Engineering geology problems in seismic areas - Vol. 4
Bari (1986)

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THE LARGEST EARTHQUAKES OF THE APENNINES, SOUTHERN ITALY

LE PLUS IMPORTANTS TREMBLEMENTS DE TERRE DE LA CHAINE DES APENNINES, ITALIE DU SUD

SUMMARY

Contouring the intensity data for the largest earthquakes recorded in Southern Italy yields areas delineated by the M.C.S. X, IX, VIII isoseisms that are markedly elongated along the axial direction of the Apennine Chain.

To evaluate the attenuation of intensity with distance, four regression curves have been calculated using empirical relations of the form:

$$I(R) - Io = a + bR + c\log R$$

in accordance with Chandra's procedure [9]. The results are compared with the attenuation relation used for the « shakeability » map of Italy. New magnitudes for historical earthquakes have been calculated and an earthquake fault map is proposed. In addition, a comparison has been made between recent and historical earthquakes in some areas, including those of different magnitude, in an attempt to quantify the energies associated with the historical events.

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RESUME

Les courbes d'isovaleur de l'intensité, selon l'échelle M.C.S. X, IX, VIII, des plus importants tremblements de terre d'Italie du Sud, montrent un allongement pronomcé le long de la direction de la chaîne Apennine.

L'évaluation de l'atténuation de l'intensité avec la distance a été obtenue en utilisant quatre regressions à partir de modèles empiriques de la forme:

$$I(R) - Io = a + bR + c\log R$$

en accord avec la méthode définie par Chandra [9]. Les résultats obtenus sont comparés avec la loi d'atténuation adoptée par [19] dans l'élaboration de la carte de risques sismiques d'Italie.

Les nouvelles magnitudes des tremblements de terre historiques on été calculées, et une carte des failles sismiques est proposée.

Deplus, une approche méthodologique comparative entre les tremblements de terre actuels et anciens, même si les magnitudes sont différentes, est utilisée pour quantifier l'énergie des tremblements de terre historiques.

1. ATTENUATION OF EARTHQUAKE INTENSITIES IN SOUTHERN ITALY

Isoseismal maps of the largest earthquakes recorded in the Apennine Chain of Southern Italy show that the areas within the high intensity isoseisms are noticeably elongated along the direction of the chain.

This trend is illustrated, for example, by the M.C.S. IX isoseisms plotted in Fig. 1.

For seismic risk and emergency analysis, it is usually assumed that the intensity distribution has no azimuthal dependence. However, since the isoseisms do show a general elongation along a direction of 135°N, it has been possible to obtain attenuation relations using:

– near and far-field data (ΔI - R);

– near-field data (ΔI - R);

– near-field data in the direction of the Apennine Chain (ΔI - R_1); and

– near-field data in the direction perpendicular to the axis of the Apennine Chain (ΔI - R_2).

The radii, R, Re, of the equal-area-circles were determined from the relation $R = (A/\pi)^{1/2}$, where A is the area enclosed by each isoseism. R_1 and R_2 are, respectively, the half-length in the direction of maximum elongation (135°N) and the half-width in the direction of minimum elongation (045°N).

The attenuation was calculated using an empirical relation of the form:

$$I(R) - Io = a + bR + c\log R$$

where *I (R)* is the intensity at a distance *R* from the epicentre of an earthquake of epicentral intensity *Io,* and *a, b,* and *c* are costants appropriate to the region under consideration.

The above equation [16, 15, 1], was used, following Chandra's procedure [8, 9, 10, 30], to derive the following expressions (assuming a constant focal depth, *h,* of 10 Km):

(1) $I(R) - Io = 2.46 - 0.05\,R - 2.46 \log(R + 10) = 0.09$

(2) $I(Re) - Io = 0.60 - 0.06\,Re - 0.60 \log(Re + 10) = 0.03$

(3) $I(R) - Io = 0.31 - 0.05\,R - 0.31 \log(R + 10) = 0.03$

(4) $I(R) - Io = 2.70 - 0.02\,R - 2.70 \log(R + 10) = 0.02$

The parameters in Equations (1), (2), and (3) were calculated using the values of R_i for I_i (X, IX, VIII), while those in Equation (4) were obtained from data on the 1857, 1930 and 1980 earthquakes (Table 1).

