Seismic Properties in the Eastern Part of the South Aegean Volcanic Arc

G. A. PAPADOPOULOS (*) *Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

ABSTRACT

The South Aegean active volcanic arc lies along the 150-km seismic isodepth of a Benioff-zone and consists in andesitic, dacitic and rhyolitic volcanoes of an orogenic calc-alkaline type. In the eastern part of the arc there are two main volcanic sites in the Nisyros and Kos islands. High shallow and intermediate depth seismic activity occurs in this volcanic area. Seismological data concerning the 1911-1980 period have been used to investigate seismic properties in that area. Two, distinct regions with different seismotectonic features have been defined. The internal region (Nisyros active volcano and its proximity) is characterized by a shallow, thin seismogenetic layer with abnormally high *b*-value, locally concentrated stresses, low seismicity and highly heterogeneous structure. These features are probably due to a magmatic body intruded in shallow depths within the crust. The possibility of magma formation in the upper surface of the descending slab or within the upper mantle wedge overlying this slab in the Nisyros-Kos area is herein discussed. On the contrary, the remaining (external) region, including the non-active volcanic island of Kos, is characterized by normal for tectonic shocks *b*-value, thick seismogenetic layer and high seismicity. It seems that in this region there is not a magmatic intrusion at least in shallow depths within the crust.

(*) Permanent address: *Hellenic Air Force Academy, Dekelia, Athens, Greece.*

INTRODUCTION

Important volcanic activity manifested itself in the Aegean and the surrounding areas during the last four myr or so, that is in the Plio-Quaternary (Fig. 1). This volcanism is exclusively localized in the inner geological zones of the Hellenides.

The South Aegean volcanic zone is an active arc which lies along the 150-km sesmic isodepth of a well-defined Benioff-zone, and consists mainly in andesitic, dacitic and rhyolitic volcanoes with a typical calc-alkaline petrochemical character. Three volcanic centers (Santorini, Nisyros, Methana; see Figure 1) have been active there in historical times (GEORGALAS, 1962). As is concluded from qualitative criteria concerning the intensity and the frequency of the volcanic activity, the relative volcanic hazard is high in Santorini, medium in Nisyros and low in Methana (PAPADOPOULOS, 1983).

Many authors have shown or accepted that seismic, volcanic, and other geophysical peculiarities of the Hellenic arc-trench system, including the South Aegean volcanic zone, may be due to the active subduction of the Mediterranean (or African) lithosphere beneath the South Aegean area (PAPAZACHOS and COMNINAKIS, 1971; MCKENZIE, 1972, 1978; NINKOVICH and HAYS, 1972; PAPAZACHOS and PAPADOPOULOS, 1977; LE PICHON and ANGELIER, 1979; COMNIKAKIS and PAPAZACHOS, 1980; PAPADOPOULOS, 1982,

