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Abstract. Javakheti Highland is one of the most seismic active regions of the Caucasus. The majority of earthquakes observed throughout the region occur within this small area ($\phi = 40.8° - 41.8°$; $\lambda = 43.3° - 44.3°$). One can expect that exclusive seismic activity of Javakheti Highland testifies to global geophysical processes which take place throughout the Caucasus region. Based on the above-mentioned, of interest was to study variation with time of the number of earthquakes occurring in Javakheti region. We analysed some 695 relatively small earthquakes ($2.5 \leq M < 6.0$) observed in Javalkheti Highland within the period of 1961–1992 with regard to large earthquakes M $\geq$ 6.0 of the region which occurred in the same period. It was found that each large earthquake of the Caucasus is anticipated by clear precursor in a form of an anomalous change in the number of relatively small earthquakes in Javakheti Highland.

1 Introduction

From geological and geomorphologic viewpoints Javakheti Highland is one of the complex regions of the southern Georgia. It lies in the northern peripheral zone of the Transcaucasus-Asia Minor volcanic area, and to certain extent comprises territories of Armenia and Turkey as well.

Javakheti Highland is of special interest due to its highest seismic activity throughout the Caucasus: 55% of all Caucasian earthquakes occur there (Duff et al., 1980; Keilis-Borok et al., 1980; Gotsadze et al., 1987; Kumaz et al., 1987; Chadwick et al., 1988, Kuloshvili et al., 1989; Handbook, 1990; Dea et al., 1991; Shebalin et al., 1999; Papadopoulos et al., 2000; Rundle et al., 2000; Sorrells et al., 2002; Westaway, 2002). Consequently, seismic activity of Javakheti Highland is the most obvious and it may reflect general changes in tectonic stress of the Caucasus region (Borisov et al., 1989; Park et al., 1993; Hayakawa et al., 2000; Tzanis et al, 2000). Therefore Javakheti Highland may be "sensitive" to the large earthquakes.

The goal of our research was to study time-variation of the number of relatively small earthquakes occurring in Javakheti region with regard to large earthquakes of the Caucasus.

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2 Data

Taking into consideration general pattern of earthquake distribution throughout the southern Caucasus, we decided to use comparatively broadened approach to Javakheti Highland, namely the territory defined by the coordinates was selected.

We have used an Earthquake Catalogue of the Caucasus region compiled by the Department of the Regional Seismology at the Institute of Geophysics, Georgian Academy of Sciences. The catalogue comprises all earthquakes with magnitude $M \geq 2.5$ observed in 1900–1992. After preliminary studies we had to restrict our analysis to the events occurred since 1961 – data on 1900–1960 earthquakes of Javakheti Highland seemed incomplete, as only 123 events were observed.

695 earthquakes of magnitude ($2.5 \leq M < 6.0$) occurred in Javakheti Highland within the time interval between 1961–1992. There were 16 large earthquakes in the whole Caucasus region with $M \geq 6.0$ including Spitak earthquake occurred on 7 December 1988 (epicentre of this earthquake was located in Javakheti Highland).

Data on the above large earthquakes are given in the Table 1. Figure 1 illustrates a map where the territory of Javakheti Highland under consideration is framed by quadrangle.

3 Discussion

Table 2, which shows monthly number of earthquakes observed during 1961–1992, was compiled to establish the rule of variation of the number of relatively small earthquakes of

