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Seismicity of the natural-technical systems in mining areas of the Murmansk region (NW Russia)

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Abstract. To evaluate an input of different factors in the seismogenic risks the study of relationship between seismicity, geomagnetic fields, and mining operations was performed in Khibiny and Lovozero natural-technical systems (NTS). The primary data were based on the regional bulletin of digital recording of seismic events with M>-1 for 1988-2009, as well as on catalogues of K-indices of the local geomagnetic field, evaluated by the "Lovozero" Observatory of Polar Geophysical Institute of Kola Science Center of Russian Academy of Sciences (PGI KSC RAS) since 1996. The time series of seismicity and geomagnetic activity are processed by spectral method based on the calculation of power spectral density.

Keywords: Natural-technical systems; Geomagnetic disturbances; Seismic energy; Spectral analysis.

1 INTRODUCTION

Large mining areas in the Murmansk Region are localized on the North-East of Fennoscandian Shield. Recent geodynamic regime of the region is controlled by three natural key factors: i) slow uprising during the last 8 thousand years due to melting of Quaternary glacier cover; ii) the lateral stress in the upper crustal layers, caused by the Eurasian lithosphere plate rotation; iii) impulse oscillation of electromagnetic fields, resulting in a variation of heliogeophysical processes in the Circumpolar Auroral belt. Moreover beginning with 1930 the intensive and large volume mining are being carried out in the region, resulting in the technogenic seismicity. Natural seismicity is rather stable and moderate: an annual total seismic energy release is about 10 000 MJ, and estimated frequency of earthquakes in 7 balls (in term of MSK-64 scale) T=10 000 years. Local anomalies of seismic activity are recording within NTS, which were developed in mining areas during XX Century. To evaluate an input of different factors in the seismogenic risks the case study of relationship between the seismicity, geomagnetic fields, and mining operations was performed in Khibiny and Lovozero NTS. The relationship between the seismicity and solar activity and geomagnetic disturbances has been repeatedly studied and discussed, starting with the Mallet (1858) (Chizhevsky 1976) as in domestic scientific literature (Shestopalov and Kharin 2004, Shestopalov and Kharin 2006, Sobolev et al. 1982, Sobolev et al. 1998, Sobolev et al. 2001, Surkov 2000, Sytinsky 1973, Sytinsky 1982, Sytinsky 1985, Vladimirsky et al. 1994, Zakrzhevskaja and Sobolev 2002, Zakrzhevskaja and Sobolev 2004), and in foreign scientific literature (Georgieva et al. 2002, Shea et al. 1991, Snyder et al. 1963). The recognition of the direct or indirect correlation of the seismicity and solar activity in the multiyear series taking into account the significant fluctuations of the solar cycle duration dominates among the points of view. However there are researches (Georgieva et al. 2002, Shestopalov and Kharin 2004, Sytinsky 1982) proving negative correlation between these phenomena. It should be noted that in both cases the most of the studies were carried out on a global scale, dealing with the strongest seismic events of the world. Recognizing the research in the Kola region differing the insignificant seismicity and incoming in Circumpolar Auroral belt of the most frequent and intensive manifestations of the geomagnetic disturbances is a new and actual.

2 INITIAL DATA

The initial data of seismicity are the registration catalogues and databases of KBGS RAS (Kola Branch of Geophysical Survey of the Russian Academy of Science) of the regional seismicity and technogenic activity at the regional and local levels during the period of 1988-2011. This data include the catalogue of monitoring by the digital registrars for 1992-2009. Seismic events were characterized by energy of the earthquakes (E, J). For convenience, the common logarithm of energy ($\log_{10}$ E, J) is used. Filtering the records of the industrial explosions and other technogenic events is carried out based on: 1) the accounting and cataloging the travel times of the seismic waves of industrial explosions; 2) infrasound monitoring in the region and adjacent territories; 3) the original algorithms of analysis of seismograms (Asming 2004). The complex designed by KBGS RAS enables the sure registration, localization and reliable recognition of the natural and technogenic events with magnitude of 0-1 within the 50 kms radius, completely covered area of Khibiny and Lovozer NTS. In the problem of the analysis of the possible correlation between the geomagnetic perturbations and the seismic activity the seismic and acoustic noise is of great importance in addition to natural earthquakes. The advantage of working with these materials consists of the possibility of their permanent registration and therefore in the completeness of data required for the analysis. At the same time the noise may be considered as seismic response significantly less energy in the possible cause-and-effect relation of “geomagnetic disturbances - seismic energy”. Therefore, in the analysis of seismicity of the Kola region the seismic and acoustic noises registered in the frequency bands of 0.2-2 Hz and 2-20 Hz during the period of 2002-2009 are used also. The initial data of geomagnetic activity is catalogs of K-indices of the "Lovozero" Observatory, published in the press (since 1996) and on the website of the PGI KSC RAS (http://pgia.ru/PGI_Data) (since 2001). The quasi-logarithmic K- indices were converted to the equivalent A_k – indices with the purpose of commensurability of the comparable parameters. A_k - index characterizes the amplitude of the diurnal perturbations in linear scale and corresponds to the centre of the amplitude interval (Zabolotnaya 2007).

