UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL ATOMIC ENERGY AGENCY
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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H4.SMR/1011 - 29

Fourth Workshop on Non-Linear Dynamics and Earthquake Prediction

6 - 24 October 1997

Prediction of a Next Large Earthquake

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PREDICTION OF A NEXT LARGE EARTHQUAKE

I. A. Vorobieva

Abstract

Many large earthquakes come in pairs separated by a relatively small distance and time. The second one may be a large aftershock of the first or an other main shock. The prediction of a next large earthquake is important for the reduction of the great hazard caused by the destabilization of manufactures, mountain slopes etc. due to the first large earthquake. Consider a large earthquake with magnitude M and occurrence time t. The problem is to predict whether a next earthquake with magnitude $M_1 \geq (M - a)$ will occur before the time $(t + S)$ within distance $R(M)$ from the epicenter of the first large earthquake; it may be a large aftershock or the next large main shock. A prediction algorithm for the reoccurrence of large earthquakes was worked out on the analysis of seismic data for California-Nevada. It is based on an analysis of the aftershock sequence following a first shock and local seismic activity before it. The data included 21 large earthquakes, 6 of these being followed by a next large earthquake. There was one error (failure-to-predict) The algorithm was then tested in different regions of the world using 98 aftershock sequences of large earthquakes for analysis, 10 of these having next large shocks. There were 2 failures-to-predict and 4 false alarms. Since 1989 18 predictions in advance have been made, including the 1991 Rachi, Georgia, FSU earthquake, 1989 Loma-Prieta, 1992 Joshua Tree, 1992 Landers and 1994 Northridge, California. There were two false alarms and one failure-to-predict. Both, the retrospective and advance predictions were made by fixed algorithm, developed on the learning stage. Following is the success to failure score:

Prediction: will a next large earthquake occur?	Number of predictions total/errors		
	in learning	in retrospect	in advance
NO	15/0	86/2	13/1
YES	6/1	12/4	5/2
Total	21/1	98/6	18/3

The statistical significance of advance prediction is 95%

Introduction

The existing algorithms for earthquake prediction are mostly devoted to the prediction of large main shock, for example CN and M8. However, many large earthquakes come in pairs, separated by a relatively small distance and time. The second one may be a large aftershock of the first or an other main shock. The prediction of the reoccurrence of a large earthquake is important both from the scientific and practical points of view. The study of phenomena preceding the reoccurrence of a large earthquake may help in understanding the process which leads to it. At the same time such prediction is important for reducing of the great hazard caused by the destabilization of manufactures, mountain slopes etc. due to the first large earthquake.

The problem of such prediction appears whenever a large earthquake occurs in a populated area; it was considered in several works [1-6] and is described in more detail in [7].

The prediction algorithm for the reoccurrence of large earthquakes used here is based on an analysis of the aftershock sequence following a first large shock and local seismic activity before it. Consider a large earthquake with magnitude M and occurrence time t. The problem is to predict whether a next large earthquake with magnitude $M_1 \geq (M - a)$ will occur before the time $(t + S)$ within distance $R(M)$ of the epicenter of the first earthquake; it may be an aftershock or a next main shock.

The algorithm was worked out [7] by analyzing seismic data for California-Nevada. The data included 21 large earthquakes, 6 of these being followed by a next large earthquake. There was one error (failure-to-predict)

The algorithm was then tested in different regions of the world using 98 aftershock sequences of large earthquakes for analysis, 10 of these having next large shocks. There were 2 failures-to-predict and 4 false alarms.

So far 18 predictions in advance have been made, including 1991 Rachi, Georgia, FSU earthquake, 1989 Loma-Prieta, 1992 Joshua Tree, 1992 Landers and 1994 Northridge, California. There were two false alarms and one failure-to-predict.

Description of Algorithm

Consider a large earthquake with magnitude M and occurrence time t. The problem is to predict whether a next large earthquake with magnitude $M_1 \geq (M - a)$ will occur before the time $(t + S)$ within distance $R(M)$ of the epicenter of the first large earthquake; this may be a large aftershock or a next large main shock. To solve this problem we analyze the aftershocks of the first earthquake during the first s days in the magnitude range between M and $M - m_a$, and the earthquakes which occurred during S' years before it in the magnitude range between M and $(M - m_f)$. The aftershocks are counted within the same distance $R(M)$; the preceding earthquakes are counted within a larger distance $CR(M)$ (Fig 1).

The idea of prediction is the same as in predicting of a large main shock from the sequence of main shocks (algorithms CN [8], M8 [9]) According to these algorithms, a large earthquake is preceded by changes in the main shocks resulting from higher activity and higher irregularity in space and time. These changes are akin to general symptoms of instability in many nonlinear systems. In our case the system is a set of earthquake-generating faults.

Hypothesis: Similar symptoms in aftershocks of the first large shock, i.e., high activity and irregularity, precede the reoccurrence of a large event in a vicinity of the first shock.

Similarity. In order to make comparable the aftershock sequences of earthquakes with different magnitudes, the aftershocks were normalized by magnitude of the large main shock M:

- lower cutoff magnitude of aftershocks to be analyzed, M - 3;
- area is a circle with radius $R = 0.03\times10^{0.5M}$ [km];
- magnitude of shocks to predict is $M \geq M$ - 1;
- period of time is 40 days to 1.5 years after first shock.

The similarity of premonitory phenomena is presumed after normalization.

The prediction algorithm for the reoccurrence of a large earthquake was found by retrospective analysis of 21 large California earthquakes with $M \geq 6.4$ [7]. It is as follows:

Prediction is made in two steps.

(i) If the number of the aftershocks is below D=10, the next large earthquake is not expected within the above time and distance range, whatever the other characteristics may be.