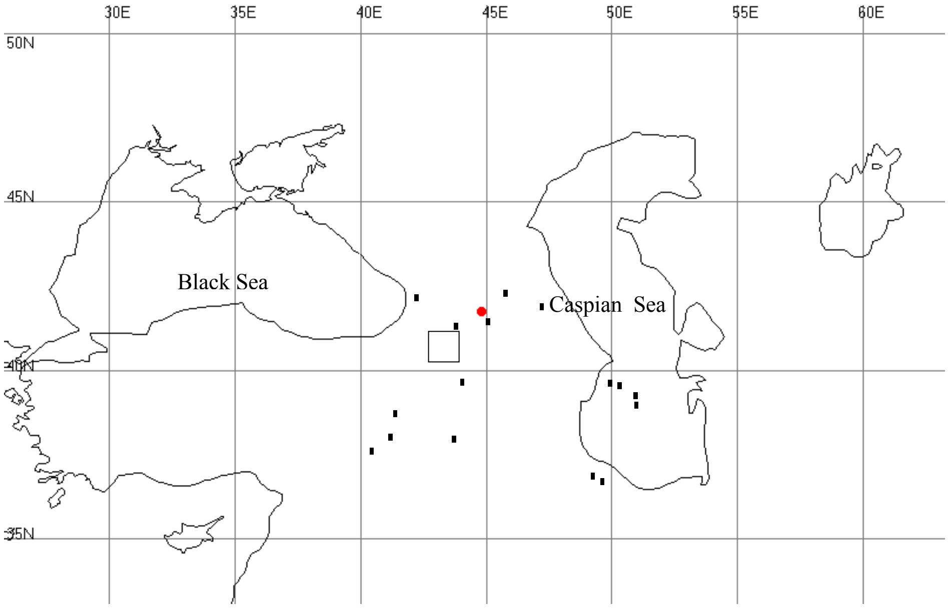

Fig. 1. Distribution of large earthquakes of the Caucasus.

Table 1. The data of large earthquakes of the Caucasus

date	φ	λ	M
18 Sept. 1961	41.066N	50.233E	6.6
27 Jan. 1963	41.080N	49.840E	6.2
16 July 1963	43.180N	41.650E	6.4
19 Aug. 1966	39.166N	41.550E	6.8
14 May 1970	43.000N	47.083E	6.6
22 May 1971	38.850N	40.516E	6.8
28 July 1976	43.170N	45.600E	6.2
24 Nov. 1976	39.100N	44.000E	7.0
4 Nov. 1978	37.610N	49.040E	6.0
4 May 1980	37.800N	49.100E	6.2
30 Oct. 1983	39.983N	41.600E	6.8
6 March 1986	40.060N	51.630E	6.1
7 Dec. 1988	40.900N	44.200E	6.9
16 Sept. 1989	40.340N	51.600E	6.3
29 April 1991	42.390N	43.680E	6.9
23 Oct. 1992	42.490N	44.990E	6.3

Javakheti Highland. The corresponding graph (Fig. 2) was drawn on the base of the data given in Table 2 (here and elsewhere dark triangles stand for the occurrence of large earthquakes throughout the Caucasus within the same period).

Variation of the number of relatively small earthquakes of Javakheti Highland with time is shown in Fig. 2. We used the method of the Creeping Mean for better separation of the anomalies. Namely, we smoothed data series, from 2 to 20 months in length, with a lag of one month until the sharp picture was observed. The 9-month series were found the most appropriate for smoothing, since they proved to be acceptable for further processing and analysing (Comparatively worse graphs were obtained in case of smoothing time series from 7 to 12 months in length. The series shorter or longer than that give distributions which are vague for interpreting) 9-month series choice has not any physical reason. It was chosen empirically because of being the best sygnal/noise

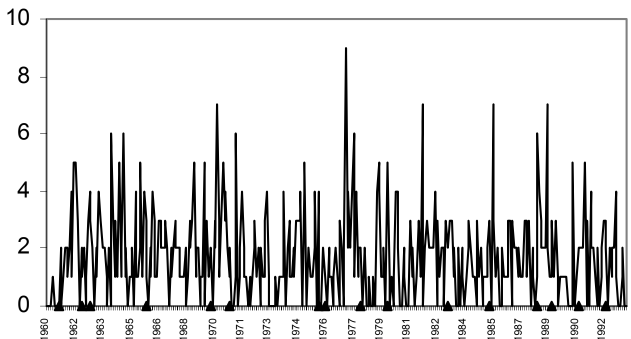

Fig. 2. Variation of the number of relatively small earthquakes with time.

