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Seismometrical observations: elaboration ad preliminary interpretation of the Norcia earthquake, 1979

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Abstract

In the present paper seismometrical data have been worked out regarding the Norcia earthquake during the 19 September - 31 December 1979 period. 479 seismic events have been identified, with a good analytical resolvance for the majority of same. With reference to main shock, as well as for 30 other after shocks the focal mechanisms were defined using different data assemblies. A contemporary inversion of hypocentral parameters of the velocity model was made on a data selected sample. The temporal variation of after shocks was also studied during the considered period.

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RIASSUNTO

Nel presente lavoro sono stati elaborati dati sismometrici relativi al terremoto di Norcia per il periodo 19 settembre - 31 dicembre 1979. Sono stati localizzati 479 eventi sismici, per la maggior parte con buona risoluzione analitica. Relativamente alla scossa principale, e per altre 30 repliche sono stati definiti i meccanismi focali utilizzando insiemi diversi di dati. E' stata effettuata un'inversione simultanea dei parametri ipocentrali del modello di velocità su di un campione selezionato di dati. E' stata anche studiata la variazione temporale delle repliche durante il periodo considerato.

FOREWORD

The interest built around the seismic phenomenon that began on 19-9-79 in the upper Nera Basin, took shape in the setting up of a local seismic network for the study of the phenomenon, under its scientific aspects, and for a better understanding of same with reference to genesis and energy propagation. The research workers assembled in the « National Seismic Network » committee in the Geodynamic Finalized Project activity.

The research workers of the following Institutes together with their instrumentations, were present:

— National Geophysical Institute. Rome	(Italy)
— Vesuvian Observatory. Naples	(»)
— Lithosphere Geophysical Institute. Milan	(»)
— Geological Institute. Florence University	(»)
— Globe Physics Institute. Paris	(France)

INTRODUCTION

On the 19th of September 1979, a seismic period got started in the area between Norcia and Cascia of discreet intensity setting up to the VIIIth degree of the MCS with the main shock.

In the preceding months there occurred in the area other quakes that were however isolated, and which did not get over the 3.0 magnitude.

The epicentral determination of the main 19th September shock were:

NEIS H_o = 21 35 36.5 (GMT) $\varphi = 42.83$N $\lambda = 13.06$E $h =$ 8 km

CSEM H_o = 21 35 39.3 (GMT) $\varphi = 42.78$N $\lambda = 13.06$E $h =$ 10 km (attributed)

The date by us elaborated gave:

H_o = 21 35 36.9 (GMT) $\varphi = 42.73$ $\lambda = 12.96$E $h =$ 6 km (attributed)

The more reliable magnitudes attributed to the shock were:

for M_l: 5.5 (RMP), 5.8 (TRI),

M_b: 5.6 (CSEM), 5.5 (NEIS),

M_s: 5.8 (NEIS).

A second strong shock took place on February 28, 1980 having as provisionally worked out parameters the following:

H_o = 21 04 42.9 (GMT) $\varphi = 42.65$N $\lambda = 12.60$E $h =$ 7 km

NEIS H_o = 21 04 40.8 (GMT) $\varphi = 42.81$ $\lambda = 13.01$E $h =$ 12 km

The magnitudes were:

for M_l: 5.1 (TRI), 4.8 (RMP),

M_b: 4.8 (NEIS).

COMPUTATION OF FOCAL PARAMETERS

The observations for localizing hypocentres can be split into three groups, i.s. prior to (49 localized events), during (380 events), after (50 events) the setting up of the stations assembled by the « National Seismic Network » commitee of the GFP, because for each group the localizing precision, on the whole, changes.

In table 1 are given the data regarding the stations set up following combined intervention or anyway consequent to the September quake; their localization is reported in fig. 1.

The data, for the calculation of hypocentral parameters, were elaborated with the « Hypo 71 » program, using as crustal model the one given in fig. 2, 3.

This model derives from a comparison made with other models obtained by means of active and passive geophysical data (Caloi, 1939, Console - Gasparini, 1975, Di Filippo - Marcelli, 1952 Giese et al., 1979), valid for the area and integrated, as regards surface, by geological notions (Calamita et al., 1979, Deiana, 1980, Scarsella, 1941).

From preceding sources one can, furthermore, understand that the ratio V_p/V_s gets to the value 1.80.

In the calculation at 6 kms depth restriction was put; the arrival times at the stations were fully weighed, for distances within 70 kms local network, and by half those between 70 and 300 kms, national network. To each station was attributed a delay determined by the velocity of the superficial layer and by the altitude layer and by the altitude of the stations itself.

The persistence of the solutions was verified using other crustal models. The results obtained did not differ relevantly from the previous ones, both as regards the planimetric distribution (fig. 4) as well as with reference to depth distributions (Fig. 5).

The data were examined also with reference to their distribution in depth, projections were made for bands of different widths made to rotate by 15° each time, so as to enable, changing

Fig. 1 - Stations's location. Legenda: x local stations, ● national station.

