LLNL-JRNL-403975

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

Short-Period Seismic Noise in Vorkuta (Russia)

S. B. Kishkina, A. A. Spivak, J. J. Sweeney

May 19, 2008

Seismological Research Letters

SHORT-PERIOD SEISMIC NOISE IN VORKUTA (RUSSIA)

S. B. Kishkina, A. A. Spivak & J. J. Sweeney*

Institute of Geosphere Dynamics, Russian Academy of Sciences,
Lenin pr. 38, bld. 1, Moscow, 119334 Russia

*Lawrence Livermore National Laboratory, L-205, P.O. Box 808, Livermore CA, 94550

Received 2008.

INTRODUCTION

Cultural development of new subpolar areas of Russia is associated with a need for detailed seismic research, including both mapping of regional seismicity and seismic monitoring of specific mining enterprises. Of special interest are the northern territories of European Russia, including shelves of the Kara and Barents Seas, Yamal Peninsula, and the Timan-Pechora region. Continuous seismic studies of these territories are important now because there is insufficient seismological knowledge of the area and an absence of systematic data on the seismicity of the region. Another task of current interest is the necessity to consider the seismic environment in the design, construction, and operation of natural gas extracting enterprises such as the construction of the North European Gas Pipeline. Issues of scientific importance for seismic studies in the region are the complex geodynamical setting, the presence of permafrost, and the complex tectonic structure. In particular, the Uralian Orogene (Fig. 1) strongly affects the propagation of seismic waves.

The existing subpolar seismic stations [APA (67,57°N; 33,40°E), LVZ

(67,90°N; 34,65°E), and NRIL (69,50°N; 88,40°E)] do not cover the extensive area between the Pechora and Ob' Rivers (Fig. 1). Thus seismic observations in the Vorkuta area, which lies within the area of concern, represent a special interest. Continuous recording at a seismic station near the city of Vorkuta (67,50°N; 64,11°E) [1] has been conducted since 2005 for the purpose of regional seismic monitoring and, more specifically, detection of seismic signals caused by local mining enterprises.

Current surveys of local seismic noise [7,8,9,11], are particularly aimed at a technical survey for the suitability of the site for installation of a small-aperture seismic array, which would include 10-12 recording instruments, with the Vorkuta seismic station as the central element. When constructed, this seismic array will considerably improve the recording capacity of regional and local seismic events. It will allow detection of signatures of seismic waves propagating in submeridional and sublatitudinal directions. The latter is of special interest not only to access the influence of the Urals on propagation patterns of seismic waves, but also to address other questions, such as the structure and dynamic characteristics of the internal dynamo of the Earth [9,13]. Recording seismic waves at low angular distances from seismically active subpolar zones will allow us to collect data on vortical and convective movements in subpolar lithosphere blocks and at the boundary of the inner core of the Earth, possibly giving essential clues to the modeling of the Earth's electromagnetic field [3,13]. The present study considers basic features of seismic noise at the Vorkuta station obtained through the analysis of seismic records from March, 2006 till December, 2007.

GENERAL SETTING OF THE VORKUTA AREA

The city of Vorkuta is situated in northeastern European Russia, in the permafrost zone, 160 km to the north of the Arctic Circle and 150 km from the coast of the Arctic Ocean. This location is affected by severe climatic conditions, with below freezing air temperatures and large average annual fluctuations. The Vorkuta area is located on the Vorkuta uplift which is the northern structure within the Kos'yu-Rogov depression and belongs to the megazone of transitional structures of the cis-Uralian foredeep located between two large tectonic regions, the eastern part of the Timan-Pechora (Pechora-Barents Sea) epi-Baikalian Platform in the west, and the northwestern part of the Uralian epi-Hercynian fold belt in the east. The cis-Uralian foredeep is a system of large depressions extending linearly along the Uralian Range that originated as a result of subsidence followed by intensive uplift. The prominent feature of the depressions is a considerable thickness of foredeep sedimentary formations (up to 6-7 km thick) with a significant part of the section represented by coal-bearing deposits.