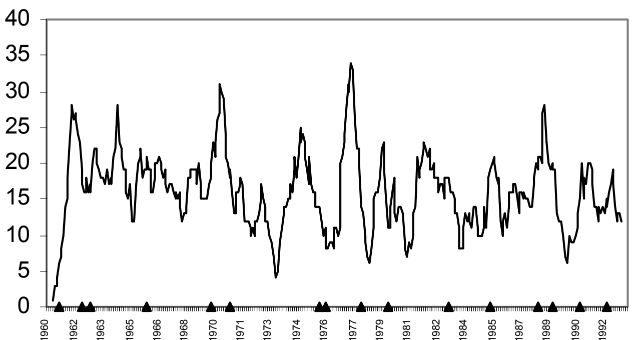

Fig. 3. A result of smoothing of the 9-month series of earthquakes distribution.

Table 2. List of relatively small earthquakes of Javakheti highland

year	month	quantity	year	month	quantity	year	month	quantity	year	month	quantity
1961	1	0	1965	2	5	1969	3	2	1973	4	1
1961	2	0	1965	5	6	1969	8	2	1973	11	0
1961	3	0	1965	6	1	1969	9	0	1973	12	0
1961	4	0	1965	5	6	1969	6	1	1973	7	4
1961	5	1	1965	6	1	1969	7	2	1973	8	1
1961	6	0	1965	7	2	1969	8	2	1973	9	0
1961	7	0	1965	8	0	1969	9	0	1973	10	0
1961	8	0	1965	9	1	1969	10	1	1973	11	0
1961	9	0	1965	10	1	1969	11	1	1973	12	0
1961	10	2	1965	11	2	1969	12	5	1974	1	1
1961	11	0	1965	12	0	1970	1	0	1974	2	0
1961	12	1	1966	1	4	1970	2	3	1974	3	1
1962	1	2	1966	2	1	1970	3	1	1974	4	1
1962	2	2	1966	3	1	1970	4	2	1974	5	1
1962	3	1	1966	4	2	1970	5	2	1974	6	1
1962	4	2	1966	5	5	1970	6	0	1974	7	4
1962	5	4	1966	6	1	1970	7	3	1974	8	0
1962	6	1	1966	7	4	1970	8	2	1974	9	2
1962	7	5	1966	8	3	1970	9	7	1974	10	3
1962	82	5	1966	9	1	1970	10	3	1974	11	1
1962	9	5	1966	10	0	1970	11	1	1974	12	1
1962	10	3	1966	11	2	1970	12	3	1975	1	2
1962	11	0	1966	12	1	1970	1	5	1975	2	1
1962	12	2	1967	1	4	1971	2	3	1975	3	3
1963	1	1	1967	2	3	1971	3	4	1975	4	3
1963	2	2	1967	3	1	1971	4	2	1975	5	3
1963	3	0	1967	4	1	1971	5	1	1975	6	4
1963	4	1	1967	5	3	1971	6	2	1975	7	0
1963	5	3	1967	6	3	1971	7	0	1975	8	4
1963	6	4	1967	7	2	1971	8	0	1975	9	5
1963	7	3	1967	8	2	1971	9	1	1975	10	0
1963	8	2	1967	9	2	1971	10	6	1975	11	2
1963	9	0	1967	10	3	1971	11	0	1975	12	2
1963	10	2	1967	11	2	1972	12	1	1976	1	1
1963	11	1	1967	12	0	1972	1	2	1976	2	1
1963	12	4	1968	1	2	1972	2	4	1976	3	2
1964	1	3	1968	2	1	1972	3	2	1976	4	4
1964	2	3	1968	3	2	1972	4	1	1976	5	0
1964	3	2	1968	4	3	1972	5	1	1976	6	4
1964	4	2	1968	5	2	1972	6	0	1976	7	0
1964	5	1	1968	6	2	1972	7	1	1976	8	0
1964	6	0	1968	7	2	1972	8	0	1976	9	2
1964	7	2	1968	8	1	1972	9	1	1976	10	1
1964	8	0	1968	9	1	1972	10	2	1976	11	1
1964	9	6	1968	10	1	1972	11	3	1976	12	0
1964	10	3	1968	11	2	1972	12	1	1977	1	2
1964	11	1	1968	12	0	1973	1	2	1977	2	1
1964	12	3	1969	1	1	1973	2	0	1977	3	1
1965	1	1	1969	2	3	1973	3	2	1977	4	0