The attenuation relations corresponding to Equations (1), (2), (3), and (4) are plotted in Fig. 2 with, for comparison, the relation used (hatched line) for the «shakeability» map of Italy [9].

TABLE 1.

Earthquake		X	IX	VIII	VII	VI	Io	Reference
5. 6.1688	*Re*	14.6	30.3	46.1			11.2	[25]
	R_1	26.0	41.6	60.0				
	R_2	6.8	16.8	28.4				
8. 9.1694	*Re*	19.9	33.3	53.8			11.5	[26]
	R_1	27.2	50.0	72.8				
	R_2	17.7	22.7	37.2				
16.12.1857	*Re*	12.1	23.9	40.7	84.0	13.0	10.8	[4]
	R_1	16.8	33.5	45.2				
	R_2	9.5	16.5	36.0				
23. 7.1930	*Re*	8.6	21.3	36.0	57.3	85.0	10.6	[29]
	R_1	11.6	26.9	46.2				
	R_2	5.0	13.8	26.9				
23.11.1980	*Re*	10.9	21.6	33.8	64.2	93.1	10.6	[20]
	R_1	14.0	29.3	46.0				
	R_2	7.5	15.7	23.0				

Re (km): radii of the equal area circle.
R_1 (Km): half-length in 135° N direction.
R_2 (km): half-width in 45° N direction.

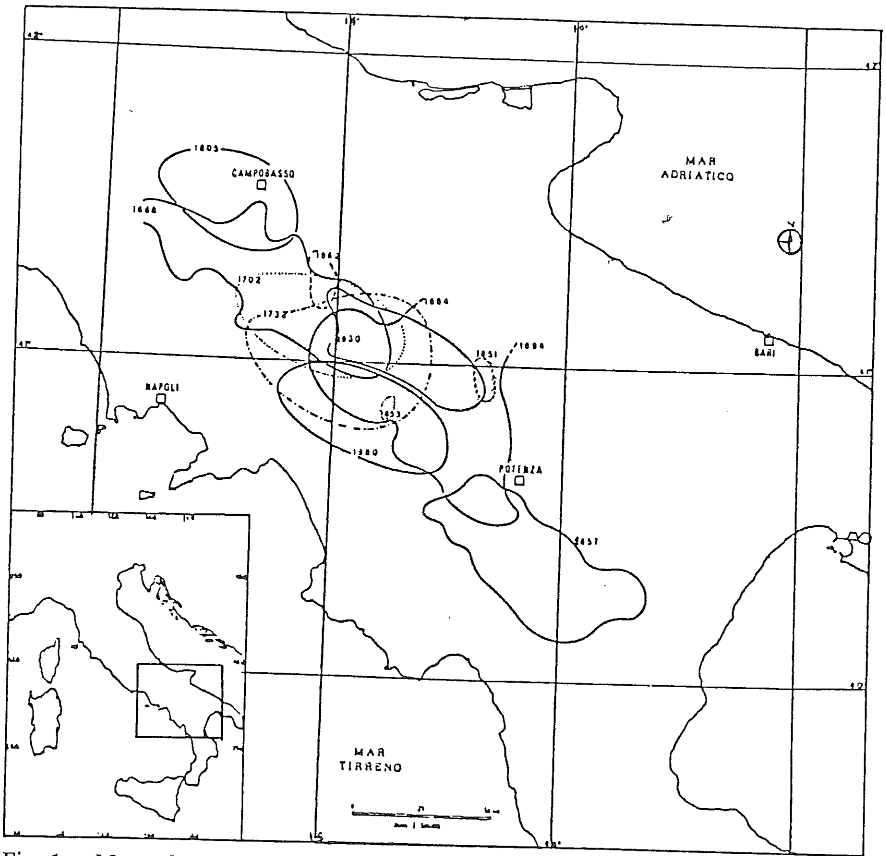

Fig. 1 - Map of the M.C.S. IX isoseismals for the earthquakes of 5 June 1688, 8 September 1694, 14 March 1702, 29 November 1732, 26 July 1805, 14 August 1851, 9 April 1853, 16 December 1857, 23 July 1930, 21 August 1962, and 23 November 1980.