(ii) If this number is D or more, eight characteristics reflecting premonitory phenomena listed below are considered. The prediction algorithm was determined by using a pattern recognition technique known as the Hamming distance [10]

Seven characteristics of the sequence of aftershocks were calculated, reflecting the number of the aftershocks, the total area of their sources, the largest distance from the main shock, and the irregularity of this sequence. One more characteristic is the number of earthquakes in the time interval (t - s', t - S') preceding the first large earthquake.

Qualitatively, the occurrence of a next large earthquake is predicted when the number of aftershocks is large, their sequence is highly irregular in time, they are concentrated close to the main shock epicenter, and the activity preceding the first large shock is low.

Functions representing the premonitory phenomena.

Large values of the following functions are premonitory:

1. N, number of aftershocks with magnitude $M \geq M - m$ during $[t + s_1 , t + s_2]$;

2. S, total equivalent source area of aftershocks with magnitude $M \geq M - m$ in $[t + s_1 , t + s_2]$ normalized by the equivalent source area of the main shock

$$S=\Sigma 10^{mi-M}$$

where m_i is the magnitude of the i-th aftershock;

3. Vm, variation of magnitude from event to event for aftershocks with magnitude $M \geq M - m$ in $[t + s_1 , t + s_2]$

$$Vm = \Sigma|m_{i+1} - m_i|,$$

where m_i is the magnitude of the i-th aftershock;

4. ***Vmed***, variation of average magnitude from day to day for aftershocks with magnitude $M \geq M - m$ in $[t + s_1 , t + s_2]$

$$\textit{Vmed} = \Sigma|\mu_{i+1} - \mu_i|,$$

where μ_i is the average magnitude of aftershocks for the i-th day.

5. ***Rz***, deviation from the Omori law for aftershocks with magnitude $M \geq M - m$ in $[t + s_1 , t + s_2]$

$$\textit{Rz} = \Sigma(n_{i+1} - n_i)$$

where n_i is the number of aftershocks in $[t + i, t + i + \tau]$; negative differences being discarded.

Small values of the following functions are premonitory:

6. ***Vn***, variation in the number of aftershocks from day to day for aftershocks with magnitude $M \geq M - m$ in $[t + s_1 , t + s_2]$.

$$\textit{Vn} = \Sigma|n_{i+1} - n_i|,$$

where n_i is the number of aftershocks for the i-th day.

7. ***Rmax***, largest distance between the main shock and the aftershock with magnitude $M \geq M - m$ in $[t , t + s_2]$ divided by R.

8. ***Nfor***, local activity before the main shock, i.e., number of earthquakes with magnitude $M \geq M - m$ during $[t - s' , t - S']$. before the first large earthquake within distance of $1.5R$.

The values of parameters in the functions were chosen as shown in Table 1.

In qualitative terms, the occurrence of a next large earthquake is predicted when the number of aftershocks is large, the aftershock sequence is highly irregular in time, they are concentrated close to the epicenter of the main shock, and the activity preceding the first large earthquake is low.

Table 1. Values of parameters.

Function	Values of parameters					Threshold values	
	m_1	s_1, hrs	s_2, days	Δt, days	τ, days		
N	3	1	10	-	-	24	-
Sn	2	1	10	-	-	0.1	-
Vm	3	1	40	1	-	0.41	-
Vmed	3	1	40	-	-	0.7	2.6
Rz	3	10 days	40	1	10	0	-
Vn	3	1	40	1	-	0.98	-
Rmax	2	-	2	-	-	0.23	-
Nfor	1	5 years	3 mon.	-	-	2	-

Reduction to pattern recognition. In terms of pattern recognition the problem is as follows. There are two types of large earthquakes: type *A*, which are those followed by a next large shock; and type *B*, single. Given a large earthquake, the *s*-days aftershocks, and the earthquakes preceding main shock, decide whether the earthquake is type A or *B*.

To find a decision rule we used "learning material" consisting of large earthquakes and their aftershock sequences of types *A* and *B* in California (objects for recognition).

The first step is discretization. Values of each function were divided into two intervals, "large" and "small", so that the numbers of objects in each interval are equal. The discretization thresholds are given in Table 1.

The second step is to determine the "typical" values. We counted for each function how often it was "large" (or "small") in A, and how often in B. If a function was "large" (or "small") for at least 2/3 of all A objects and less than 1/2 of B objects, this value was assumed to be typical of A, and similarly for B.

The last step is voting. We counted for each aftershock sequence two numbers n_A and n_B. n_A is the number of functions that are typical of A, while n_B is the same for B.

Decision rule: If $n_A - n_B \geq 3$, the earthquake is of type A (a next large shock will occur); if $n_A - n_B < 3$ the earthquake is of type B (a next large shock will not occur).

This rule and all algorithm parameters were determined for California (for the results of learning see below Table 2) and then tested on independent data.

Performance

The algorithm was tested with prefixed parameters in the following eight regions [7, 11] (the lowest value of M considered is bracketed): the Balkans (7.0), the Pamir and Tien-Shan (6.4), the Caucasus (6.4), Iberia and Maghrib (6.0), Italy (6.0), Baikal and Stanovoi Range (5.5), Turkmenia (5.5), and the Dead Sea Rift (5.0).

The results of retrospective testing are given in Table 2.

Table 2. Results of learning and retrospective test of algorithm.

