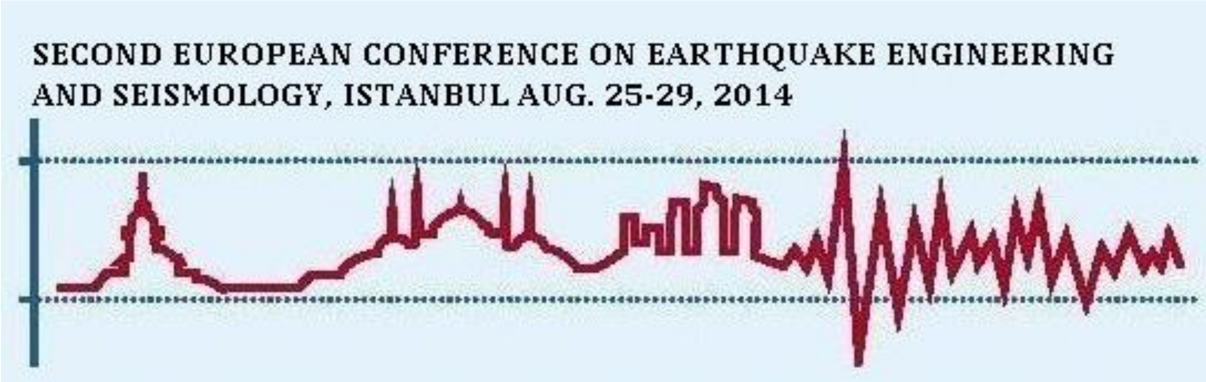

MONITORING AND FORECAST THE VAN EARTHQUAKE (OCTOBER 23, 2011) IN THE SEISMIC SYSTEM ARMENIAN UPLAND

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Seismic system Armenian Upland and the ensemble of strong earthquakes (M ≥ 7.1). Results of monitoring of the Van earthquake in seismic systems (SS) Armenian Upland, which was held since 2008 in online mode on the www.geoq.ru, are presented. To describe the dynamics and the development of instability in the system has been applied method of seismic entropy (Akopian, 1995a, b, c, Akopian, 1998a). In this approach the preparation of strong earthquakes with magnitudes above a certain threshold M_{th} occurs in a specific volume of the lithosphere – the SS, which characterized by the configuration on the Earth's surface and depth. Relatively weak earthquakes with magnitudes less than the threshold, $M < M_{th}$, called the indicator earthquakes. They carry information about the dynamic state of the SS structures. To monitor the dynamics and describe the critical behavior of the lithosphere in the SS volume were introduced seismic parameters cumulative energy E_c, the number of system states S and their logarithms, cumulative energy class K_c and entropy W

$$E_c(T) = \sum E_i, \quad K_c = \lg E_c, \quad S = T E_c - \sum \{T_i E_i\}, \quad W = \lg S, \qquad (1)$$

where T is the current time in the j - th seismic cycle, E_i, T_i radiation energy and time when the i - th indicator earthquake occurs. Summation is over all indicator earthquakes within the selected volume of the lithosphere with $M > M_h$ (M_h - minimal magnitude of an equilibrium indicator earthquake).

On the basis of the kinematic model Tauro-Caucasus region has been identified the SS Armenian Upland with the threshold magnitude M_{th} = 7.1, depth 60 km and configuration L on the Earth's surface, including the Caucasian sector and buffer zone (Fig. 1a). Fig. 1a shows epicenters of indicator earthquakes in the Caucasian sector, buffer zone, source areas and focal mechanisms of the ensemble of strong earthquakes (Akopian & Rogozhin, 2013). Mechanisms of earthquakes before 1939 are hypothetical, they are built with the assistance of macroseismic data. The results of calculation of the parameters (1) and inelastic coefficients for SS Armenian Upland are shown in Table 1. The mean recurrence interval of strong earthquakes ensemble in the SS Armenian Upland, after completing 7 seismic cycles, is equal to $\overline{T}$ = 28.5 yr. Calculation time step was 1 month.

