Some seismologieal results and geostructural suggestions from a study of the Reggio Calabria earthquake of 16 January, 1975

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Summary. — Starting from the analytic determination of the most important parameters of the Reggio Calabria earthquake, several geostructural hypotheses are analyzed and discussed.

The statistical hypocentre, calculated in two separate phases for the epicentral coordinates ($\varphi = 38°04'28''$; $\lambda = 15°38'55''$) and for the depth ($h = 10.04$ km), is consistent with an earlier macroseismic estimation.

The travel times for the first arrivals, limited to the distance interval $0 \leqslant \Delta° \leqslant 12$ can be approximated by means of the three linear equations:

$$T = 0.96 + \Delta/5.39 \qquad 0 \leqslant \Delta° \leqslant 1.1$$
$$T = 4.81 + \Delta/7.71 \qquad 1.1 \leqslant \Delta° \leqslant 6.0$$
$$T = 9.37 + \Delta/8.14 \qquad 6.0 \leqslant \Delta° \leqslant 12.0$$

which can be interpreted as the travel-time curves of the direct (Pg) and refracted (P_{n_1}, P_{n_2}) longitudinal waves.

The existence of a focal mechanism, compatible with a couple + oppositely directed force model is deduced from a study of the signs of the first impulses. This model includes faulting and displacement with dislocation plane N 22°E and inclination of ~ 75° towards N112°E. Considering the focal location and our geostructural knowledge of the area involved, the Reggio Calabria earthquake can be explained by a process of tectonic distension due to the drift of the Calabrian Arc and to other reliable geostructural elements. The explanation is critically evaluated in relation to the tectonic forces involving the Strait of Messina and the volcanic zone of Etna.

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RIASSUNTO — Muovendo dalla determinazione analitica di alcuni parametri del terremoto di Reggio Calabria, sono analizzate e discusse alcune ipotesi geostrutturali.

L'ipocentro statistico, calcolato in due fasi e separatamente per le coordinate epicentrali ($\varphi = 38°04'28''$; $\lambda = 15°38'55''$) e per la profondità ($h = 10{,}04$ km), è consistente con una precedente stima macrosismica.

I tempi di tragitto dei primi arrivi, limitatamente all'intervallo di distanze $0 \leqslant \Delta \leqslant 12°$, sono approssimabili mediante le tre rette di equazioni:

$$T = 0{,}96 + \Delta/5{,}39 \qquad 0 \leqslant \Delta° \leqslant 1{,}1$$
$$T = 4{,}81 + \Delta/7{,}71 \qquad 1{,}1 \leqslant \Delta° \leqslant 6{,}0$$
$$T = 9{,}37 + \Delta/8{,}14 \qquad 6{,}0 \leqslant \Delta° \leqslant 12{,}0$$

interpretabili come equazioni delle dromocrone delle onde longitudinali dirette (Pg) e rifratte (P_{n_1}, P_{n_2}).

Dallo studio del segno dei primi impulsi risulta poi un meccanismo focale compatibile con un modello teorico di coppia + forze dirette ed opposte, determinanti movimento di taglio e distacco, con piano di dislocazione N22°E ed inclinazione di ~ 75° verso N112°E.

In considerazione della ubicazione focale e delle conoscenze geostrutturali dell'area interessata, il terremoto di Reggio Calabria è riconducibile al processo di distensione tettonica riferibile al moto di deriva dell'Arco Calabro e ad altri elementi geostrutturali attendibili. Queste ultime risultanze sono infine criticamente vagliate in relazione alle direttrici tettoniche interessanti lo Stretto di Messina e la zona vulcanica dell'Etna.

INTRODUCTION

The Reggio Calabria earthquake of 16 January 1975 ($M = 4.7$), the origin of which was in a fulcrum zone between the volcanic areas of the Southern Tyrrhenian Sea and Eastern Sicily, offers, among other things, the possibility of a geostructural investigation relative to some problems of great interest.

In the contest of research promoted by the Geophysical and Geodetical Institute of the University of Messina, the authors of the present note deal with some problems which are mentioned in a preceding note which is, at the time of writing, in course of publication.

STATISTICAL DETERMINATION OF THE FOCAL PARAMETERS

A first evaluation of the focal parameters, using forty arrival times of the P (or Pn) and a statistical procedure (Bottari and Sciré,

1973) (6) derived from a well-known method of Caloi (1943) (14), gives the following results:

$$
\begin{aligned}
\varphi &= 38^\circ 04' 46.4''\ \mathrm{N}\ (\pm\ 1.85') \\
\lambda &= 15^\circ 29' 10.2''\ \mathrm{E}\ (\pm\ 1.42') \\
h &= 9.63\ \mathrm{km} \qquad (\pm\ 14.26\ \mathrm{km}) \\
H &= 00^{h}09^{m}45^{s}.2 \qquad (\pm\ 1.76\ \mathrm{sec})
\end{aligned}
\qquad [1]
$$

where, φ, λ, h and H indicate, respetively, the geographic latitude, the longitude, the depth, and the origin time. In the calculations of [1], as standard travel-times for the longitudinal waves, those of Jeffreys and Bullen (1948) (30) have been used.