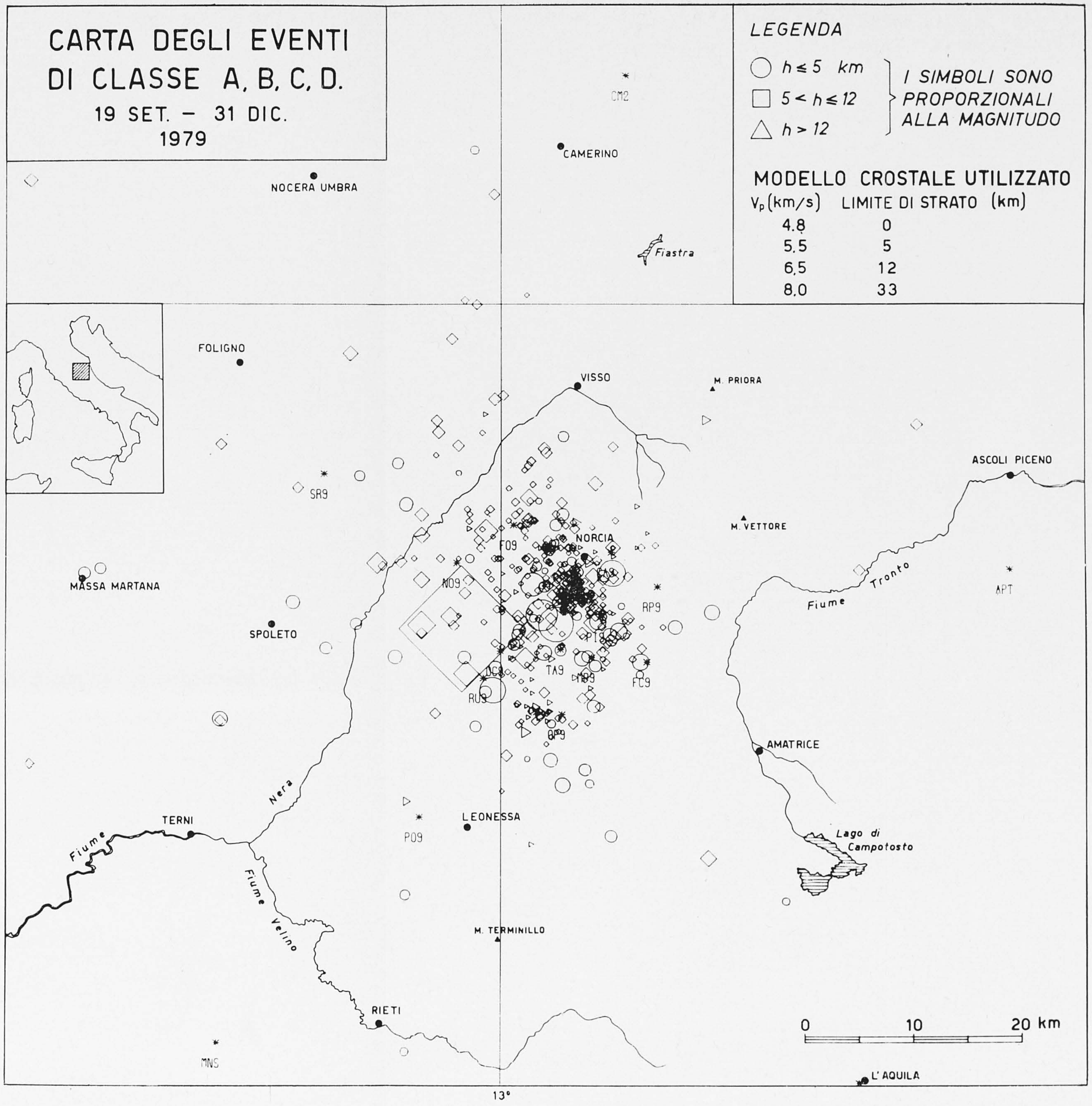

Fig. 2 - Map of the events. Class A, B, C, D.

