EARTHQUAKE PRECURSORS' DISPLAY FEATURES IN THE TERRITORY OF ARMENIA

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Based on retrospective analysis of multidisciplinary observations in research seismoactive zone for current seismic hazard assessment, practically all seismic events which had occurred from 1983 till 2002 in the territory of Armenia and adjacent territories are systematically tested. The precursory anomalies of 11 strong regional (M≥6.0) and 7 perceptible local earthquakes (M≥3.7) are classified.

Practice shows that small-but-perceptible local earthquakes of previous years invariably caused some panic among the local population, and damage of buildings and structures. For this reason, our study includes the local small-but-perceptible earthquakes with 3.7< M< 5.0 as well.

Time-series providing many years of data on 15 different types of parameters from more than 80 stations of the National observation network of Armenian NSSP are processed (some stations having been in operation for more than 24 years). The medium-term, short-term and operative probably-seismogenic anomalies as well as co-seismic and post-seismic effects anticipating the tested seismic events are distinguished. The vertical scales of time-series are defined so that 2σ and more are included in 1 mm, where σ is an error of measurements.

The classification is performed and the parameters of precursory anomalies are determined. The graphic images of each anomaly are allocated and the *probability of seismic realization of anomalies P* is determined as the relation *m/n*, where *m* is quantity of those anomalies, after which the tested seismic events with M≥3.7 occurred, and *n* is the total of such anomalies at the given station and on given parameter available in the Armenian NSSP database. The Catalogue of precursory anomalies of the tested earthquakes is completed. It includes 167 anomalies-tests displaying the features of 656 anomalies. The precursory anomalies were grouped by earthquake. The value of P, the epicentral distance of the monitoring station, the moment of the seismic event and its magnitude were each shown. The overwhelming majority of precursors was classified and represented in the Catalogue for the first time. There are many examples, in particular, the imposing of precursory anomalies of different order, as well as the presence of pre-, co-, post-seismic periods in observed anomalies (fig.1). At the end of the Catalogue, the summary table is given (table 1), where the data on parameters of the tested earthquakes and precursory anomalies are provided.

The tests were made within several years, with inclusion of new seismic events occurred and in process of new data acquisition from observation stations. The Catalogue of precursors was supplemented few times, and the anomalies included were critically overestimated and sometimes rejected. Naturally, the Catalogue will be supplemented with the tests of future strong regional and perceptible local earthquakes.

The Catalogue is in daily use at the Unified Center for Seismic Hazard Assessment of Armenian NSSP for current seismic hazard assessment.

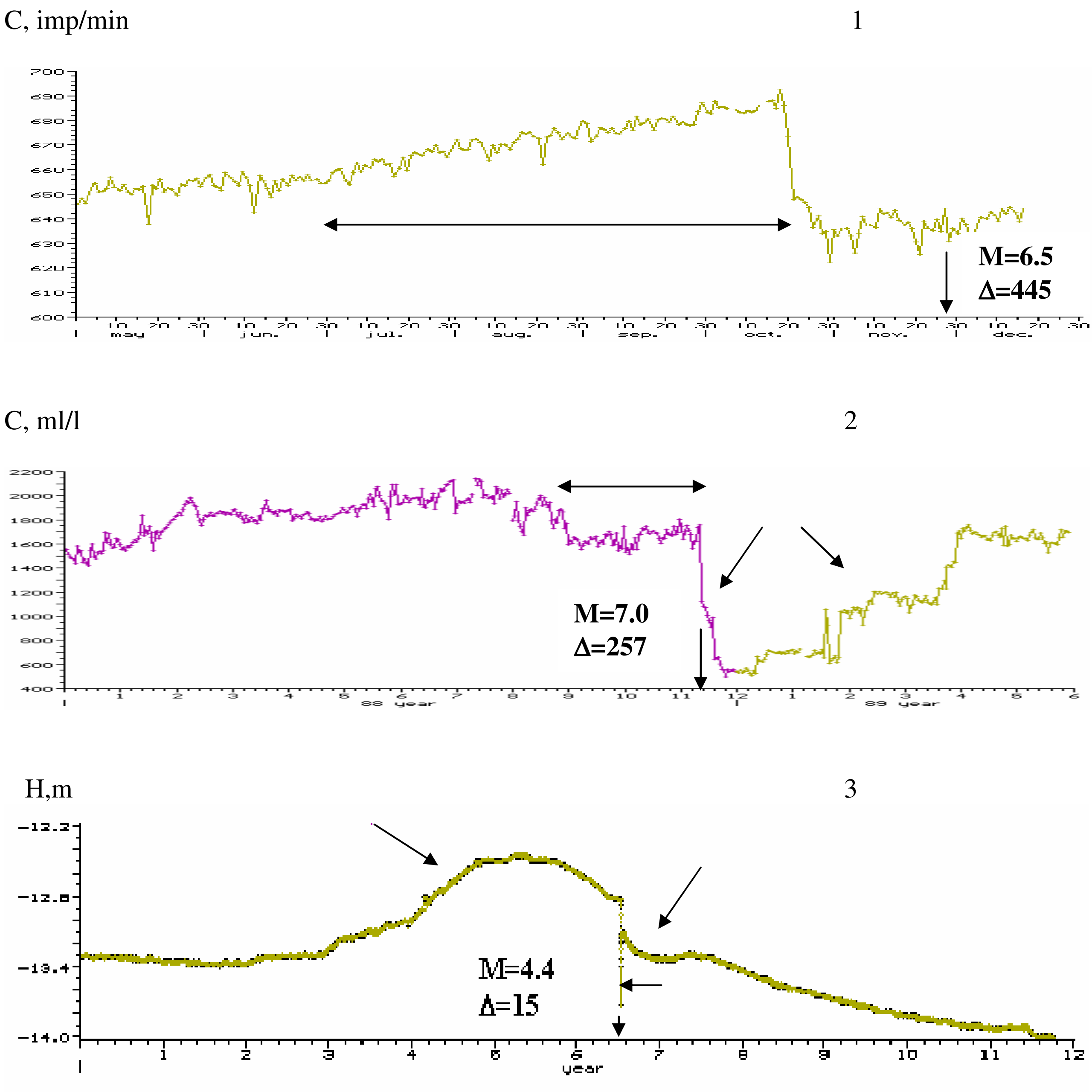

Fig.1. The pre-seismic anomaly of subsoil Radon concentration at the Noemberyan station before the Baku (2000, M=6.5) earthquake (1); pre-, co-, and post-seismic anomalies of Helium concentration at the Kajaran station, Spitak (1988, M=7.0) earthquake (2); pre-, co-, and post-seismic anomalies of underground water level at the Noemberyan station, Noemberyan (1997, M=4.4) earthquake (3).

The moments of seismic events are marked by vertical arrows, and anomalies - by horizontal and inclined arrows.