3 ANALYSIS OF TIME SERIES OF THE SEISMICITY OF KHIBINY AND LOVOZERO NTS

Khibiny and Lovozero NTS are located in the central part of Kola peninsula (NE of Fennoscandian Shield). The NTS include several large mines, dressing plants, and many unexploited deposits (Fig. 1). The complex apatite-nepheline ores are extracted in Khibiny massif and the ores of the rare and rare-earth metal are extracted in Lovozero massif. The largest technogenic objects of Khibiny NTS are: 1) Kirov, Yukspor and Rasvumchorr underground mines and the dumps of the mines; 2) Saamsky, Central, Koashva, Newrkpakhk, Oleny Ruchey open pits; 3) the apatite-nepheline dressing plants (ANDP) and them tailings storages; 4) the electric power plant of Apatity and the stored waste of the plant activity (slags, ashes) also. Such objects of Lovozero NTS are: 1) the dormant mine of Umbozero (concentrating territory, mine, spoil banks); 2) Karnasurt mine; 3) the dumps and tails near to a village of Revda (Pozhilenko et al. 2002).

Results of the analysis and comparison of the time series of Khibiny and Lovozero NTS confirm ruls earlier established:

- the greatest contribution to natural seismicity is made by the differentiated isostatic uplift of blocks of the crystalline shield in postglacial time (Sharov et al. 2007);

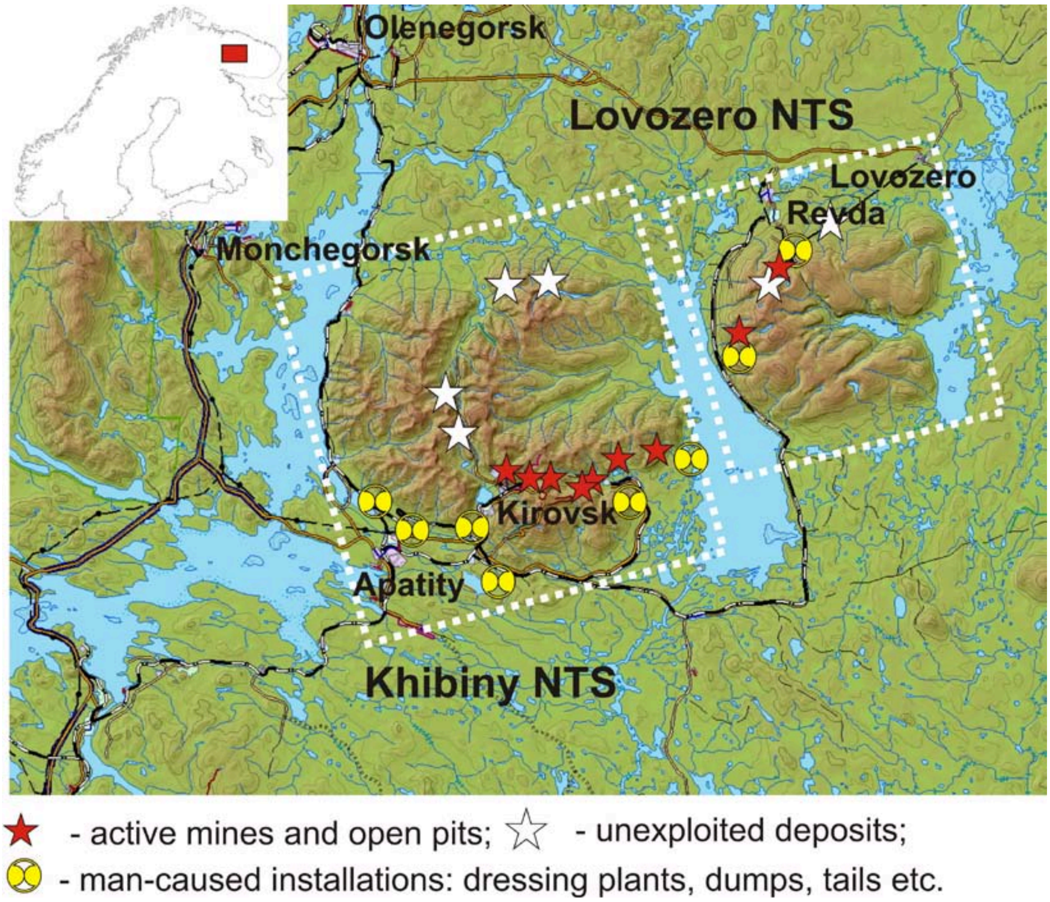


Figure 1. Khibiny and Lovozero NTS with an arrangement of mining objects

- the technogenic seismicity of the areas of NTS haves the direct correlation with the intensity of the ores extraction, transportation of rocks and them storage in the dumps and tails (Fig. 2) (Melnikov & Mining Group 2002);
- the 10-12-years cycles of regional seismic activity are revealed; these cycles correspond to solar activity cycles to a first approximation.

Moreover the new rules and trends are ascertained:

- the seismicity in the Kola region does not reveal the direct correlation between the frequency of events and their total seismic energy;
- the diagrams of the mean monthly frequency of events and the seismic energy of Khibiny and Lovozero NTS are not agreed among themselves and have essential distinctions both in the long-term and in seasonal (monthly) time series (Fig. 2);
- the largest seismic events (up to E 10^{8-10} J) occur in the area every ten - twelve years in Khibiny and Lovozero NTS alternately by a principle of "swing" (negative correlation), and at the same time in each of regarded NTS the events are repeated every twenty – twenty two years (Fig. 3). During the periods between the large events the annual seismic energy of Khibiny and Lovozero NTS is identical for first approximation. During the period of activation the seismic energy significantly grows due to the large event.

