greece. In the first section, a brief overview of the history of Seismology and related research in Greece is given. The second part of the report focuses on the developments and achievements in seismology and related fields, which are briefly presented and the most recent results are summarized. A large part of this report is based the results presented in the book of Papazachos and Papazachou (1997).

1. History of Seismology

Greece exhibits the highest seismic activity in the whole western Eurasia. On the average, a M=6.3 earthquake occurs every year in the broader Aegean area, which is roughly bounded by the 34^0N-43^0N parallels and the 18^0E-30^0E meridians. Figure (1) shows the epicenters of all known strong (M≥6.0) shallow (h=0-60km) and intermediate depth and deep (61-300km) earthquakes, which occurred in the broader Mediterranean area during 1901-2002.

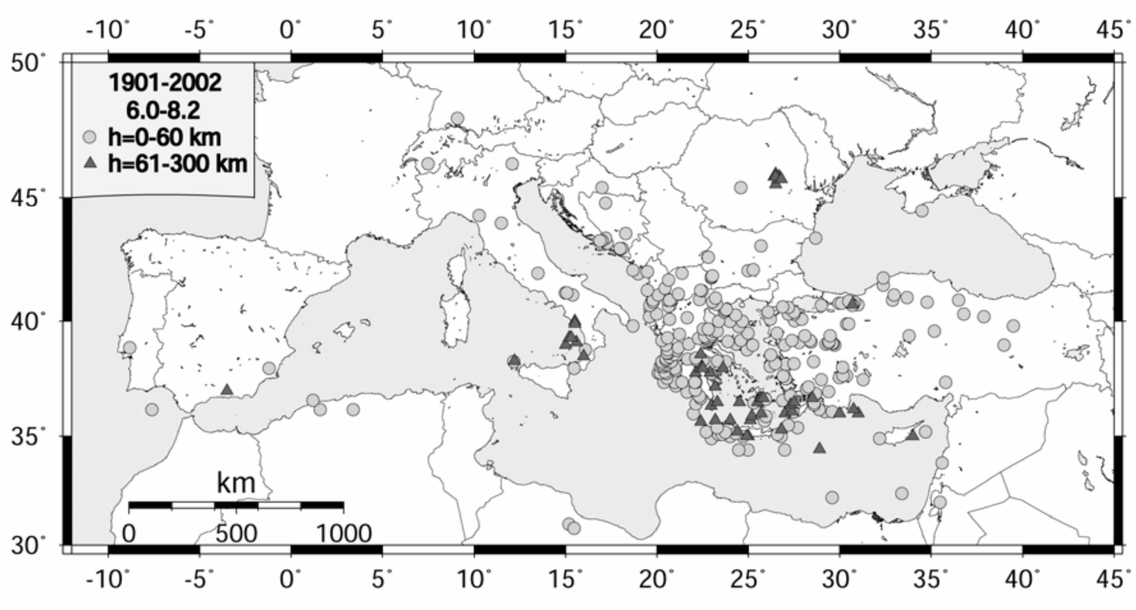

Fig. 1. *Epicenters of all known strong (M≥6.0) earthquakes that occurred in the Mediterranean area during 1901-2002.*

This high seismic activity is usually attributed to the convergence of the Aegean lithosphere (front part of Eurasian lithospheric plate) and the eastern Mediterranean lithosphere (front part of the African lithospheric plate) in an about north-south direction. The rate of this convergence is considerable with respect to stable Europe (~4cm/yr), and is mainly due to the overriding of the

Aegean lithosphere on the Mediterranean lithosphere (~3-3.5cm/yr). It is also partly due to the northward motion of the African lithospheric plate (0.5-1cm/yr) with respect to the Eurasian lithospheric plate and subduction of the eastern Mediterranean lithosphere under the southern Aegean lithosphere (Papazachos 1999; McClusky et al., 2000).

The first historically documented information in Greece on an earthquake dates back to 6th century. Cicero writes that a strong earthquake occurred in 550 BC that ruined Sparta and that a section of the summit of Mt Taygetos broke off. Incidentally, this event is related with the first short-term prediction of an earthquake, since it occurred shortly afterwards the natural philosopher Anaximander gave a warning to the Spartans to abandon the city and their houses because there would soon be an earthquake.

No historic (literary) information on the effects of earthquakes before the 6th century BC exists. The ideas of people on the causes of earthquake generation for the fore-philosophical period had a mythological character. Thus, according to the tradition, Engelados, son of Tartaros and of Earth and leader of Giants, causes the earthquakes. Several myths are known for Engelados. According to the most known of them, he was killed by Athena who chased him, threw Sicily against him and completely covered him. Since then, Engelados moves and sighs in his grave and causes the earthquakes and the volcanic eruptions.

Even up to the middle of the nineteenth century, information on the earthquakes is coming from nonspecialists on the subject (philosophers, historians, travellers, etc). For this reason, the information comes mainly from macroseismic effects of large shocks (destructions of buildings, ground changes, tsunamis, deaths, etc.) and only fragments of some ideas about the way and causes of earthquake generation are stated. Therefore, we can get a preliminary idea about the historical evolution of the earthquake study by examining the time variation of the rate (number of earthquakes) of the known, from historical data, destructive earthquakes.

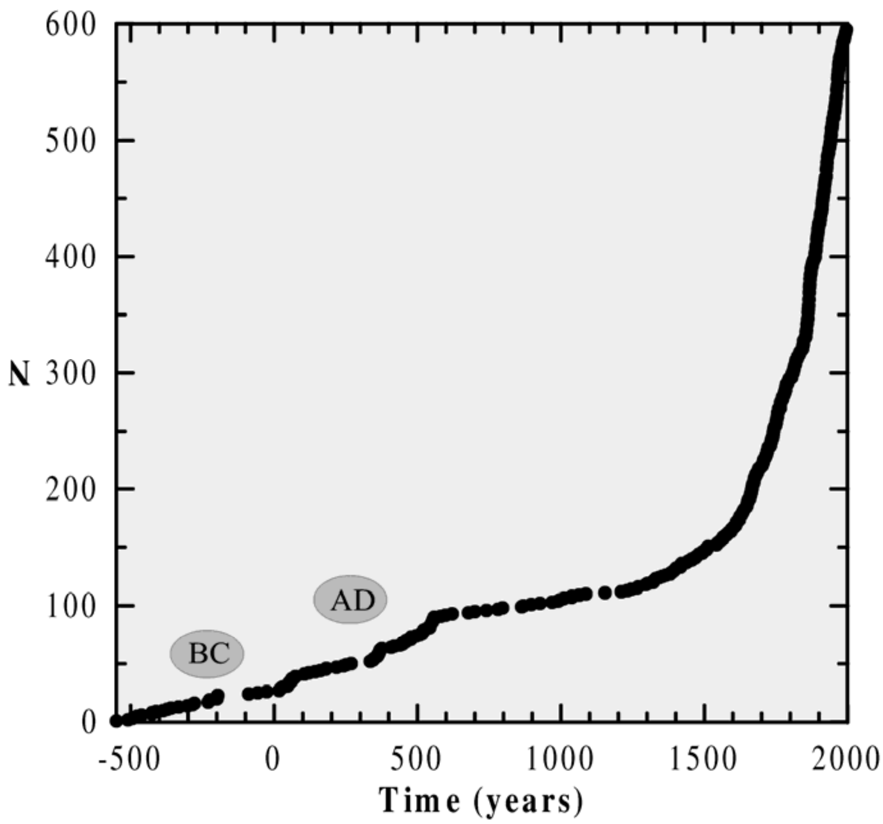

Fig. 2. *Time variation of the cumulative number, N, of known strong (M≥6.0) in the area of Greece since 550BC up to 1995 (Papazachos and Papazachou, 1997).*

Figure (2) shows the cumulative number of the known strong (M≥6.0) earthquakes of Greece and surrounding area as a function of time, during the time period 550BC-1995 AD. The total number of these known strong earthquakes is about 600. From this figure it can be concluded that this time period can be separated into three main time intervals, according to the number of earthquakes which have been studied, namely: 550 BC-1550 AD, 1550-1845, 1845-present.

The first time interval covers the time from the sixth century BC until the middle of the sixteenth century (550BC - 1550AD). The beginning of this time period coincides with the beginning of the classic Hellenic civilization in the Ionian cities of Asia Minor and of the Greek colonies in southern Italy and Sicily. During this time period, information exists for a total number of about 150 strong earthquakes, that is, for an average of about 7 strong earthquakes per century, while, as it is shown below, the expected number of the strong earthquakes ($M \geq 6.0$) which occur in this area per century is about 200.

The second time interval covers the period from the middle of the sixteenth century up to the middle of the nineteenth century (1550-1845). The beginning of this interval almost coincides with the Renaissance, that is, with the beginning of modern science. This time interval includes the scientific revolution and the industrial revolution. The total number of earthquakes of this interval is about 170 and therefore their frequency is about 60 earthquakes per century. It is seen that this rate is much larger than the corresponding rate of the previous period. This can be attributed to the fact that the observational (experimental) research started to dominate and scientific observations become the base of the new science. There is now conscious attempt for determination of the causes of the natural phenomena. Not only very important seismic phenomena are described but also the macroseismic effects of smaller shocks are also often provided. Nevertheless, the rate of the strong shocks ($M \geq 6.0$), which were studied during this time interval, is about thirty per cent (~30%) of the rate of shocks, which are expected during this time. This is due to the fact that many strong earthquakes occur in the sea and to the fact that the macroseismic effects of earthquakes during this period have been described by men who had other interests and were involved in the study of earthquakes only by chance (travellers, monks, etc).

The third time interval covers the period 1845-present. There are observations for almost all strong shocks which occurred during the first part of this period (1845-1910) and definitely for all these shocks, which occurred after 1910, because in 1911 the first seismometer (Mainka type) was installed in Athens and since then modern seismometers were in continuous operation. The total number of strong earthquakes ($M \geq 6.0$) that have been studied during this period is 270, which suggests that the mean rate of strong earthquake generation in this area is about 200 earthquakes per century. This period is separated in three phases (1845-1928, 1928-1964, 1964-present). During the first phase of this time period, the earthquakes were studied by scientists who dealt with earthquakes and other subjects (geologists, etc), while during the next two phases the earthquakes were studied by specialists on the subject (seismologists, geophysicists, etc).

Early instrumental observations

In 1895, after an initiative of D. Eginitis (1862-1934) a new law was passed by which the National Observatory of Athens was separated in three Departments: The Astronomical, the Meteorological and the Geodynamic; the latter was responsible for the study of earthquakes. In 1898 the first seismograph, Agamemnone type, was installed in Athens, while the first reliable seismometer, Mainka type of two horizontal components, was installed in 1911 in Athens and is still in operation. One horizontal seismometer of two components, Wiechert type, was also installed in Athens in 1922 while a few years later (1928), a vertical seismometer also of Wiechert type was installed.

In 1959, the first electromagnetic seismometer (vertical - Benioff type) was installed in the National Observatory of Athens and in 1962 the seismological station of Athens became one of the stations of the international network (standardized stations) by the installation of short period three component seismometers (Benioff type), as well as three components long period instruments (Willmore type). Of great importance for the collection of seismological observations is the establishment of a new network of macroseismic observations in 1950 in all parts of Greece and the publications of these observations along with the other observations which come from analysis of seismograms (arrival times, geographic coordinates of epicentres, magnitudes of earthquakes, etc) in the Bulletins of the Geodynamic Institute of the National Observatory of Athens. The publication of this bulletin continues till now. Thus, the available observations after 1950 are published in these bulletins. The publication of the *Seismological Bulletin of the Geodynamic Institute*, which contributed much to the development of Seismology in Greece, is due to work of professor Galanopoulos. There are also seismological data, especially for the period 1928-1949, which have been presented in the publications of several scientists.

