Some characteristics of the seismicity of the Tyrrhenian Sea Region

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Summary. — In the first part of the paper the seismic strain release of the Tyrrhenian Sea Region (including Italy), as the function of time, is examined on the basis of the data of the earthquakes that took place from 1901.01.01 to 1970.12.31, between the northern latitudes of 34° and 44° and between the eastern longitudes of 8° and 18.5°, respectively. All registered shocks with a Richter-magnitude of 5.5 or over it were considered, independently from the focal depth. Three periods were recognized in the activity; the lengths of which are not the same, however.

In the second part the elastic strain release in accordance with the focal depth of the same earthquakes is treated briefly. It was found that the total strain-release had a maximum value in the depth between 0 and 74 kms and there was a minimum between the depth of 300 and 524 kms with an interval between 375 and 449 kms within which no earthquakes occurred at all. The general pattern of the distribution of seismicity as the function of hypocentral depth reminds to the well-known picture, one can experience in other regions where intermediate and deep shocks occur. This statement is consistent with the idea, according to which the seismicity of the Tyrrhenian Sea Region can be discussed and explained in the light of the theory of new global tectonics.

Finally, in the third part of the study, the authors have stated that in some cases multiple events occurred beneath the Tyrrhenian Sea Region. Such multiple seismic events were detected in the case of other areas, such as the Fiji-Tonga-Kermadec Region, the seismic belt of South America etc., — but, according to the knowledge of the authors, this is the first occasion when multiple seismic events are demonstrated in the Tyrrhenian Sea Region.

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RIASSUNTO. — Nella prima parte della nota viene studiata l'energia sismica liberata nella regione del Mar Tirreno (Italia compresa) in funzione del tempo, in base ai dati di terremoti che ebbero luogo, dal 1-I-1901 al 31-XII-1970, fra i 34° e i 44° di latitudine Nord e gli 8° e i 18°,5 di longitudine Est, rispettivamente. Sono state prese in esame tutte le scosse registrate con magnitudo ≥ 5,5 (magn. Richter), indipendentemente dalla profondità ipocentrale. I periodi di attività studiati sono stati tre, la cui durata tuttavia non è stata sempre la stessa.

Nella seconda parte, vengono brevemente trattate le tensioni elastiche liberate in relazione alla profondità ipocentrale, sempre dagli stessi terremoti. Si è trovato che la tensione totale liberata ha il massimo valore alla profondità compresa fra 0 e 74 km, il minimo fra i 300 e i 524 km, mentre nell'intervallo fra i 375 e i 441 km non si è avuto alcun terremoto. Il modello generale della distribuzione di sismicità in funzione della profondità ricorda quello ben noto, relativo a scosse che avvengono a profondità intermedia e profonda. Questa asserzione è compatibile con l'idea secondo cui la sismicità della regione del Mar Tirreno può essere discussa e spiegata alla luce della teoria di nuove tettoniche globali.

Infine, nella terza parte della nota, gli A.A. hanno trovato che in alcuni casi, eventi molteplici sono avvenuti al di sotto della regione del Mar Tirreno. Eventi simili si sono manifestati anche in altre zone, come quelle delle Isole Fiji, Tonga e Kermadec, l'arco sismico del Sud America etc., ma a conoscenza degli A A., è questa la prima volta che viene dimostrato che eventi sismici molteplici avvengono nella regione del Mar Tirreno.

1. – TEMPORAL VARIATION OF ELASTIC STRAIN RELEASE

As a "by-product" of another investigation, belonging to the program of the *Hungarian Research Group on Geophysical Volcanology*, we have compiled a list of the earthquakes of the Tyrrhenian Sea Region (Table I), and on this basis we made some investigations as regards the seismicity of our area. At first we constructed a graph to show the elastic strain release characteristics of the region under consideration. The data of earthquakes No. 1. ⊢⊣ No. 40 originally were given by Kárník (6). The data of the shocks No. 41. ⊢⊣ No. 66 were published by Rothé (8). Rothé's referred book consists of all the registered earthquakes that occurred until the end of 1965. Data of shocks, took place between 1966.01.01 and 1970.12.31 are to be found in the volumes of Regional Catalogue of Earthquakes, issued by the *International Seismological Centre*, Edinburgh.