4 SPECTRAL ANALYSIS OF THE DATA

4.1 The analysis of the geomagnetic perturbations (A_K) and the seismic energy of earthquakes (E) by power spectral density.

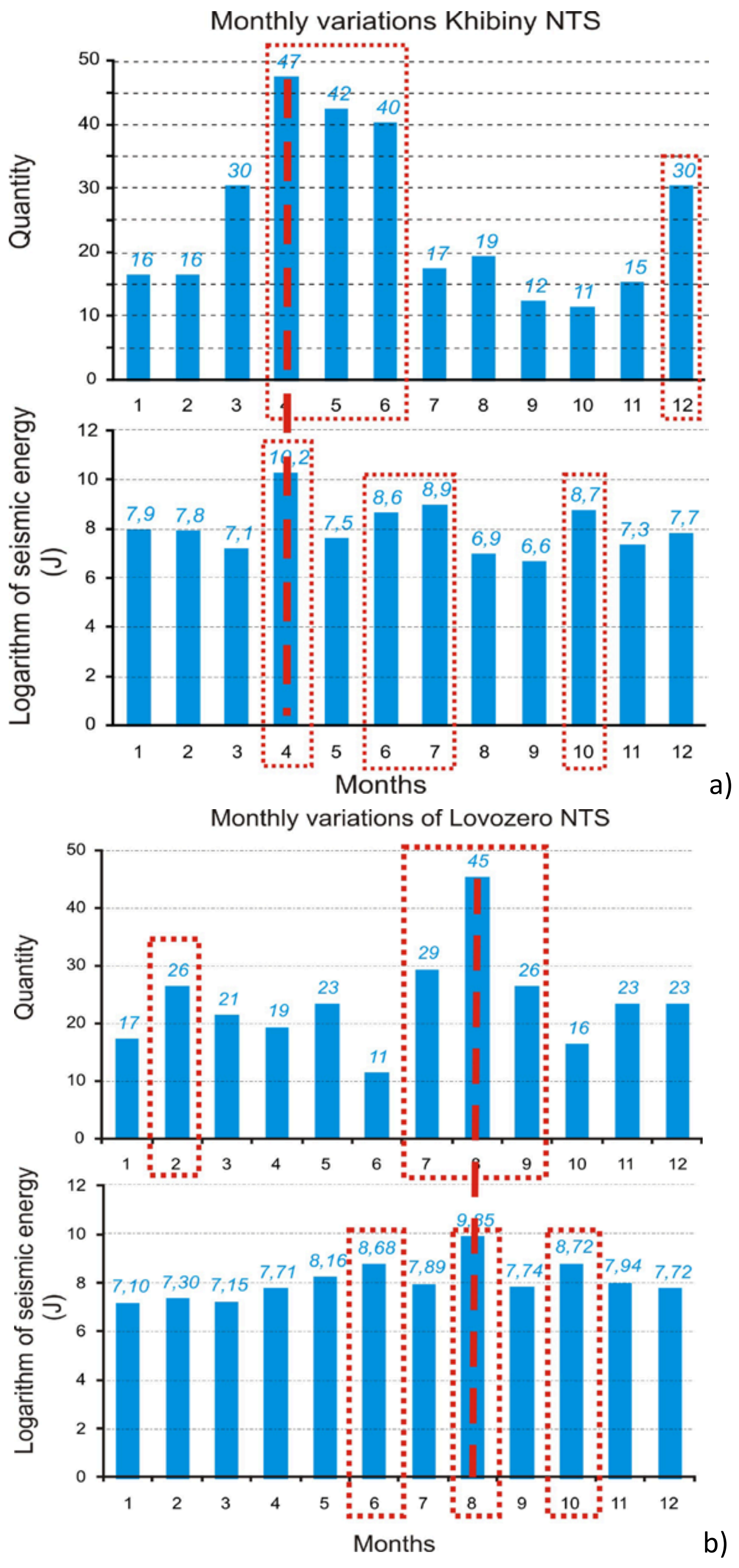
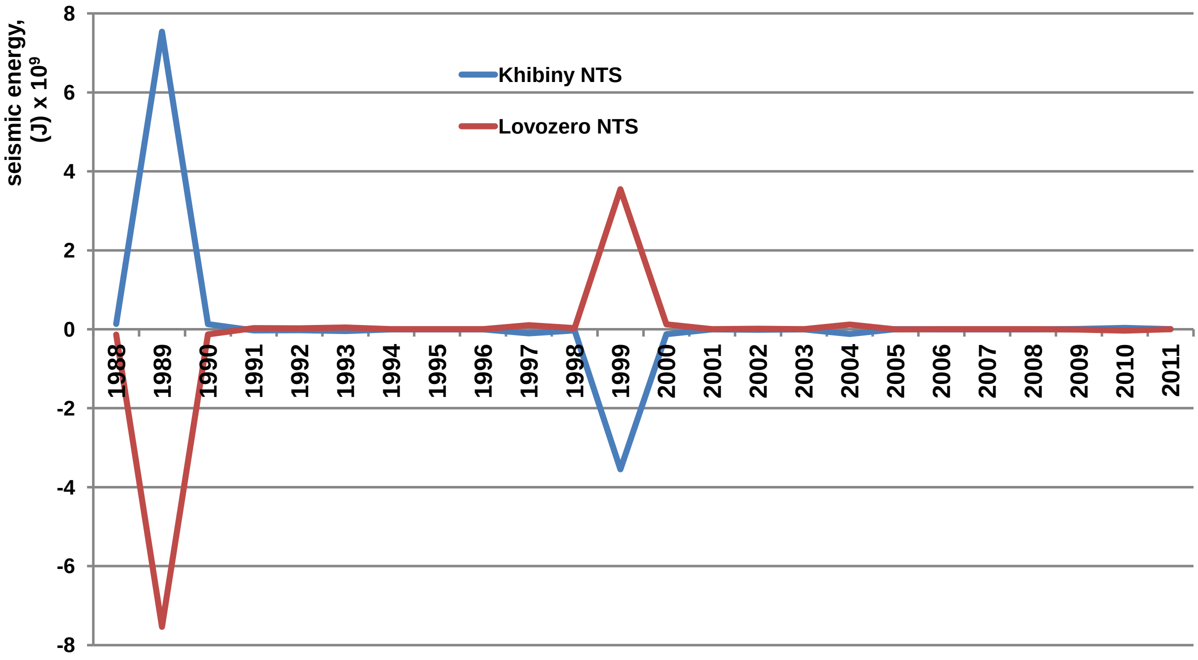
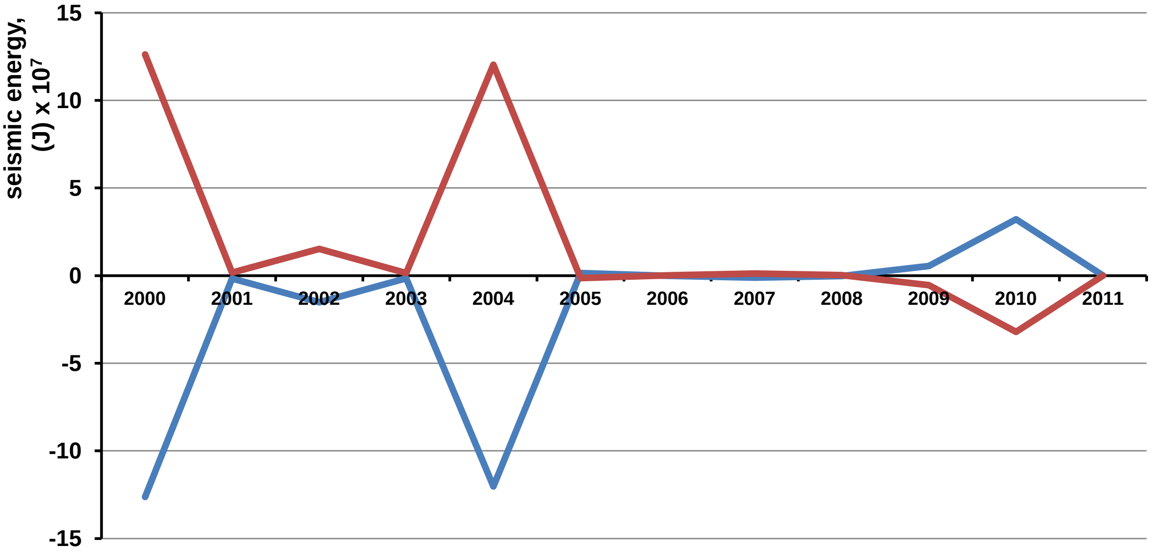