An important feature of the region is the presence of permafrost. The existence and development of permafrost is influenced by climatic, paleoclimatic, physiographic, and hydrogeological factors [2,6]. In the northern part of the region permafrost reaches thicknesses of 300-400 m; in the Vorkuta area it is up to 200 m thick. The Vorkuta seismic station is located at the southern boundary of zones of continuous, discontinuous, and sporadic permafrost. In the city of Vorkuta, the structure of the continuous permafrost zone is complicated by local natural and cultural conditions. In the discontinuous and sporadic zones, the permafrost has a two-layered structure with an upper layer is up to 100 m thick that is underlain by 60 m of talik, and a second (relict) permafrost layer that is several tens of meters thick [6]. In the summer-fall period, the upper part of the permafrost is exposed to seasonal thermal effects, resulting in a seasonal melting layer that exists between June and the end of September. The onset of below freezing average daily air temperatures in October promotes the complete freezing of the seasonally melting layer by mid December. The thickness of this layer varies from 0.2 to 1.8 meters. Seasonal fluctuation of ground water levels can reach 1.4-2 m. The maximum level of ground water is observed between July and November. The base of the Vorkuta seismic station is located at an elevation of 209 m and below the zone of seasonal thawing.

THE SEISMIC OBSERVATORY

We have conducted three types of seismic observations at the Vorkuta seismic station. Seismometers of pendular type (model SM-3KV) operating in a velocimeter mode are used as basic seismic gauges. The main characteristics of the SM-3KV are given in Table 1; amplitude-frequency characteristics are shown in Fig. 2. The seismometers are installed on a concrete base at a depth of 6 m below the ground surface in a special underground vault. Digital recording at a sampling frequency of 100 Hz is carried out using a computer-based 6-channel 16 bit digitizer with 30 Gb of data storage capacity and time synchronization via a thermostatic generator. Characteristics of the utilized seismic bandwidth allow recording in the range of 0.5 to 30 Hz. This ensures the continuous recording of both weak seismic signals from teleseismic earthquakes and local impulse signals, as well as signals caused by explosive operations at mining enterprises located in the vicinity of Vorkuta.

For the analysis of seismic noise, we used parts of seismic records free of expressed seismic events and their coda. An example of 30 seconds of a three-component seismic record is given in Fig. 3. Altogether about 100 record intervals have been processed. The characteristics of seismic noise were investigated by computing the power spectral density of vibration velocity. Power spectral density was calculated separately for each component of the three-component seismic record, and separately for night-time and day-time. Power spectra were determined according to a technique described in [4] using the Fourier transform with a 50% overlap of the data record and averages over 11 minute intervals. After obtaining spectra for a finite time interval, the median spectrum was estimated and accepted as the most probable spectrum of seismic noise for this time interval. For the estimations, we asume that seismic noise for each time interval is stationary.

AMPLITUDE-TIME AND SPECTRAL CHARACTERISTICS OF SEISMIC NOISE

Analysis of seismic noise data at Vorkuta show a strong consistency over time. Analysis of the standard deviation of seismic noise during one week at the same time of year from 2006 and 2007 showed that the general characteristics of the noise from year to year are quite similar. Significant weekly amplitude variations in the frequency range of 0.5-30 Hz are small; this indicates that the cultural component of the seismic noise is either minimal or constant in time. This is further supported by data comparing daily amplitude variations of noise in midweek (e.g., a Thursday) with those during a weekend day (e.g., a Saturday).

However, there are significant differences between daytime and night-time niose characteristics, as shown in Fig. 4. The spectral amplitude of seismic noise in the daytime (hour 6-22 of Fig. 4) exceeds that of the night period by 10-12 dB in the range of 1-10 Hz and by 15 dB at 20 Hz. Enhancement of seismic noise during the day is emphasized at the higher frequencies. An example comparison with the Peterson model [8] in Fig. 5 shows that the spectral amplitude of the seismic noise in the frequency range of 1-5 Hz occupies the middle amplitude range of the Peterson model, and in the range of higher frequencies (>5 Hz) the noise tends to approach a minimum level of the model. Comparative analysis of different components of the seismic noise, shown in Figure 6, reveals a near coincidence of spectral amplitudes of vertical and horizontal vibration velocities in the frequency range of 0.5-12 Hz (the difference does not exceed 3-4 dB). The amplitude of the horizontal component is 7-9 dB higher than that of the vertical one in the range of 12-18 Hz, and 15 dB higher at 20-26 Hz (Fig. 6).

An additional prominent feature of the noise spectral amplitudes is the presence of strong peaks reflecting quasi-monochromatic components of the noise as seen in Fig. 4 by intermittent horizontal bands. These peaks are present both in the vertical and horizontal components and may be of cultural or natural origin [10]. These peaks (12.4 Hz, 16.6 Hz, and 24.8 Hz in Fig. 4; also 8.3 Hz and 18.9 Hz at other times) are present at some level in the spectrum much of the time, and their central frequencies change within a very narrow range (not more than 0.15 Hz). The amplitude of other peaks (1.27; 2.2; 6.7; 11.5; 14.9 Hz) change greatly over time, and they may be absent during separate time periods.