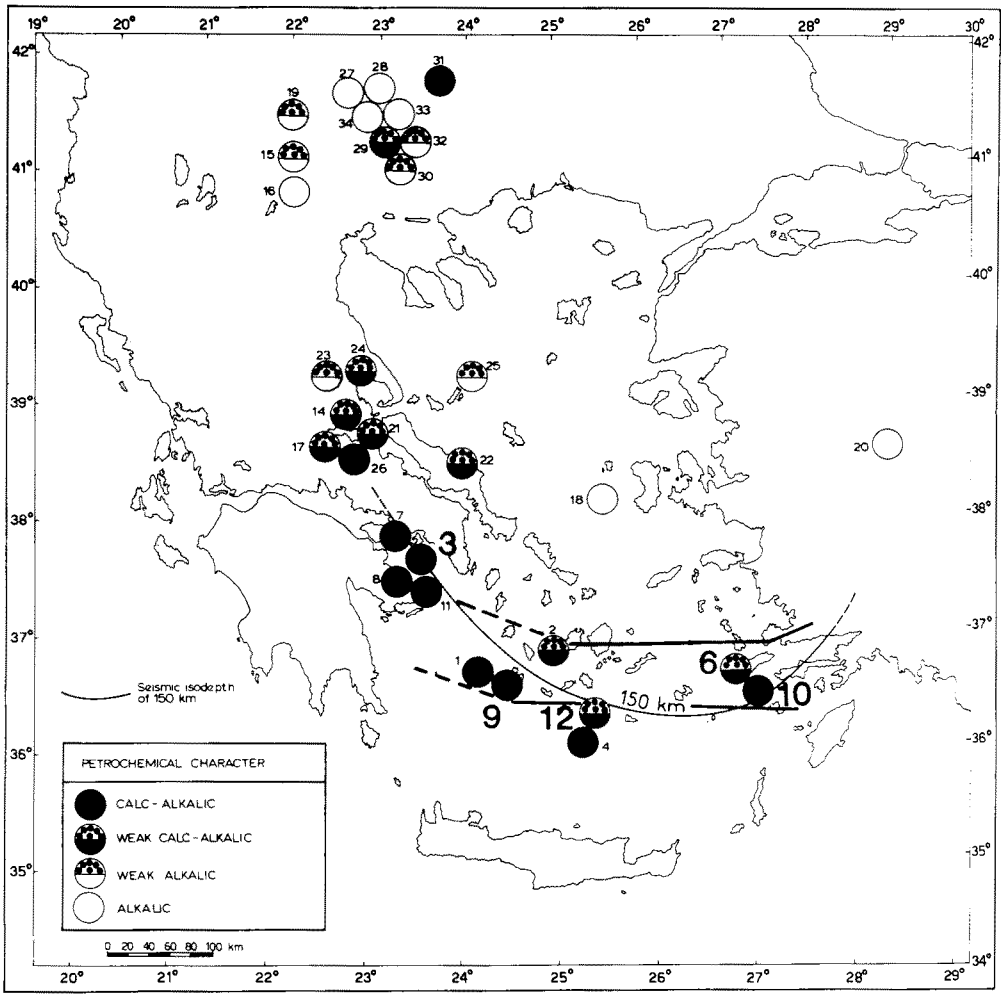

FIG. 1 – Spatial distribution of the Plio-Quaternary volcanics in the Aegean and surrounding areas (after PAPADOPOULOS, 1982; 1984). South Aegean active volcanic arc: 1-12 (Methana = 3, Kos = 6, Melos = 9, Nisyros = 10, Santorini = 12). Boundaries of the seismotectonic segment along the central and eastern part of the South Aegen arc are after PAPAZACHOS (1980). The 150-km seismic isodepth is after COMNINAKIS and PAPAZACHOS (1980).

1984). In general, this volcanic zone has the basic geophysical, volcanological and petrochemical features of the Indo-Pacific active volcanic arcs.

In the eastern part of the South Aegean arc there exist two main volcanic sites in the Nisyros and Kos islands, as well as some volcanic islets in the proximity of the former. High seismic activity occurs and intense volcanism has occurred there during recent geological times.

The main purpose of this paper is to investigate the seismic properties of the Nisyros-Kos volcanic area and their

possible tectonic correlations with deep magmatic conditions.

VOLCANIC AND SEISMIC ACTIVITY

After research made by several authors (GEORGALAS, 1962; DAVIS, 1968; DI PAOLA, 1974), one may conclude that the recent volcanism in the Nisyros volcano has as follows: at the end of an intense explosive stage (between 0.2 myr B.P. and Present) the top of the volcano collapsed forming a caldera which is still perfectly preserved; a post-caldera activity with eruptions of huge, viscous domes and lava flows of uniform composition concluded this stage of the volcano evolution. Phreatic explosions and probably weak normal eruptions occurred inside the caldera in

TABLE 1 – Information on the shallow ($h < 70$ km) earthquakes which occurred in Nisyros-Kos volcanic area during the period 1911-1980.

