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Identification of the possible criteria for prognostication of earthquakes on the ground of the data of the observed deformographic processes and triggered micro-earthquakes

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Abstract

Here we consider some latent process of deformation caused by the forces in the Earth's crust or/and cosmic, latent as well, ones. These processes represent a certain regularities in the nature where, as we know, all physical events are caused by other events and in their turn produce some other ones. To such events belong naturally crust deformations. These events are in organic cause-effect relation with earthquakes and cosmic tidal processes. Many signs and criteria are related to the period of preparation of earthquakes, and it is necessary to attempt to predict to some extend their (earthquakes') parameters (time, place, strength…) on this ground.

The Earth is characterized by multi-geophysical processes. The problems of studying their nature and their control represent some of the main subjects of scientific investigation. There are some processes which are easy to identify. To their class belong, among others, strong earthquakes. However, it is impossible to control them. The only possible thing to do here is taking some preventive measures, such as, for instance, are reinforcement of buildings and constructions, in order to avoid or alleviate the catastrophic consequences. Unfortunately this will not give us absolute guarantee, for there are still many factors of which we have very little knowledge.

There are also processes which are weakly manifested though they accompany and promote the development of strong processes. To such processes belong: change of inclination of the Earth's surface, deformation in the Earth's crust, triggered earthquakes and other. The present article is dedicated to the study of such processes, namely, of the connection of the nature of earthquakes and the structure of the Earth's crust.

An earthquake is perhaps the most destructive phenomenon for human society (either for human lives or material objects) among all the natural ones that threaten it. Its hardness increases due to the unexpectedness of its occurrence. However it is impossible yet to calculate even approximately where and when it will occur and of what strength it will be. These questions are of a particularly importance for seismoactive regions, such as are the Caucasus and Georgia, as its integral part. It is well known, what disaster brought the Spitak Earthquake of M=6.9, 1988 (Armenia), Racha-Ossetian, M=7.1, 1991, Baris Akho, M=6,3, 2003 (Georgia).

The picture given in Fig. 1 gives some idea of seismic activity of the Caucasus.

Considering what was said above, it is not necessary to look for the additional arguments for stressing the urgent necessity for the Caucasus (Georgia) to carry out the works which

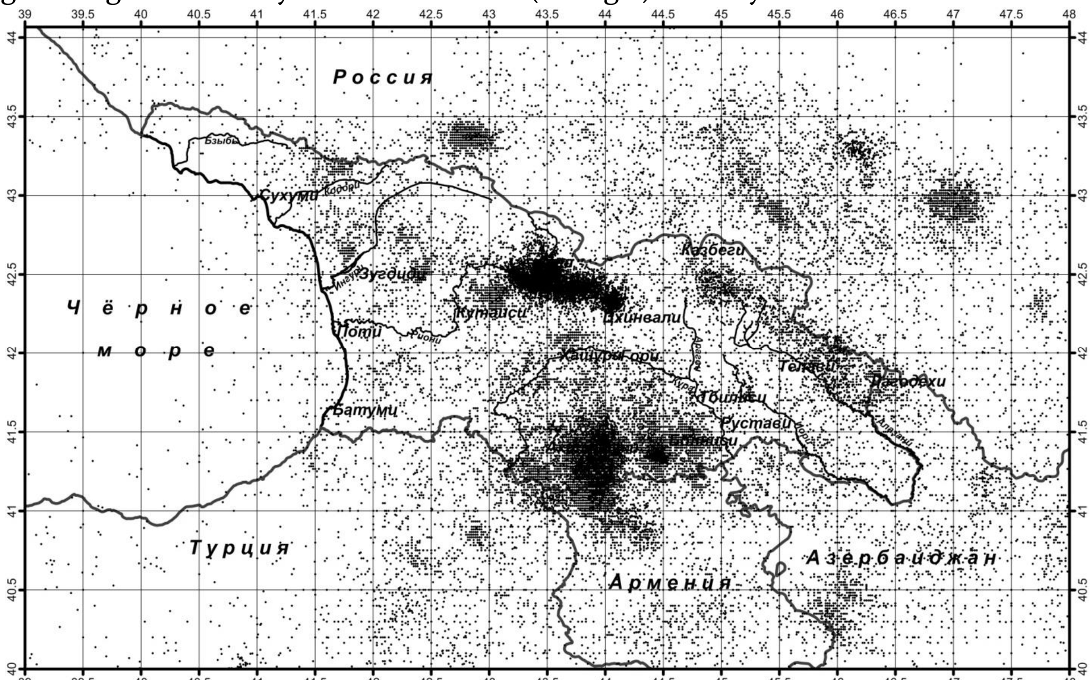


Fig. 1 The scheme of distribution of the instrumentally recorded earthquakes which took place in Georgia and its acjacent territories in 1900-2008.

could help us to advance on our way to the achievement of the above stated goal – prediction of the possible earthquake's place, time and magnitude. In Fig. 2 a seismic zoning of the territory in relation to intensive earthquakes (M>3.5) is presented. And we have all the grounds to expect the similar picture of seismic activity in the future.

