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Seismic hazard in Irpinia and considerations about the seismogenic area

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Abstract
An analysis of historical seismic data has provided new clues for a macrozonation of the Southern Apennines, suggesting that the most hazardous zone is in the Irpinia region. The use of *Weibull* statistics allows the definition of mean return times for shocks with $I_0 \geq$ IX MCS. The high number of events exceeding IX degree, so frequent in time, suggests movements along large active structures which can lead morphological trends, lineament swarms and regional macroseismic propagations. A comparison among macroseismic fields, maximum isoseismal elongations and lineament swarms is performed.

1. Introduction

A long-standing problem in seismology is the possible correlation between the morphology and the distribution of the felt effects of earthquakes, which can help to better clarify the relationships between the stress field, morphological trends and felt effects propagation. In the past these different data sets were difficult to compare because they were very sparse and not collected in data-bases. In the last years the creation of automatic data bank containing the different data sets was performed and therefore it is possible to search for a correlation that can be particularly significant for areas with a strong seismicity like Irpinia region.

2. Macrozonation and statistics

The different geologic conditions and seismotectonic characteristics in Italy determine the necessity to subdivide the seismological data in coherent groups. In previous papers the Italian territory was divided in 11 zones with similar seismotectonic characteristics. For each of these zones a mean azimuthal propagation model of intensity was computed by means of isoseismal digitized maps ($I_0 \geq$ VI MCS) and was applied to the earthquakes without isoseisms. Italy was then subdivided in elementary cells (0.1° by 0.1°) for each of which some parameters were evaluated, using the available isoseisms or the models. In particular an index (C), to obtain more complete information for seismic-hazard problems, was defined with the aim to carry out a macrozonation. This index is a function in a cumulative way of the felt intensities, the number of events for each class of intensity and a relative weighting function for each event (Basili *et al.*, 1990; Favali *et al.*, 1990):

$$C = \log \sum_{k=1}^{N_t} R(k) \cdot 10^{\left[I_f(k)-s\right]} \qquad (1)$$

where

$R(k) = [R_i(k) \cdot R_c(k)]$ — The reliability factors (R_i and R_c) take into account the error assigned to the epicentral intensities and coordinates in the National Seismic Catalogue (Console *et al.*, 1979).

$I_f\ (k)$ — Intensity felt in the cell (observed or estimated).

s — Shift factor assumed equal 8 to obtain $C = 0$

when at least a VIII degree effect is felt in the cell (observed or estimated).

N_t — Number of felt events.

Most of available historical seismic data has been used starting from a suitable date for their reliability (1500 A.D. for macroseismic maps and 1 A.D. for catalogue) to compute C-index (Favali *et al.*, 1986; 1990). The data have been derived by the ING catalogue (ING, 1989) and macroseismic atlases (ING, 1983a; 1983b; 1988; Postpischl, 1985).

Higher values of C characterize the seismically most hazardous areas and, as we could expect, a well-defined elongated area with high C covers the Irpinia zone up to Sannio-Matese.

In fig. 1 the isolines of C-index in association with the main seismicity (earthquakes with $I_0 \geq$ VIII) are shown roughly between 40.5° and 42° latitudes.

We have chosen for the statistical analysis the area bounded by the closed 1.5 isoline (roughly defined by the dashed polygon) (fig. 1) because this isoline includes almost the totality of the earthquakes with $I_0 \geq$ VIII.

Considering the high magnitudes of the earthquakes occurred in this zone (table I), we did not apply any statistical method to define the maximum expected magnitude (*e.g.*, Gumbel-III), but more appropriately we use the Weibull distribution (Weibull, 1951; Rikitake, 1976) to estimate the mean return time in the above-mentioned polygonal area, in this case considered as a seismogenic zone. A completeness analysis (Stepp, 1973) has been performed, for the purpose of evaluating the part of the catalogue to be used, obtaining the following results:

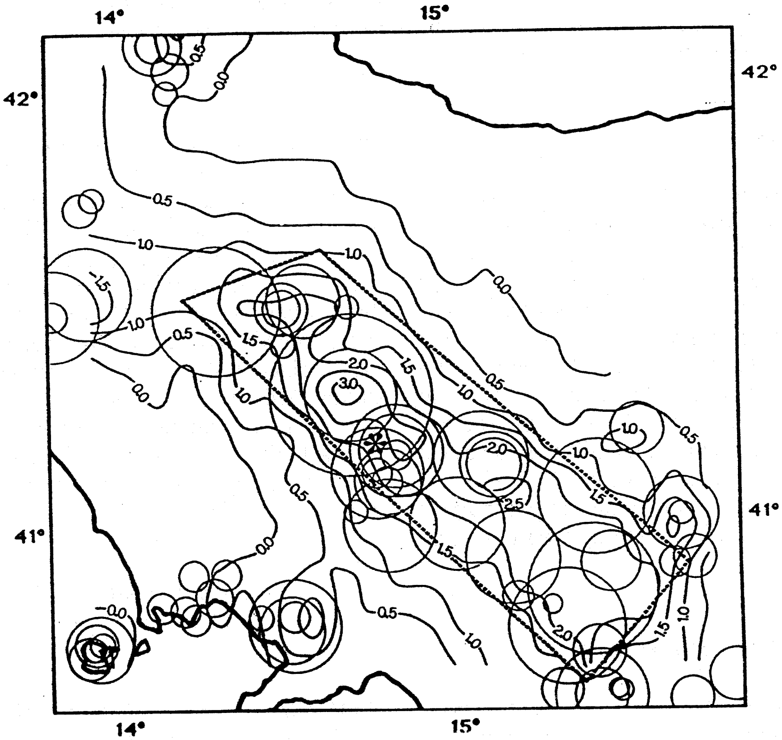


Fig. 1. Isolines of C with superimposed the epicentres of events with $I_0 \geq$ VIII occurring in the area since 1000. The maximum value is 3.035 at NW of Benevento (the location of the city is represented with a star in the figure); the equidistance is 0.5. The dashed line, drawn on the basis of 1.5 isoline, roughly represents the seismogenic zone on which the Weibull distribution has been applied. The mean return time of earthquakes with I_0 = IX is 20 ± 12 years.

Intensity (M.C.S.)	Time interval (years)
$I \geq$ IV	$\simeq$ 90 (1895-1988)
$I \geq$ V	$\simeq$ 90 (1895-1988)
$I \geq$ VI	$\simeq$ 130 (1853-1988)
$I \geq$ VII	$\simeq$ 130 (1853-1988)
$I \geq$ VIII	$\simeq$ 300 (1688-1988)
$I \geq$ IX	$\simeq$ 300 (1688-1988)

The completeness time interval is equal for VIII and IX degree events, but it has not to wonder because a lack of data of nearly 300 years between the 14th and 16th centuries is evident (see table I), obviously conditioning the result of the Stepp analysis. The mean return time of earthquakes with I_0 IX was the following (Basili *et al.*, 1990):

$$E(t) = 20 \pm 12 \text{ years}$$

	Year m d	Epic. coord.	I_0 M
	1125 10 11	41.100 15.000	X 6.3
	1125 10 12	41.100 15.000	IX 6.1
	1180 – –	41.150 15.080	X 6.3
	1294 – –	41.500 14.500	IX 5.8
	1456 12 05	41.510 14.510	XI 6.8
	1456 12 31	41.510 14.510	X 6.3
	1466 01 14	40.700 15.400	IX 5.8
*	1688 06 05	41.310 14.560	XI 6.6
*	1694 09 08	40.860 15.430	XI 6.6 A
*	1702 03 14	41.110 14.950	X 6.3 B
*	1732 11 29	41.060 15.100	X 6.3 C
*	1805 07 26	41.517 14.567	X 6.1 D
*	1853 04 09	40.833 15.230	IX 5.8 F
*	1910 06 07	40.900 15.450	IX 5.8 H
*	1930 07 23	41.830 15.330	X 6.1 I
*	1962 08 21	41.250 15.950	IX 5.6 K
*	1980 11 23	40.760 15.309	X 6.5 L

Table I. List of earthquakes ($I_0 \geq$ IX) occurred in the Sannio-Matese and Irpinia area (inside dashed line in fig. 1) starting from 1000 A.D. The letters of the last column are referred to the isoseismal maps shown in fig. 3. I_0 is the epicentral intensity; M is the magnitude; * means available macroseismic map.

