A TIME AND MAGNITUDE PREDICTABLE MODEL FOR STRONG EARTHQUAKES AND ITS APPLICATION FOR LONG TERM EARTHQUAKE PREDICTION IN THE AEGEAN AREA

Papazachos,B.C. and Papaioannou,Ch.A.

Geophysical Laboratory, University of Thessaloniki, GR-54006 Thessaloniki, Macedonia, GREECE.

A B S T R A C T

Instrumental and historical data on strong mainshocks in 76 seismogenic sources of the Aegean and surrounding area have been used to show that the interevent time, T_t (in years), between two strong earthquakes and the magnitude, M_f, of the following mainshock are given by the relations:

$$logT_t = 0.24M_{min}+0.25M_p-0.36\log\dot{M}_o+7.36$$

$$M_f = 1.04M_{min}-0.31M_p+0.28\log\dot{M}_o-4.85$$

where M_{min} is the surface wave magnitude of the smallest mainshock considered, M_p the magnitude of the preceding mainshock and $\dot{M}_o$ the moment rate per year in each source. On the basis of these relations, the probability for the occurrence of a mainshock during the decade 1993-2002 as well the magnitude of this expected mainshock in each seismogenic source of this region have been calculated.

ΕΝΑ ΕΞΑΡΤΟΜΕΝΟ ΧΡΟΝΙΚΑ ΜΟΝΤΕΛΟ ΓΙΑ ΤΗ ΓΕΝΕΣΗ ΤΩΝ ΙΣΧΥΡΩΝ ΣΕΙΣΜΩΝ ΚΑΙ ΕΦΑΡΜΟΓΗ ΤΟΥ ΣΤΗ ΜΑΚΡΟΠΡΟΘΕΣΜΗ ΠΡΟΓΝΩΣΗ ΣΕΙΣΜΩΝ ΣΤΟ ΧΩΡΟ ΤΟΥ ΑΙΓΑΙΟΥ

Παπαζάχος,Β.Κ. και Παπαϊωάννου,Χρ.Α.

Π Ε Ρ Ι Λ Η Ψ Η

Ενόργανα και ιστορικά δεδομένα ισχυρών σεισμών σε 76 σεισμογόνες πηγές του Αιγαίου και των γύρω περιοχών χρησιμοποιήθηκαν για να δειχθεί ότι ο χρόνος, T_t, (σε έτη), μεταξύ δύο ισχυρών σεισμών και το μέγεθος, M_f, του σεισμού που ακολουθεί δίνονται από τις σχέσεις:

$$logT_t = 0.24M_{min}+0.25M_p-0.36\log\dot{M}_o+7.36$$

$$M_f = 1.04M_{min}-0.31M_p+0.28\log\dot{M}_o-4.85$$

όπου M_{min} είναι το επιφανειακό μέγεθος του μικρότερου κυρίου σεισμού που θεωρούμε, M_p το μέγεθος του κυρίου σεισμού που

προηγήθηκε και $\dot{M}_o$ η ετήσια έκλυση της σεισμικής ροπής για κάθε σεισμική πηγή. Με βάση τις σχέσεις αυτές, υπολογίστηκαν η πιθανότητα γένεσης ενός κυρίου σεισμού κατά τη δεκαετία 1993-2002 καθώς και το μέγεθος αυτού του αναμενόμενου σεισμού σε κάθε σεισμογόνα πηγή αυτής της περιοχής.

INTRODUCTION

Although most of the earthquake generation models currently used for seismic hazard evaluation assume a Poisson or other memoryless distributions, recent work has shown that large earthquakes in several regions are temporally dependent (Bufe et al., 1977; Shimazaki and Nakata, 1980; Sykes and Quittmeyer, 1981; Papazachos, 1989). Two kinds of time dependent models have been proposed: the slip-predictable model, according to which the size (coseismic slip, magnitude) of a future earthquake in a seismic source depends on the time elapsed since the last earthquake, and the time predictable model, according to which the time of occurrence of a future earthquake depends on the size and on the time of occurrence of the last earthquake in the seismic source. Almost all of the aforementioned investigations as well as other independent data (Mogi, 1981; Karakaisis et al., 1991) favor the time predictable model.

During the last five years, an investigation to identify time dependent relations between strong shallow earthquakes which occurred in seismogenic sources in Greece has been carried out (Papazachos, 1988a, 1988b, 1989). This research was recently expanded to cover a broader area and a time and mangitude predictable model was proposed for the generation of shallow earthquakes in this area (Papazachos, 1992). In this model, the interevent time, T_t, and the magnitude, M_f, of the following mainshock is quantitatively expressed in relation to the magnitude, M_{min}, of the smallest considered mainshock and to the magnitude, M_p, of the preceding mainshock in each seismogenic source. In the same model, the magnitude, M_f, of the following mainshock is also expressed in relation to M_{min} and M_p.

In the present paper, a further step is attempted by including a new term in the relations both for the return period and the magnitude of the expecting mainshock. This term depends on the yearly moment rate in each seismogenic source. Furthermore, this model is applied to estimate the probability of occurrence of the next mainshock during the next Δt(=10 years) and the magnitude of this expected mainshock in each seismogenic source of the Aegean area. This is an area which includes the well known Hellenic arc, the Aegean, which is also a well known marginal sea, and the surrounding areas (Greece, Albania, southern Yugoslavia, southern Bulgaria, western Turkey).

SEISMOGENIC SOURCES AND DATA

The method applied in the present paper is based on the separation of the whole area under investigation in several seismogenic sources as well as on determining the mainshocks in each source and their interevent (repeat) times. Therefore, the first step for this work is to define the seismogenic sources of the shallow as well as of the intermediate depth earthquakes in the Aegean and surrounding area.

The Aegean area has been separated in several seismic zones (Papazachos, 1990) and each zone is separated in seismogenic sources (Papazachos, 1992) on the basis of several seismological, geological and geomorphological criteria, such as spatial clustering of the epicenters of strong earthquakes, seismicity level, maximum earthquake observed, type of faulting, geomorphological features, etc. The fit of the data of each seismogenic source to the time predictable model has been used as a supplementary criterion for this separation. Each seismogenic source includes a main seismic fault, where the maximum (characteristic) earthquake occurs, but it can also include other smaller faults where smaller mainshocks may also occur.