The summary table of earthquakes' test-precursors (the 1-st page)

Table 1

N	Earthquake	Parameter	Station	Δ (km)	Duration of time-series	ΔT (days)	Amplitude of anomaly	Type of anomaly	Probability P = m/n
1	2	3	4	5	6	7	8	9	10
1	Narman, Turkey	Geomagn.-	Gyulag.- Jermuk	262	since 80 /	510	22	m/t	1/1
	30.10.1983	SD	Ararat	264	80	236	195	sh/t	2/4
	M = 6.8	He	Surenavan	267	since 07.78	180	360	sh/t	1/1
		He	Kajaran	397	since 12.79	142	1130	sh/t	1/4
		He			since 01.83				
2	Spitak, Armenia	Geomagn.-	Gyulag.- Jermuk	19	since 80 /	1020	32	m/t	1/1
	07.12.1988	SD	Metsamor	85	80	840	52	m/t	1/2
	M = 7.0	HGD	Goris	235	since 01.86	457	48	m/t	1/2
		HGD	Sevan	71	since 01.87	380	198	sh/t	1/1
		HGD	Noemberyan	59	since 01.87	247	220	sh/t	2/5
		HGD	Dzorakhbyur	87	since 01.86	234	70	sh/t	1/1
		HGD	Surenavan	133	since 01.88	220	0.8	sh/t	1/5
		Cl	Kajaran	257	since12.79	165 and	1.22	sh/t	1/5
		HCO_3			since 01.83	reaction	2.44	---	---
			Kajaran	257		157 and	*	sh/t	1/8
		pH			since 01.83	reaction	0.34	---	---
			Kajaran	257		127 and	0.72	sh/t	1/4
		Cl			since 01.83	reaction	0.8	---	---
			Ararat	125		117	0.85	sh/t	1/2
		pH	Kajaran	257	since 07.78	68 and	480	sh/t	5/9
		He			since 01.83	reaction	1280	---	---
			Dzorakhbyur	87		57	13	sh/t	1/4
		HGD	Goris	235	since 01.88	39	9	sh/t	1/1
		HGD	Kumayri	32	since 01.87	34	18	sh/t	1/13
		Radon s/s	Noemberyan	59	since 01.86	14	247	sh/t	1/1
		HGD	Surenavan	133	since 01.86	reaction	0.43	---	---
		pH			since 12.79				

Legend:

HGD – hydrogeodynamics - underground water level (cm)

Hydrogeochemical regional network:

He – concentration of Helium in mineral water (ml/l $\cdot 10^{-6}$)

Cl - concentration of chlorine in mineral water (ml/l $\cdot 10^{-6}$)

pH - acidity of mineral water

HCO_3 – concentration of HCO3 in mineral water (ml/l $\cdot 10^{-6}$)

Hydrogeochemical READINESS network:

Conduct. – electrical conductivity of mineral water (msim/cm)

Flow – flow of mineral water (l/sec)

Water temp. – temperature of mineral water (°C)

Radon in water – Radon concentration in mineral water (imp/min)

pHr – acidity of mineral water

Radon s/s – subsoil Radon concentration (imp/min)

INP – electromagnetic monitoring by "Irreversibility of non-stationary processes" techniques (W/m^3)

Geomagn.- SD – geomagnetic observations – sinchronical difference (nTl)

Geomagn.- geomagnetic observations (nTl)

ULRW – ultra long radio waves (ionospheric observations) (mcs)

Fishes – activity of aquarium fishes (imp/hour)

Atm. press. – atmospheric pressure (mm)

* - non-amplitude anomaly

Type of precursor:

m/t – middle-term

sh/t – short-term

oper- operative

reaction – co-seismic and post-seismic effects

The earthquake precursors are characterized by the following features:

1. The preparation of earthquakes with various magnitudes (M≥3.7) was accompanied by the appearance of precursors in various physical fields (fig. 2 –5).

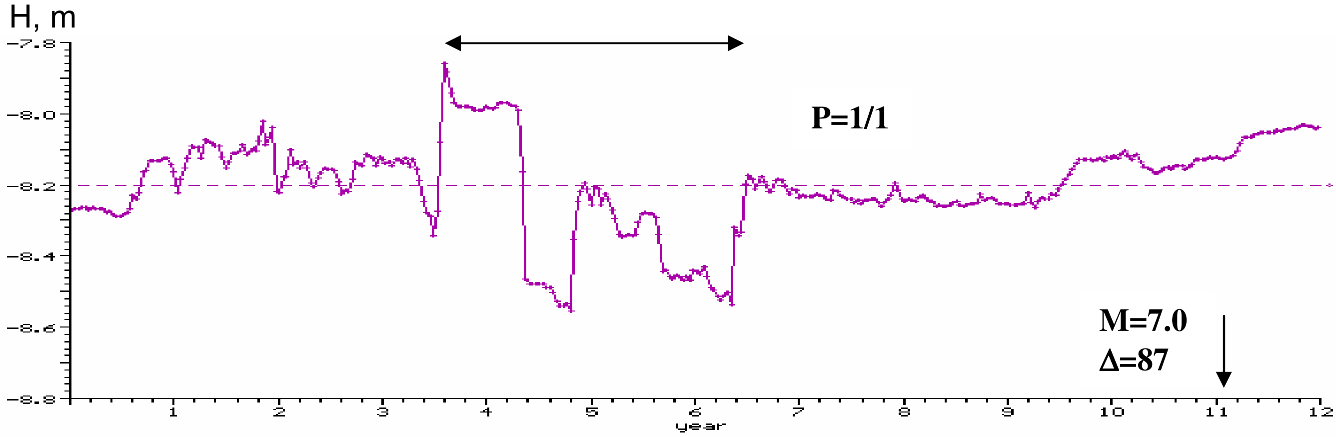

Fig. 2. The example of variations of underground waters level at the Dzorakhbyur station. Spitak earthquake (Armenia, 07.12.1988, M=7.0).

2. The precursors and co-seismic effects were apparent at distances up to 1300 kms from the epicenter of the seismic event (M=7.4) (fig. 6, 7).

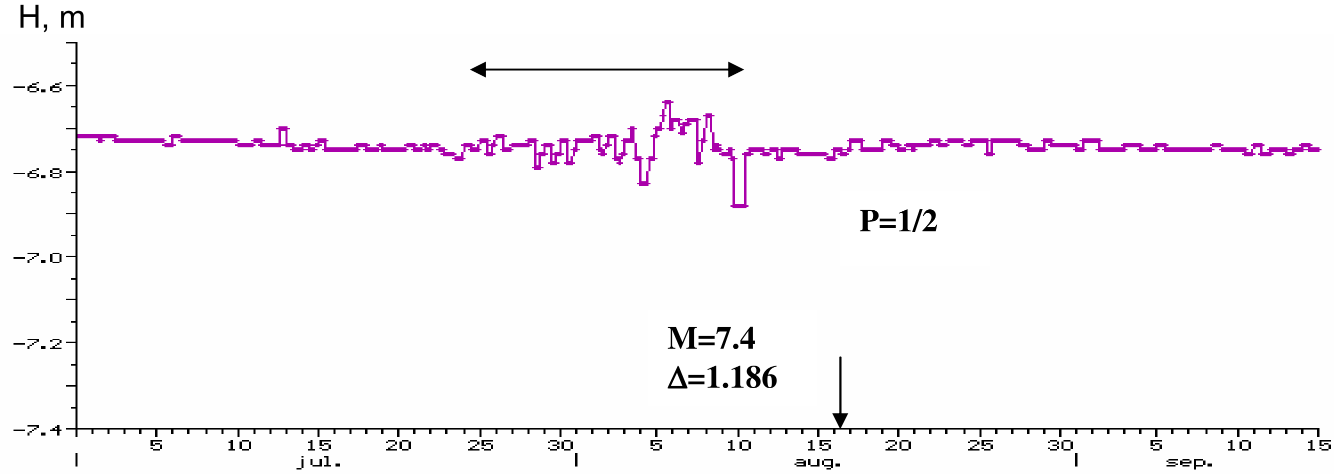

Fig. 6. Variations of underground waters level at the Ashotsk station. Izmit earthquake (Turkey, 17.08.1999, M=7.4).