Figure 2. The seasonal variations of the seismic events and seismic emission as a result of the monthly averaging and overlap of the data of different years, on the example of the Khibiny (a) and Lovozero (b) NTS. The peaks of the seismic activity are showed by a dotted line.



A



B

Figure 3. The cycles of the seismic activity and the seismic energy in Khibiny and Lovozero NTS (during the period of 1988-2011) (A) and the fragment in the other scale (during the period of 2000-2011) (B). X-line shows years and Zero level is half of summary seismic energy of both NTS, Y-line shows the seismic energy of NTS: 1) blue line demonstrates an abmodality (i.e. deviation from the average) of the seismic energy of Khibiny NTS; 2) red line demonstrates an abmodality of the seismic energy of Lovozero NTS.

The time series of parameters studied are processed by the spectral analysis based on the calculation of power spectral density (PSD).

The problems of search of the periodicity of the seismic and geomagnetic activity at regional and local levels were solved. The results of calculations of the spectral power of the time series studied are submitted below. Power spectral density of $A_к$ - indexes of geomagnetic variations and seismic energy of earthquakes ($\log_{10}$ E) are obtained. Figures 4 and 5 show the spectra of power of the $A_к$ - and $\log_{10}$ E- time variables accordingly. The most significant harmonics of the spectra are determined. The

