Crustal blocks and seismicity in the Central Apennines of Italy

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Summary. — Kinematics and geodynamics of crustal-block structures separated by compliant zones with viscoelastic rheology play an important role in defining the conditions for many deformation events such as ordinary seismic ruptures, silent and slow earthquakes and aseismic fault creep phenomena. New seismological data from the Latium-Abruzzi carbonatic platform of central Italy fit a block-tectonic modelling previously proposed for this area on the basis of structural and paleomagnetic evidences.

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1. – Introduction

In the last decades evidences have been found that large portions of the Earth's crust are broken by dense sets of parallel or subparallel faults which are organized in domains [1-2]. Nur [3] proposed a kinematic block tectonic model on the basis of structural and paleomagnetic data and suggested that when such domains are subjected to tectonic shear stress they deform by distributed fault slip and block rotations, rather than by uniform straining. Boundary conditions concerning stress, strength and friction reveal that when rotations are sufficiently large (25°–45°) new domains of multiple sets are produced.

Crustal blocks were considered to be quasi-rigid and separated by compliant zones with viscoelastic rheology [4-6].

In revealing such discrete structures, there is the possibility to develop suitable and realistic seismogenic models, to study nonordinary (silent and slow) earthquakes and, more in general, to correlate the slow deformation processes with fast (elastodynamic) ruptures.

Up to now, slow rupture processes at the source are not well understood and theoretical explanations of the above-mentioned correlations are inexistent [7]. On the contrary, there are evidences of tilt and strain fields at distance from a fault and generated by elastic strain accumulation and elastic and anelastic strain release, associated to earthquakes [8-10]. They were computed on the basis of dislocation [11] or dilatancy [12] models. Also aseismic fault creep phenomena caused by slowly propagating deformation processes in central Italy were observed prior to local earthquakes [13-14]. By considering a block-boundary viscoelastic rheology, a 1D model was developed in order to justify slow propagations of tilt and strain fields through discrete structures [4].

On the basis of what mentioned above, evidences of crustal blocks in seismic areas and their kinematics and dynamics are of great importance and constitute one of the most fascinating tools in solid-earth geophysics, and, particularly, in earthquake preparation studies.

In central Italy such tectonic structures were observed by Salvini [15]. Favali *et al.* [16] correlated this deformation zone to the areas next to this one.

Salvini [15] suggested that the Latium-Abruzzi platform of the Central Apennines of Italy is subdivided into a series of NW-SE-trending elongated rigid blocks. These evidences were proposed on the basis of geological and paleomagnetic data.

The aim of this paper is to look for their further confirmation by making use of spatial patterns of seismicity.

2. – The Latium-Abruzzi carbonatic platform

The geodynamic model proposed by Favali *et al.* [16] for the central Italy region is reported in fig. 1. According to this model, the occurrence of micro-earthquakes whose fault-plane solutions indicate a right-lateral strike-slip motion, the structural data and a morphological change of about 1000 m in the depth of the Adriatic basin (characterized by a positive Bouguer anomaly), support the existence of an E-W-trending defor-