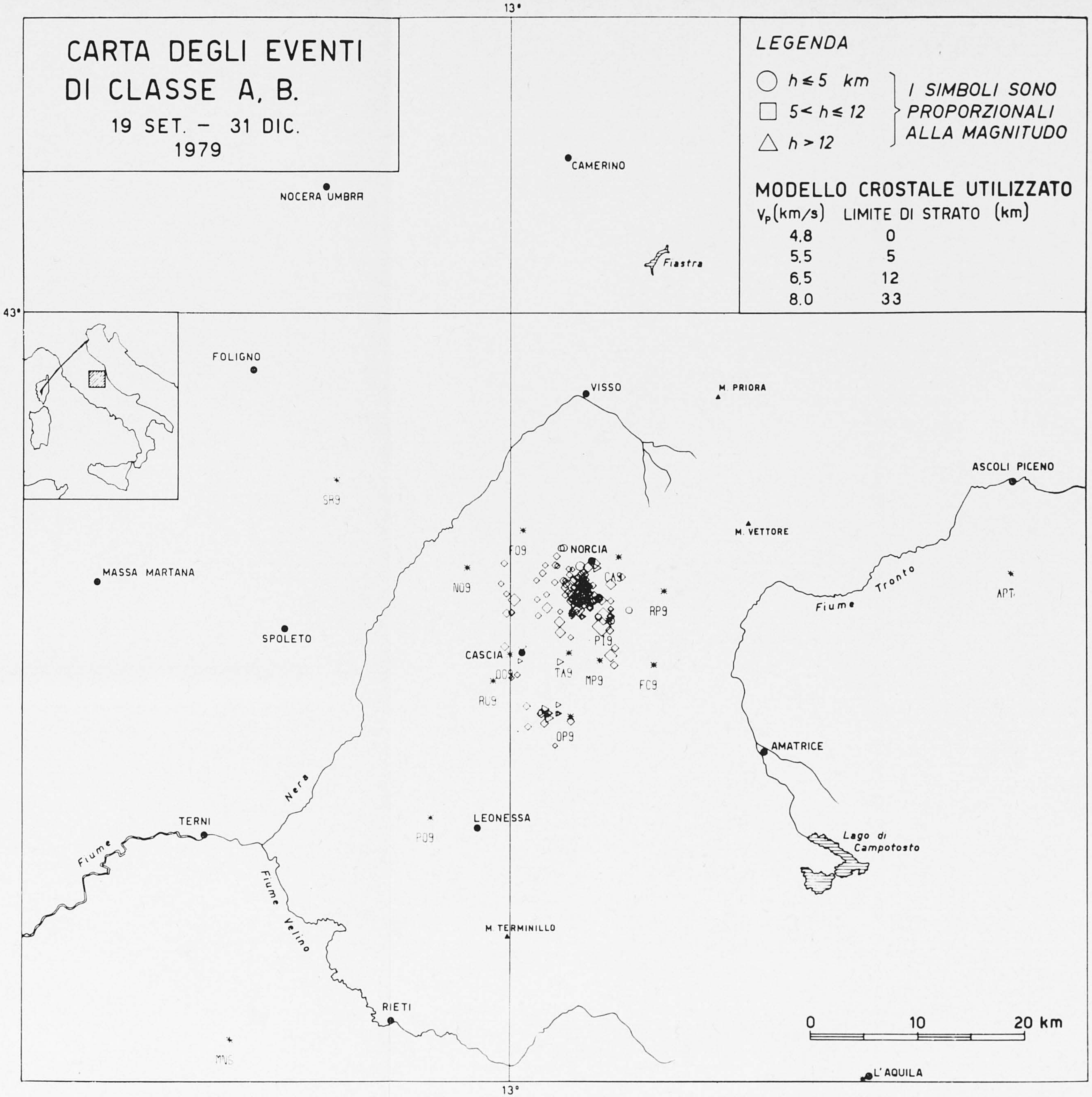

Fig. 3 - Map of the events. Class A, B.

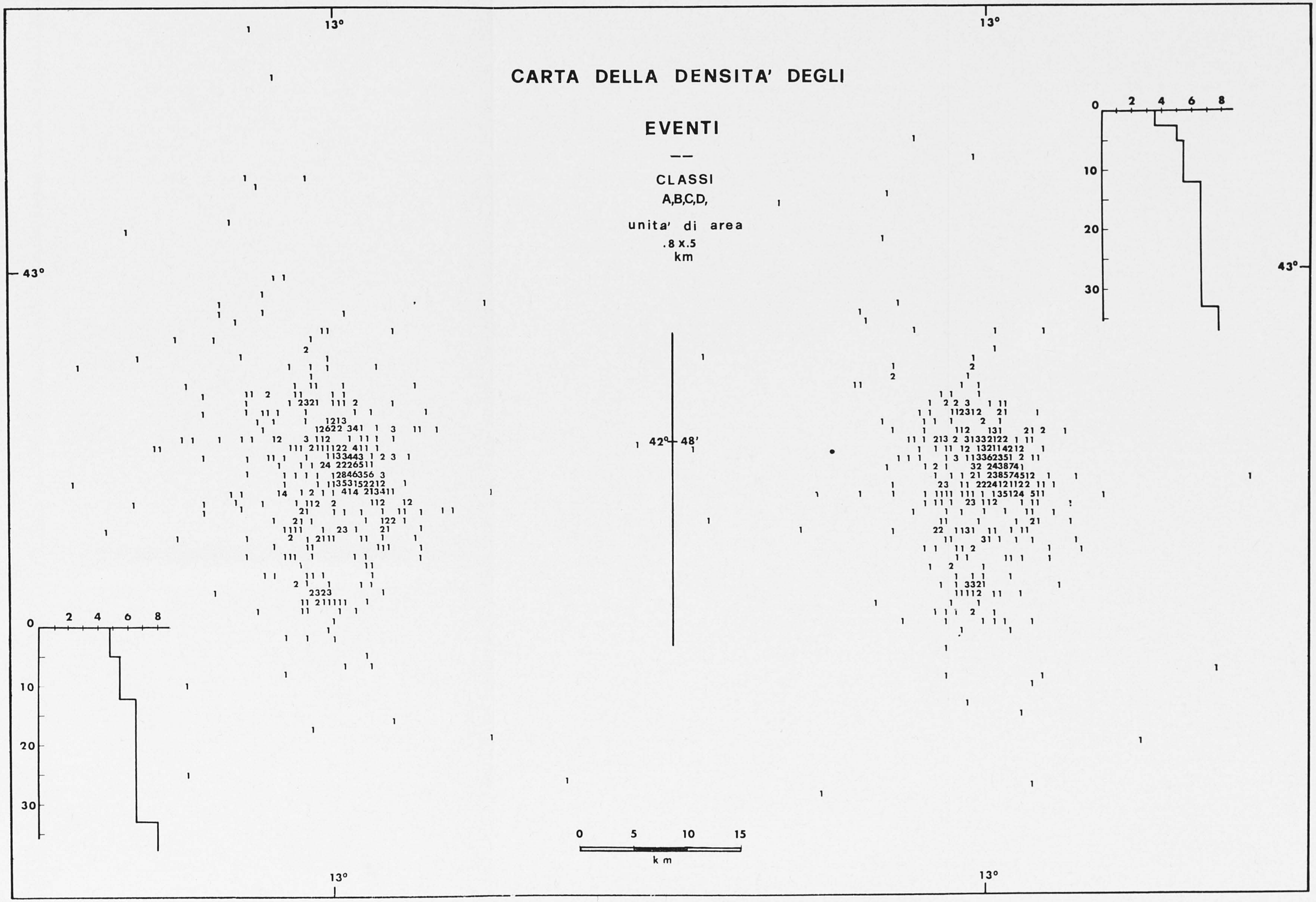

Fig. 4 - Density map of the events. Class A, B, C, D.

TABLE 1

N°	Code	Station name	Agencies Code	Altitude m	Geogr. Co-ordinates		Operative period	
					nord	est	beginning	end
1	PI9	Piediripa	ING	700	42 44.50	13 06.32	23 sett.	19 oct.
2	NO9	Nortosce	ING	850	42 47.20	12 57.03	23 »	19 »
3	CA9	Cappuccini	ING	754	42 47.74	13 07.50	23 »	19 »
4	RP9	Rifugio Perugia	OV-IGL	1510	42 46.00	13 10.62	23 »	18 »
5	OP9	Opagna	OV-IGL	1317	42 39.63	13 04.17	24 »	18 »
6	MP9	M.te Pozzoni	OV-IGL	1351	42 42.47	13 06.18	23 »	28 nov.
7	FC9	F.ca Capatuio	OV-IGL	1370	42 42.25	13 09.92	25 »	18 oct.
8	FO9	Forsivo	OV-IGL	1200	42 49.10	13 00.88	23 »	18 »
9	PO9	Polino	ING	1320	42 34.50	12 54.51	2 oct.	operating
10	OC9	Ocosce	IGL	906	42 42.80	12 59.98	25 sett.	operating
11	RU9	Rua La Cuma	IGF	995	42 41.45	12 58.83	25 »	20 oct.
12	TA9	Tazzo	IGL	842	42 42.86	13 04.06	26 »	20 »
13	SR9	M.te Serano	ING	1000	42 51.65	12 47.93	19 oct.	3 nov.
14	AM9	Amelia	ING	400	42 35.12	12 25.61	8 nov.	operating
15	CM2	Camerino	IGL	940	43 11.55	13 08.52	29 »	operating