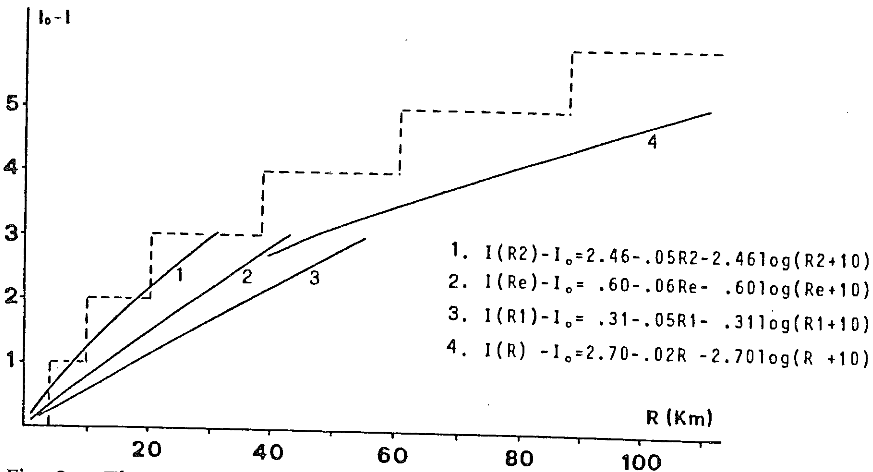

Fig. 2 - The attenuation of earthquake intensity with distance from the epicentre. The solid lines show the relations used in this paper (note the specific measure of distance used for each curve, ad identified in the corresponding equations); the hatched line shows the relation used for preparing the « shakeability » map of Italy [19].

2. EVALUATION OF EARTHQUAKE MAGNITUDES

The isoseismal maps for recent and well-studied Italian earthquakes were used to obtain an empirical relation between earthquake intensity (I) and magnitude (M) of the form [27]:

$$Ii = b'M - \nu \log (\Delta^2 + h^2)^{\frac{1}{2}} + c' \tag{5}$$

were Δ is a distance defined in Table 2, Blake's attenuation coefficient $\nu = 4.0$ [18], and the constants $b' = 1.5$ [27] and $c' = 4.4$ ($\sigma = 0.13$), c' being determined from the data in Table 2 and in the I.N.G. Seismological Bulletin.

TABLE 2.

Earthquake		IX	VIII	VII	VI	V	Reference
23.11.1980	Δ	10.4	32.3	55.5	93.1	180.0	[21]
6. 5.1976	Δ	9.1	23.0	45.9	91.3	148.8	[14]
19. 9.1979	Δ		7.0	23.0	45.0	83.0	[12]
7. 5.1984	Δ			18.0	34.0	66.0	[6]
9.11.1983	Δ				17.5	56.5	[6]

Δ (Km): radii of the equal-area-circle and or half-length in axial direction of Apennine Chain.

The relation between intensity and distance ($\Delta = R$ or R_1) described by Equation (5) is shown, for $h = 10$ Km and different values of M, by the solid, discontinuous lines in Fig. 3; also plotted are the changes with intensity of the

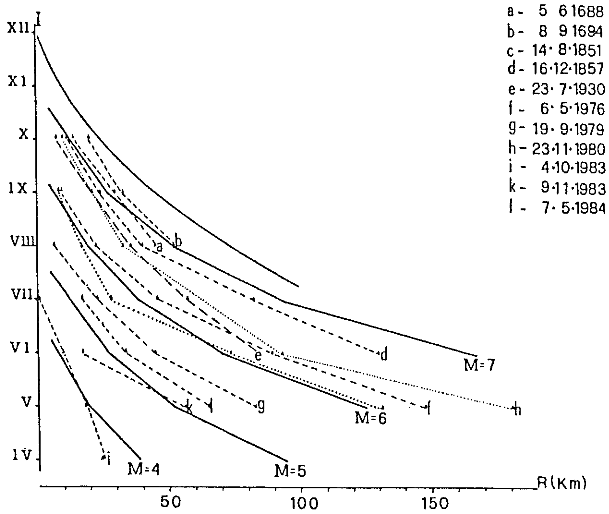

Fig. 3 - The variation of intensity with distance from the epicentre of earthquakes in Italy. Three sets of relations are shown: 1) Solid, discontinuous line: derived from the Intensity-Magnitudo-Distance relation, described by Equattion (5); 2) Solid curve at top of figure: derived from the Attenuation of Intensity-Distance relation described by Equation (3); 3) Triangles joined by Broken or dotted lines: determined from evaluation isoseismis; in this case, the distances refer to the radii of the corresponding equal-area-circles.