As was to be expected the values of [1] present large uncertainties for h and H. In this connexion it is well known that the statistical method for the calculation of the four parameters of the source leads, in the case of shallow earthquakes, to different degrees of precision in the estimation of φ, λ, h and H. In fact, while the uncertainties regarding the values of φ and λ are in general compatible with the physical dimensions of the focal zone and with the propagation anomalies, on the contrary the uncertainties regarding the depth value of the hypocentre appear large when observation data are not available from stations near the epicentre. The negative implications of this fact are reflected both in the origin time, which becomes rather uncertain, and in the impossibility of individualizing the crustal structures primarily involved in the seismic phenomenon. For these reasons it was decided to determine separately the epicentral coordinates (φ, λ) and the hypocentral depth (h). The value of the origin time (H) was determined successively by repeating the determinations of φ and λ, and by using for the standard times a travel-time curve of Jeffreys and Bullen interpolated for the depth value previously estimated. In this case the depth value, (h), having already been calculated, no longer figures as an unknown. These latter values of φ and λ were assumed as the definitive values of the epicentral coordinates. Therefore, the procedure followed can be schematized as follows:

a) *Determination of the epicentral coordinates*

The P (or Pn) travel-times observed in 36 stations, with $D \geqslant 200$ km, imply (with the focal depth assumed to be $h = 0$) to allow the following as the most probable epicentre:

$$
\begin{aligned}
\varphi &= 38^\circ 04' 08.5''\ \pm\ 0^\circ.02677 \\
\lambda &= 15^\circ 39' 06.5''\ \pm\ 0^\circ.02379
\end{aligned}
\qquad [2]
$$

b) *Determination of the hypocentral depth*

Assuming for epicentre the coordinates [2], and as provitional values the origin time of [1] and the focal depth $h = 10$ km, and namely

$$\begin{aligned} \varphi &= 38^{\circ}04'08.5'' \\ \lambda &= 15^{\circ}39'06.5'' \end{aligned} \qquad [3]$$

$$\begin{aligned} h &= 10 \text{ km} \\ H &= 00^{h}09^{m}45.2^{s} \end{aligned} \qquad [4]$$

where the values [3] are satisfactory while [4] must be approximated. A procedure similar to that used by Nordquist (1962) ([33]) is used for the calculation of the focal depth. Such a method, of which we omit the details, uses the travel times of the direct and refracted waves (P_{n1} and P_{n2}) in a crustal model consisting of homogeneous and isotropic horizontal layers.

The crustal model which we have used (Fig. 1) consists of a first layer, called superficial layer, with $h_1 = 5$ km, and the velocity of the P waves, $V_1 = 3.7$ km/sec; a second layer, the intermediate layer, with $h_2 = 20$ km and $V_2 = 5.5$ km/sec; and a third layer, beginning at a depth of 25 km, with $V_3 = 7.8$ km/sec. The values for the thickness of the layers and for the velocities of the longitudinal waves has been

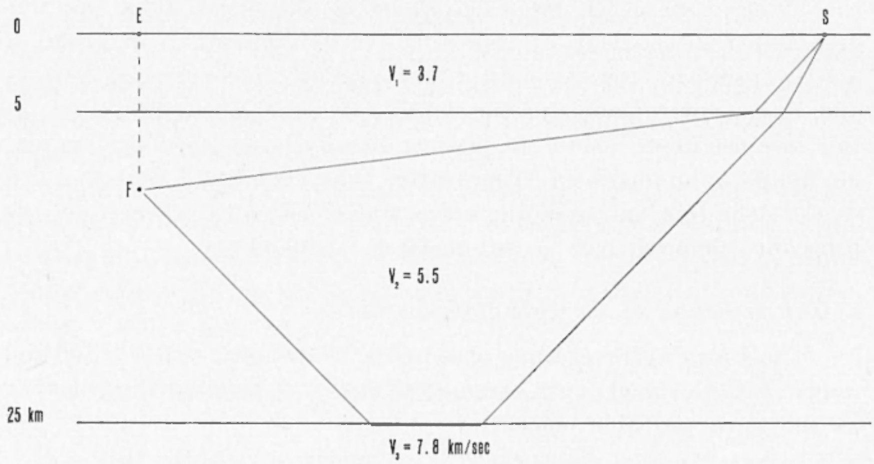

Fig. 1 – Scheme of simplified crust-model preliminarily adopted.

estimated using results obtained, for the zone of the Southern Tyrrhenian Sea and for Sicily, from seismic exploration and from seismological investigation (Cassinis et al., 1969; Latter, 1970; Finetti e Morelli, 1972; Fahlquist, 1969; Colombi et al., 1974; Bottari and Girlanda, 1974) (18,31,26,25,19,7).

Elements of the depth calculation for the eight closest stations used ($D \leqslant 160$ km) are presented in Table 1, with the following key: RCI = Reggio Calabria; MES = Messina University; SLN = Serra La Nave; CAT = Catania; LLI = Lipari; PLI = Panarea; ACL = Alicudi; FUS = Fuscaldo.

TABLE 1

No.	Station Code	Δ km	t (+00^h) min sec	T_o sec	T_c sec	R sec	a sec/km
1	RCI	2.97	09 46.9	1.7	2.35	—0.65	+0.054
2	MES	15.77	49.7	4.5	4.05	+0.45	+0.287
3	LLI	73.78	59.5	14.3	14.52	—0.22	+1.341
4	PLI	79.79	10 00.4	15.2	15.55	—0.35	+1.451
5	SLN	73.42	00.8	15.6	14.40	+1.20	+1.335
6	CAT	79.39	01.9	16.7	15.50	+1.20	+1.444
7	ACL	124.06	06.2	21.0	21.55	—0.55	—0.120
8	FUS	152.31	09.4	24.2	25.15	—0.95	—0.120

Key of the symbols:

Δ = epicentral distance
t = arrival time of the Pg or Pn wave
T_o = observed travel-time
T_c = J-B standard travel-time
$R = T_o - T_c$
$a = \frac{\partial T}{\partial h}$

The calculation can be reduced to the resolution of the following system of eight equations by means of the least-square method:

$$a_i \delta h + \delta H - R_i = v_i \qquad [5]$$

where the unknowns δh and δH indicate the corrections which have to be made to the initial values of h (10 km) and of H ($00^h09^m45.2^s$), respectively. R_i, v_i and a_i indicate, respectively, the difference between the observed and the standard travel-time, the residual, and the partial derivative with respect to h, of the function representative of the travel-time curve.