Date	Time	φ_N^O	λ_E^O	h(km)	M
1926 02 08	19:48:32	36.8	27.1	n	5.4
1932 12 07	07:55:46	36.8	27.5	n	5.0
1933 04 23	05:57:37	36.8	27.3	n	6.6
05 15	20:01:42	36.2	26.6	n	5.1
1942 09 01	09:42:15	36.4	27.4	n	5.8
1944 01 05	05:05:03	36.4	27.4	n	5.0
01 05	07:44:04	36.4	27.4	n	5.6
1953 06 07	13:52:49	36.0	27.0	n	4.8
12 05	20:14:26	36.5	26.7	n	4.9
1954 01 02	01:13:21	36.5	27.5	n	5.5
1956 07 10	01:59:41	36.7	26.5	n	5.2
1958 03 04	11:32:08	36.4	27.0	n	4.8
09 04	00:02:56	36.6	26.7	n	5.4
1959 05 20	16:36:52	36.8	26.6	n	5.2
1960 04 30	10:12:42	36.7	27.2	n	4.9
1961 02 23	21:45:54	36.7	27.1	n	5.6
02 23	21:46:36	36.7	27.1	n	4.8
02 23	21:56:51	36.7	27.4	n	5.0
02 27	21:40:05	36.6	26.9	n	5.3
02 27	21:43:42	36.6	26.9	n	5.1
02 27	21:54:33	36.5	27.1	n	4.9
03 13	15:31:56	36.6	27.0	n	4.9
05 25	13:11:42	37.0	26.9	n	4.9
1962 04 28	11:18:59	36.1	26.8	n	5.8
04 28	12:43:49	36.1	26.9	n	5.6
1965 01 07	10:22:17	36.5	26.8	35	5.2
1966 04 07	00:40:33	36.8	26.7	26	4.5
1967 10 11	07:48:45	36.1	27.1	34	4.9
1968 02 20	16:50:45	36.1	27.4	64	5.0
09 05	18:42:32	36.3	26.7	1	4.5
10 27	22:06:27	36.2	27.1	0	4.5
10 31	03:22:14	36.6	27.0	2	5.7
1968 11 04	20:05:59	36.4	27.0	35	4.9
11 11	23:34:21	36.6	27.1	23	5.1
11 11	23:53:07	36.6	27.1	33	4.6
11 12	03:37:39	36.7	27.1	26	5.1
11 12	03:41:56	36.6	27.1	0	4.5
11 12	04:01:02	36.4	26.6	0	4.5
11 12	06:08:56	36.6	27.2	24	4.9
11 12	06:52:26	36.1	27.3	0	4.5
11 26	04:30:03	36.2	27.3	41	4.5
12 04	18:43:28	36.3	27.0	43	4.7
12 04	18:52:18	36.5	27.0	36	4.5
12 04	19:37:22	36.5	27.0	32	4.9
12 04	20:30:24	36.7	27.2	58	4.5
12 05	07:52:11	36.6	26.9	31	6.0
12 09	20:22:17	36.5	27.1	44	4.5
12 21	00:36:40	36.6	27.1	30	4.9
12 21	03:04:40	36.6	27.3	0	4.8
1969 02 26	12:35:49	36.7	27.2	33	4.6
10 16	02:52:23	36.4	27.2	0	4.6
10 16	06:58:01	36.9	27.4	0	4.6
10 27	01:12:34	36.5	27.2	0	4.5
11 03	09:25:05	36.4	27.1	0	4.6
1970 02 20	10:06:13	36.4	27.2	33	4.5
02 20	20:19:32	36.5	27.3	20	4.5
1971 04 17	08:27:30	36.0	27.3	33	4.6
11 12	12:30:51	36.6	27.1	23	5.0
1972 01 20	00:52:19	36.6	27.1	16	4.7
01 20	02:15:07	36.6	27.2	34	4.9
03 31	20:32:01	36.6	27.1	18	4.5
1974 05 09	17:02:24	36.6	27.2	26	4.7
05 16	15:07:28	36.1	27.3	32	4.5
1975 06 02	03:19:08	36.5	26.5	31	4.7
1977 03 28	10:50:20	36.8	27.5	35	5.0

historical times. Nowadays there is a considerable number of solfataras and fumaroles (up to 100°C), as well as of hot springs (up to 50°C). It is generally thought that the Nisyros volcano is not yet extinct.

Although there is not a detailed knowledge on the volcanic evolution in the Kos island, we can say that the main volcanic event was the eruption of a pumice tuff sheet in younger Pleistocene times (BIANCHI, 1928; KELLER, 1969). Nowadays some hot springs with temperatures up to 45°C exist in Kos. As generally is believed, the volcanic activity in this island is extinct.

Along the central and eastern parts of the volcanic arc there is (PAPAZACHOS, 1980) a seismotectonic segment of shallow earthquakes (boundaries of this segment are shown in Fig. 1). High, shallow seismic activity occurs in the eastern part of this same segment (Nisyros-Kos area). The eastern portion of the Benioff-zone, which is inclined under the South Aegean from approximately SSW to NNE at an angle of 38°, is lying beneath this area. For this reason, the intermediate depth seismicity is also high in the Nisyros-Kos area.

THE DATA

A catalogue (COMMINAKIS and PAPAZACHOS, 1982) of earthquakes, which occurred in the Greek area during the present century (1901-1980), has been used as a data source. This catalogue is complete as far as the magnitudes $M \geq 4.9$ (1911-1949), $M \geq 4.8$ (1950-1963), and $M \geq 4.5$ (1964-1980) are concerned. The errors in the epicenters are less than 30 km, while the errors in the focal depth are of the same order. These errors are probably even smaller for the period 1964-1980. The errors in the surface wave magnitudes are less than 0.3.

Information for historical earthquakes has been derived from the catalogue published by PAPAZACHOS and COMNINAKIS (1982).

Tables 1 and 2 give information on the shallow ($h < 70$ km) and intermediate focal depth ($h \geq 70$ km) earthquakes which occurred in the Nisyros-Kos volcanic area (36°-37°N, 26.5°-27.5°E) from 1911 up to 1980.