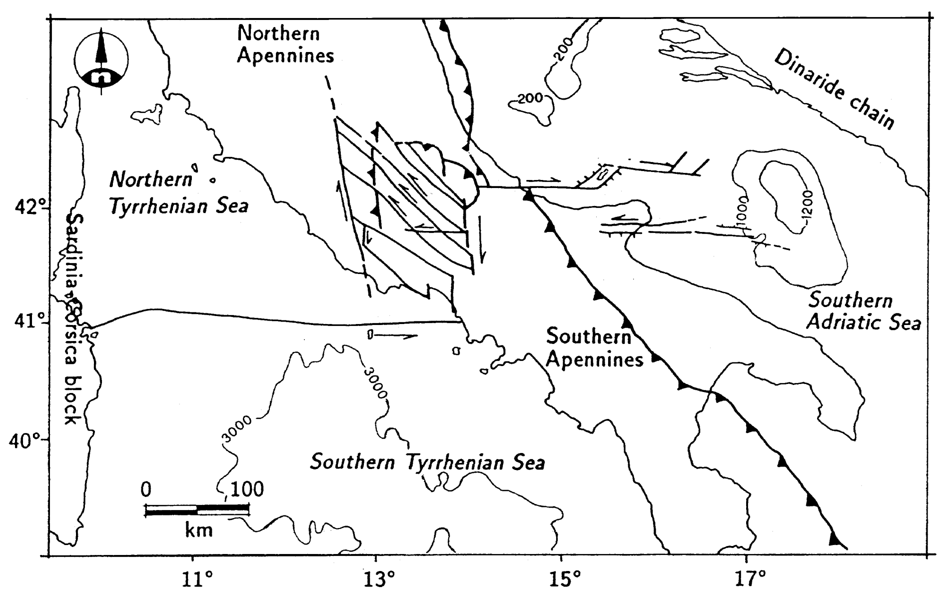

Fig. 1. – Geodynamic model proposed for the Central Apennines of Italy (after Favali *et al.* [16]).

mational belt of lithospheric importance in the central Adriatic basin at about 42° N. A possible prolongation of this active zone through the central Apennines is marked by the important structures of the Latium-Abruzzi carbonatic platform. This is constituted by a series of NW-SE elongated crustal blocks separated by subvertical faults mainly with left-lateral strike-slip motions [15]. On both the eastern and western edges of the platform there are two N-S-trending tectonic discontinuities (Ortona-Roccamonfina and Olevano-Antrodoco "faults") with recent right-lateral strike-slip movements.

Geochemical, petrological and seismic data from volcanic rocks of the Tyrrhenian area suggested the existence of another lithospheric discontinuity in the Tyrrhenian basin along 41° N. This discontinuity is as a kind of transform fault which, since late Tortonian times, has been separating the Tyrrhenian sea into two sectors with different tectonic histories.

All this frame fits with the block rotation model proposed by Nur *et al.* [3].

3. – Results and discussions

In the Latium-Abruzzi carbonatic platform, seismic activity is characterized by frequent and shallow earthquakes (generally, less than 15 km of depth) but of low magnitude (rarely, greater than 5.0).

The seismic data were gathered by the seismic network of the National Institute of Geophysics of Italy (ING) consisting of 80 analogic stations [17]. Ten of them are located in the area under study or in its neighbourhood. Before 1983, the ING seismic network was constituted by about 30% of the present number of stations. Then, we took into account only earthquakes occurred in the area under study after 1983. The data relative to the period 1984-1996 are plotted in fig. 2. They are reported as circles superimposed to the crustal block model proposed by Salvini [15]. This 13-year record of seismicity is constituted by about 1380 earthquakes: 950 of which with magnitude $M \geqslant 2.5$, 15 with $4.0 \leqslant M < 5.0$ and only 2 with $M \geqslant 5.0$. All hypocentres do not exceed a depth of 15 km.

Figure 3 shows that for $M \geqslant 2.5$ these events follow the Gutenberg-Richter relationship, with a b-value equal to -0.92 and a correlation coefficient $r = 0.96$.

An increase in the spatial density of earthquakes can be observed in three different zones of fig. 2: the Val Comino-Val di Sangro (SE of the platform), the L'Aquila basin, and the NW area of the platform. In these zones two seismic sequences occurred in May 1984, and in May 1985, respectively [18-20]. These sequences are also shown in the time series of fig. 4, and in the spatial representation of fig. 2. Here, they are limited by two poligons marked by dashed lines. Two seismic swarms but of minor importance were also detected in August 1992 and in June 1994, in the western part of the Gran Sasso massif, by a local seismic network installed by the National Seismic Survey of Italy [21-22].