Table 1. Data of catastrophic earthquakes, the values of cumulative parameters K_c, W and inelastic coefficients η_{sc}, E_{sf}, in the seismic cycles of the SS Armenian Upland (Akopian & Rogozhin, 2013).

j	Date	Lat.	Lon.	K_s	M_s	K_c	W	η_{sc}%	E_{sf} % (10^{-18})	Location
1	1840.07.02	39.50	43.90	16.1	7.4	15.58	17.74	0.07	17.2	Ararat*
2	1903.04.28	39.13	42.65	15.8	7.1	15.85	18.07	0.03	23.0	Malasgird
3	1916.01.24	40.30	36.80	15.8	7.1	15.38	17.22	0.13	4.8	Tokat
4	1930.05.06	38.00	44.50	15.9	7.2	15.08	16.65	0.53	1.5	Salmas
5	1939.12.26	39.70	39.70	16.6	7.8	15.37	17.27	0.57	7.0	Erzincan
6	1976.11.24	39.10	44.00	15.8	7.3	15.67	17.78	0.04	14.2	Chaldiran
7	2011.10.23	38.63	43.48	15.8	7.3	15.94	18.33	0.02	37.9	Van

* data not the full

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The trajectory diagram is the dependence of logarithm of the cumulative energy indicator earthquakes in seismic cycles from entropy. Fig. 1b shows the track diagram and attractor for SS Armenian Upland. Attractor includes the points at which the tracks are terminated by strong earthquakes. Diagonal is a line of equilibrium. Origin of coordinates in the figure corresponds to the selected minimum level of indicator earthquakes energy, $M_h = 5.0$.

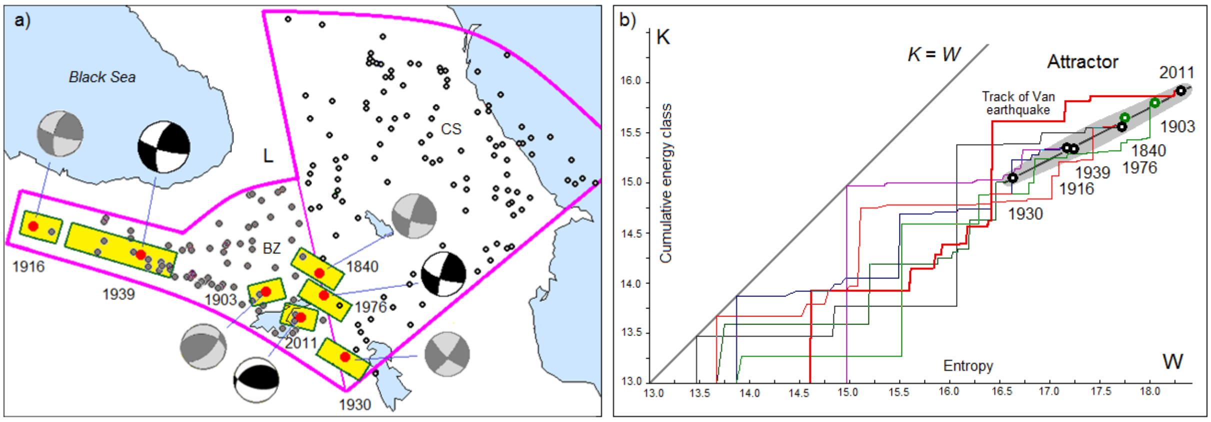

Figure 1. a) Configuration *L* of SS Armenian Upland. Showing the source areas (squares), focal mechanisms (gray – hypothetical) of strong earthquakes with $M \geq 7.1$, small circles – epicenters of indicator earthquakes of the Caucasian sector (CS) and the Buffer zone (BZ) with $5.0 \leq M < 7.1$. b) The trajectory diagram and attractor for SS Armenian Upland. Shows the track of the Van earthquake (Akopian & Rogozhin, 2013)

The equation of the regression line on the track diagram, calculated on the basis of K_j, W_j (j = 2 – 7) of Table 1, has the form