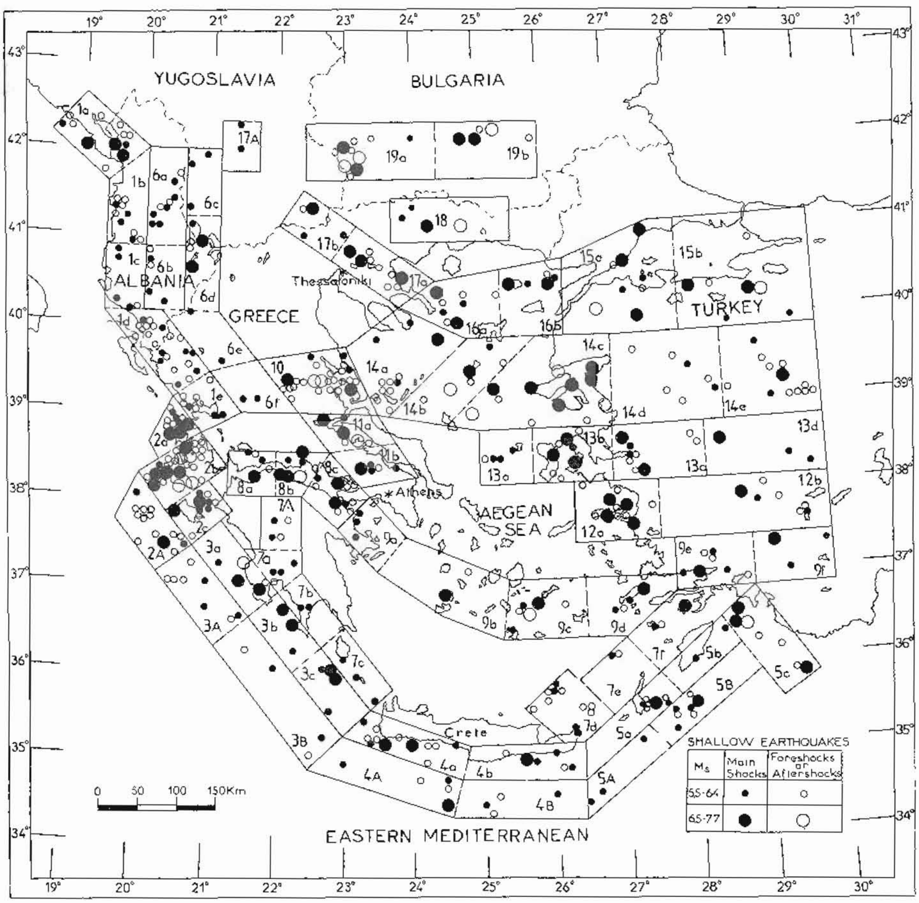

Fig.1. The 69 seismogenic sources of shallow earthquakes in the Aegean and surrounding area.

In this way, the whole Aegean area has been separated in 69 seismogenic sources of shallow earthquakes, which are shown in figure (1) together with the epicenters of the complete data used in the present study. Black circles show epicenters of mainshocks. Open circles show epicenters of foreshocks and aftershocks in the broad sense, that is, earthquakes within the complete sample of data, which may occur up to several years before or after the mainshock, respectively. We use the term "aftershock" and "foreshock" in their broad sense because in the present paper we want a model which can predict the mainshocks in each seismogenic source, that is, the strong earthquakes which occur at the beginning and the end of each seismic cycle and not smaller earthquakes which occur during the preseismic and postseismic activations. In particular, we consider as foreshocks or aftershocks the earthquakes which precede or follow mainshocks with magnitudes 5.5-5.7, 5.8-6.0, 6.1-7.0, and larger than 7.0 up to 6, 7, 9 and 12.5yrs, respectively (Papazachos, 1992). The seperation of seismic sources shown in figure (1) is very similar to that made by Papazachos (1992) with some minor changes. For two of the shallow sources (7e,9b) only one strong mainshock is known, that is, for 67 seismogenic sources at least one interevent time is available.

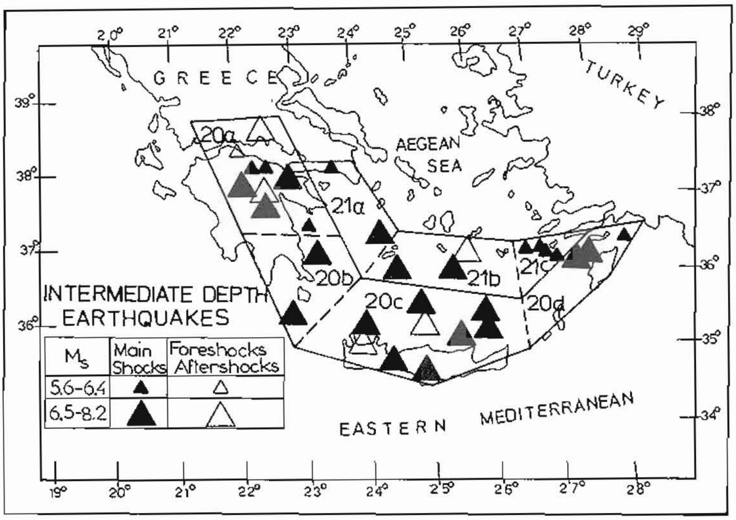

Fig.2. The seismogenic sources of intermediate depth earthquakes in the southern Aegean area.

Figure (2) shows the seismogenic sources of the intermediate depth ($60km<h\leq180km$) earthquakes in the Aegean area which have been defined in the same way with the sources of shallow earthquakes. This separation is very similar to that proposed by Papazachos (1993). The sources (20a, 20b, 20c, 20d) concern earthquakes with focal depths between 60Km and 100km and the sources (21a, 21b, 21c) concern earthquakes with focal depths between 100Km and 180km. Black triangles show mainshocks, open triangles show "aftershocks" or "foreshocks" in the broader sense. For each of these 7 intermediate depth sources there is

at least one repeat time available. Therefore, for 74 seismogenic sources (shallow and intentermediate depth) there is one or more interevent times available.

Information on the surface wave magnitudes and on the epicenters of the earthquakes plotted in figures (1), (2) were received from the catalogue of Comninakis and Papazachos (1986) for the period 1901-1985 and from the monthly bulletins of the National Observatory of Athens and of the Geophysical Laboratory of the University of Thessaloniki for the period 1986-1992. For historical earthquakes such information was derived from the book of Papazachos and Papazachou (1989).

Information on the data used in the present study is given in Table (1). In the first column of this table a code number, corresponding to the same area numbers of Figure 1, and a name are written for each seismogenic source.

The second column of Table 1 shows the time (year) during which the data are complete for each magnitude range and the minimum magnitude of this range, respectively. For the first source, for example, the complete samples are: all earthquakes with $M_s \geq 6.5$ which occurred in the period 1855-1992 and all earthquakes with $M_s \geq 5.5$ which occurred in the period 1905-1992. This completeness has been determined for each source on the basis of information given in the catalogues, which have been used as data sources, and of plots of the frequency-magnitude relation for each magnitude range.

Table 1. Information on the basic data used for each seismogenic source.

Source	Completness	D a t e	Epicenter	M_S	M
1a	1855, 6.5	03:07:1855	41.9,19.6	6.5	6.5
M.Negro	1905, 5.5	01:06:1905	42.0,19.5	6.6	6.6
		27:08:1948	42.0,19.5	5.6	5.6
		20:08:1966	42.2,18.6	5.7	5.7
		15:04:1979	42.0,19.0	7.1	7.1
1b	1869, 6.2	28:09:1870	41.1,19.6	6.4	6.5
Dirrachio	1920, 5.5	17:12:1926	41.3,19.5	6.1	6.2
		01:09:1959	40.9,19.8	6.4	6.5
		09:01:1988	41.2,19.7	5.6	5.6
1c	1893, 6.2	14:07:1893	40.1,19.8	6.4	6.5
Avlona	1917, 5.7	21:11:1930	40.2,19.6	6.3	6.3
		18:03:1962	40.7,19.6	6.0	6.0
		16:11:1982	40.8,19.6	5.7	5.7
1d	1823 6.2	19:06:1823	39.5,20.3	6.4	6.4
Igumenitsa	1917 5.5	20:09:1858	40.0,20.0	6.4	6.6
		11:02:1872	39.7,20.2	6.2	6.2
		14:07:1893	40.1,19.8	6.4	6.7
		21:10:1920	39.6,20.3	5.8	6.1
		09:02:1967	39.9,20.3	5.8	6.0
		10:03:1981	39.4,20.8	5.6	5.9
		16:06:1990	39.2,20.5	6.1	6.1