The seismic sequence of Val Comino-Val di Sangro zone has been the most important one occurred in the region during the last 20 years. It was characterized by two main shocks with magnitude $M = 5.4$–5.1, respectively. Console *et al.* [18], considered this sequence of the type 1-B1 according to Utsu [23]. Del Pezzo *et al.* [19], showed that the hypocentral depth ranged between 5 and 15 km. Moreover, they observed that the epicentral distribution was apparently charaterized by a complex geometry, which was not simply related to the fault-plane solutions of the two major

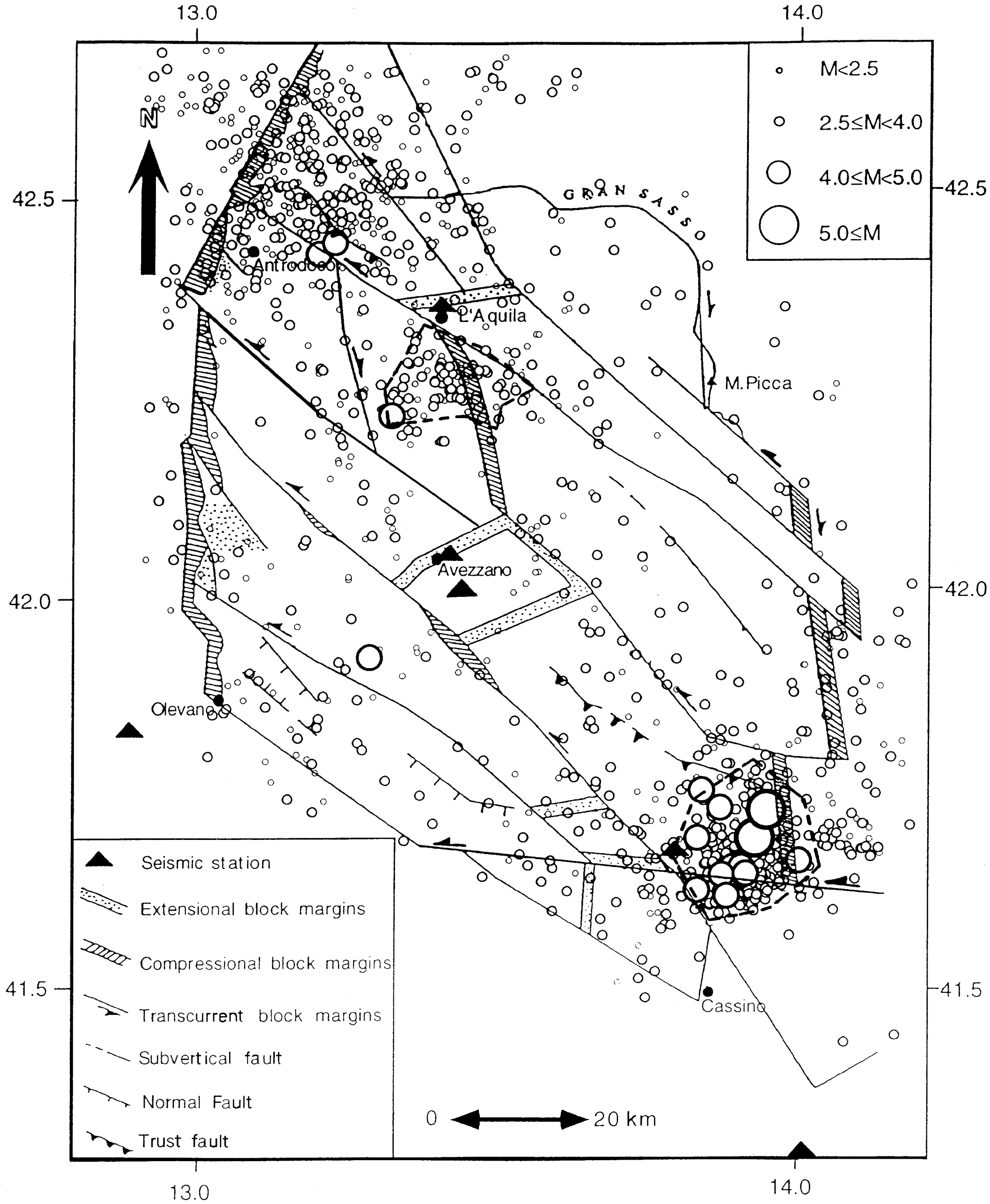

Fig. 2. – Seismicity of the Latium-Abruzzi carbonatic platform of the Central Apennines in the period 1984-1996. Earthquakes are reported with circles superimposed to the crustal-block model proposed by Salvini [15]. Two poligons indicate areas where earthquake sequences occurred in May 1984 and in May 1985, respectively. The poligons are marked with dashed lines.