The solutions of system [5] are the following:

$$\begin{aligned} \delta h &= (\ \ 0.71 \pm 0.20)\ \text{km} \\ \delta H &= (-0.48 \pm 0.39)\ \text{sec} \end{aligned} \tag{6}$$

and thus, according, to the crustal model adopted, the most probable depth and the corresponding origin time, are:

$$\begin{aligned} h &= (10.71 \pm 0.20)\ \text{km} \\ H &= 00^{h}09^{m}44.72^{s} \pm 0.39^{s} \end{aligned} \tag{7}$$

The first of [7] confirms fully the depth value obtained by the preliminary analytic method, as well as that estimated on the basis of macroseismic criteria (Bottari and Lo Giudice, 1975b) (9). However, the crustal model used may occasion some objections and lead to some hesitations because of the way it has been structured.

In particular, the data from CAT and SLN seem to be in substantial disagreement with the model. It was therefore decided not to use a single structural model for all the crustal sections relative to the eight stations chosen for the depth determination, but to use calculated travel-times compatible with different crustal sections. In other words, the reference travel-times were estimated separately assuming, for each couple epicentre-station, the most appropriate crustal section. These crustal section models were elaborated on the basis of the work of Scarascia and Colombi (1971) (44), Colombi et al. (1974) (19).

The resolution of system [5], this time limited to six equations because adequate models are not available for the CAT and SLN sections, leads to the following results:

$$\begin{aligned} h &= (9.14 \pm 2.77)\ \text{km} \\ H &= 00^{h}09^{m}45.44^{s} \pm 0.04^{s} \end{aligned} \tag{8}$$

This last estimation of the depth is not substantially different from that in [7]. It seems possible, therefore, to locate the focus of the earthquake between a depth of 9 and 12 km, with a average value for the hypocentral depth of 10.04 $\pm$ 1.36 km.

c) *Determination of the origin time*

Resorting to a frequently used criterion, the determination of φ, λ, and H was successively repeated with the condition that $h = 10.04$ km. The procedure, applied to the data from forty stations (with $D \geqslant 160$ km, and the standard travel-times of Jeffreys and Bullen) gives the following results:

$$\begin{aligned} \varphi &= 38^{\circ}04'28.0'' \pm 1.43' \\ \lambda &= 15^{\circ}38'55.4'' \pm 1.24' \\ H &= 00^{h}09^{m}45.53^{s} \pm 0.23^{s} \end{aligned} \qquad [9]$$

The [8] locate the epicentre 0.7 km further to the N-NW than the preceding epicentral determination [2], which, is substantially confirmed. As it appears in the third of [9], the value of H differs by only $\sim$ 0.1 sec from the value obtained by using the sections and velocities of Colombi et al. (1974) ([19]). The standard deviation of the residuals, for the forty travel-times used in the determination, is then 0.92 sec. Elements of the calculations are presented in Table 2, and the definitive focal parameters of the Reggio Calabria earthquake are therefore (Fig. 2):

$$\begin{aligned} \varphi &= 38^{\circ}04'28.0'' \pm 1.43' \\ \lambda &= 15^{\circ}38'55.4'' \pm 1.24' \\ h &= (10.04 \pm 1.36) \text{ km} \\ H &= 00^{h}09^{m}45.53^{s} \pm 0.23^{s} \end{aligned} \qquad [10]$$

Pg, *Pn*: TRAVEL-TIMES AND VELOCITIES

In order to emphasize the dependance of the travel-times on the epicentral distance, sixty five time-distance couples were analized. Relative to the observed first arrivals, the data does not include those times for which the difference from the corresponding Jeffreys-Bullen values are greater than $\pm$ 4 sec.

The relation $T = T(\Delta)$ in particular, in the distance interval $0 \leqslant \Delta^{\circ} \leqslant 12$, can be represented by three segments belonging to the lines of equations:

$$T = (0.96 \pm 0.81) + \Delta/(5.39 \pm 0.38), \qquad 0<\Delta^{\circ}< 1.1 \quad [11]$$

$$T = (4.81 \pm 0.77) + \Delta/(7.71 \pm 0.10), \qquad 1.1<\Delta^{\circ}< 6.0 \quad [12]$$

$$T = (9.37 \pm 0.91) + \Delta/(8.14 \pm 0.06), \qquad 6.0<\Delta^{\circ}<12.0 \quad [13]$$