So, any attempt to any scope in this direction is undoubtedly justified. Particularly when there are parametric data of absolutely new physical essence connected with earthquake processes, recording them from the moment of their formation and to the end of the event.

It is acknowledged that tiltometeric and extenzometric (deformographyc) measurements of the Earth's crust as well as these of micro-earthquakes provoked by dynamic triggering represent at present stage one of the most important and perspective means for the study of tidal processes in the Earth's crust, mechanisms of tectonic deformation and seismicity.

The study of the tidal processes in the Earth's crust in Tbilisi has started since 1960 by gravimetric observation of the tidal variations of gravitation force.

From 1963 an underground observatory of 102 m length with horizontal tunnel at 60 m depth from the surface with 0.005^0C variation of temperature was founded, where the following scientific-research equipment was installed:

1. Askania Werker, two fixed gravimetric recorders of tidal variations of gravitation force of Gal $.10^{-7}$/mm sensitiveness.

2. Deformation recording ternary linear quartz deformograph:

a) Base 42 m, horizontal, azimuth N 66,5˚, E sensitiveness 0.22 10^{-9}/mm.

b) Base 14.5 m, horizontal, azimuth N 30˚,W, sensitiveness 0.7 10^{-9}/mm.

c) Base 6.45 m, vertical, sensitiveness 0.15 10^{-9}/mm.

3. Eight photo-electric tiltmeters, which were placed on two independent basalt platforms, four on each one and oriented by pairs in N-S (№45, №87) and E-W(№33, №85) azimuths, with sensitiveness 0.01 m sec/mm.

The research works in dynamic triggering of seismicity was started in Tbilisi by uninterrupted acceleration observations in November 2010.

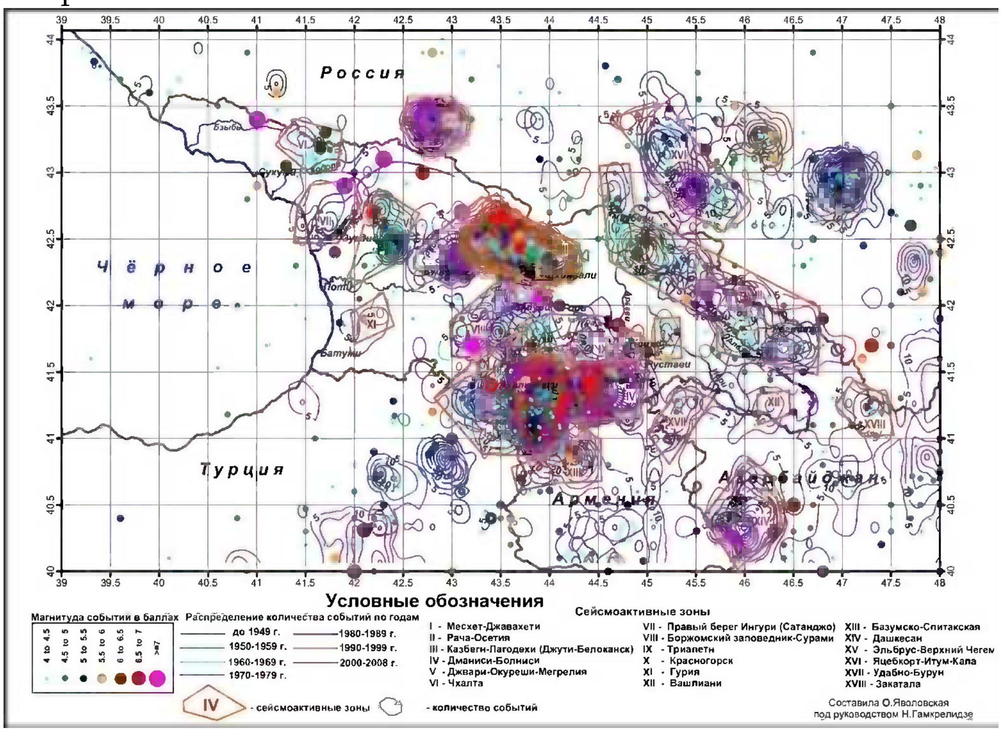


Fig. 2 The general scheme of seismicity and seismic regularities of Georgia and its adjacent territories for the period of 1900-2008

In both cases and particularly in the first one (a half of the century of observation) a unique experimental material has been accumulated which needs theoretical and practical processing with consequent generalization: study of the genesis, of the mechanisms of working, the role of the structure of the environment, and other aspects.

a) The noted parameters are recorded with frequent significant anomalous divergences from the background values which (divergences) according to express-interpretation data are connected with the forces caused by cosmic bodies and the processes that take place in Earth's crust (earthquakes etc.).

The drawing on Fig. 3 needs study by spectral analysis. Intuitively it may be said that there takes place a drift in time-interval in the north-western direction with a tendency of increasing inclination and uneven gradient, in which a periodicity of 5 years interval is observable. This fact is of much interest, and namely, how is it connected with other geophysical facts.