SEISMIC EVENTS OF NATURAL AND CULTURAL ORIGIN

Earthquakes. The above considered amplitude and spectral properties of seismic noise indicate a high potential sensitivity of the Vorkuta seismic station. In fact, during the seismic recording at the Vorkuta station, a significant number of seismic signals of different origin, including those of teleseismic earthquakes, were detected. As an example, Fig. 7 illustrates seismic signals from a teleseismic earthquake which occured near Japan. Groups of longitudinal *P*, transverse *S*, and surface *LR* waves are indicated in seismograms. The maximum signal amplitude approaches 100 micron/s, and the order well exceeds the level of local seismic noise. These records indicate a high sensitivity of the Vorkuta station and its ability to detect and identify seismic signals at the background of seismic noise.

Industrial explosions. Significant disturbance of natural seismic noise is caused by industrial explosions of chemical explosives at mining enterprises located near Vorkuta. Mass explosions, both underground and in quarries, are the most common sources of seismic signals in the Vorkuta area. Fig. 8 illustrates seismograms from a mass explosion at one of the mines. The seismograms clearly show phases of longitudinal, transverse, and surface waves. The amplitude of body waves amounts to about 50 micron/s, and in surface waves, to about 25 micron/s. Recordings of industrial chemical explosions with known source parameters (the mass and location of explosives, time of explosion) permits accurate calibration of the Vorkuta seismic station as well as the determination of local Vp and Vs velocities, inferred from hodographs, of 5.5 and 2.8 km/s, respectively.

CONCLUSIONS

A model of the seismic noise at Vorkuta in the frequency band 0.5-30 Hz has been constructed based on analysis of the seismic data. Amplitude levels of the seismic noise in the Vorkuta area are characterized in general by high stability. The amplitude of noise variation depends on frequency: vibrations in seismic noise at 1-5 Hz vary from –140 to –150 dB during the day and from –152 to 158 dB at night; at 8-15 Hz noise varies from –140 to –155 dB during the day and from –155 to –165 at night. Daily variations of the seismic noise amplitude over the entire 0.5-30 Hz band are weak, but noticeable variations are observed for the 1.5-3 Hz and 14-17 Hz frequency bands. During daytime, the amplitude of noise changes by 7 dB, and the variation in the amplitude of the horizontal component is on average 5 dB higher than that of the vertical component. Some stable spectral peaks are present in the noise for which the central frequency did not change more than 0.15 Hz during the entire period of instrumental observation. Detection of signals from teleseismic earthquakes and local industrial HE explosions with high signal to noise ratio suggest that Vorkuta is an excellent site for a regional seismic array

.

ACKNOWLEDGEMENTS

Large thanks to V.I. Kulikov and A.I. Goncharov who provided the seismic data. This research was sponsored by the Civilian Research and Development Foundation (project No. RUG2-1714-VR-07) and Russian Foundation for Basic Research (grant No. 08-05-00359). Prepared by LLNL under Contract DE-AC52-07NA27344.

LIST OF REFERENCES

1. Adushkin V.V., A.I.Goncharov, S.B.Kishkina, V.I.Kulikov, A.A.Spivak. Seismic noise at the Vorkuta region// Physical fields and the dynamica of the interecting geospheres. Moscow, Russia. 2007. Pp.240-249 (in Russian).
2. Adushkin V.V., A.A.Spivak, E.M.Gorbunova. Geodynamic problems of the oil/gas pipe lines at the Nothern areas of Russia// Problems of geodynamic safety. S.-Petersburg, VNIMI. 1997. pp.210-219 (in Russia).
3. Aksenov V.V. Earth's electric field. Novosibirsk, IVM&MG. 2006. 165 p. (in Russia).
4. Brian W.P., Flannery B.P., Teulkolsky S.A., Vettering W.T. Numerical recipes. Cambridge University Press, 1987. 818 p.
5. Gurrola B.H., Minster J.B., Given H., Vernon F., Berger J., Aster R. Analysis of high-frequency seismic noise in the western United States and eastern Kazakhstan// Bull. Seism. Soc. Am. 1990. V.80. No.4. P.951-970.
6. Engineering cryopedology. Leningrad, NEDRA. 1991. 439 p. (in Russia).
7. Okada H. The microtremor survay method. Tulsa, OK. Soc. Explor. Geophys., 2003. 135 p.
8. Peterson J. Observation and modeling of seismic background noise. U.S. Geol. Surv. Tech. Rept .Open-File, 93-322. Albuquerque, NM. 1993. 95 p.
9. Rotary processes in geology and physics/ Editor – E.Milanovsky. Moscow. KomKniga. 2007. 242 p. (in Russia).
10. Spivak A.A., Kishkina S.B. The use of seismic background for the identification of active geotectonic structure and determination of geodynamic

characteristics// Physics of the Solid Earth. 2004. Vol.40. No.7. P.573-586.

