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CORRELATION PROPERTIES OF WEAK SEISMICITY AT BISHKEK GEODYNAMIC TEST SITE IN RELEVANCE TO ACTIVE MONITORING PROBLEM

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The work is devoted to examination of the possibility of local seismicity variation due to electric impacts that have been used sometimes for deep sounding of terrestrial crust at Bishkek geodynamic test site. It has been demonstrated with the use of some approaches to data treatment that the electric pulses cause increment of microseismicity. This is to facilitate overstress relaxation in geological medium. Comparative consideration of electric impacts produced by MHD-generators and that generated by usual source is important to reveal the mechanisms of electric pulses influence over inelastic straining processes in heterogeneous geophysical geological medium (terrestrial crust). Change in the rate of such processes manifests itself as a variation of weak seismicity. Attention is paid that the activation typically occurs with some days lag after power electric impacts.

Introduction. The aim of the represented work is to discuss the possible microseismicity effect of power electric current pulses induced in the terrestrial crust by the same source (ESG-electrical soundings generator) that has been applied for electromagnetic monitoring at Bishkek geodynamic test site [1]. Impulsive geophysical MHD Generator was used previously as energy source for electrical soundings. Some papers, for instance [2], issued the challenge can physical factors accompanying MHD Generators firing runs influence on local weak seismicity or not. It was performed that action of powerful electric pulses during the launch of the generator stimulates the alteration of regional seismic behavior. Such electric impact seems to promote the release of seismic energy stored in seismic generating zones by growth of flow of low-magnitude seismic events of 8–13 energetic class K (with the magnitude from 2,2< M_b<5 respectively). Presently electromagnetic monitoring of strained state of rock masses at Bishkek geodynamic test site has been making with the use of sounding square pulses supplied by ESG. The technique of Time- Domain Electromagnetics on the base of powerful electric sourses like ESG which allows to specify electric resistivity of crust has been described in details in [1]. An additional electric soundings are taken place approximately once in 35 days from January 2000 at Bishkek test site. Every additional probe session involves supply of 200 unipolar pulses with duration of 5 or 10 seconds. Both: energy influx and electrochemical transfer turns out to be larger by times than in case when MHD-generators were applied.

Due to the fact that daily energy input to conducting terrestrial medium is comparable with the energy of weak earthquake one can consider sounding pulses as the Energy Impacts (EI) affecting on the crust structures. It will be demonstrated in the given paper that an evident activation of weak seismicity occurs in 5-7 days after action of EGP pulses; the pulses shape and other electric parameters being similar to those for pulses produced by MHD generators. The activation was revealed for seismic events of energetic classes K within range 6,5–10, meanwhile events of 7,5–8,5 classes give the main contribution into the increment of seismic activity. According to physical and geological conceptions on induced seismicity reviewed in [3], this activation can promote the tectonic overstress relaxation and, hence, it is to reduce the probability of strong earthquake occurrence.

Besides sounding electric pulses of EGP various irregular factors such as remote earthquakes, explosions, lunar-solar tides, ionospheric disturbances etc. also can trigger seismicity alterations. In particular it has been proved recently that deep-focus earthquakes in Hindukush influence considerably the seismicity of North Tien-Shan [1]. We succeeded in finding correlation (on the background of between of these factors) weak seismicity change in the region of Bishkek test site and electromagnetic impacts with the help of statistical data manipulation based on method of observational periods superposition. Moreover, several cases of unequivocal, caused by EI, response of seismic activity were recorded, the peak of activation essentially exceeding dispersion.

Technique and obtained results. The catalogue of seismic events for 1996–2003 based on the data of KNET seismic network has been used for analysis of seismicity alteration. The location of all recorded seismic events occurring in experiment period (2000–2002) is shown on Fig. 1. The data analysis was started by construction of earthquake repeatability plot [4] for entire observation period (Fig. 2) as well as for each year separately. Because of sensitivity of seismic network KNET the seismic events of energy class K more than 5 have been used as data of reference. Ramp-down intervals of repeatability plots giving the most confidence statistics of seismicity have been specified.