1e	1891, 5.5	27:06:1891	39.0,20.7	6.0	6.0
Preveza		13:09:1921	38.9,21.2	6.0	6.2
		29:10:1966	38.9,21.1	6.0	6.2
2a	1825, 6.3	19:01:1825	38.7,20.6	6.7	6.7
Leukada	1911, 5.5	28:12:1869	38.8,20.7	6.6	6.6
		27:11:1914	38.8,20.6	6.3	6.4
		13:03:1938	38.8,20.6	5.8	5.9
		22:04:1948	38.7,20.5	6.5	6.8
		04:11:1973	38.9,20.5	5.8	5.9
2b	1767, 7.2	22:07:1767	38.2,20.3	7.2	7.2
Cephalonia	1862, 6.3	04:02:1867	38.2,20.4	7.2	7.2
	1912, 5.7	24:01:1912	38.1,20.8	6.8	7.2
		12:08:1953	38.2,20.6	7.2	7.4
		17:09:1972	38.3,20.3	6.3	6.3
		17:01:1983	38.1,20.2	7.0	7.0
2c	1840, 6.0	30:10:1840	37.9,20.9	6.7	6.7
Zakynthos	1911, 5.8	25:10:1873	37.9,21.0	6.1	6.1
		17:04:1893	37.9,20.9	6.4	6.4
		20:09:1939	38.0,20.9	6.3	6.3
		15:11:1959	37.8,20.5	6.8	6.9
		16:10:1988	37.9,21.0	6.0	6.0
2A	1938, 5.5	14:02:1943	38.0,20.0	5.8	6.0
Ionian Sea 1		27:08:1958	37.4,20.7	6.4	6.6
		11:05:1976	37.4,20.4	6.5	6.6
3a	1885, 6.1	27:08:1886	37.0,21.5	7.5	7.5
Pylos	1911, 5.9	06:10:1947	36.9,21.8	7.0	7.0
		20:08:1989	37.2,21.2	5.9	5.9
3b	1867, 6.8	20:09:1867	36.5,22.3	7.1	7.1
Mani	1925, 5.5	01:07:1927	36.6,22.0	7.1	7.1
		02:01:1958	36.2,22.3	5.7	5.7
3c	1866, 6.5	06:02:1866	35.9,22.9	6.8	6.8
Off NW Crete	1932, 5.5	11:08:1903	36.0,22.8	7.4	7.4
		30:09:1932	36.0,22.7	5.6	5.6
		31:08:1951	35.5,22.8	5.6	5.6
3A	1919, 5.5	24:02:1919	36.7,21.0	6.3	6.4
Ionian Sea 2		01:06:1947	36.6,21.5	5.8	6.0
		16:12:1963	37.0,21.0	5.9	6.0
3B	1922, 5.7	19:09:1926	36.0,22.0	6.3	6.4
Ionian Sea 3		26:01:1962	35.2,22.7	6.2	6.3
4a	1805, 7.2	03:07:1805	35.1,24.0	7.2	7.2
SW Crete	1916, 5.6	30:08:1947	35.1,23.4	6.3	6.4
		14:05:1959	35.1,24.6	6.3	6.3
		04:05:1972	35.1,23.6	6.5	6.6
		21:06:1984	35.4,23.3	6.2	6.2

4b SE Crete	1815, 6.7	00:12:1815	34.9,25.6	6.7	6.7
	1927, 5.6	24:03:1927	35.0,26.0	5.6	5.6
		10:02:1938	34.8,26.2	5.6	5.8
		29:01:1978	34.9,25.7	5.7	5.9
		19:03:1991	34.8,26.3	5.8	5.8
4A Lybic Sea 1	1930, 5.6	06:03:1930	34.7,24.5	5.8	5.8
		17:12:1952	34.4,24.5	7.0	7.0
		11:09:1977	34.9,23.0	6.3	6.3
4B Lybic Sea 2	1918, 5.6	06:03:1930	34.5,26.0	5.6	5.6
		12:06:1969	34.4,25.0	6.1	6.2
5a Karpathos	1932, 5.5	09:02:1948	35.5,27.4	7.1	7.1
5b Rhodos	1919, 5.6	27:01:1921	36.0,28.0	5.6	5.6
		05:01:1987	36.3,28.5	5.6	5.6
5c Marmaris	1851, 6.8	28:02:1851	36.4,28.6	7.2	7.2
	1926, 5.6	18:03:1926	35.8,29.5	6.9	6.9
		25:04:1957	36.5,28.6	7.2	7.3
5A Stravo 1	1957, 5.5	30:10:1957	35.1,27.2	5.6	5.6
		09:05:1966	34.4,26.4	5.8	5.8
		27:09:1985	34.5,26.6	5.5	5.5
5B Stravo 2	1922, 5.5	11:08:1922	35.4,27.7	6.3	6.3
		30:10:1957	35.2,27.7	5.5	5.5
		30:05:1968	35.4,27.9	5.9	6.0
6a Elbasan	1843, 6.2	05:09:1843	41.2,20.1	6.2	6.2
	1920, 5.5	16:08:1907	41.1,20.1	6.2	6.2
		18:12:1920	41.1,20.1	5.8	6.0
		31:03:1935	41.3,20.3	5.7	5.7
		27:08:1942	41.6,20.4	5.9	6.0
		30:11:1967	41.4,20.4	6.3	6.3
6b Tepeleni	1860, 6.2	10:04:1860	40.2,20.3	6.4	6.5
	1920, 5.5	26:11:1920	40.3,20.0	6.3	6.3
		03:04:1969	40.7,20.0	5.8	5.8
6c Maliq	1922, 5.5	07:12:1922	41.8,20.6	6.1	6.1
		07:01:1953	41.3,20.6	5.6	5.6
		12:03:1960	41.9,20.9	5.7	5.7
6b Ochrida	1896, 6.0	28:09:1896	41.1,20.7	6.1	6.1
		18:02:1911	40.9,20.8	6.7	6.8
		26.05:1960	40.6,20.7	6.5	6.5
6e Jannena	1919, 5.5	22:12:1919	40.1,20.7	6.3	6.3
		01:05:1967	39.5,21.2	6.4	6.4
6f Karpenisi	1915, 5.5	04:06:1915	39.1,21.5	5.8	5.8
		05:02:1966	39.1,21.7	6.2	6.2

7A Megalopolis	1911, 5.5	24:12:1901	37.2,22.2	5.8	5.9
		05:04:1965	37.7,22.0	6.1	6.3
7a Kalamata	1846, 6.1	11:06:1846	37.1,22.0	6.4	6.4
	1901, 5.5	13:04:1955	37.2,22.3	5.9	5.9
		13:09:1986	37.1,22.1	6.0	6.0
7b Sparti	1842, 6.0	18:04:1842	36.7,22.3	6.4	6.4
	1911, 5.0	30:07:1944	36.7,22.5	6.0	6.0
7c Kythera	1798, 6.4	00:06:1798	36.0,23.0	6.4	6.4
	1913, 5.5	06:07:1913	35.9,23.2	5.7	5.7
		27:04:1965	35.6,23.5	5.7	5.7
7b Sitia	1918, 5.5	29:02:1940	35.7,25.9	6.0	6.2
		30:07:1956	35.8,26.0	6.0	6.1
		22:09:1975	35.2 26.3	5.5	5.7
		05:09:1988	35.2,26.3	5.5	5.5
7e Karpathos Sea	1956, 5.5	28:04:1962	36.1,26.8	5.8	5.9
7f Symi	1896, 6.7	27:10:1896	36.6,27.9	6.7	6.7
	1918, 5.6	01:09:1942	36.4,27.4	5.8	5.9
		28:08:1990	36.4,27.2	5.6	5.6
8a Patra	1804, 6.0	08:06:1804	38.2,21.7	6.6	6.7
	1914, 5.7	24:12:1917	38.4,21.8	6.0	6.0
		30:06:1975	38.5,21.7	5.7	5.9
8b W.Corinthiakos	1748, 6.3	25:05:1748	38.2,22.2	6.8	6.8
	1909, 5.6	23:08:1817	38.2,22.1	6.5	6.5
		01:08:1870	38.5,22.5	6.8	7.0
		30:05:1909	38.4,22.2	6.2	6.2
		06:07:1965	38.4,22.4	6.3	6.5
		18:11:1992	38.3,22.4	5.9	5.9
8c E.Corinthiakos	1858, 6.7	21:02:1858	37.9,22.9	6.7	6.7
	1916, 5.5	22:04:1928	37.9,23.0	6.3	6.4
		05:09:1953	37.9,23.1	5.8	5.9
		24:02:1981	38.2,23.0	6.7	6.8
9a Methana	1873, 5.5	25:07:1873	37.7,23.2	6.0	6.0
		08:08:1922	37.5,23.2	5.6	5.6
		04:07:1968	37.8,23.2	5.5	5.5
9b Milos	1733, 6.4	20:07:1738	36.8,24.5	6.5	6.7
	1918, 5.5				
9c Santorini	1866, 6.1	31:01:1866	36.4,25.4	6.2	6.2
	1919, 5.5	25:10:1919	36.7,25.6	6.1	6.1
		09:07:1956	36.7,25.8	7.5	7.6
9d Kos	1920, 5.6	23:04:1933	36.8,27.3	6.6	6.6
		23:02:1961	36.7,27.1	5.6	5.6
		05:12:1968	36.6,26.9	6.0	6.1