During the last four decades the first permanent network of seismological stations was established in the area of Greece (in 1965, by the Geodynamic Institute of the National Observatory of Athens), as well as the first telemetric network of seismological stations (in 1981, by the Geophysical Laboratory of the University of Thessaloniki) and the network of the strong motion instruments (accelerometers). In addition to the two seismological centres in Athens, that is, the Geodynamic

Institute of the Observatory of Athens and the Seismological Laboratory of the University of Athens, two new seismological centres were established in Thessaloniki, the Geophysical Laboratory of the University of Thessaloniki (1977) and the Institute of Engineering Seismology and Earthquake Engineering (1979). The Seismological Laboratory of the University of Patras has been established recently.

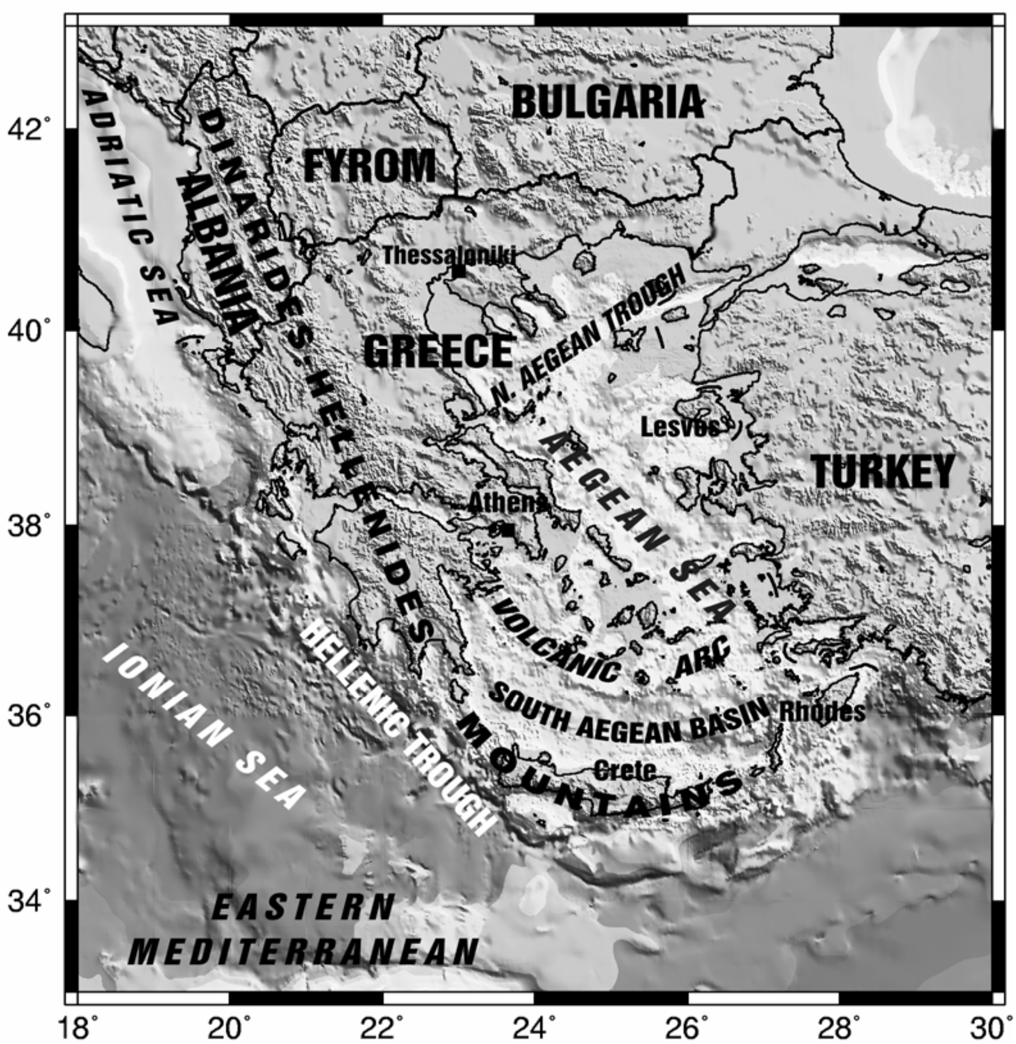

***Fig. 3.** Map of the main morphological features of tectonic origin of the broader Aegean Sea.*

2. Active tectonics

The high seismic activity in the broader Aegean area (figure 3), which belongs to the Eurasian-Melanesian zone of the continental fracture system, is mainly due to the fact that this area is part of the boundary zone of the Eurasian and African lithospheric plates. About thirty years ago, studies on the spatial distribution of earthquake foci (Papazachos and Comninakis, 1970, 1971) and on fault plane solutions (Papazachos and Delibasis, 1969) resulted in the identification of a Benioff zone in southern Greece, where subduction of the eastern Mediterranean lithosphere (sometimes considered as the front part of the African plate) under the area of Greece (front part of the Eurasian plate) takes place. This Benioff zone, which was identified through the accurate location of intermediate-depth ($60km \leq h \leq 180km$) earthquakes, defines the boundary between the Eurasian and African lithospheric plates along the Hellenic arc. Later studies on the crustal and upper mantle velocity structure by tomographic methods (Spakman, 1986; Papazachos et al., 1995; Papazachos and Nolet, 1997) fully supported the idea of the subduction in the southern Aegean area.

It has been shown that the Benioff zone consists of the shallow part ($h<100km$) which dips at a low angle where earthquakes with magnitudes up to 8.2 occur and of the deeper part

(100km≤h≤180km) which dips at a larger angle where earthquakes with magnitudes up to 7.0 occur (Papazachos, 1990; Kiratzi and Papazachos, 1995; Papazachos, and Nolet, 1997; Papazachos et al., 2000). Figure (4) shows a map with well-located epicentres of shallow and intermediate-depth earthquakes in the southern Aegean area (Papazachos et al., 2000), as well as three cross-sections where the foci of these shocks have been projected on vertical planes (along the lines shown on the map).

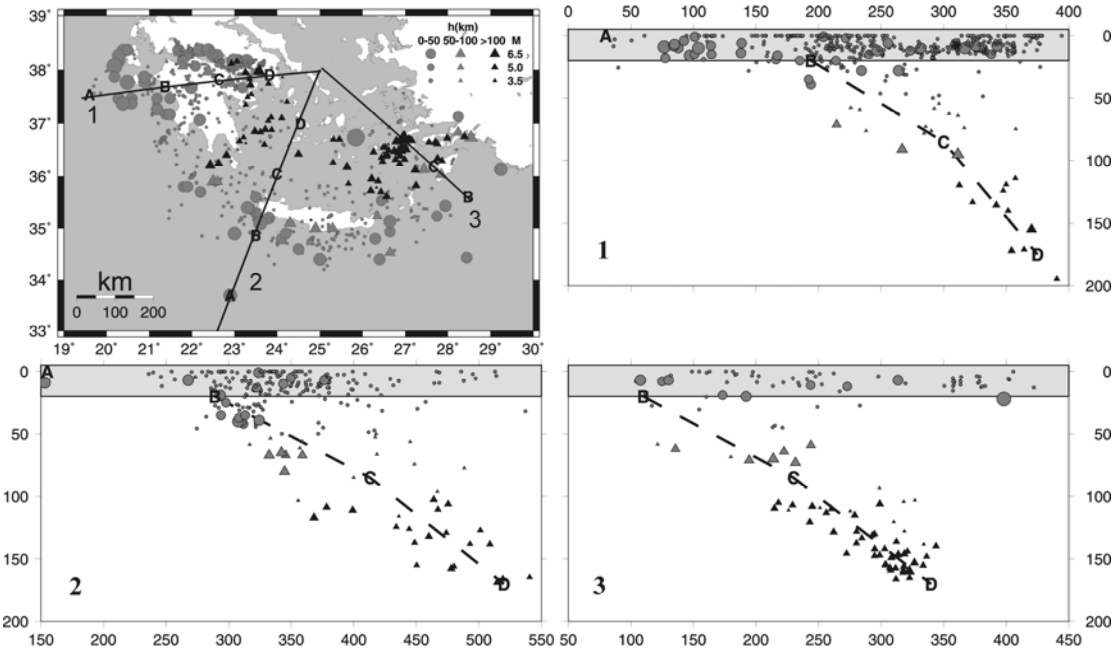

Fig. 4. *Map of accurately located epicenters of earthquakes in the southern Aegean Sea. The three cross-sections show the projection of the earthquake foci on vertical planes along the three solid lines shown on the top-left map (Papazachos et al., 2000).*

A lot of important results, which contributed to our knowledge on active tectonics, have been on fault plane solutions of large earthquakes. Early fault plane solutions of earthquakes in Greece had been determined by the use of first arrivals of teleseismic P-waves (Hodgson and Cock, 1956; Papazachos, 1961; Delibasis, 1968; Papazachos and Delibasis, 1969; Ritsema, 1974; McKenzie, 1972, 1978), whereas later fist onsets of P-waves of local earthquakes (e.g. Hatzfeld et al., 1989; Hatzidimitriou et al., 1991) and waveform modelling of teleseismic body waves were used (Kiratzi and Langston, 1989, 1991; Taymaz et al., 1990; Papadimitriou, 1993). These results quickly showed that the subduction along the Hellenic arc can not account for all the geodynamic phenomena observed in the broader Aegean area and that the quick westward motion of Anatolia, originally proposed by McKenzie (1972), had to be incorporated in order to explain the geotectonic setting of the area.

The most recent model that has been proposed to account for the present-day active tectonics of the area is shown in Figure (5). It is based on a large number of studies of fault plane mechanisms (McKenzie, 1972, 1978; Shirokova, 1972; Ritsema, 1974; Papazachos, 1975; Soufleris and Stewart, 1981; Papazachos et al. 1983, 1984, 1988, 1991, 1992; Dziewonski et al. 1984; Scordilis et al. 1985; Eyidogan and Jackson, 1985; Christodoulou, 1986; Anderson and Jackson, 1987; Kiratzi et al., 1987, 1991; Lyon-Caen et al., 1988; Pedotti, 1988; Ekstrom and England, 1989; Kiratzi and Langston, 1989; Ioannidou, 1989; Taymaz et al., 1990, 1991; Besnard, 1991; Amorese, 1993; Papadimitriou, 1993; Karakaisis et al., 1993; Baker et al., 1997; Louvari et al., 1999), deformation studies (Eyidogan, 1988; Jackson and McKenzie, 1988a,b; Ambraseys and Jackson, 1990; Papazachos et al., 1991; Kiratzi, 1991, 1993; Papazachos and Kiratzi, 1992, 1996; Jackson et al., 1992; Kiratzi and Papazachos, 1995), paleomagnetic (McKenzie, 1978; Le Pichon and Angelier, 1979; Kissel and Laj, 1988; Kondopoulou, 2000), conventional geodetic (Billiris et al., 1991; Stiros, 1993), the emerging after the 1990 GPS information (e.g. Oral et al., 1991,1995; Oral, 1994; Kahle et al., 1995, 1998; Straub, 1996; Reilinger et al., 1997; Straub et al., 1997; McClusky et al., 2000) as well on the combined interpretation of the previous data (e.g. McKenzie, 1972, 1978; Taymaz et al., 1991; Jackson, 1994; Papazachos, 1999).