The samplings of events of magnitudes 1,6 < Mb < 3,6, i.e. of energy class K: 6,5<K<10,5, appear to be representative. Angular coefficient of annual repeatability plot appears to vary in limits from 0,58 to 0,7; the trend during some last years decreasing. This corresponds to the enhanced percentage of events of 8–10 class during years of experiment on crust probing by power electric impacts. As a supplementary evidence for this fact Fig.3 gives the plot of relative part of weak seismic events occurring within 35 days period versus period number (X axis is equivalent to time due to windows periodicity). One can see a tendency of events part decrease for 6,5–7,5 classes and increase of events ratio for 7,5–8,5 classes with the beginning of the experiment at Bishkek test site.

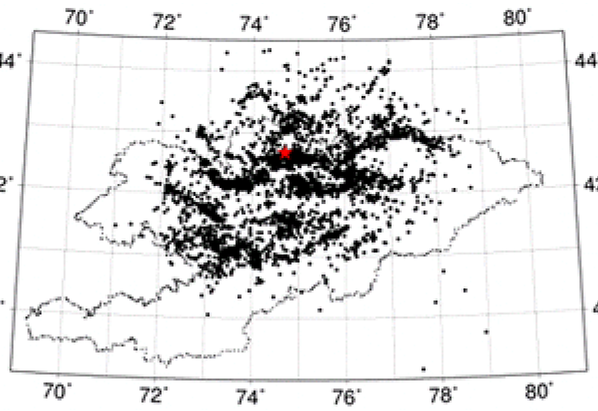

Fig. 1 Seismicity in 2000–2002 and the position of test site for electromagnetic soundings and (formerly) MHD generator runs.

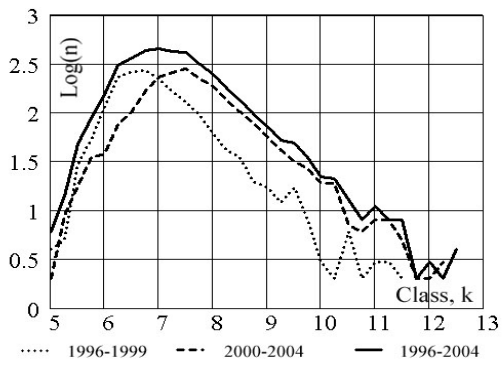

Fig. 2. The plot of earthquakes repeatability by the data of network KNET.

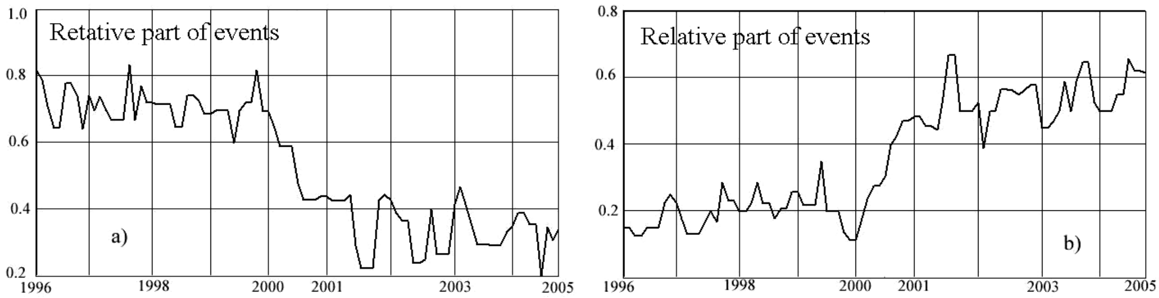

Fig. 3 Change of the part of weak earthquakes versus time starting from 1996:
a – for the events of 7,5–8,5 classes and b – for the events of 6,5–7,5 classes.

