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Pattern recognition of the relation between seismicity and gravity anomalies in Italy

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Sismologia. — *Pattern recognition of the relation between seismicity and gravity anomalies in Italy.* Nota di MARCO BENVENUTI e MICHELE CAPUTO, presentata (*) dal Socio M. CAPUTO.

RIASSUNTO. — Il metodo del pattern recognition è già stato applicato con successo alla topografia della regione italiana per determinare le regioni che hanno vocazione a terremoti con magnitudo maggiore di 6. In questa Nota si applica lo stesso metodo alle anomalie di gravità e si trova una correlazione fra sismicità e gradiente delle anomalie, inoltre si confermano i risultati precedentemente ottenuti.

INTRODUCTION

In this paper we consider the determination of the areas where the epicenters of strong earthquakes (M ≥ 6) may be situated in Italy. The problem was studied using the pattern recognition method previously applied for Central Asia (Gelfand *et al.*, 1972), Anatolia and adjacent regions (Gelfand *et al.*, 1974), California (Gelfand *et al.*, 1976) and Italy (Caputo *et al.*, 1980).

These papers concluded that epicenters of strong earthquakes are only situated within specific areas which are associated with only some parts of active faults.

Concerning the Italian region it was confirmed that the epicenters of the catalogue determined instrumentally satisfy the hypothesis. Furthermore, the new epicenters (Friuli May 1976, Irpinia Nov. 1980) occurred in two points recognized as dangerous in the study by Caputo *et al.* (1980).

Parameters related to the Bouguer anomaly have been used in this study to determine by the pattern recognition method the areas where strong earthquakes may occur. These parameters have been used also in combination with the elevation parameters for checking the results. The previous results (Caputo *et al.*, 1980) have also been checked using the elevation parameters only in a modified learning process.

The recognition of such areas is very important for earthquake prediction studies, for studies of seismic risk, and for studying the mechanism of development of active faults associated with earthquakes.

The result of this paper confirms those of Caputo *et al.* (1980). For details on the risk of the various areas we refer to that paper considering the present results of qualitative value.

(*) Nella seduta del 25 giugno 1982.