3. Macroseismic fields and lineaments

The studied area, as shown, produces very high magnitude earthquakes with short return time, therefore it is characterized by active tectonics involving regional seismogenic structures. Moreover, the typical depth range of the hypocentres (10÷30 km) suggests that these structures are located under the sedimentary covers. The stress field has produced progressive deformation of these deep regional structures, which affected the evolution of the covers with an important influence on the morphology; the lineaments represent an effect of this activity (Wise *et al.*, 1985). Many authors argue an evolution of the Dinarides and Apennines due to the interaction of the Adriatic lithosphere with these two margins (*e.g.*, Malinverno and Ryan, 1986; Moretti and Royden, 1988; Royden, 1988; Favali *et al.*, 1991), hypothesizing a deep and larger-scale process driving the plate movements.

At present the stress conditions are different along the two previous margins. These differences are testified by evidences of inverse structures at surface and compressional interactions in depth (earthquakes typically with thrust movements) along the Dinarides. On the contrary we can note, at the surface scale, compression only along the Apennine front, not associated to large seismogenic processes, while a tensile regime is present along the chain with important seismogenic extensional processes. The Apennine chain is also conditioned by the opening of the oceanic Tyrrhenian basin, occurred in the last 7-10 Ma and probably still active.

In the Southern Apennines Wise *et al.* (1985) recognized that the lineaments are grouped in swarms azimuthally distributed and partially superimposed each other. Every swarm is linkable to past or still active stress fields. The existence of defined lineament swarms suggests also a substantial regularity in the aseismic and seismic basement movements, conditioning in the latter the propagation of seismic energy and therefore the macroseismic effects. This is valid especially for strongest earthquakes, while the low-magnitude events, whether do not produce surficial effects — if they are located in the basement — or are connected with more little structures in the covers. On the basis of these previous considerations, it is reasonable to endeavor a comparison between azimuthal maximum elongations of macroseismic fields and prevalent lineament swarms with the aim to evaluate their structural meaning, recognizing the deep structures (eventually also seismogenic) and consequently the regional stress field.

The available data for the Southern Apennines are the isoseismal digitized maps ($I \geq$ VI), from which the direction of the maximum elongation of the isoseism of each intensity degree has been extracted (Favali *et al.*, 1986), and lineament directions (Wise *et al.*, 1985). An event with a macroseismic field with two or more isoseisms of different degree can be associated to two or more different directions of elongation. We have weighted by a quality factor ($0 \leq Q \leq 1$) the isoseismal data assuming greater importance to more regular shapes and more marked elongations.

In fig. 2 a comparison between the two data sets is shown. Generally it is possible to note a good agreement in each cell between directions both of isoseismal elongations and lineaments, more markedly in the cells with greater data density (Frugoni *et al.*, 1990). In fact when the strikes of elongations change, the main directions of lineaments also change in the same way.

The lineament and isoseismal data sets show in the eastern region of the Apennines predominant directions, E-W in the Gargano promontory (A in fig. 2e)-f)) and Apenninic in the Bradano foredeep (B in fig. 2e)-f)). Along the axis of the chain two directions are prevalent for the lineaments (fig. 2f)), evidence of different stress fields which have interested the evolution of Apennines. On the contrary the elongation of the isoseismal data shows an Apenninic preferential strike (fig. 2e)).

Relation between the basement structures and seismic-energy propagation for the greatest earthquakes occurred in Irpinia area is possible to point out (fig. 3). The trend of the macroseismic field elongations coincides — for the events A, B, C, D, G, I, L — with the Apenninic strike of the predominant lineament swarm. The E and F events are correlated with the anti-Apenninic swarm, while the H and K events do not show a well-defined correlation with the lineament.

Even if we cannot explain in detail the physical process on which the correlation between both data sets is based, we are aware this relation exists. The prevalent isoseismal elongation is influenced by important regional structures (with Apenninic direction) which are able to drive the macroseismic propagation. On the other hand, also the seismogenic structures show the same strike. Furthermore the lineament swarm — predominant in percentage and therefore younger — is striking in the same way. Then we can hypothesize that the same stress field that has been active until now controls the evolution which leads to similar directions of lineaments, isoseisms and strikes of the seismogenic structures.