11. Stutzmann E., Roult G., Astiz L. GEOSCOPE station noise level// Bell. Seism. Soc. Am. 2000. Vol.90. No.3. Pp.690-701.
12. Tabulevich V.N. Seismic and infrasonic waves. Springer-Verlag, 1992. 150 p.
13. Tectonics and geophysics of the Earth's lithosphere. Moscow. GEOS. 2002. Vol.1. 368 p., Vol.2. 378 p.
14. Webb S.C. Seismic noise on land and on the see floor//International Handbook of Earthquake and Engineering Serismology/ Academ Press, 2002. Vol.81A. P.305-318.
15. Wilson D., Leon J., Aster R et al. Broadband seismic background noise at temporary seismic stations observed on a regional scale in the Southwestern United State// Bull. Seism. Soc. Am., 2002. Vol.92. No.8. Pp.3335-3341.

Table 1. Performance attributes of seismometer SM-3KV

Parameter	Unit	Value
Working frequency band	Hz	0.5 – 100
Transformation corfficient:		
- working coil	V-s/m	135 ± 20
- attenuation coil	- " –	13 ± 2
Threshold of sensitivity	m/s	$3x10^{-9}$
Intrinsic noise	m/s	$3x10^{-10}$
Natural period	s	2.0 ± 0.1
Pendulum's moment of inertia	kg-m	$8.5x10^{-3}$ ± 2%

Figure captions

Fig.1. Location of the Vorkuta seismic station; triangles – IRIS seismic station (LVZ and NRIL) and Russian Academy of Sciences seismic station (APA); star – seismic station Vorkuta

Fig.2. Response characteristics of the seismometer SM-3KV in velocimeter regime.

Fig.3. Typical example of a seismic record; Vorkuta, 06 March 2006; 00:00 GMT (03:00 local time).

Fig.4. Spectrogram plot of seismic data during a 24-hour period. Power spectral density of seismic velocity is in decibels referenced to 1 $(m/s)^2/Hz$.

Fig.5. Power spectral density of the seismic noise velocity at the Vorkuta seismic station during the day (1) and night (2); local time (hour): 1 – 14:00; 2 – 02:00; 3,4 – maximum and minimum noise according to the Peterson model.

Fig.6. Power spectral density for different seismic noise components at the Vorkuta seismic station (26 March, 2006; 01:16 GMT); 1 – Z; 2 – NS; 3 – EW.

Fig.7. Seismograms of a seismic event recorded at Vorkuta seismic station on 08

March, 2007 (earthquake; 05:03:32 GMT; 29,908 N; 140,204 E; M=6.1; depth 140 km). *P, S* and *LR* – groups of the longitudinal, transverse and surface waves accordingly.

Fig.8. Seismograms of a nearby chemical explosion, 01 June, 2006 (02:09 GMT).