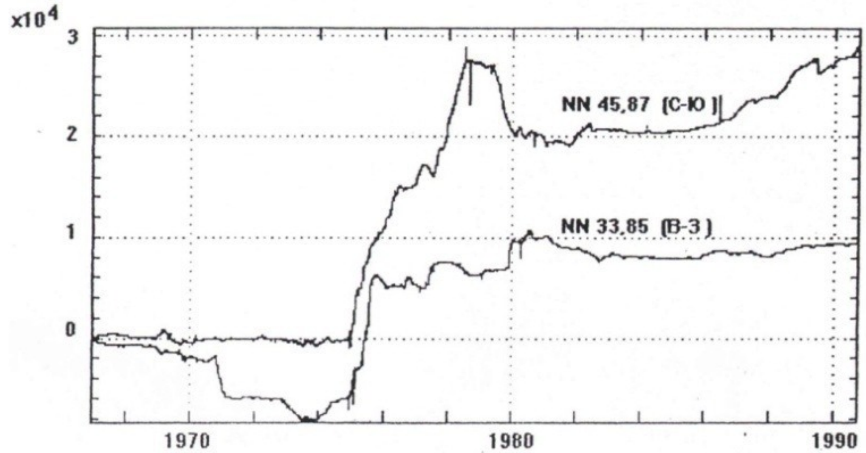


Fig. 3 Averaged drifts of tiltmeters on the Earth's surface in Tbilisi 1967-1991

The summary move of the inclinations is given on Fig. 4 in the shape of a vector diagram. Such presentation of inclinations is often rather convenient, because it gives an opportunity to define for any moment the value of the inclination as well as its direction. The summary

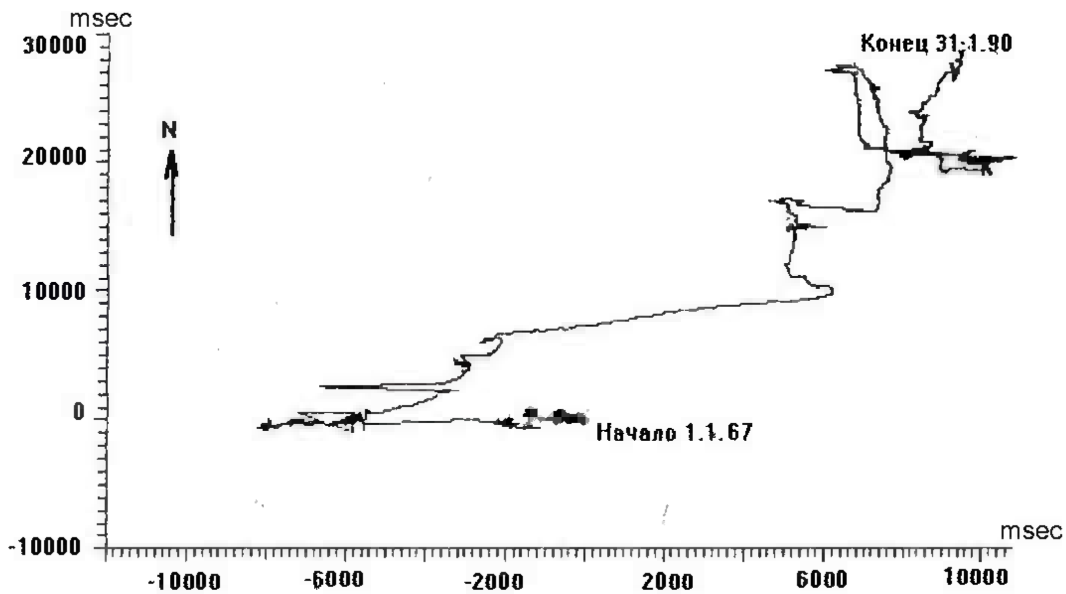


Fig. 4 The vector diagram of inclinations of the Earth's surface in Tbilisi in 1967-1991

inclination during 24 years of observation made up 27",0 in northern direction and 9",2 in eastern. The module of the summary inclination made approximately 28",5, which gives us 1",2 yearly or 0,",003 for a day, which points to stability of the point of observation. At moments, the change of inclination shows itself here more sharply than on Fig. 3, due, it seems, to the processes that take place in the crust.

b) Non-tidal inclinations in Tbilisi during the Spitak and Racha earthquakes. According to modern theories, genesis of earthquakes is ascribed to tectonic processes. These processes produce in the beginning cracks which gradually broaden up to large complex fracturing, which causes change in the volumes and properties of rocks, and produce defects in them.

On the basis of measurement and calculation it is noted [2] that a tension of 1000 N/cm^2 may be accumulated in a hearth, which is caused by deformation of the rocks of which the value may reach 10^{-5}-10^{-4}. Such accumulations should mainly be connected with the block structure of the Earth's crust. The blocks differ from each other in size as well as physical-mechanical properties. There takes place a distribution of the additional energy they receive among them and the change in their energetic condition takes place. In certain conditions the system may become instable, one of the possible results of which may be an earthquake. Immediately before the earthquake the character of deformation changes which causes variation of different background geophysical fields and produces some so called earthquake's preconditions, which are characterized by an interval of formation and the radius of possible spread.