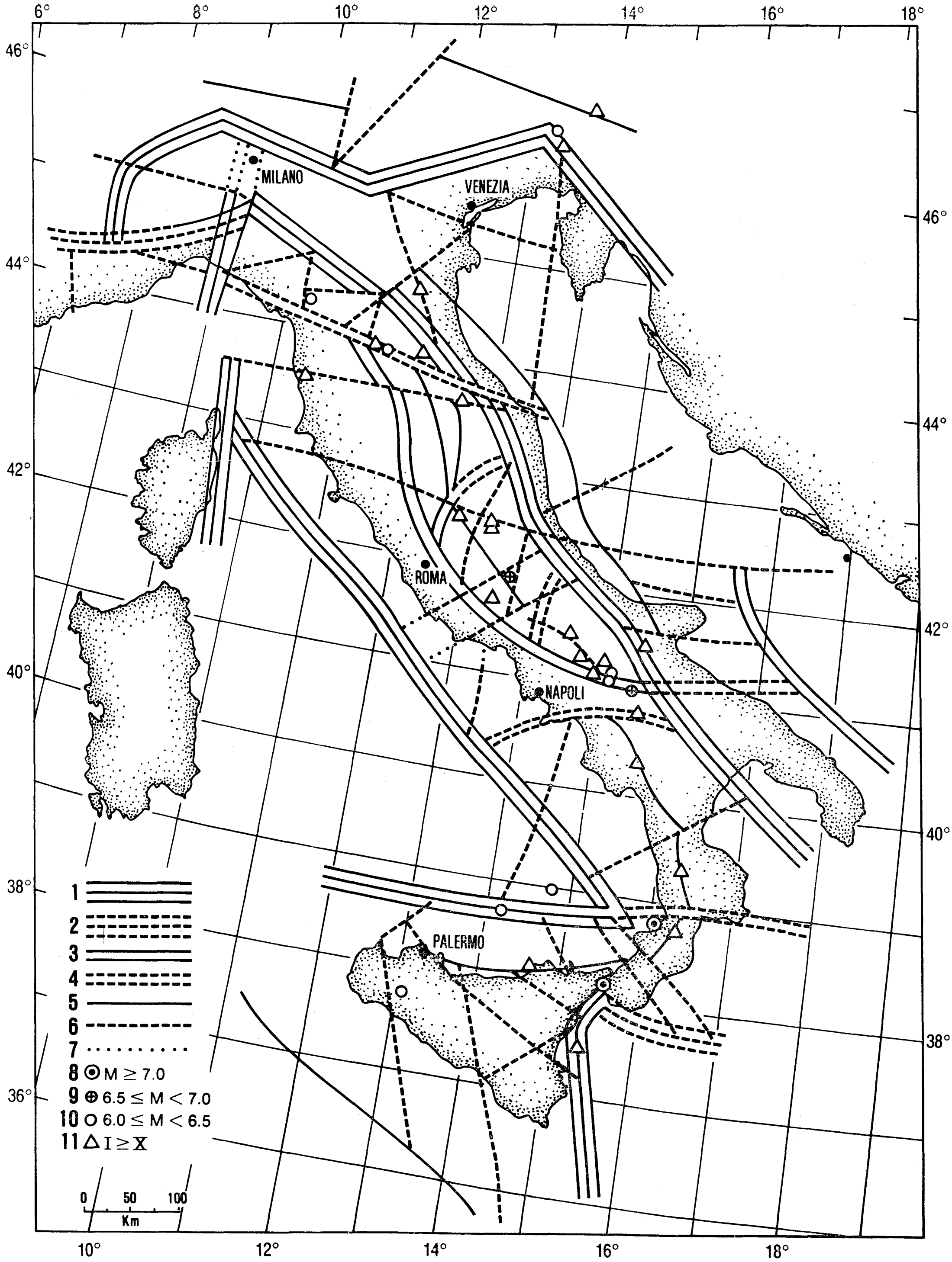

Fig. 1. – Map of the major lineaments of the Italian region; the intersections of the lineaments are considered as potentially dangerous. Numbers in the main diagram correspond to earthquakes listed in Table I. Numbers in the key refer to the following classification of lineaments, epicenters, boundaries and intersections. Lineaments: 1, 2, first order; 3, 4, second order; 5, 6, third order; 1, 3, 5, longitudinal; 2, 4, 6, transverse; the transverse lineaments 2, 4, 6 are not expressed in topography, 7 uncertain lineaments (covered by sediment or sea). Epicenters 8, 9, 10, 11.

Major lineaments

We refer to the major lineaments of the Italian region shown in Fig. 1. The definition of the lineaments and the criteria for their recognition are given by Gelfand *et al.* (1976).

In Fig. 1 the territory of Italy is divided into five morphostructural provinces: (I) Alpine; (II) Adriatic depression; (III) Apennines; (IV) Sicily and (V) Tyrrhenian sea. They are separated by first order lineaments. Each province is divided into megablocks by second order lineaments, and some megablocks are subdivided by third order lineaments. The scheme in Fig. 1 is thought to be satisfactory for this study, but there is also a need for further improvement. For example, the accuracy of the position of the boundary between Alpine and Apennine morphostructural provinces is doubtful. Moreover, the southern boundary of region III (Apennines) is sometimes placed further north by others. The lineament pattern shown in Fig. 1 is slightly different from the previous one used by Caputo *et al.* (1980)—namely, the lineament lying in the E–W direction, which separates the Alpine province from the others, has been moved slightly north and the boundary between provinces II and III is now further East than in the previous paper.

Formulation of the problem

The problem is to determine where epicenters of future strong earthquakes may be situated.

A list of previous strong earthquakes is given in Table I, (macroseismic intensity $I \geq X$ of Mercalli Scale). This table is based on the ENEL catalogues (Caputo 1981) and those of Carrozzo *et al.* (1973).