We wish to point out that we took into consideration all earthquakes of tectonic origin, provided that their Richter-magnitude

TABLE I

No.	Date	Lat. °N	Long. °E	h km	M	$\sum E^{0.5}$. ergs$^{0.5}$. 10^{10}
1	1901.07.22	43.0	17.6	n	5.7	1.50
2	1901.08.10	44.0	15.6	n	5.7	3.00
3	1902.04.26	44.0	16.2	n	5.7	4.50
4	1904.02.24	42.1	13.2	n	5.6	5.76
5	1905.09.08	38.8	16.1	n	7.3	29.48
6	1907.08.01	43.2	17.6	n	5.7	30.98
7	1907.10.23	38.0	16.1	n	5.9	33.09
8	1908.12.28 *	38.0	15.5	10	7.0	47.25
9	1910.06.07	40.9	15.4	n	5.9	49.36
10	1910.08.01	39.0	15.0	200 ±	6.8	59.36
11	1911.04.05	40.0	15.5	200 ±	6.3	63.58
12	1913.06.28	39.5	16.3	n	5.5	64.64
13	1915.01.13	42.0	13.5	10	6.8	74.64
14	1915.07.07	39.0	15.0	275	5.9	76.75
15	1917.04.26	43.5	12.1	n	5.5	77.81
16	1918.11.10	43.8	11.9	n	5.7	79.31
17	1919.06.29	44.0	11.5	n	6.2	82.86
18	1919.10.22	41.4	12.6	n	5.6	84.12
19	1922.12.29	41.8	13.7	n	5.5	85.18
20	1923.02.06	43.3	17.2	n	5.5	86.24
21	1923.03.15	43.3	17.1	n	6.2	89.79
22	1923.09.18	35.5	14.5	n	5.5	90.85
23	1926.08.17	39.0	14.7	100	6.0	93.36
24	1928.03.07	38.5	16.0	100	6.6	100.44
25	1930.07.23	41.1	15.4	7	6.5	106.40
26	1930.10.30	43.7	13.3	4	5.9	108.51
27	1933.09.26	42.0	14.2	10	5.5	109.57
28	1937.10.17	39.3	15.2	300	5.8	111.35
29	1938.04.13	39.3	15.2	275	7.1	128.15
30	1939.05.27	42.0	17.3	n	5.5	129.21
31	1941.03.16	38.3	12.2	100	6.9	141.09
32	1941.03.16	38.3	12.2	100?	6.2	144.64
33	1942.12.29	43.4	17.2	n	6.0	147.15
34	1943.09.17	39.5	15.2	270 ±	5.5	148.21
35	1947.05.11	38.7	16.8	30	5.6	149.47
36	1947.07.31	39.2	15.2	290 ±	5.6	150.73
37	1950.09.05	42.5	13.3	~35	5.5	151.79
38	1952.12.26	39.8	15.6	265	6.2	155.34
39	1954.11.23	38.5	14.9	230	5.8	157.12