ratio among other variants. Figure 3 shows graph obtained as a result of smoothing of the 9-month series of earthquakes distribution. Some character of variation with time of relatively small earthquakes number of Javakheti Highland was revealed as a result of the analysis, and the necessity for further study was obvious.

We have applied the qualitative method for anomaly separation, namely the method for summation with variable sign (Handbook, 1990) widely used in Geophysics, to separate "useful" anomalies from disturbances. The method is quite convenient even in case when the amplitude of disturbances equals or exceeds the amplitude of "useful" anomalies.

Table 2. continued

year	month	quantity	year	month	quantity	year	month	quantity	year	month	quantity
1977	5	1	1981	7	0	1985	9	2	1989	11	1
1977	6	2	1981	8	0	1985	10	2	1989	12	3
1977	7	1	1981	9	3	1985	11	1	1990	1	1
1977	8	0	1981	10	1	1985	12	1	1990	2	0
1977	9	3	1981	11	2	1986	1	1	1990	3	1
1977	10	2	1981	12	0	1986	2	2	1990	4	1
1977	11	0	1982	1	1	1986	3	3	1990	5	1
1977	12	2	1982	2	3	1986	4	0	1990	6	1
1978	1	9	1982	3	3	1986	5	7	1990	7	1
1978	2	2	1982	4	1	1986	6	3	1990	8	1
1978	1	9	1982	3	3	1986	5	7	1990	7	1
1978	3	4	1982	5	7	1986	7	1	1990	9	0
1978	4	2	1982	6	0	1986	8	2	1990	10	0
1978	5	4	1982	7	2	1986	9	2	1990	11	0
1978	6	6	1982	8	3	1986	10	0	1990	12	5
1978	7	1	1982	9	2	1986	11	0	1991	1	0
1978	8	4	1982	10	2	1986	12	2	1991	2	1
1978	9	1	1982	11	2	1987	1	1	1991	3	1
1978	10	2	1982	12	2	1987	2	1	1991	4	2
1978	11	2	1983	1	2	1987	3	1	1991	5	2
1978	12	0	1983	2	4	1987	4	3	1991	6	2
1979	1	2	1983	3	0	1987	5	3	1991	7	2
1979	2	2	1983	4	3	1987	6	0	1991	8	5
1979	3	0	1983	5	1	1987	7	3	1991	9	0
1979	4	0	1983	6	2	1987	8	2	1991	10	3
1979	5	1	1983	7	2	1987	9	2	1991	11	0
1979	6	0	1983	8	0	1987	10	1	1991	12	4
1979	7	0	1983	9	3	1987	11	2	1992	1	2
1979	8	1	1983	10	2	1987	12	1	1992	2	2
1979	9	0	1983	11	2	1988	1	1	1992	3	1
1979	10	4	1983	12	3	1988	2	1	1992	4	0
1979	11	5	1984	1	3	1988	3	3	1992	5	2
1979	12	4	1984	2	1	1988	4	3	1992	6	0
1980	1	1	1984	3	2	1988	5	1	1992	7	1
1980	2	1	1984	4	0	1988	6	3	1992	8	2
1980	3	2	1984	5	0	1988	7	0	1992	9	3
1980	4	0	1984	6	2	1988	8	2	1992	10	3
1980	5	5	1984	7	0	1988	9	1	1992	11	2
1980	6	1	1984	4	2	1988	10	0	1992	12	0
1980	7	0	1984	9	1	1988	11	1	1993	1	2
1980	8	1	1984	10	0	1988	12	6	1993	2	1
1980	9	0	1984	11	1	1989	1	4	1993	3	2
1980	10	1	1984	12	2	1989	2	3	1993	4	2
1980	11	4	1985	1	3	1989	3	2	1993	5	4
1980	12	4	1985	2	2	1989	4	2	1993	6	1
1981	1	2	1985	3	1	1989	5	2	1993	7	0
1981	2	0	1985	4	1	1989	6	7	1993	8	0
1981	3	0	1985	5	1	1989	7	2	1993	9	1
1981	4	2	1985	6	0	1989	8	1	1993	10	2
1981	5	1	1985	7	3	1989	9	1	1993	11	0
1981	6	0	1985	8	1	1989	10	3	1993	12	0