IGF = Istituto di Geologia. Firenze
IGL = Istituto per la Geofisica della Litosfera. Milano
ING = Istituto Nazionale di Geofisica. Roma
OV = Osservatorio Vesuviano. Napoli

rotation centre, a behavioral image at depth of the events fig. 6. The most relevant prophile seemed to be n. 30 that shows events densifying up with an almost vertical behaviour and a deeper

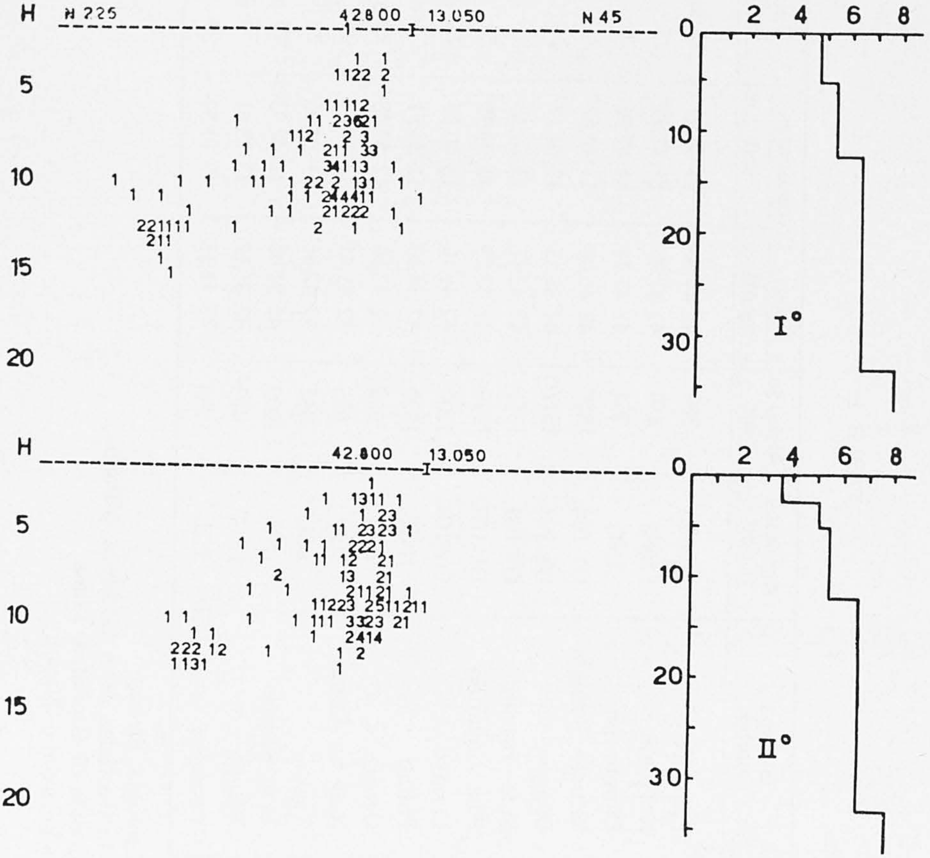

Fig. 5

appendix towards SSW. This prophile results transversal to the Piediripa - Ospedaletto direction, which coincides with the maximum area densification of events.

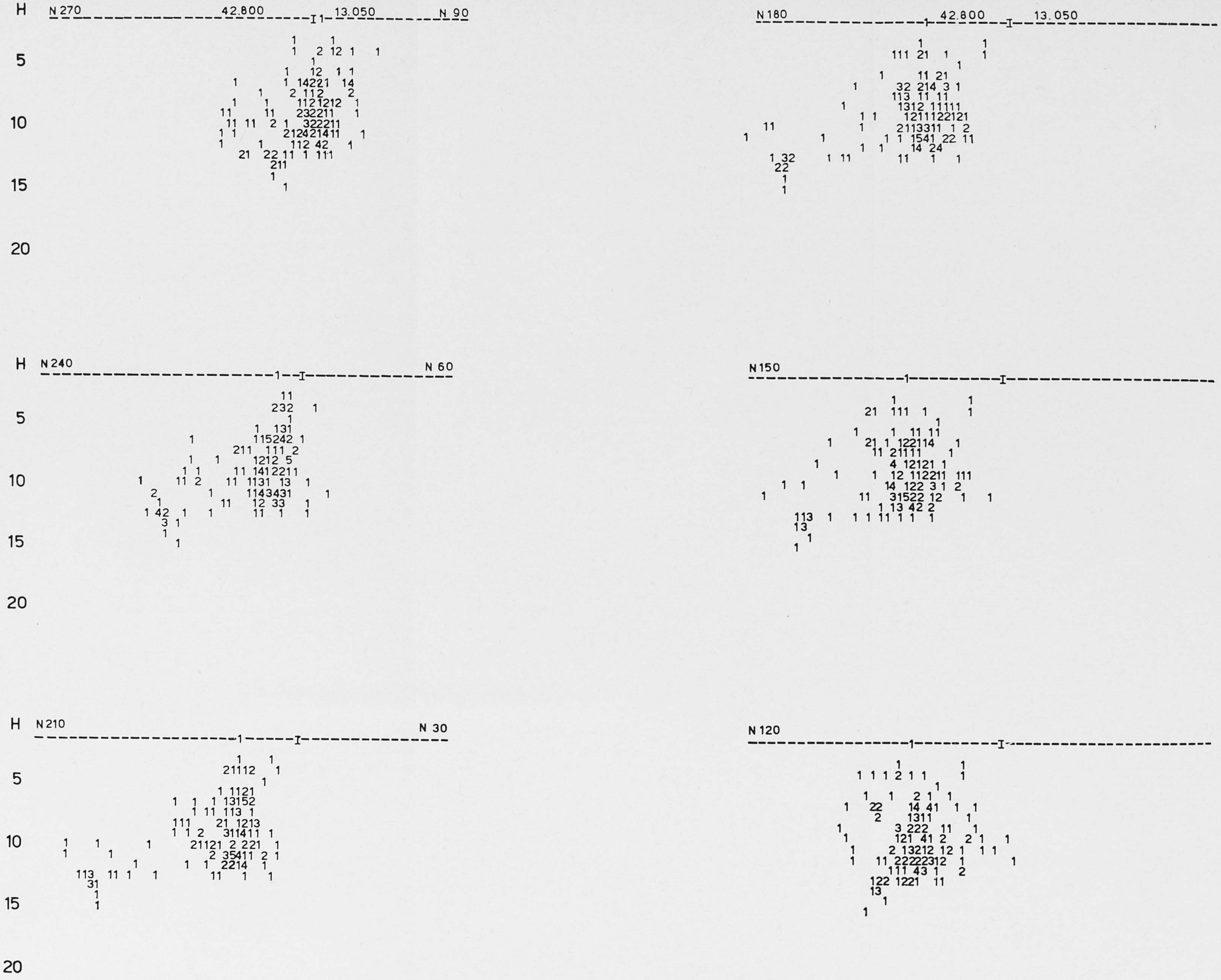
H
N 270
42.800
13.050
N 90
N 180
42.800
13.050
N 240
N 60
N 150
N 210
N 30
N 120
5
10
15
20

