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Application of Algorithm for Prediction of a Strong Aftershock to the Landers Earthquake's Aftershock Sequence

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I have investigated the aftershock sequence of the Landers earthquake June,28 1992 in order to estimate the possibility of reoccurrence of a strong earthquake. The analysis of this data set shows that the earthquake with magnitude $M_a \geq 6.5$ may occur during the following 1.5 year within the radius R=169 km from the epicenter of the main shock. I used the algorithm developed by Vorobieva & Levshina [1], which allowed to predict the strong repeated event in 80% of cases.

The data.

One of the strongest earthquakes in Southern California occurred on June,28 1992. According to the Caltech [2] the main shock started at the northern end of the aftershock sequence of the Joshua Tree earthquake, its magnitude is equal to 7.5 and its epicenter is located at the point 34.2 N; 116.44 W. I have also used the preliminary data from QPDE [3] and weekly Caltech report [4] because the data provided by [2] are not complete. Namely, several aftershocks which occurred in first several hours after the strong earthquake were missing in [2]. The catalog of aftershock sequence has been compiled from [2], [3] and [4] together. The maximum of magnitudes listed in [2] and [3] catalogs was taken as a true value according to the procedure used in [1]. The list of final catalog is given at the Table 1, their epicenters are shown in the Figure 1. There were 34 aftershocks with magnitude $M_a \geq 4.5$ during first 40 days. During this period of time 3 aftershocks with magnitude $M_a \geq 5.5$ have occurred.

The seismic history.

There were 6 strong earthquakes in the southern part of Southern California since 1948 (Table 2,Figure 2). Five of them had the magnitude $M \geq 6.4$ and the recent Joshua Tree earthquake had magnitude $M = 6.1$. Aftershock sequences of first five events have been used as a learning material for developing the algorithm mentioned above. Two of aftershock sequences belong to the class A (i.e., strong earthquakes occurred after main shocks) and three others belong to the class B (no strong earthquakes happened after main shocks). The aftershock sequence of the Joshua Tree earthquake has been recognized as A, and the corresponding report on a high probability of strong repeated shock has been submited on June,5 1992. The Landers earthquake on June,28 1992 with magnitude M=7.5 occurred within 33 km from the Joshua Tree earthquake. We consider this event being successfully predicted in the frame of our approach to the problem.

The application of the algorithm.

Plot of cumulative number of aftershocks (N) versus time is shown in Figure 3. In Figure 4 the plot of cumulative normalized area covered by aftershocks faults (S_n) versus time is shown. Normalization is done relatively to the area of main shock fault zone. One could see that the values of functions S_N and N on day tenth is slightly larger than the threshold. Nevertheless, the previous analysis of aftershock sequences has shown that none of the precursors is distinct enough to be used alone to solve this problem.

The result of application of recognition rule for forward prediction is shown in Table 3. The score of voting is equal $n_a - n_b = 7 \geq \Delta = 3$, so 7 functions out of 8 have the values that are typical for class A. The value of function V_{med} belongs to the range "medium value" and thus have not been taken into consideration. So this aftershock sequence is characterized by the following features:

1. High seismic activity:

N - number of aftershocks with magnitude $M \geq 4.5$ during first ten days;

S_n - number of aftershocks with with magnitude $M \geq 5.5$ during first ten days, weighted according to their energy;

V_n - variation of number of aftershocks with magnitude $M \geq 4.5$ during first forty days (rate of attenuation of aftershock process);

2. Irregularity of behaviour:

V_m - variation of magnitude of aftershocks with magnitude $M \geq 4.5$ during first forty days;

R_z - anomalous increase of the number of aftershocks in time (divergence from Omori law) with magnitude $M \geq 4.5$ during first forty days;

3. Spatial clustering:

R_{max} - the maximum distance between main shock and its aftershocks with magnitude $M \geq 6.5$ during first two days;

4. Quiescence (seismic history):

N_{for}- number of foreshocks with magnitude $M \geq 6.5$ during five years before the earthquake.

On stability of prediction

As a procedure of merging different source catalogs into one may be considered as doubtful we applied the same pattern recognition technique to three original catalogs, namely QPDE [3], weekly Caltech reports [4] and the eventual Caltech catalog [2]. Results of voting for high probability of the strong repeated event are about the same as before: 6:1 for QPDE and weekly Caltech report and 5:2 for final Caltech report.