TABLE 2 – Information on the intermediate focal depth ($h \geq 70$ km) earthquakes which occurred in Nisyros-Kos volcanic area during the period 1911-1980.

Date	Time	φ_N^O	λ_E^O	h(km)	M
1926 06 26	19:46:34	36.5	27.5	100	8.0
07 05	09:21:54	36.5	27.0	150	5.6
1929 03 27	07:41:46	36.7	26.5	120	5.9
11 11	07:36:15	36.8	26.5	150	5.2
1936 04 28	23:15:23	36.7	26.7	170	5.7
1938 01 16	13:37:15	36.5	27.2	200	5.3
1942 06 21	04:38:44	36.0	27.0	90	6.3
1943 11 16	13:08:53	36.5	27.5	110	6.3
1944 05 27	23:52:30	36.0	27.5	100	6.2
1954 09 04	04:19:23	36.6	27.1	160	5.0
1958 05 27	18:27:45	36.8	26.8	166	5.4
06 30	08:42:44	36.4	27.3	109	6.0
09 04	02:51:06	36.4	27.0	140	4.9
1962 04 16	07:19:06	36.2	27.2	140	5.0
1965 05 07	14:42:22	36.7	26.9	162	4.6
06 10	15:24:17	36.4	26.6	142	4.9
11 28	05:26:05	36.1	27.4	73	6.0
1966 09 06	12:31:57	36.7	26.6	158	4.5
09 10	10:55:17	36.5	26.9	146	4.5
1967 08 28	17:36:41	36.7	26.7	169	4.5
12 05	05:20:03	36.5	26.8	137	4.8
1968 02 07	22:22:19	36.6	26.7	153	5.3
1971 03 18	16:08:02	36.3	27.0	141	4.7
1972 03 10	22:13:18	36.5	27.0	150	4.8
1974 02 05	15:05:25	36.7	26.9	156	4.9
05 12	00:20:58	36.7	26.9	149	4.6
1975 09 23	21:34:14	36.6	26.8	158	4.6
1976 08 17	17:37:55	36.7	27.1	160	5.2
08 18	17:06:35	36.7	27.4	157	4.7
1977 07 12	13:32:56	36.6	27.0	157	4.5
1978 03 01	22:51:06	36.0	27.1	94	4.8
1980 05 16	00:37:33	36.0	27.4	71	5.6

SEISMIC PROPERTIES OF THE NISYROS-KOS AREA

Spatial Distribution of the Shallow Earthquakes Epicenters

Figure 2 illustrates the spatial distribution of the shallow earthquakes epicenters in the Nisyros-Kos area. As one may observe, almost the whole area is covered by epicenters, but there is a high concentration of epicenters in the Nisyros region which is approximately delimited by the geographic coordinates 36.4°-36.6°N and 27.0°-27-3°E. In this region (internal region) the maximum seismic magnitude that has been observed during the 1901-1980 time-period is 5.7. On the contrary, four earthquakes with magnitudes $6.6 \geq M \geq 5.8$ occurred in the remaining area (external region) during this same period. At least two, large shocks (magnitudes: 6.5 and 6.8) occurred in the external region in historical times (479 B.C.-1900 A.D.), while three others occurred very closely to this region (magnitudes: 6.7, 7.0 and 7.0). Such earthquakes have not been reported to occur in the internal region. For these reasons, the Nisyros-Kos volcanic area has been empirically divided into two separate regions as described earlier.

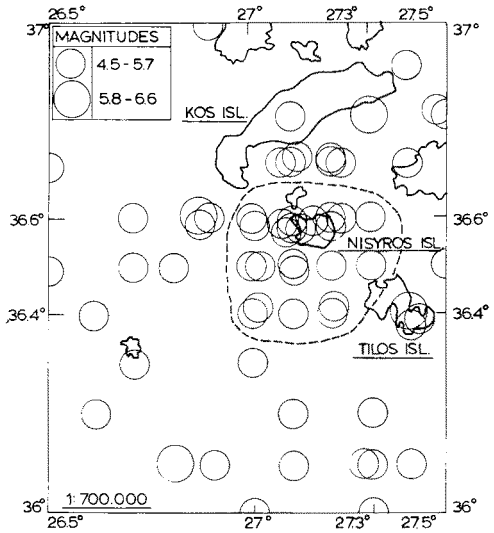

FIG. 2 - Spatial distribution of the epicenters of the shallow ($h < 70$ km) earthquakes which occurred in the Nisyros-Kos volcanic area from 1911 to 1980 (data in Table 1). The dashed-line delimits the internal region (Nisyros isl. and its proximity). The remaining area is the external region (see details in the text).