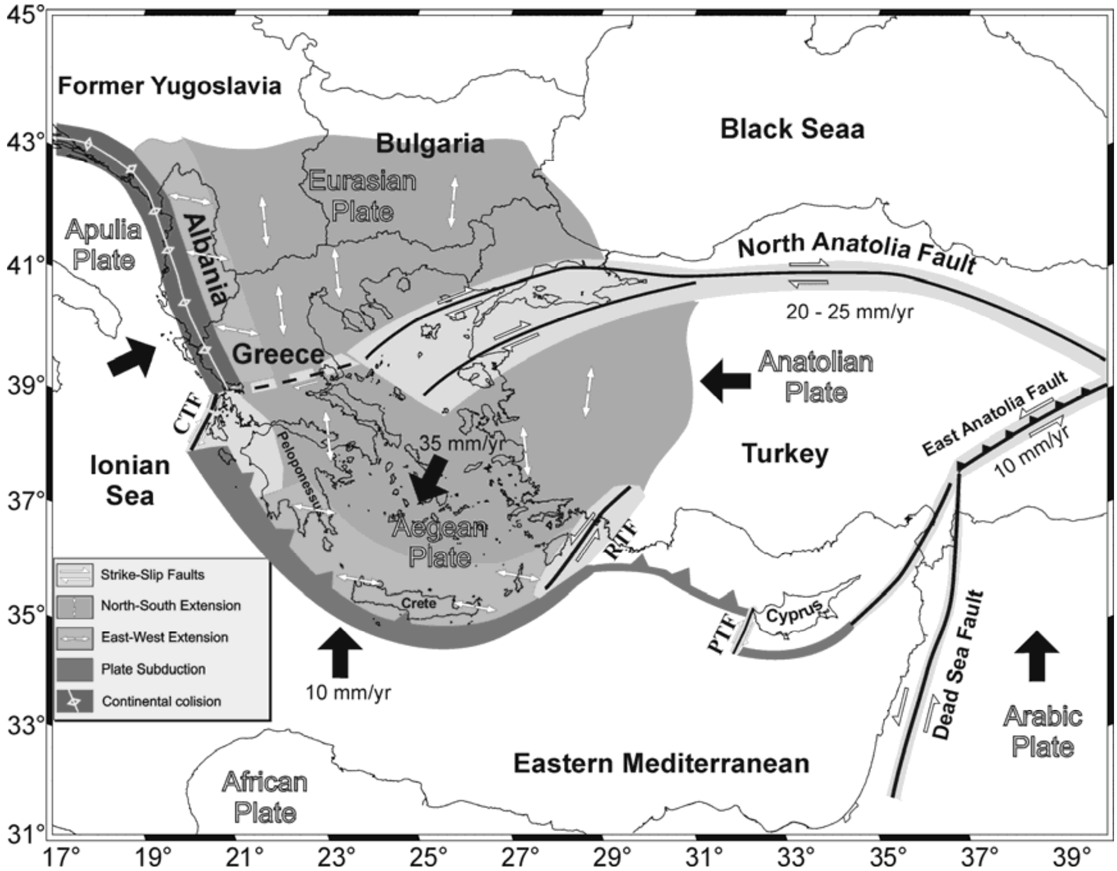

Fig. 5. *Plate motions which affect active tectonics in the Aegean and surrounding area (modified from Papazachos et al., 1997).*

According to this model, the Anatolia plate is rotating counterclockwise, relatively to Eurasia, at a rate of 1.2^o/ma about an Euler pole located north of the Sinai peninsula (31.1^{o}N, 33.4^{o}E), which results in a slip velocity of 2.5cm/yr in the North Anatolia Fault (Oral et al., 1995). This westward motion of Anatolia does not result in a compressional field in the Aegean area, which on the contrary, is dominated by an extensional stress field. Moreover, the Aegean moves as a more or less coherent unit in respect to Eurasia with much high velocity (~3.5cm/yr) than the corresponding velocity of the Anatolia plate (Kahle et al., 1998). For this reason the Aegean area can be considered as separate microplate, the Aegean plate following the original ideas of McKenzie (1970).

The two zones of Apulia and the outer Hellenic arc exhibit reverse faulting due to the collision of the lithospheres of Apulia and eastern Mediterranean, respectively, with the Aegean plate. The eastern Mediterranean lithosphere is subducted under the Aegean and the associated Benioff zone shows strike-slip faulting with a reverse component. In the back-arc area normal faulting prevails along two zones, a dominant one with North-South extension and a secondary one following the Hellenides mountain chain with East-West extension. Along the North Aegean Trough and the transform zone between Apulia and eastern Mediterranean in the Cephalonia Transform Fault area (CTF in figure 5) a fifth zone is observed, which exhibits dextral strike-slip faulting. The eastern limit of the Hellenic arc is defined by the sinistral Rhodes Transform Fault (RTF in figure 5), which is the only main strike-slip fault in the Aegean area, which is not dextral.

All data mentioned previously exhibit a consistent geotectonic setting, which is characterized by a dominant extension regime in the Aegean after Lower Miocene. The kinematic status of the Aegean shows a gradual increase of deformation velocities, with respect to Europe, from 1cm/yr in the North Aegean Trough up to 3.5-4cm/yr in the southernmost Hellenic Arc. The corresponding velocity direction changes from ENE-WSW in the central coasts of western Turkey to NNE-SSW in the southern Aegean, showing that additional forces (except from the Anatolia westward motion) exist in the Aegean, related either to the slab pull or the gravitational collapse of the Hellenides, which are responsible for this velocity acceleration and change of direction from almost EW at $\lambda=31^o$ to almost N-S at $\varphi=35^o$, $\lambda=23^0$.

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3. Seismicity

Early seismicity studies of the 20th century for the broader Aegean area had been of qualitative character and were based on catalogues containing information mainly on the macroseismic effects and the epicentres of earthquakes (Montesus de Balore, 1900; Maravelakis, 1936; Galanopoulos, 1953a, among others). Earthquake catalogues which included all the basic focal parameters of earthquakes in this area were compiled during the last four decades (Galanopoulos, 1960, 1961, 1963; Karnik, 1969, 1971; Papazachos and Comninakis, 1972; Comninakis and Papazachos, 1978, 1986, 1989; Makropoulos et al., 1989; Papazachos and Papazachou, 1997; Papazachos et al., 2000).

On the basis of these catalogues numerous semi-quantitative (Galanopoulos, 1953b, 1963; Papazachos and Comninakis, 1971; Makropoulos, 1978; Comninakis and Papazachos, 1978, 1980; Papazachos and Papazachou, 1989) and quantitative studies have been carried out (Delibasis and Galanopoulos, 1965; Comninakis, 1975; Makropoulos and Burton, 1984; Stavrakakis and Tselentis, 1987; Papazachos, 1990; Hatzidimitriou et al., 1994).

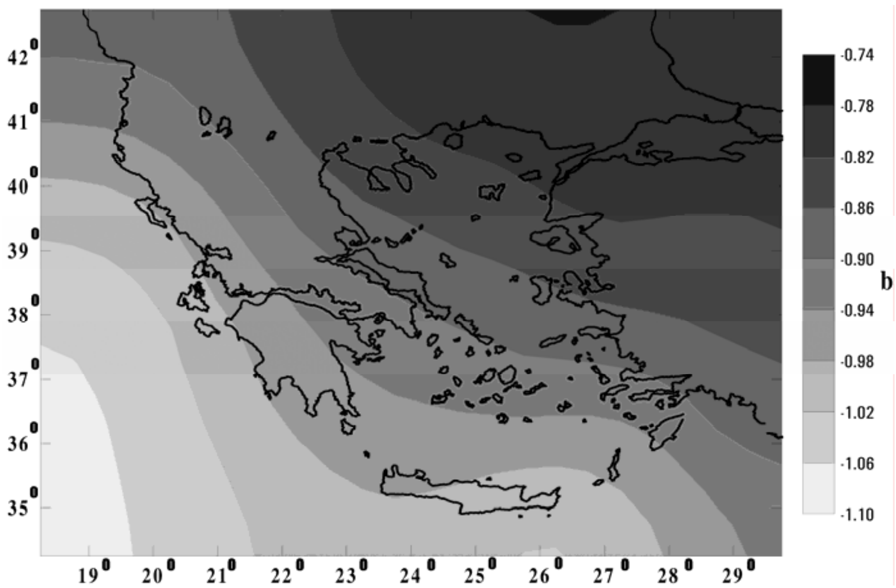

Fig. 6. *Geographical variation of the b values for shallow earthquakes in Greece and the surrounding areas (Papazachos, 1999).*

In one of the recent studies (Papazachos, 1999) a new method has been proposed for the reliable estimation of the two most commonly used measures of seismicity, that is, the *a* and *b* parameters of the Gutenberg and Richter (1944) relation. This method is based on the assumption that the variation of b values depends on the seismotectonic setting of each one of the sub-regions into which a broader area is divided and therefore spatial correlation and small *b* value variation must be expected, whereas for the *a* value a less significant spatial correlation is imposed since it reflects seismicity which may change rapidly in space. Figure (6) shows the spatial distribution of the *b* value in Greece and surrounding areas that has been determined by applying the method mentioned above. It is observed that the *b* values decrease systematically from SW to NE, that is, from the outer (convex) side of the Hellenic arc (Mediterranean Sea) to the inner part of the arc (Aegean Sea). A similar spatial variation of the *b* values has also been observed previously (Hatzidimitriou et al., 1985; 1994) and was correlated with the geologic zones of Greece for which the age increases from SW (external zones) to NE (internal zones).

On the basis of these parameters it has been found that the most probable maximum magnitude of shallow earthquakes in the broader Aegean area for a period of one year is 6.3, whereas a M=7.0 event occurs every about 6 years in this area (Papazachos and Papazachou, 1997).

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4. Crustal and upper mantle structure

In the first systematic study of the crustal structure of the Aegean by the use of body and head waves, an average crustal thickness of 42km was proposed, while a relatively low P_n wave velocity equal to 7.87km/sec was calculated (Papazachos et al., 1966). Papazachos et al. (1967), Papazachos (1969) and Payo (1967, 1969), studied the surface wave dispersion and determined an average crustal thickness for SE Europe (35-45km). Results from seismic refraction experiments (Deep Seismic Profiles - DSP) were presented in a series of papers by Makris (1972, 1973, 1976, 1978). Makris in his pioneering work, proposed an average crustal thickness for the Aegean and the Hellenides mountain range that varied between 30 and 44km, respectively, whereas for the southern Aegean (Cretan sea) between 20 and 25km and less than 20km for the Ionian Sea. Makris (1977) also compiled the first map of the Mohorovicic discontinuity depth in the broader Aegean area by combining data from these seismic experiments with gravimetric data. Similar results were also obtained from DSP data by Delibasis et al. (1988) and Voulgaris (1991) and from inversion of gravity data by Makris and Stavrou (1984), Brooks and Kiriakidis (1986), Chailas et al. (1992), Papazachos (1994) and Tsokas and Hansen (1999).