Condition for application of the method is availability of an anomalous curve, which cuts off approximately equal areas from the axis of abscissas. We computed average value of those data, according to which Fig. 3 was drawn. This value equals 15.72. Drawing of the “zero line” across the average value made possible to apply the above-mentioned method for summation with variable sign (Naturally, the number of earthquakes was subdivided into “positive” and “negative”

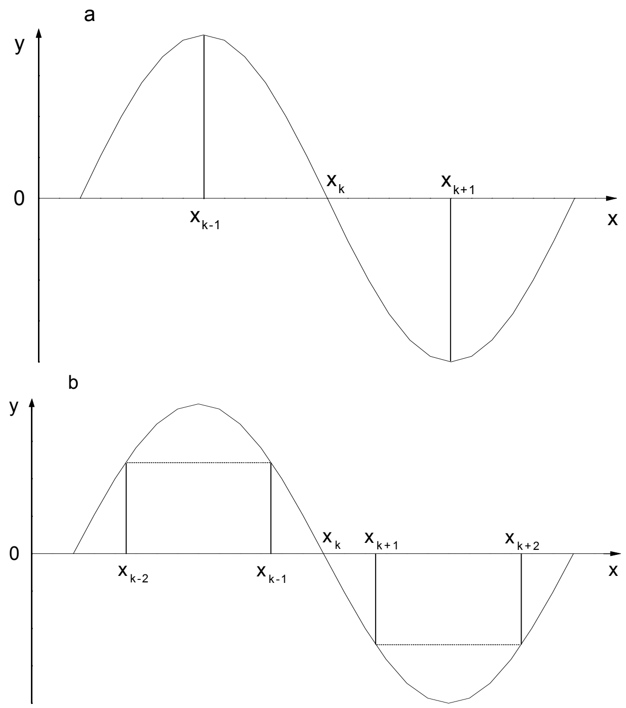

Fig. 4. Ilustration of the method of summation with variable sign.

values as a result of drawing the "zero line". The "negative" values imply decrease in the number of earthquakes).

The method of summation with variable sign is based on the amplitude doubling of the maximum anomalous signal in case of dissecting minimum value (with own sign) from the maximum one.

Difference between the ordinates of x_{k-1} and x_{k+1} points (Fig. 4a) is denoted by $y'(x_k)$, and attributed to x_k point:

$$y'(x_k) = y(x_k - 1) - y(x_k + 1). \tag{1}$$

If while transforming the anomaly we use four (or more) ordinates of the anomalous curve instead of two, as shown in Fig. 4b, we will have:

$$y(x_k) = y(x_{k-2}) + y(x_{k-1}) - y(x_{k+1}) - y(x_{k+2}). \tag{2}$$

Consequently, the above method transforms each idealized anomaly with the "variable sign" into the anomaly with corresponding sign and with twofold, fourfold (multifold) amplitude.

Ratio of the amplitude of the desired signal y_0 to the square root of the amplitude's dispersion of the disturbance σ_0 significantly increases in case of the above transformation, and the applied operator "works" as a filter which amplifies the desired signal.