TABLE 2

No.	Station Code	Δ deg	t (+00h) min sec	T_o sec	T_c sec	O-C sec
1	PLR	1.822	10 17.0	31.47	31.57	—0.10
2	NPL	2.914	10 33.0	47.47	47.18	+0.29
3	VLS	3.898	10 47.3	61.77	61.15	+0.62
4	SBS	4.384	10 52.2	66.67	68.05	—1.38
5	JAN	4.357	10 53.7	68.17	67.67	+0.50
6	TIR	4.610	10 56.8	71.27	71.27	0.00
7	AQU	4.607	10 57.8	72.27	71.22	+1.05
8	OHR	5.002	11 01.5	75.97	76.83	—0.86
9	KZN	5.252	11 06.7	81.17	80.40	+0.77
10	SKO	5.908	11 14.9	89.37	89.60	—0.23
11	VAY	6.244	11 21.0	95.47	94.38	+1.09
12	ATH	6.371	11 21.5	95.97	96.17	—0.20
13	ATU	6.371	11 21.7	96.17	96.17	0.00
14	PTL	6.483	11 23.5	97.97	97.76	+0.21
15	PRT	6.746	11 28.0	102.47	101.44	+1.03
16	LJU	8.006	11 43.1	117.57	119.09	—1.52
17	ZAG	7.823	11 43.3	117.77	116.52	+1.25
18	KDZ	8.267	11 47.9	122.37	122.75	—0.38
19	PRK	8.394	11 49.2	123.67	124.52	—0.85
20	EZN	8.499	11 51.0	125.47	125.98	—0.51
21	DIM	8.589	11 53.5	127.97	127.23	+0.74
22	ISO	8.904	11 56.7	131.17	131.57	—0.40
23	PVL	8.836	11 57.0	131.47	130.64	+0.83
24	IZM	9.145	12 00.3	134.77	134.91	—0.14
25	DEV	9.484	12 05.5	139.97	139.58	+0.39
26	MLL	9.822	12 08.9	143.37	144.25	—0.88
27	DMK	10.015	12 11.0	145.47	146.90	—1.43
28	JOS	11.006	12 26.9	161.37	160.38	+0.99
29	ELL	11.420	12 31.0	165.47	166.09	—0.62
30	STU	11.646	12 36.0	170.47	169.19	+1.28
31	BSF	11.706	12 36.8	171.27	169.99	+1.29
32	PRU	11.937	12 37.5	171.97	173.15	—1.18
33	CDF	11.979	12 38.0	172.47	173.71	—1.24
34	CLL	13.366	12 56.0	190.47	192.14	—1.67
35	TIO	20.155	14 22.7	277.17	277.15	+0.02
36	NUR	23.167	14 53.0	307.47	307.52	—0.05
37	KER	25.587	15 16.7	331.17	330.78	+0.39
38	SHI	31.785	16 10.6	385.07	386.62	—1.55
39	KIC	36.596	16 54.4	428.87	427.90	+0.97
40	LWI	41.916	17 39.0	473.47	472.11	+1.36

Key of the symbols: Δ = epicentral distance; t = P-wave arrival-time; T_o = observed travel-time; T_c = J–B standard travel-time; O-C = travel-time residual.

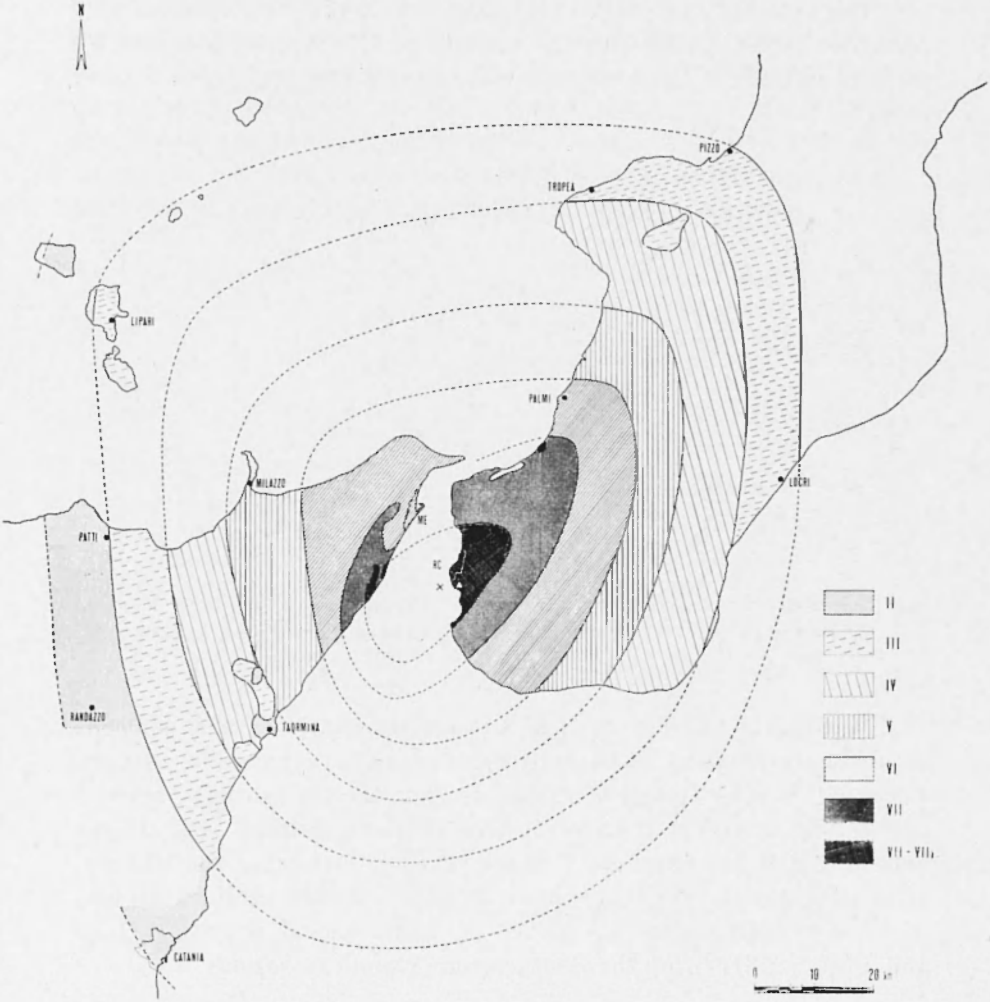

Fig. 2 – Relieved isosciste-map where the cross and the open triangle indicate respectively the macroseismic and the analytical epicentre.

which can be interpreted as the travel-time equations (Fig. 3) of the direct waves (Pg) and of the refracted waves (P_{n1}, P_{n2}).