Region	*Mo*	Total $M \geq Mo$	With few aftershocks,	Tested by pattern recognition		
			Single #/Err	Total #	Single #/Err	With the next shock #/Err
			Learning			
California	6.4	21	4/0	17	11/0	6/1
			Retrospective test			
Pamir & Tien-Shan	6.4	12	4/0	8	7/1	1/0
Caucasus	6.4	5	0/0	5	5/0	0/0
Baikal & Stanovoi r.	5.5	6	4/0	2	2/1	0/0
Iberia & Maghrib	6.0	13	11/0	2	1/0	1/0
Dead Sea rift	5.0	11	10/0	1	1/0	0/0
Turkmenia	5.5	12	7/1	5	4/0	1/1
Balkans	7.0	19	7/0	12	9/1	3/0
Italy	6.0	20	9/0	11	8/1	3/0
Total retr. test		98	52/1	46	37/4	9/1
Total		119	56/1	63	48/4	15/2
Total test M_0+0.2		67	31/0	36	26/1	10/1
Total test M_0-0.2		171	90/6	81	62/7	19/5

There are two significant parameters which can be adjusted when dealing with different regions. These are the region itself and the cut off magnitude of large earthquakes, M_0.

Choice of region. The formal definition of the algorithm enables it to be applied to any large earthquake, if a representative catalog is available. However, there are regions where algorithm does not work. These are the Pacific subduction zones. The seismicity in these regions has higher intensity and more numerous earthquakes that are followed by a next large shocks. In the regions listed in Table 2 the percentage of earthquakes with a next shock does not exceed 15%. In the subduction zones this value is 30-40% of shallow earthquakes, if the same $R(M)$ and time intervals are used. The most important fact is that the occurrence of a next large shock does not depend on the rate of events in the aftershock sequence of the first earthquake. For example, consider the Japanese earthquakes. There are 75 large shallow earthquakes with magnitude $M \geq 7.0$. Of these 29 have less than 10 aftershocks with magnitude $m \geq M-3$ within the circle $R(M)$ during 40 days, and 46 earthquakes had more than 10 aftershocks. The portion of earthquakes which are followed by next large shocks is the same for earthquakes with few and many aftershocks: 11 of 29 and 16 of 46, respectively (compare with Table 2). This fact demonstrates that an algorithm based on the rate of events in the aftershock sequence will not work in such regions.

So far, the algorithm works quite well in all regions, other that the Pacific subduction zones, where representative catalogs are available.

Choice of cutoff magnitude M_0. Usually the magnitude M_0 was chosen in accordance with the lowest magnitude completely reported, because the algorithm requires aftershocks with magnitude $m \geq M-3$ to test an earthquake with magnitude M. However, the tests were carried out with magnitudes $M_0+0.2$ and $M_0-0.2$ for all regions under study (Table 2). As was to be expected, higher cutoff magnitudes did not make the result worse: there are two errors (one false alarm and one failure-to-predict) in a total of 67 earthquakes in nine regions (2). Lower cutoff magnitudes lead to considerable increases in the number of errors. There are 18 errors (7 false alarms and 11 failures-to-predict) in a total of 171 earthquakes. The increase of the number of failures-to-predict can be explained by catalog incompleteness, but there are 3 more false alarms, all in California (2). This fact shows that one must be careful when diminishing M_0, even if the catalog is complete. This needs special investigation in each region.

The results of 1989-1997.1 monitoring. All large earthquakes that occurred in the nine regions (Table 2) were monitored by the algorithm with prefixed parameters. [12,13] The results of the prediction in advance are given in Table 3.

Table 3. The results of 1989 - 1997.1 monitoring.

Origin Earthquake	*Will a next shock occur?*	*Outcome of prediction*	*Note*
California			
Loma-Prieta, 7.1 10/18/1989	NO	No shocks with $M \geq 6.1$	Success
Mendocino 6.9 7/13/1991	NO	No shocks with $M \geq 5.9$	Success
Mendocino 7.1 8/17/1991	NO	No shocks with $M \geq 6.1$	Success, first step
Johua Tree 6.3 4/23/1992	YES	Landers is predicted $M=7.6$	Success
Landers 7.6 6/28/1992	YES	Northridge $M=6.8$ occurred 19 days after end of alarm	False alarm
Nothridge 6.8 1/17/1994	NO	No shocks with $M \geq 5.8$	Success
Mendocino 7.1 4/25/1992	NO	No shocks with $M \geq 6.1$	Success
Mendocino 7.1 9/1/1994	NO	Earthquake with $M=6.8$ occurred	Failure, first step
Mendocino 6.8 2/19/1995	NO	No shocks with $M \geq 5.8$	Success, first step
California-Nevada 6.3 border 9/12/1994	YES	Earthquake with $M=5.5$ occurred	Success
Caucasus			
Iran 7.7 6/20/1990	NO	No shocks with $M \geq 6.7$	Success
Rachi 7.1 4/29/1991	YES	Earthquake with $M=6.6$ occurred	Success
Rachi 6.6 6/15/1991	NO	No shocks with $M \geq 5.6$	Success
Erzincan 6.8 3/13/1992	YES	No shocks with $M \geq 5.8$	False alarm
Pamir & Tien-Shan			
Kazakhstan 7.5 8/19/1992	NO	No shocks with $M \geq 6.5$	Success
Iran 7.1 11/19/1996	NO		Monitoring till 1998.5.19
Iberia & Maghrib			
Morocco 6.0 5/26/1994	NO	No shocks with $M \geq 5.0$	Success
Dead Sea Rift			
Gulf of Aqaba 5.8 8/3/1993	YES	Earthquake with $M=4.9$ occurred	Success
Gulf of Aqaba 7.3 11/22/1995	NO	No shocks with $M \geq 6.3$	Success

There were fifteen more large earthquakes in the regions under study which have not been tested: nine shocks were close-in-time (during 40 days) foreshocks and aftershocks of the earthquakes listed in Table 3 while no data were available for six earthquakes.

The prediction results with the prefixed parameters can be summarized as follows:

Table 4. The prediction summary with prefixed parameters.