The radius of earthquake's precursors $\rho_{\varepsilon\ (km)}$ is defined by the following ratio between relative deformation ε and the magnitude M of the earthquake (Kasakhara, 1985) $\rho_{\varepsilon} = \dfrac{10^{0.433M-2.73}}{\varepsilon^{\frac{1}{3}}}$

Other Japan scientists propose the following linear relation between magnitude M and τ at the time of earthquake's preparatory period: lg τ =0.79M – 1.88, where τ is measured in 24 hours. The connection between magnitude M and seismic energy E (erg) is calculated: lg E-=1.5 M – 11.8

There in the records of tiltmeters some anomalies were noted of which the origin according to express-interpretation should be connected only with strong earthquakes.

The summary moves of inclination of the Earth's surface at Spitak and Racha earthquakes at the periods before and after the occurrences are shown on Fig. 5 in the shape of vector diagrams. It must be noted, in the first place, that the diagrams deeply differ formally from each other, changing with different gradients and in different direction. The Racha Earthquake is characterized by several 2-3 abrupt changes of inclination, while in the Spitak Earthquake diagram such thing is hardly observable and/or may be noted only once. Studying the resemblance and difference of their diagrams, several factors must be taken into consideration: first, these objects are situated on different sides from Tbilisi, correspondingly in southern and in northern; and they are in different geological and seismological conditions. In what ones, and why? These questioins must be answered by investigation.

In addition, it may be said in regard of the Spitak diagram, that starting from January 1988 the Earth's surface in Tbilisi had been inclining with constant speed and in northern direction, where the angle of inclination during 6 months was 2. 2" (second), and in eastern direction –0.4". During 5 months after the earthquake the inclinations changed direction from east to west. It may be seen on the diagram that two months before the earthquake the direction of the vector of inclination coincided with the direction towards the epicenter.

a) b)

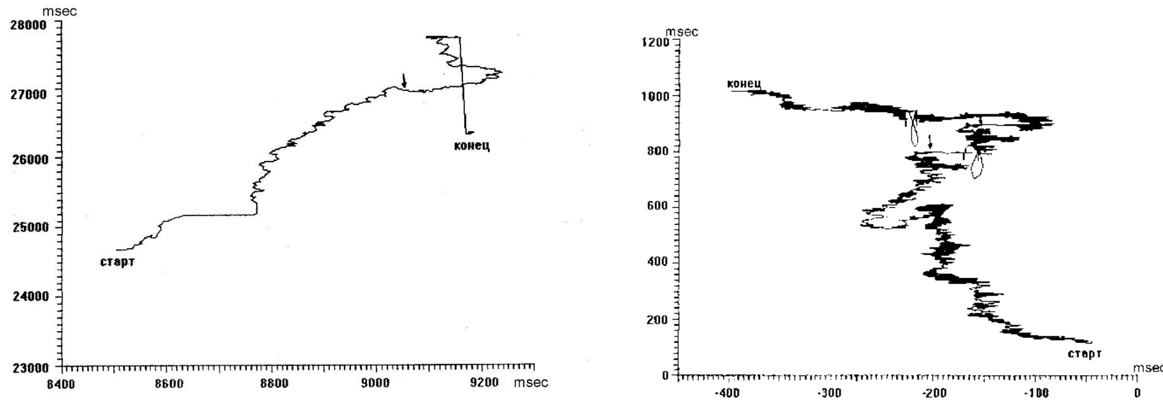


Fig. 5 Vertical diagrams of the inclinations of the Earth's surface in Tbilisi during the Spitak 1988 (a) and Racha 1991 (b) earthquakes, at the anterior and posterior periods of their occurrences.

On the vector diagram of inclination for 11.10.1990-5.9.1991 of the Earth's surface during Racha earthquake, two earthquake occurrences may be noticed; one the properly Racha 29.04.1991, K=15.5, Δ_{Tb}= 140 km and Java - 15.06.1991, K=11.5, Δ_{Tb}= 115km. The arrows point to some moments of the earthquake. In both cases the direction of the vector coincides with the line connecting epicenter of the earthquake and the recording equipment.

Physical grounds of anomalous inclinations in the period of preparation and the preceding period of an earthquake are considered in different theoretical models, where it is shown that the variations of the velocity of deformation in the zone of seismic focus should have a bay-like character. It may be supposed that outside the focus zone the variations of deformation must have the same character. Here it must be noted that the existence of the anomalous tectonic regime in the zone of earthquake's preparation arouses a great interest of scientists not only because it can be observed long before the earthquake. This circumstance is particularly important because it gives us the opportunity of localizing future earthquake's epicenter with the help of integral investigations.

With the help of the above given empirical relations we estimated the radius of manifestation of the earthquake's precursors ρ_ε for the Spitak (7.12.1988) and Racha (29.4.1991) earthquakes. The time of manifestation of anomalous symptoms corresponding to the precursors τ has also been estimated. For the value of the anomalous precursor we take the inclination of the Earth's surface in Tbilisi, which exceeds 20 msec (20 msec represents the summary tidal inclination for Tbilisi as well as the zone of Enguri Power Station in E-W direction). The Table 1 shows the corresponding values.

