ANALYSIS OF THE WAVE PATTERN OF NUCLEAR EXPLOSIONS RECORDS FROM LOP NOR TEST SITE BY CENTRAL ASIA STATIONS

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Lop Nor Test Site (LNTS) is located in Xinjiang province (north-west China), about 600 km south-eastward of Kazakhstan-Chinese border. In 1964-1996 there were 47 nuclear explosions conducted including 3 surface, 19 atmospheric, and 25 underground explosions [1]. Underground nuclear tests were conducted in vertical shafts and horizontal tunnels (Figure 1). The information on charge depth is absent. Maximum yield of atmospheric nuclear explosions reached Y=4 Mt (test of November 17, 1976), and for underground nuclear explosions it reached Y=660 Kt (explosion of 21 May, 1992) [1]. The region of LNTS is located in seismically active region of Eastern Tien Shan where earthquakes with M>7.0 occur; it is characterized by complex tectonic setting. In addition to large Dzhungar fault coming from the Semipalatinsk Test Site (STS) side, the Test Site region is traversed by regional tectonic faults of the east-west trending according to orogenic structures of the East Tien Shan. All these faults including Dzhyungar fault are seismically active [2].

Monitoring system and materials used

During the operation period of LNTS on the territory of the USSR, at regional distances from the Site several national networks of seismic stations have been installed. For a long period of time the stations were analog with recording on photo paper and paper by ink pen; then, starting from 1990-s the seismic stations were upgraded, and equipped with digital instruments. On the territory of Kazakhstan the seismic monitoring was conducted by stations included into the network of Seismological Experience-Methodical Expedition MES RK (SEME MES RK) located mainly on the territory of North Tien Shan. The North Tien Shan stations were equipped with narrow-band instruments SKM-3 with amplification V=20000-40000 [4], and, in addition, the most stations were equipped with broadband instruments SKD with amplification of 1000. The EME network task was earthquakes monitoring in the south and south-east of Kazakhstan. Starting from 2003 the SEME stations network was equipped with digital instruments. Other seismic stations (permanent and temporary on the whole USSR territory) were included into the seismic network of Complex Seismological Expedition (CSE) established by the Institute of Physics of Earth (IPE) AS USSR in Talgar. The network task was not only earthquakes monitoring and study of lithosphere structure, but detection and discrimination of nuclear tests at regional and teleseismic distances. All stations were equipped with high sensitive instruments of SKM-3, USF, CSE and RVZT types with amplification V from 40000 to 120000 [5]. During Soviet period, on the territory of Kazakhstan geophysical observatories Borovoye, Kurchatov, Aktyubinsk, Makanchi have been established especially for monitoring of nuclear explosions conducted at different regions of the world. In 1994, the stations were transferred to the Institute of Geophysical Research of RK. Borovoye station started digital recording of seismic events in 1965. The archive of Borovoye seismic station (IGR RK) contains large amount of nuclear explosion seismograms including those from Lop Nor Test Site [7,8]. The digital network of the IGR RK started its operation in the mid of 1994 [9]. In Kyrgyzstan, seismic monitoring was conducted by the stations included into the network of the Institute of Seismology of Kyrgyzstan (IS NAS KR); Kyrgyz stations were equipped with SKM-3 instruments with amplification V=20000-40000 and SKD with amplification 1000; the network task was monitoring of earthquakes occurring in Kyrgyzstan [9]. The first digital station, Ala-Archa, was installed in 1991, and in 1992 KNET digital stations network started its operation, in 2007 KRNET network was put into operation [10].

Nuclear explosions seismograms accumulated in archives of Central Asia are unique and invaluable materials for works on seismic discriminating and investigation of geodynamic processes at Test Sites regions.

Figure 2 shows location of seismic stations operated in different years which seismograms were used for investigations.

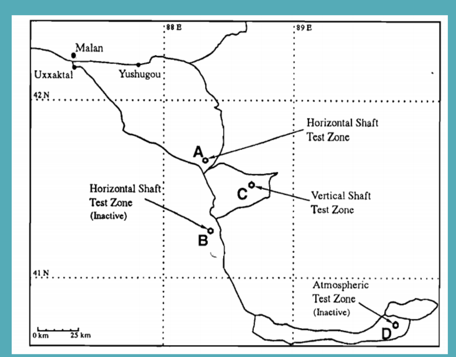

Figure 1. The layout of the Chinese Test Site. A, B - testing sites with horizontal tunnels; C- testing site with vertical shafts; D – zone of atmospheric tests [3].