Distribution of the Seismic Magnitudes

It is well known from many years (GUTENBERG and RICHTER, 1954) that the number, N_k, of earthquakes with magnitudes, M, or lager, which occur in a specified region of surface, S, and in a certain time-interval, k, is given by the relation

$$\log N_k = a_k - bM \qquad (1)$$

where a_k and b are parameters which depend on the seismicity of the area. Parameter a_k also depends on S and k. For time-interval of one year ($k=1$) the relation (1) becomes

$$\log N = a - bM \qquad (2)$$

Where

$$a = a_k - \log k \qquad (3)$$

Logarithms of the cumulative distribution, N_k, for the shallow and intermediate focal depth earthquakes of the Nisyros-Kos area, as well as for the shallow earthquakes of the internal and external regions, are plotted as a function of M in Fig. 3 and 4. The samples were complete for the whole period 1911-1980 ($k=70$) only for earthquakes with $M \geq 4.9$, while they are complete as far as the magnitudes $M \geq 4.8$ and $M \geq 4.5$ and the time-intervals 1950-1980 and 1964-1980 are respectively concerned. In order to increase the samples and extend the curves to magnitudes $M < 4.9$, the frequencies of the magnitudes $4.8 \geq M \geq 4.5$ have been reduced to the whole time-interval.

The least-squares method has been applied to determine the parameters a_k, b, and a for each earthquakes group and to draw the straight lines through the plot points in Fig. 3 and 4. Table 3 shows the values determined for these parameters.

It is clear that the b-value for the shallow shocks of the internal region is abnormally high and corresponds neither to typical tectonic earthquakes ($b = 0.6$-1.0) nor to typical volcanic earthquakes ($b = 1.8$-2.6). The b-parameter of the other earthquakes groups have normal values for tectonic earthquakes in Greece. A high b-value (1.22), which is intermediate between that of tectonic earthquakes and that of volcanic ones, has been determined for a swarm broken out in the Melos volcanic island at the end of August, 1971 (DRAKOPOULOS and DELIBASIS, 1973).

Statistical Definition of Seismicity

Several quantities are in use as criteria for the statistical definition of the seismicity in a specified region. The mean return period, T_m, of earthquakes with a certain magnitude, M, or larger, and the maximum seismic magnitude, M_T, which was the maximum probability to occur within a given time-interval, T, are such quantities. The quantity T_m is given by the formula

$$T_m = 10^{bM-a} \qquad (4)$$

which results from the relation (2). The quantity M_T is given (CURTIS, 1973) by the formula

$$M_T = \frac{a}{b} + \frac{\log T}{b} \qquad (5)$$

Tables 4 and 5 give values of the quantities T_m and M_T determined for the area of Nisyros-Kos. Taking as criteria these values, one may conclude that the shallow seismicity of the internal region is, as expected, lower than that of the external region. On the other hand, shallow seismicity of the whole area is lower than that of the intermediate depth one.

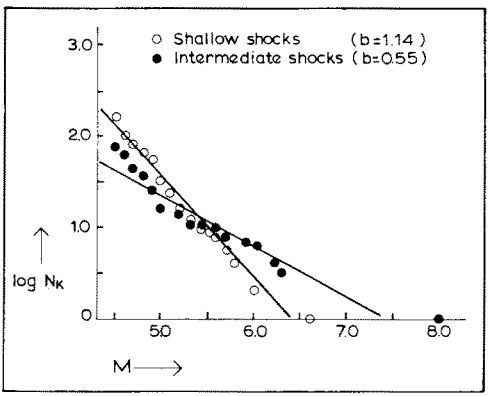

FIG. 3 – Plot of the logarithms of the cumulative distributions, N_K, for the shallow and intermediate focal depth earthquakes in the Nisyros-Kos area as a function of seismic magnitudes, M.

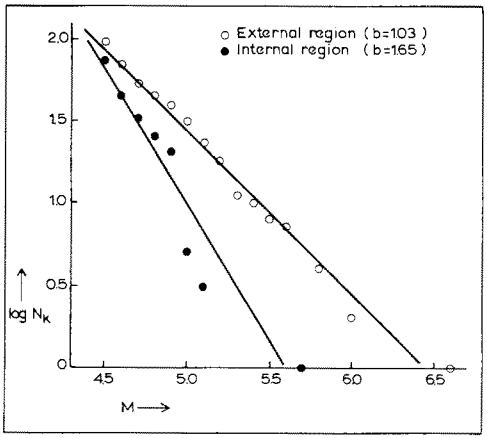

FIG. 4 – Plot of the logarithms of the cumulative distributions, N_K, for the shallow earthquakes of the internal and external regions of the Nisyros-Kos area as a function of seismic magnitudes, M.