Conclusion

The earthquake with $M \geq 6.5$ may be expected during 1.5 years within the circle of radius R=169 km around the epicenter of main shock.

References

1.I.Vorobieva, T.Levshina. Prediction of the reoccurrence of strong shock using aftershock sequence.(Computational seismology, v.25, Moscow, Nauka,1992)

2. Earthquake catalog for Southern California. CIT-USGS, Pasadena,Ca

3.Preliminary determination of epicenters (PDE). USGS - NEIS, Boulder,Co

4.Weekly Earthquake Report for Southern California. CIT-USGS, Pasadena,Ca

Table 1
Catalog of mainshock & its aftershocks

Year	month	day	hour	min	lat	lon	M(CIT)	M(QPDE)	M(WCIT)	M
1992	6	28	11	57	34.20	-116.44	7.50	7.50	7.40	7.50
1992	6	28	12	13	34.20	-116.44	0.00	0.00	4.50	4.50
1992	6	28	12	36	34.14	-116.43	0.00	5.10	5.10	5.10
1992	6	28	12	40	34.34	-116.53	5.20	4.80	5.20	5.20
1992	6	28	12	44	34.20	-116.44	0.00	4.50	4.50	4.50
1992	6	28	13	10	34.41	-116.46	4.80	4.60	5.20	4.80
1992	6	28	13	26	34.18	-116.40	4.90	4.70	4.90	4.90
1992	6	28	13	50	34.11	-116.41	4.90	4.60	4.70	4.90
1992	6	28	14	43	34.16	-116.86	0.00	5.40	5.30	5.40
1992	6	28	15	5	34.20	-116.83	6.50	6.60	6.50	6.60
1992	6	28	15	24	34.21	-116.76	4.50	4.90	4.50	4.90
1992	6	28	16	1	34.03	-116.38	4.10	4.50	4.10	4.50
1992	6	28	17	1	34.18	-116.92	4.70	5.00	4.70	5.00
1992	6	28	17	5	34.19	-116.54	4.60	4.60	4.60	4.60
1992	6	29	1	18	35.16	-117.36	0.00	4.50	4.70	4.50
1992	6	29	1	26	35.18	-117.34	0.00	0.00	4.50	4.50
1992	6	29	14	8	34.11	-116.40	4.90	4.90	4.90	4.90
1992	6	29	14	13	34.11	-116.40	5.40	5.40	5.40	5.40
1992	6	29	14	41	34.12	-117.00	4.40	4.50	4.40	4.50
1992	6	29	16	1	33.88	-116.27	5.20	5.20	5.20	5.40
1992	6	29	16	41	34.25	-116.72	4.90	4.50	4.90	4.90
1992	6	30	12	26	34.02	-116.35	4.70	0.00	4.70	4.70
1992	6	30	14	38	34.00	-116.36	4.80	5.10	4.80	5.10
1992	6	30	21	22	34.13	-116.73	4.80	4.50	4.70	4.80
1992	7	1	7	1	34.10	-116.38	4.30	4.50	4.30	4.50
1992	7	1	7	40	34.33	-116.46	5.20	5.20	5.20	5.20
1992	7	5	10	55	35.03	-116.97	4.60	4.60	4.60	4.60
1992	7	5	21	18	34.58	-116.32	5.50	5.30	5.50	5.50
1992	7	8	2	23	34.58	-116.34	4.70	4.70	4.70	4.70
1992	7	9	1	43	34.24	-116.84	4.90	5.50	5.30	5.50
1992	7	10	1	29	34.23	-116.85	4.10	4.50	4.10	4.50
1992	7	20	13	13	34.99	-116.95	4.50	4.50	4.50	4.50
1992	7	24	18	14	33.90	-116.28	4.70	4.70	4.90	4.70
1992	7	25	4	31	33.94	-116.31	4.70	4.70	4.70	4.70
1992	8	5	22	-	-	-	4.70	0.00	0.00	0.00

M(CIT) - [2]; M(QPDE) - [3]; M(WCIT) - [4]; M - final magnitude;
* - the latest aftershock near Barstow