(*) The Messina earthquake

Segue table I

No.	Date	Lat. °N	Long. °E	h km	M	$\sum E^{0,5}$. ergs^{0,5}. 10^{10}
40	1955.02.17 *	39.6	13.1	450	5.6	158.38
41	1956.02.01	39.1	15.6	215	6.4	163.40
42	1956.08.15	43.2	16.0	n	6.0	165.91
43	1957.02.20	36.2	8.9	n	5.6	167.17
44	1957.05.20	38.7	14.1	60	5.8	168.95
45	1957.05.21	38.7	14.1	n	6.1	171.94
46	1958.06.24	42.2	13.4	n	5.5	173.00
47	1959.12.23	37.7	14.4	100	5.5	174.06
48	1960.01.03	39.5	15.5	250	6.2	177.61
49	1961.03.23	43.6	12.6	25	5.5	178.67
50	1961.05.10	35.1	15.8	n	5.5	179.73
51	1961.12.02	36.9	8.0	n	5.5	180.79
52	1962.01.07	43.2	17.1	n	6.0	183.30
53	1962.01.11	43.3	17.0	n	6.1	186.29
54	1962.03.25	39.1	14.7	343	5.5	187.35
55	1962.04.17	42.4	17.4	25	5.5	188.41
56	1962.06.11	43.6	18.3	n	6.3	192.63
57	1962.08.21	41.1	15.1	36	5.6	193.89
58	1962.08.21	41.1	15.1	34	6.1	196.88
59	1962.08.21	41.2	15.1	n	6.0	199.39
60	1963.02.13	40.7	15.6	n	5.5	200.45
61	1963.02.17	43.9	17.2	n	5.5	201.51
62	1963.06.01	39.0	15.0	285	5.5	202.57
63	1963.07.19	43.4	8.2	n	5.7	204.07
64	1963.07.19	43.4	8.2	n	6.2	207.62
65	1963.09.29	36.1	18.0	47	5.7	209.12
66	1964.04.14	39.0	14.5	306	5.5	210.18

(*) The deepest shock ever observed in the Tyrrhenian Sea Region

reached the value of 5.5. It is noteworthy, furthermore, that on our area investigated no earthquakes of $M > 5.5$ occurred between 1966.01.01 and 1970.12.31. Magnitude d, can be found in certain cases in the catalogues, was regarded by us as $M = 5.5$.

For the calculation of seismic energy we have employed the well-known equation, due to Gutenberg and Richter:

$$\log E = 11.8 + 1.5\ M,$$

where E is the released seismic energy, expressed in ergs and M the

Richter-magnitude. The elastic strain release is proportional to $E^{0,5}$ and its dimension is $\text{ergs}^{0,5}$.

Our Fig. 1, shows the characteristics of the distribution of elastic strain release as the function of time. On the diagram altogether three periods of activity can be recognized, although the beginning of the first one is not known. The first period, namely, began before 1901.

It seems that the first period ended (and the second one began) in the year 1926. The end of the second period and the beginning of the third one can be found in 1941. It can be supposed, furthermore, than the third period ended in 1964 and since this time (at least until the end of 1970) there was a calm period, which may be the introducing part of a longer period of activity.

In Table I h means the focal depth and N means a "normal" depth, for which $0 < h \leqslant 70$ km.

$$\sum E = \sum_{\text{No. } 1}^{\text{No. } 66} E = 1741.571 \cdot 10^{20} \text{ ergs.}$$

Thus the total energy corresponds to an individual earthquake the magnitude of which amounts roughly to 7.63.

The average energy can be computed by using the formula:

$$\bar{E} = \frac{\sum E}{n},$$

where n is the number of shocks considered, that is $n = 66$. The result is:

$$\bar{E} = 26.387 \cdot 10^{20} \text{ ergs.}$$

The equivalent magnitude of this energy is 6.41.

This value permits us to take an interesting comparison with other areas. According to an earlier study of one of us (4), the so called equivalent magnitude of the "North Polar Region" [Area 44 (3)], furthermore that of the "Pacific Basin" [Area 39 (3)], "Tasmania to Antarctica and Antarctica" [Areas 45 and 50 (3)], and "Fiji Island" [Area 13 (3)] is between 6.00 and 6.49; although in the quoted paper for the calculation of the equivalent magnitude the equation

$$M_{\text{equ}} = \left| \log \left(\frac{\sum_{t_1}^{t_2} E}{k} \right) - 11.0 \right| \cdot 1.6^{-1} \qquad [1]$$