The problem is the following: to separate the intersection into two groups, D (dangerous) and N (non dangerous), near which the epicenters of strong earthquakes may or may not be situated.

The intersections are then divided into three classes, depending on the distance of each intersection from the closest known epicenter.

The first class contains intersections coinciding with epicenters up to 1980 with $M \geq 6$ and intersection with distance less than $r_1 = 20$ km from the closest epicenter.

The second class contains the intersections with distance greater than $r_2 = 100$ km from the closest epicenter.

The remaining intersections belong to the third class Here r_1 is less than usual to avoid the errors arising from the dubious location of ancient epicenters.

The problem now is: (*i*) to find the characteristic features of intersections of types D and N, (*ii*) to use these features to classify all intersections as D or N.

Table I

Earthquakes recorded in the Italian region from the year 1100 (magnitude large or equal to 6 or intensity larger or equal to X) *used in this analysis.* R_0 *is the distance to the nearest epicenter.*

Date		Latitude (°N)	Longitude (°E)	Magnitude or intensity	Code	R_0
1169	4/2	37.30	15.20	XI	CT169	0
1456	12/5	41.18	14.42	XI	BN456	50
1509	25/2	38.05	15.35	X	CZ509	40
1511	26/3	46.15	13.20	X	UD511	5
1624	19/3	44.35	11.50	X	FE624	7
1638	27/3	39.00	16.15	X	CZ638	20
1693	11/1	37.10	15.1	X	SR693	15
1703	16/1	42.35	13.10	XI	RI703	10
1703	2/2	42.27	13.20	XI	AQ703	30
1731	20/3	41.30	15.30	X	FG731	60
1781	3/6	43.34	12.37	X	PS781	20
1783	18/5	38.25	15.20	XI	RC783	0
1783	19/7	38.30	16.15	XI	CZ783	35
1805	26/7	41.31	14.34	X	CB805	20
1846	14/8	43.30	10.30	X	LI846	65
1851	14/8	41.00	15.40	X	PZ851	10
1857	16/12	40.17	15.55	X	PZ857	45
1905	8/9	38.50	16.06	6.1	CZ905	15
1908	28/12	38.10	15.35	6.9	ME908	20
1915	13/1	41.59	13.36	6.6	AQ915	8
1919	29/6	43.57	11.28	6.1	FI919	25
1920	7/9	44.15	10.17	6.2	MS920	10
1930	30/10	43.44	13.20	6.1	PZ930	10
1976	6/5	46.20	13.15	6.2	UD976	10

DATA USED FOR RECOGNITION

Each intersection is described by a number of parameters which are listed in Table II.

Parameters 1, 6, 7, 8, 9, 12, 15, 16, 17 have been chosen since they represent the intensity of neotectonic movements (parameters referring to elevation).

TABLE II

Parameter used in the learning stage. L *is the distance between the two extreme values. The parameters indicated by* (**) *have been measured in a circle with a 25 km radius.*

N°	NAME OF PARAMETER
1	Elevation H (m)
2	Gravimetric anomaly B (mGal)
3	Distance of the closest 1st order lineament R_{11} (km)
4	Distance of the closest 2nd order lineament R_{12} (km)
5	Distance from the second closest 1st order lineament R_{21} (km)
6	Maximum elevation Hmax (M)
7	Minimum elevation Hmin (M)
8	Maximum difference of elevation $\Delta H = Hmax - Hmin$ (M)
9	Gradient $(Hmax - Hmin)/L$
10	Maximum gravimetric anomaly Bmax (mGal)
11	Minimum gravimetric anomaly Bmin (mGal)
12	Maximum variation $\Delta B = Bmax - Bmin$ (mGal)
13	Gradient $\Delta B/L$
14 **	Maximum elevation Hmax (M)
15 **	Minimum elevation Hmin (M)
16 **	Maximum variation $\Delta H = Hmax - Hmin$ (M)
17 **	Gradient $(Hmax - Hmin)/L$
18 **	Maximum gravimetric anomaly Bmax (mGal)
19 **	Minimum gravimetric anomaly Bmin (mGal)
20 **	Maximum variation $\Delta B = Bmax - Bmin$ (mGal)
21 **	Gradient ΔB/distance (km)
22 **	Number of extremal values of gravity

Parameters 2, 9, 10, 11, 12, 13, 18, 19, 20, 21 were chosen because we believe that they are related to the shear strain associated with the topographic features and their isostatic compensation.