earthquakes of the sequence (with nodal planes striking NW-SE), but a major cluster was apparently oriented NE-SW. Console *et al.* [18], revealed that the spatial distribution of the shocks was in agreement with the elongation of isoseismal drew for

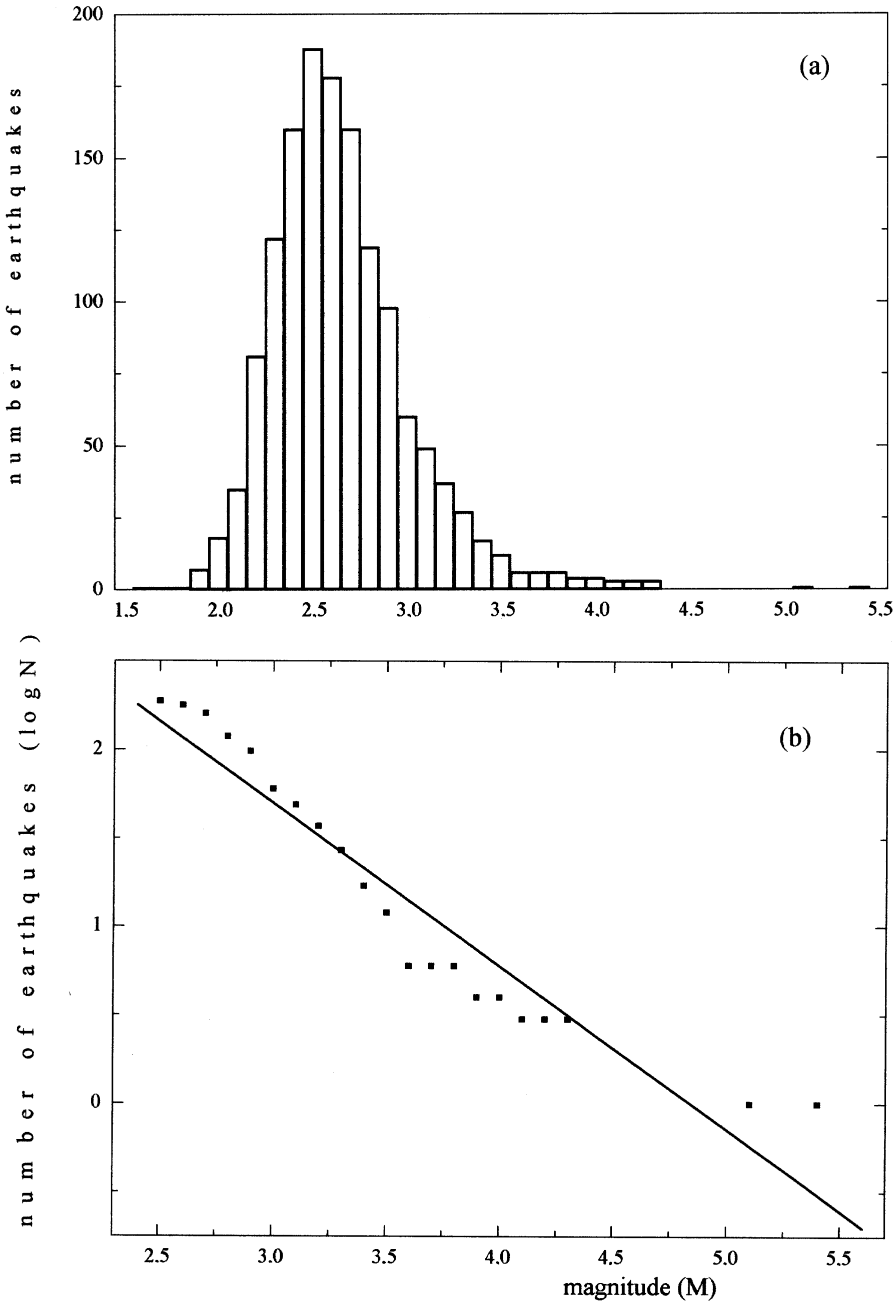

Fig. 3. (a) Number of earthquakes *vs.* magnitude. (b) Gutenberg-Richter relationships for earthquakes with $M \geqslant 2.5$ ($b = -0.92$; $r = 0.96$).

the first main shock. From this sequence these authors obtained a b-value equal to -0.93 with a correlation coefficient $r = 0.99$.