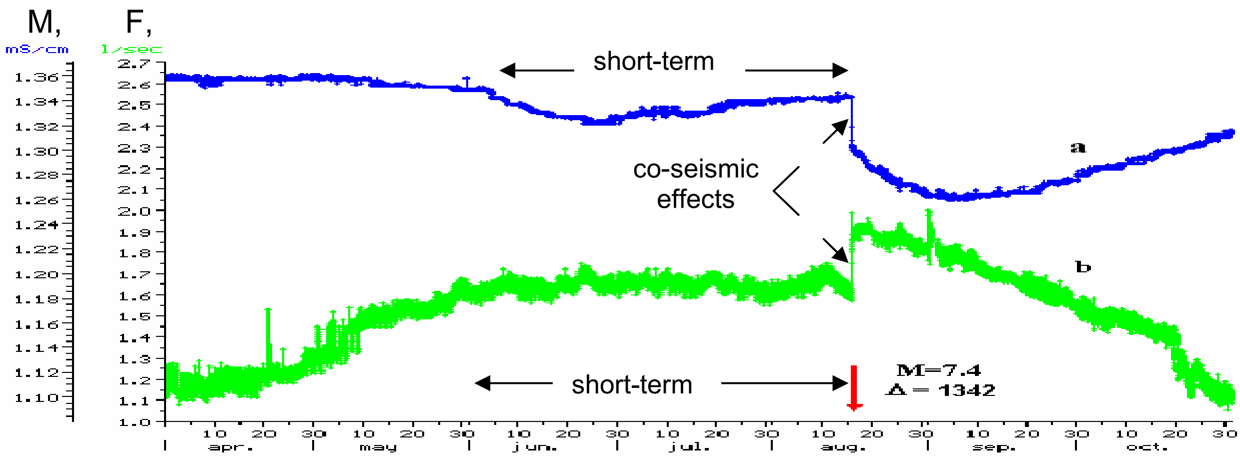

Fig. 7. Short-term anomalies and co-seismic effects of conductivity (a) and flow (b) of mineralized waters in the Kajaran borehole. Izmit earthquake (Turkey, 17.08.1999, M=7.4).

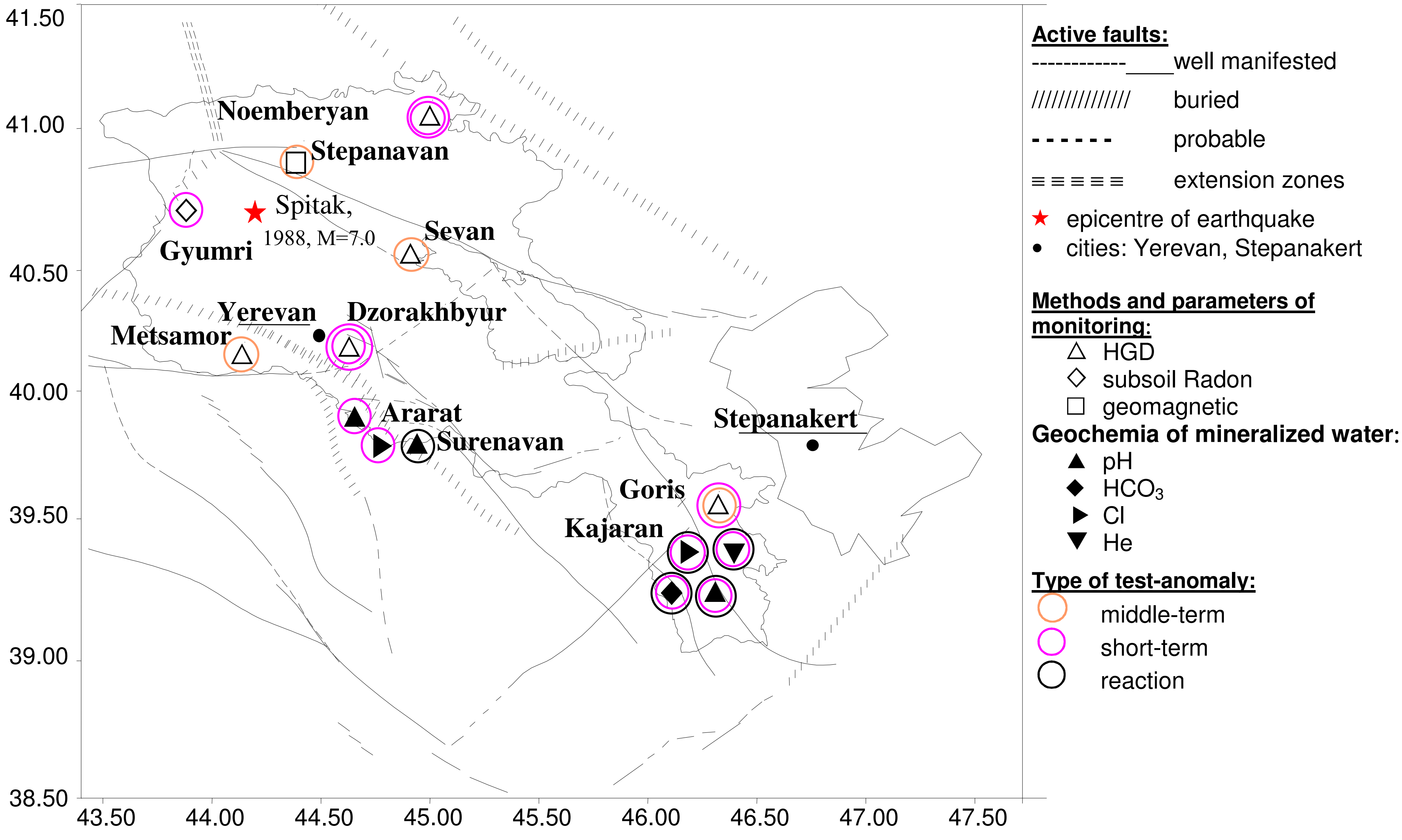

Fig.3. An example of strong regional earthquakes (11 maps overall): sensitivity of the observation stations in the territory of Armenia during the preparation and realization of Spitak (Armenia, 07.12.1988, M=7.0) earthquake.