Fig. 6

ANALYSIS OF FOCAL MECHANISMS

128 first impulses for analysis of focal mechanisms were gathered, with reference to the main shock. The data reached us from world-wide stations through questionnaires, bulletins, but mostly through the direct readings of the seismogram.

The determination of focal mechanisms was made through a reworked program based on Wickens and Hodgson (1967) which has the possibility of supplying a statistical evaluation of the solution by means of a weight given by:

$$\text{Weight of solution} = \frac{\sum \mathrm{W_p} \cdot \mathrm{A} \cdot \mathrm{B}}{\sum |\mathrm{W_p}|}$$

in which, A and B are respectively the observed and theorical polarities, $\mathrm{W_p}$ is the function of weight.

In the elaboration of data we have used as source model the double couple, which identifies two nodal planes that must satisfy as best as possible the experimental data.

The nodal planes are identified, in Wulff's projection (lower hemisphere) by segments of a circle that separate the compression quadrants from those of dilatation. Each polarity point is determined by azimuth, between epicentre and station, and by the angle that the seismic ray makes with the vertical leaving the epicentre. Such angle have been calculated using the relation:

$$\text{sen } i = (v/r)\ \mathrm{d}T/\mathrm{d}\Delta$$

where: i, v and r are respectively, the hypocentral angle, the velocity at focus and the difference between terrestrial ray and focal depth, $\mathrm{d}\Delta/\mathrm{d}T$ is the apparent velocity at the epicentral distance Δ. The apparent velocities were worked out by means of the Herrin (1968) travel times.

With reference to the main shock, $M_L = 5.5$ various solutions were determined with different data selection criteria:

a) with all data at disposal (good and bad), fig. 7a;

b) with data selected from long and short periods, fig. 7b;

c) with point *b* data excluding those within 20°, fig. 7c;

d) with data of long periods only, fig. 7d;