Fig.1

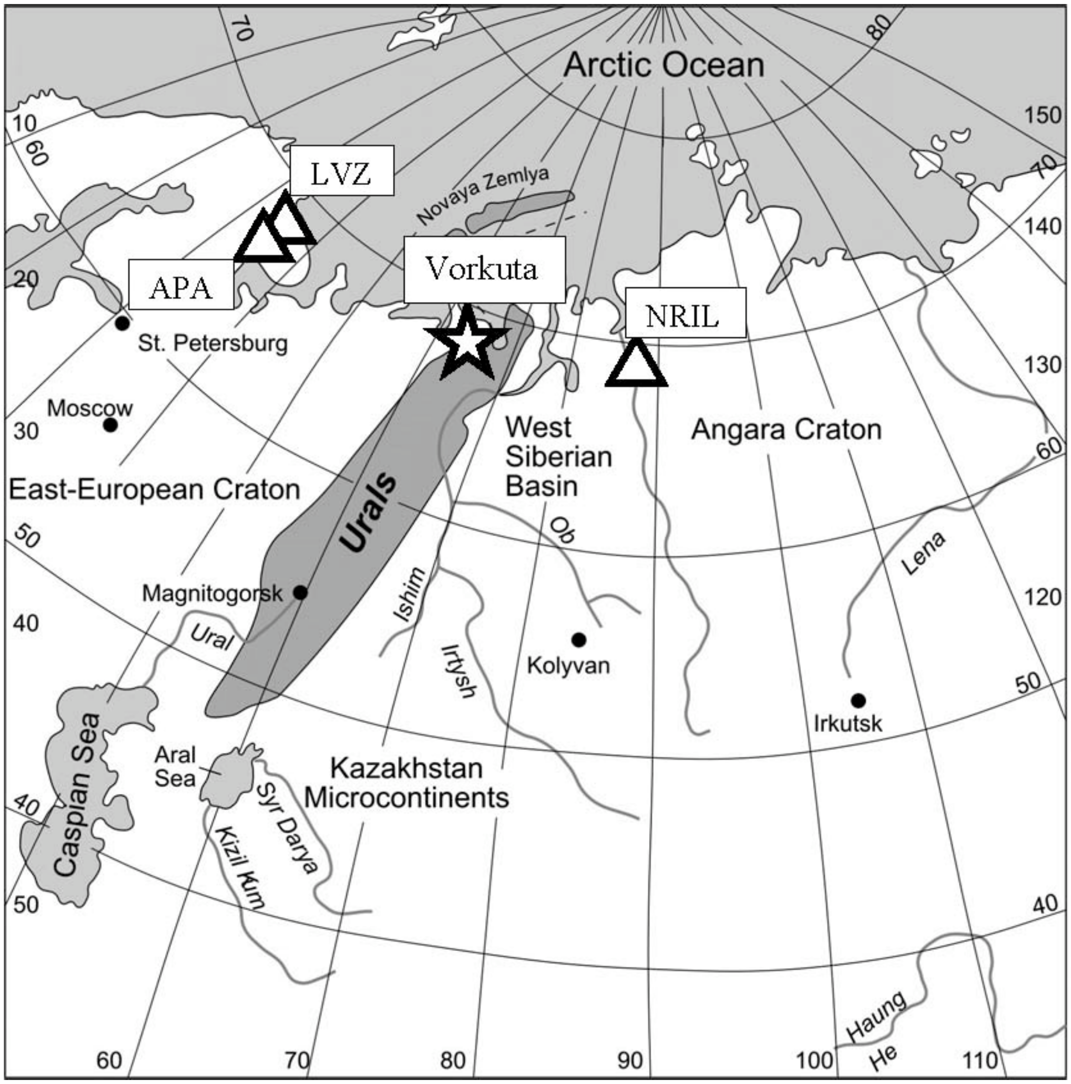

Arctic Ocean
LVZ
APA
Vorkuta
NRIL
Novaya Zemlya
St. Petersburg
Moscow
East-European Craton
Urals
West
Siberian
Basin
Angara Craton
Magnitogorsk
Ural
Ishim
Irtysh
Ob
Kolyvan
Lena
Irkutsk
Caspian Sea
Aral
Sea
Kazakhstan
Microcontinents
Syr Darya
Kizil Kum
Haung
He
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150