Discretization was independent for classe I and II. The method of discretization was as follows. The histogram of each parameter was smoothed and the point where the two histograms assume the same value as the normalized frequency was taken as the threshold value for that parameter.

TABLE III

Thresholds for the parameters used for the characteristic feature listed in Table IV ; (**) as in Table II ; (●●) indicates a parameter not used in learning.

N°	PARAMETER	THRESOLD	N°	PARAMETER	THRESOLD
1	H	352	15 **	Hmin	—930
2	B	50	18 **	Bmax	73
3	R 11	80	19 **	Bmin	—5
4	R 12	80	20 **	B	100
5	R 21	125	8 ●●	H	1500
6	Hmax	1390	9 ●●	H/L	0.075
7	Hmin	—700	13 ●●	B/L	2.0
10	Bmax	50	16 ●●	H	1500
11	Bmin	0	17 ●●	H/L	0.050
12	B	75	21 ●●	B/L	2.0
14 **	Hmax	1460	22 ●●	Ng	2

Parameters for which no splitting occurs between the two classes were dropped. The values of the selected thresholds for each parameter are listed in Table III.

Discretization was then done according to the CORA 3 algorithm introducing a binary vector for each intersection point.

RESULT OF RECOGNITION

The CORA 3 algorithm was used for recognition. This alghorithm was introduced by Bongard *et al.* (1966); both are described by Gelfand *et al.* (1976). For details of the recognition procedure see Caputo *et al.* (1980) and Gelfand *et al.* (1976).

TABLE IV

Characteristic features of D *and* N *intersections determined using topography and gravity anomalies.*

	H	B	R11	R12	R21	r = 12.5 Km					r = 25 Km				
						Hmax	Hmin	Bmax	Bmin	ΔB	Hmax	Hmin	Bmax	Bmin	ΔB
D 1															≤ 100
D 2												> -979		≤ -5	
D 3											> 1460			≤ -5	
N 1				≥ 80											> 100
N 2											≤ 1460		> 73		
N 3							≤ -700						> 73		
N 4					> 120								> 73		

TABLE V

Voting based on the characteristic features listed in Table IV.

$K_1 = 16$, $\bar{K}_1 = 6$, $K_2 = 11$, $\bar{K}_2 = 7$, $\bar{\Delta} = 0$

NUMBER OF VOTES FOR N CLASS	NUMBER OF VOTES FOR D CLASS			
	0	1	2	3
4	—3NA62 —3NA63 —3PA70 —9TP73 —9PA76 4TR34			
3	—3ME68 —3ME69 6PT23	*9CT81 —6FG48 —4BA54 —3SA65 —9PA75 3PE40 6LT53		
2	*SR693 *CT169 *ME908 *CZ905 *RC783 *1CZ67 —6FG43 9AR28 2AQ45 3TA64	*RC509 *PE624 *FG731 —6FG37 6SP20 2FO24	3CS66	
1	*CZ638 *CZ783 —9AG80 9N25	*LI846 1RC77	—3BS06 —1CN18 9AQ46	
0	9ME72	*3PS26 —6GR33 9TE32 6RM47 6IS51 9FR52 4NA55 3SR82	*PZ930 *FI919 *9PR16 *6MS22 3RE13 2MC30 9RI38 9AQ39 6RM49 6AV56 6AV59 3MT61	*PZ857 *PZ851 *CB805 *RI703 *AQ703 *PS781 *AQ915 *BN456 *UD976 *UD511 *MS920 *1UD03 *9RI36 *9AQ42 *3CB50 *2FG58 —9BZ01 9PR15 9FI27 9ME74

The results of the learning stage for the given values of the thresholds K_i, $\overline{K}_i$ (e.g. Caputo 1980) are shown in Table IV. The upper part of the Table shows the characteristic features of D, whereas the lower part shows those of N.