Prediction: will a next large earthquake occur?		Number of predictions total/errors	
		in retrospect	in advance
Step (i)	NO	52/1	4/1
Step (ii)	NO	34/1	9/0
Step (ii)	YES	12/4	5/2
Total		98/6	18/3

The rate of failures-to-predict (wrong NOs) is particularly low, while the rate of false alarms is considerably higher.

Statistical significance and the effectiveness of the algorithm. The statistical significance and effectiveness of the algorithm is estimated by the method, proposed by G.Molchan [14]. Using the results of this prediction-in-advance it is possible to estimate the probability of getting such a result accidentally. The probability of guessing 3 or more subsequent large earthquakes of a total of 4 among 18 cases using 5 alarms is:

$$\varepsilon = [C_{14}^{2}\, C_{4}^{3} + C_{14}^{1}\, C_{4}^{4}\ ]/C_{18}^{5} \approx 4.4\%,$$

where C_n^k are binomial coefficients.

It is possible that there are regions among the selected ones to which the algorithm is inapplicable. Accordingly we test how the level of statistical significance ε is changed when the number of aftershock sequences N is varied. We do not change the number of alarms and successes. The following Table 5 shows that ε is stable when N is varied:

Table 5. The dependence of ε on N

ΔN	1	0	-1	-2
ε,%	3.7	4.4	5.2	6.3

So the result can be considered as statistically significant at the 95% level.

The result of the prediction can be characterized by two quantities n and τ. Here n is the relative number of the failures-to-predict, and τ is the relative alarm in the entire prediction space. The quantity e=1-n-τ is a characteristics of prediction effectiveness, because the case e=0 corresponds to the strategy of the random guess. We can estimate the effectiveness of an algorithm only approximately, because the short period of the monitoring and, consequently, the small number of N does not allow us to estimate n and τ reliably. In our case n is 0.25 (one failure-to-predict among four next large earthquakes), and τ is 0.28 (five alarms among eighteen tested large earthquakes), so we have e=47%.

Case histories

We wish to discuss several case histories of prediction for series of large earthquakes occurring in southern California.[12,13], Caucasus [13] and Dead Sea Rift zone.

Joshua Tree – Landers – Northridge, southern California. The Joshua Tree earthquake occurred 4/23/1992 and had magnitude M=6.3. The map of its aftershocks with magnitude $m\geq3.3$ used for prediction are shown in Fig. 2. The aftershock sequence of this earthquake had a high rate (54 aftershocks with $m\geq3.3$), so the Joshua Tree earthquake produced an alarm for an earthquake with $M\geq5.3$ within the distance $R(6.3)$=42 km and within 1.5 years after Joshua-Tree. The voting of functions after Joshua Tree is shown in Table 6. The subsequent Landers earthquake occurred within this distance in 64 days after Joshua-Tree.

The Landers earthquake of 6/28/1992, M=7.6 was then tested for the occurrence of a next large shock. Its aftershocks with magnitude $m\geq4.6$ used for prediction are shown in Fig. 2. The aftershock sequence had not many aftershocks (20 aftershocks with $m\geq4.6$), but they were strong and had large total equivalent source area. It was predicted in [10] that an earthquake with $M\geq6.6$ will occur within the distance $R(7.6)$=199 km and within 1.5 years after Landers so that the alarm expired on 1993/12/28. The voting of functions after Landers is shown in Table 6. The subsequent Northridge M=6.8 earthquake occurred within this distance, but 19 days after the expiration of the alarm, so that prediction was counted as a false alarm.

The Northridge earthquake of 1/17/1994 was also tested for the occurrence of an earthquake with magnitude $M\geq5.8$. Its aftershocks with magnitude $m\geq3.8$ used for prediction are shown in Fig. 2. In spite of many aftershocks (77 events with magnitude $m\geq3.8$) this earthquake did not produce an alarm. It was predicted that an earthquake with $M\geq5.8$ will not occur within the distance $R(6.8)$=75 km and within 1.5 years, so there has been no such earthquake. The voting of functions after Northridge is shown in Table 6.

Gulf of Aqaba earthquakes in 1993-1995, Dead Sea Rift. The 8/3/1993 earthquake occurred in the Gulf of Aqaba and had magnitude 5.8 The map of its aftershocks with magnitudes $m\geq2.8$ used for prediction is shown in Fig. 3. This earthquake had 171 aftershocks and produced an alarm. It was predicted that an earthquake with $M\geq4.8$ will occur within a distance $R(5.8)$=22 km and within 1.5 years. The voting of functions after this earthquake is shown in Table 6. The earthquake with magnitude 4.9 occurred 92 days after the first one.

The largest earthquake in this region with magnitude 7.3 occurred in the same place two years later on 11/22/1995. The map of its aftershocks is shown in Fig. 3. It had 14 aftershocks with magnitude $m\geq4.3$, and did not produce an alarm. It was predicted that an earthquake with $M\geq6.3$ will not occur within the distance $R(7.3)$=135 km and within 1.5 years, and there has been no such earthquake. The voting of functions after this earthquake is shown in Table 6

Probably the earthquake of 1993, which produced an alarm, was an precursor of the 1995 earthquake, but the time distance between them was more than two years. Later in 1996 two earthquakes with magnitudes 5.0 and 5.4 occurred, but unfortunately the data to test these earthquakes are not available.

Rachi, Caucasus, Georgia, FSU earthquakes of 1991. The Rachi earthquake of 4/29/1991 had magnitude M=7.1. The map of its aftershocks is shown in Fig. 4. This earthquake had a large aftershock sequence: 77 events with magnitude m≥4.1 and with a large total equivalent source area. This earthquake produced an alarm. It was predicted that an earthquake with magnitude M≥6.1 will occur within the distance R(7.1)=105 km and within 1.5 years. This prediction was confirmed by the earthquake of 6/15/1991 with magnitude 6.6.