TABLE 3 – Values of the parameters a_k, a, and b for the Nisyros-Kos area.

Earthquakes group	a_K	a	b
Shallow (whole area)	7.28	5.43	1.14
Shallow (internal region)	9.23	7.38	1.65
Shallow (external region)	6.60	4.76	1.03
Intermediate depth (whole area)	4.12	2.28	.55

Thickness of the Seismogenetic Layer

The thickness of the seismogenetic layer of shallow earthquakes can be suggested as a measure of the lithospheric thickness. This thickness has been determined for the internal and external regions of the Nisyros-Kos area using the focal depth of the shallow earthquakes which had magnitudes $M \geq 4.5$ and occurred there in the 1964-1980 time-interval. The data used (Table 1) are complete and homogeneous. The statistical maximum depth, h, for both regions has been computed from the formula

$$h = \bar{h} + 2\sigma \qquad (6)$$

where $\bar{h}$ is the average focal depth and σ is the corresponding standard deviation. The same formula has been used by PAPADOPOULOS and PAVLIDES (1984) to determine the thickness of the shallow seismogenetic layer in the outer (convex) part of the Hellenic arc.

Table 6 gives the values of $\bar{h}$, σ, and h as well as the number of the observations, η. Values of h clearly show that the lithospheric thickness in the internal region, that is in the Nisyros volcano and its proximity, is significantly smaller than that in the external region, including the Kos island.

Intermediate Depth Seismicity and Magmatism

It has been known for many years now (KTENAS, 1930; DAVIS, 1968) that the volcanics of Nisyros have a calc-alkaline character. More reently, DI PAOLA (1974) showed that the volcanic rocks of Nisyros and its neighbouring islands belong to a typical orogenic calc-alkaline series (from basic andesites through andesites-dacites-rhyodacites to strongly silicic rhyolites) with normal K_2O contents. On the other hand, according to KTENAS (1930) and KELLER (1969), the Kos pumice is also inserted in a typically calc-alkaline series ranging from andesites to acid rhyolites.

These conclusions are completely consistent with the general result that the

TABLE 4 – Mean return period, T_m (yrs), of the earthquakes with magnitude, M, 4.5 or larger in the Nisyros-Kos area.

M	Shallow earthquakes			Intermediate depth earthquakes (whole area)
	Whole area	Internal region	External region	
4.5	.5	1.1	.7	1.6
5.0	1.9	7.4	2.5	3.0
5.5	6.9	49.4	8.0	5.6
6.0	25.7	331.1	26.3	10.5
6.5	95.5		86.1	19.7
7.0	354.8		281.8	37.2
7.5				70.0
8.0				131.8

TABLE 5 - Maximum seismic magnitude, M_T, which has the maximum probability to occur in the Nisyros-Kos in a time-interval T.

T (yrs)	Shallow earthquakes			Intermediate depth earthquakes (whole area)
	Whole area	Internal region	External region	
1	4.8	4.5	4.6	4.1
6	5.4	4.9	5.4	5.6
10	5.6	5.1	5.6	6.0
25	6.0	5.3	6.0	6.7
50	6.3	5.5	6.3	7.2
100	6.5	5.7	6.5	7.8

totality of the South Aegean volcanics belong to a typical orogenic calc-alkaline series similar to those of the active Indo-Pacific island-arcs (NICHOLLS, 1971; NINKOVICH and HAYS, 1972; PE and PIPER, 1972; BARBERI *et al.*, 1974; PAPADOPOULOS, 1982, 1984). The last-mentioned has collected from around 100 different sources a large amount of whole rock chemical analyses of the South Aegean volcanics and has applied the diagram proposed by NINKOVICH and HAYS (1972) in which the K_2O and SiO_2 content is plotted against depths of Benioff-zones occurring in the active Indo-Pacific convergent plate margins. This application has shown that melts of the rocks in question correspond to a 125-176 km depth range (137 km and 169 km for the Nisyros and Kos volcanics respectively). Depth increases from the outer (convex) to the inner (concave) part of the arc, that is, exactly as the focal depth of the intermediate depth earthquakes does. The same author, applying a statistical method in five different petrochemical diagrams, has defined a petrochemical index concerning the degree of calc-alkalinity (or olkalinity) of the Cenozoic magmatic rocks in the Aegean area. On the basis of this index, he has found that the calc-alkalinity of the South Aegean volcanics systematically decreases (or the alkalinity increases) from the outer to the inner part of the arc. Thus, the Nisyros and Kos volcanics were found to be calc-alkaline and weak calc-alkaline respectively.