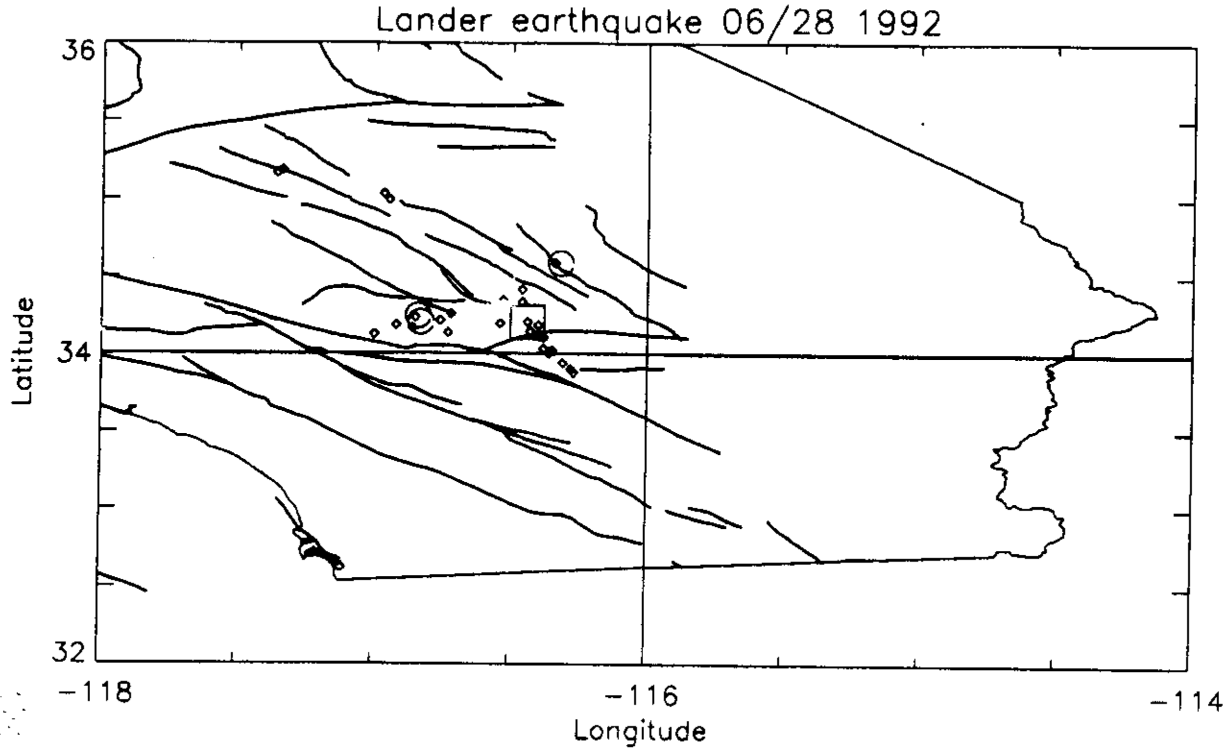
Table 2
Parameters of mainshock & its strongest aftershock

Object	Epicenter	M	R_0	ΔM	ΔR	ΔT
class A						
1968 04 09	33.18 -116.12	6.4	46.5	0.3	0.54	384
1979 10 15	32.63 -115.33	7.0	94.5	0.6	0.59	237
Joshua Tree earthquake						
1992 04 23	33.96 -116.32	6.1	33	-1.4	0.86	66
class B						
1948 12 24	33.93 -116.38	6.5	52.5	2.4	0.08	404
1980 06 09	32.22 -114.98	6.4	46.5	2.9	0.77	484
1987 11 24	33.01 -115.84	6.7	66	2.0	0.27	64
Landers earthquake						
1992 08 23	34.20 -116.44	7.5	169	?	?	?

Where M is a magnitude of strong earthquake; R - radius of aftershock zone; ΔM - difference between magnitude main shock and its strongest aftershock; ΔR - the distance between main shock and its strongest aftershock, normalized by radius of aftershock zone; ΔT - the period of time (in days) between the main shock its strongest aftershock.