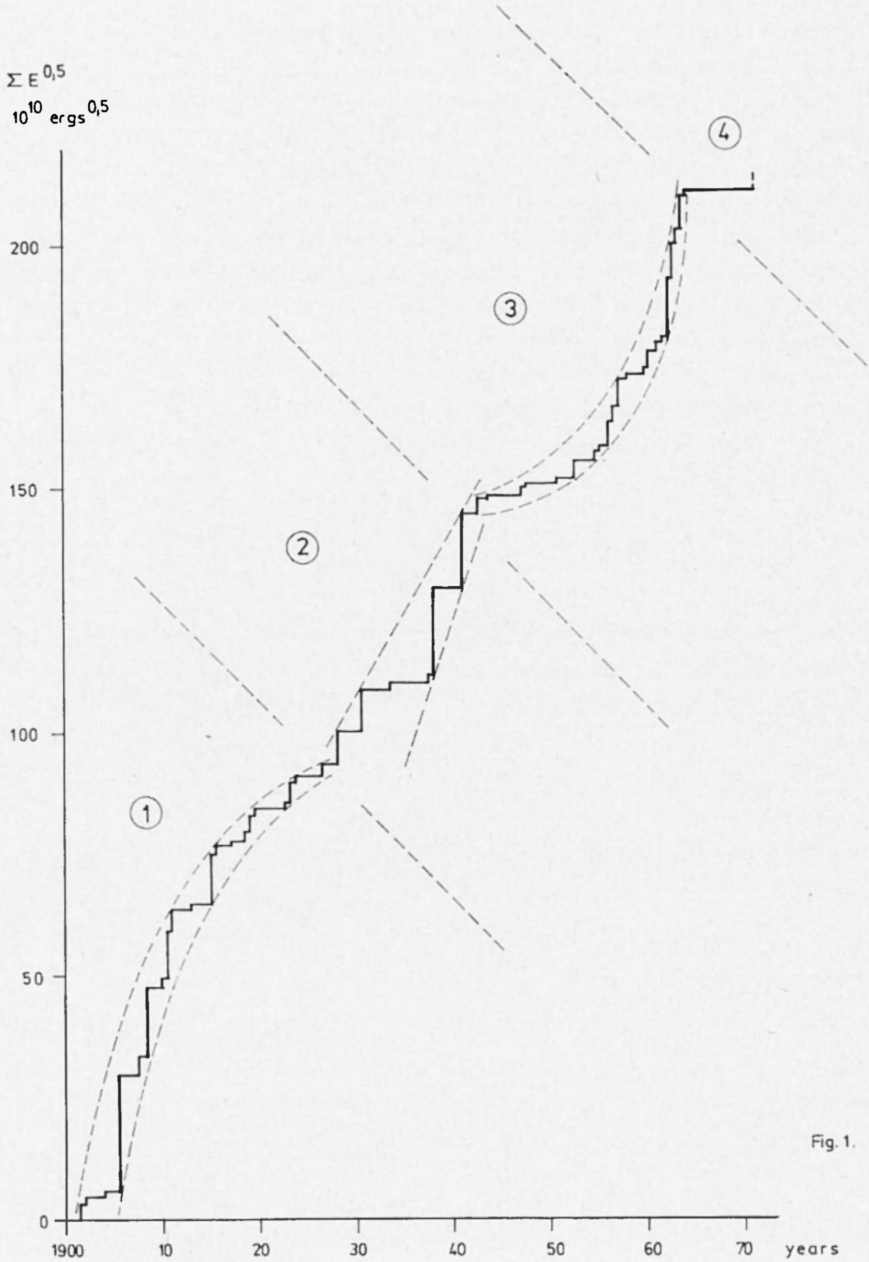

Fig. 1 – Cumulative curve of the value $\sum E^{0.5}$ for the Tyrrhenian Sea Region. 1, 2, 3 and 4 mean periods of activity; the beginning part of period 1 as well as the continuation of period 4 is unknown as yet. For all the observed shocks, independently from the focal depth, $M \geqslant 5.5$.