9e Alicarnasos	1869, 6.2 1920, 5.5	01:12:1869	37.0,28.1	6.8	6.8
		13:12:1941	37.2,28.3	6.2	6.4
		25:04:1959	37.0,28.5	6.2	6.2
		28:04:1989	37.0,27.9	5.5	5.5
9f Denisli	1703, 6.8 1920, 5.5	00:00:1703	37.3,29.2	6.8	6.8
		01:03:1926	37.0,29.4	6.2	6.2
		30:01:1964	37.4,29.9	5.5	5.5
10 Thessalia	1905, 5.5	20:01:1905	39.6,23.0	6.3	6.4
		31:03:1930	39.5,23.0	6.1	6.3
		01:03:1941	39.6,22.5	6.3	6.3
		30:04:1954	39.3,22.2	7.0	7.2
		09:07:1980	39.2,23.1	6.5	6.6
11a N.Evoikos	1758, 6.8 1894, 5.5	00:05:1758	38.9,22.7	6.8	6.8
		18:03:1874	38.6,23.5	6.0	6.0
		27:04:1894	38.7,23.0	7.0	7.1
		27:09:1916	38.9,23.0	5.9	6.0
11b S.Evoikos	1853, 6.0 1912, 5.5	18:08:1853	38.3,23.3	6.8	6.8
		23:05:1893	38.3,23.4	6.2	6.2
		17:10:1914	38.3,23.4	6.0	6.1
		20:07:1938	38.3,23.8	6.0	6.0
		04:03:1981	38.2,23.1	6.4	6.4
12a Samos	1865, 6.0 1904, 5.8	31:01:1873	37.8,27.1	6.6	6.8
		12:03:1893	37.9,26.9	6.6	6.6
		11:08:1904	37.7,26.9	6.9	6.9
		16:07:1955	37.6,27.2	6.9	6.9
		06:11:1992	38.1,27.0	6.2	6.2
12b Aidin	1899, 6.2 1961, 5.5	20:09:1899	37.9,28.8	7.0	7.0
		12:05:1971	37.6,29.7	6.2	6.3
		11:10:1986	38.0,29.0	6.0	6.0
13a Psara	1890, 6.0 1921, 5.5	26:05:1890	38.5,25.5	6.2	6.2
		14:03:1933	38.4,25.3	5.5	5.5
		29:03:1986	38.4,25.2	5.8	6.0
13b Chios	1856, 6.4 1931, 5.5	13:11:1856	38.4,26.1	6.6	6.6
		15:10:1883	38.3,26.4	6.5	6.7
		23:07:1949	38.6,26.3	6.7	6.7
		06:04:1969	38.5,26.4	5.9	5.9
13c Ismir	1880, 6.5 1904, 5.5	29:07:1880	38.6,27.1	6.7	6.7
		10:10:1904	38.4,27.2	5.8	5.9
		31:03:1928	38.2,27.4	6.5	6.6
		01:02:1974	38.5,27.2	5.5	5.7
13d Alasehir	1918, 5.5	16:01:1918	38.3,29.5	5.7	5.7
		29:07:1933	38.2,29.8	5.9	5.9
		28:03:1969	38.5,28.5	6.6	6.6
14a Skopelos	1916, 5.5	05:12:1923	39.8,23.5	6.4	6.5
		04:06:1947	40.0,24.0	6.1	6.1

		09:03:1965	39.3,23.8	6.1	6.2
		18:01:1982	39.8,24.4	6.9	6.9
14b	1947, 5.5	12:04:1947	39.7,25.2	5.7	5.7
Ag.Eustratios		19:02:1968	39.4,24.9	7.1	7.2
14c	1845, 6.5	11:10:1845	39.0,26.2	6.8	6.8
Lesbos	1919, 5.6	07:03:1867	39.2,26.4	6.8	7.0
		25:10:1889	39.2,25.8	6.7	6.7
		06:10:1944	39.4,26.7	6.9	7.1
		19:12:1981	39.2,25.2	7.2	7.3
14d	1919, 5.5	18:11:1919	39.3,26.7	7.0	7.0
Demirci		15:11:1942	39.4,28.1	6.2	6.4
		23:03:1969	39.1,28.5	6.1	6.3
14e	1928, 5.5	02:05:1928	39.6,29.1	6.2	6.2
Gediz		25:06:1944	39.0,29.3	6.1	6.3
		28:03:1970	39.2,29.5	7.1	7.1
15a	1766, 7.4	05:08:1766	41.0,27.5	7.7	7.7
Hellispondos	1912, 6.0	09:08:1912	40.6,27.2	7.6	7.6
		04:01:1935	40.4,27.5	6.4	6.6
		18:03:1953	40.0,27.4	7.4	7.4
		05:07:1983	40.3,27.2	6.1	6.1
15b	1855, 6.9	28:02:1855	40.2,29.1	7.2	7.3
Prusa	1905, 5.7	15:09:1939	39.8,29.6	5.7	5.7
		19:03:1952	39.8,28.7	5.8	6.0
		06:10:1964	40.3,28.2	6.9	6.9
16a	1905, 5.5	08:11:1905	40.3,24.4	7.5	7.5
Athos		03:08:1954	40.1,24.5	5.9	6.0
		20:12:1965	40.2,24.8	5.6	5.8
		06:08:1983	40.0,24.7	6.8	6.8
16b	1893, 6.5	09:02:1893	40.4,25.5	6.5	6.5
Samothraki	1955, 5.5	02:06:1955	40.4,25.8	5.5	5.5
		23:08:1965	40.5,26.2	5.6	5.6
		27:03:1975	40.4,26.1	6.6	6.6
17a	1902, 5.7	05:07:1902	40.8,23.1	6.5	6.5
Volvi		26:09:1932	40.5,23.9	7.0	7.1
		20:06:1978	40.8,23.2	6.5	6.5
17b	1905, 5.5	18:11:1905	41.0,23.0	5.6	5.6
Doirani		08:03:1931	41.3,22.5	6.7	6.7
		21:12:1990	41.0,22.4	5.9	5.9
17A	1921, 5.5	10:08:1921	42.3,21.4	5.8	5.8
Skopje		26:07:1963	42.0,21.4	6.1	6.1
18	1829, 6.5	05:05:1829	41.1,24.3	7.3	7.4
	1901, 5.5	23:10:1905	41.3,23.0	5.5	5.5
Drama		09:11:1985	41.2,23.9	5.5	5.5