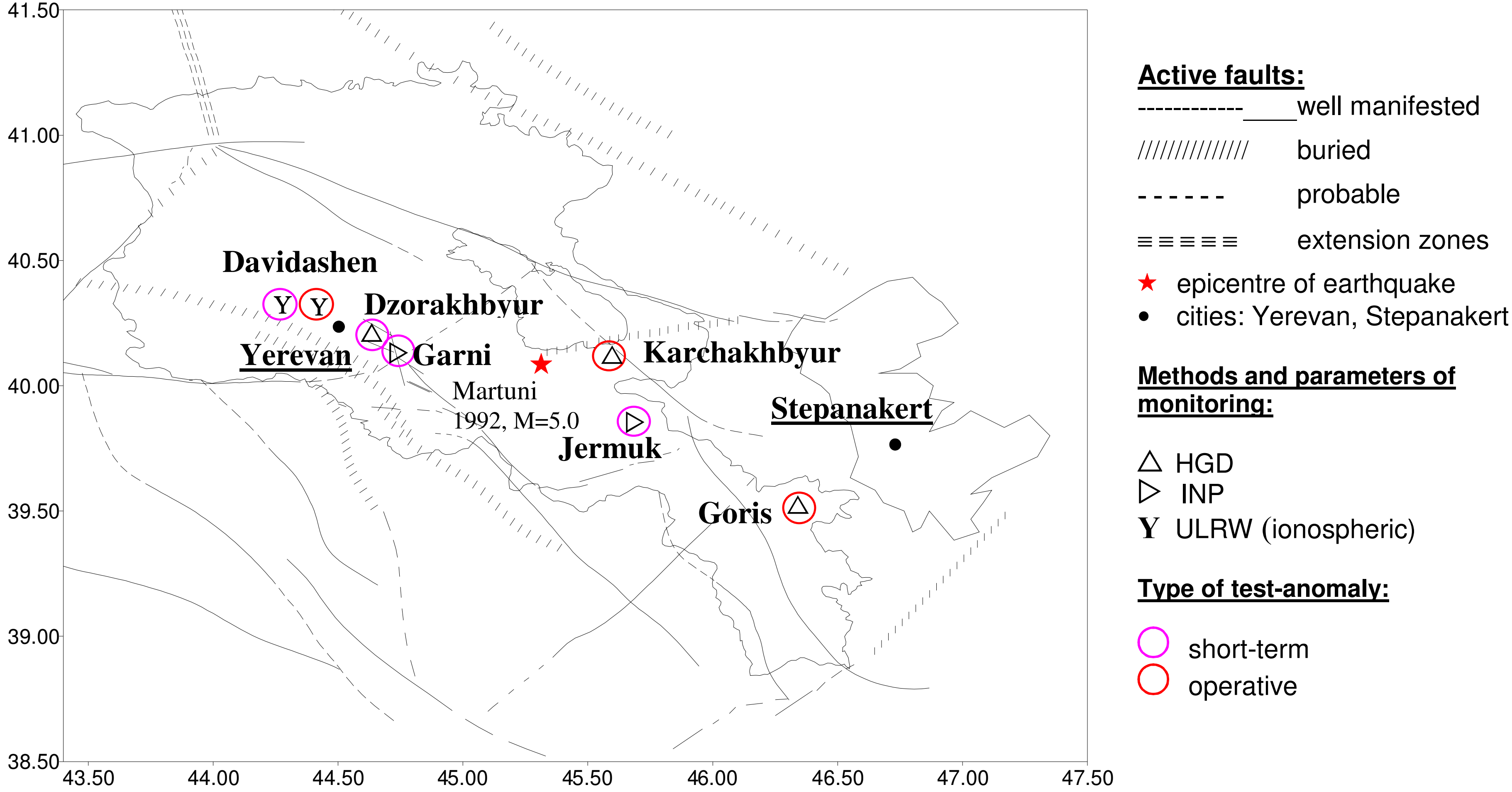

Fig. 4. An example of perceptible local earthquakes (7 maps overall): sensitivity of the observation stations in the territory of Armenia during the preparation and realization of Martuni (Armenia,10.12.1992, M=5.0) earthquake.

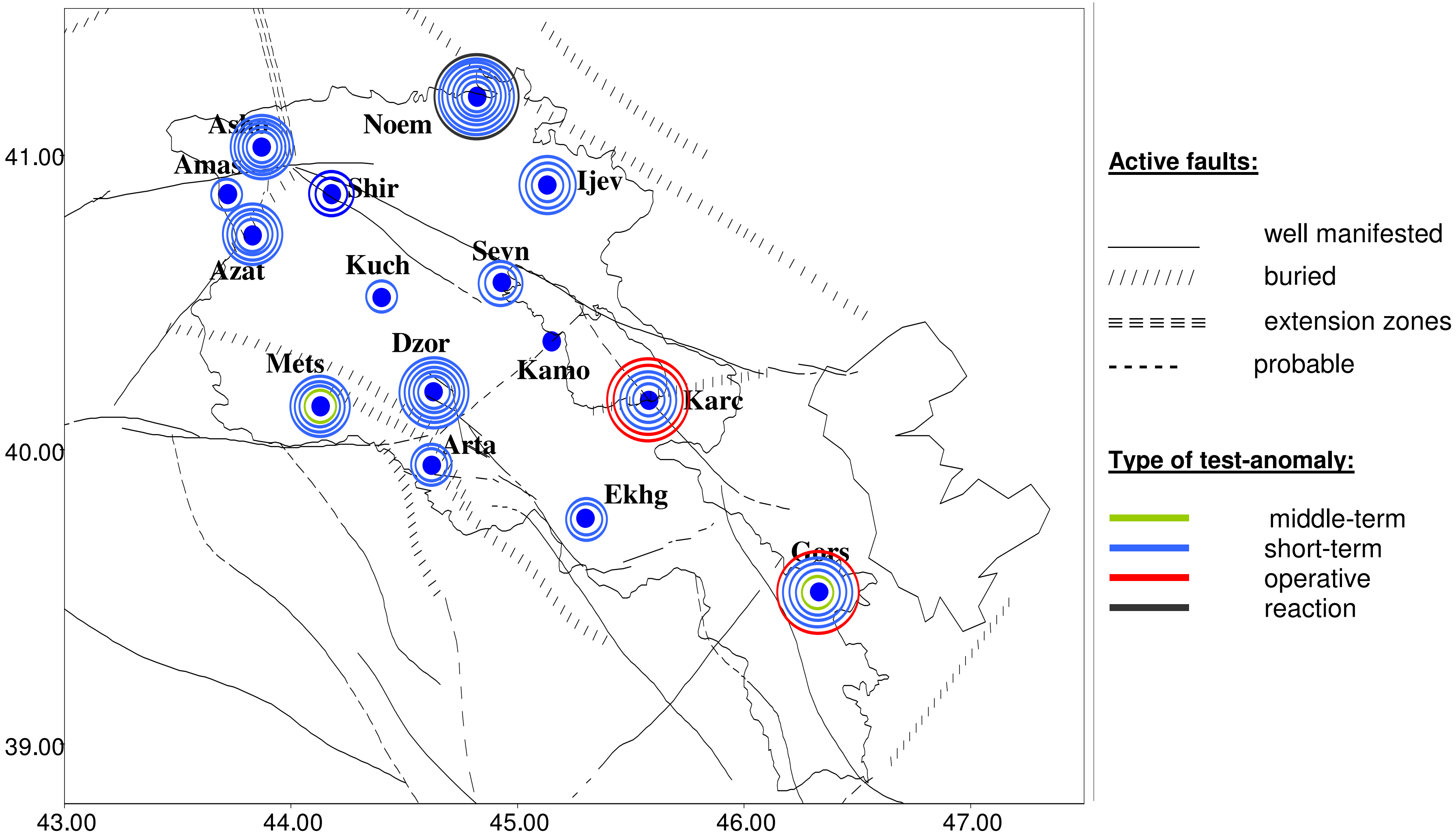

Fig. 5. An example of sensitivity maps (15 maps overall): sensitivity of HGD-monitoring stations in the territory of Armenia during the preparation and realization of earthquakes.

3. **The quantity of precursors and the forms of their display are increased at the last stage of the seismic event preparation (fig. 8, tables 2, 3).**

The late short-term precursors (the time of display of precursor ΔT, that is a time interval between the occurrence of a precursor and the seismic event, - more than 3 days and less than 3 months) in the variations of 14 investigated parameters from 15 (except for the flow) are showed. They reflected the preparation of 17 tested earthquakes out of 18. More than half of 656 precursority anomalies and 167 test-anomalies make the late short-term precursors, and the forms of their display are diversified and cover almost all forms of the anomal variations. It is obvious, that at the last stage of the preparation of seismic events the quantity of precursors, anomal parameters and forms of display of precursority anomalies are increased.