was employed, instead of the expression

$$M_{equ} = \left[\log \left(\frac{\sum_{t_1}^{t_2} E}{k} \right) - 11.8 \right] \cdot 1.5^{-1}. \qquad [2]$$

In [1] and [2] k is the number of all earthquakes, occurred within the time-interval $t_1 \mapsto t_2$ over the area examined, E the released seismic energy and M_{equ} the equivalent magnitude. Equation [2] corresponds to the expression

$$\log E = 11.8 + 1.5\, M.$$

which today is generally accepted, but when the above-mentioned investigation had been in preparation, we employed the earlier formula, according to which

$$\log E = 11.0 + 1.6\, M.$$

Taking into account the fact that for the Tyrrhenian Sea Region

$$M_{equ} = 6.41,$$

we can state that *on a world scale the seismicity of the Tyrrhenian Sea Region is rather slight*, in spite of the fact that a few earthquakes had a magnitude of 7.0 or greater. By other words the seismic level of our region investigated is comparable with that of Areas 44, 39, 45, 50 and 13 of Gutenberg and Richter (3).

Using equation [1] we have classified the surface of the Earth in accordance with the value of the equivalent magnitude. This is given in Table II.

TABLE II

M_{equ}	Category
0.00 — 5.99	I ...... Ascismic and very weakly seismic
6.00 — 6.49	II ..... Weakly seismic
6.50 — 6.99	III ... Moderately seismic
7.00 — 7.49	IV .... Strongly seismic
7.50 — 8.00	V...... Very strongly seismic

The Areas, mentioned above, fall into Category II, and the same is true for the case of the Tyrrhenian Sea Region as well.

2. – Spatial Variation of Elastic Strain Release

In this chapter the distribution of seismic activity according to the focal depth will be examined on the basis of data, presented in Table I. At first we show the effective data:

Table III

Focal depth h km	$\sum E^{0.5}$, ergs$^{0.5}$. 10^{10}	Number of shocks
0 — 70		
	128.53	46
100	26.08	5
200	14.22	2
215	5.02	1
230	1.78	1
250	3.55	1
265	3.55	1
270	1.06	1
275	18.91	2
285	1.06	1
290	1.26	1
300	1.78	1
306	1.06	1
343	1.06	1
450	1.26	1
	210.18	66

Dividing the Earth's interior into horizontally lying layers, the thickness of which is 74 kms, we received the following values:

TABLE IV

Layer km	$\sum E^{0.5}$, ergs$^{0.5}$. 10^{10}
0 — 74	128.53
75 — 149	26.08
150 — 224	19.24
225 — 299	31.17
300 — 374	3.90
375 — 449	0
450 — 524	1.26

The general pattern of the distribution of seismic activity with the depth beneath the Tyrrhenian Sea Region is very similar to those ones, which are experienced in other areas, where intermediate as well as deep earthquakes take place. For example, let us see the curve, representing the variation of elastic strain release in the case of the Sunda Arc (7); or the diagrams, valid for the Earth as a whole (1.-) and let us compare these curves (Fig. 2) with the one, valid for the Tyrrhenian Sea Region (Fig. 3). The two most conspicuous features of these curves are as follows:

a) – A strong maximum is existing in the uppermost layer, that is near the Earth's surface;

b) – One can find a remarkable minimum around the depth of 420 – 450 kms.

It is well-known by way of many other research that the theory of global plate tectonics is excellently applicable for the case of the Tyrrhenian Sea Region as well. The pattern of the variation of seismic activity with the depth in the case of our area investigated is perfectly consistent with the models of plate tectonics.