From the above described remarks, it follows that, in the case of the South Aegean volcanic arc, could be suggested as applicable the hypothesis of magma generation along the upper surface of the descending slab or at increasingly greater depth toward the continent within the upper mantle overlying the descending slab. This hypothesis has been proposed by many authors for other active subduction zones (KUNO, 1966; GREEN and RINGWOOD, 1967; DICKINSON, 1968, 1975; RINGWOOD, 1969; ANDERSON *et al.*, 1976). This point of view is reinforced, as far as the volcanics of Nisyros and Kos are concerned, because the average focal depths of the intermediate depth earthquakes beneath these volcanoes (144 km and 156 km respectively, data in Table 2) are compatible with the corresponding depths which have been found using petrochemical data, and also with the petrochemical character of the volcanics.

TABLE 6 - Thickness of the shallow seismogenetic layer in the Nisyros-Kos area.

	$\bar{h}$ (km)	h (km)	n
External region	28 ± 19	66	19
Internal region	20 ± 14	48	21

CONCLUSION AND DISCUSSION

Results obtained from the study of the shallow seismic activity in the eastern part of the South Aegean active volcanic arc, show that in this area there are probably two distinct regions, the internal and external ones, with different seismic properties. The internal region (Nisyros and its proximity) is characterized by high concentration of seismic epicenters, absence of large earthquake magnitudes, unusually high *b*-value, low seismicity and thin seismogenetic layer. On the contrary, the external region is characterized by normal concentration of epicenters, occurrence of large earthquakes, *b*-value typical for tectonic earthquakes, high seismicity and thick seismogenetic layer. It is, therefore, interesting to investigate an explanation for the seismotectonic peculiarites of the internal region.

The high concentration of epicenters, the absence of large seismic magnitudes, as well as the high *b*-value imply that the lithosphere of the internal region has probably a highly heterogeneous structure with locally concentrated stresses. This heterogeneity favors the origin of small magnitude earthquakes. For this reason the seismicity is low in the internal region. The existence of a magmatic body intruded in shallow depths within the crust may be responsible for the highly heterogeneous structure, the small thickness of the seismogenetic layer, and the atypical *b*-value. The great amount of geothermal manifestations (phreatic eruptions, strongly detonating solfataras, hot springs), the weak normal eruptions which probably occurred in recent historical times, and a geothermal field of high enthalpy (M. FYTIKAS, personal communication, 1983) existing in the Nisyros caldera, reinforce this point of view. The possibility for magma formation along the upper surface of the descending lithospheric slab, or within the upper mantle wedge overlying this slab in the Nisyros-Kos area, has been already discussed.

It seems that in the external region, including the Kos island, there is not a magmatic intrusion at least in shallow depths within the crust.

Although the existence of a magmatic body beneath the Nisyros area might be responsible for the heterogeneous structure mentioned earlier, it is not the main geodynamic cause for the shallow seismicity in the eastern part of the South Aegean volcanic arc. This seismicity may be mainly due to the general geodynamic conditios which exist in the Helenic arc as a whole.

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REFERENCES

ANDERSON, R. N., UYEDA, S. and MIYASHIRO, A., 1976, *Geophysical and Geochemical Constraints at Converging Plate Boundaries - Part I: Dehydration in the Down-going Slab.* Geophys. J.R. Astr. Soc., *44*, p. 333-357.

BARBERI, F., INNOCENTI, F., MARINELLI, G. and MAZZUOLI, R., 1974, *Vulcanismo e Tettonica a Placche: Essempi nell'Area Mediterranea.* Ist. Miner. Petr., Pisa, p. 327-356.

BIANCHI, A., 1928, *Le Rocce Effusive dell'Isola di Coo.* Mem. Ist. Geol. R. Univ. Padova, *8*, p. 1-86.

COMNINAKIS, P. E. and PAPAZACHOS, B. C., 1980, *Space and Time Distribution of the Intermediate Focal Depth Earthquakes in the Hellenic Arc.* Tectonophysics, *70*, p. T35-T47.

———, 1982, *A Catalogue of Earthquakes in Greece and the Surrounding Area for the Period 1901-1980.* Geophys. Labor. Univ. of Thessaloniki, *Publ. No. 5*, p. 1-146.

CURTIS, J.W., 1973, *A Magnitude Domain Study of the Seismicity of Papua, New Guinea and the Solomon Islands.* Bull. Seismol. Soc. Amer., *63*, p. 787-806.

DAVIS, E.N., 1968, *Zur Geologie und Petrologie der Inseln Nisyros und Jali (Dodekanes).* Geol. Rund., *57*, p. 811-821.

DICKINSON, W.R., 1968, *Circum-Pacific Andesite Types.* J. Geophys. Res., *73*, p. 2261-2269.