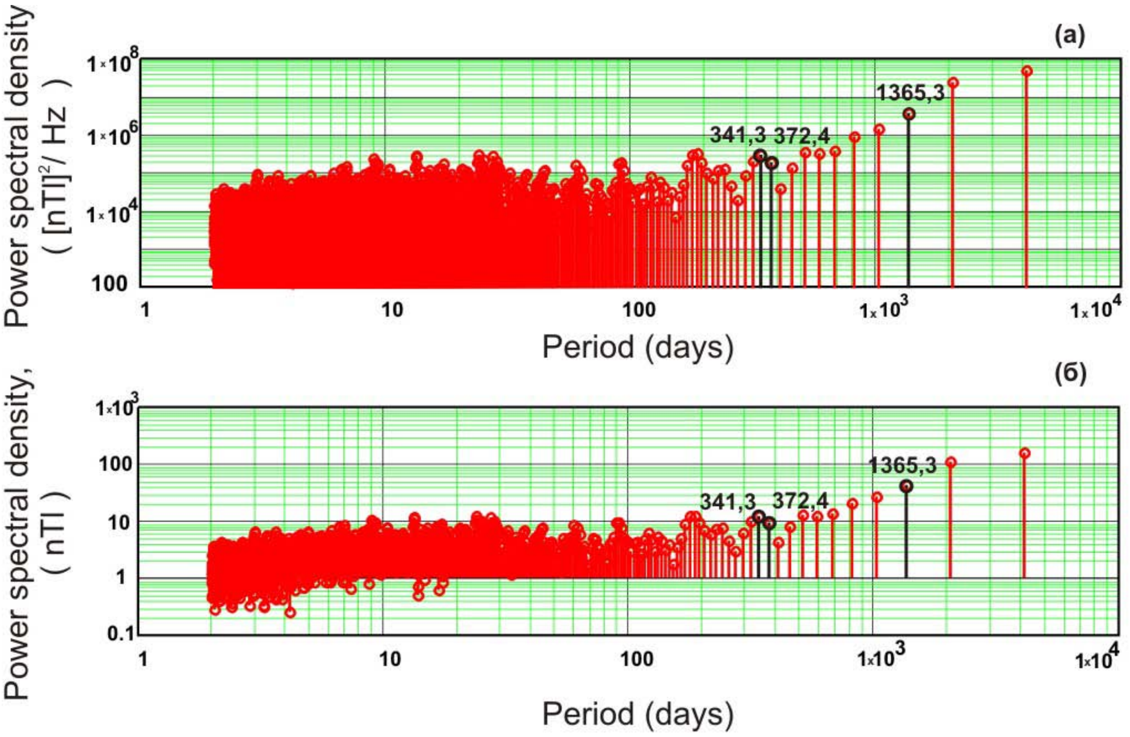


Figure 4. The spectres of the A_k - time variable: (a)- the power spectral density, (б)- the power spectral density in terms of amplitude.

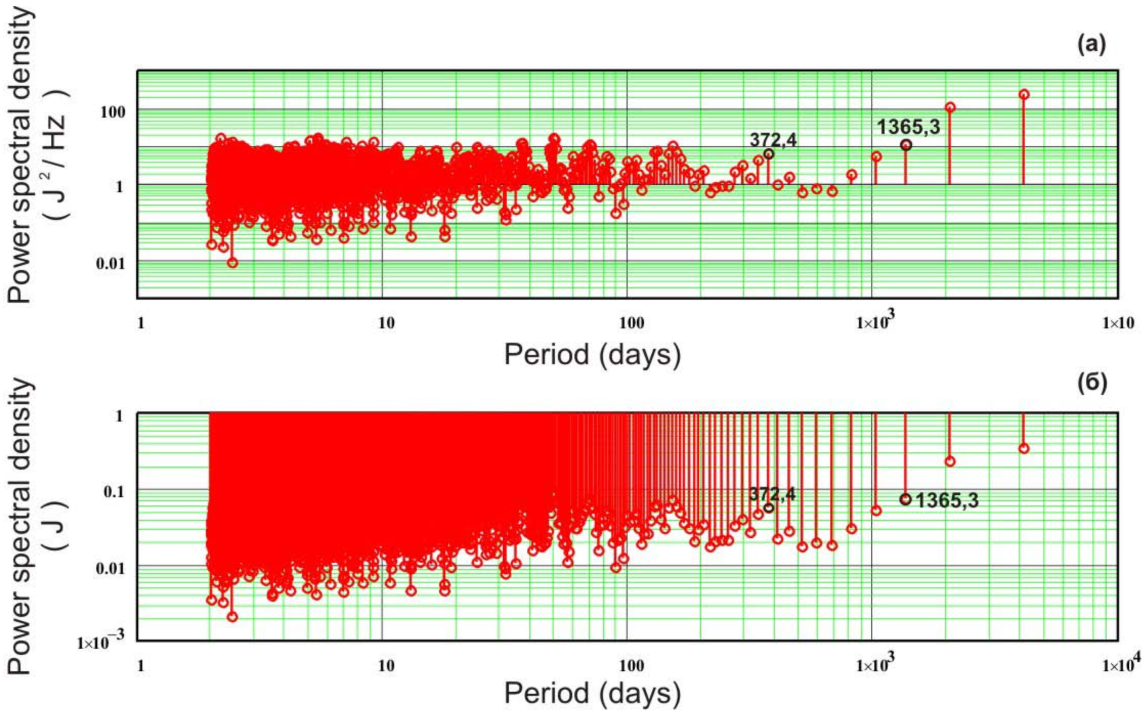


Figure 5. The spectres of the $\log_{10}$ E- time variable: (a)- the power spectral density, (б)- the power spectral density in terms of amplitude.

significance of harmonic is defined by exceeding of the power spectral density of harmonic over noise level. For the purposes of the further joint analysis of $A_к$ - and $\log_{10}$ E- variables the sinusoids of the similar periods are selected.