According to [2], stimulated effect of MHD-Generators runs is to become apparent most-distinctly during the first 5–7 days after impact in near-surface layer at a depth till 5 kilometers. Taking this into account as well as the periodicity of EI (once in 35 days) we consider for further analysis the distribution of daily earthquakes amount and daily released seismic energy during the periods (windows) $\{t_j\text{-}17,\ t_j\text{+}17\}$, where t_j, j =1…35 denotes the time of scheduled action. Preliminary we excluded the explosions and all events with energy classes below 6,5 and above 10. The time of power action (energy impact, EI) corresponds to 18-th day. The seismicity during some days before and after action has been compared. Investigation of earthquakes amount distribution in each window has showed that the response of the medium to EI has an ambiguous character. In most windows (56 %) seismicity increases on 5-7 days after EI, but in some cases (40% of all windows) it descends. No reaction after EI was revealed in a few windows. It should be remarked that in very narrow range of energy class (7,5< K< 8,5) 72% of windows give positive reaction due to EI on 5–7 days after EI. But the difference between total numbers of earthquakes occurring in 17-days half –periods before and after EI correspondingly is not so contrasting. To distinguish the effects of EI on the background of non-regular factors all windows $\{t_j\text{-}17,\ t_j\text{+}17\}$ were superimposed and cumulative distributions of daily seismic events amount were built (Fig. 4) for half-windows before and after EI. Similar cumulative plots were built for 1997–1999 in order to make a comparison.

During the creation of comparative plots each of 35-daily windows for the period of 2000–2002 was associated with the calendar period of 1997–1999, then conditional periods were superimposed like $\{t_j\text{-}17,\ t_j\text{+}17\}$ windows. One can see on Fig.4 that the form of plots for the average daily earthquake amount, homogenized by 35 windows for 2000–2002 (c, d) differs from corresponding plots of 1997–1999. (a, b). Scattering plot of events number 4c, 4d demonstrates temporary increase of seismic activity, taking place with 4–5 days delay after impacts. During lagging period even some decrease of activity is to occur

In relevance to the fact that the activation of weak seismicity takes place on 5–7 day period after EI, it is of interest to compare the space distribution of earthquakes hypocenters for events happened during 7 days after EI with that for events occurred in 7 days interval before EI. For this purpose we draw the map of earthquakes hypocenters for 6,5–10,0 and 7,5–8,5 classes and for the time period of 7 days before and after EI using the KNET 2000–2002 catalogue (Fig. 5). Here we can see that the increment of events amount after EI is accompanied by spatial re-distribution of their hypocenters. In the vicinity of EI source (ESG with exciting dipole) the events, hypocenterc of which are located along regional faults, contribute significantly (or even mainly) the seismic activity response to electric pulses (Fig. 5, sections a, b). The wire of primary, exciting dipole moves up to the edge of closest Alamedin fault, and one of earthed dipole ends is located at fault zone where the resistivity falls off. It is of great importance that the microseismicity at regional Alamedin Fault is retraced to be activated. Hypocenters of EI stimulated events are situated in a zone strongly elongated in latitudinal direction (along the fault). This also may speak (let, in indirect manner) in a favor of possible weak seismicity stimulation by EI.

The distribution of hypocenters of stimulated seismic events by depth is a point of peculiar interest. To compare results with that of [2] we considered (like before) earthquakes of 6,5–10,0 energy class happened during 7 days before and 7 days but located in 4 layers differing by depth. Fig. 5 also shows schematically the distributions of such events hypocenters deepened by 0–5 km, cases (c, d), 5–10 km (e, f), and 10–15 km (g, h). The number of recorded events with deeper hypocenters is not enough to analyze change in their mapping.