Table 1

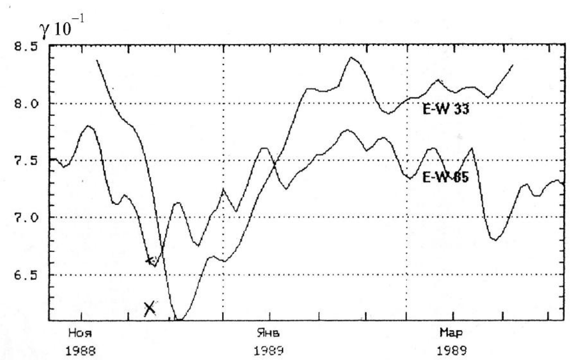
##	The time of the earthquake	Magnitude M	Distance from the epicenter, km	ρ_ε, km	T, year
1	Spitak 7.12.1988	6.9	105, Tbilisi 300, Enguri	380	8.0
2	Racha 29.4.1991	7.1	140, Tbilisi	470	11.4

As can be seen from this evaluation, the radius of manifestation of the precursors ρ_ε is different for the noted earthquakes, the time of manifestation of the deformational precursors τ is also substantially different. Here it must be noted: if for the given ρ_ε, and τ and different earthquake's epicenters their formation takes place at the same time, it is possible that their precursors superimpose each other and anomalous disturbances have a complex form, which can, of course, impede their identification.

The noted empirical examples allow us to suppose with the sufficient confidence that they are perhaps the precursors of earthquakes and there are other similar deformational-mechanical and geophysical precursors which are necessary to study with the deepest possible scientific earnestness. And this in our firm opinion will quite certainly take place in the nearest future.

It must be said that the equipment for registration of tidal processes gives us an opportunity to make registration of long-period seismic waves, which is impossible for classic seismic equipment. On one of such recordings in Tbilisi observatory have been received some distant $\Delta>100^\circ$ many times going round the globe Rayleigh R_1, R_2 .....R_{10} and Love L_1, L_2 ....L_{10} waves caused by an earthquake, according to which the S_1, S_2 ....S_{10} and T_1, T_2 ......T_{10} specters of free oscillation of the Earth were determined . The earthquake that took place in the south of Tonga Island on June 22, 1977 (M=7.9; $\Delta=141.2^\circ$; h=65 km) with deformometer component N 66.5° E, recorded in Tbilisi

It is known that the tension which exists inside the Earth is produced and changes under the influence of the forces acting inside it. At particular places and in particular conditions some accumulation of energy takes place; then upon reaching the limits of durability of solid bodies the latter snap. Accumulation of elastic energy, which is unleashed during the earthquake, needs certain time, for which reason an earthquake is preceded by a certain period of preparation. We can connect earthquake's precursors with these processes which are reflected on the change of the conditions of tension as well as on different characteristic parameters of geophysical fields. Having this circumstances in view, we tried to calculate tidal inclinations of the Earth's surface registered in Tbilisi in connection with the two last and most intensive earthquakes in the Caucasus (Spitak, 1988 and Racha, 1991), the so called tiltmeter γ-factor (γ is the ratio of the tidal inclination angle and the theoretic angle of the place) by the method of harmonic analysis of main tidal 12-hour wave M_2 by means of 60 day long time series. Then the central moment of the series was replaces by two days and the diagram of γ-function was drawn. To determine this factor only M_2 wave was used, correspondingly, for N-S and E-W azimuths. Theoretical amplitudes for these azimuths at Tbilisi latitude are A_{N-S}=7.85 msec; A_{E-W}=11.79 msec.



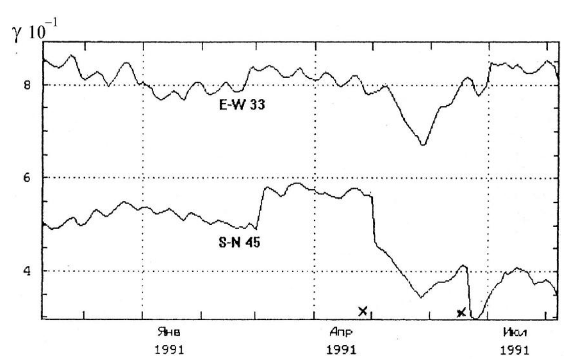


Fig. 6 The change of γ-function during Spitak 1988 (a) and Racha 1991 (b) earthquakes

It turned out that before both events – the earthquakes in Tbilisi and in Enguri – the reduction of the value of γ took place. Fig. 6 shows the diagram of change of γ-factor at Spitak and Racha earthquakes. In the noted time the interval value of γ in Spitak was systematically reducing and reached its minimum on November 12, 26 days before the earthquake. Then the growth began and reached its maximal value by the end of December. The whole change made 15% of the average value of γ, γ_{av} =0.64.

After that it was interesting to study the specters of tidal waves. In order to find out how the spectral densities of tidal waves changed for the above mentioned two earthquakes we built spectral time diagrams for corresponding periods with the help of the periodogram analysis. The results obtained show that during the earthquakes a sharp reduction of amplitudes of 12-hour and 24-hour waves took place, and in some cases even the whole disappearance of 24-hour waves (Fig. 7).