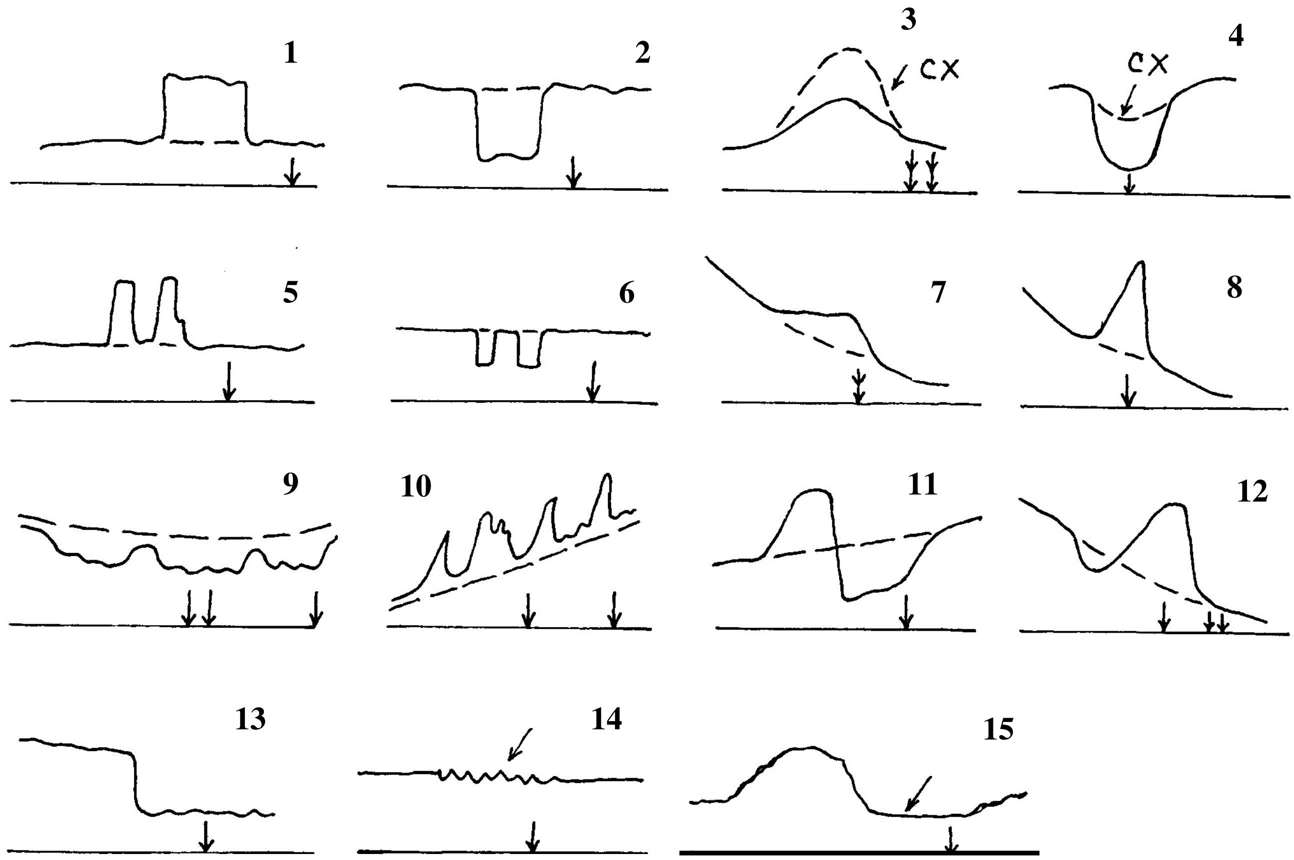

Fig. 8. The basic forms of display of the variations of underground waters level at the NSSP stations: 1 and 2 - single local anomalies; 3 and 4 - infringements of the seasonal course; 5 and 6 - double local anomalies; 7 and 8 - single positive anomalies at the background of underground waters level falling; 9 and 10 - series of negative and positive anomalies; 11 and 12 - sign-variable anomalies; 13 – step-form anomaly; non-amplitude anomalies as an increase (14) and a full loss (15) of background dispersion. The vertical arrows mark the moments of earthquakes.

Table 2

N	Type of precursors	General quantity of anomalies	Quantity of test-anomalies	P_{min}	P_{max}	P_{av}
1	Long-term	0	0	---	---	---
2	Middle-term	7	5	1/2	1/1	0.80
3	Short-term, including:	562	150	1/22	1/1	0.38
	- HGD	142	43	1/15	1/1	0.51
	- Geochemical (regional network):	140	28	1/22	1/1	0.29
	- Geochemical (READINESS netw.):	60	11	1/12	1/1	0.30
	- Subsoil Radon	128	31	1/13	1/1	0.40
	- INP method	46	20	1/8	1/1	0.40
	- Geomagnetic	15	5	1/5	1/2	0.37
	- ULRW (ionospheric)	19	10	1/5	3/5	0.44
	- Fishes activity	5	1	2/5	2/5	0.40
	- Atmospheric pressure	7	1	2/7	2/7	0.29
4	Operative	87	12	1/15	1/1	0.25
	TOTAL	656	167	1/22	1/1	0.48

Table 3

N	Method (parameter)	Regional earthquakes M≥6.0		Local earthquakes M≥3.7		P_{av} for all earth-quakes
		Quantity of tests	P_{av}	Quantity of tests	P_{av}	
1	HGD	33	0.52	15	0.47	0.50
2	Geochemical (READINESS network):	10	0.27	2	0.29	0.27
	- flow of water	3	0.17	---	---	0.17
	- temperature	2	0.67	---	---	0.67
	- conductivity	2	0.33	2	0.29	0.31
	- Radon	2	0.10	---	---	0.10
	- pH	1	0.08	---	---	0.08
3	Geochemical (regional network):	20	0.31	8	0.27	0.30
	- pH	3	0.26	1	0.33	0.28
	- HCO_3	2	0.27	2	0.35	0.31
	- Cl	2	0.23	1	0.25	0.24
	- He	13	0.48	4	0.15	0.39
4	Subsoil Radon	21	0.40	12	0.35	0.38
5	INP method	10	0.30	11	0.47	0.39
6	Geomagnetic	7	0.45	2	0.50	0.46
7	ULRW (ionospheric)	10	0.43	2	0.32	0.41
8	Fishes activity	---	---	2	0.40	0.40
9	Atmospheric pressure	1	0.29	---	---	0.29

4. **The sequence of earthquake preparation stages and the development of rock destruction process are reflected in the anomalies of different orders available, which are superimposed on each other with the approach of the moment of the earthquake's main fault formation (fig. 9 -11).**

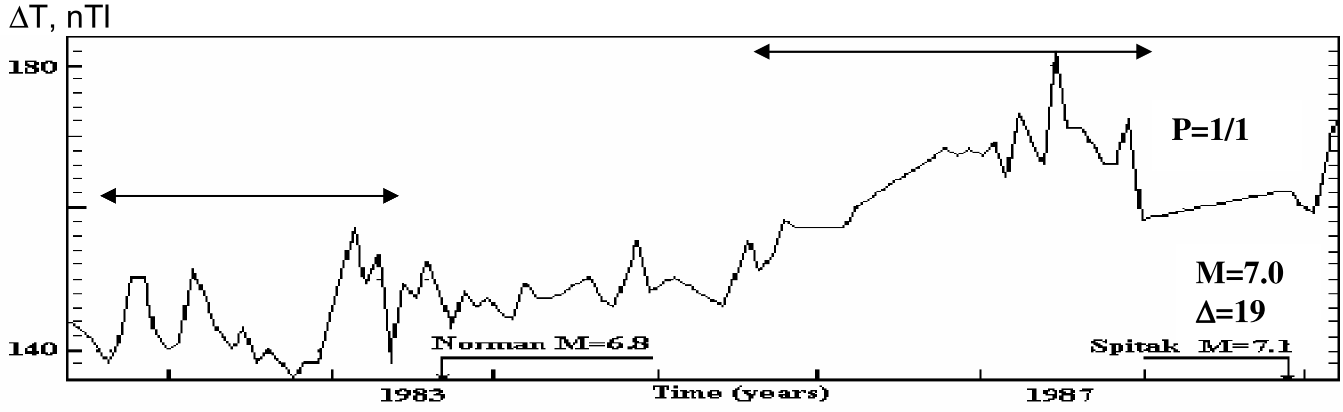

Fig. 9.Variations of a synchronous difference of intensity ΔT of geomagnetic field at the Stepanavan station (in relation to the Jermuk station) during the preparation of Narman (Turkey, 30.10.1983, M=6.8) and Spitak (Armenia, 07.12.1988, M=7.0) earthquakes.