isoseismal radii of equal-area-circles (triangles joined by dashed of dotted lines) and of R_i (solid curve at top of figure; Equation (3].

The overall agreement in the shapes of the curves is satisfactory.

However, the clear non-parallelism apparent in the comparative trends of earthquakes *C*, *K* and *I* strongly supports the conclusions from earlier work that:

– for *C*, it is possible that two shocks occurred, with different magnitudes and focal depths [7];

– for *K*, a greater focal depth was involved, perhaps between 20 Km [24] and 35 Km [32]; and

– for *I*, a shallower focal depth, of 2.46 Km [5], was involved.

The magnitudes calculated from Equation (5) are presented in Table 3. However, caution must be exercised in the general application of this equation, for it represents a « first-approximation » relation and does not take into account either:

– the errors associated with each variable; or

– the regional setting of the area of interest: for example, in Italy, the NW-SE tectonic trend of the Mainland peninsula, with different structures, such as the foreland, foredeep, Apennine Chain and backdeep, running parallel with the Apennine Chain from the Adriatic to the Tyrrhenian Sea. Furthermore, the nature of the seismic energy distribution will have been significantly influenced by local, as well as regional, structural conditions. The relative effects of these two factors are difficult to evaluate and, indeed, it is only with the detailed analisys of recent earthquakes that it has been possible to separate regional from local contributions, an example is shown in Fig. 4.

TABLE 3.

Earthquake	ML	MK	M
5. 6.1688		6.6	6.9
8. 9.1694		6.1	7.0
14. 3.1702		6.1	6.6
29.11.1732		6.1	6.7
26. 7.1805		6.5	6.6
14. 8.1851		6.1	5.7
9. 4.1853		5.6	5.2
16.12.1857		7.0	6.7
23. 7.1930	6.5	7.0	6.5
21. 8.1962	6.0	6.5	6.2
6. 5.1976	6.1		6.2
19. 9.1979	5.5		5.4
23.11.1980	6.5		6.5

MK (macroseismic magnitude calculated according to Karnik) and ML (local magnitude) from [23], M (macroseismic magnitude calculated according to (5) relation).