It is assumed that earthquakes are the results of abrupt shift of the masses of tectonic dislocation, which is characterized by a period of preparation – continuous physical changes.

In order to observe the precursors of these changes it possible to use any physical quantity which reflects tension in the rocks as well as its change. It may be change of seismic regime of the region reflected in different properties of geophysical fields. The changes of the parameters which are connected with the change of the physical properties of the rocks.

The materials of tidal inclinations with mechanical properties were processed for the Spitak and Racha earthquakes, the change in time of which may have caused the changes of inclinations and deformations of the Earth's surface around them and as a result the change of amplitudes of tidal waves. So, for instance, shrinking of the Earth's surface may cause consolidation of the rocks in the zone of dislocation, while stretching can cause the opposite effect. In the first case, the amplitude of tidal wave inside the zone would diminish and grow again outside it. Such is the apriori conception proposed in literature, let us see how it will work in regard of Spitak and Racha earthquakes' materials and in the differing seismic and geological conditions of Javakheti.

a) b)

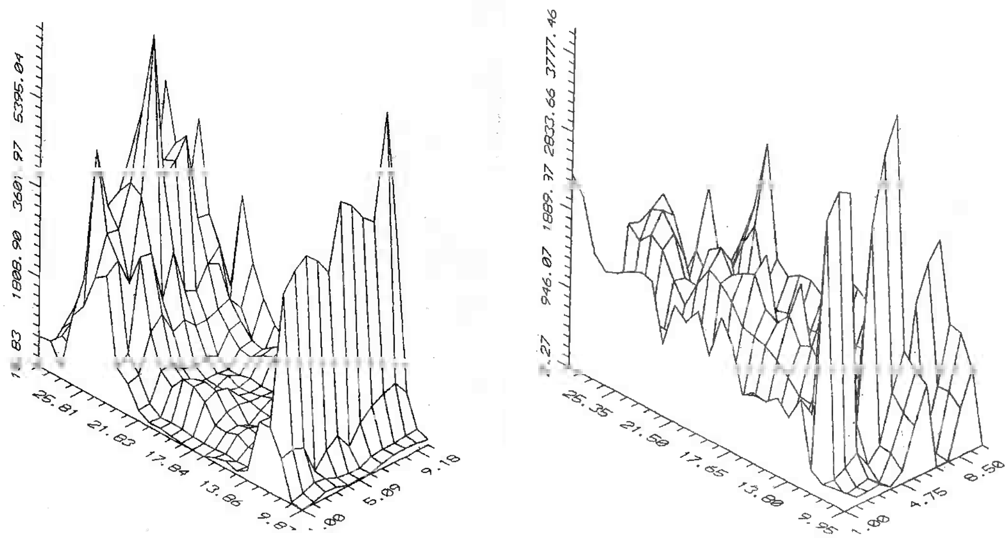


Fig. 7 Change of spectral density of tidal waves during Spitak 1988 (a) and Racha 1991 (b) earthquakes

A physics of earthquakes uses the theory of dislocation. However, the scope of dislocation investigations was substantially broadened and enriched after development of the Voltera theory. For determination of the residual shift we have to integrate the following (Voltera-Vaingartner) equation:

$$U_m(Q) = \iint\limits_{\Sigma} \Delta U_k(P) W_{kl}^{m}(P,Q) \nu_l(P) d\Sigma$$

where Σ-is the surface of the dislocation, W_{kl}^{m} – the kl component of Green tensor for homogenous half-space caused by elementary force of M direction applied to a point; ΔU_k(P) - the shift on the surface of dislocation; ΔU_k(Q) – the shift in the observation point; γe – normal in p-point to the dislocation surface;

$\Delta U_k(P) = U_k^{+} - U_k^{-}$ - represents shift on the dislocation surface in P-point; and U_k – the shift of right and left surfaces relative to initial location.

In general, it is impossible to integrate this equation. For its solution it is necessary to make a simplified model of dislocation. Here the rectangular vertical dislocation was considered to be of 2L length, and immersion of the lower boundary – D, immersion of the upper boundary – d.

The calculations may be made for two cases:

1. The shift on dislocation is made along the fall of the dislocation in horizontal direction (Straight-Slip)

2. The shift on dislocation is made along the fall of the dislocation in vertical direction (Deep-Slip)

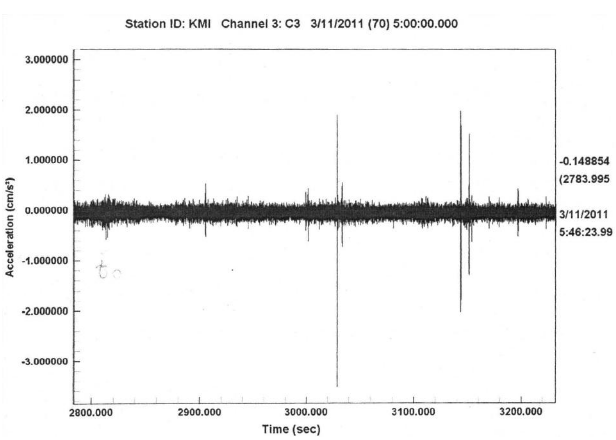
For these cases the shift components u_1, u_2, u_3 are found out.