19a Kresna	1866, 6.5	06:12:1866	42.0,23.0	7.0	7.0
	1904, 5.5	04:04:1904	41.8,23.1	7.5	7.6
		03:11:1977	42.1,24.0	5.5	5.5
19b Philippoupoli	1750, 6.8	00:10:1750	42.1,24.8	6.8	6.8
	1924, 5.5	18:04:1928	42.2,25.0	7.0	7.2
20a Peloponesse	1897, 6.3	28:05:1897	37.5,22.5	7.5	7.5
		06:07:1925	37.8,22.1	6.6	6.6
		18:09:1938	38.0,22.5	6.4	6.4
		11:09:1948	37.2,23.2	6.4	6.4
		31:07:1962	37.8,22.9	6.8	7.0
		17:09:1972	38.0,22.4	6.3	6.3
20b Kythera Isl.	1897, 6.3	30:08:1926	36.8,23.3	7.2	7.2
		21:11:1992	35.9,22.5	6.5	6.5
20c Creta Isl.	1810, 7.0	16:02:1810	35.5,25.6	7.8	7.8
	1908, 6.6	12:10:1856	35.6,26.0	8.2	8.2
		17:07:1887	35.7,26.0	7.5	7.5
		18:02:1910	35.7,24.0	6.9	6.9
		01:08:1923	35.0,25.0	6.8	6.8
		25:02:1935	36.0,25.0	7.0	7.0
		24:07:1948	35.2,24.4	6.6	6.6
20d Rhodes Isl.	1863, 7.8	22:04:1863	36.4,27.7	7.8	7.8
	1911, 6.4	26:06:1926	36.5,27.5	8.0	8.0
		23:05:1961	36.7,28.5	6.4	6.4
21a Methana area	1862, 6.0	21:06:1862	36.9,24.4	7.0	7.0
		17:07:1964	38.0,23.6	6.0	6.0
21b Thera area	1911, 6.6	04:04:1911	36.5,25.5	7.1	7.1
		14:02:1930	36.5,24.5	6.7	6.7
21c Nisyros	1926, 5.6	05:07:1926	36.5,27.0	5.6	5.6
		28:04:1936	36.7,26.7	5.7	5.7
		30:06:1958	36.4,27.3	6.0	6.0
		27:09:1983	36.7,26.9	5.6	5.6

The third, fourth and fifth columns of Table 1 give the date, epicenter (North latitude, East longitude) and the surface wave magnitude for the mainshocks which satisfy the completeness condition defined in the second column.

The sixth column gives the cumulative magnitude, M, of each sequence, that is, the magnitude which corresponds to the total moment released by the major shocks (main shock and large foreshocks and aftershocks) of each sequence according to a relation between surface wave magnitude and seismic moment which holds for earthquakes in this area (Papazachos and Kiratzi, 1993). These cumulative magnitudes were used in this study instead of the magnitudes of the mainshocks, although the differences are small.

The data used in the present study are almost the same with those already published (Papazachos, 1992, 1993). Also, the way of the elaboration of the data in the present paper is similar to that already described in those published papers.

THE TIME AND MAGNITUDE PREDICTABLE MODEL

The time and magnitude predictable model proposed in the present paper is expressed by the relations:

$$\log T_t = bM_{min} + cM_p + d\log \dot{M}_o + t \quad (1)$$

$$M_f = BM_{min} + CM_p + D\log \dot{M}_o + m \quad (2)$$

where T_t is the interevent time, M_{min} the surface wave magnitude of the smallest mainshock considered, M_p the magnitude of the preceding mainshock, M_f the magnitude of the following mainshock, $\dot{M}_o$ the moment rate in each seismogenic source per year, and b, c, d, t, B, C, D, m parameters the same for all sources, to be determined by the available data.

To determine these parameters we need data which include the (T, M_{min}, M_p) values, which can be derived from table (1), and a value of the moment rate $\dot{M}_o$ for each seismogenic source. These values of the moment rate are listed on table (2) and have been determined by a method suggested by Molnar (1979). This method makes use of the maximum magnitude, M_{max}, and of the parameters b,a of the Gutenberg and Richter (1944) relation:

$$\log N = a - bM \quad (3)$$

normalized for one year, which are also listed on table (2), as well as of the parameters r,k of the moment-magnitude relation:

$$\log M_o = rM + k \quad (4)$$

which for the Aegean area are r=1.5 and k=15.89 for shallow earthquakes (Papazachos and Kiratzi, 1993) and k=16.00 for intermediate depth earthquakes (Kiratzi and Papazachos, 1993).

Table 2. Information on the basic parameters used for every source. The first two columns give the code number and the name of every source. The constants for the Gutenberg-Richter relation are given in the next two columns. In the last two columns, the maximum magnitude and the logarithm of the moment rate are given.

Code No	Source Name	a	b	M_{max}	$\log \dot{M}_o$
1a.	Montenegro	4.77	1.00	7.0	24.64
1b.	Dirrachio	4.57	1.00	6.4	24.14
1c.	Avlona	4.49	1.00	6.4	24.06
1d.	Igoumenitsa	4.45	1.00	6.4	24.40
1e.	Preveza	4.45	1.00	6.1	23.87
2a.	Lefkada	4.68	1.00	6.8	24.45

2b.	Cephalonia	5.15	1.00	7.2	25.12
2c.	Zakinthos	4.77	1.00	6.8	24.54
2A.	Ionian Sea 1	4.99	1.00	6.6	24.66
3a.	Pylos	4.13	0.90	7.2	24.74
3b.	Mani	3.69	0.90	7.2	24.30
3c.	NW of Crete	3.93	0.90	7.2	24.54
3A.	Ionian Sea 2	3.89	0.90	6.4	24.02
3B.	Ionian Sea 3	4.16	0.90	6.4	24.29
4a.	SW of Crete	4.76	1.00	7.0	24.63
4b.	SE of Crete	4.50	1.00	7.0	24.37
4A.	Sea of Libya 1	4.78	1.00	6.7	24.50
4B.	Sea of Libya 2	4.56	1.00	6.6	24.23
5a.	Karpathos	4.57	1.00	7.1	24.49
5b.	Rhodos	3.83	1.00	7.0	23.70
5c.	Marmaris	4.66	1.00	7.2	24.63
5A.	Stravo 1	4.66	1.00	6.5	24.08
5B.	Stravo 2	4.67	1.00	6.6	24.34
6a.	Elbasan	4.53	1.00	6.2	24.00
6b.	Tepeleni	4.29	1.00	6.4	23.86
6c	Maliq	3.61	0.90	6.1	23.56
6d.	Ochrida	3.96	0.90	6.6	24.21
6e.	Jannena	3.81	0.90	6.4	23.94
6f.	Karpenissi	3.62	0.90	6.2	23.63
7A.	Magalopolis	3.73	0.90	6.1	23.68
7a.	Kalamata	3.66	0.90	6.2	23.67
7b.	Sparti	3.44	0.90	6.4	23.57
7c.	Kythera	3.47	0.90	6.4	23.60
7d.	Sitia	3.96	0.90	6.2	23.97
7e.	Sea of Karpathos	3.69	0.90	6.1	22.84
7f.	Simi	3.80	0.90	6.7	24.11
8a.	Patra	4.43	1.00	6.6	24.10
8b.	W.Corinthiakos	4.53	1.00	6.8	24.30
8c.	E.Corinthiakos	4.68	1.00	6.7	24.40