4. Conclusions

A macrozonation of the Southern Apennines by means of the spatial analysis of an index (C) linked to the effects of macroseismic propagation was performed. In particular the most dangerous area was pointed out in Irpinia up to Sannio-Matese with an Apenninic elongated shape. Then the *Weibull* distribution — considering only the complete part of the catalogue ($\simeq$ 300 years) — was applied to the events occurred in the most dangerous area obtaining a mean return time for shocks with $I_0 \geq$ IX of 20 ± 12 years.

The short return time of earthquakes with high-energy release ($I_0 \geq$ IX) suggests the existence of dimensionally large and very active structures. The typical depth range in which the seismogenic processes occur ($10 \div 30$ km) and the thickness (about 5 km) of the sedimentary covers (Mostardini and Merlini, 1986) assure that the primary cause of those deformations is not located within the covers, but conditions their morphological evolution.

In the attempt to clarify the relation between the deep structures and the covers, a comparison between the maximum elongation of macroseismic effects (surficial expression of the seismic-energy propagation) and the lineament swarms (surficial expression of the regional past or still active stress fields) was tried. The comparison in the Southern Apennines allows one to recognize their relation mainly according to some well-defined directions. In Irpinia the marked Apenninic trend of the two data sets suggests that both could be influenced by a recent and unique regional stress field, which may be related — more