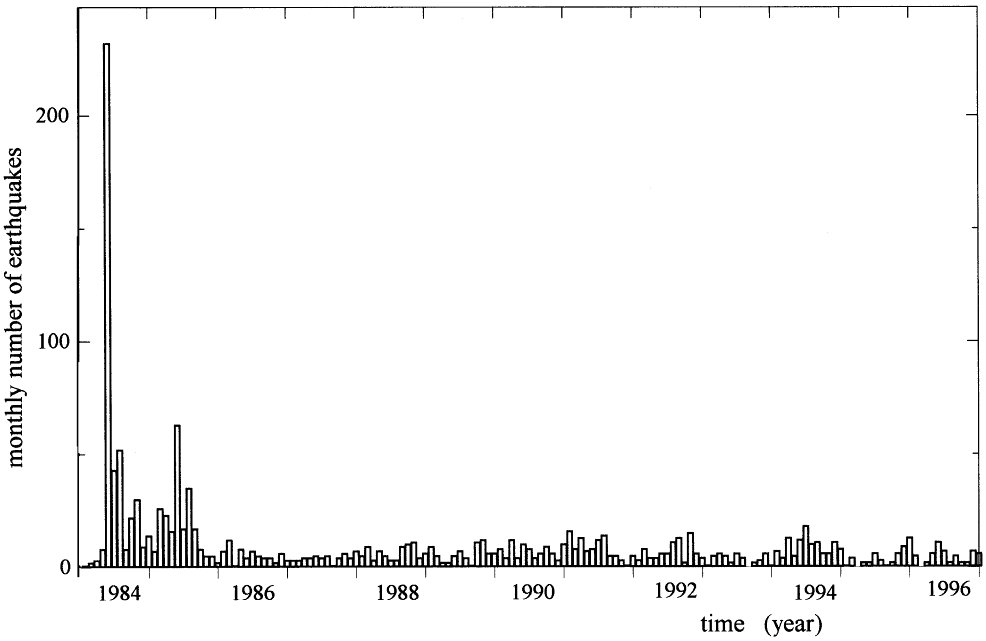

Fig. 4. – Monthly number of the earthquakes reported in fig. 2.