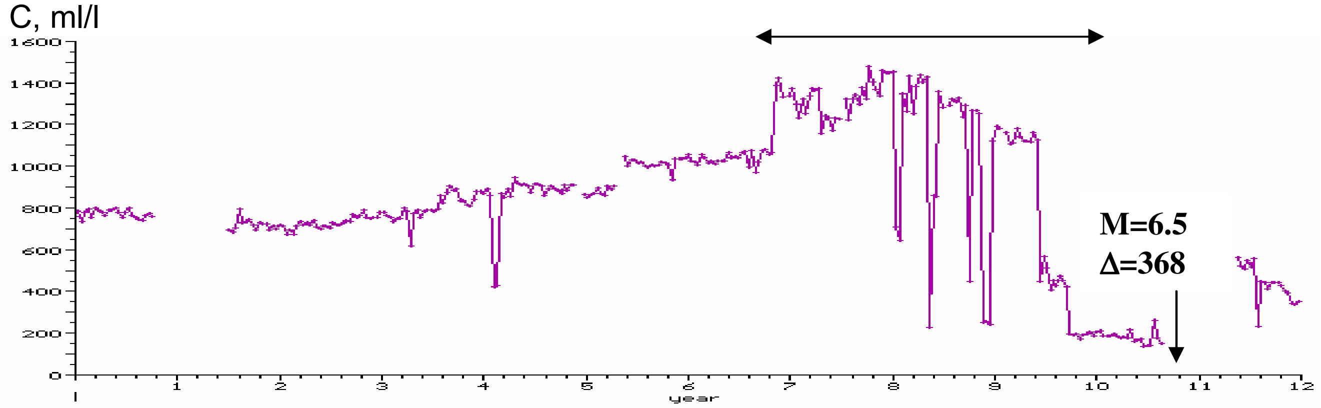

Fig.10 Variations of helium concentration at the Karchakhbyur station. Baku earthquake (Azerbaijan, 25.11.2000, M=6.5).

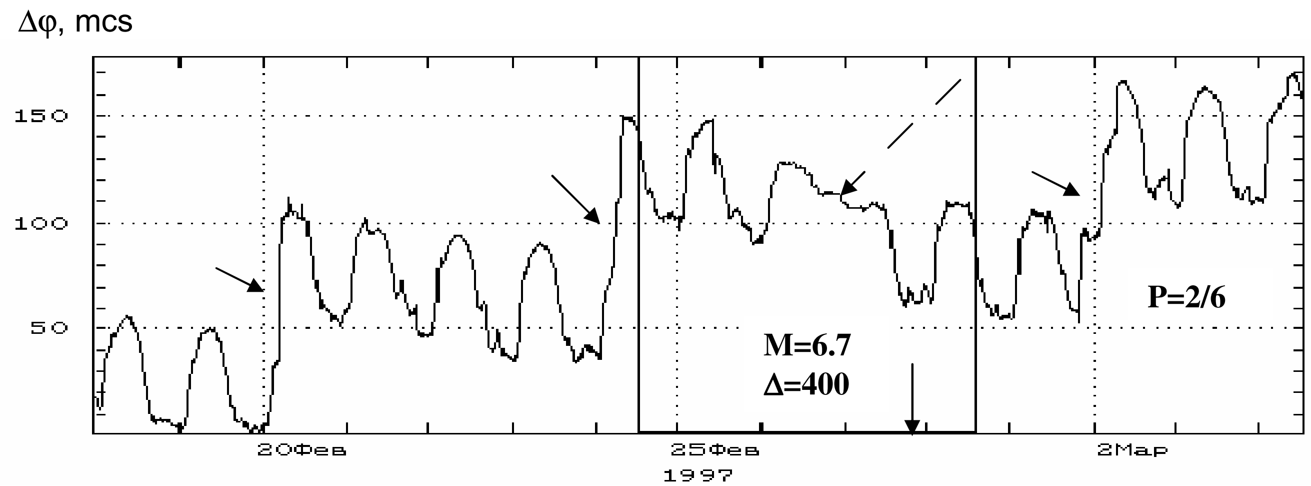

Fig. 11. The diagram of the difference of phases Δφ for the indignant ionosphere on line Reunyon-Yerevan. Ardebil earthquake (Iran, 28.02.97, M=6.7).

5. The forms of precursory occurrences are rather diverse (fig. 12 - 15):

5a. The middle-term precursors (ΔT more than 1 year) have the form of multi-monthly trend or multi-monthly sharp infringement of the seasonal trend (fig. 12);

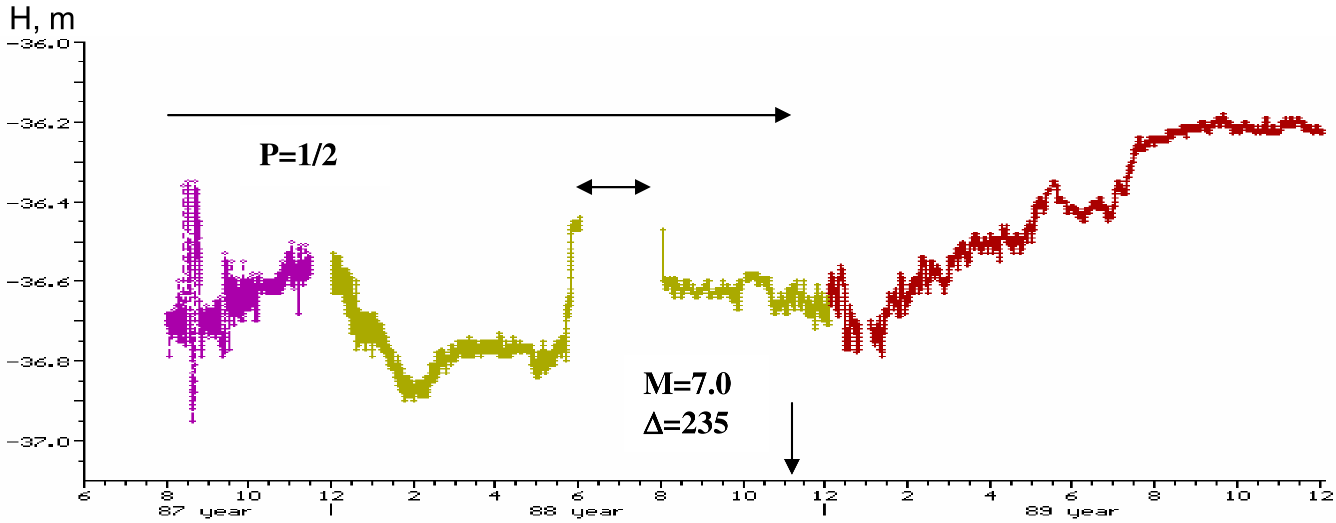

Fig. 12. Variations of underground waters level at the Goris station. Spitak earthquake.

5b. The short-term precursors (ΔT - more than 3 days and less than 1 year) have more often the form of short (from several weeks up to several months) infringements of the seasonal trend, positive or negative smooth anomalies or series of anomalies, steps, decrease or increase of a background dispersion (fig. 13);

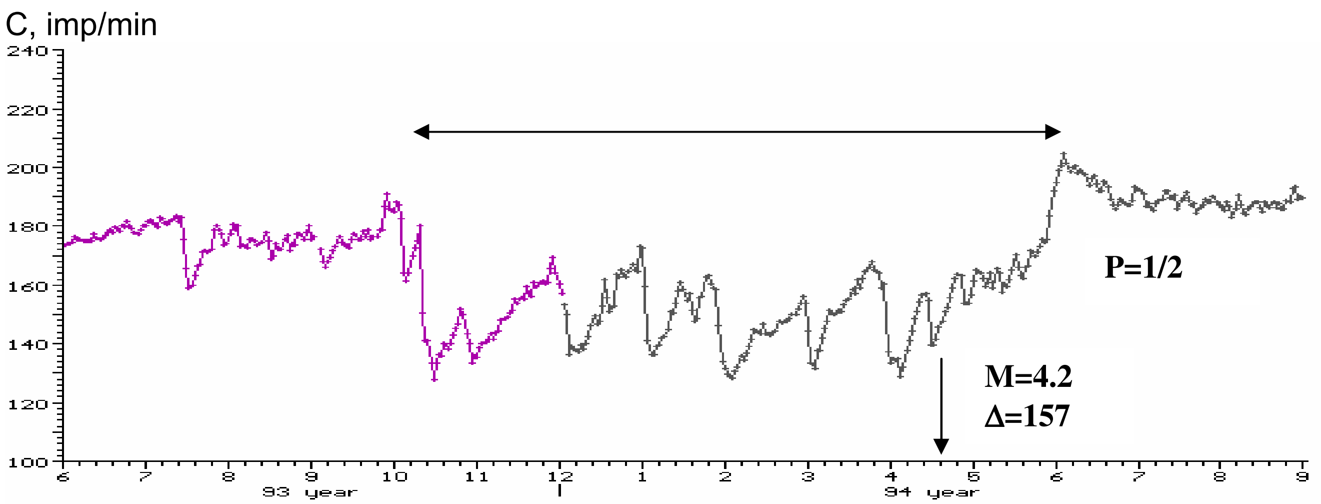

Fig. 13. Variations of subsoil Radon contents at the Ekhegnadzor station. Bavra earthquake (Armenia, 18.05.1994, M=4.2).