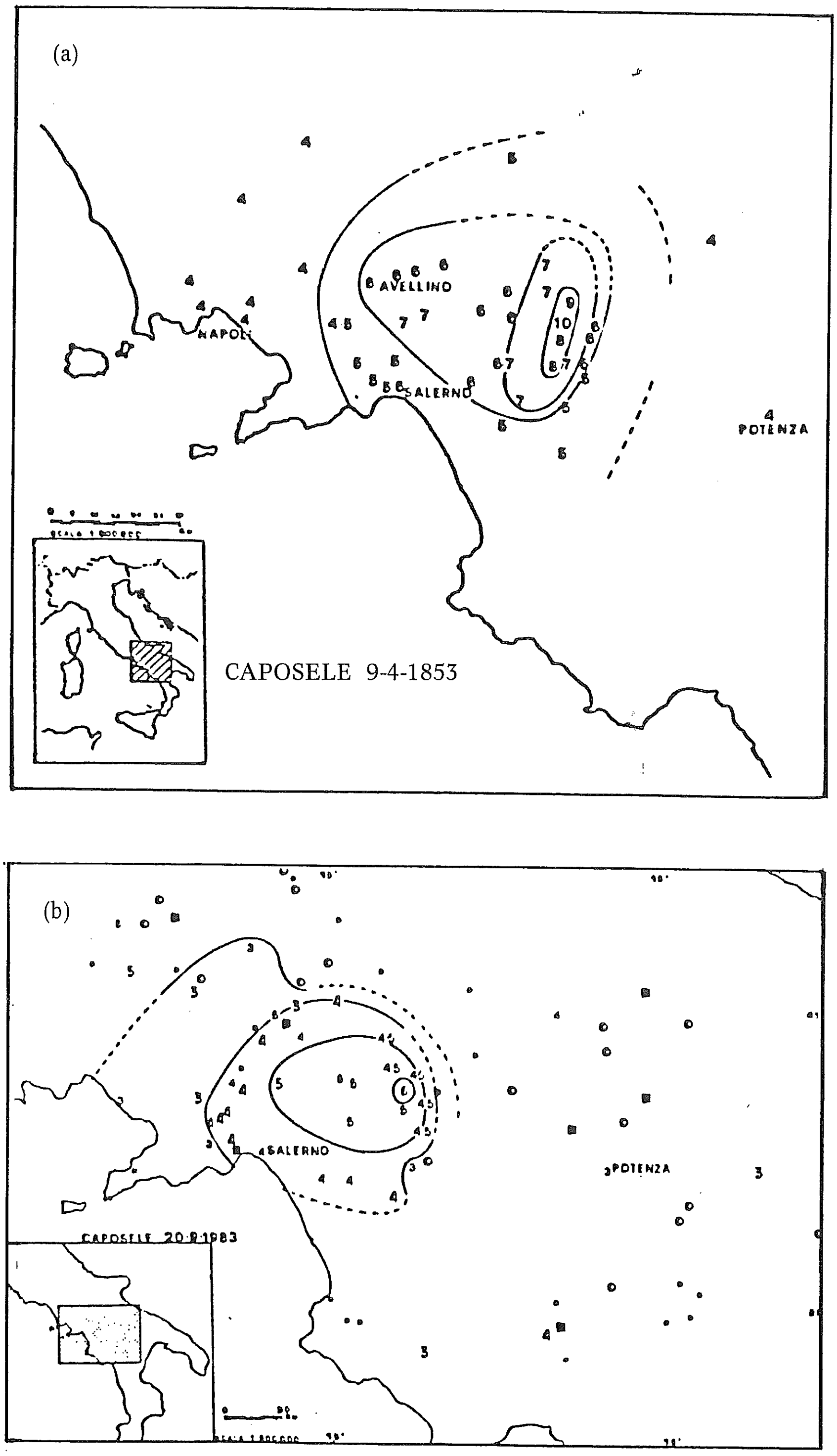

Fig. 4 – Isoseismal maps for the earthquakes of (a) 9 April 1853, and (b) 20 September 1983. The numbers show specific intensity data.

3. RELATION BETWEEN EARTHQUAKE MAGNITUDE AND FAULT LENGTH

Several relations are available linking earthquake magnitude to fault length, and a summary of these various regions and types of faults are presented in [17]. All are empirically determined and have the general form:

$$\log L = p + qM$$

were L denotes the length of a fault for a given magnitude M.

As Bolt [2] has emphasised, the error in data on L and M must be taken into account before a realistic regressional analysis may be performed. Such an analysis has been presented by Bonilla [3], following a critical review of existing data. Some of the factors which affect the random variation of the variables are the incomplete surface data on seismogenic faulting, differences in stress drop and shear modulus, the type of faulting, the nature of the region in which faulting occurs, and the relation of the faulting to plate boundaries.

Some of the relations are illustrated in Fig. 5, as well as the fault lenghts determined by the model in [27] (filled squares). However, for the November 23, 1980 earthquake, the mainshock-aftershock mechanisms do not show a simple correlation [11], and the length of the surface distribution of the aftershocks is much greater than would have been predicted by any of the rela-