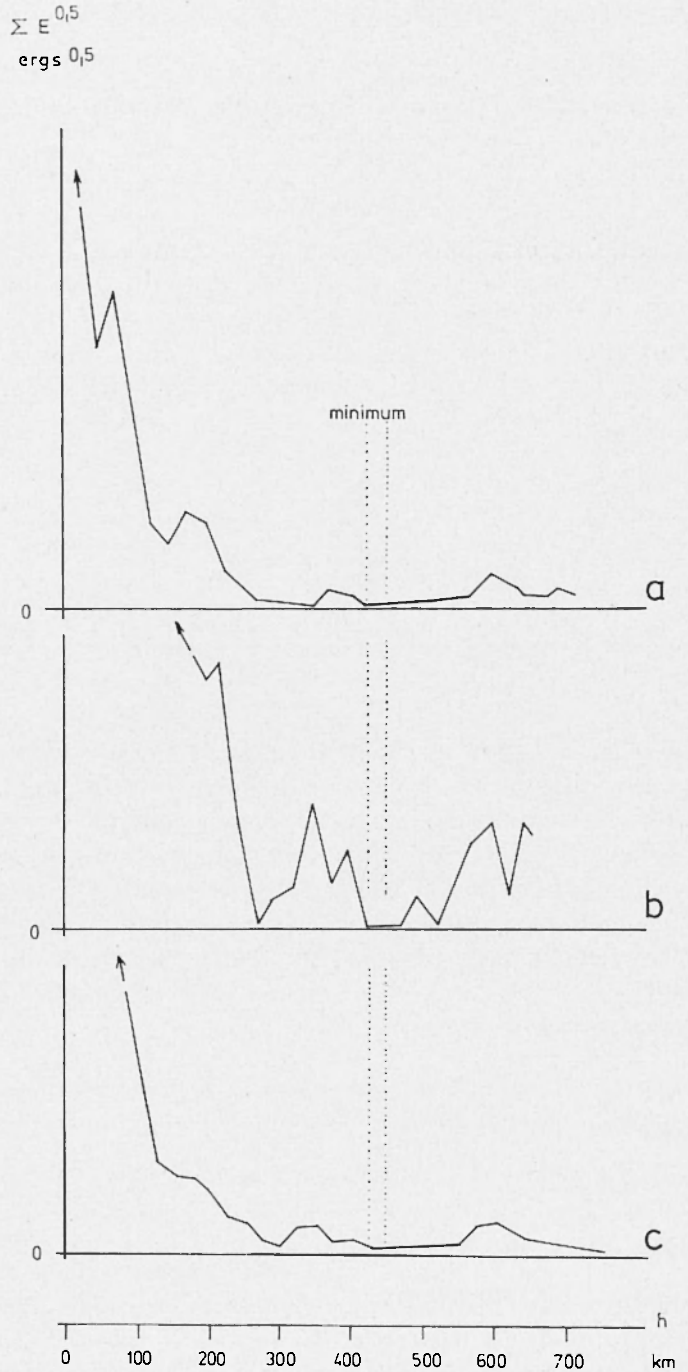

Fig. 2 – Seismic activity versus focal depth. **a**) For the Sunda arc [after Ritsema (7)]; **b**) for the Earth as a whole [from the data of Båth and Duda (1)]; **c**) for the Earth as a whole [from the data of Galanopoulos (2)].

3. – Multiple Seismic Events

Isacks, Sykes and Oliver (5) have demonstrated that certain earthquakes exhibit "clustering" which refers to a concentration of shocks both in space and time. The earthquake-sequences and swarms can be regarded as special kinds of clusters. The earthquake-sequences of shallow events are usually called aftershocks, provided that at the beginning of the series there is a strong shock with a higher magnitude, called main-shock. In the absence of a main-shock we often speak