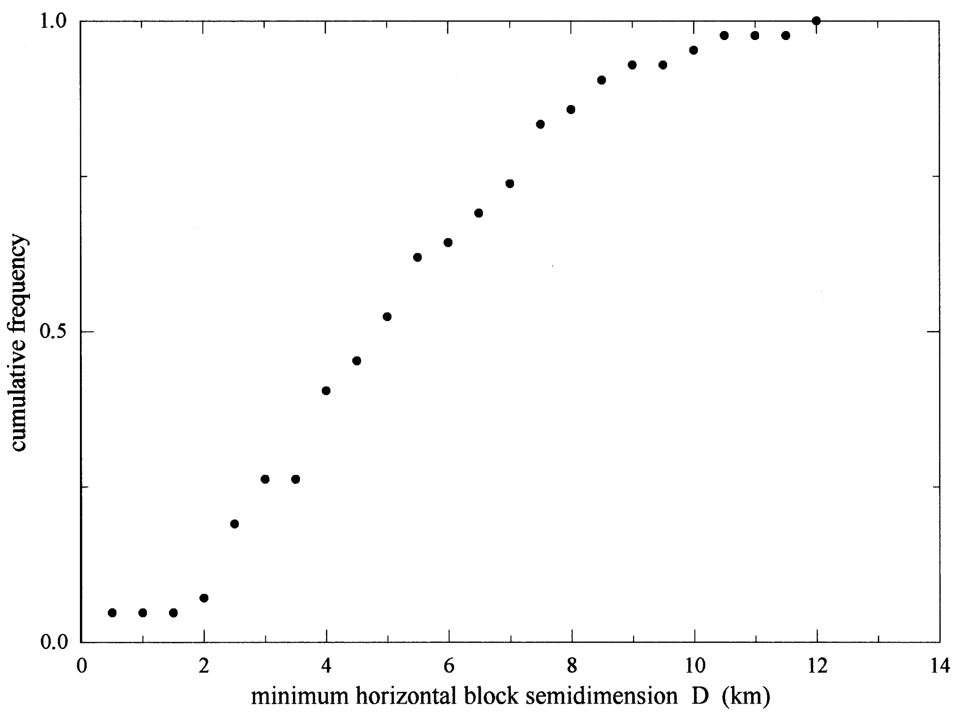

Fig. 5. – Cumulative frequency of the horizontal block semidimensions (D). It can be seen that only about 25% of blocks has $D < 3$ km.

The sequence occurred in the L'Aquila basin in May 1985 had a main shock with $M = 4.0$ [20], while the largest events observed in the north-western zone of the platform on the occasion of the seismic swarms of August 1992 and June 1994 had $M = 3.9$ and $M = 3.7$, respectively [21, 22]. In all these cases, both the b-values and the focal-plane solutions were close to those reported above and, more in general, to those assumed for the Centre-southern Apennines [24].