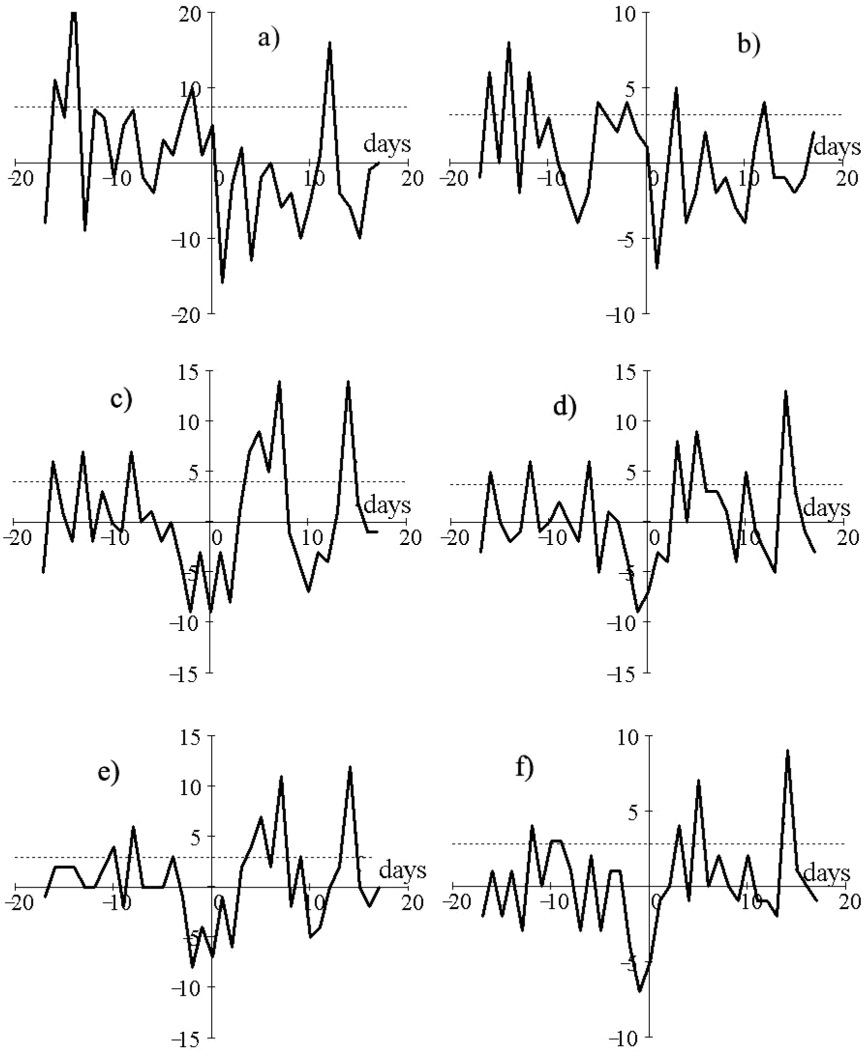

Fig. 4. Declinations from mean value of seismic events amounts: a, b – events of 6,5–10 and 7,5–8,5 Classes correspondingly occurred in 1997–1999 (31 windows before the experiment); c, d – the same distributions but for period 2000–2003 (35 windows during experimental EI); e, f – distributions for the same period as c,d but calculated by 23 from 35 windows,- no windows corresponding to months of major thunderstorm activity are taken into account, everywhere Class interval 6,5–10 is on the left, 7,5–8,5 – on the right. The position of vertical axis is the day of EI. Dotted line – RMS deviation, determined in first 17 days (before EI).