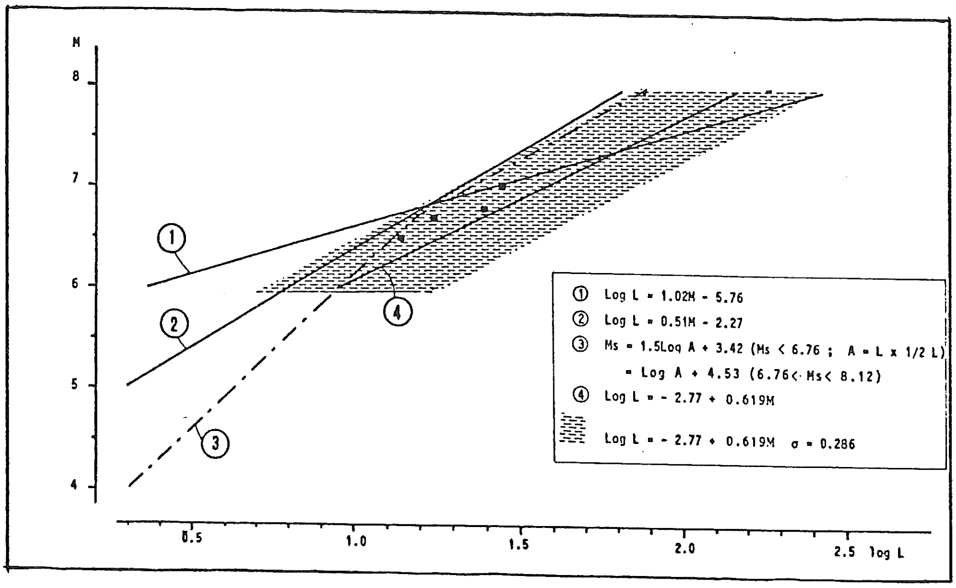

Fig. 5 - The Magnitude-Rupture length relations proposed by: 1) TOCKER [31]; 2) OKADA [33]; 3) GELLER [13]; 4) BONILLA [3]. The dashed area represents the range of error (at ± 1 σ) associated with relation (4). The filled squares mark the position of the 1694, 1688, 1857, and 1930 earthquakes, using the model of SHEBALIN [27]. The filled circle shows the length of the after-shocks-area for the 23 November 1980 earthquake. Note the logarithmic length scale, L being in kilometres.

tions shown in Fig. 5, the distance of about 80 km being similar to that of the maximum elongation of the VIII isoseism.

In Fig. 6a, b are plotted the rupture lengths for the earthquakes shown in fig. 1 estimated in according to Bonilla [3] and the time-space distribution of the earthquakes respectively. The direction of segments is just like the direction of maximum elongation of the isoseisms. In the same picture (Fig. 6a)