This later earthquake was also tested. The map of its aftershocks is shown in Fig. 4. It was predicted that an earthquake with magnitude M≥5.6 will not occur within the distance R(6.6)=59 km and within 1.5 years, and there has been no such earthquake.

The case of the Rachi earthquake of April 1991 is important, because all known large earthquakes since 1900 with magnitudes M≥6.4 (12 events) in the Caucasus were single. The aftershock sequences of the seven Caucasian earthquakes in 1962-1992 are shown in Fig 5 as functions of time. The aftershock sequence of the April 1991 Rachi earthquake was considerably more active, than the others, while the aftershock sequence of the next Rachi earthquake of June 1991 had normal activity.

Table 6. Voting of functions for Joshua-Tree, Landers, Northridge, Gulf of Aqaba and Rachi earthquakes..

Earthquake	*N*	*S*	*Vn*	*Vm*	*Vmed*	*Rz*	*Rmx*	*Nfor*	*Voting*
Joshua-Tree	yes	no	yes	yes	yes	no	yes	yes	6:2 YES
Landers	no	yes	yes	yes	-	yes	yes	yes	6:1 YES
Northridge	yes	yes	yes	yes	yes	no	no	no	5:3 NO
1993 Aqaba	yes	yes	yes	yes	yes	yes	no	yes	7:1 YES
1995 Aqaba	no	no	yes	no	no	yes	no	yes	3:5 NO
Apr. 1991 Rachi	yes	yes	yes	yes	yes	yes	no	yes	7:1 YES
Jun. 1991 Rachi	no	no	no	yes	yes	no	yes	yes	4:4 NO

Conclusions

The algorithm for prediction of a next large shock based on the analysis of the aftershock sequence of a first large shock was successfully applied in different seismic regions of the world. Eighteen large earthquakes were tested for the last eight years producing only three errors: two false alarms and one failure-to-predict. These results confirm the statistical significance of the prediction of a next large earthquake; it is 95%. The algorithm can be used in other seismic regions, if the data are available. Of course, each region requires testing of the algorithm on past data.

Even though the results given above are satisfactory, there are possibilities to develop the method. The main problem is the prediction of the reoccurrence of large earthquakes in subduction zones. Probably, the algorithm for such prediction should be based on other features of aftershocks and preceding seismicity.

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Figure captions

Fig. 1. Formulation of problem

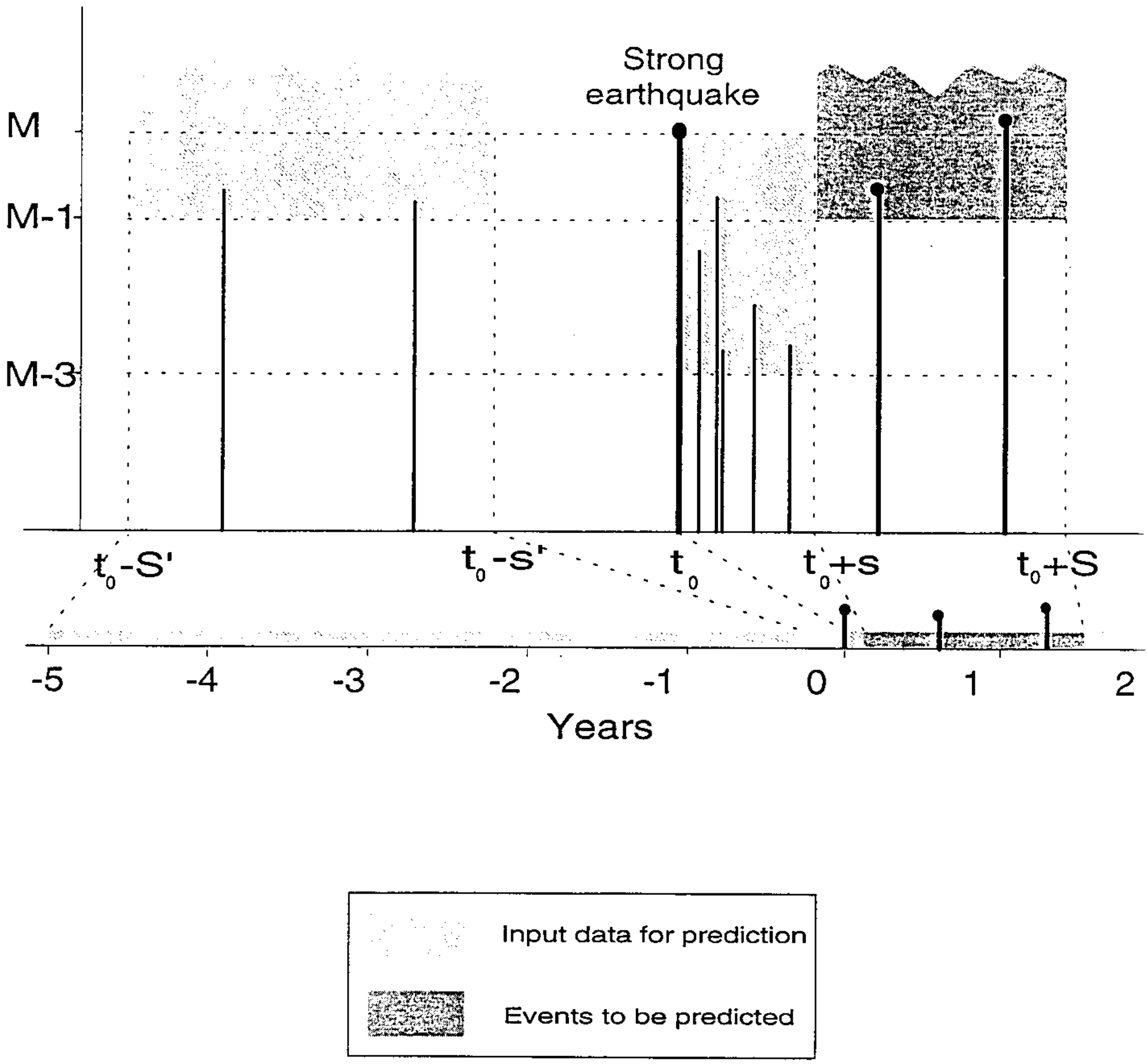
Fig. 2 The Joshua Tree, Landers & Northridge earthquakes and their aftershocks