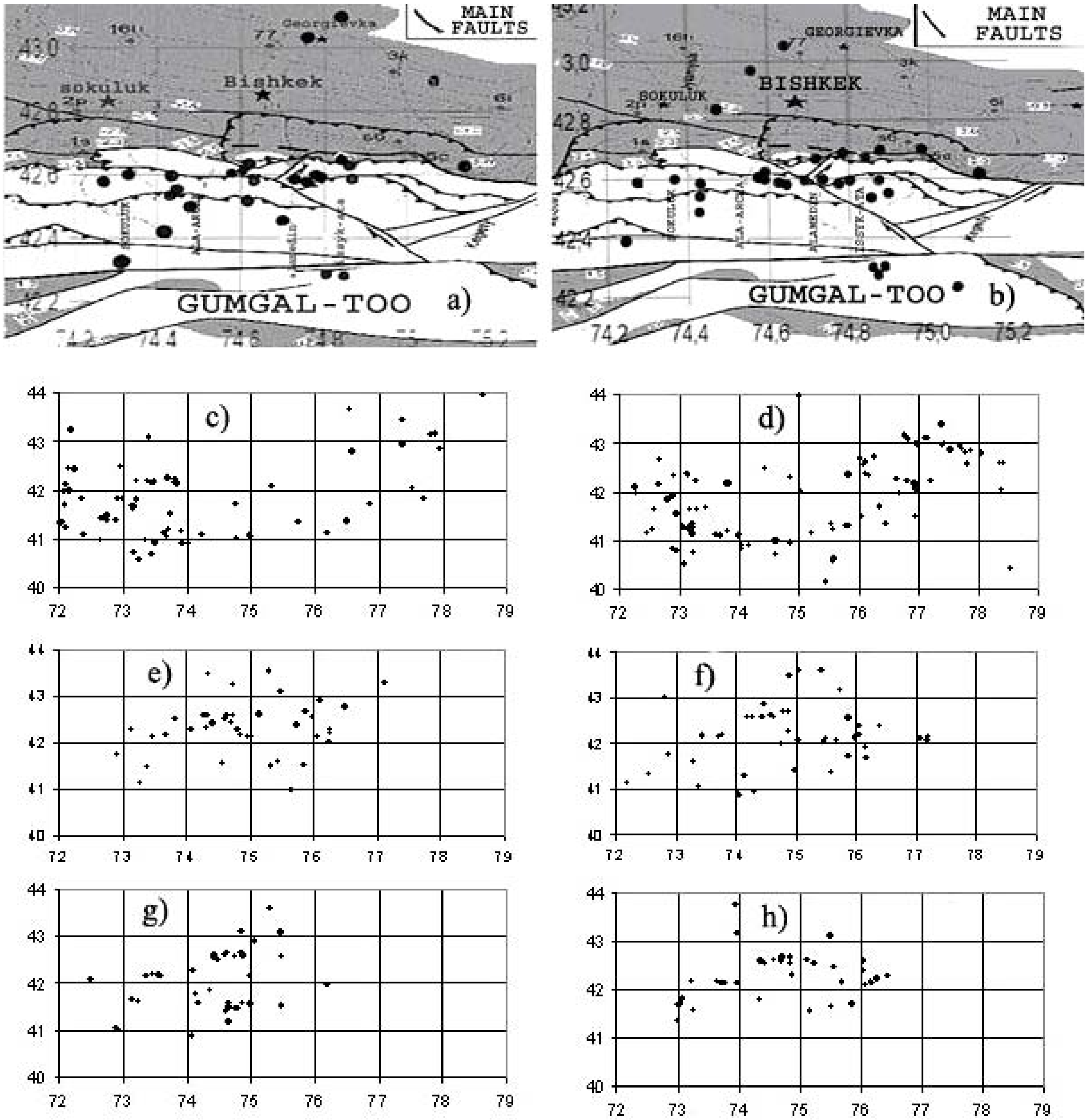

Fig. 5. Areal mapping of seismic events near supplying dipole. Plots a, c, e, g (left column) are for events happened during 7 days intervals before EI, and plots b, d, f, h (right column)- for events in 7 days intervals after EI: a, b – total cumulative distributions, the figure demonstrates the main faults (──) and thrusts (‾▼‾▼‾). Then: areal mapping of seismic events grouped by their hypocenters depths, c, d – in 0–5 km depth enclosing layer, e, f – the same in 5–10 km, g, h – the same in 10–15 km. Coordinates of supplying dipole are 42,8° North, 74,7° East.