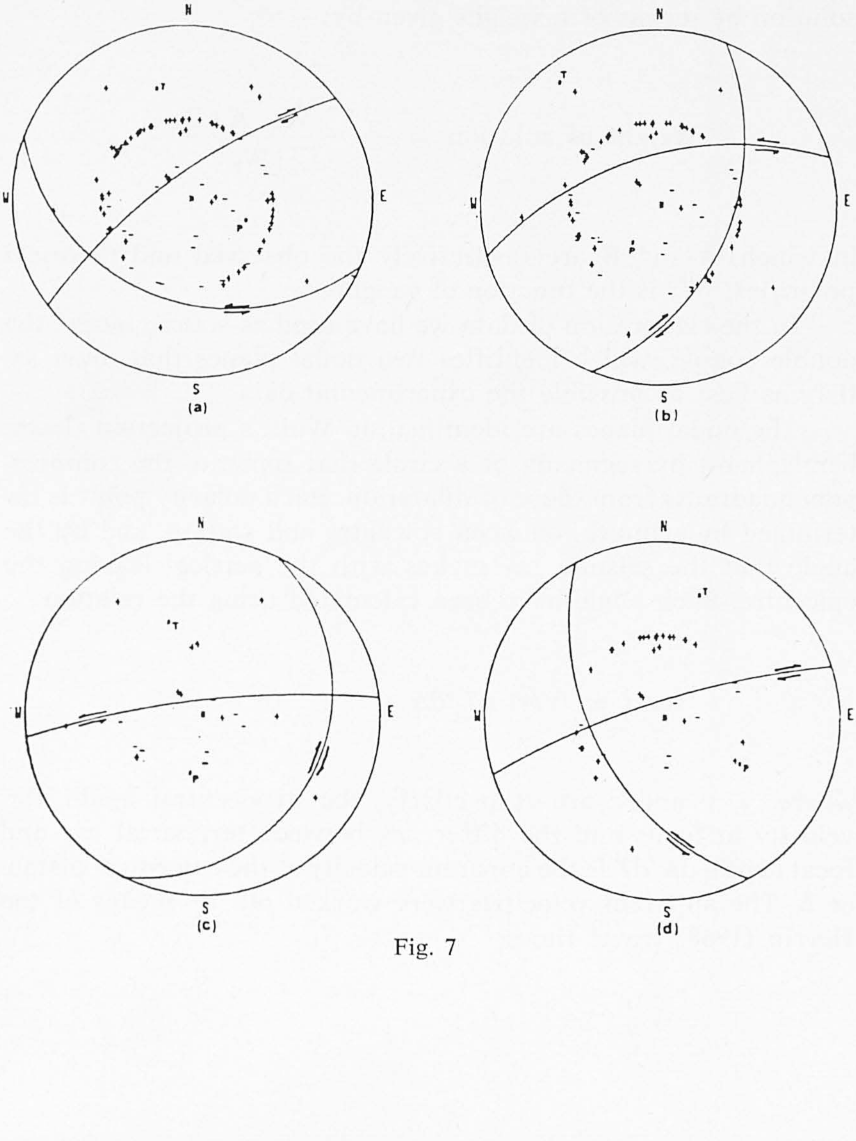

Fig. 7

We deem that the last elaboration made be considered optimal. In table 2 are given the values obtained for these mechanisms. Analyses of focal mechanisms for 30 aftershocks have also been carried out. In fig. 8 we have reported in the usual representation the projections of axes of maximum pression P and maximum tension T of all the 30 solutions obtained. This representation renders possible that the T axes, in the various aftershocks have a prevalent direction of about ENE-WSW and with a predominantly subhorizontal inclination. The P axes are pseudovertical with a prevalent direction in the lower quadrants.

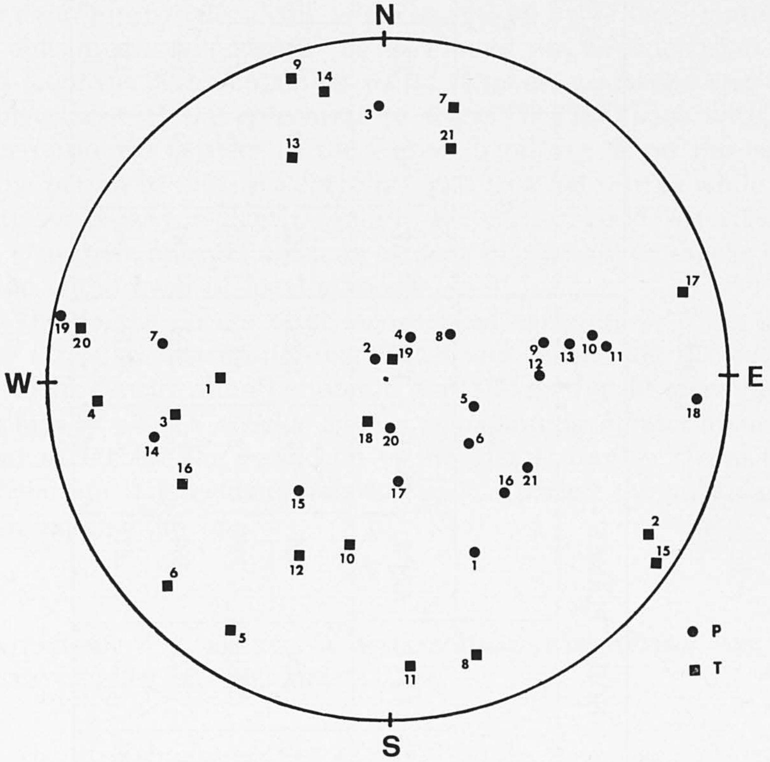

Fig. 8

TABLE 2

SOLU.	NODAL PLANES						AXES					
	A			C			B		P		T	
	AZIM.	INCL.	TYPE	AZIM.	INCL.	TYPE	AZ.	INC.	AZ.	INC.	AZ.	INC.
a	203	54	SIN.	325	13	DES.	202	59	111	29	345	59
b	113	44	DES.	345	32	SIN.	55	62	219	29	321	83
c	116	70	DES.	354	11	SIN.	81	74	194	37	340	58
d	343	12	DES.	242	42	SIN.	266	45	122	52	16	71

TEMPORAL BEHAVIOUR OF AFTER SHOCKS

The space variations of aftershocks represented along the direction NE-SW (Norcia-Cascia) show from the start of the seismic period down to about the 23rd September the maximum epicentral fluctuation due prevalently to their bad localization. The data improve decidedly with the setting up of local stations, the epicentres begin densifying in a band not broader than 4-5 kms from the 30th September to 1st October, we have a decided displacement of the epicentres to the SSW (M. Pizzo) with an interruption of activity in the former band, fig. 9; on the work of the period in this area there are just isolated shocks while activity starts very evidently again in the former band. After October 17th there appears again an evident fluctuation of shocks due to the withdrawal of local stations.

The depths do not offer any marked variation in time, they have a regular distribution between 1 and 14 kms fig. 10, with a prevalent densification between 8 and 11 kms fig. 11 gives histographically all the shocks having a magnitude greater than or equal to 3.0, for the period up to the 31st December; from this distribution it is evident that for such a period the subsidance is an exponential one.

CONTEMPORARY INVERSION OF HYPOCENTRAL PARAMETERS AND OF VELOCITY MODEL IN THE NORCIA AREA.