Fig.2

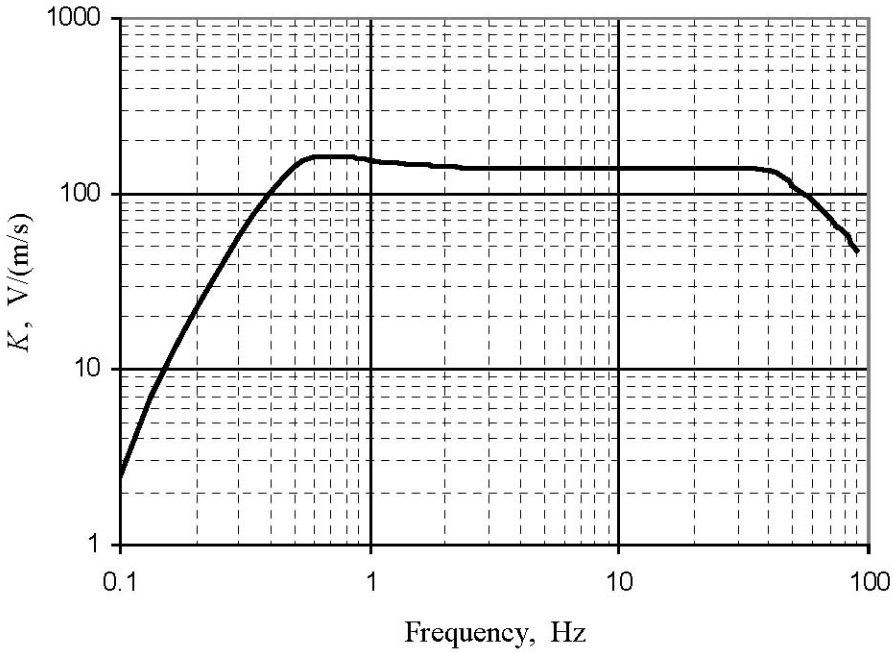


Fig.3

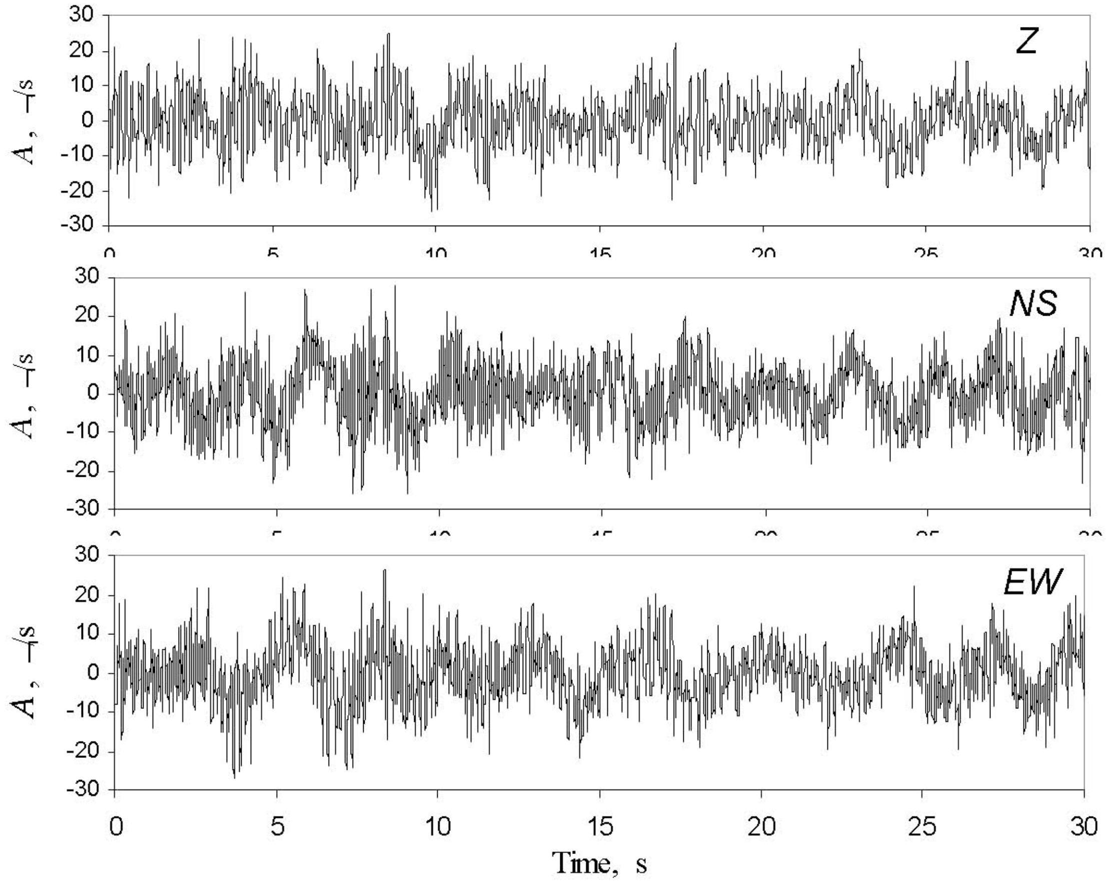