It was noted earlier in [2] that the seismic activity mainly at shallow depths (up to 5 km) was triggered when MHD generator launch at Bishkek test site. In contrast to this Fig. 5 demonstrates unexpected result: in the case of ESG supplied pulses the manifestations of triggered effect are the most distinctive in a depth 10–15 km (fig. 5 h) rather than in a shallow layer (fig. 5 d). The location of zone of maximal geological medium sensitivity to energy impacts appears to be correspondent with the horizon where the regional seismic activity at Central Tien Shan reached maximum. Weak and moderate seismic events are to denote this horizon as a site where inelastic straining processes are localized. Subcritical conditions of stressed -strained state of that imbedded rocks may pre-determine the sensitivity of such zone to triggering influence. The responses to energy impacts are to originate at that depth as well as in shallow layer in spite of more vertical remoteness from surface mounted EI source. According to data of seismic tomography the zone of seeming hypocenters attractor (relevant to stimulated activity lock-on) is located just above so-called seismic waveguide (softened layer with reduced values of seismic waves velocities) [5].

Discussion. Integrally the results obtained are consistent with that of works devoted to seismological effects of MHD generators pulses ([2], for instance) and with the concept of inelastic straining rate triggering by electromagnetic fields. This consistency as well as the publications on electromagnetic triggering caused by other energy source (magnetic storms in ionosphere, inducing pulsed terrestrial currents, [6]) may denote that the basic effect is still established. However an explanation of its physical nature is a problem to be solved in the future. The effect of electromagnetic triggering seems to take place as one of several modes depending on conditions of stressed-strained state, electromagnetic source power etc. Let’s outline peculiarities of triggering effect of sounding pulses produced by ESG.

Data processing demonstrated that the effect of ESG electric current pulses are to influence the seismicity during less than 10 days. The manifestation of EI effect is not so apparent as that considered in [2] (the case of MHD generator produced pulse). One can identify the seismic variations observed in first 18 windows (corresponding to minor energy input and electric charge transfer) neither as reliable confirmation of EI effect over seismicity regime neither as disproof of the effect. Probably the amplitude and duration of such impacts (600 A current pulse) is just correspondent with the threshold value to seismicity triggering. Meanwhile the electric current pulses initiated by MHD-generator (I~2 kA) are to exceed the threshold. When the power was doubled due to increase of electric pulses duration (windows 19–35) the effect was distinguished clearly in some 35 days surveys and on the cumulative distribution of seismic events (scattering plots in Fig. 4). The delay of weak seismicity increment after experimental soundings with ESG supplied 600 A pulses is 5–7 days (Fig. 4 c, d). Meanwhile in the case with higher current pulses produced by MHD generator (I~2 kA) the lag of stimulated seismic activity was typically 2–4 days. So the tendency is that the stronger electric impacts applied externally the shorter delay of activation being treated as microseismic response to power action.

Special attention should be paid to the strange cases (in comparison with results [2]) when the drop of seismic activity was recorded after EI. This is unexpected aspect from viewpoint of stimulation concept. But these strange cases are related to the limit of resolution of measuring apparatus as intrinsic feature of all instrumental surveys. Following example may explain this easily. Let EI actually triggered the increment of activity of week events with K<6 (because of negligible overstress and so on) and this was accompanied by the reduction of amount of more energetic events. But in the flow of events recorded such situation looks like negative response to EI since the minor events with K<6 are under resolvability. Thus no contradiction with general statement on activation effect of EI arises.

The presence of unlike responses to EI of the same kind was recorded when the laboratory modeling experiments were performed at Research Station of RAS in Bishkek city. The results obtained during the tests of samples of terrestrial materials on spring rheological machine UDI with additional of electric current impacts are as follows. In a steady mode of sample straining the first EI-pulse entails (after some delay) the growth of Acoustic Emission (AE). Repeated EI as well as EI superimposed on transition straining processes result in short-term AE activation in the most cases; sometimes the opposite responses being observed (Fig. 6).