Fig. 3. The Gulf of Aqaba earthquakes of 1993, 1995 and their aftershocks.

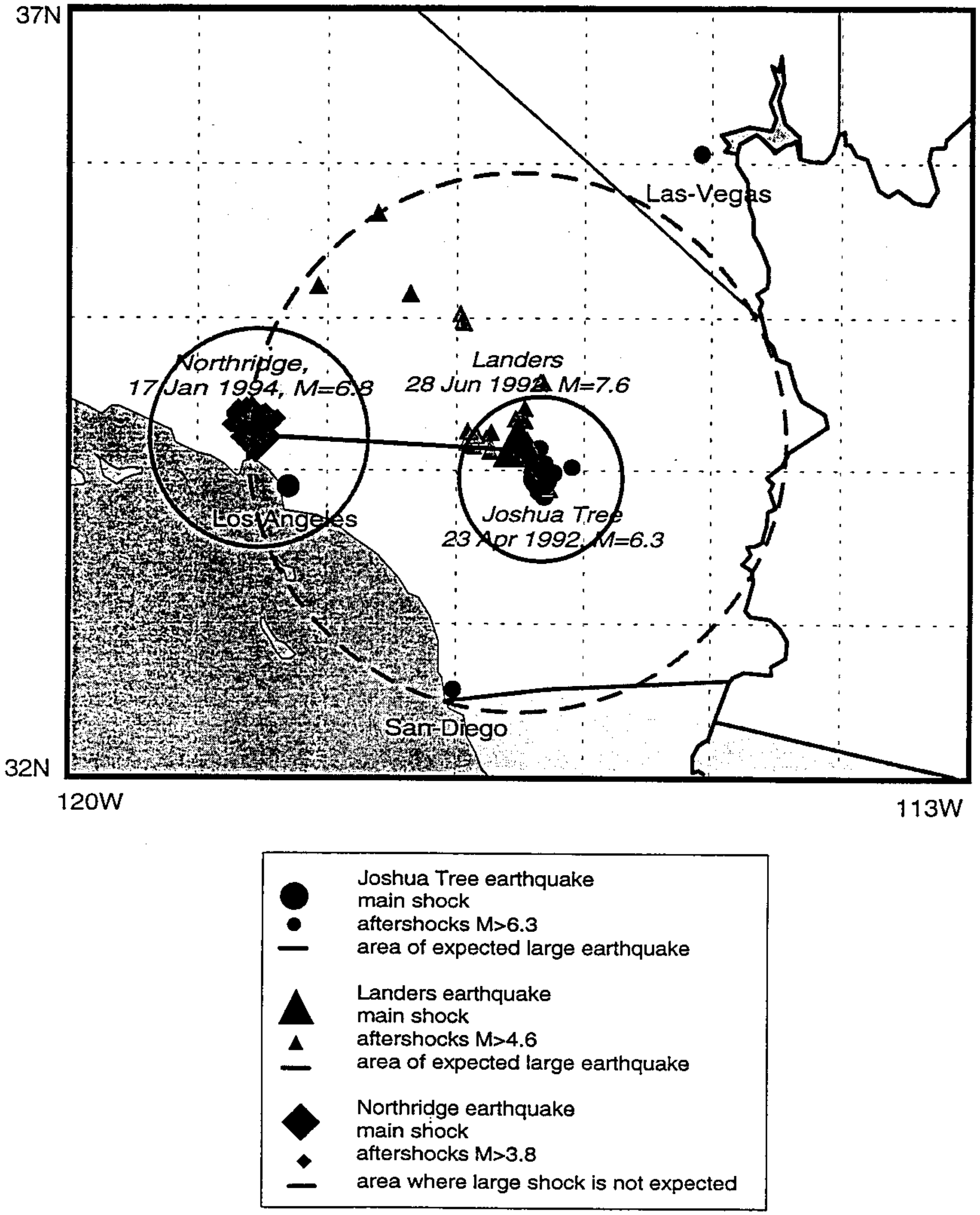
Fig. 4. The Rachi earthquakes of 1991 and their aftershocks

Fig. 5. The aftershock sequences of 1962-1992 Caucasian earthquakes in time.