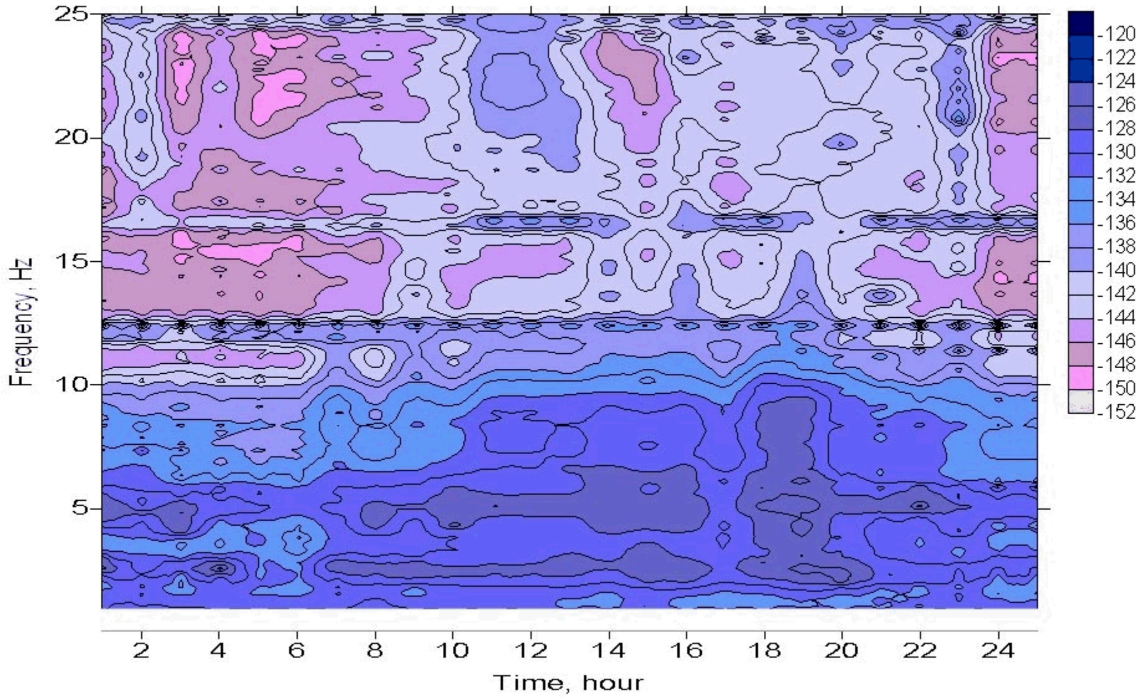
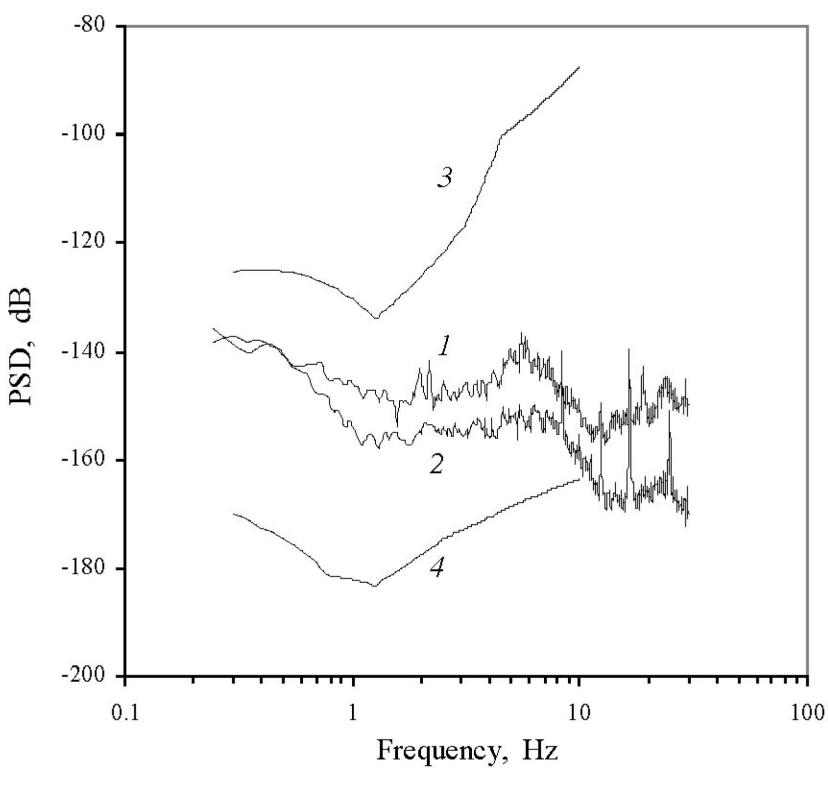