Panagiotopoulos and Papazachos (1985) after determining P_n residuals for 50 seismological stations in SE Europe, calculated an average crustal thickness of about 31km for the broader Aegean area (38-45km in western Greece and Albania, 30-35km in southern Aegean, central Greece and western Turkey and 24-30km in the Greece-Bulgaria border region). They found that the representative P-wave velocities for the sedimentary, upper-crustal and lower-crustal layers that were determined are 5.0, 6.0 and 6.8km/sec, respectively, while for the upper mantle they confirmed the relatively low velocities (~7.9km/sec) found by Papazachos et al. (1966). Moreover, the average thickness of the sedimentary layer was found to be 1-2km and the thickness of upper crust about 60% of the total crustal thickness.

Since the mid-90’s important results have been determined using travel-time and surface-wave tomography. In several papers, Spakman and co-workers (Spakman 1986, 1988; Spakman et al., 1993) showed that the subduction beneath the Aegean area is visible and extends up to ~800-900km. They also showed the presence of slab detachment in the subducted lithosphere on the western segment of the subduction (approximately section of the arc which is located NW of the Cephalonia island-SW Peloponessus area). Both these results have important geotectonic implications, since the large length of the subduction (which has an active Benioff zone only up to ~160km) imposes certain constraints on the age of the subduction, which were larger and contradicted previous estimates (e.g. LePichon and Angelier, 1979) and the slab detachment can partly account for the stress distribution in southern Aegean. Another important application of these results, as was initially shown by DeJonge et al. (1993) was the fact that tomographic models created from the broader Aegean area also helped to resolve between competing models of geotectonic reconstruction.

A large number of regional- or local-scale tomographic results have been published for several sub-regions or the broader Aegean area (e.g. Martin, 1988; Christodoulou and Hatzfeld, 1988; Drakatos, 1989; Ligdas et al., 1990; Drakatos and Drakopoulos, 1991; Ligdas and Lees, 1993; Papazachos et al., 1995). Papazachos et al. (1995) were the first to identify the presence of a low velocity layer-LVL (which can not be found be conventional seismic measurements) at the depth of ~10km along the Hellenides (part of the Alpine mountain chain – accretionary prism) using tomographic results, which can explained as a typical result of accretion and crustal thickening due to the subduction, in agreement with the original ideas of Mueller (1977) about the crustal structure of orogenic belts. Recently, Papazachos and Nolet (1997) presented new tomographic results for the P- and S-wave velocity distribution in the Aegean area using non-linear inversion of travel times through 3-D ray tracing, which allowed the detailed description of the regional 3-D structure of the crust and uppermost mantle (up to ~160km). Figure (7) shows the spatial distribution of P-velocities along three cross-sections (Papazachos and Nolet, 1997), where strong crustal thickness variations and mid-crustal low velocity layers are found. Moreover, the signature of the relatively thin subducted slab in the upper mantle, as well as its detailed geometrical characteristics are clearly identified.

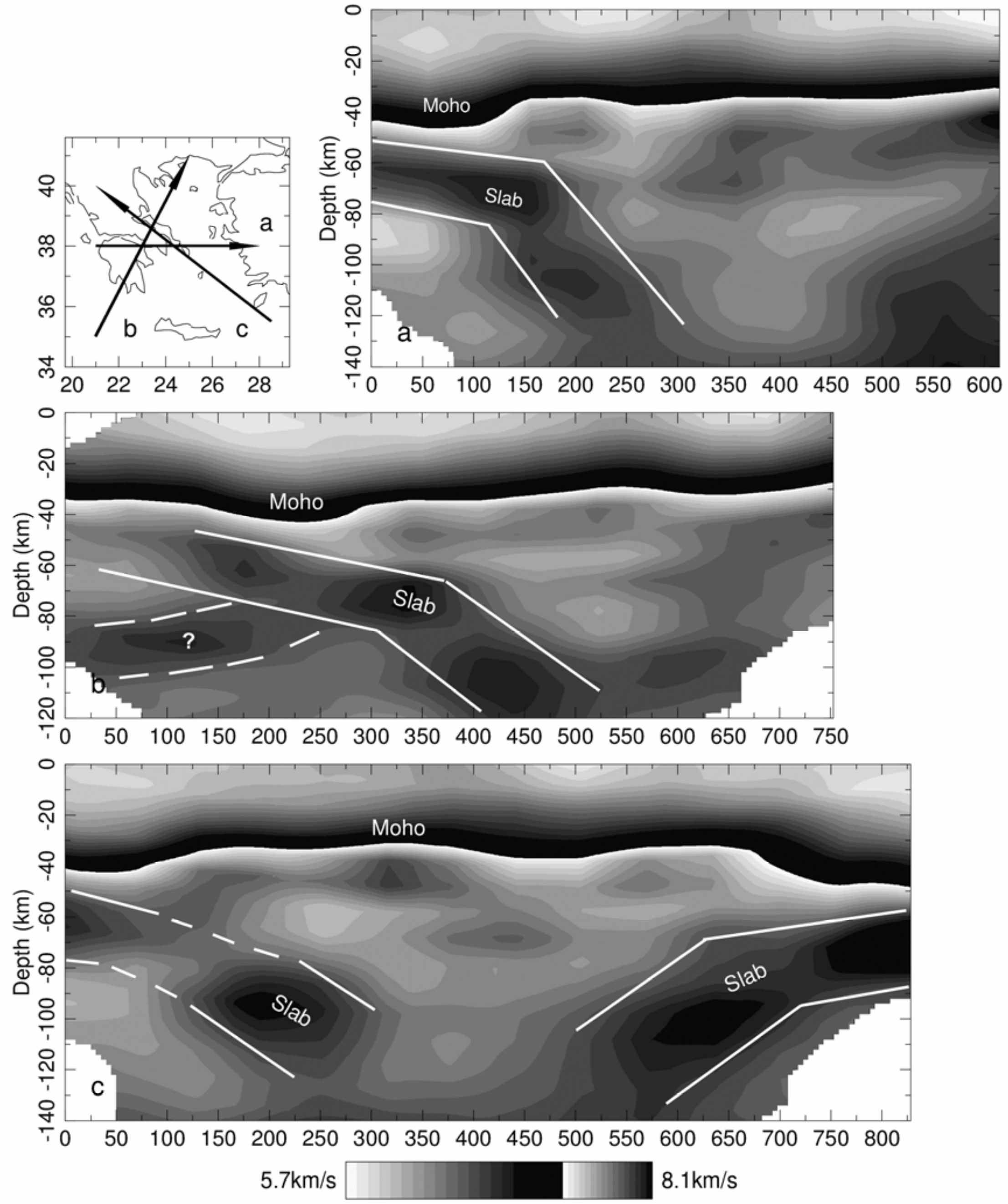

Fig. 7. *Distribution of P-velocities along three cross-sections in the Aegean area (Papazachos and Nolet, 1997).*

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5. Earthquake prediction

Research work in Greece related to earthquake prediction mainly concerns the investigation of preshock seismic sequences, seismicity regularities and earthquake precursors.

Investigations on seismic sequences usually dealt with the magnitude and time distribution of foreshocks and aftershocks (Papazachos et al., 1967; Comninakis et al., 1968; Drakopoulos, 1968; Papazachos, 1973, 1974, 1975; Karakaisis, 1984; Papadopoulos, 1988a; Papanastasiou et al., 1989; Papazachos and Papazachou, 1989; Papadopoulos et al., 1991, 2000; Latoussakis et al., 1991; Drakatos and Latoussakis, 1994; Latoussakis and Drakatos, 1994, among others) as well as with the spatial distribution of foreshocks and aftershocks (Papazachos et al., 1982; Karakaisis et al., 1985; Papazachos et al., 2000a). One of the most important results of the related work on the foreshocks is the observation that a large percentage of strong shallow mainshocks are preceded by foreshocks with their foci close to the focus of the mainshock, while the probability for an event to be a foreshock decreases with time. Moreover, the *b* parameter of the magnitude distribution is smaller for the foreshocks than for the aftershocks or than the normal (background) seismic activity.

Research on seismic regularities includes observations on seismic gaps (Purcaru and Berkemer, 1982; Papadimitriou, 1984; Papadimitriou and Papazachos, 1985a, b; Papadopoulos, 1986; Karakostas et al., 1986), on seismic quiescence (Wyss and Baer, 1981; Karakaisis et al., 1987; Papadimitriou et al., 1988) on migration of the seismic activity (Papazachos and Papadimitriou, 1984; Papadimitriou et al., 1985; Papadimitriou, 1986; Papazachos et al., 2000b; Papadimitriou and Sykes, 2001), on repeat times of strong earthquakes (Papazachos, 1989, 1992, Papazachos and Papaioannou, 1993), on the behavior of the seismic activity during the seismic cycle (Karakaisis et al., 1991) and on other types of seismicity regularities (e.g.Papazachos and Comninakis 1982; Ferraes, 1985; Stavrakakis and Tselentis, 1987; Papadopoulos, 1988b; Latoussakis and Kossobokov, 1990; Latoussakis and Stavrakakis, 1992).

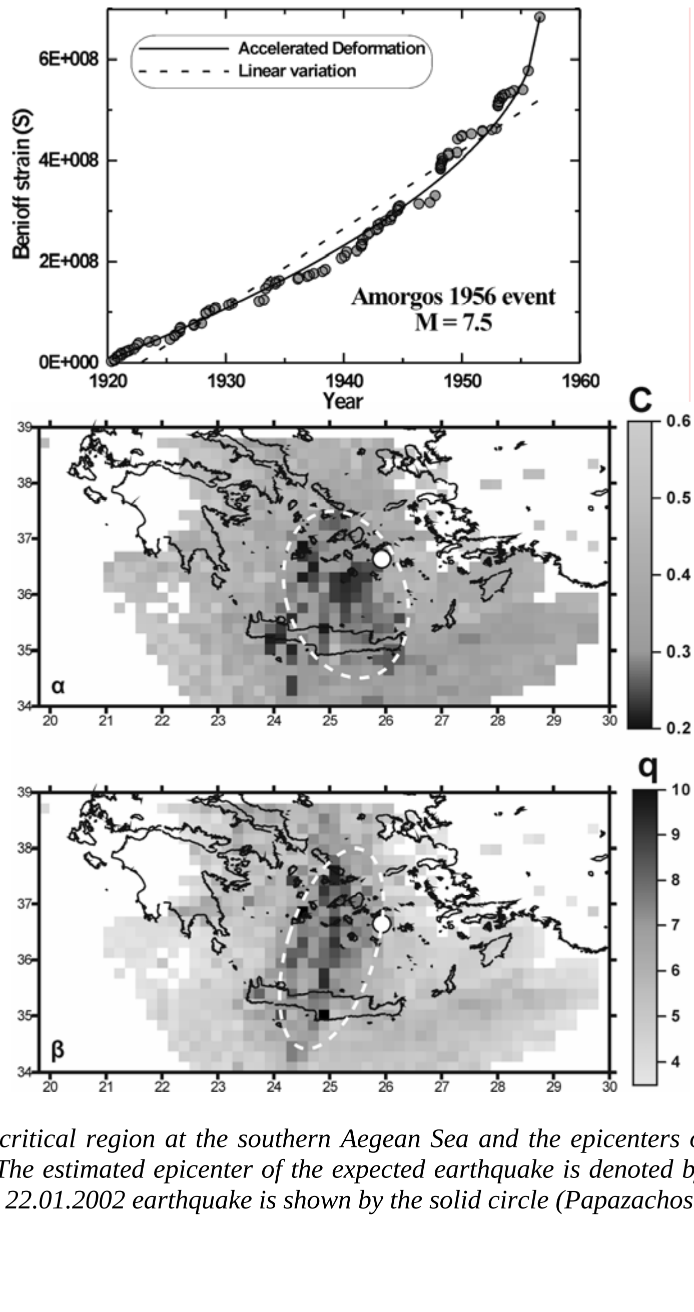

Fig. 8. *The elliptical critical region at the southern Aegean Sea and the epicenters of the preshocks (gray circles). The estimated epicenter of the expected earthquake is denoted by a star and the epicenter of the 22.01.2002 earthquake is shown by the solid circle (Papazachos et al., 2001).*