5c. The operative precursors (ΔT - 3 days and less) have usually the form of spasmodic single or sign-variable pulses from several hours up to 1-2 days (fig. 14, 15).

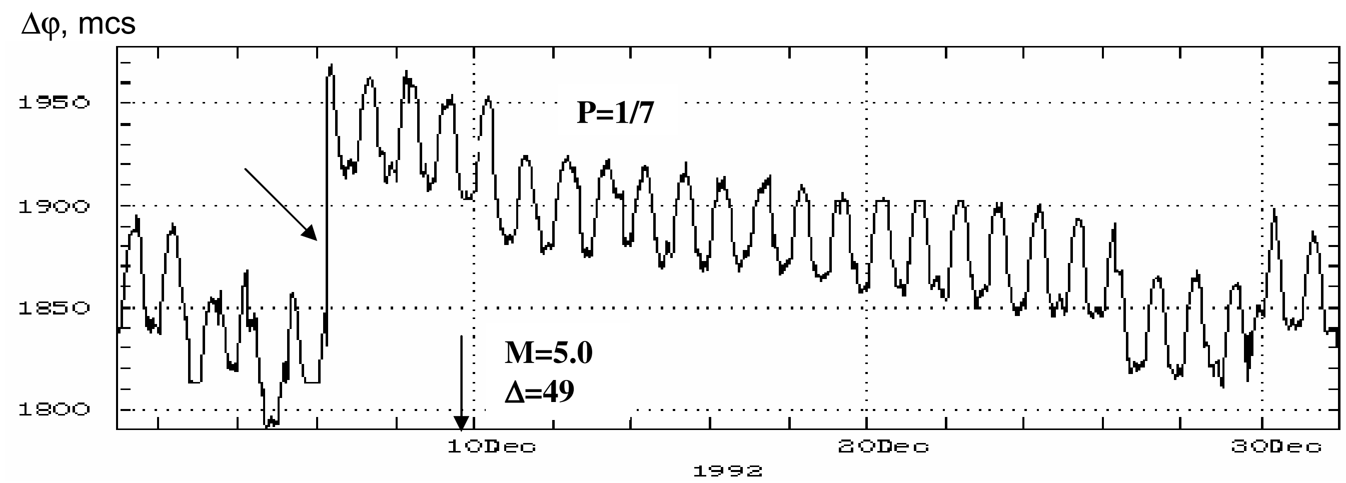

Fig. 14. Variations of the difference of phases on the Reunyon-Yerevan line (at the Davidashen station). Martuni earthquake (Armenia, 10.12.1992, M=5.0).

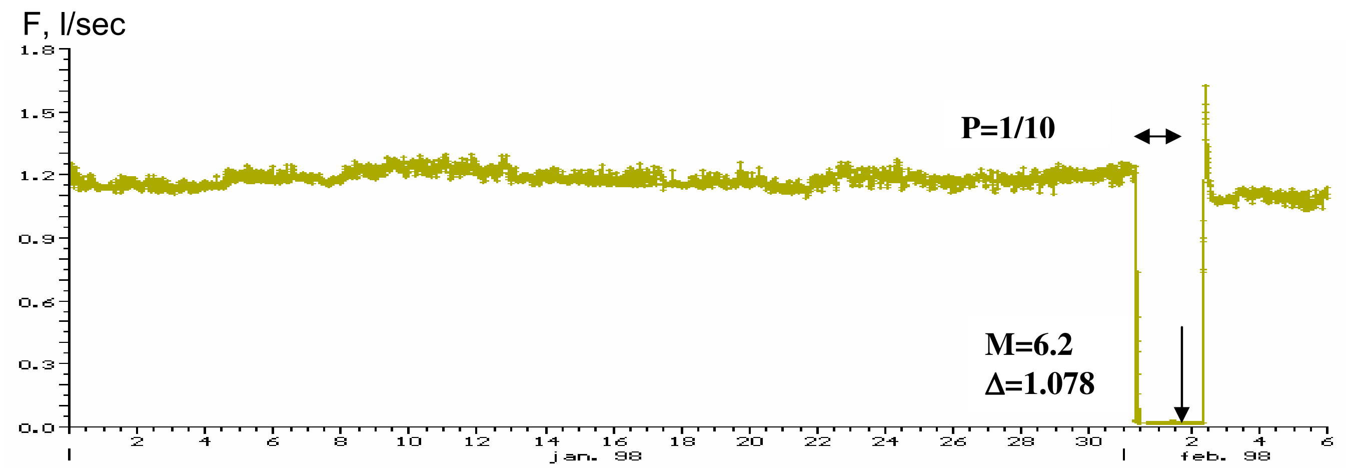

Fig. 15. Variations of mineral waters flow in the Akhurik borehole. Bolvadin earthquake (Turkey, 03.02.2002, M=6.2).

6. The dependence of the precursors distribution areas on magnitude of earthquake (fig. 16, 17).

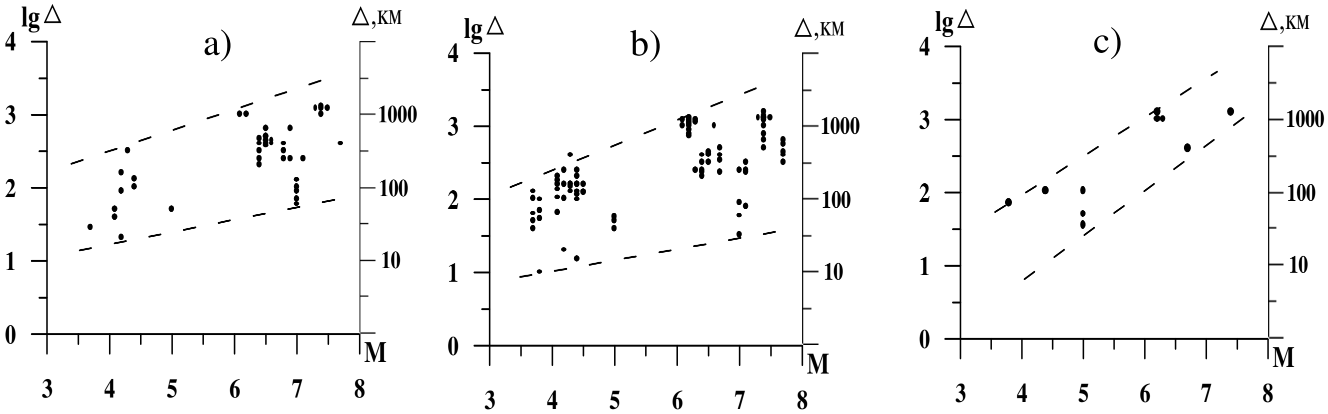

Fig. 16. The dependence of the precursors distribution areas on M: a - early short-term, b - late short-term, c - operative precursors.