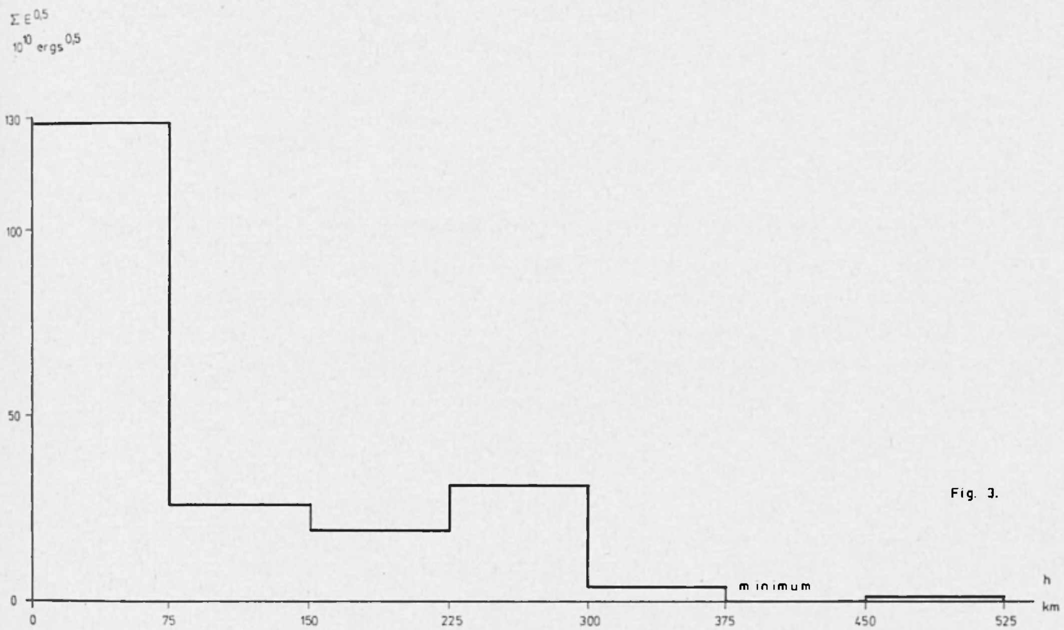

Fig. 3 – Seismic activity versus focal depth in the case of the Tyrrhenian Sea Region (for a detailed explanation see the text).

about swarms, the members of which are more or less similar to one another in their magnitudes. Swarms usually are of volcanic origin while the sequences are due to tectonic causes. The aftershock-sequences as well as the swarms include large number of events. Intermediate and deep earthquakes, however, do not exhibit such sequences and swarms. Many intermediate and deep shocks are alone, that is without well-observable connection with other intermediate and deep events;

but some of them occur in clusters. The hypocenters of the members of such clusters are very near to one another in the space; sometimes the foci are the same or are only in a distance 1 – 2 to 80 kilometres from one another. The time-interval between the occurrence of the events may be as low as some seconds (!) (5) or some hours or about one day (9). In the Fiji – Tonga – Kermadec Region most deep multiplets were doublets, some were triplets and there were cases when 7. 8 or even 12 events followed fastly, one after the other, from foci which were very near to one another. Clustering of earthquakes were observed beneath the North Island (New Zealand), at the Bonin Islands Region, at the Solomon Islands and in the seismic belt of South America, too. Now we shall show that some clusterings occurred in the case of the Tyrrhenian Sea Region as well. The clusters are listed in Table V.

TABLE V

No.	Date	h	m	s	Lat. °N	Long. °E	*h* km	*M*
31	1941.03.16	16	35	02	38.3	12.2	100	6.9
32	1941.03.16	18	48	21	38.3	12.2	100?	6.2
44	1957.05.20	19	57	34	38.7	14.1	60	5.8
45	1957.05.21	11	44	06	38.7	14.1	n	6.1
57	1962.08.21	18	09	07	41.1	15.1	36	5.6
58	1962.08.21	18	19	33	41.1	15.1	34	6.1
59	1962.08.21	18	44	51	41.2	15.1	n	6.0
63	1963.07.19	05	45	28	43.4	8.2	n	5.7
64	1963.07.19	05	46	05	43.4	8.2	n	6.2

We should like to point out that there were two interesting cases for which the foci seems to be very near to one another, the time-difference between the occurrence of the events, however, was greater than one day. We call such events as *quasi-multiplets*. The data of these *quasi-multiplets* are to be found in Table VI.