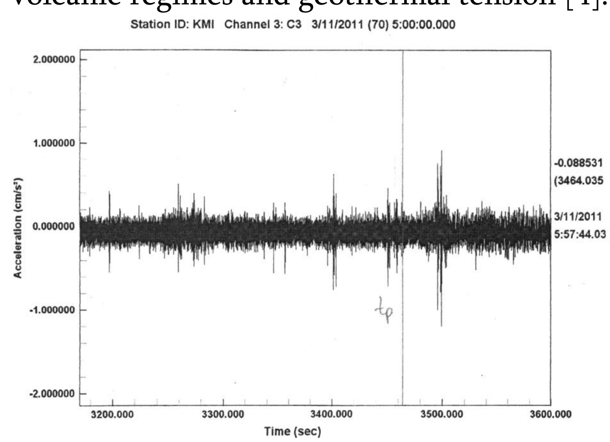
In this way, the materials obtained in Tbilisi with the help of the old Reber-Elest horizontal three-component pendulum in 1899-1916 as well as more resent – photo-electric tiltmeters, three-component quartz extezometer, fixed plotter with gravimeters Askania Werke, will be processed.

Such investigations will give us the opportunity to calculate also the deformational energy of the Earth which is discharged during strong earthquakes.

As it was noted, the events of triggering and synchronization can be observed in many geophysical processes, because the Earth generates a broad specter of oscillations and itself takes part in these processes. To strong geophysical forces often correspond more unobvious forces, of which the periodicity varies in wide range, from seconds up to years. Their influence on other weak or powerful geophysical processes is not easy to estimate and they may even have catastrophic effects. It is often underlined in scientific literature the far-reaching influence of weak outside forces in connection with the change of intensity of seismic regime, which is explained by nonlinear nature of seismic processes, inadequacy of cause-effect factors. To such events belong micro-seismic oscillations caused by triggering of strong earthquakes. Of great interest in this respect is the monitoring and analysis of local micro-seismicity triggered by distant strong earthquakes, which may turn out to be an effective means of controlling the existing tension in the Earth's crust and a criteria for indentifying seismicity. This approach is new and perspective in seismology of earthquakes. In the conditions of present dense seismo-metric net and high-frequency wide-diapason seismic equipment it is possible to record dynamically triggered processes and connect them with strong earthquakes, on the one side, and with the local structure of the Earth's crust and the processes in it, on the other.

Many examples can be brought from the literature, though we will mention here just a few ones: dynamic triggering processes of Lander (1992), Denal (2002), Hector mine (1999), Sumatra (2004) and other earthquakes caused increased seismicity at different distances. Particular raise of seismicity was observed in the areas of active volcanic regimes and geothermal tension [4].





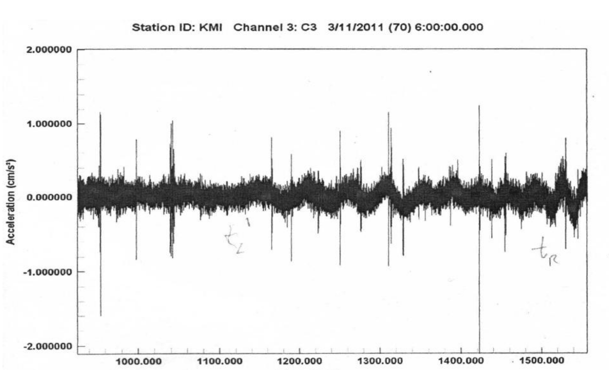


Fig. 8 The fragments of the record of triggering oscillations in Tbilisi by an accelerometer
a) before the arrival of background waves b) at the time of arrival P-waves c) at the moment of arrival surface
waves

As it was noted, triggering processes in our country are recorded by accelerometers. An important informational empirical material has been accumulated. To analyze and generalize the results it is necessary to compare it with the records of highly sensitive wide-frequency range equipment of seismic stations,.

The Fig. 8 shows the oscillations caused by strong Japan-Tohiku earthquake (11.03.2011), M=9, Δ≈7800 km recorded in Tbilisi: the corresponding parameters are given in Table 2.

Table 2

N	Earthquakes	Components	|max|+|min| cm/sec^2	|A2D|cm/ sec^2	|A2D|sm/s ec^2
	11.02.2011 (Japan) T=06^{h}1615^S	Ch1(z) Ch2(N550.5) Ch3(N340.5)	8.20 4.95 7.20	8.74	12.0

In order to establish the nature of triggered micro-seismic processes, the records in Tbilisi of two distant earthquakes had been chosen for express-interpretation: 1. New Zeeland of 21.02.2011 M=6.3, Δ≈17000 km and 2. Japan-Tohiku 11.03,2011 M=9, Δ≈78000 km. The values of acceleration of ground for their maximal tremors (micro-seisms) in plane and space have been determined. Here the azimuth of the vector of acceleration is directed from the point of observation to the epicenter of the observed occurrence. It must be mentioned that on the seismogram a clear arrival of Love and Rayleigh surface waves with velocity dispersion can be noticed.