By changing the values of the thresholds in the learning stage one obtains fewer but more selective characteristic features, as we verified in variants not reported here.

The results of the voting stage are shown in Table V representing the N, D plane. N and D are respectively the number of characteristic features belonging to the objects in the tessera. Each intersection is represented by a number. For example, intersection no. 17 (which is near Borgo Val Taro, Parma) has 4 features of D and O features of N, as well as the other intersections in the same tessera.

It should be noted that the intersections are well divided by voting: only a small percentage of the learning material lies on the main diagonal D N; this is encouraging and allows their subdivision into D and N groups, this division being dependent on another threshold $\overline{\Delta}$ given by the value $\Delta = D - N$. We assume an object to be D if $\Delta > \overline{\Delta}$.

The lower the threshold $\overline{\Delta}$, the greater the probability that incorrect classifications as D will occur, and the lower $\overline{\Delta}$, the greater, the probability of a failure to recognize dangerous intersections.

The selected value for $\overline{\Delta}$ is shown in Table IV.

Among the D points there are those points where strong earthquakes are possible though they are still known as places where seismic events have not occurred in the past. In the southern part of Italy (Sicily and Calabria) it must be noted that most of the old epicenters are not recognized as D, all variants considered. This is surprising but could be explained by geological considerations on the great structural difference between this region and the others. The use of the gravimetric anomaly in recognition reveals the difficulty in using parameters related to the deep geological features, whereas the parameters used in the previous papers did not evidence such behaviour. This will be shown when the altitude parameters and the Bouguer anomaly parameters are used separately.

Elimination of parameters

For better testing our results some control experiments have been done. Parameters referred to the gravity were eliminated from learning changes in voting affected mostly the southern areas which, as previously mentioned, are geologically different. These results confirm the fact that gravity is a good parameter mostly for homogeneous areas. The stability of results compared with the previous ones is considered satisfactory.

TABLE VI

Voting based on the characteristic features determined using gravity anomalies only.

$K_1 = 18, \quad \overline{K}_1 = 5, \quad K_2 = \overline{K}_2 = 10, \quad \overline{\Delta} = 0$

NUMBER OF VOTES FOR N CLASS	NUMBER OF VOTES FOR D CLASS						
	0	1	2	3	4	5	6
6	—3NA62 —3NA63 —3PA70	—9PA75	—9TP73				
5	*RC783 —3ME69 6PT23	*CZ638 —3ME68					
4	*9CT81 —9AG80 4TR34	—9PA76	*1CZ67 —3SA65	*CZ905			
3	*SR693 *CT169 *ME908 *CZ783 —6FG43 3PE40	—6FG48 —4BA54 2AQ45	2FO24	*RC509 3TA64			

Segue : TABLE VI.

NUMBER OF VOTES FOR N CLASS	NUMBER OF VOTES FOR D CLASS						
	0	1	2	3	4	5	6
2	6SP20 2MC30 3SR82	9AQ46 3CS66	—3BS06 —6FG37	—1CN18	9TE32	*FG731	
1	3MT61	*FE624 —9BZ01 9AN25 6LT53	9FR52		6RM49	*LI846 *UD976 *UD511 *1UD03 —6GR33	1RC77
0	6AV59 9ME72	*6MS22 3RE13 6RM47 4NA55	*3CB50 9AQ39	*9PR16 *3PS26 9RI38	*PZ930 *MS920 9AR28 9ME74	*PS781 *FI919 9FI27 6AV56	*PZ857 *PZ851 *CB805 *RI703 *AQ703 *AQ915 *BN456 *9RI36 *9AQ42 *2FG58 9BR17 6IS51

CHANGES IN THE LEARNING MATERIAL

These changes have been made by moving some points from classes I and II into the third class, subsequently varying the values of the thresholds for discretization; new learning and voting were effected to test our hypothesis.