9a.	Methana	4.03	1.00	6.1	23.45
9b.	Milos	3.96	1.00	6.5	22.56
9c.	Santorini	4.58	1.00	7.4	24.65
9d.	Kos	4.53	1.00	7.0	24.40
9e.	Alicarnassos	4.51	1.00	6.6	24.18
9f.	Denisli	4.28	1.00	6.5	23.90
10.	Thessalia	3.85	0.80	7.0	24.97
11a.	N.Evoikos	3.17	0.80	7.0	24.29
11b.	S.Evoikos	3.31	0.80	6.6	24.15
12a.	Samos	4.05	0.90	6.8	24.42
12b.	Aidin	4.15	0.90	6.8	24.52
13a.	Psara	3.19	0.80	6.1	23.68
13b.	Chios	3.43	0.80	6.7	24.34
13c.	Ismir	3.33	0.80	6.7	24.24
13d.	Alasehir	3.16	0.80	6.6	24.00
14a.	Skopelos	3.62	0.80	6.8	24.60
14b.	Ag. Efstratios	3.59	0.80	7.0	24.71
14c.	Lesbos	3.71	0.80	7.0	24.83
14d.	Demirci	3.50	0.80	7.0	24.62
14e.	Gediz	3.82	0.80	7.0	24.94
15a.	Hellispontos	3.07	0.70	7.4	25.15
15b.	Prusa	3.00	0.70	7.4	25.08
16a.	Athos	2.94	0.70	7.4	25.02
16b.	Samothraki	2.82	0.70	7.0	24.58
17a.	Volvi	2.97	0.70	6.8	24.57
17b.	Doirani	2.00	0.60	6.7	24.14
17A.	Skopje	2.33	0.70	6.1	23.37
18.	Drama	2.00	0.60	7.2	24.59
19a.	Kresna	2.32	0.60	7.4	25.09
19b.	Philippoupolis	2.12	0.60	7.0	24.53
20a.	Peloponese	1.90	0.50	7.5	25.58
20b.	Kythera	1.54	0.50	7.5	25.32
20c.	Crete isl.	2.00	0.50	7.8	25.98

20d.	Rhodes isl.	1.94	0.50	7.8	25.92
21a.	Methana area	2.48	0.70	7.0	24.35
21b.	Thera	2.79	0.70	7.0	24.66
21c.	Nisyros	2.72	0.70	6.2	23.95

By the use of the above mentioned data (T, M_{min}, M_p, M_0) and the application of a well known technique (Draper and Smith, 1966; Weisberg, 1980), the following values were calculated for the parameters of the relation (1):

$$b=0.24, \quad c=0.25, \quad d=-0.36, \quad t=7.36 \qquad (5)$$

with a multiple correlation coefficient equal to 0.75 and a standard deviation equal to 0.18. In a similar way, the following values were calculated for the parameters of the relation (2):

$$B=1.04, \quad C=-0.31, \quad D=0.28, \quad m=-4.85 \qquad (6)$$

with a multiple correlation coefficient equal to 0.91 and a standard deviation equal to 0.22.

EXPECTED SHALLOW MAINSHOCKS

The quantity $\log(T/T_t)$, where T is the observed and T_t the calculated by the relation (1) repeat times, follows a normal distribution with $\mu=0$ and $\sigma=0.18$. This leads to the conclusion that we can calculate the probability of occurrence of a strong earthquake (e.g. $M\geq6.0$) during the next Δt years (e.g. $\Delta t=10$yrs) (Wesnousky et al., 1984), since the time, t, from the previous mainshock, the magnitude, M_p, of this mainshock and the interevent time, T_t, are known for each seismogenic source. Also, the magnitude of the expected earthquake in each seismogenic source can be calculated by the relation (2).

Table 3. Information on the expected shallow mainshocks. Epicenter coordinates, φ_N, λ_E and the corresponding uncertainties, 2σ, magnitudes, M_f, and corresponding probabilities, P, for the occurrence of strong ($M_{min}\geq6.0$) and large ($M_{min}\geq6.7$) shallow earthquakes during the period 1993-2002.

Code No	φ_N	2σ ±	λ_E	2σ ±	$M_{min}\geq6.0$ M_f	$M_{min}\geq6.0$ P	$M_{min}\geq6.7$ M_f	$M_{min}\geq6.7$ P
1a.	42.07	0.33	19.24	0.72	6.1	0.15	6.8	0.03
1b.	41.14	0.34	19.65	0.27	6.0	0.41	*	*
1c.	40.38	0.61	19.68	0.20	6.2	0.49	*	*
1d.	39.72	0.50	20.29	0.64	6.5	0.43	*	*

1e.	39.04 0.24	20.84 0.44	6.1	0.28	*	*
2a.	38.81 0.16	20.56 0.15	6.4	0.62	6.8	0.29
2b.	38.33 0.32	20.58 0.42	6.2	0.37	7.0	0.11
2c.	37.86 0.27	20.90 0.31	6.4	0.35	6.8	0.23
2A.	37.61 0.42	20.31 0.54	6.2	0.43	*	*
3a.	37.07 0.26	21.60 0.48	6.3	0.49	6.9	0.36
3b.	36.45 0.37	22.27 0.09	6.0	0.40	6.7	0.24
3c.	35.85 0.41	22.80 0.14	6.0	0.40	6.7	0.29
3A.	36.89 0.42	20.94 0.74	6.2	0.46	*	*
3B.	35.60 1.02	22.20 0.86	6.2	0.50	*	*
4a.	35.11 0.24	23.84 0.80	6.3	0.35	7.0	0.31
4b.	34.89 0.16	25.91 0.71	6.5	0.47	6.8	0.34
4A.	34.66 0.32	24.12 1.16	6.3	0.43	6.8	0.23
4B.	34.43 0.17	25.33 0.79	6.2	0.44	*	*
5a.	35.44 0.29	27.26 0.56	6.4	0.31	6.8	0.23
5b.	36.15 0.29	28.23 0.46	6.3	0.04	*	*
5c.	36.13 0.54	29.05 0.75	6.0	0.37	6.7	0.17
5A.	34.67 0.62	26.73 0.68	6.3	0.54	*	*
5B.	35.41 0.22	27.83 0.23	6.3	0.58	*	*
6a.	41.33 0.39	20.28 0.28	6.1	0.30	*	*
6b.	40.57 0.38	20.00 0.00	6.2	0.41	*	*
6c.	41.67 0.52	20.70 0.28	6.1	0.38	*	*
6d.	40.88 0.32	20.70 0.13	6.2	0.38	*	*
6e.	39.80 0.60	20.95 0.50	6.1	0.24	*	*
6f.	39.10 0.00	21.60 0.20	6.1	0.18	*	*
7A.	37.60 0.32	22.08 0.17	6.0	0.18	*	*
7a.	37.10 0.14	22.12 0.26	6.1	0.01	*	*
7b.	36.70 0.00	22.45 0.10	6.1	0.36	*	*
7c.	35.87 0.41	23.23 0.41	6.0	0.32	*	*
7d.	35.54 0.37	26.14 0.53	6.2	0.45	*	*
7e.	36.10 0.00	26.85 0.10	6.0	0.05	*	*
7f.	36.44 0.19	27.48 0.52	6.3	0.58	6.8	0.31
8a.	38.38 0.23	21.74 0.20	6.2	0.43	*	*