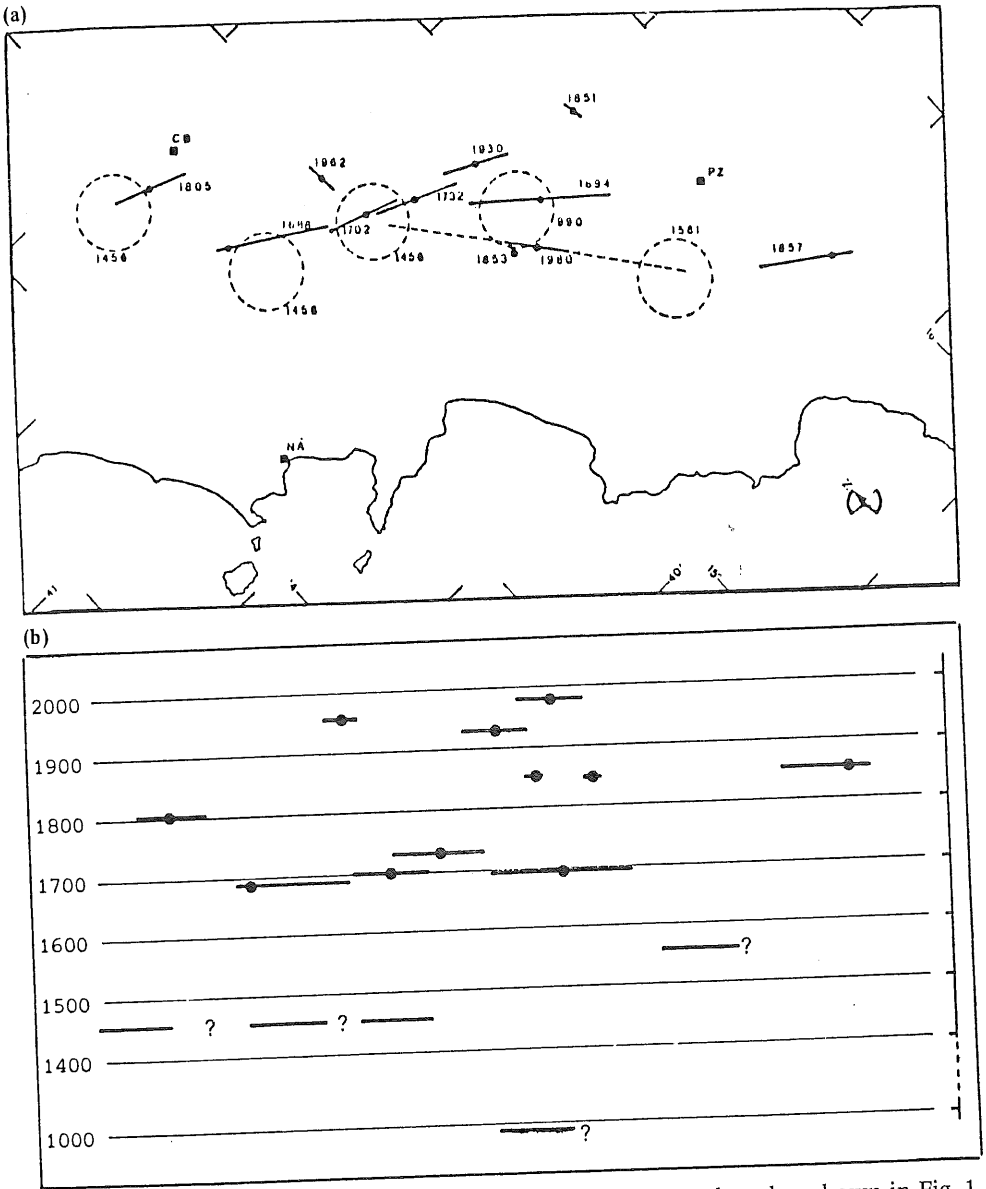

Fig. 6 – (a) Plot of the rupture lengths (solid lines) for the earthquakes shown in Fig. 1. The dashed line shows the length of the after shocks-area for the 23 November 1980 earthquake. The dashed circles show the epicentral area of 990, 1456 and 1561 earthquakes; (b) the distribution of earthquake locations with time, showing also the associated rupture lenghts. The rupture were calculated from the relation of BONILLA [3].

are also shown the epicentral areas of events preceding the 1688 earthquake, for which it is'nt possible, up to day, to determine a preferential elongation.

The distribution of the intensities is analysed according to simple attenuation lows, but it is necessary to separate this contribution from that of the source mechanism. This last is, generally, very large in the near field and it produces some misunderstandings in the estimate of the characteristics of the seismic process.

4. CONCLUSIONS

The revision of the largest earthquakes recorded in Southern Apennine has allowed to find mutual peculiarity such as isoseism elongations in according to the axial direction of the Chain, and to obtain new attenuation relations of intensity with a simmetry different of the circular shape, which let to define better the seismic risk of Southern italian peninsula.

It has been possible to estimate the magnitudes of the historical events comparing the shaked areas with those of the recent earthquakes. Particularly the 1694 earthquake, the largest analysed event, shows a 7.0 rather 6.1 [23] magnitude.

Besides, in the seismogenetic belt considered it is possible to observe that:

– the bulk of seismic energy is relased in central part;

– the width of the belt is determined by 1694-1930-1980 earthquake succession;

– smaller events (1851, 1853, 1962) have an apparent trend in the direction perpendicular to the axis of the Apennine chain;

– the migration of seismic activity is generally random, but there is a tendency to migrate as confirmed by the 1688-1702-1732-1910-1930 earthquakes succession;

– there are, in a broad sense, seismic gaps on the other sides of the 1805 and 1857 earthquakes, NW and SE respectively.

The headlines shown above, obtained by the analysis of the largest earthquakes occurred in the three last centuries should be completed by the careful revision of the great historical events occurred before that of 1688 and by a detailed analysis of recent earthquakes.

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