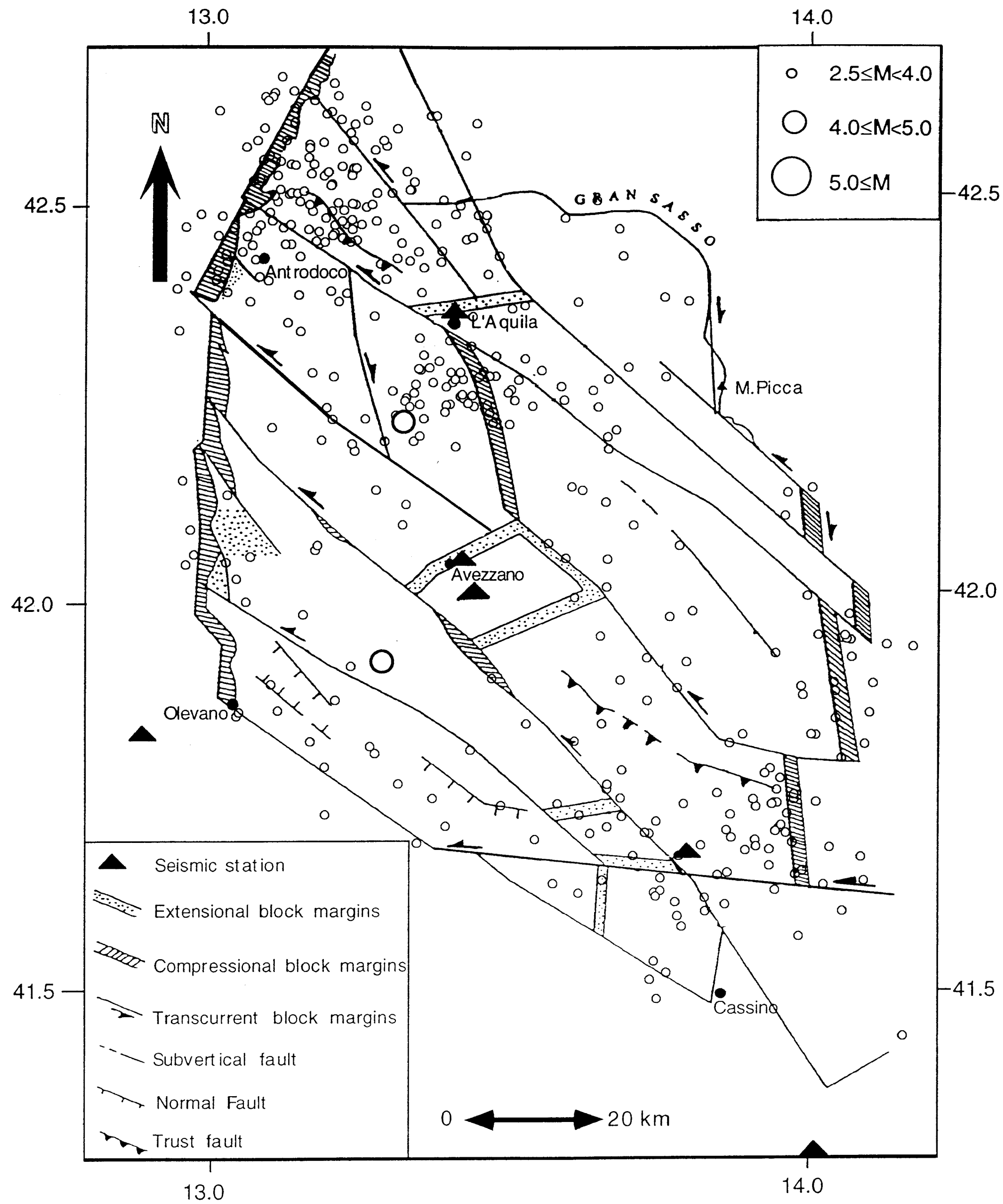

Fig. 6. – Earthquakes with $M \geqslant 2.5$ and epicentral error < 3 km recorded in the Latium-Abruzzi platform (fig. 2) in the period 1984-1996.

TABLE I. – *Statistical comparison between D and R for three different earthquake selections.*

Variable	Experimental data	Degrees of freedom	Poissonian theoretical mean (km)	Probability (χ^2-test)
D	40	8	4.62 ± 0.35	0.90
R (events with $M \geqslant 2.5$ period: 1984-1995)	612	170	1.26 ± 0.39	0.99
R (events with $Q = A$ period: 1984-1995)	97	25	0.76 ± 0.17	0.99
R (events with $M \geqslant 2.5$ and err < 3 km period: 1985-1995)	433	158	1.92 ± 0.76	0.90

Since, on the basis of the above-mentioned seismological and block-boundary evidences, the hypocentral focal depths resulted to be in the range of the vertical fault dimensions, we studied the spatial pattern of seismicity to test the location of

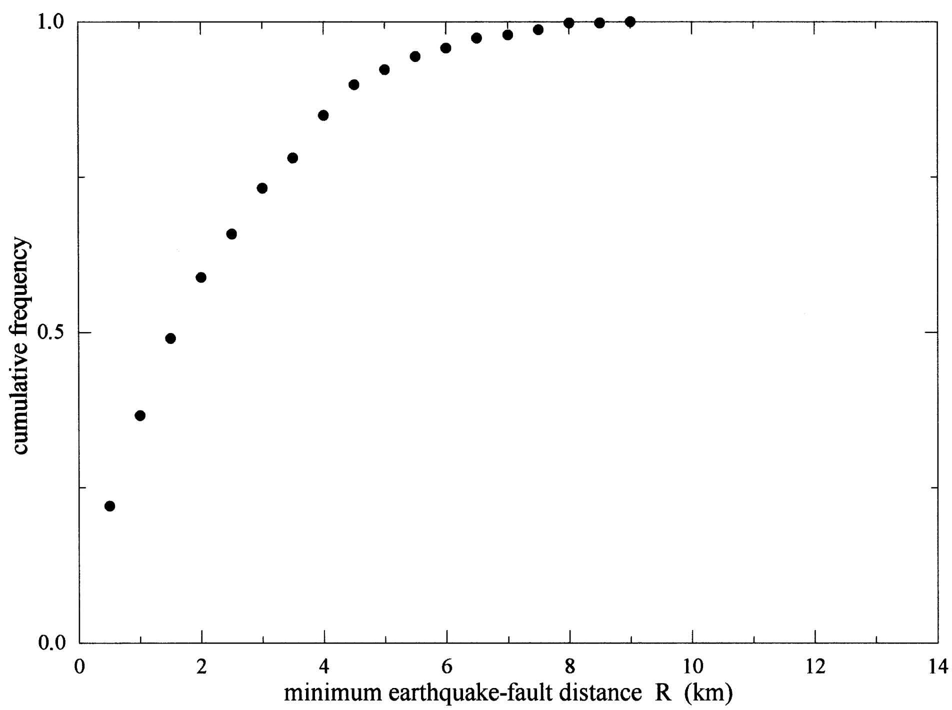

Fig. 7. – Cumulative frequency of the minimum earthquake-block boundary (fault) distance (R). The plot indicates that about 75% of earthquakes has $R < 3$ km.