$$K_c = 0.525\,W + 6.322 \qquad (16.60 < W < 18.35) \qquad (2)$$

In general, the following prognostic criteria are observed, when monitoring earthquakes with M ≥ 7.1 in the SS Armenian Upland. With increasing entropy, first enters into the unstable state of the Kurdistan node, then the eastern segment of the North Anatolian Fault, after the southern part of the Transcaucasian uplift. When all of these areas are locked, only then begins activated the buffer zone, sandwiched between them. The Van earthquake seismic cycle has accumulated the highest values of entropy. The trajectory of this earthquake (Fig. 1b) has accumulated a large energy due to the Spitak (1988, M6.9), Racha (1991, M6.8) and Barisakho (1992, M6.3) indicator earthquakes, top passed the attractor and only by 2011 approached to the critical zone instability, eq. (2). Location and magnitude of this earthquake was predicted accurately by Akopian (1998b), there was stated «Large earthquake is expected to 2002 with $M = 7.3$ in the region of Van Lake ...». Since then, the monitoring was carried out based on the SS Armenian Upland with a lower threshold magnitude, $M_{th} = 6.6$, then it do not reflect the entire process of preparation Van earthquake, the waiting time was specified in 2002. Later (since 2008), was monitoring with the involvement of the higher hierarchical system, the Armenian Upland with $M_{th} = 7.1$, fully responsible for the preparation of the Van earthquake. Fig. 1b shows, the trajectory approach to the critical zone of instability only by February 2011. Since this date the earthquake in the east of Turkey was expected, and it occurred 8 months later, on October 23. The waiting time was ≈ 2.0% of the total preparation time, beginning with 1976. Also was calculated the probability parameters of the dynamic growth energy P_K, entropy P_W and their product P (Akopian, 1995c). These probabilities are the additional parameters of SS states, controlling dynamics origin of instability in the system. Before the Van earthquake they reached values P = 75% (P_W = 83%, P_K = 91%). The results are shown in Fig. 2a.

Phase diagram of the Van earthquake. The process of Van earthquake preparing in the system can be clearly illustrated by the phase diagram (Akopian, 1995b), which are commonly used in catastrophe theory (Arnold, 1984). Fig. 2b shows the phase diagram (a spiral path) of the Van earthquake, built by this method. In preparation of the Van earthquake, the spiral trajectory, aiming to the center of balance, approaches and crosses the critical circles, corresponding to the intersection trajectory with the attractor. At the time of indicator earthquakes sharply increases the velocity of the approaching trajectory to the center. Fig. 2b marked section of the diagram from 144-th to 171-th month, between which there were the strong Spitak, Racha and Barisakho indicator earthquakes. Dangerous period starts from 409-th month, the Van earthquake occurs after 419 months.

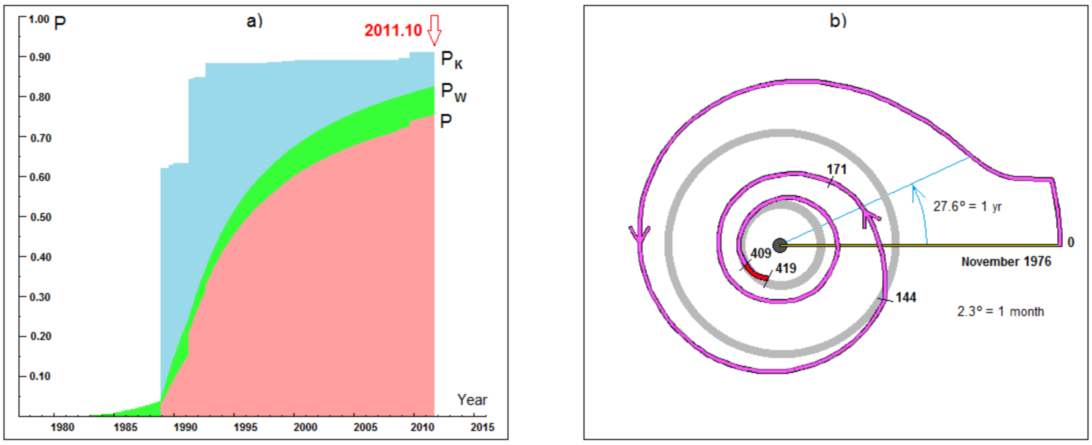

Figure 2. a) The dynamics of growth probability of the cumulative energy P_K, entropy P_W, and their product P in the seismic cycle of Van earthquake. b) Spiral track of the Van earthquake. Rotation by 2.3 degrees corresponds to 1 month. A spiral path starts after 1976 and ends by Van earthquake after 419 months. Radii of the circles correspond to the values of entropy, at which the trajectory intersects the regression line (2)

Construction of phase, trajectory and energy diagrams allows controlling the rate of movement of the Arabian Plate to the north, doing seismic monitoring over long time intervals and with some accuracy to predict the generation of instability. The Armenian Upland systems with the threshold magnitudes 6.6 and 7.1, complementing each other, allow to do reliable monitoring and the forecast of strong earthquakes in the region on the lower ($6.6 \le M < 7.1$) and upper ($7.1 \le M < 7.8$) energy levels. Number of the previous ended seismic cycles of strong earthquakes in the SS determine forecast accuracy.

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