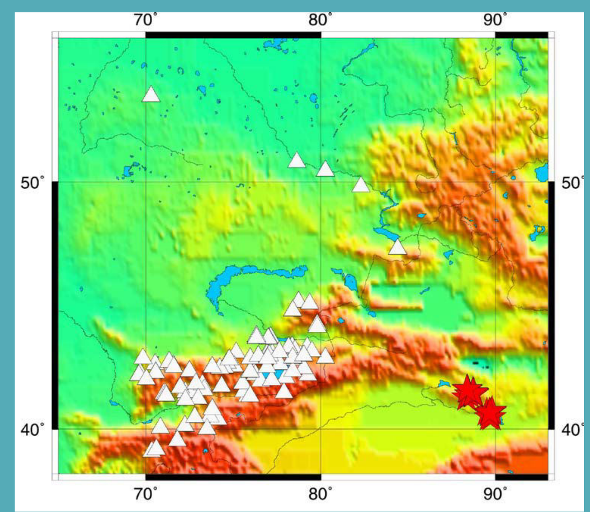

Figure 2. The map of epicenters location of nuclear explosions and seismic stations which records were used for investigations.

As analog form of record is complicated for application, especially while solving the tasks requiring digital mathematic processing, and most of nuclear explosion seismograms from LNTS were digitized. "NXSCAN" software was used for digitization [11]; the software allows digitizing of preliminary scanned seismograms in semi-automated mode. The seismograms were digitized with 40 Hz frequency. The fragments of analog seismograms digitized by NXSCAN software were saved in SAC format (Seismic Analysis Code), and after that those were converted into CSS3.0 format (Center for Seismic Studies v.3.0) [12]. The digitized material was entered the especially created data base, each record in which contains the following CSS 3.0 tables: wfdisc, site, sitechan, assoc, origin. Figure 3 shows the digitized seismograms of UNE.

To investigate the peculiarities of the wave pattern of atmospheric and underground nuclear explosions, the digitized analog records from the archives of CSE, IGR, SEME, and IS NAS KR as well as digital records from the IGR RK stations were used. In total, 565 seismic records for 23 nuclear explosions were processed; among them there were 476 UNEs at distances of 710-2550 km (Figure 4), and 89 atmospheric and surface nuclear explosions at distances of 698-2003 km (Figure 5).

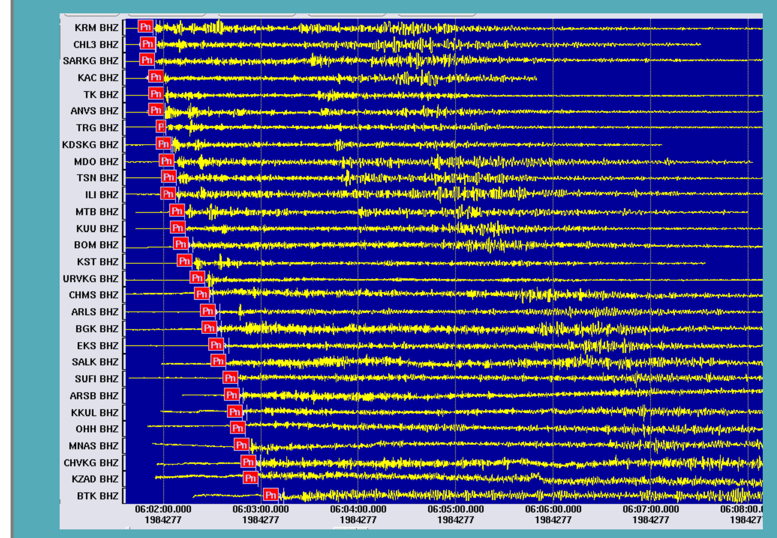

Figure 3. Seismograms of the underground nuclear explosion of October 3, 1984, t0=05-59-57.99, φ=41.5713°, λ=88.7216°, mb=5.2. Z-component.

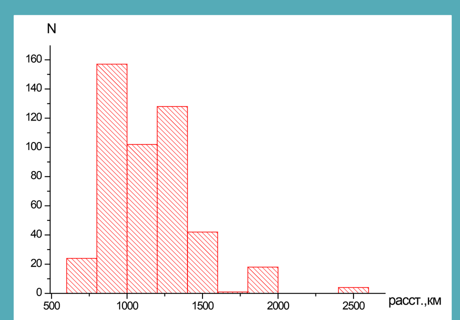

Figure 4. The diagram of UNE seismograms amount distribution from the region of Lop Nor Test Site by epicentral distances.

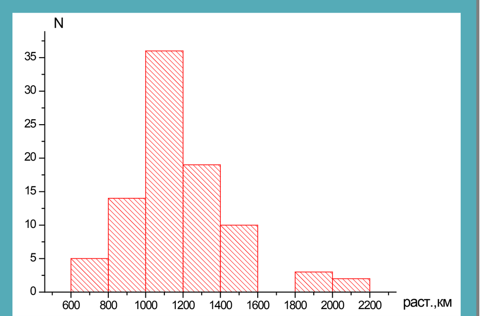

Figure 5. The diagram of atmospheric nuclear explosions seismograms amount distribution from the region of LNTS by epicentral distances.