The aftershocks of the 19-9-1979 quake have been recorded in several stations of the national seismic network and of the temporary network set up in the epicentral area. Among these, due to the high number of events recorded, to the distance from epicentral area, as well as due to the accuracy of experimental data, 15 stations were chosen for a united study of hypocentral parameters and of velocity model according to the outline proposed by Crosson (1976). This procedure, through the relocalization of a group of quakes, enables, for modern networks acquiring

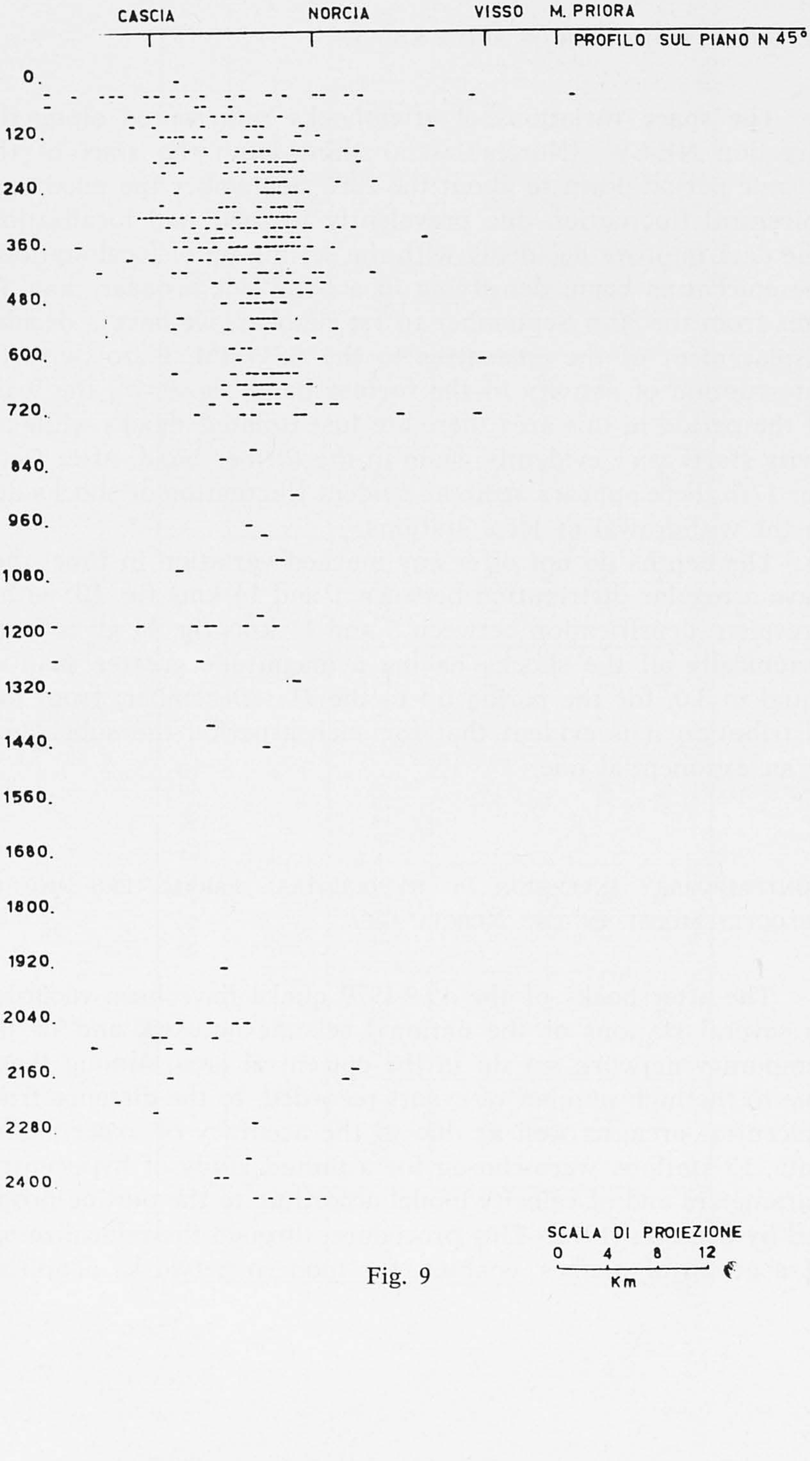
CASCIA
NORCIA
VISSO
M. PRIORA
PROFILO SUL PIANO N 45°
0.
120.
240.
360.
480.
600.
720.
840.
960.
1080.
1200
1320.
1440.
1560.
1680.
1800.
1920.
2040.
2160.
2280.
2400.
SCALA DI PROIEZIONE
0
4
8
12
Km

Fig. 9

seismological data, also the evaluation of a model of velocity that better fits the experimental data. In this case the outline of inversion of travel times is much more efficient than with the traditional Wiechert-Hergoltz method, with the generalization in case of slow layers of Gerver and Markuscevitch (1966), because the smoothing of experimental data is cleared out, different phases

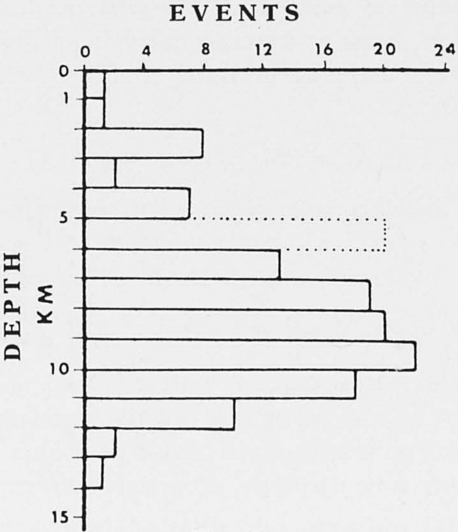

Fig. 10

can be simultaneously inverted, there is no need of a complete travel time curve and the propagation of observation errors in the model can be worked out.

The method consists in the aligned algebrical inversion of the first arrivals in a medium consisting of flat, parallel and homogeneous layers. The differences between observed and calculated values of travel times, compared to an initial model, are linked to the unknown parameters l through the functional F:

$T_{ij} = F_i(l)$ for j stations and i events. Since a rule F is not linear, the first derivates are calculated compared to the initial value, while terms of a higher order are omitted. The final