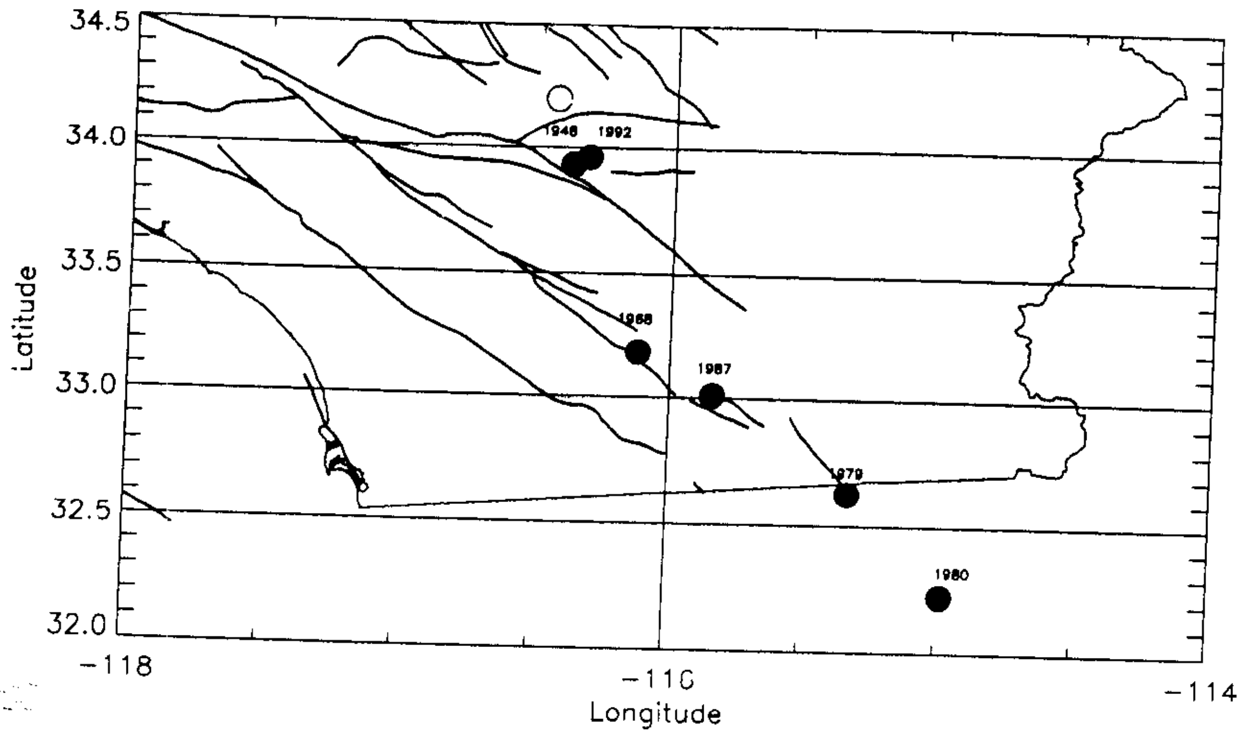
Table 3

Object	N	S_n	V_n	V_m	V_{med}	R_z	R_{max}	N_{for}	Voting
class A									n_A:n_B
1968 04 09	A	A	A	A	-	A	B	B	5:2
1979 10 15	A	A	A	A	-	B	B	A	5:2
1992 04 23	A	A	A	B	A	B	A	A	6:2
class B									n_A:n_B
1948 12 24	B	B	B	A	B	A	A	B	3:5
1980 06 09	B	B	B	B	B	B	B	B	0:8
1987 11 24	B	B	A	B	B	B	A	A	3:5
Forward prediction									
1992 06 28	A	A	A	A	-	A	A	A	7:0