The velocity of 5.39 km/sec for the Pg (eq. [11]), which agrees with the values obtained by Latter (1970) ([31]) for the Aeolian Island zone, also agrees with the average of those proposed by several researches (Cassinis et al., 1969; Scarascia and Colombi, 1971; Finetti and Morelli, 1972; Colombi et al., 1974) ([18,44,26,19]) for various crustal sections of Sicily, Calabria and Southern Tyrrhenian basin.

The velocity 7.71 km/sec (eq. [12]), which can be attributed to a refraction phase agrees with the velocity of 7.78 km/sec, obtained by Bottari and Girlanda (1974)(7), for the Middle Western Mediterranean basin.

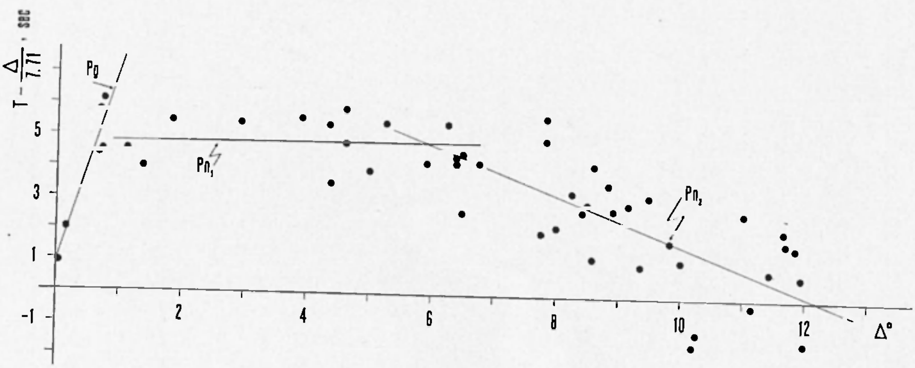

Fig. 3 – Reduced travel-time curves for P_g waves ($V = 5.39$ km/sec) P_{n_1} waves ($V = 7.71$ km/sec) and P_{n_2} waves ($V = 8.14$ km/sec).

Finally, the velocity value of 8.14 km/sec (eq. [13]), also confirms an earlier estimation (8.15 km/sec) obtained by the same authors. Because this velocity values is deduced from the travel-times observed prevalently at the stations of Middle Southern Europe (Fig. 4), we believe that it expresses the P–wave velocity, just below the Mohorovicić discontinuity, for this region. In addition, this result recalls also the Pn velocity-values mentioned in seismological literature (Iosif and Iosif, 1973) (29) for the Southeastern European region.

Geostructural context

The geological literature concerning Sicily and Calabria has, in a variety of ways, been characterized by overthrust models which have supplanted the earlier model of total autochtony which was given by Cortese (1882; 1895) (20,21). This geologist was the first to indicate the Messina Straits fault.

Limanowski (1913) (32), following tectonic models with great recumbent folds, considers the whole *Calabria-Peloritani Complex* as a reversed nappe carried up over the *Sicilide* nappes. The Straits of Messina, for this author, would be therefore a "*cuesta*" furrow, due to the erosion of the phyllite nucleaus of the syncline between the normal sequence of Aspromonte and the reversed sequence of the Peloritani mountains, and the fault suggested by Cortese would be limit of the nappe. In the light of modern models, based on overthrusts, this explanation of the origin of the Straits is no longer acceptable.