Fig.4



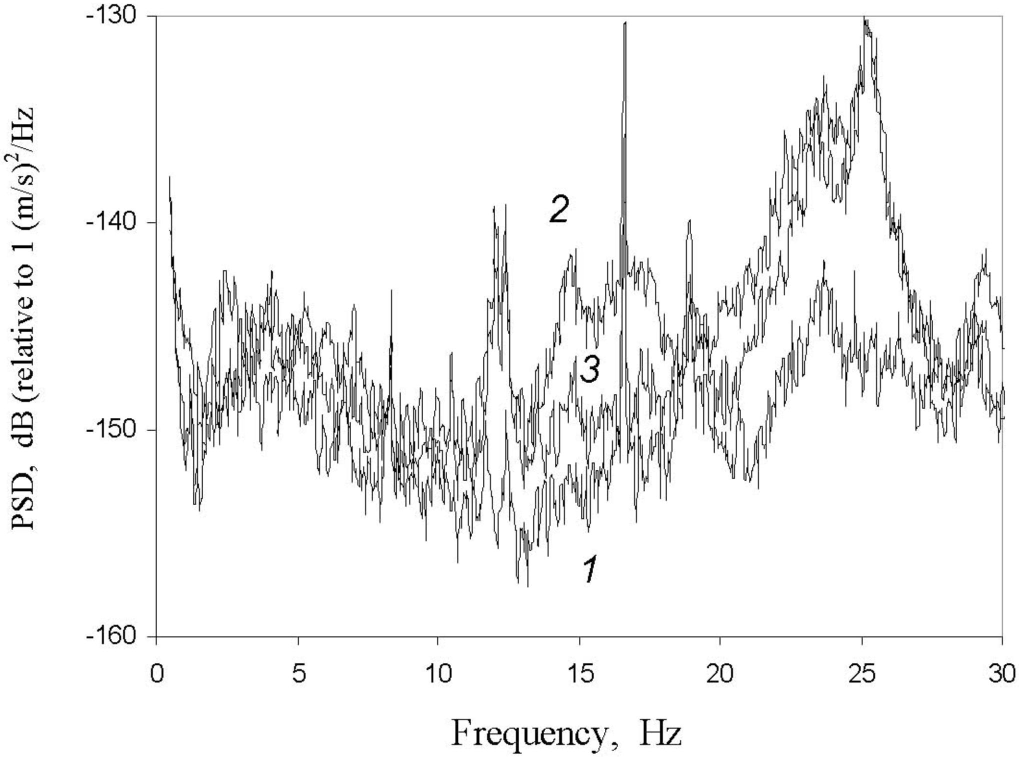
Frequency, Hz
Time, hour
25
20
15
10
5
2
4
6
8
10
12
14
16
18
20
22
24
-120
-122
-124
-126
-128
-130
-132
-134
-136
-138
-140
-142
-144
-146
-148
-150
-152

Fig.5



PSD, dB
Frequency, Hz
-80
-100
-120
-140
-160
-180
-200
0.1
1
10
100
1
2
3
4

Fig.6



-130
-140
-150
-160
0
5
10
15
20
25
30
PSD, dB (relative to 1 (m/s)^2/Hz
Frequency, Hz
2
3
1

Fig.7

30

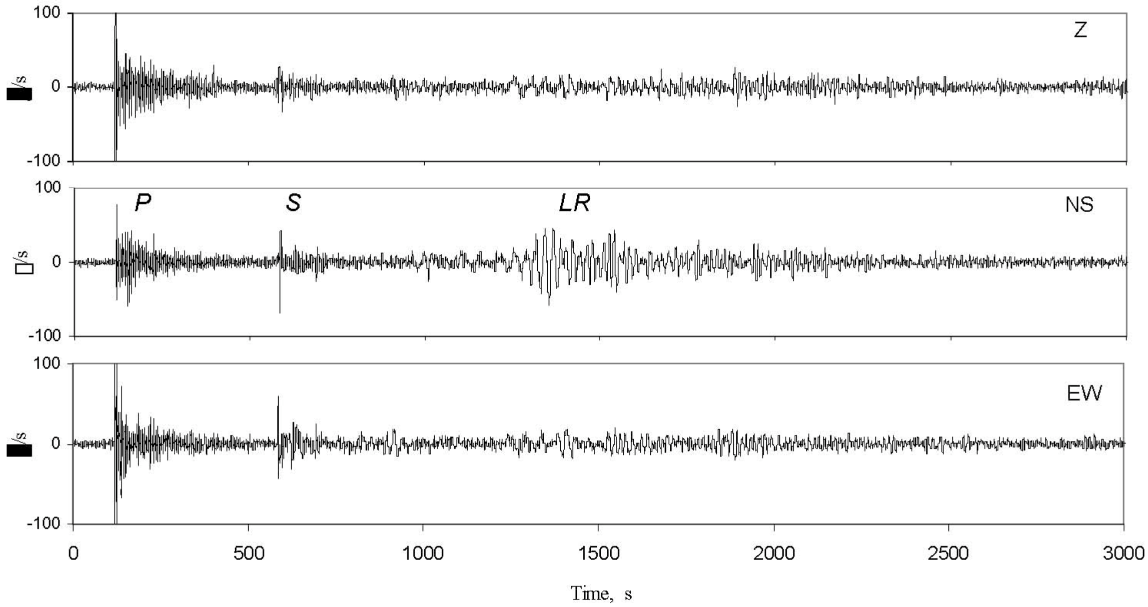


Fig.8