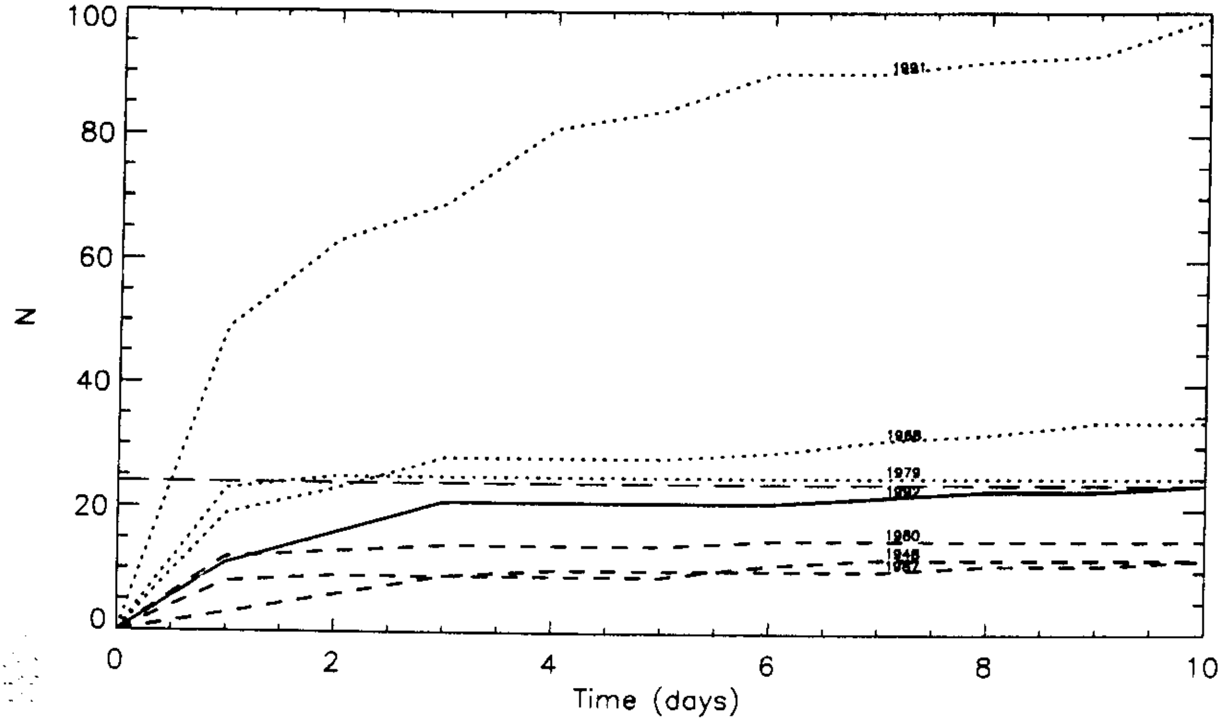
□ – earthquake 1992 06/28 with magnitude M = 7.5;
◇ – its aftershock with magnitude 4.5≦ M < 5.5;
○ – its aftershock with magnitude 5.5≦ M < 7.5;
▬ – faults.

Fig. 1



• – strong earthquakes since 1948 with magnitude M≥6.4;
o – Lander 1992 06/28 with magnitude M = 7.5;
▬ – faults.