Besides, the laboratory modeling allowed to reveal following peculiar feature of electric pulses effect over inelastic staining process involving changes in AE activity. At the fixed load the positive response of AE to recurring EI of the same kind reduces from shot to shot or vanishes et all (Fig. 6b). However, after change of strained state (on the next step of load) the increment of AE has been remarked again as a response to the same electric impact. It is of importance that the above peculiarity seems to be very similar with the successiveness of seismicity responses to EI in windows 1–4 (i.e. just in the beginning of experiment), and in windows 19–22 (the start of EI with increased energy of electric pulses).

For the sake of completeness we note that the well known observation [6] of unlike phases of correlation between regional seismicity alteration and magnetic storms are of similar implication as seeming unlike responses to the same kind of electric impact.

Comparison with random process model. Many attempts were made earlier in order to treat the distribution of seismicity as a stochastic process, Poisson process in particular. But it has been found while analyzing the distributions of earthquakes daily amount (using KNET data for the period of 1996–1999) that the observations of weak seismicity match with so-called Poya distribution better than with other known discrete distributions of random quantities (including Poisson distribution). In the considered period values of fiducial probability for actual distribution compliance of earthquake number during the day and for Poya distribution during the moving interval of 300 days turned out to be P > 0,82 by "χ-squared" criterion. Mentioned Poya distribution describes random process with aftereffect. It's fundamentally important for the flow of seismic events for which aftershocks and earthquakes swarms are evident manifestations of aftereffect. Earlier attempts to use more popular discrete Poisson distribution were effective only provided that aftershocks records are deleted from considerable time seismic series before further data processing. One can cancel the restrictions in seismic series modeling as simplest flow of random events (this means the stationary, ordinary flow without aftereffect) by using Poya distribution rather than Poisson one. This allows to consider Poya distribution as a convenient tool for the analysis of statistical confidence of seismicity changes, in particular due to power effects (energy impacts, EI). Density distribution function for Poya law has the form as follows:

$$P_m = \left(\frac{t}{1+at}\right)^m \frac{1(1+a)....[1+(m-1)a]}{m!} P_0, \quad (1)$$

where P_m – probability of m events happened in the time unit, $P_0=(1+at)^{-1/a}$ – probability of events absence, t = M; a = (D/M – 1)/M – parameters of law distribution connected with the average of distribution M and dispersion D.

During the consideration of daily distributions for the earthquakes numbers for the period of 35 days as possible implementations of (1) distribution, we can evaluate probability of their occurrence. The estimate of probability of spontaneous spike but with the same pulse shape as shown on Fig. 7 after EI (arrow) is of the most interest. Probability of such a random spike that takes place during i, i+1, … i+k days and represents the consequence $\{m_i, m_{i+1}, \ldots, m_{i+k}\}$ of corresponding events numbers can be determined as the following composition: $P_{ran} = P(m_i)\, P(m_{i+1}) \ldots P(m_{i+k})$ (Here we imply that m exceeds statistical expectation M for some i at least).

Using abovementioned formula one can calculate, for example, that for the window #24 (Fig. 7) P_{ran} probability is less than 0,02%. But for distributions, corresponding to the less contrasting responses to EI, this probability varies from units to tens percents, meanwhile the typical value of probability of statistical expectation occurrence is within the range $P_M \approx P_1 \sim 0{,}25 \div 0{,}35$. Since far as the value of statistical expectation M is close to unity for the majority windows, the normalization $z_{ran} = P_{ran} / (P_1)^k$ turns out to be informative. In case of windows with distinct spikes of activity (Fig. 7) $z_{ran,23} \sim 0{,}011$. For less contrasting responses the correspondent value of z_{ran} lies within the range 0,07–0,2. But for bursts that are observed sometimes before EI (Fig. 4) and have been characterized as spontaneous activation, it doesn't fall less than 0,15. Taking into consideration all aforesaid we can give the positive reply to the question about the presence of certain correlation between week seismicity and ESG supplied electric sounding pulses at Bishkek geodynamic test site.