During the last decade several studies have been carried out on time-dependent seismicity which led to the development of the *regional time and magnitude predictable model* (Papazachos, 1992; Papazachos and Papaioannou, 1993) which has been used to determine probabilities of occurrence of strong earthquakes during the next years in Greece and almost all areas of the world where earthquakes occur (Papazachos et al., 1997a, b). Intensive work is focused lately on the the critical earthquake concept and specifically on the *accelerating moment release model* (Varnes, 1989; Sykes and Jaume, 1990; Sornette and Sammis, 1995; Bowman et al., 1998). Within this context considerable progress has been made, which resulted in the definition of several relations that can be used as additional constraints for this model, thus enhancing its robustness (Papazachos and Papazachos, 2000, 2001). Figure (8) shows the accelerated deformation (in terms of Benioff strain) observed before the large 1956 Amorgos (M=7.5) event. The bottom figure shows the spatial distribution of the curvature parameter, C, (ratio of RMS misfit between accelerated and linear time variation of strain) as defined by Bowman et al. (1998) and of parameter *q* which has been proposed by Papazachos and Papazachos (2001) as an alternative measure of acceleration for the same area 6 months before the event, as this is calculated by an accelerated deformation search algorithm proposed by Papazachos (2001). The circle corresponds to the epicenters of the observed mainshock, which is clearly observed within the elliptical areas of high *C* and *q* values. By the application of this model two strong earthquakes, which occurred in the Aegean area (26.7.2001 M=6.3; 22.01.2002 M=6.3) have been predicted, that is, their basic focal parameters were within the error limits that had been defined before the generation of these events (Karakaisis et al., 2001; Papazachos et al., 2001).

Research on earthquake precursors were mainly focused on preseismic variations of the electric field (Varotsos et al., 1981, 1982, 1993; Chouliaras and Rasmussen, 1988; Thanassoulas and Tselentis, 1993; Vargemezis et al., 1994). However, the results obtained, being in debate, show that these efforts are still at the stage of basic research and cannot directly contribute to seismic risk mitigation at present.

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6. Seismic hazard

The basic work on seismic hazard in Greece concerns the geographical distribution of the maximum observed intensity (Galanopoulos and Delibasis, 1972), the maximum expected macroseismic intensity (Shebalin et al., 1976; Papaioannou, 1984; Papazachos et al., 1985;), peak ground acceleration or velocity (Algermissen et al., 1976; Drakopoulos and Makropoulos, 1983; Papaioannou, 1984; Makropoulos and Burton, 1985) and the duration of the strong ground motion (Margaris et al., 1990; Papazachos et al., 1992). Much of this work and further studies on the same subject (Papazachos et al., 1990, 1993; Theodulidis, 1991; Margaris, 1994) is based on the separation of the broader Aegean area into several seismogenic sources (Algermissen et al., 1976; Papazachos, 1980; Hatzidimitriou, 1984; Papazachos et al., 1985; Makropoulos et al., 1988; Papazachos and Papazachou, 1989), the application of a method suggested by Cornel (1968) and the use of the code of McGuire (1976). Early seismic hazard studies made use of attenuation relations of strong ground motion derived for other areas (Algermissen et al., 1976; Makropoulos, 1978; Makropoulos and Burton, 1985) but later studies were based on attenuation relationships of the macroseismic intensity, peak ground acceleration and velocity derived for Greece and surrounding areas (Papaioannou, 1984, 1986; Papoulia and Stavrakakis, 1990; Theodulidis, 1991; Theodulidis and Papazachos, 1992). A number of papers concerns the evaluation of the results obtained through the work mentioned before

(Drakopoulos and Makropoulos, 1983, 1985; Drakopoulos et al., 1986; Makropoulos et al., 1988; Stavrakakis, 1988; Drakopoulos and Stavrakakis, 1988; Papazachos et al., 1990). A synthetic result of the previous publications is the separation of Greece in four zones of equal seismic hazard (Papazachos et al., 1989) and constitutes part of the Seismic Code of Greece.

In one of the most recent of seismic hazard studies (Papaioannou and Papazachos, 2000) an improved procedure was followed in which all new information concerning seismicity (Papazachos, 1990, 1999), seismotectonics (Papazachos et al., 1998; 1999; 2000a), attenuation laws of macroseismic intensities (Papazachos and Papaioannou, 1997, 1998) and local site conditions were taken into account. The results of the time-independed approach were given in terms of the expected macroseismic intensity at 144 sites in the studied area for a mean return period of 475 years (probability of exceedence 10% in 50 years) while, for the first time, the time-depended hazard at these sites was estimated and expressed in terms of occurrence probability of strong seismic motion (I≥VII) for the period 1996-2010.

Figure (9) shows the probabilities for the occurrence of strong ground motion (I≥VII) at each one of 144 sites in the area of Greece during the period 1996-2010 (Papaioannou and Papazachos, 2000). The revision of the seismic hazard map of Greece, which is underway, is based on new attenuation relations for the horizontal strong ground motion of shallow earthquakes that have been proposed very recently and are based on the largest set of strong motion recordings ever used in Greece (Margaris et al., 2001). Moreover, the faults, which have caused the known major shallow main shocks in the Aegean area, will be considered (Papazachos et al., 2001). Another fundamental input required for seismic hazard studies is an earthquake catalogue; such catalogue has been compiled recently and contains valuable information for historical events, which occurred in the broader Aegean area (Papazachos et al., 2000b).

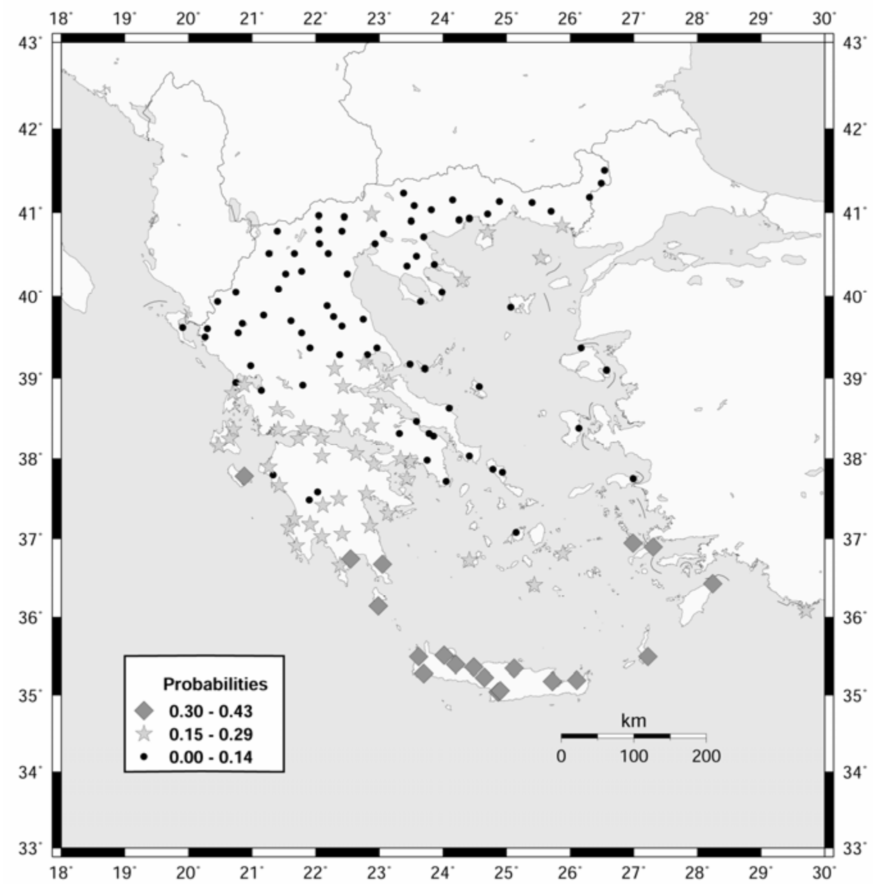

Fig. 9. *Probabilities for the occurrence of strong ground motion (I≥VII) at each one of 144 sites in the area of Greece during the period 1996-2010 (Papaioannou and Papazachos, 2000).*

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History

After Greece's independence the State showed its immediate interest in earthquakes. J. Schmidt, the first Director of the Observatory, was the first to collect data about the earthquakes occurring allover Greece. He compiled detailed catalogs of earthquakes between 1840-1878. He also described several major earthquakes of that period (such as the Heliki earthquake of 26-12-1861). In addition, Schmidt completed the older catalogs of A. Perrey and R. Mallet. At that time the Observatory was combining information on earthquake occurrence with contemporary astronomical and meteorological phenomena, putting emphasis on the timing of earthquakes and not on the their effects to the society and the environment. On the other hand, B. Lersch's catalog provides a lot of information about many earthquakes of that period so that it was possible for other scientists to study them better and to construct isoseismal maps.

In 1893, the Greek Seismological Survey was formed. Later, the Survey became the core of the Geodynamics Institute. Observations were done in Athens using two Brassart seismoscopes and around the various Greek provinces using personnel employed in the local meteorological stations. The first instruments were put in operation in 1897. They were five (5) seismographs of "Agamemnon" type, that were installed in Athens (June 1899), Khalkis (June 1900), Kalamata (September 1900), Zakynthos (October 1902) and Egion (January 1903). This was the first seismological network in Greece. Due to many problems caused by instrument malfunction this network operated for a short period of time: the peripheral stations operated up to 1912; the Athens station up to 1920. In 1910 the

Observatory installed a two-component Mainka seismograph, which operated during 1911. This instrument was the first precise instrument in the whole of Eastern Mediterranean and 1911 marked the first year of measurements with reliable instruments.

In 1924 a two-component Wiechert seismograph was installed after a donation from a Hamburg citizen of Greek origin. In 1928 the Observatory buys and installs another Weichert seismograph (vertical component). In 1932, N Kritikos, Director of the Geodynamics Institute, constructed a seismograph with a horizontal component (N-S) of a small gain and installed it for the measurement of local earthquakes. In 1957, after a donation form Canada a Beniof-type seismograph was installed. This instrument is regarded as the first with high gain (amplification). In 1962 a WWSSN station was installed in Athens (WWSSN stands for World Wide Standard Stations Network). The station consists of three (3) short-period seismographs (one vertical and two horizontal component instruments) of Beniof-type, as well as of three (3) long-period seismographs of Sprengnether-type. In 1963 a vertical-component Weichert instrument was installed in Patras. Én 1964 Hiller-type seismographs (vertical and two horizontal components) were installed in Athens.