Fig. 2

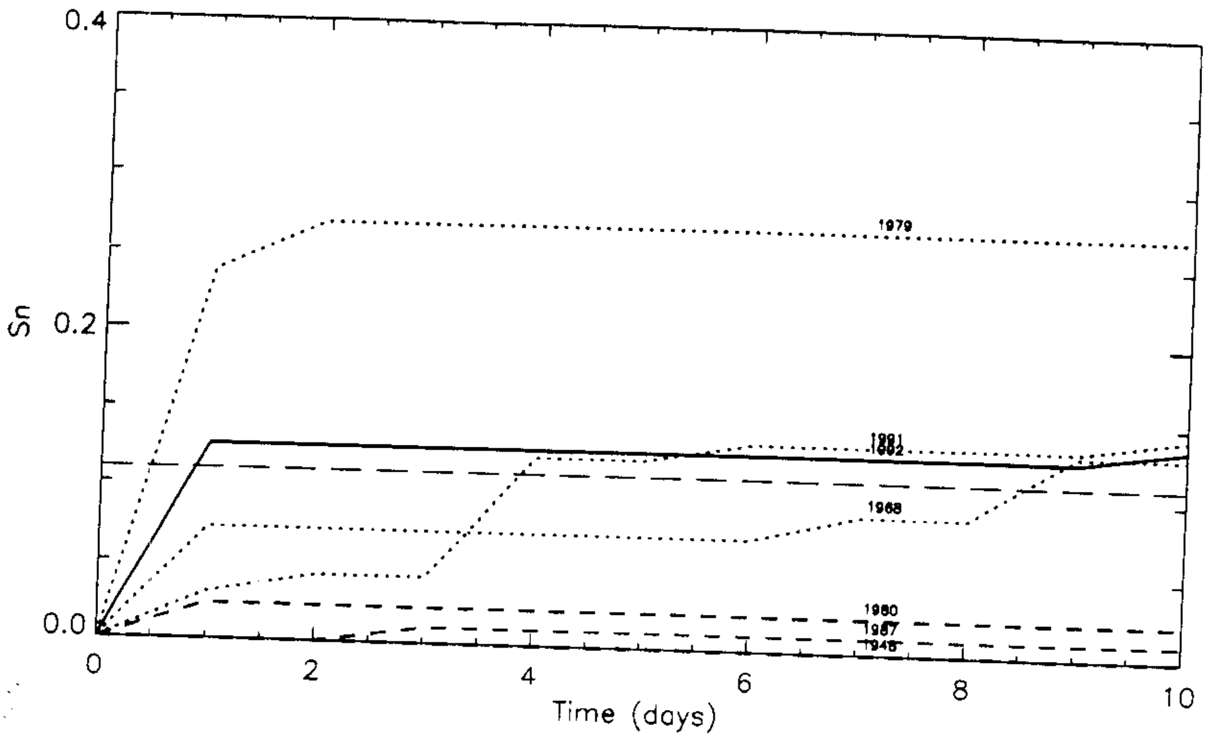


— — – aftershocks sequences of A–class;
... – aftershocks sequences of B–class;
– – aftershock sequence of the Lander earthquake;
– – – threshold.