In the spectrum of A_k- variable the sinusoids of the large periods have the maximal power spectral density. These are such periods of harmonics as: 1365.3; 1024.0; 819.2; 682.7; 512.0; 585.1; 186.2; 341.3 days. In contrast to A_k- data in the spectrum of $\log_{10}$ E- variable the sinusoids of the small period have the maximal amplitude. These are such periods of sinusoids as: 5.4; 50.0; 5.4; 2.2; 50.6; 5.0; 5.4; 5.0; 7.1 days. As stated above we are interested in the harmonics corresponding to the maximal power spectral density on the one hand, and having the close periods on the other hand. As a result of calculation of power spectral density the sinusoids of such periods are not revealed, except for the sinusoids of the period of 1365.3 days (3.74 years). In the spectrum of A_k- data this harmonic is the most significant. While in the spectrum of $\log_{10}$ E- data this harmonic is 16-th in the list (in descending value of spectral power). The calculation of the coherence function will allows to more authentically determine the close harmonics of two random processes.

4.2 Coherence Function

At the analysis of the data the important characteristic is coherence function. Coherence function is determined by the normalization of reciprocal spectral density and is the analogue of the correlation coefficient in the frequency domain. Coherence function reflects the degree of linear relationship of the harmonic components of the processes considered. By analogy with the correlation coefficient the coherence gives the information about the degree of correlation, but only in the frequency domain.

The closer is the coherence to unity on this frequency, the more is the coincidence of the harmonic components at this frequency. As a rule, just coherence function is used in practical applications for the analysis of coupling processes in the frequency domain. Figure 6 shows the estimated coherence function for A_k- and $\log_{10}$ E- data. In the spectrum of the coherence function the significant and common to the A_k- and $\log_{10}$ E- data are harmonic with small periods (in days): 5.15; 3.14; 3.72; 2.95; 9.62; 6.62; 12.64; 4.53; 7.80; 2.07; 2.05. There is a weak correlation at a level of the harmonics with the period of about year (372.4 days). The harmonica with the period of 372.4 days corresponds to coherency of 0.9826. The harmonica with a period of 1365 days (3.74 year) corresponds to the coherency of 0.9711.

4.3 Spectral analysis of the seismic and acoustic noise.

The power spectral density of seismic and acoustic noise are obtained. The seismic noise is recorded in 0.2- 2 Hz and 2-20 Hz frequency bands during the period of 2002-2009. The acoustic noise is recorded in 0.2- 2 Hz frequency band during the period of 2004-2007. Figures 7 and 8 show the power spectral density at the different frequency and the dominating maximums.

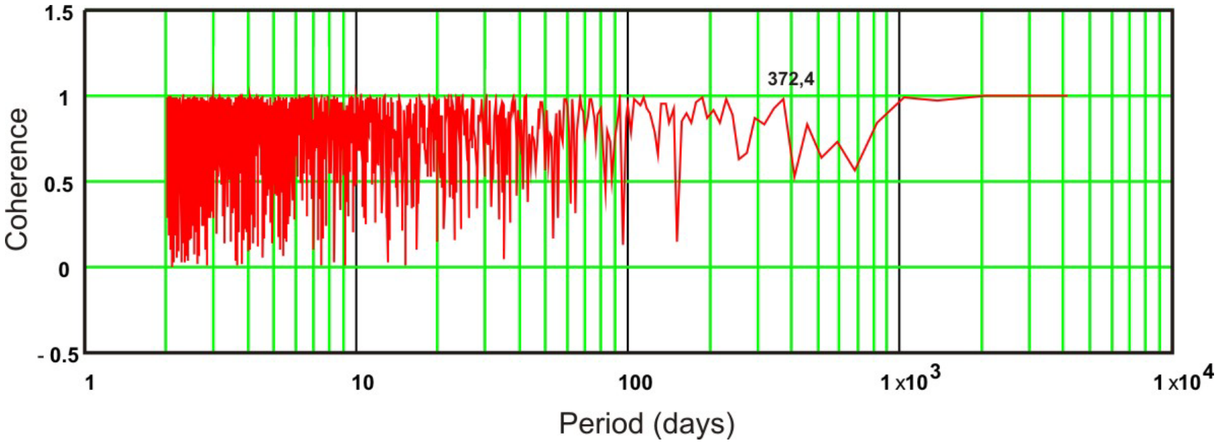


Figure 6. Coherence Function of the $A_к$ -data and $\log_{10}$ E- data.