In 1965 a Wood-Anderson seismograph (2 horizontal components) was installed in Athens. This instrument is used until today to calculate local earthquake magnitude ML. During the same year four (4) new stations were installed in Hagia Paraskeui (Lesvos), Valsamata (Kefallinia), Rhodes and Vamos (Crete). These stations were composed of short-period seismographs of Sprengnether type (vertical and horizontal components). The Rhodes station was transferred in Archangellos during March 1967. In 1968 two new stations were installed in Ioannina and Chalkidiki (Poligiros). These stations were also composed of short-period seismographs of Sprengnether type (vertical and horizontal components). In 1971 a Beniof-type seismograph was installed in Pendeli. During May 1972 the Hiller seismographs were transferred to Pendeli and continue operation from there. The July of the same year a new station was installed in Kozani with the operation of a Beniof-type seismograph. During July 1973 a new station was installed in Neapolis (Eastern Crete). A vertical-component CBK-M3 seismograph and horizontal-component CBK-M3 were installed. A Wood-Anderson seismograph was installed in Valsamata (Kefallinia) during October 1973. This instrument operated until September 1988.

During March 1974 a vertical-component seismograph Press-Ewing was installed at the Pendeli station to record distant earthquakes. At the same station the Hiller seismographs stopped operating in December. During October 1974 a new station was installed in Ithomi (Messinia) with CBK-M3 seismographs in operation. During October 1975 the Kozani station seismograph was replaced with a Sprengnether instrument. During November of the same year a new station was installed in Apeiranthos (Naxos) with Sprengnether instruments, too. During June 1976 a new station was installed in Riolos (Achaia) with a vertical-component seismograph of thermal recording type. The seismometer was a S-13 velocity type made by Teledyne Geotech seismograph (Willmore type). The Patras station stopped operating.

Since March 1983 a telemetry network started operating between Athens, Valsamata, Kozani, Hagia Paraskevi, and Neapolis stations. The new network consists of vertical-component seismographs of thermal recording type. The seismometers were S-13 velocity type made by Teledyne Geotech. At the Athens station two (2) horizontal-component seismometers were also installed. During February 1988 the Athens WWSSN station is converted to thermographic. The spring of the same year twelve (12) new telemetry stations were installed in Kerkyra (Corfu), Karpenissi, Pelio, Rhodopi, Samos, Laconia, Karpathos, Rhodes, Ithomi, Vamos, Poligiros, and Kastellorizo.

In 1993 the installation of the digital network starts. The first stations are: Athens, Ioannina, Valsamata, Ithomi, Samos, Poligiros, Karpenissi, Pelio, and Thera (Santorini). In 1994 in collaboration with ING (Rome) a new station was installed in Anogia (Crete) that becomes part of the Mediterranean Network - MEDNET. The sensitive, broadband seismometers were put at the bottom of a 5m-depth well that was constructed in order to diminish noise. This station started operating in 1995 and since 1999 it has become part of the Global system of monitoring nuclear explosions that is operated by the United Nations.

Since 1998 new seismological stations are being progressively installed in Atalanti, Skyros, Lemnos, Khios, Nevrokopi, Kastoria and Tripolis. In addition, the rest of the stations were converted to digital, real-time transmission. All the seismometers have been replaced with advanced broadband instruments.

Research activities

The research activities of the Geodynamics Institute cover a broad spectrum of Seismology, Physics of the Earth's Interior and Geophysics. In particular, we do research in the following fields:

Seismicity

- Preshock, mainshock, aftershock sequences
- Variations of seismic activity
- Seismotectonics of various regions
- Microseismic activities along selected seismic zones
- Seismic potential of active faults
- Seismic quiescence of regions of Greece and surrounding areas
- Spatial evolution of seismic activity
- Induced seismic activity
- Activation of seismic regions
- Interaction of active faults
- Recognition of characteristics of seismic activity

Focal mechanisms of earthquakes - Properties of the seismic source

- Focal mechanisms of earthquakes
- Spectral characteristics of preshocks, mainshocks and aftershocks
- Rupture mode of strong earthquakes
- Dynamic parameters of ruptures

Propagation of seismic waves - Strong Ground Motion

- Attenuation of strong ground motion
- Directivity of propagation of seismic energy
- Synthetic strong ground motions (stochastic procedures)
- Synthetic strong ground motions using Green functions

Seismic hazard - Microzonation studies

- Improvement of algorithms for calculation of expected seismic accelerations, velocities and displacements
- Correlation of different methodologies
- Improvement of algorithms for calculation of statistical parameters
- Improvement of microzonation methods

Structure

- Structure of Earth's crust and mantle
- Distribution of seismic velocities
- Seismic tomography and determination of seismic parameters

Earthquake prediction

- Multidisciplinary, parametric investigation of geophysical-seismological parameters Recognition of characteristic patterns of seismicity
- Geophysical methods (magnetotelluric)
- Statistical methods
- Spatio-temporal evolution of seismicity
- Algorithms of amalgamation of the different characteristics of seismic activity

Seismotectonics - Paleoseismology

- Active faults and tectonic stress levels
- Correlation of microseismic activity with active faults and discovery of new fracture zones
- Historical seismicity and association with known faults

Seismic Sea Waves (Tsunamis)

- Catalogue compilation
- Generation mechanisms and propagation
- Wave simulation
- Palaeotsunami investigation
- Hazard assessment
- Development of protection measures
- Awareness and Education

Geological Remote Sensing

- Remote sensing of active faults
- Remote sensing of landslides
- Fault segmentation - neotectonics
- Thermal remote sensing of volcanic arcs and known faults
- Hyperspectral remote sensing of hydrothermal mineralisations
- Digital geomorphometry

- SAR Interferometry
- Archaeological applications of remote sensing

Applied Geophysics

- Reflection and Refraction Seismics
- Seismic tomography
- Geoelectrical imaging
- Ground Penetrating Radar
- Magnetic and Gravity methods
- Electromagnetic methods

The above methods are applied to:

- Construction works,
- Geological, mining, environmental projects
- Archaeological surveys

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SEISMOLOGICAL LABORATORY

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History

The Department of Geophysics & Geothermy consists of two Laboratories.

1) The Seismological Laboratory and
2) The Geophysical Laboratory.

The Seismological Laboratory belongs to the Department of Geophysics and Geothermy of the National and Kapodistrian University of Athens. It is situated at the Geology Faculty Building in Panepistimioupolis. Its space facilities include offices, laboratories, auditorium and recording instrument rooms. The Laboratory first operated in 1929.

Ever since, its major axes of contribution have been the education of students as well as the monitoring of seismicity of the area of Greece, in cooperation with the Geodynamic Institute of the National Observatory of Athens. Major contributions and progresses were made in the fields of Seismology and Geophysics over the years, which have been equally recognized by the Greek and the international scientific community. The large number of scientific publications in international and Greek scientific journals, the participation in conferences, the organization of international conferences, seminars and lectures and the Greek and EU research contracts, exhibit the competitive status of the Laboratory, not only on Greek, but also on an international basis.

Permanent & Portable Equipment

Greece is a natural laboratory by itself, exhibiting the highest seismicity in Europe and accounting for over 50% of its seismic energy release. The Seismological Laboratory has all the required technical equipment to fulfill the numerous and vital seismological and geophysical needs. Its constant presence, especially at emergency cases due to catastrophic earthquakes, is crucial. The Laboratory operates three modern digital telemetric station networks: CORNET and VOLNET in the areas of the gulf of Coring and central Greece. The new, also telemetric seismic network, ATHENET, covers approximately an area 100km radius around Athens, and consists of eight satellite stations equipped with broad-band seismometers and on-site 24 bits digitizers. Data are transmitted to the central processing station, situated at the Laboratory building.

In addition to the permanent networks, the Laboratory has a reach poll of portable equipment, which at the present consists of: a) 22 High resolution, 3ch, 24bit digitizers, (seismographs, REFTEK type), with 33 disk recording systems of 4.0Gb capacity each, b) 5 High resolution, 3ch, 16bit digitizers (seismographs, Lennartz type), c) 10 broadband seismometers (30s-50Hz), Guralp type, Ψ 17 1Hz and 0.2Hz seismometers, Lennartz type, d) 20 High resolution, 3ch, 24bit, 18bit and 16bit accelerometers (Kinemetrics type), e) 1 48ch, seismograph, Geometrics type, f) 1 Resistivity meter, IRIS type, g) 1 Geo-Radar, SIR-2000 type, h) 5 Radon probes-loggers.

Seismic data processing is facilitated by UNIX, DOS and WINDOWS environments, as well as by specialized seismic data processing and analysis software.

Activities

During the last 60 years the Seismological Laboratory has greatly contributed to scientific advances in the field of Seismology in Greece. In the course of its activities over the years, a better understanding of the seismicity, seismic hazard and seismic risk of the area of Greece was accomplished. Several local seismic networks were deployed, monitoring the seismicity and determining the seismotectonic regime of certain seismogenic areas. Moreover, applications of theoretical seismology to Greek data resulted in revised and/or local seismic intensity and seismic energy attenuation laws and in the determination of seismic source parameters for a large number of earthquakes At the same time, a large number of microzonation studies aiming at the mitigation of seismic risk was performed. In recent years, major advances were also made in the field of engineering seismology, mainly due to the application of dynamic, seismic, electromagnetic and magnetotelluric methods. Emphasis is given on the application of modern methodologies, i.e. seismic and geoelectric tomography, high-resolution reflection including shear waves reflection, etc. The Laboratory welcomes a large number of physics and geology undergraduates, pursuing post-graduate studies in the field of Seismology, thus contributing to the education of the young generation of scientists.

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DEPARTMENT OF GEOPHYSICS

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Objectives

The Department of Geophysics carries out research activity on environment-related fields (Seismology, Physics on the Earth's Interior and Applied Geophysics).

Short History

The Laboratory of Geophysics of the Aristotle University of Thessaloniki was established in 1976 by Presidential degree together with the Chair of Geophysics. Since 1983 the Laboratory belongs to Department of Geophysics, which is one out of five departments of the School of Geology of Aristotle University of Thessaloniki.

The Department of Geophysics was the first educational and research Geophysics Institution in Northern Greece as well as the first such Institution in Greece outside Athens. Since its establishment, the Department rapidly developed research, educational and broader social activity in problems related to Seismology, Physics of the Earth's Interior and Applied Geophysics.

Since 1981 a telemetric network of one central and 16 permanent peripheral seismological stations is installed and is in operation 24 hours/day, providing the public and authorities with data concerning the seismic activity in the broader area of Greece, as well as information on strong earthquakes all over the world.

Teaching Activity

The educational activity of the Laboratory is related to Seismology, Physics of the Earth's Interior and Applied Geophysics, for both undergraduate and post-graduate students**.** *Undergraduate Studies:* 15 courses are available to the undergraduate students of the School of Geology, the School of Physics and School of Mathematics. These include: Philosophy of Science, Introduction to Seismology, Introduction to the Physics of the Earth's Interior, Physics of the Lithosphere, Applied Geophysics I (Seismic methods), Theory of Mechanical Vibrations and Elastic Waves, Applied Geophysics II (Gravity and Magnetic methods), Applied Seismology, Geophysical Field work for Undergraduate Students, Methods of analysis and interpretation of geological data, Applied Geophysics III (Electrical - Electromagnetic - Radiometric methods), Seminars in Geophysics, Thesis for undergraduate students, Geophysics and Seismology, Seismology. *Postgraduate studies:* Within the framework of the "Program for Postgraduate Studies", which is in operation since 1995 in the School of Geology, 14 courses are taught by the staff of the Laboratory and constitute the branch of "Geophysics" of the above mentioned program. These courses are: Advanced Seismology, Advanced Physics of the Earth's Interior, Mathematics for Geophysicists, Active Tectonics, Geophysical Prospecting for the Solution of Hydrogeological and Engineering Aspects, Engineering Seismology, Archaeometry, Advanced Applied Geophysics, Application of Computer Programming in Geophysics, Geophysical Field Work, Geophysical Prospecting in Ore Deposits, Geophysical Prospecting in Geothermal Fields, The Geophysics of Greece, Special Seminars in Geophysics, Dissertation for the Master Degree.