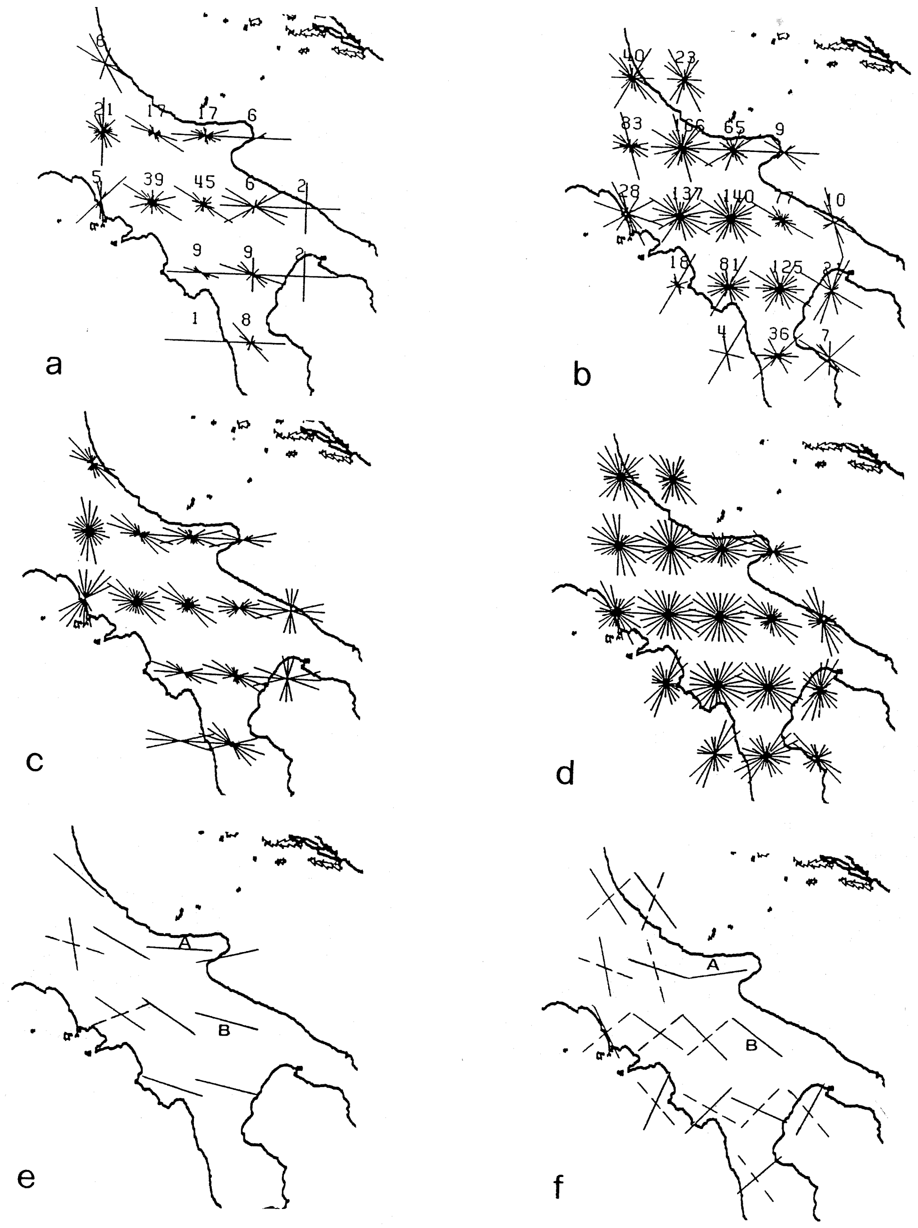


Fig. 2. Comparison between isoseismal elongations and lineament swarms. The area has been subdivided in cells (1.0° lat. by 1.0° long.; 0.25° superimposed). The data of each cell have been grouped in 12 classes of 15°. The values on the top of every cell in a) and b) indicate the number of isoseisms and lineaments respectively. a) Normalized *Q*-weighted number of maximum isoseismal elongations for each direction; b) normalized number of lineaments for each direction; c) mobile averages on 3 values of elongation represented in a); d) mobile averages on 3 values of lineaments represented in b); e) prevalent isoseismal elongations, derived from c); f) prevalent lineament directions, derived from d). In e) and f) the information concerning cells with few data has been eliminated.