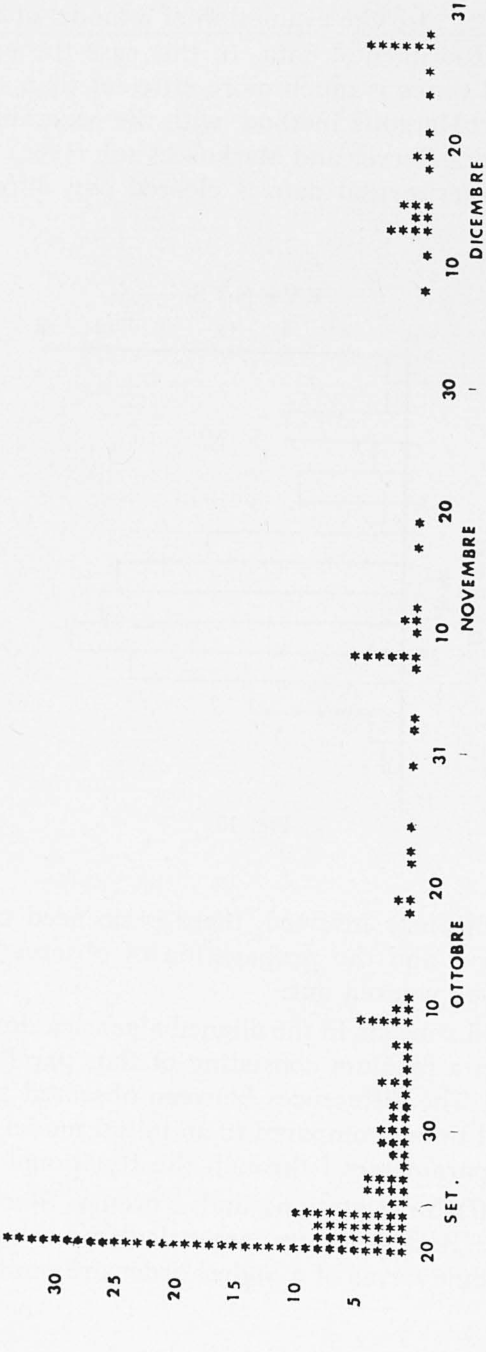
30
25
20
15
10
5
20
SET.
30
10
OTTOBRE
20
31
10
NOVEMBRE
20
30
10
DICEMBRE
20
31

Fig. 11

expression in matricial form can be written as: $\Delta T = A \Delta x$ (l). This system of equations can be resolved through the method of least squares, for each iteration, until convergency is reached.

To resolve the system (I) to least squares means finding a solution of:

$\tilde{A}\ A\ \Delta\ x = \tilde{A}\ \Delta\ t$ where $\tilde{A}$ is the transposition of A.

Since this type of problem can be misplaced, as e.g. due to an incorrect parametrizing or due to lack of some data, a modification of the classical least squares is used, called Levenberg-Marquardt algorythm. This method consists in minimizing the function

$$(A\ \Delta\ x - \Delta\ t)^t \cdot (A\ \Delta\ x - \Delta\ t) + \Theta^2\ \Delta\ \tilde{x}\ \Delta\ x$$

whre Θ is a coefficient to be arbitrarily selected.

The system to be resolved thus becomes:

$(\tilde{A}\ A + \Theta^2\ I)\ \Delta\ x = \tilde{A}\ \Delta\ t$ where I is the identity matrix.

It is possible to show that the parameter Θ gives rise to a diminution of variancy, to the detriment of the resolution (Jackson, 1972). As a rule it is better to choose Θ as small as possible, through a compromise between stability and resolvance.

So as to take into account the possible lateral variations compared to the model employed, also the station residues have been inserted as unknown parameters. Obviously, in this case, at least one of the residues must remain fixed, to avoid a « coupling » between velocity parameters and stations residues.

In the case of Norcia, just the first arrivals of the compression phase were used, and, among the events localized, those were chosen that belonged to the most trustworthy classes (*A* and *B* according to outline HYPO 71), that covered more uniformly the study area, with particular reference to depth.

Thus about 40 seismic events resulted useful with reference to an inversion according to the outline described above. As initial parameters the results described in the chapter on instrumental seismicity, were used.

At this research phase we preferred, so as to be brief, not to assign weights to the readings of the first arrivals, even if due to the dishomogeneity of the instrumentation used, at least two quality classes can be identified (according to the different recording velocities possible).

The data of the set of 40 events have besides been split into two event groups, both in order to accelerate elaboration velocity and so as to test the stability of results in function of different data, chosen by chance. As a rule a swift convergence in the process of successive iterations has been found, on substantially stable parameters. A series inversions have been realized with models having an increasing degree of complexity (greater number of layers), and with the greatest penetrations corresponding to the greatest depths of the events examined (about 12-13 kms). Since the number of events selected in the first 4 kms of crust is relatively low, it was not possible to determine more than a mean velocity value in this section of crust. In table 3 are reported some of the resulting models. As can be seen, all the models show a marked inversion of velocity between 4 and 8-10 kms depth. The lateral variations from such models (centered under station *P* 19) and referring essentially to the epicentral area, are not very strong and show a slight dependance from the height. The variations of such residues are on the average of about 0.1 seconds, the diagonal elements of the resolving matrix for variable speeds are all above 0.75.

It is worthwhile to note that, always in the Umbria region, about 60 kms north of the epicentral area, seismic deep refraction probings (Giese et. al., 1979) have shown the presence of a slow layer that was also very pronounced, in the upper part of the crust, at about 5-8 kms depth.

TABLE 3

Model A

Inversion of 203 arrival times *P* corresponding to 20 quakes.
Freedom degrees 105.

Depth (km)	Velocity (Km/sec)	Standard error (km/sec)
0.0	5.27	0.14
4.0	3.62	0.32
8.0	5.06	0.24
12.0	6.45	0.25

Model B

Inversion of 203 arrival times *P* corresponding to 20 quakes.
Freedom degrees 104.

Depth (km)	Velocity (km/sec)	Standard error (km/sec)
0.0	5.11	0.14
4.0	3.83	0.35
7.0	4.26	0.35
10.0	5.88	0.32
13.0	6.37	0.29

Model C

Inversion of 354 arrival times *P* corresponding to 34 quakes.
Freedom degrees 200.

Depth (km)	Velocity (km/sec)	Standard error (km/sec)
0.0	5.40	0.11
4.0	3.90	0.31
8.0	5.67	0.19
12.0	6.81	0.17

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