Figure 5 shows complicated anomalous pattern obtained from Fig. 3 by means of the method of summation with variable sign (with 16 ordinates). Analysis of the obtained curve, based on the gradual approximation, makes possible to delineate the certain zone with margins from +53.1 to −51.8. The "useful" anomalies observed beyond the zone, give evidence

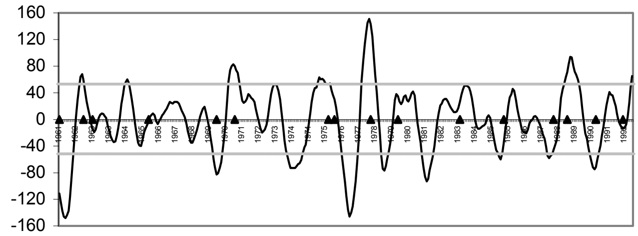

Fig. 5. Result of summation with variable sign of relatively small earthquakes.

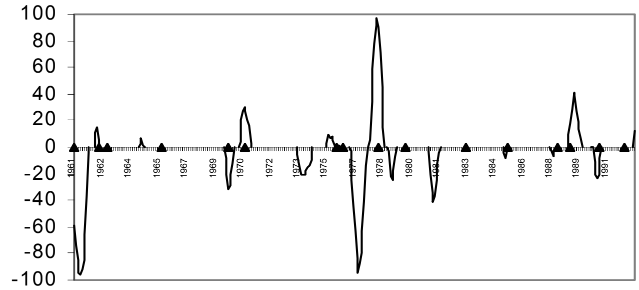

Fig. 6. "Reduced" graphs of anomalous.

of their attribution to large earthquakes. Figure 6 represents the so called "reduced" graph which was obtained after taking into consideration margins of the zone. The pattern reflects anomalous increase in the number of relatively small earthquakes occurred in Javakheti Highland as a precursor of each large earthquake.

As we did not take into consideration earthquakes of Javakheti Highland occurred before 1961 due to inferior results of computations that can be attributed to peculiarities of the method (lack of the read off points is implied), we have neglected large earthquakes only of 1961 and 1992 (just 2 events). For all the other 14 large earthquakes of the Caucasus the regularity is observed.

Figure 6 illustrates good quantitative coincidence of anomalous picks with the number of earthquakes with one exception: the large earthquake occurred in 1978 was preceded by two anomalous picks.

Table 3 was compiled as a result of the critical analysis of Fig. 6. The table helped us to establish the minimal size of the anomaly the numeral value increase of which shows us the possibilities of an occurrence of large earthquake. The minimal size of the anomaly was found to equal |6.2|. Maximum and minimum time lags from the starting point of the anomaly till earthquake occurrence are 31 months and 1 month, respectively.

4 Conclusion

We should state that all the large earthquakes ($M \geq 6.0$) which occurred in the Caucasus within the period from 1961 till 1992 were preceded by anomalous change in the number of relatively small earthquakes ($2.5 \leq M < 6.0$) of Javakheti

Table 3. Estimate of anomalous

Occurrence time of the earthquake	Magnitude	Distance from Javakheti Highland (km)	The maximum value of anomaly	The minimum value of anomaly	Time lag between the starting point of the anomaly and earthquake occurrence (month)
18 Sept. 1961	6.6	538.9			
27 Jan. 1963	6.2	505.9	14.9	−96	16
16 July 1963	6.4	273.9	14.9	−96	22
19 Aug. 1966	6.8	304.6	6.9		15
14 May 1970	6.6	330.1		−31	2
22 May 1971	6.8	390.2	29.9		4
28 July 1976	6.2	255.3	9	−21	27
24 Nov. 1976	7.0	245.2	9	−21	31
4 Nov. 1978	6.0	608.7	97.9	−94	19
4 May 1980	6.2	598.1		−25	11
30 Oct. 1983	6.8	236.4		−41	25
6 March 1986	6.1	674.3		−8.2	3
7 Dec. 1988	6.9	55.7		−6.2	4
16 Sept. 1989	6.3	664.7	40.9		1
29 April 1991	6.9	121.6		−23	4
23 Oct. 1992	6.3	164.9			

Highland. We consider this peculiarity as the marked precursor.

Getting results show that special seismoactivity of Javakheti Highland reflects the global process of preparing of large earthquakes throughout the whole Caucasus region.

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