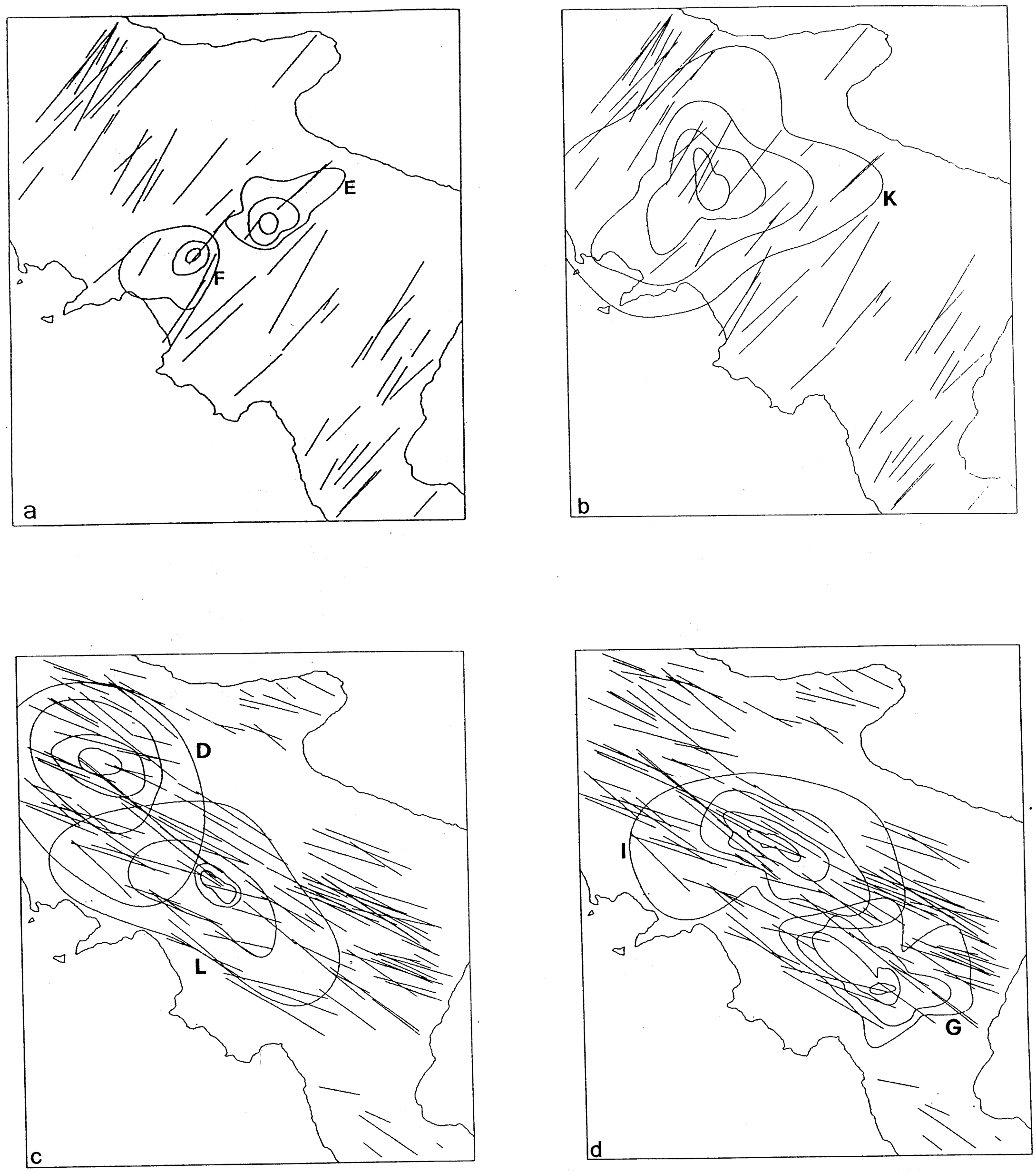
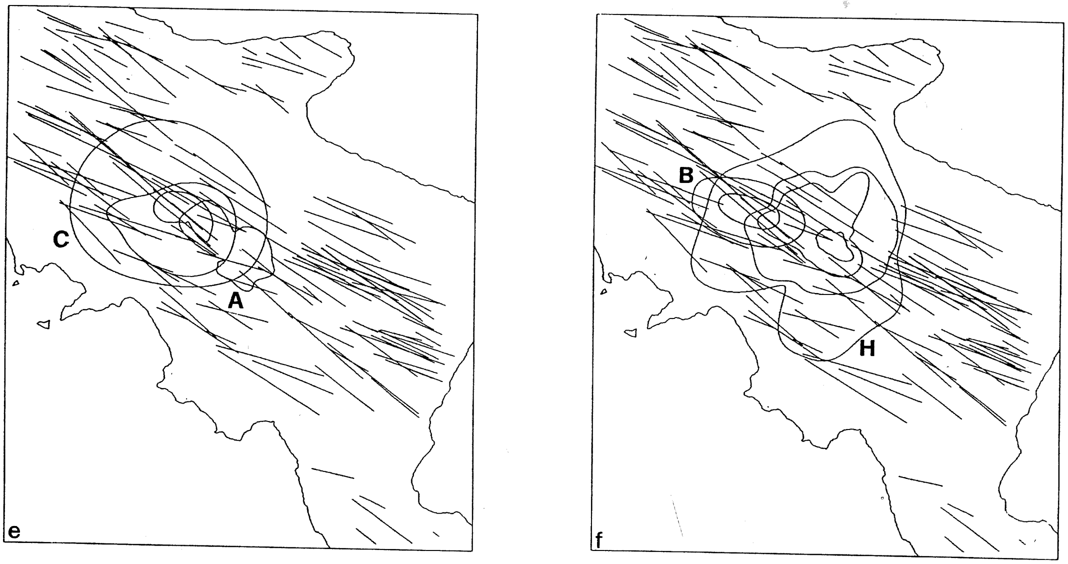


Fig. 3. Comparison between digitized isoseismal maps of the main earthquakes ($I_0 \geq$ IX MCS) and two prevalent lineament swarms. a),b) the macroseismic fields are superimposed to the N40°E ± 10° lineament swarm (11 % on the total); c)-f) the isoseismal maps are compared with the N60°W ± 15° lineament swarm (23% on the total). Detailed information about the events is linked in table I except for E (Vulture, 1851; I_0 = X) and G (Basilicata, 1857; I_0 = XI) earthquakes, the epicentral coordinates of which fall out of the dashed line drawn in fig. 1.



or less directly — with the Tyrrhenian active basin and the present stage of the fold-and-thrust interaction of the lithostratigraphic units of the Apennine zone (Bigi *et al.*, 1989).

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