TABLE VI

No.	Date	h	m	s	Lat. °N	Long. °E	*h*	*M*
52	1962.01.07	10	03	14	43.2	17.1	n	6.0
53	1962.01.11	05	05	04	43.3	17.0	n	6.1
63	See in Table V							
64	See in Table V							
64a	1963.07.27	05	58	23	43.5	8.4	n	5.4

It is interesting to note that in the case of all shallow multiplets as well as in the case of one of the *quasi-multiplets* the magnitude of the first shock is smaller than that of the second quake, contrary to the case of normal shallow earthquake-sequences, where usually the first shock is the strongest within the whole series and the so called foreshocks are rather rare phenomena.

4. – CONCLUSIONS

The main theses of this article can be summarized as follows:

a) Although the seismicity of the Tyrrhenian Sea Region is remarkable relative to other parts of Europe and many of the marginal seas of this continent, it is relatively slight on a world scale. The temporal variation of elastic strain release is not a regular process: on the contrary, at least three periods of different lengths can be distinguished between 1901 and 1971.

b) The pattern of the spatial variation of elastic strain release — that is the pattern of seismic activity in accordance with the hypocentral depth — is similar to the cases, one can experience beneath other areas, where intermediate ($h = 70 \vdash\!\dashv 300$ km) and deep

($h > 300$ km) shocks occur. The deepest shock, ever observed on our region under investigation originated in a depth of about 450 km beneath the surface.

c) The new theory of global plate tectonics is applicable for the case of the Tyrrhenian Sea Region. In another paper we showed that a part of the African lithosphere is being consummated underneath the Tyrrhenian Sea and the dip-angle of the *Benioff*-zone, developed there, is about 51 – 52 degrees. "Seeing from volcano Stromboli the greatest dip — as it is revealed by the inclined seismic zone, by other words: by the *Benioff*-zone — can be experienced in the direction of N 64° W approximately" (from the Abstract of the paper: "*Some Words on the Deep Structure of Italian Volcanoes*", "Contribution No. 06/74/HRGGV).

d) In the occurrence of both shallow and intermediate earthquakes, we can observe certain clustering, more or less similar to the case of the Fiji–Tonga–Kermadec Region as well as some other parts of the world.

REFERENCES

(1) Båth, M., Duda, S. J., 1963. – *Strain Release in Relation to Focal Depth.* "Geofisica Pura e Applicata", **56**, pp. 93-100.

(2) Galanopoulos, A. G., 1964. – *Note on Strain Release Variation with Depth.* "Annali di Geofisica", **XVII**.

(3) Gutenberg, B., Richter, C. F., 1954. – *Seismicity of the Earth.* Princeton.

(4) Hédervári, P., 1964. – *Investigations Regarding the Earth's Seismicity.* Part II: *The Circumpacifical, Indonesian and Eurasian Earthquake Belts.* "Gerlands Beiträge zur Geophysik", **73**, 4.

(5) Isacks, B. L., Sykes, L. R. and Oliver, J., 1967. – *Spatial and Temporal Clustering of Deep and Shallow Earthquakes in the Fiji-Tonga-Kermadec Region.* "Bull. Seis. Soc. of Am.", **57**, 5.

(6) Kárník, V., 1968. – *Seismicity of the European Area.* 1, Praha.

(7) Ritsema, A. R., 1954. – *The Seismicity of the Sunda Arc in Space and Time.* "Indonesian Journal for Natural Science", Nos. 1, 2, 3.

(8) Rothe, J. P., 1969. – *The Seismicity of the Earth 1953-1965.* Paris.

(9) Santo, T., 1969. – *Characteristics of Seismicity in South America.* "Bull. Earth. Res. Inst.", **47**, 4.