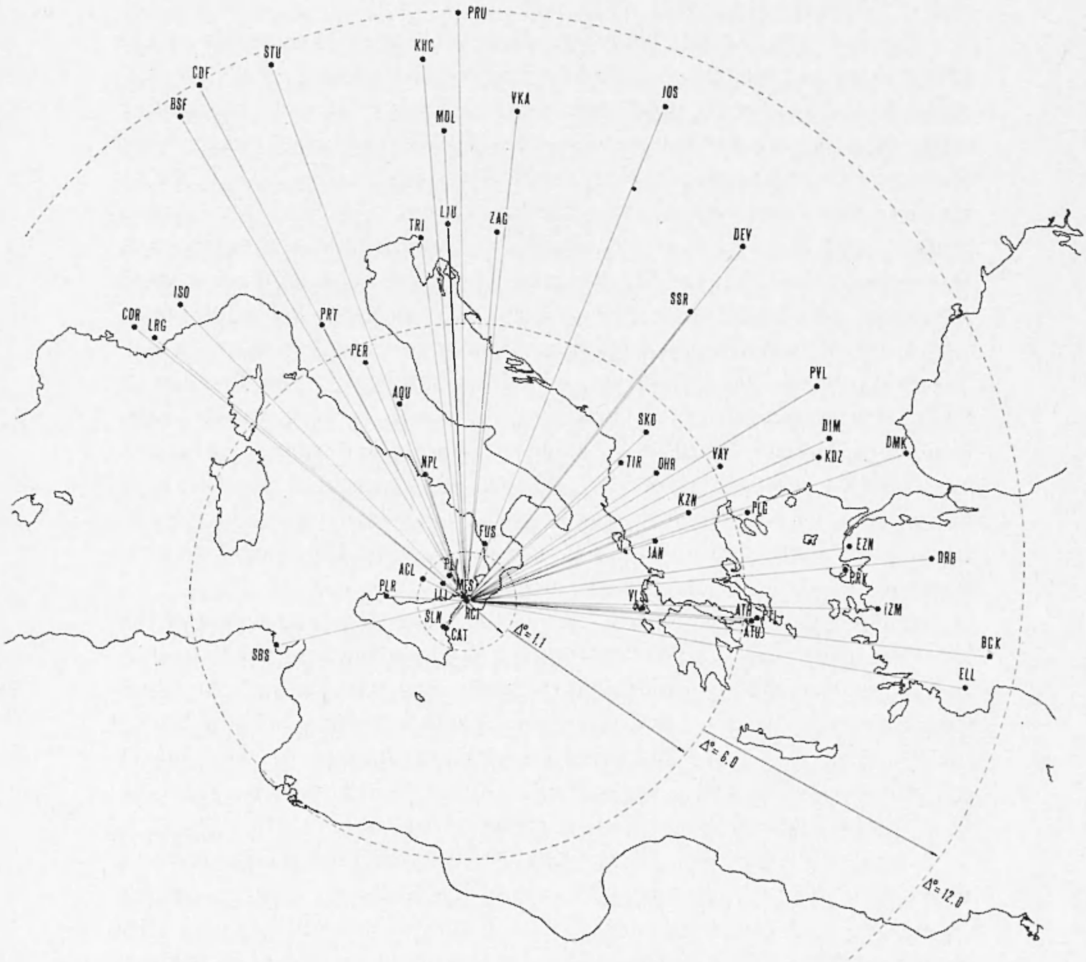

Fig. 4 – Map of Middle-Southern Europe. The abbreviations indicate the seismic stations used in order to determine the *P*-wave travel-time curves.

Trevisan (1954)([46]), in a study of Quaternary tectonic movements, argues that they are related to other, previous movements, of which they are the continuation. Same author divides Sicily into four separate units — of these the two eastern zones are the Peloritani and the Ragusa plateau — and the second of these two units is considered to be divided from Western Sicily by a system of faults with NE-SW strike and active at least from the Miocene to the Quaternary period. Trevisan also points out that the higher level of seismic activity of Sicily (up to the north-west extremity) and the volcanic activity of the Iblei and of Etna lie along this alignment.

Beneo (1949 and following) ([2,3]) does not accept the models of the overthrusts and recognizes only the gravitational gliding of the "*Variegated Shales*", the only allochthonous formations relative to the Alpine orogenesis. In his schematic map of Italy, he individuates two systems of large faults: an earlier fault transversal system, with a NE-SW strike which dates from before the overthrust, and a second Appeninian system, with a NW-SE strike, which is subsequent to the overthrust. Beneo recognizes that the Straits have a tectonic origin, and are located along the principal transversal system. In addition, he individuates within the Messina Straits a third and less important system and which has E-W strike. This direction, which we also find in the Tyrrhenian basin (the volcanism of Ustica and Palinuro), is very ancient and, according to Selli (1970) ([45]), has been re-activated successively.

Vecchia (1956) ([47]), considers that the fault system in the Straits is active, and, given the continuity of positive isostatic anomalous zones, both in the Peloritani and Calabrian areas, favours the idea of vertical movements along a large fault-system.

Glangeaud (1952a, b) ([27,28]) formulates a geo-dynamic model of the Mediterranean area, by putting forward the hypothesis of the existence in the Mesozoic of two continental blocks, one African and the other European, divided by a Sial-free-zone. In this tectonic scheme, Sicily and Calabria (the latter detached from the Apennines in the zone of Sangineto) are clockwise turned and, shifted South, because they are part of the edge of the African continental block.

Ogniben (1960, 1966, 1971, 1973) ([34,35,36,37]), taking up Limanowski's ideas, develops an Alpine type structural model for the centre-southern Apennines and for Sicily; this is based on the overthrusts of entire "*complexes*", and each of these is, in turn, a piling up of several nappes. According to this model, he recognizes in the Calabria-Peloritani massif the "*Calabride Complex*", which is constituted, in turn, of four nappes which began overthrusting between upper Eocene and lower Oligocene. The positioning of the whole "*Calabride Complex*", paleogeographically the most internal, took place in the last orogenic phase and was completed before the beginning of the Miocene. On the basis of gravimetric maps and on the basis of the position of the isostatic uplift axes, he emphasizes the probable Pleistocenic nature of the great transcurrent-fault of the faulting zone Gela-Catania-Messina-S. Eufemia, with anticlockwise transcurrent movement.

Most recently Caire (1970, 1973a-b, 1974) ([10,11,12,13]) who does not seem to deviate much from the structural scheme proposed by Glangeaud, has put forward a tectonic model which it would be useful to examine in some detail. On the basis of various data and observations including the demostrated anticlockwise rotation of the Corsican-Sardinian block, Caire proposes that, in the Mesozoic, the Tyrrhenian basin was less closed and therefore more typical than the present Tyrrhenian arc. He displaces, with a clockwise rotation towards NW, both the Corsican block and, in order, the Calabria-Peloritani massif and central Sicily, obtaining thereby an hypothetical linkage, though a very flat arc line, of the Kabyli (North African massif), the Calabria-Peloritani massif, and the Tuscan ridge. From the Mesozoic onwards the gradual closure of the Tyrrhenian arc would have occurred, according to this hypothesis, because of the drift of the *Calabrian-Sicilian Complex* towards E-SE. If, as seems clear on the basis of a variety of evidence, the tendency of the Tyrrhenian arc is to continuing closure due to the E-SE drift of the Calabria-Peloritani arc (Ritsema, 1969) ([38]), one should expect, in our opinion, the continuance o fa distensive process in the Messina Straits with a fanshaped opening towards the South. In addition, for Caire, the helicoidal distribution of the Alpine structures in the Mediterranean area, is to be considered the image of a spiral tectonic model. Such a tectonic pattern is due to two joined radial bundles ("*gerbes*") of curving and divergent faults, active at least from the Oligocene onwards. The convergence point of the principale bundle is in the West Paduan Plain; this bundle consists of transcurrent anticlockwise movements. According to Caire, the fault passing through the Messina Straits and the Ragusan plateau belongs to this fault system. The present authors believe that, in addition, the faults of the clockwise fault system, which converge in Sardinian-Balearic basin, also cross the Messina Straits in a more-or-less NW-SE direction. The faults of this system although in general less evident than those of the first system, are more developed in the Ragusa plain and in the Palermo mountains.