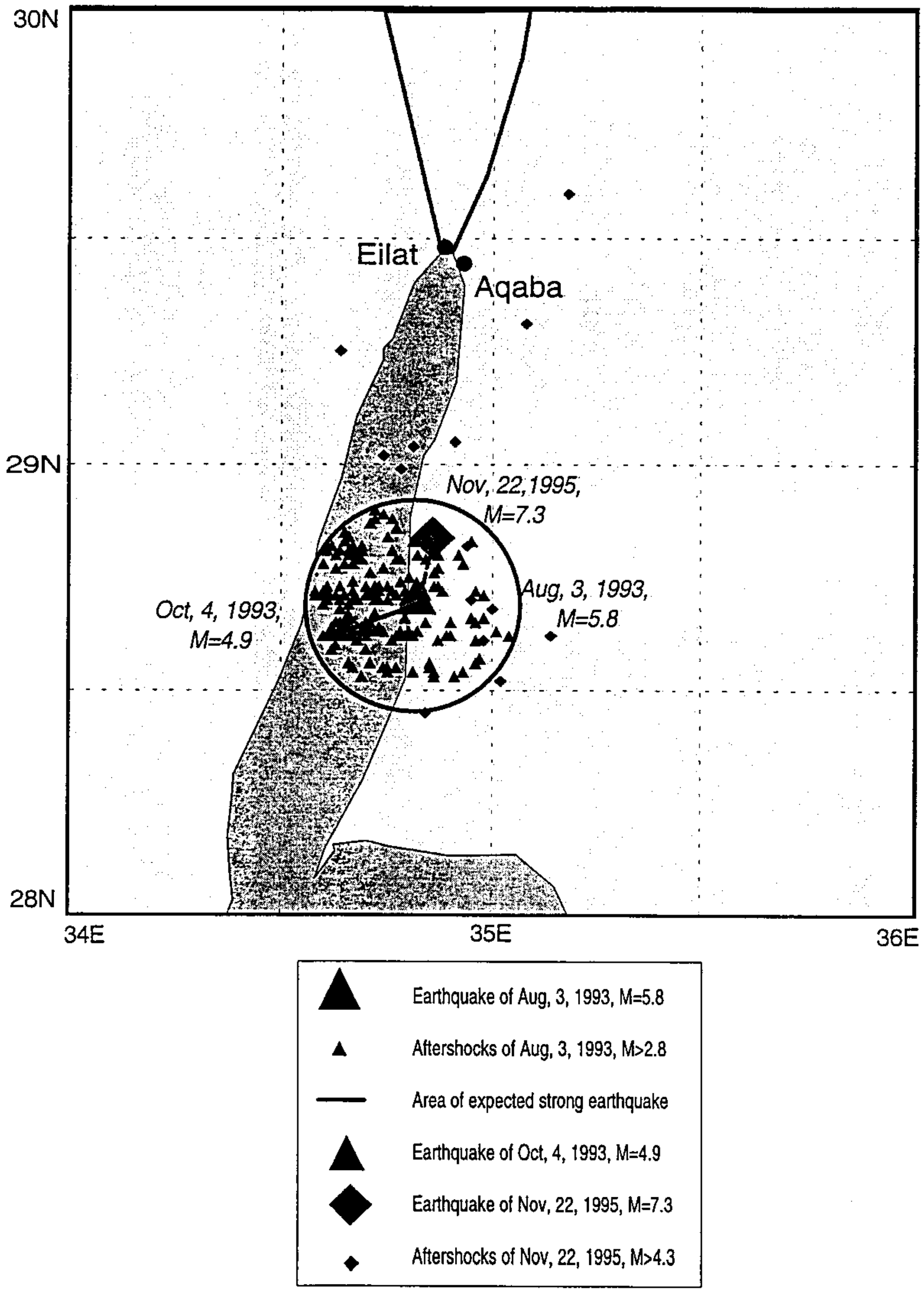
Formulation of the problem



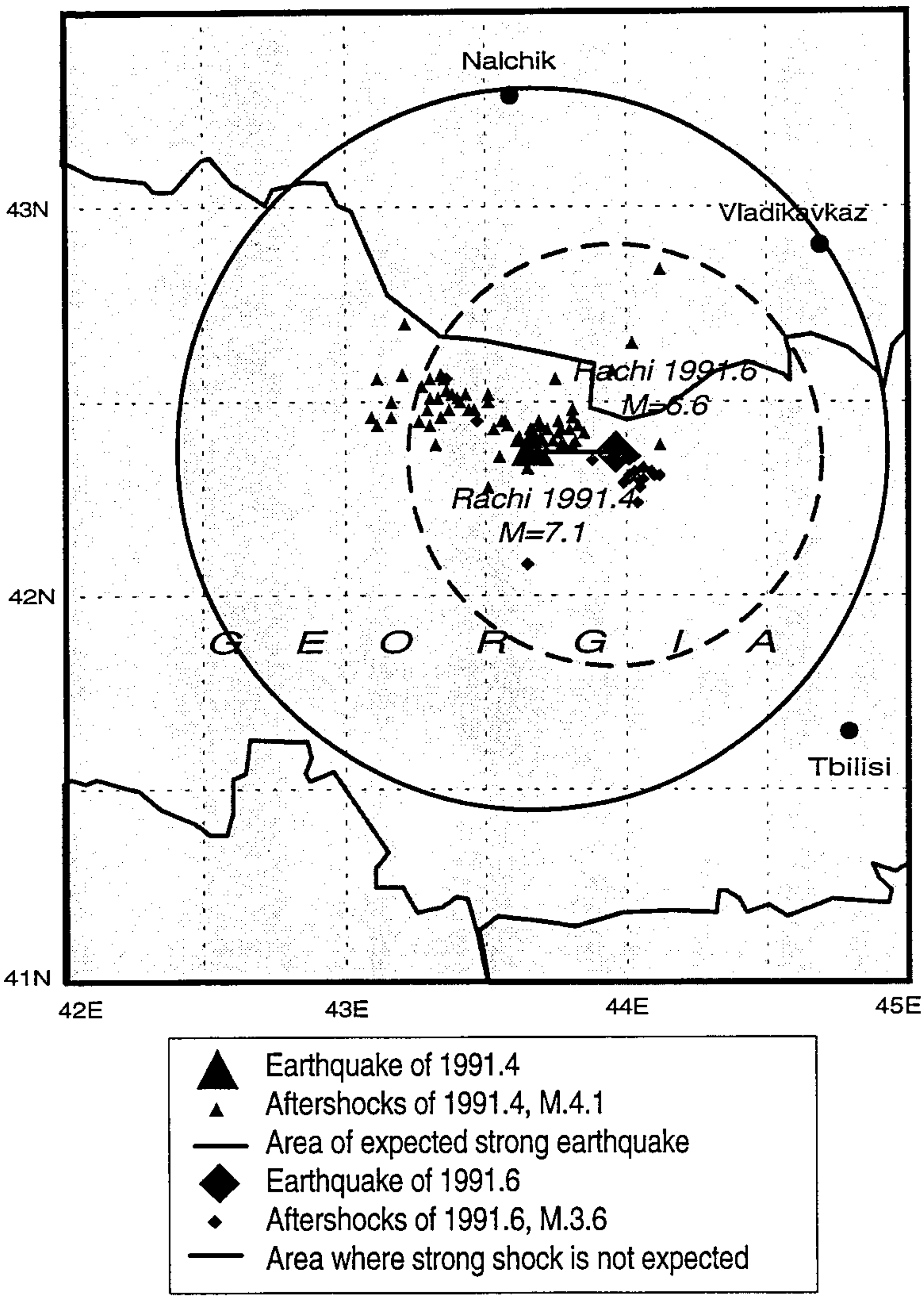
Joshua Tree -- Landers -- Northridge

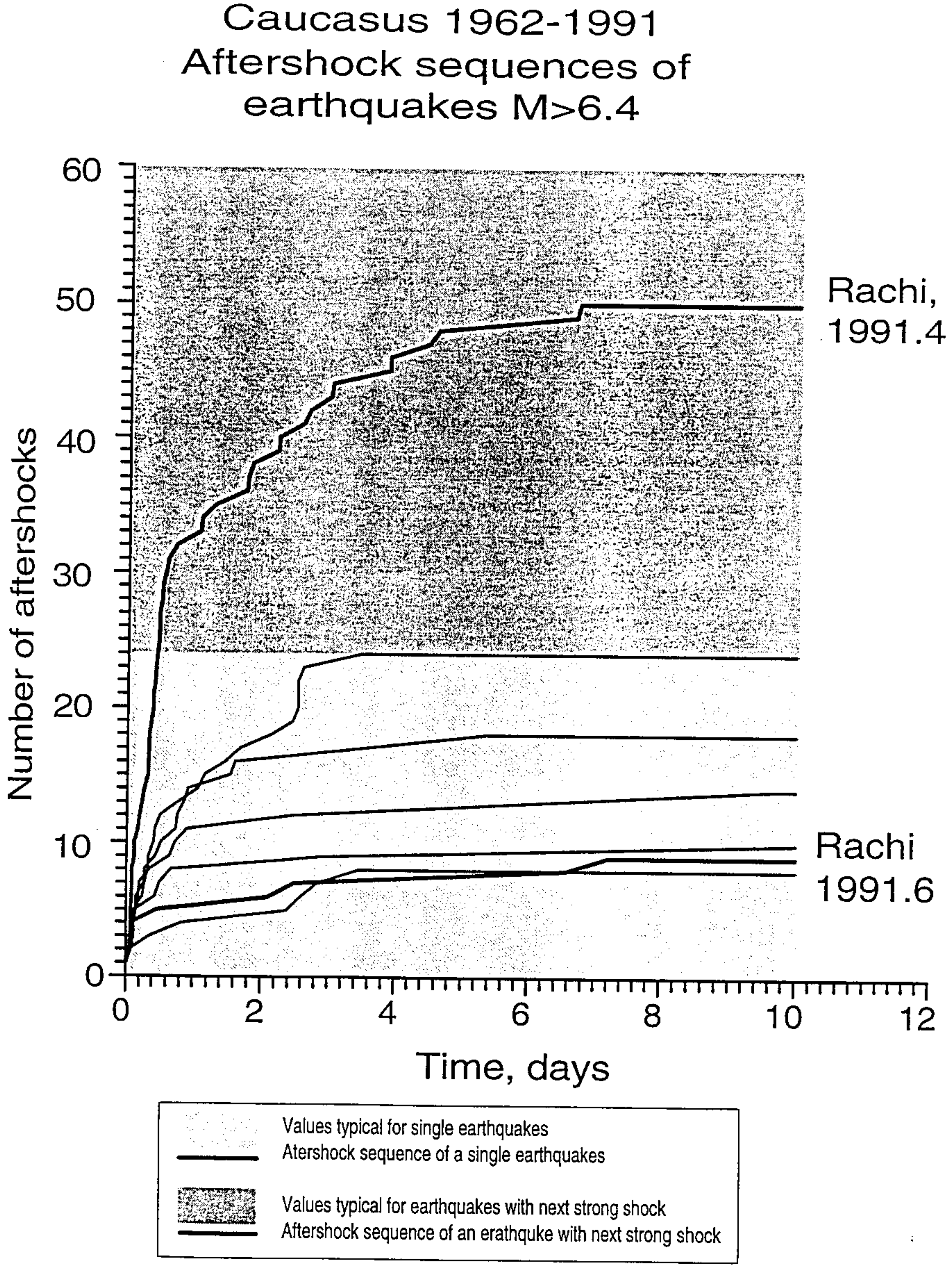


Gulf of Aqaba 1993 - 1995



Rachi earthquakes 1991




Caucasus 1962-1991
Aftershock sequences of
earthquakes M>6.4
Number of aftershocks
0
10
20
30
40
50
60
Time, days
0
2
4
6
8
10
12
Rachi,
1991.4
Rachi
1991.6
Values typical for single earthquakes
Atershock sequence of a single earthquakes
Values typical for earthquakes with next strong shock
Aftershock sequence of an erathquke with next strong shock