Particularly interesting is the case when all intersections south of latitude 40° are assigned to the IIIrd class; in this case parameters 7, 15 and 20 show a drastic change in the thresholds and the characteristic features also change drammatically since the role of topography is now almost nil. The result of voting is very satisfactory because most intersections near epicenters and recognized as D in the previous study (Caputo *et al.* 1980) are now recognized as D. This suggests that there is a great difference in the features of the deep structure of Southern with respect to Central and Northern parts of Italy which is reflected in gravity anomalies. In order to check this result recognition was done again with the distribution of intersections as in the first variant considered in this paper but using only gravity anomalies. Voting recognized as D most of the intersection recognized as D in the previous experiments with the exception of those below latitude 40°. This confirms that gravity anomalies in Italy are not homogeneous and that in the South they have different features. Although seismic history of South Italy is one of the longest in the world it is still too short to allow a separate study. The region is moreover too small to give a sufficient number of intersections for a reliable use of the pattern recognition method. However, it is seen that gravity anomalies play a major role in the recognition of areas prone to large earthquakes and that probably there is a relatioship between the gradient of the gravity anomalies and seismicity. This should be expected because of the shear stress field caused by the load and bouyancy of the masses causing the gradient of the gravity anomalies.

EARTHQUAKE HISTORY AND EARTHQUAKE FUTURE

In the earthquake history experiment we have tried to simulate a recognition done in the past. For this purpose we used as normal points the epicenters of the historical earthquakes in reverse order starting from the most recent up to the 1905 earthquake. Learning and voting were repeated. Only a recent southern epicenter escapes recognition. The intersections near these epicenters are recognized as D.

In the earthquake future experiment the objects recognized as D were transferred to class I. Despite previous classifications only 3 new intersections were assumed to be D. In subsequent runs the rate of new D objects was never more than 2 objects per run.

Greater values of $\bar{\Delta}$ led this rate to zero after 7 interations. The convergence check was satisfactory.

Listing of intersections coordinates

NAME	°Lat N	°Long E	NAM	°Lat N	°Long E
	First Class			Third Class	
1UD03	46.15	13.26	3RE13	44.38	10.10
9PR15	44.30	9.41	9PR16	44.23	10.11
6MS22	44.07	10.10	6SP20	44.10	9.54
3PS26	43.38	12.21	6PT23	44.10	11.00
9RI36	42.28	13.03	2FO24	43.49	12.07
9AQ42	42.06	13.27	9AN25	43.40	13.42
3CB50	41.38	15.16	9FI27	43.38	11.30
2FG58	40.59	15.30	9AR28	43.38	12.02
1CZ67	38.59	15.59	2MC30	43.03	13.04
9CT81	37.20	15.00	9TE32	42.46	14.20
			4TR34	42.44	12.12
	Second Class		9RI38	42.18	13.02
			9AQ39	42.17	13.48
9BZ01	46.53	11.41	3PE40	42.15	14.01
3BS06	45.39	10.26	2AQ45	41.57	14.23
1CN18	44.17	7.41	9AQ46	41.48	13.58
6GR33	42.26	11.46	6RM47	41.77	13.00
6FG37	42.23	16.32	6RM49	41.43	12.56
6FG43	42.02	15.16	6IS51	41.38	14.15
6FG48	41.44	17.01	9FR52	41.37	13.40
4BA56	41.14	17.44	6LT53	41.28	13.27
3NA62	40.34	13.36	4NA55	41.13	14.08
3NA63	40.29	13.44	6AV56	41.02	15.05
3SA65	39.56	14.33	6AV59	40.52	15.05
3ME68	38.46	14.41	3MT61	40.38	16.10
3ME69	38.41	14.14	3TA64	40.09	16.58
3PA70	38.37	13.25	3CS66	39.14	15.33
9TP73	38.11	12.45	9ME72	38.14	15.10
9PA75	38.04	13.28	9ME74	38.05	14.30
9PA76	38.02	13.53	1RC77	37.57	15.43
9AG80	37.22	12.59	3SR82	37.05	15.34

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