Recently, D'Amico et al. (1973) [22] have described the Messina Straits in a way which is compatible with vertical distensive movements extending in various directions (NE-SW, North-South, East-West). These authors, comparing the metamorphic rocks on the two shores by means of petrographic parameters, esclude the possibility of transform movements of some importance along the NE-SW direction. In contrast, along the directions E-NE and W-SW, horizontal movements are possible and in any case compatible with their observations.

Finally, in the last few years the overthrust models have been joined by global tectonics. According to the supporters of the latter, following the approch of the two continental blocks of Europe and Africa (including Sicily) a subduction of the oceanic crust began which continued until the middle Miocene when the encounter of the two blocks was accompanied by the formation of the Peloritani mountains (Ritsema, 1971; Caputo et al., 1970; Finetti and Morelli, 1972; Barberi et al., 1973; Bottari and Lo Giudice, 1975a) [39,16,26,1,9]. The subduction under the Calabrian arc seems to be continuing still. The impact of the ywo continental blocks occurred in different phases, progressing in an anticlockwise direction from West to East. In the lower Miocene, East Sicily was the limit between the zone of collision of the continental blocks and the zone of the subduction of the oceanic crust under the Calabrian arc. Sicily, therefore, was involved in a local distentive tectonics perpendicular to the direction of movements of the oceanic crust. The origin of the Messina Abyssal Plain and of the Messina Cone, which begins in the south of the Straits, is therefore based on this distensive tectonics, opening up in an anticlokwise direction.

The basic character of the volcanism in East Sicily is, in fact, a clear indication of a distensive tectonics (Rittmann, 1967, 1973; Romano and Villari, 1973) [40,41,42]. This volcanism is present prevalently along tectonic axes oriented NE-SW and NW-SE, both of these axes being present in the Messina Straits. In addition, the evolution over time of this volcanism is also favourable to the model of a distensive tectonics. In fact, there is, between the Miocene and the Quaternary, a shift of the volcanism from the South (Iblei) towards the North (Etna) and this is a clear indication of a distensive opening towards the North. Moreover, in the volcanic zone of Etna in a time period which is, in geological terms, very short, there has been a shift from the East towards the West of volcanic activity, and this is an additional indication of a distensive opening, in the Cone and in the Messina Batial Plain.

Interesting results are also available from geophysical studies. From deep seismic refraction, the crustal section of the two sides of the Straits prove to be almost identical.

In a study of the seismic activity of the Straits over the twenty year period 1950-1969, Bottari (1971) [5] obtained a distribution of the epicentres where the principal seismic foci are found to be located more-or-less along a line travelling in a NE-SW direction. There seem also to be secondary epicentral distributions in a direction which is more-or-less perpendicular to the preceding line.

From the oceanographic seismic reflection explorations (Finetti and Morelli, 1972) [26] it seems that the African continental shelf continues beyond the Messina Straits and the Ionian Sea up to the southern edge of the Calabrian arc, and includes the Ragusa massif. From these explorations it is also clear that the African continental shelf, due to a system of subvertical direct faults along the eastern edge of Sicily, is still subsiding under the Ionian Sea.

The first result of geodimetric measurements carried out between the two shores of the Messina Straits (Caputo et al. 1974) [17] gives cautious support to the idea of a northward drift of Sicily and an anticlockwise rotation of the Calabrian arc.

From above summary, it is evident that the recent literature on the subject is almost unanimous in holding that the Messina Straits is the result of a tectonic mechanism which is still active. Ideas differ, however, as to the precise mechanism of the movements. In the most wide spread theories appear to be:

i) anticlockwise transcurrent
ii) vertical
iii) southward anticlockwise fan-like opening.

Earthquake mechanism

The totality of the signs (compression, dilatation) observed in twenty-seven stations located around the epicentre were used in order to investigate the focal mechanism of the Reggio Calabria earthquake. In general, the data relative to the I, the II and the IV quadrants are well distributed.

Transfering the station points to equatorial stereographic projection, following a well known method (Di Filippo, 1950) [23] the circle projection of the intersection of the two nodal planes with the earth's surface were traced (Fig. 5). These planes are defined as follows:

a) strike plane N22°E with dip angle of ~ 75° at N112°E.

b) secondary plane N112°E dipping ~90°.

The sign distribution of the first impulses registered on the vertical component (the only data in our possession) is compatible with the following models (Bessanova et al., 1960) (4):

1 – Couple determining movement of the sides along the rupture plane.