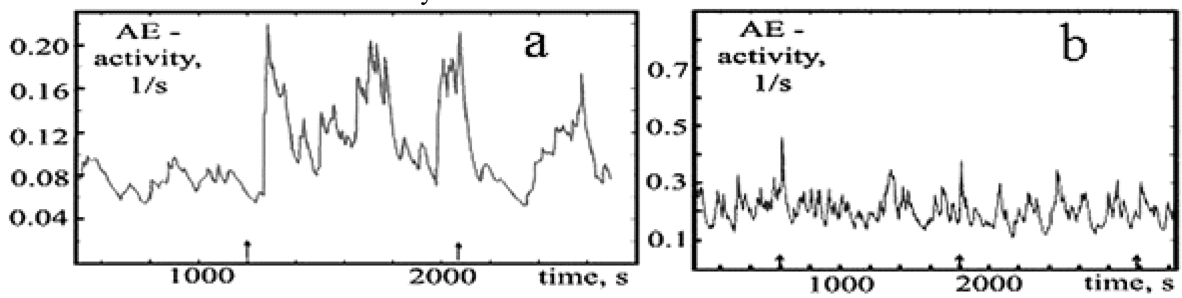

Fig. 6. Some results of laboratory modeling on specimens:
a – the presence of unlike responses of AE of quartzite specimen to same type EI (single-shot pulse of capacitor discharger; the voltage amplitude being 800 V); b – degradation of AE response of loaded halite specimen while repeated EI. Each impact noted by arrow is a series of 10 discharges of 900 V Voltage, and 0,5 мs duration

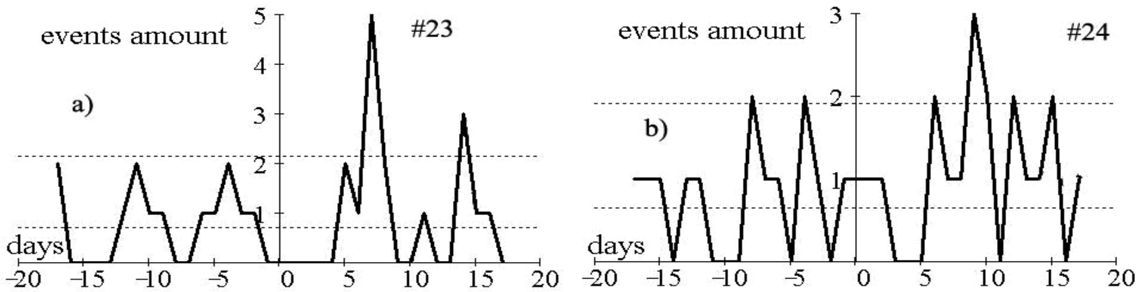

Fig. 7. An example of daily number events distribution in a window demonstrating the clear responses (activations) to EI. The arrow indicates EI day. Dotted line – RMS deviation, determined in first 17 days and its triple value: a – explicit response to EI clearly distinguished after pre-history; b – example to show the difference between response to external action (days 23–29) and spontaneous spike exceeding RMS value (9–13 days).

Resume. The main result of the work is the demonstration of that one can reveal correlations between changes in weak seismicity and electromagnetic impacts using technique of observation periods superposition. The results obtained indicate the existence of seismo-electrical modes of faulting, the explanation of which requires to exit outside pure mechanical paradigm for seismic processes. The prolongation of experiment or new experimental soundings like already performed are represented to give the base information for grounds and development of new models being more adequate for earthquakes predictions and mitigation of seismic hazard.

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