———, 1975, *Widths of Modern Arc-Trench Gaps Proportional to Past Duration of Igneous Activity in Associated Magmatic Arcs.* J. Geophys. Res., *78*, p. 3376-3380.

DI PAOLA, G., 1974, *Volcanology and Petrology of Nisyros Island (Dodecanese, Greece).* Bull. Volcanol., *38*, p. 944-987.

DRAKOPOULOS, J.C. and DELIBASIS, N.D., 1973, *Volcanic Microearthquake Activity in Melos, Greece.* Ann. di Geof., *26*, p. 131-153.

GEORGALAS, G.C., 1962, *Catalogue of the Active Volcanoes of the World Including Solfatara Fields, Part XII.* Greece. Inter. Assoc. Volcanol., Roma, p. 1-40.

GREEN, D.H. and RINGWOOD, A.E., 1967, *The Genesis of Basaltic magmas.* Contr. Min. Petr., *15*, p. 103-190.

GUTENBERG, B. and RICHTER C.F., 1954, *Seismicity of the Earth and Associated Phenomena.* Princeton Univ. Press, New Jersey, p. 1-310.

KELLER, J., 1969, *Origin of Rhyolites by Anatectic Melting of Granitic Crustal Rocks, The Example of Rhyolitic Pumice from the Island of Kos (Aegean Sea).* Bull. Volcanol., *33*, p. 942-959.

KTENAS, K.A., 1930, *Report on the Geological Researches Made During 1928 and 1929.* Praktika of Athens Academy, *5*, p. 92-105, (in Greek).

KUNO, H., 1966, *Lateral Variation of Basaltic Magma Type Across Continental Margins and Island Arcs.* Bull. Volcanol., *29*, p. 195-222.

LE PICHON, X. and ANGELIER, J., 1979, *The Hellenic Arc and Trench System: a Key to the Neotectonic Evolution of the Eastern Mediterranean Area.* Tectonophysics, *60*, p. 1-42.

MCKENZIE, D., 1972, *Active Tectonics of the Mediterranean Region.* Geophys. J.R. Astr. Soc., *30*, p. 109-185.

———, 1978, *Active Tectonics of the Alpine-Himalayan Belt: the Aegean Sea and Surrounding Regions.* Geophys. J.R. Astr. Soc., *55*, p. 217-254.

NICHOLLS, A.I., 1971, *Santorini Volcano, Greece - Tectonic and Petrochemical Relationship with Volcanics of the Aegean Region.* Tectonophysics, *11*, p. 377-385.

NINKOVICH, D. and HAYS, J.D., 1972, *Mediterranean Island Arcs and Origin of High Potash Volcanoes.* Earth and Plan. Sci. Lett., *16*, p. 331-345.

PAPADOPOULOS, G.A., 1982, *Contribution to the Study of the Active Deep Tectonics of the Aegean and Surrounding Areas.* D. Sci. Thesis, Univ. of Thessaloniki, p. 1-176, (in Greek).

———, 1983, *The Volcanic Hazard in Greece.* Bull. Geol. Soc. Greece, in press, (in Greek).

———, 1984, *Cenozoic Magmatism and Deep Tectonics in the Aegean Area.* Submitted to Earth and Plan. Sci. Lett.

———, and PAVLIDES, S.V., 1984, *Shallow Seismogenetic Layer in the Outer Part of the Hellenic Arc.* Boll. Geof. Teor. Appl., in press.

PAPAZACHOS, B.C., 1980, *Seismicity Rates and Long-Term Earthquake Prediction in the Aegean Area.* Quaterniones Geodaesiae, *3*, p. 171-190.

——— and COMNINAKIS, P.E., 1971, *Geophysical and Tectonic Features of the Aegean Arc.* J. Geophys. Res., *76*, p. 8517-8533.

———, 1982, *A Catalogue of Historical Earthquakes in Greece and Surrounding Area, 479 B.C.-1900 A.C.* Geophys. Labor. Univ. of Thessaloniki, *Publ. No. 5*, p. 1-24.

——— and PAPADOPOULOS, G.A., 1977, *Deep Tectonic and Associated Ore Deposits in the Aegean Area.* Proc. 6th Colloq. Geol. Aegean Region, Athens, *3*, p. 1071-1080.

PE, G.G. and PIPER, D.J.W., 1972, *Vulcanism at Subduction Zones: the Aegean Area.* Bull. Geol. Soc. Greece, *8*, p. 133-144.

RINGWOOD, A.E., 1969, *Composition and Evolution of the Upper Mantle.* In: Hart, P.J., ed., The Earth's Crust and Upper Mantle. Amer. Geophys. Union Geophys. Monogr., *13*, p. 1-17.

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