Fig. 3

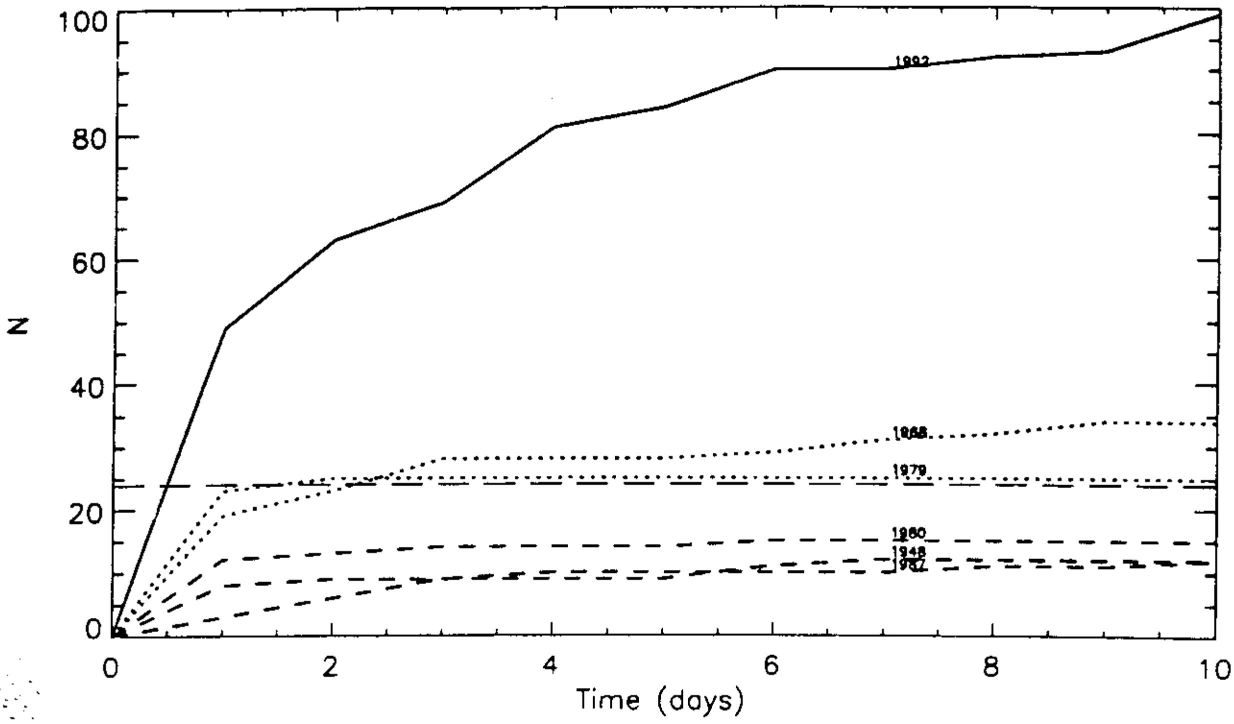
28.8

0.56



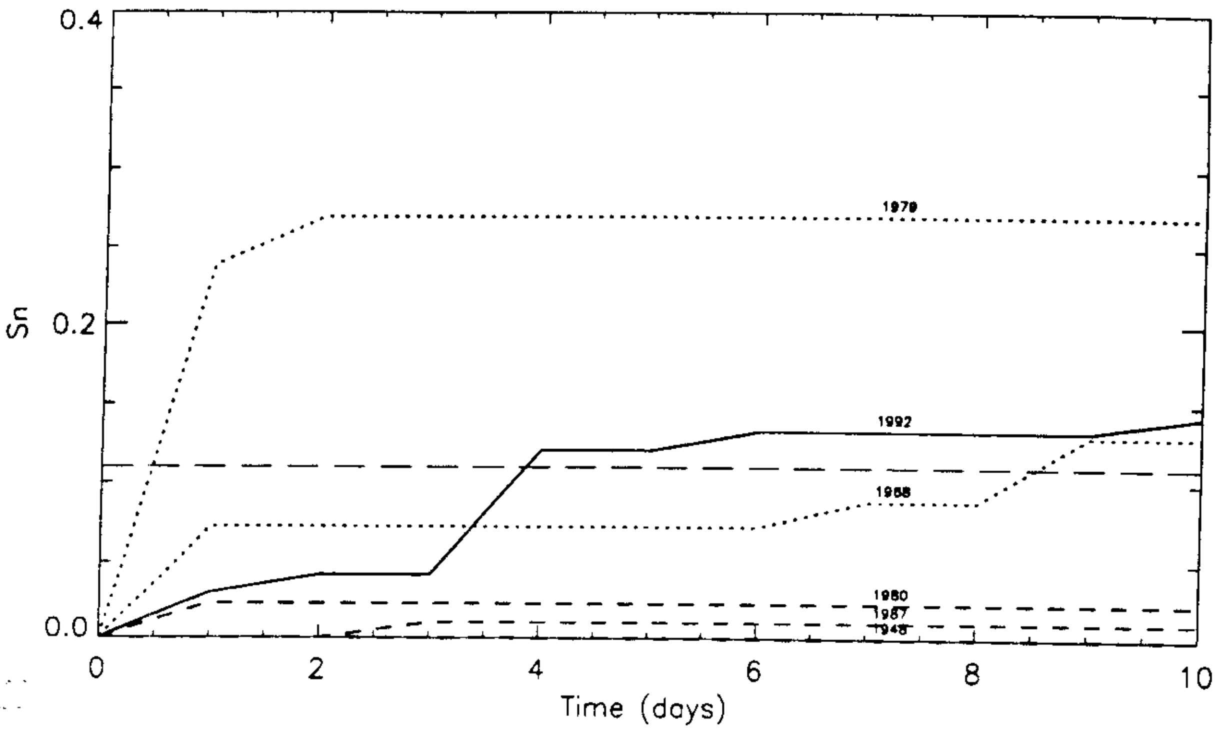
— — – aftershocks sequences of A–class;
⋯ – aftershocks sequences of B–class;
▬ – aftershock sequence of the Lander earthquake;
— — – threshold.

Fig. 4



... – aftershocks sequences of A–class;
– – – aftershocks sequences of B–class;
— – aftershock sequence of Joshua Tree earthquake;
– – – threshold.

Fig. 3



... – aftershocks sequences of A–class;
— – – aftershocks sequences of B–class;
▬ – aftershock sequence of Joshua Tree earthquake;
_ _ – threshold.

Fig. 4

The problem:

an earthquake with magnitude M
did occur

knowing the aftershocks sequence
for the first n days (n = 10 to 40)

to evaluate the possibility
of a second strong earthquake
with magnitude > M-1

within R(M) from the first one