Research Activity

The staff of the Laboratory of Geophysics contributed directly to the solution of important problems of the Greek Society by participating in the development of the New Seismic Code of Greece, by advising the authorities for the antiseismic construction of several important technical structures, by giving lectures on seismic risk and other problems, by giving reliable information to the inhabitants and the Government during seismic excitations, by detecting sites of economic and archaeological importance, etc. Numerous projects have been conducted and are currently conducted on the following subjects:

Long term earthquake prediction, Short term earthquake prediction, Crust and upper mantle structure, Propagation and attenuation of seismic waves, Crustal deformation, Palaeomagnetism and tectonics, Magnetostratigraphy, Archaeomagnetism, Global seismicity, Seismotectonics of the broader Aegean area, Archaeometry, Study of seismic sequences, Seismicity of the broader area of Greece, Seismic hazard, Microzonation studies, Dynamic fields, Pure research on seismic methods, Telluric field continuous monitoring, Applied geophysics on the Hydrogeological and Engineering practice, Applied geophysics on the detection of ore deposits, Magnetotelluric prospecting.

Telemetry Seismlogical Network

The establishment of the Laboratory of Geophysics in 1977 was followed by the installation of a telemetry seismological network in the area of northern Greece which officially started operating on 1 January 1981. The seismological network obtained its present configuration in three phases.

During the first phase (1980-1989) the network consisted of the central seismological station of Thessaloniki (THE) and seven peripheral stations in Sochos (SOH), Litohoro (LIT), Griva (GRG), Paliouri (PAIG), Kentriko (KNT), Ouranoupolis (OUR) and Serres (SRS). The selection of these sites was done on the basis of both scientific and social purposes. The network of these eight stations adequately covered the part of the Serbomacedonian zone which belongs to the Hellenic territory. The seismicity of this zone is the highest in the area of northern Greece. This network was the first telemetry network in the area of Greece and the first one supported by computer system in the whole Balkan area. The network was expanded in 1989 (second phase) with the installation of four new seismological stations at Igoumenitsa (IGT), Florina (FNA), Alexandroupolis (ALN) and Agios Georgios (AGG).

All these stations are equipped with three (Z, N-S, E-W) short period seismometers (S-13 Teledyne-Geotech). Additionally, in the central station of Thessaloniki 3-component long-period seismometers (SL-210 Teledyne-Geotech) are in operation since 1981. The seismic signals from these seismologic stations are transferred directly to the central seismological station of Thessaloniki by leased telephone lines. This network was the first telemetry network in the area of Greece and the first one supported by computer system in the whole Balkan area.

During the period 1996-1999 (third phase) four more stations were installed in Lemnos island (LOS), Alonissos island (AOS), Xorichti (XOR) in Pelion Mountain and Lefkada island (LKD), improving the azimuthal coverage of North Aegean area and Ionian islands, which is of particularly high scientific interest and increasing the detectability of the network. In these stations vertical short-period seismometers (S-13 Teledyne-Geotech) are installed, while the transmission of the seismic signals to the central seismological station is wireless in UHF frequency band. Three more stations are about to be installed (2002) in northern and southern Aegean as well as in northern Greece.

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INSTITUTE OF ENGINEERING SEISMOLOGY & EARTHQUAKE ENGINEERING (ITSAK)

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Overview

The Institute of Engineering Seismology and Earthquake Engineering (**ITSAK**) was established in Thessaloniki (Greece) in 1979, after the disastrous earthquake (*M*6.5) that stroke the city on June 20, 1978. The first scientific, technical and administrative staffs was hired during the period 1981 - 1984. Today 10 researchers (all with doctoral degrees) work at ITSAK. The main objective of the Institute, according to its Organizational Chart, is the applied research in the fields of Engineering Seismology, Soil Dynamics and Earthquake Engineering, aiming at upgrading the Greek Seismic Code and mitigating damage from earthquakes.

The Institute's principal R&D results, achieved during the past 20 years in collaboration with national and foreign university laboratories and research centres, are briefly mentioned below:

• Deployment and operation of a free-field strong-motion network, which today is nation-wide, consisting of 78 accelerographs and covering most of the country's major towns

• Installation of a complete semi-automatic and automatic strong-motion data processing system, including a maintenance laboratory and computer facilities

• Compilation of an extensive databank of strong-motion recordings, comprising Greek, European and other accelerograms from around the world; organisation of a specialized library in the fields of Engineering Seismology, Earthquake Engineering and Soil Dynamics, open to interested scientists and Organizations

• Construction, with basis on the aforementioned databank, of design spectra incorporated into the Greek Seismic Code, in the elaboration of which ITSAK played a significant role

• Instrumentation and monitoring of the dynamic behaviour of buildings and large-scale engineering structures (installation of a permanent monitoring accelerometer array on the Halkis cable-stayed bridge, use of special mobile structural array on various structures throughout Greece)

• Deployment of a dense 3D accelerograph array close to Thessaloniki, in the sedimentary basin traversed by the active seismic fault that caused the earthquake of June 20, 1978

• Study of the aftershock sequences of all strong earthquakes occurred in Greece

• Publications of ITSAK (>200) in scientific journals and proceedings of international conferences

• Organization, with support from the European Commission, of an European Advanced Study Course on Seismic Risk

• Organization, with support from EPPO, of the inaugural meeting of the Association for Seismic Protection of the BSEC Member States (ASPBSEC) for the approval of the statute for the Association constitution and host of the secretariat of the ASPBSEC

Current Research Activities

To date, the research staff of the Institute has been actively involved in various National and European research programmes, such as EPOCH, ENVIRONMENT I & II, HUMAN CAPITAL AND MOBILITY, BRITE-EURAM, ESPRIT, INTAS, FP5. Moreover, in a national level numerous technical studies have been performed. The principal research fields are: Source characteristics from strong-motion data, Attenuation and empirical modelling of strong-motion characteristics, Site effects (assessment and modelling), Seismic and geophysical structure of the geologic medium (crust, lithosphere, sedimentary basins, etc.), Simulation of strong ground motion (deterministic & stochastic), Seismicity (including fractal-multifractal studies) and crustal deformation, Evaluation and exploitation of historical macroseismic data, Probabilistic seismic-hazard analysis, Dynamic soil-structure interaction, Evaluation of the dynamic properties of soils and rocks, Wave-propagation problems and dynamic behaviour of buried structures, Evaluation and analysis of damage caused by earthquakes, Retrofitting and repairing techniques for structures, Dynamic behaviour of structures, structural elements, materials and special installations under seismic load (*in-situ* measurements and analytical approaches), Energy-related measures of the seismic action, Dynamic properties of materials: damping, stiffness, strength and failure, Mechanics of base isolation and energy-dissipation materials and devices, Finite-element techniques for dynamic failure of concrete and rock, Numerical models for efficient analysis of shell-structures, Improvement of the provisions of the Greek Seismic Code, Development of inelastic pseudoacceleration and displacement response spectra based on Greek earthquakes, Development of guidelines for the seismic evaluation of existing buildings in Greece.

Applied Research Performed at ITSAK

Greek Seismic Code: seismic zonation map, design forces and spectra, computational guidelines and analytical examples. Participation in post – earthquake damage assessment surveys; dissemination of technical knowledge to professionals. Microzonation studies in cities after disastrous events (Thessaloniki 1978, Kalamata 1986, Kozani-Grevena 1995, Limassol 1999, Athens 1999). Site-specific hazard analysis, dynamic and equivalent static analysis for important large-scale engineering structures in Greece (dams, hospitals, storage silos, chemical storage tanks, high bridges, electric-power facilities, Olympic Athletic Center of Athens, Egnatia Motorway). Instrumentation and monitoring of the dynamic behaviour of the Halkis cable-stayed bridge (funded by the Ministry of Environment, Physical

Planning and Public Works). Deployment and operation of strong – motion networks in earthquake stricken areas and assessment of site effects

Collaborating Institutes

ITSAK collaborates with a considerable number of seismological and geophysical institutes, as well as with other organizations in Greece and in other countries:

Greece: Laboratory of Geophysics, University of Thessaloniki; Laboratory of Soil Mechanics and Foundation Engineering, University of Thessaloniki; Laboratory of Strength of Materials, University of Thessaloniki; Laboratory of Reinforced Concrete, University of Thessaloniki; Laboratory of Applied Statics, University of Thessaloniki; Laboratory of Reinforced Concrete, University of Thrace; Laboratory of Applied Mechanics, University of Thrace; Geodynamic Institute, National Observatory of Athens; Laboratory of Seismology, University of Athens; Laboratory of Earthquake Engineering, National Technical University of Athens; Laboratory of Geotechnical Engineering, National Technical University of Athens; Earthquake Planning and Protection Organization, Athens; Laboratory of Earthquake Engineering, Department of Civil Engineering, University of Patras; Public Power Corporation, Athens.

Cyprus: Water Resources Department, Ministry of Environment, Resources & Agriculture, Nicosia; Geological Survey Department, Ministry of Environment, Resources & Agriculture, Nicosia.

France: Laboratoire de Geophysique Interne et Tectonophysique, University Joseph Fourier, Grenoble; Centre d'Etudes Techniques de l'Equipement, CETE Mediterrannee, Aix-en-Province; Laboratoire de Pont et Chaussees, Nice; Laboratoire de Mechanique des Sols-Structures Materiaux, Ecole Centrale de Paris, Chatenay-Malabry; Institute de Physique du Globe, Paris; Centre Sismologique EuroMediterraneen, Bruyeres-le-Chatel.

United Kingdom: Imperial College of Science and Technology, London; Civil Engineering Department, University College of London.

Belgium: Laboratoire de Geologie de L'Ingenieur d'Hydrogeologie & de Prospection Geophysique, Universite de Liege.

Portugal :Instituto de Ciencas da Terra e do Espacio, University of Lisbon,;Instituto Superior Tecnico, Lisbon.

Italy: Dipartimento di Scienze della Terra, University of Trieste; Istituto Nazionale di Geofizica, Rome; ENEA, Casaccia-Rome; ENEL, Direzione Construzioni, Roma.

Spain: Servei Geologic, Institut Cartografic de Catalunya, Barcelona; Politecnical University de Catalunya, Barcelona; Instituto de Investigacion Tecnologica, Universidad Pontificia Comillas, Madrid.

Denmark: Civil Engineering Department, Aalborg University.

Germany: Geophysikalisches Institut, Universitat Federiciana Karlsruhe; GeoForschungsZentrum Potsdam; Structural Engineering Laboratory, University of Bochum.

The Netherlands: Institute of Hydraulic and Environmental Engineering (IHE), Amsterdam; International Institute for Infrastructural, Hydraulic and Environmental Engineering, Delft.

Russia: Joint Institute of Physics of the Earth, Russian Academy of Sciences, Moscow.

USA: United States Geological Survey; University of California at Santa Barbara; Department of Geology and Geophysics, Princeton University.