subvertical faults separating the blocks proposed by Salvini [15]. For this purpose, the clustering of earthquakes along block margins was tested by comparing the minimum earthquake-block boundary (fault) distances (R) with the minimum horizontal block semidimensions (D).

Figure 5 shows the cumulative frequency of D. It can be observed that only about 25% of blocks has $D < 3$ km.

We plotted and considered only the best located earthquakes. Taking into account the results of figs. 3 and 5 mentioned above, we selected two classes of events: a) earthquakes with $M \geqslant 2.5$ (see fig. 3); b) earthquakes with $M \geqslant 2.5$ and with epicentral error < 3 km (see figs. 3 and 5). This class of events is reported in fig. 6. Moreover, we also considered a third sample of earthquakes having a good location (number of stations > 10, azimuthal gap $< 90°$). This data set is indicated in table I with the equality $Q = A$.

Some trends in the earthquake spatial concentration along block-boundaries seem to appear in the data of fig. 6 (particularly when they are compared with those of fig. 2), and of fig. 7. This figure shows the cumulative frequency of R; it indicates that about 75% of earthquakes has $R < 3$ km. A statistical comparison including all the three selected series of earthquakes confirmed this trend.

A χ^2-test revealed that D and R (for the three series of selected earthquakes) follow a Poissonian distribution. The results of the statistical comparison are reported in table I. In this table, all the R values show to be significantly less than that of D when comparing the average values together with the corresponding fluctuations (errors) and statistical significance. Therefore, the spatial pattern of seismicity seems to confirm that earthquake epicentres well approximate the structural lineaments (block-boundaries) hypothesized by block tectonic modelling proposed by Salvini [15].

Besides, we tested the possibility that at least the two seismic sequences of May 1984 and 1985 be the possible result of a slow deformation front propagating along the Apennines, in agreement with what proposed and observed in many different seismic areas, such as the northern Anatolia, China and Japan [25-27]. We estimated the distance between the "baricentral" points of the two poligons of fig. 2, taking into account the magnitude as the equivalent of mass. We found that there were no substantial differences in taking into consideration the distance between the main shocks. Then, we carried out a time shift analysis (based on the well-known cross-correlation method), on the monthly number of earthquakes of the two sequences. The best correlation coefficient, obtained by shifting these two normalized signals one relatively to the other, gave the time interval between them. On the basis of the above-mentioned distance and time interval we estimated the possible velocity of migration. This was equal to (0.27 ± 0.04) km/day with a correlation coefficient $r = 0.95$, that is comparable with the velocity values obtained in other seismic regions [4, 25-27].

4. – Conclusions

The spatial patterns of seismicity in the Latium-Abruzzi platform of central Italy support the model of block tectonics proposed by Salvini [15] on the basis of structural and paleomagnetic data.

The results seem to be independent of the earthquake selection we adopted, on condition that events follow the Gutenberg-Richter relationship.

Under the hypothesis that the two seismic sequences occurred in the 13-year record of seismicity could be the consequence of the migration of a deformation front (which, as is well-known, might trigger other earthquakes, if it impacts areas of high seismic potential), a velocity value for this possible phenomenon has been estimated. Of course, this is not a proof of the existence of such slow propagating effect along the Apennines.

Favourable conditions for the study were the comparable values of the hypocentral depths and of the vertical dimensions of the blocks (that is of the faults) and the subvertical fault geometry; the unfavourable ones were the limited number of seismic stations, of earthquakes, and epicentral errors. Of course, the last two parameters depend on the number of stations as was demonstrated in a recent paper [28]. Therefore, a major number of seismic stations is requested for a better monitoring of the two above-mentioned phenomena.

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