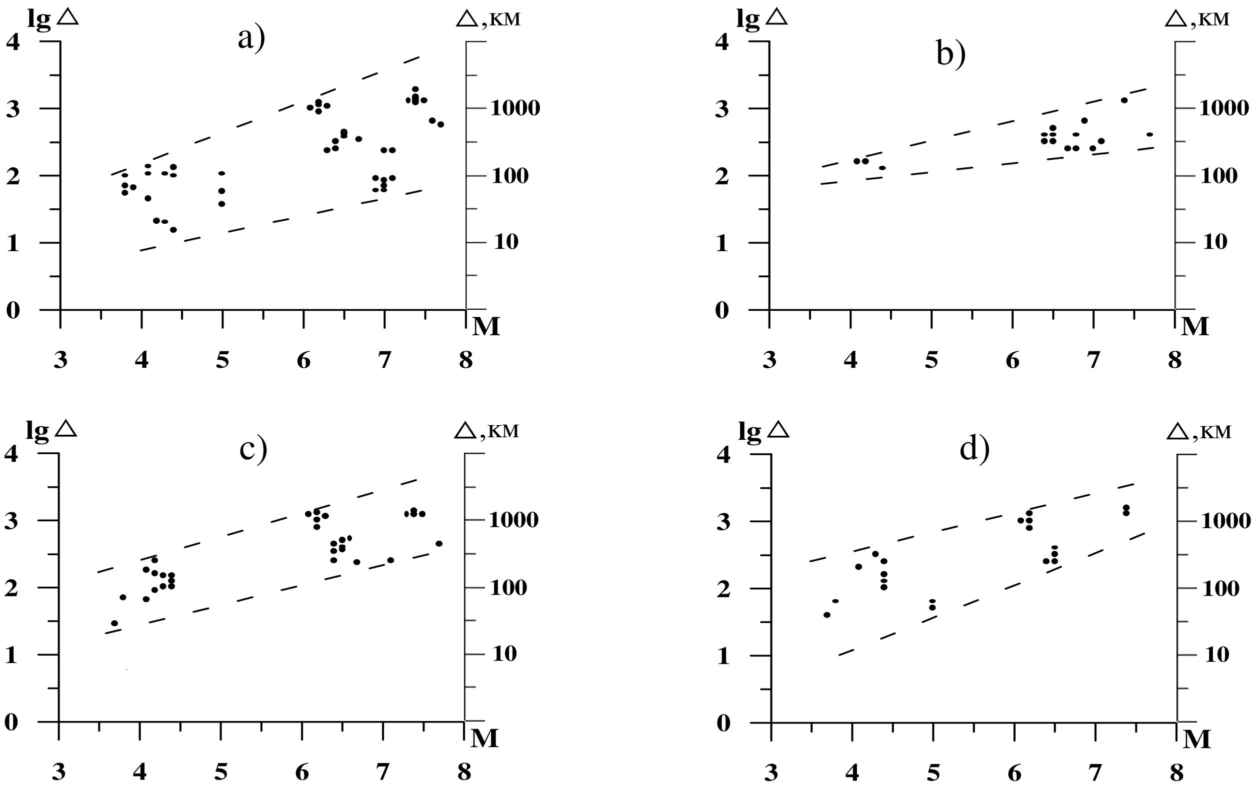

Fig. 17. The dependence of the precursors distribution areas on M: a - underground waters level, b - helium, c - subsoil radon, d - irreversibility of non-stationary processes.

The areas of distribution of some precursority types are shown in fig.16, and in fig. 17 are the areas of distribution of some precursority parameters (methods), observed on the territory of Armenia. The areas of different types and parameters (methods) are similar: they are the zones limited to straight lines like *y=kx+b.* The distance of precursors display is directly proportional with the magnitude of the earthquake.

7. The dependence of the precursor amplitude on magnitude of earthquake and on epicentral distance (fig. 18).

The dependence of *A* on *M*/lgΔ with the use of all HGD precursors is shown as an example on fig. 18a. Similar figures reflecting the absence of the dependence of *A* on *M*, on Δ and on *M*/lgΔ, are characteristic for the other four parameters, too. For the exception of the influence of different geological conditions of the positions of observation sites (the neutralization of site- effects) on the investigated regularity, we have tried to receive the amplitude dependences for each station separately in five investigated parameters. Certain dependences of *A* on *M*/lgΔ have been received only for eight observation sites and for three parameters (fig. 18 b, c).

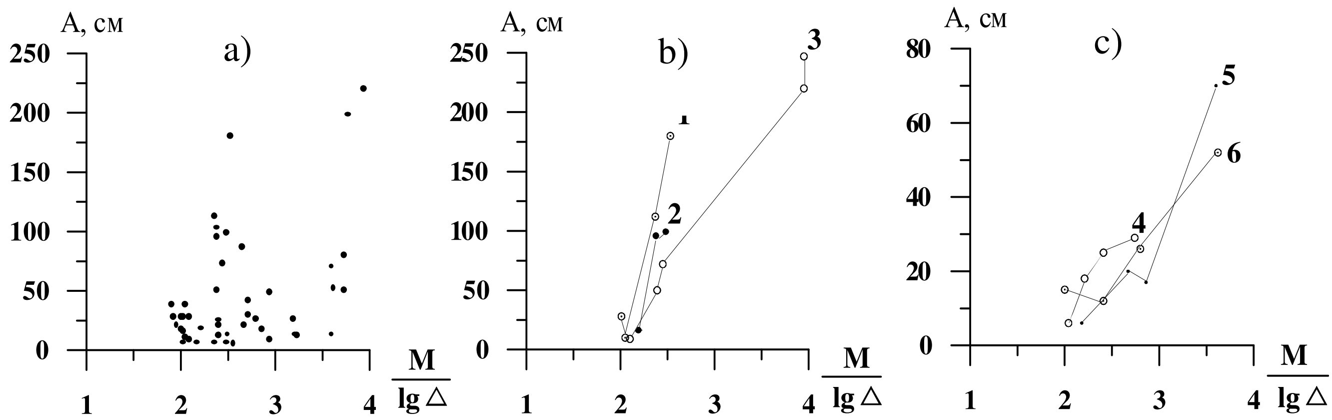

Fig.18. The dependence of the HGD precursor's amplitude A on M (adjusted for epicentral distance Δ) for all HGD precursors (a) and for separate HGD stations (b, c):
1 - Karchakhbyur, 2 - Ijevan, 3 - Noyemberyan, 4 - Ashotsk, 5 - Dzorakhbyur, 6 - Metsamor.

The amplitude of anomalies elaborated for these stations, grows with the increase of *M*/lgΔ. The successful results gained practically only on variations of the underground waters level are probably explained by the fact, that the changes of the HGD-field is a direct deformometer, reflecting the changes of intense-deformed conditions of the earth's crust. The direct dependence of an amplitude of precursority anomalies on earthquake's magnitude at certain stations may be explained by high sensitivity of these observation sites towards the processes of the preparation of seismic events, which reflects the high activity of those parts of active faults, within the range of which these monitoring sites are located.

Conclusion

It is desirable further:

1. to continue the testing of the strong regional and perceptible local seismic events and, after the careful check and the analysis of data, to add the Catalogue of earthquakes precursors by the tests of the occurrence of future seismic events;

2. to assess the reliability of precursors not only on monoparameter observations but in their complexity as well, using the formulae of full probability and the Bayes’ formula, or the theory of recognition of images.

References

1. Petrosyan H.M. et al. (1999) Testing of strong and perceptible earthquakes for current seismic hazard assessment in the territory of Armenia. Gyumri, pp. 238-244 (in Russian).

2. Petrosyan H.M. (2004) Testing of seismic events in the territory of Armenia and adjacent countries for current seismic hazard assessment. The thesis of Doctor of Geology. Yerevan, 181 p. (in Russian).

3. Petrosyan H. (2004) Testing of Izmit large earthquake in the territory of Armenia. Proceedings of 5-th International Symposium on Eastern Mediterranean Geology. Thessaloniki, Greece, 14 to 20 April 2004, pp. 635-638.

4. Sidorin A.Ya. The dependence of the times of occurrence of earthquakes’ precursors on the epicentral distance. DAN SSSR, 1979, vol.245, N4, pp.825-828 (in Russian).

5. Sobolev G.A. The principles of the prediction of earthquakes. M., Nauka, 1993, 313 p. (in Russian).

6. Zubkov S.I. The times of occurrence of earthquakes precursors. Izv. AN SSSR. The Physics of the Earth. 1987, vol.5, pp. 87-91 (in Russian).