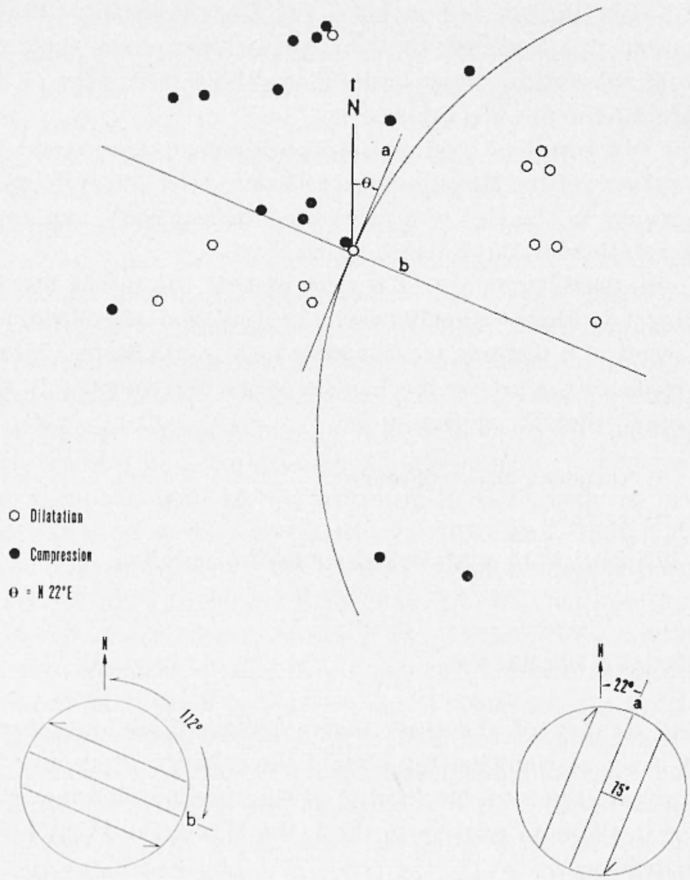

Fig. 5 – Graphical distribution of the first motion signs together with some elements of earthquake mechanism. "**a**" and "**b**" indicate the nodal planes.

2 – Double couple determining simultaneous shear along two perpedincular planes.

3 – Superposition of couple and oppositely directed forces determining symmetrical combination of shear and break-off.

Given the macroseismic axes recognized (Bottari and Lo Giudice, 1975) (9), given the prevalent orientation (NE-SW) of the horizontal acceleration observed at Reggio Calabria, and given our geostructural and morphological knowledge of the Messina Cone, one can exclude the possibility of a focal mechanism of the type according with model 2 (two perpendicular couples). The possible displacement, which in any case is prevalently horizontal, is therefore referable to a strike plane N22°E with a dip angle of ~75° at N112°E, according to a model of type 1 or type 3.

Results and discussion

The results of the present study can be summarized and discussed.

The epicentre of the Reggio Calabria earthquake of 16 January, 1975 can be located by macroseismic and analytic means some kilometers South of the Calabrian city (Fig. 2). The refined analytic determination of the epicentre:

$$\varphi = 38°04.46' \pm 1{,}43';\ \lambda = 15°38{,}92' \pm 1{,}24'$$

and the other source parameters have, for the first time, been obtained for a seismic event originating in the Messina Straits. The focal depth, which is relatively modest, differs only a little in the two estimations, the macroseismic (12.5 km by Bottari and Lo Giudice, 1975b) and the analytic (10.0 km).

An examination of the travel-times for the first arrivals (Pg, Pn) permitted an accurate determination, this too for the first time for an Straits earthquake, of the travel-time curves of the Pg and the Pn waves. Using the relationship $T = T(\Delta)$, the Pg velocity ($V = 5.39$ km/sec) and the Pn velocities ($V = 7.71$ km/sec; $V = 8.14$ km/sec) have been determined. The velocity value for the Pg waves agrees substantially with the results of seismic explorations conducted in the areas adjacent to the Straits. In addition the velocity values of the P_{n_1} waves and P_{n_2} waves confirm and seem to extend the applicability of a precedent estimation of Bottari and Girlanda (1974) (7).

The distribution in quadrants of the first motion signs observed at twenty-seven stations is compatible with a prevalently horizontal movement in the focus.

In a preceding macroseismic study (9) we have observed that the general trend of the isoseismal lines reveals several preferential axes (NE; SSW; NW), and that, in particular, two structural characteristics differentiate the northern part (aligned on the direction ENE-WSW) from the southern part of the Straits (the Messina Cone).

Then, various considerations concerning the distribution of the first motion signs, the morphological and geostructural context, and the results of macroseismic studies, indicate two possible focal mechanism models, having the dislocation plane N22°E with dip angle of ~75° at N112°E. The two possible models are, first, the clockwise couple model, which causes a symmetrical displacement in relation to the plane of rupture, with movement of the sides along this plane in opposite directions, and, second, the clockwise couple superimposed on oppositely directed forces, which cause the symmetrical combination of shear and break-off. Given the location of the focus, at the apex of the Messina Cone, given the distensive tectonics of the Cone, and given the drift of the Calabrian arc and other elements of the structural context which we have already described, the second model seems to be physically the more realistic. In this case, the direction of the forces which determine the break is near the direction of the Calabro-arc-drift, and in addition the orientation and the dip angle of the dislocation plane are significantly similar to those of the faults which Finetti and Morelli (1972) (26) discovered along the Ionian continental slope of Sicily (Cape Passero).

From what has already been said, it is therefore evident that the Straits of Messina is involved in various tectonic forces. This is true, even if it is not easy to identify which of these tectonic forces are to be considered the most active, and so what type of mechanism. We therefore believe it is unrealistic to consider the displacment mechanics to be single and irreversible in time. It is unrealistic also because, a fault system may be reactivated by a force distribution different from the primary distribution which caused the fault system, even with possibilty of a reversal of the direction of the initial movement.

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