Future Activities and Perspectives

Today the Institute's manpower consists of 10 PhD researchers (4 seismologists, 2 geotechnical engineers and 4 structural engineers), 6 technicians and 10 administratives. This highly qualified staff and the existing infrastructure enable the Institute to embark on an ambitious research and development program that, among others, includes: Further development/digital upgrade of the free-field strong-motion accelerograph network and instrumentation/monitoring of structures of special interest. Development of laboratory techniques for investigating soil behaviour and properties under dynamic loading. Development of numerical models for dynamic fracture of rock. Experimental evaluation of mechanical and dynamic characteristics of structures through a mobile monitoring system and development of new techniques for studying the seismic response of structures. Participation in the update of the Greek Seismic Code. Involvement in public and private projects by performing special studies and providing consulting. Participation in national, European and international research projects on seismic-risk mitigation. Expansion of collaboration with relevant research institutes and industry in Europe and beyond (with emphasis on the Eastern Mediterranean, Balkan and Black Sea regions).

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THE UNIVERSITY OF PATRAS SEISMOLOGICAL LABORATORY (UPSL)

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History

The University of Patras Seismological Laboratory (UPSL) started operating in 1990 and its achievements to date, place it among the most modern and well equipped labs in Europe.

In 1992 started installed a small 5 stations permanent seismological network around the Patras gulf which eventually has been evolved into one of the greatest seismological networks in Greece with 36 stations all telemetered via radiolink to the central processing station in the University campus.

Recently the lab is expanding its seismological monitoring capabilities by installing a 24 stations 24-bit BB network by Nanometrics all over Southern Greece using satellite telemetry.

In addition to its extended permanent seismological network, the lab possesses one of the greatest portable microearthquake networks, in the Academic community today. This consists of 62 24-bit seismographs by EarthData all GPS synchronized and equipped with various seismometers. This network is used for the monitoring of aftershock sequences and in passive tomography surveys in Greece and abroad.

UPSL operates and an earthquake prediction centre which consists on the simultaneous monitoring of various parameters and their comparison with the recorded seismicity. Parameters that are currently measured are electrotelluric variations, variations of groundwater temperature and level, electromagnetic variations at various spectra bands and seismic parameters such as attenuation and seismicity.

In 1997 the lab started developing a seismic reflection unit which today has been evolved into a fully independent seismic section consisting of two 120 channel 24-bit seismic recorders, many thousands of geophones, many Km of seismic cables to suit various projects from high resolution shallow seismic reflection investigations for coal exploration to deep hydrocarbon or crustal surveys.

During 2000 UPSL acquired two big vibroseis trucks of 50,000lb impact force each.

Special emphasis has been given towards the development of an autonomous processing unit, which today consists of one Origin2000 supercomputer, 3 Ultra Sparc systems and about 50 Pentiums and various other printing and plotting facilities.

The lab participates in various R&D projects throughout international relations and has recently developed close links with the oil industry for the implementation of new geophysical technologies in hydrocarbon exploration.

The Patras Seismological Lab Seismic Network (PATNET), covers up to date the wider Western Greece area, the Peloponnese, and the Southern Aegean. It consists of: the Base station at the University of Patras, four (4) Broad Band stations, thirtyfour (34) Short Period stations and six (6) Repeaters. The Repeaters are installed at locations, where the link between transmitter and receiver and consequently the direct signal transmission to the Base station at the University of Patras, was impossible.

Very recently UPSL acquired a network of 54 24bit PR2400 Earthdata portable stations and a permanent network of 12 Nanometrics Libra satellite stations.

UPSL's Personnel
Prof. G-Akis Tselentis (Director, tselenti@upatras.gr)
Dr. Tim Sokos (Senior Seismologist)
Dimitris Paliatsas (Geophysical Engineer)
Adreas Sotiriou (Geophysicist)
Dr. Lakis Ifantis (Physicist)
Nick Martakis (Geophysicist)
Paris Paraskevopoulos (Geophysicist)
Anna Serpetsidaki (Seismologist)
Nick Germenis (Electronic Engineer)
Criss Scarpelos (Technician)
Chrissa Kokmotou (Secretary)

AGGELOS GALANOPOULOS

Aggelos Galanopoulos was born in Achaia (Peloponnese) in 1910. He graduated from the School of Sciences of the National University of Athens in 1932 and in 1934 he became assistant to the Seismological Laboratory of N.U.A. In 1937 he was awarded with the Ph. D. in Seismology. In 1943 he was elected as Senior Lecturer of Seismology and in 1944 as Senior Lecturer in the National Technical University of Athens (N.T.U.A.).

In 1949 he became Director of the Institute of Geodynamics of the National Observatory of Athens where he served until 1978. During 1950, after receiving a research fellowship, he went to the University of Toronto, Canada, and in 1951 he worked in the Seismological Laboratory in Pasadena, U.S. In 1959 he was elected full professor of Seismology in N.U.A., where he served until 1978. He was appointed national representative of Greece to various international organizations related to seismology.

Under his guidance, the Institute of Geodynamics was equipped with modern seismographs installed in several high seismicity regions of Greece, while the collection of macroseismic data was organized. Prof. Galanopoulos wrote numerous papers on seismology, seismotectonics and seismic hazard of Greece.

He became Emeritus Professor and member of the National Academy of Athens. Prof. Galanopoulos died in Athens in 2001.

Selected publications

Delibasis, N. and Galanopoulos, A.G. (1965). Space and time variations of strain release in the area of Greece. *Ann. Geol. Pays Helleniques*, **18**, 135-146.

Galanopoulos, A. G. (1953a). Katalog der erdbeben in Griechenland fur die ziet von 1879 bis 1892. *Ann. Geol. Pays Hellen*., **5**, 144-229.

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JOHN DRAKOPOULOS

He was born in 1937 in Arcadia (Peloponnese). He graduated in 1960 (Physics) from the National University of Athens (N.U.A.) and he was awarded the M. Sc. in Electronics in 1965 and the Ph. D. in Seismology (1968). He went to Japan for post-doctoral studies (technical seismology) in 1970-1971. In 1974 he took up the post of Senior Lecturer of Seismology in N.U.A. and he was made full Professor in 1979.

During 1982-1994 he served as Director of the Department of Geophysics (N.U.A.), Director of the Institute of Geodynamics of the National Observatory of Athens and President of the Earthquake Protection and Planning Organization. He had also been President of the School of Geology of N.U.A. since 1983 for three consecutive terms. In 1994 he was elected Vice-rector of N.U.A. and re-elected in 1997. He was nominated as national representative on seismology in several international and European organizations. He died in Athens on 29 April 1999.

He had published more than 200 papers in Greek and international journals and proceedings. He wrote books on Geophysics and Technical Seismology and he was invited lecturer in numerous international conferences.

His main scientific interests concerned studies on seismic sequences, seismicity, seismic hazard, earthquake prediction and microzonation.

Selected publications

Comninakis, P.E., Drakopoulos, J., Moumoulidis, G. and Papazachos, B.C. (1968). Foreshock and aftershock sequences of the Cremasta earthquake and their relation to the water loading of the Cremasta artificial lake. *Ann. di Geofisica*, **21**, 39-71.

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DIMITRIS PAPASTAMATIOU

D. Papastamatiou was born in Athens in 1941. He graduated from the National Technical University of Athens (N.T.U.A.) in 1964 (Engineering) and from the Imperial College Engineering Seismology Section in 1971 with a Ph. D. on Earthquake Engineering. He continued at Imperial College and then worked for six years as Senior Engineer in Dames & Moore in London. In 1980-1981 he was Director of Geognosis Ltd. in London, where he also established his own consultancy, Delta Pi Associates. He served as an UNESCO consultant to the Institute of Earthquake Engineering and Engineering Seismology at Skopje, Yugoslavia.

In 1988 he left London and returned to Greece to take up the post of Assistant Professor in Engineering Seismology in the Civil Engineering Department of N.T.U.A.. In 1994 he was promoted to Associate Professor and he was to have been made full Professor when he died on 4 July 2000.

His research interests concerned seismic hazard, strong motion data acquisition and analysis, site effects, earthquake response of structures and seismotectonic studies and he published numerous papers on these topics.

Selected publications

Papastamatiou, D. (1976). The May 6, 1976 Friuli earthquake: field measurements. *Boll. di Geof. Teor. ed appl*., **XIX**, 851-860.

Berberian, M. and papastamatiou, D. (1978). Khurgu earthquake of March 21, 1977: preliminary field report and seismotectonic discussion. *Bull. Seism. Soc. Am*., **68**, 411-428.

Papastamatiou, D. (1980). Incorporation of crustal deformation to seismic hazard analysis. *Bull. Seism. Soc. Am*., **70**, 1321-1335.

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BASIL C. PAPAZACHOS

He was born in 1930 in Karditsa (central Greece). He was awarded the B. A. in Physics (Athens University), M. Sc. in Geophysics (Saint Louis University, USA) and Ph. D. in Seismology (1961).

He has been a Research Assistant in Seismology at the Geodynamic Institute of the National Observatory of Athens (1958-1961), invited lecturer in Geophysics at the Saint Louis University (1961-1964), lecturer in Seismology at the Geodynamic Institute, National Observatory of Athens (1964-1977) and was elected Professor of Geophysics at the University of Thessaloniki (1977-1998).

He has published more than 200 papers in international journals and proceedings of international meetings and 5 books in Seismology and Geophysics.

He has been the Director of the Laboratory of Geophysics of the University of Thessaloniki (1977-1998), President of the Institute of Engineering Seismology and Earthquake Engineering (1983-2002) and President of the School of Geology of the University of Thessaloniki (1982-1985). He has also been member of several national and international committees. He has been invited and gave lectures on Geophysics and Seismology in several Institutes (Rice University Houston Texas, University of Uppsala, University of Strasbourg, etc.). He established the telemetry seismic network of the Aristotle University of Thessaloniki in 1980.

His scientific work concerns active tectonics (identification of the subduction of the African lirhospheric plate under the Aegean lithosphere, definition of major active faults in the Aegean area, etc.), crustal and upper mantle structure, seismicity, long-term earthquake prediction based on time dependent seismicity, characteristics of seismic sequences, and seismic hazard.

Since 1998 he has been working on accelerating seismic crustal deformation.

Recently, Prof. Papazachos was decorated with the medal of Taxiarhi of Foinikas by the President of the Hellenic Republic, in recognition of his sustained exceptional contribution to advancing science.

Selected publications

Papazachos, B.C., (1964). Dispersion of Rayleigh waves in the gulf of Mexico and Caribbean sea. *Bull. Seis. Soc. Am.*, **54**, 909-925.

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PANAGIOTIS COMNINAKIS

Panagiotis Comninakis was born in Ag. Paraskevi, Lesvos island in 1931. In 1951 he entered the University of Athens (School of Physics). Soon after his graduation (in 1957) he became Research Assistant at the Geodynamic Institute of the National Observatory of Athens. In 1975 he received his Ph.D. on the seismicity of the Aegean area and became Senior Researcher at the Geodynamic Institute. P. Comninakis was one of the first, along with B. Papazachos and N. Delibasis, who proposed that subduction of the African lithosphere takes place under the Aegean lithosphere.

Perhaps the biggest among his many contributions was the compilation of earthquake catalogues. He meticulously marked, along with his colleagues in the Institute, P- and S-wave arrivals for many years from all instrumental records since 1911 and measured waveform amplitudes, while he also collected and classified countless damage reports from strong earthquakes. All this information was included in the catalogues he compiled, which formed the basis for almost all seismicity catalogues studies which are related to the broader Aegean area.

His diligence and persistence left a legacy for seismologists and his work is acknowledged by all his colleagues in Greece and abroad.

He died in Athens in 2001.

Selected Publications

Comninakis, P. E. (1975). Contribution to the study of seismicity of the Greek area. *Ph. D. Thesis, Univ. of Athens*, 110 pp.

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