The object of investigation is the concept that seismic response of the lithosphere with a certain probability represents one of the most important means of determination of the epicenter mechanisms or, in particular, of evaluation of the environmental durability in relation to its critical condition.

One more theoretic consideration: the tensions which seismic waves transport over tele-distance are 10^5 times less than corresponding tensions in depth where the generation of seismic waves takes place. In spite of such ratio, according to the theory of synchronization, even weak forces can have great influence on the resonance rhythms of oscillating systems, the results of which are sometimes catastrophic! Resonance process, in particular, should be connected with the arrival of surface waves, triggered oscillations are also connected with the arrival of these waves.

c) The role of the Earth’s tides as starting mechanism for earthquakes

Here, too, the considerations are hypothetical, grounded on the fact that the tension and deformations in the Earth’s crust are not even in space and permanent in time. In some areas, and particularly there where the intensive tectonic processes are observed even the small changes in tension and deformation cause all kinds of dislocations, including faults of tension, and manifest themselves through earthquakes. There are different manifestations of nonlinear properties of geological environment, among which we note:

1. Seismic emission belongs to the class of nonlinear seismic events which shows itself in the fact that comparatively weak long-periodic oscillations can cause high-frequency oscillations of the environment (dynamic triggering).

2. Strong response to weak impact – is neatly manifested and frequently observed effect. It is apparent in the cases when the tension of the environment reaches a certain critical limit and at that moment some additional force (for instance, tides caused by the Moon or the Sun) affects it. It is noted in literature that such influence can cause earthquakes (static triggering).

As an experiment we tried to check the role of the tidal tension in inducing earthquakes, according to the seismic and tidal data on the Caucasus 1960-1979. For this the most seismically active Javakheti region was selected, which is located at $\Delta \tilde{} 150$ km distance on the average from the epicenters of strong ($M \geq 5$) earthquakes. This choice was motivated by the following circumstances:

1. Javakheti region, having $\varphi = 40^\circ.8 \div 41^0.3$; $\lambda = 43^\circ.3 \div 44^\circ.3$ coordinates, is situated in a particularly seismically active zone and is characterized by a complex seismological-geological structure. In the noted period here occurred 65% of all the earthquakes of the Caucasus, among which $K \leq 7$; =80%; $K = 8$; =40%; $K = 9 \div 11$; =10%; not one of them with $K>13$;

2. Close to Javakheti Plateau (in 150 km on the Turkish side) several epicenters of strong earthquakes ($M=6.1<65$) are located of which the influence on the seismicity of the region has not been noted. On the other hand, the tidal maximum in the noted period often correlates with the earthquake occurrences of $M<3$.

The seismic response represents an urgent problem for study and must characterize many important details of tectonic structure of the place, such as durability and stability moment.

If dynamical triggering causes the discharge of the static environmental tension it must be considered a positive event, and it may be noted: if that is so whether it is not possible to cause gradual discharging in the seismically tense areas? Such thing could be perceived as a preventive measure. Though if the artificial dynamic cause comes in resonance with static tension it may trigger a strong earthquake which can have a devastating effect on the environment. These problems deserve certainly the closest attention on the part of the scientific society.

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გეოდეფორმოგრაფიულ და ტრიგერირებულ სეისმურ მონაცემთა ზოგიერთი შედეგები მიწისძვრების პროგნოზირების შესაძლო კრიტერიუმების დადგენის მიზნით

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მ. ნიკოლაიშვილი, ო. იავოლოვსკაია

რეზიუმე

ganixileba miwis qerqSi mimdinare faruli deformaciuli procesebi, gamowveuli Sida qerqSive arsebuli an/da kosmosuri aseve faruli ZalebiT. es procesebi nawilia bunebis kanonzomierebisa, sadac warmoiqmneba fizikur movlenaTa simravle da TviTon warmoqmnian raRac movlenebs. aseT movlenebs ganekuTvneba qerqis deformaciebi. es movlenebi organul mizez-Sedegobriv kavSirSia miwisZvrebTan da kosmiur mimoqcevebTan. miwisZvrebis momzadebis periods ukavSirdeba qerqis deformaciis mravali niSani da kriteriumo, ris safuZvelzedac SesaZlebelia gakeTdes raime doneze maTi warmoqmnis adgilis, intensivobis da drois prognozireba.

Некоторые результаты геодермографических и тригерированных сейсмических данных с целью установления возможных прогностических критерий землетрясений.

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Резюме

Рассматриваются происходящие в земной коре скрытые деформационные процессы, вызванные действующими внутри нее или внешними космическими силами. Эти процессы представляют часть природных закономерностей, где возникает все разнообразие физических явлений и, в свою очередь, вызывают какие-то явления. К таким явлениям относятся также коровые деформации. Эти явления находятся в причинно-следственной связи с землетрясениями и космическими приливными явлениями. С подготовительным периодом землетрясений связано множество признаков критериев деформации коры, на основании которых возможно строить определенного уровня прогнозирование места, интенсивности и времени землетрясений.