8b.	38.29 0.24	22.31 0.34	6.4	0.35	6.8	0.30
8c.	38.02 0.28	22.91 0.39	6.1	0.10	6.8	0.02
9a.	37.67 0.25	23.20 0.00	6.1	0.37	*	*
9b.	36.95 0.30	24.65 0.30	6.0	0.10	*	*
9c.	36.66 0.24	25.74 0.48	6.0	0.27	6.6	0.12
9d.	36.67 0.17	27.08 0.30	6.3	0.57	6.9	0.38
9e.	37.07 0.23	28.30 0.53	6.2	0.50	*	*
9f.	37.23 0.34	29.50 0.59	6.1	0.46	*	*
10.	39.33 0.25	22.67 0.65	6.3	0.53	7.0	0.23
11a.	38.73 0.25	23.05 0.43	6.3	0.59	6.7	0.28
11b.	38.28 0.07	23.40 0.42	6.1	0.11	*	*
12a.	37.82 0.31	26.99 0.47	6.6	0.27	6.8	0.21
12b.	37.83 0.36	29.26 0.95	6.6	0.43	6.8	0.36
13a.	38.41 0.10	25.28 0.29	6.1	0.01	*	*
13b.	38.39 0.36	26.29 0.26	6.4	0.61	6.8	0.27
13c.	38.42 0.28	27.43 0.78	6.1	0.48	6.8	0.33
13d.	38.33 0.25	29.97 1.11	6.0	0.18	*	*
14a.	39.43 0.64	23.81 0.59	6.1	0.14	6.8	0.02
14b.	39.37 0.39	24.87 0.78	6.1	0.35	6.8	0.13
14c.	39.11 0.40	26.06 1.26	6.1	0.12	6.8	0.02
14d.	39.27 0.42	28.00 0.74	6.3	0.61	6.8	0.38
14e.	39.16 0.39	29.44 0.70	6.1	0.49	6.9	0.24
15a.	40.39 0.55	27.17 0.77	6.5	0.77	6.8	0.39
15b.	40.32 0.66	29.00 0.79	6.2	0.66	7.0	0.45
16a.	40.17 0.24	24.70 0.53	6.3	0.37	7.2	0.33
16b.	40.44 0.10	25.94 0.52	6.2	0.40	6.9	0.15
17a.	40.63 0.31	23.50 0.62	6.2	0.37	6.9	0.29
17b.	41.15 0.31	22.58 0.50	6.3	0.38	6.8	0.27
17A.	42.15 0.30	21.40 0.00	6.0	0.13	*	*
18.	41.18 0.15	24.24 0.63	6.0	0.38	6.7	0.31
19a.	41.97 0.24	23.19 0.59	6.0	0.51	6.8	0.40
19b.	42.16 0.10	25.22 0.75	6.0	0.44	6.7	0.29

Table (2) gives information on the expected strong ($M \geq 6.0$), and large (M≥6.7) shallow earthquakes based on the model expressed by the relations (1), (2). The first column gives the code numbers of the seismogenic sources shown in figure (1). The second and third columns give the mean geographic latitudes and longitudes (± two standard deviations) of all strong (M≥5.5) shallow shocks which fulfil the completeness criterion for each seismogenic source. The last four columns of this table give the highest probabilities, P, for the occurrence of strong (M_{min}=6.0-6.6) and large (M_{min}≥6.7) shallow earthquakes during the next decade (1993-2002) and the corresponding magnitudes, M_f, of the expected earthquakes, as these magnitudes were calculated by the relation (2). As error in the expected magnitude we can consider the 2σ of the relation (2), which is 0.4.

Figure (3) shows a map of the centers of the seismogenic sources with proper symbols in order to indicate the range of probabilities for the occurrence of strong (M≥6.0) shallow earthquakes during the decade 1993-2002. White, half white and half black, and black circles indicate probabilities in the range 0.00-0.39, 0.40-0.49 and 0.50-0.99, respectivelly, for the occurrence of strong (M≥6.0) shallow mainshocks. The number of the seismogenic sources with the highest probabilities (P≥50%) in figure (3) is 14. This is almost equal to the expected (average) number of mainshocks with M≥6.0 per decade in the Aegean area (Comninakis and Papazachos, 1986).

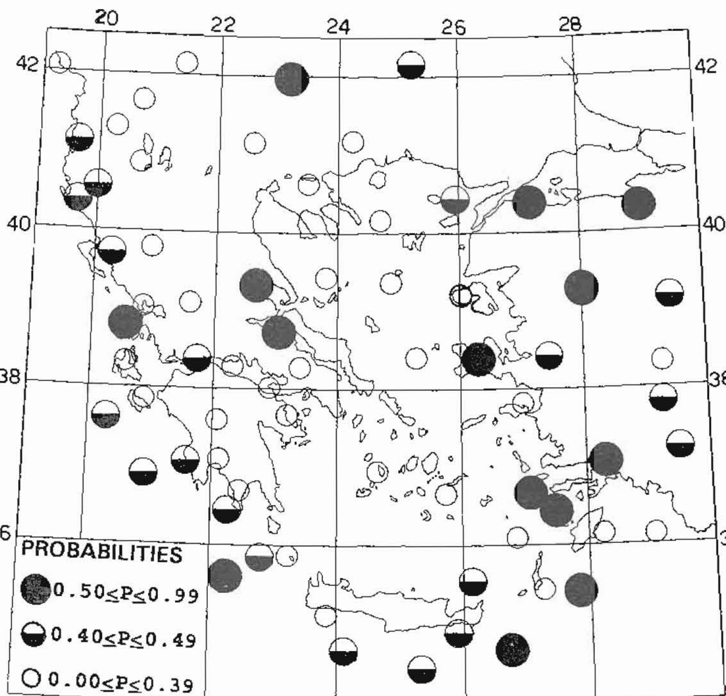

Fig.3. Centers of seismogenic sources and probabilities of occurrence of strong (M≥6.0) shallow earthquakes in the Aegean and surrounding area.

EXPECTED EARTHQUAKES OF INTERMEDIATE FOCAL DEPTH

Table (3) gives information on the expected strong (M≥6.0), and large (M≥6.7) intermediate depth earthquakes in the southern Aegean area on the basis of the model expressed by the relations (1), (2). The first column gives the code numbers of the seismogenic sources shown in figure (2). The second and third columns give the mean geographic latitudes and longitudes (± two standard deviations) of all intermediate depth shocks with M>5.6 which fulfil the completeness criterion for each seismogenic source. The fourth column of this table gives the focal depth, h (in Km), of the expected earthquake. The last four columns of this table give the highest propabilies, P, for the occurrence of strong (M_{min}=6.0-6.6) and large (M_{min}≥6.7) intermediate depth earthquakes during the next decade (1993-2002) and the corresponding magnitudes, M_f, of the expected earhtquakes, as these magnitudes were calculated by the relation (2).

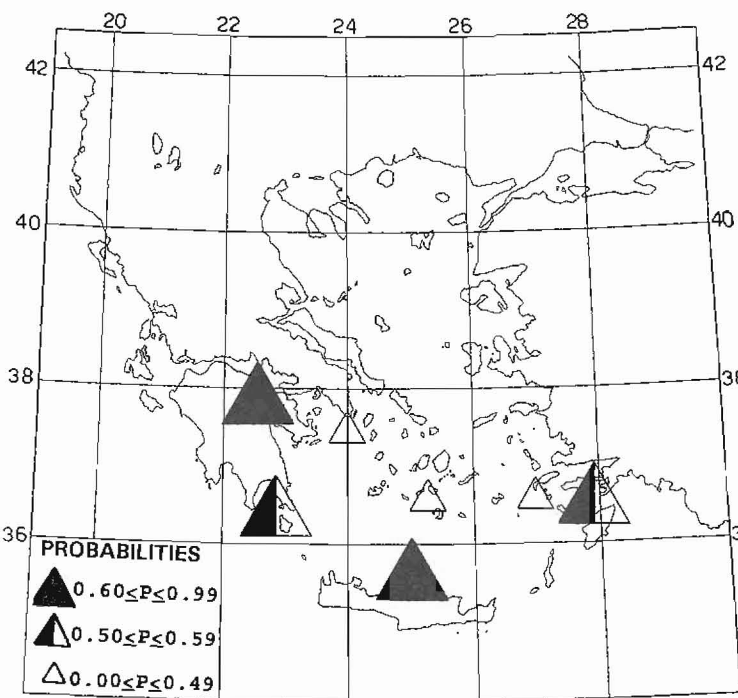

Fig.4. Centers of the seismogenic sources and probabilities of occurrence of large (M≥6.7) intermediate depth earthquakes in the southern Aegean area.