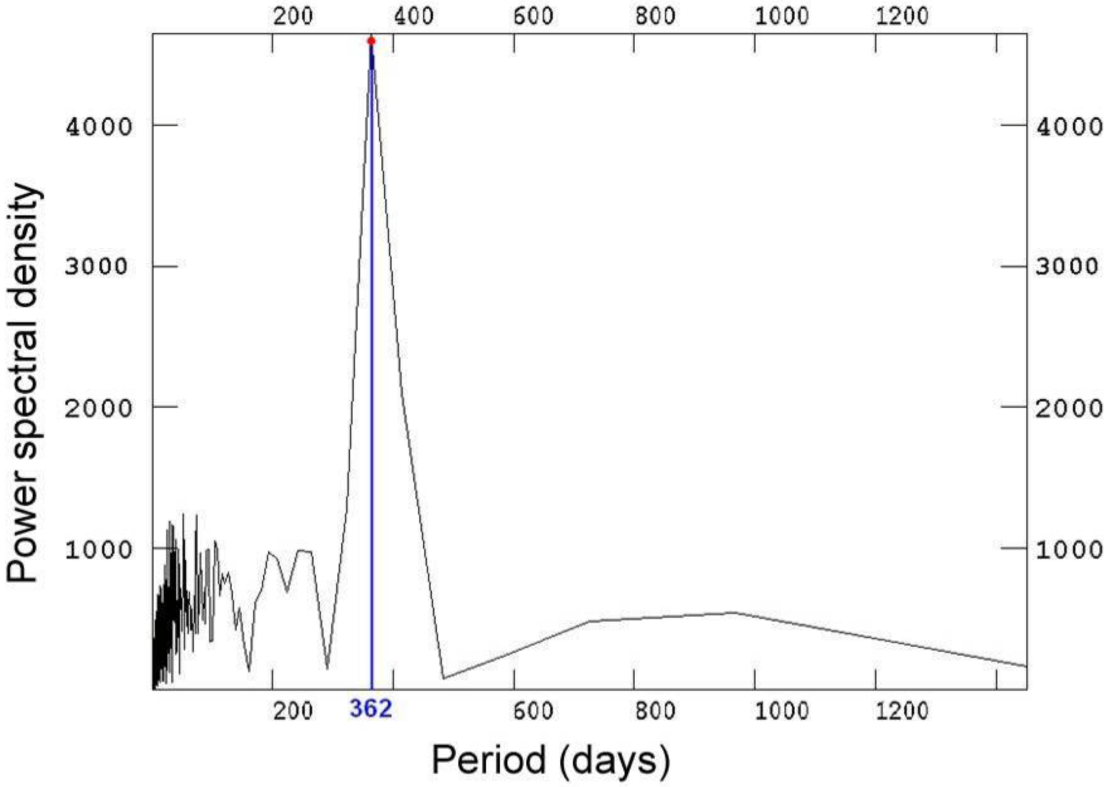


Figure 7. Power spectral density of the seismic noise of the frequency band of 0.2-2 Hz (for the period of 2002-2009). The dominating period (362 days) is depicted by the blue line.

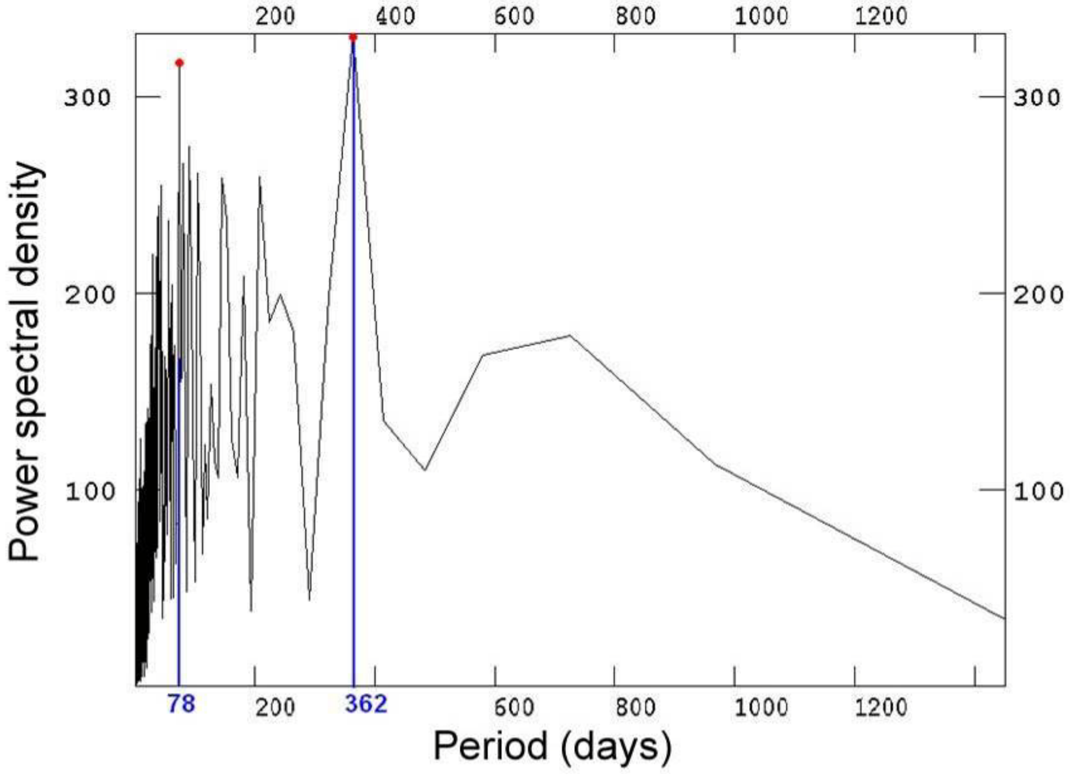


Figure 8. Power spectral density of the seismic noise of the frequency band of 2-20 Hz (for the period of 2002-2009). The dominating periods (362 days and 78 days) are depicted by the blue line.