It results from table (3) that the probabilities for the occurrence of large (M≥6.7) earthquakes are high (≥0.50) for the four external zones (20a, 20b, 20c, 20d) of the intermediate focal depth earthquakes (h=80±20Km) in the southern Aegean area. The large intermediate depth earthquakes and particularly the very large ones ($M \geq 7.5$) constitute a major threat, during the next decades, for the whole southern Aegean area and even for areas in other countries of the eastern Mediterranean (Egypt, Middle East, Cyprus, southwestern Turkey) etc. This is due to the fact that the seismic waves of these earthquakes are transmitted without considerable attenuation in large distances along the Hellenic arc (Dodecanese, Crete, Peloponese) as well as to the areas (eastern Mediteranean countries) which are in the convex side of the Hellenic arc (Papazachos et al., 1985).

Table 3. Information on the expected intermediate depth mainshocks. Epicenter coordinates, φ_N, λ_E and the corresponding uncertainties, 2σ, focal depth, h, magnitude, M_f, and corresponding probabilities, P, for the occurrence of strong ($M_{min} \geq 6.0$) and large ($M_{min} \geq 6.7$) intermediate depth mainshocks during the period 1993-2002.

Code	φ^o_N	2σ	λ^o_E	2σ	h	$M_{min} \geq 6.0$		$M_{min} \geq 6.7$	
No		±		±	(Km)	M_f	P	M_f	P
20a.	36.37	0.87	22.87	0.86	80±20	6.6	0.90	7.1	0.65
20b.	37.81	0.78	22.56	0.63	80±20	6.4	0.20	7.1	0.52
20c.	35.56	0.57	25.00	1.45	80±20	6.6	0.88	7.3	0.81
20d.	36.50	0.16	27.90	0.86	80±20	6.6	0.92	7.0	0.54
21a.	37.45	1.10	24.00	0.80	140±40	6.3	0.61	6.7	0.32
21b.	36.57	0.19	25.27	1.11	140±40	6.2	0.58	6.9	0.44
21c.	36.58	0.26	26.98	0.43	140±40	6.2	0.46	*	*

In the map of figure (4), the triangles show the centers of the seismogenic sources of the intermediate focal depth shocks. White, half white and half black, and black triangles indicate probabilities in the range 0.00-0.49, 0.50-0.59 and 0.60-0.99, respectivelly, for the occurrence of large ($M \geq 6.7$) intermediate focal depth mainshocks.

The results presented on tables (3), (4) and on figures (3), (4) are of practical interest for several reasons. One such reason is that these results can be used to focus the preparandness measures in special areas (e.g. of high probability, in combination with the existence of important structures), instead of spreading these measures all over the country. Another one is that special scientific experement can be more effective if are made or prepared (installation of strong motion instruments, monitoring for precursors of earthquakes, etc) in areas for which the probability for the occurrence of strong earthquakes is high.

ACKNOWLEDGMENTS

A computer program for determination of the parameters of the relations (1), (2), written by C.Papazachos, and another one for distinghuishing foreshocks and aftershock, written by M.Scordilis, were used. We express our sincere appreciation for their help. The authors express their sincere gratitude to Earthquake Planning and Protection Organisation of Greece for financial support (Project 8113/93).

REFERENCES

Bufe,C.G., Harsh,P.W., and Burford,R.D., (1977). Steady-state seismic slip: A Precise recurrence model, Geophys. Res. Lett., 4, 91-94.

Comninakis,P.E., and Papazachos,B.C., (1986), A catalogue of earthquakes in Greece and surrounding area for the period 1901-1985, Publ. Geophys. Lab. Univ. Thessaloniki 1, 167pp.

Draper,N.R. and Smith,H., (1966), Applied regression analysis, Wiley, New York, 407pp.

Gutenberg,B. and Richter,C.F., (1944). Frequency of earthquakes in California, Bull. Seismol. Soc. Am. 34, 185-188.

Karakaisis,G.F., Kourouzidis,M.C. and Papazachos,B.C., (1991). Behaviour of seismic activity during a single seismic cycle, Int. Conf. Earthq. Pred., Strasbourg FRSNLE 15-18, October 1991, 1, 47-54.

Kiratzi,A.A. and Papazachos,C.B., (1993). Active seismic deformation in the southern Aegean Benioff zone, Publ. Geophys. Lab., Univ. of Thessaloniki, 1, 17pp.

Mogi,K., (1981). Seismicity in western Japan and long-term earthquake forecasting. In: Earthquake Prediction, An International Review Maurice Ewing Ser. Vol. 4, (eds Simpson D.W. and P.G. Richards), AGU, Washington, D.C., 43-52.

Molnar,P., (1979). Earthquake recurrence intervals and plate tectonics, Bull. Seismol. Soc. Am., 69, 115-133.

Papazachos,B.C., (1988a). Seismic hazard and long-term earthquake prediction in Greece, European School of Earthquake Sciences, Course on Earthquake Hazard Assessment, Athens GREECE, 9-16 May, 1988, pp. 1-10.

Papazachos,B.C., (1988b). Long-term prediction of earthquakes in seismogenic sources of Greece, UN Sem. on: Prediction of Earthquakes, Lisbon-PORTUGAL, 14-18 November 1988, pp. 1-10.

Papazachos,B.C., (1989). A time-predictable model for earthquake generation in Greece, Bull. Seismol. Soc. Am. 79, 77-84.

Papazachos,B.C., (1990). Seismicity of the Aegean and surrounding area, Tectonophysies. 178, 287-308.

Papazachos,B.C., (1992). A time and magnitude predictable model for generation of shallow earthquakes in the Aegean area, Pageoph, 138, 287-308.

Papazachos,B.C., (1993). Long term prediction of intermediate depth earthquakes in southern Aegean region based on a time predictable model, Natural Hazards (in press).

Papazachos,C.B. and Kiratzi,A.A., (1993). A formulation for reliable estimation of active crustal deformation and its application in Greece, Geophys. Journ. Intern. 111, 424-432.
Papazachos,B.C. and Papazachou,C.B., (1989). The earthquakes of Greece, Ziti publishing Co, Thessaloniki-GREECE, pp.365, (in Greek).
Papazachos,B.C., Papadimitriou,E.E., Karacostas,B.G. and Karakaisis,G.F., (1985). Long term prediction of great intermediate depth earthquakes in Greece, Proc. 12th Reg. Sem. on: Earthq. Engin., EAEE-EPPO, Halkidiki-Greece, September 1985, 1-12.
Shimazaki,K. and Nakata,T., (1980). Time-predictable recurrence of large earthquakes, Geophs. Res. Lett., 7, 279-282.
Sykes,L.R. and Quittmeyer,R.C., (1981). Repeat times of great earthquakes along simple plate boundaries. In: Earthquake Prediction, An International Review (eds. Simpson,D.W., and Richards,P.G.) Maurice Ewing-Series, AGU, Washington D.C., 4, 297-332.
Weisberg,S., (1980). Applied linear regression, Wiley New York, 283pp.
Wesnousky,S.G., Scholz,C.H., Shimazaki,K. and Matsuda,T., (1984), Integration of geological and seismological data for the analysis of seismic hazard: a case study of Japan. Bull. Seism. Soc. Am. 74, 687-708.