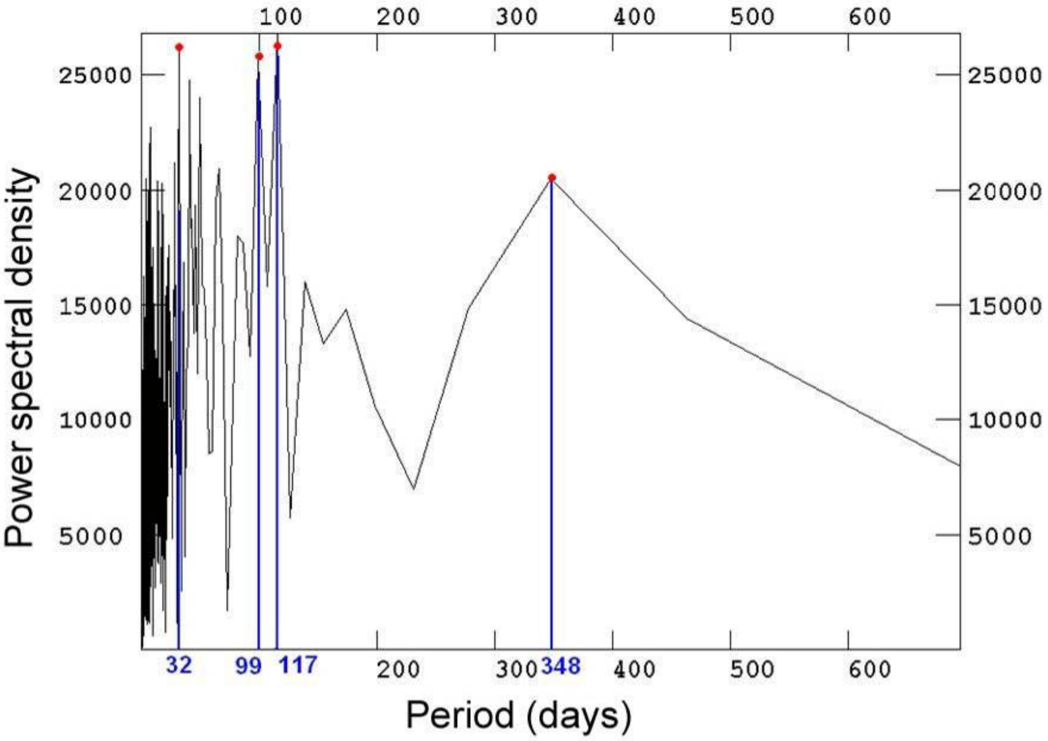


Figure 9. Power spectral density of the acoustic noise of the frequency band of 0.2-2 Hz (for the period of 2004-2007).

Figure 9 shows and power spectral density of the acoustic noise with the several dominating maximums. As a whole, figures 7-9 demonstrate the most significant harmonica of seismic spectrum which period is 362 days. In the spectrum of the acoustic noise (0.2-2 Hz frequency band) the predominant harmonica is the harmonica with the periods of 117.32 and 99 days.

5 CONCLUSIONS

As the result, the following conclusions are obtained.

- The technogenic seismicity of the areas of NTS haves the direct correlation with the intensity of the ores extraction, transportation of rocks and them storage in the dumps and tails;
- The couple of NTS with similar geological structure, but with different style and scale of “incorporated” mines displays an autonomic rhythm of seismic time series, evidencing an advantage of anthropogenic factors over a tectonic framework;
- The largest seismic events (up to E 10^{8-10} J) occur in the area every ten - twelve years in Khibiny and Lovozero NTS alternately by a principle of "swing" (negative correlation), and at the same time in each of regarded NTS the events are repeated every twenty – twenty two years (Fig. 4). During the periods between the large events the annual seismic energy of Khibiny and Lovozero NTS is identical for first approximation. During the period of activation the seismic energy significantly grows due to the large event.
- There are significant harmonicas of about one year period in the all analysed spectra (A_k- and $\log_{10}$ E- data, seismic and acoustic noise). So, the dominating harmonics in the spectrum of seismic noise (frequency of 2-20 Hz and 0.2-2 Hz) are harmonics with the period of 362 days. And the significant harmonic in the spectrum of acoustic noise (frequency of 0.2-2 Hz) is harmonic with the period of 348 days.

- The significant harmonicas of about one year period (372.4 days) are revealed in the spectra of A_k- and $\log_{10}$ E- data also. However the coherence function has the maximal values for high-frequency components of the spectrum. The local time series of seismicity and $A_к$ -indexes show some common harmonics (with period 1.08, 4.34 years, etc.), but in a whole the heliogeophysical factors affect the NTS geodynamic regimes insignificantly. Thus, the correlation of the seismicity of Kola region and geomagnetic perturbations is weak and its influence can be considered from the point of view of the trigger for already prepared events.
- The most significant factors of the seismicity in the Kola region are the technogenic activity, the regional and local fields of the stress, caused by: i) slow uprising during the last 8 thousand years due to melting of Quaternary glacier cover; ii) the lateral stress in the upper crustal layers, caused by the Eurasian lithosphere plate rotation.

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