The peculiarities of explosions conducted in different medium wave pattern.

The range of epicentral distances from LNTS to Central Asia stations corresponds to regional distances at which the wave pattern is significantly influenced by the structure of S-wave attenuation field [11, 12]. However, it is possible to reveal some similar features for the seismograms of atmospheric nuclear explosions. Figure 6 shows seismic records of the atmospheric nuclear explosion conducted on October 16, 1980, t0=04-30-29.7, φ=40.719°, λ=89.651°, the explosion yield was Y=1000 kt, the height of blasting is unknown. The records of atmospheric nuclear explosions conducted at LNTS are of low frequency, and possess all specific signs of atmospheric explosions: in seismograms Lg-wave dominates by amplitude, P-wave arrival is indistinct, S/P ratio is more than 1. Some seismograms have surface waves. The records of acoustic signal were not revealed in seismograms.

Figure 7 shows seismic records of underground nuclear explosion conducted in a vertical shaft on October 14, 1978, t0=00-59-58.01, φ=41.523°, λ=88.722°, the explosion yield is Y=3.4, depth of charge is unknown. All seismic records are of high frequency, P-wave dominates by amplitude, or S/P ratio is close to 1, first arrival is distinct, signs of first arrivals on vertical component are positive.

Figure 8 shows seismograms of different nature events occurred on the territory of LNTS Site and recorded by Borovoye seismic station located in the north of Kazakhstan at epicentral distances of 1870-2000 km. The seismograms of atmospheric nuclear explosions are of lower frequency than underground ones, Sn-wave is clearly seen, its amplitude as well as Lg-wave amplitude are close to Pn amplitude, and surface wave is observed. UNE seismogram is of higher frequency, P-wave amplitude dominates, Sn/Pn<1, Lg/Pn<1, and in the records of tectonic earthquake with epicenter close to the Test Site territory Lg-wave dominates, Lg/Pn>1.

Figure 9 shows events seismograms of different nature occurred on the territory of LNTS and recorded by Talgar seismic station located in the North Tien Shan at epicentral distances of 945-1070 km. The seismogram of the surface nuclear explosion is similar to the record of atmospheric one, only the level of Pn amplitude is higher than for the atmospheric; Sn and Lg waves are clearly seen, its maximum amplitudes are close to each other, S/P ratio >1. The UNE seismogram is of high frequency, P-wave amplitudes dominate, Sn(Lg)/Pg close to 1. On the records of the tectonic earthquake with epicenter close to the territory of the Test Site Lg-wave dominates, Lg/Pn>1.

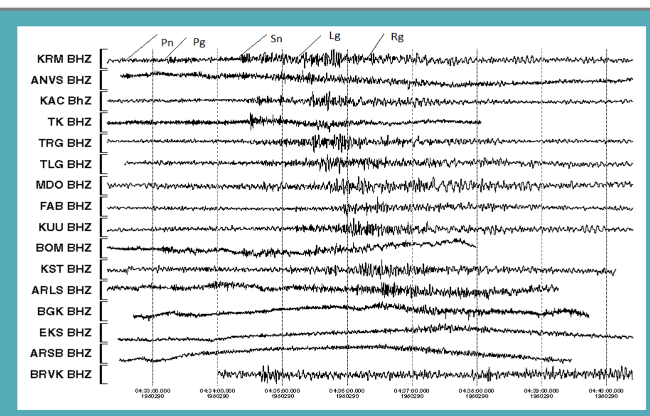

Figure 6. Seismograms of atmospheric nuclear explosion of October 16, 1980, t0=04-30-29.7, φ=40.719°, λ=89.651°.

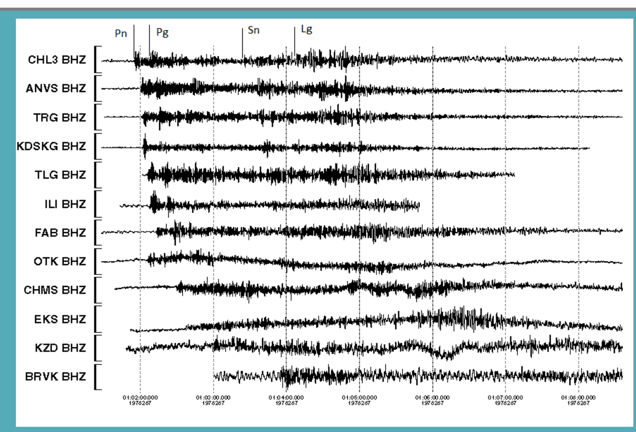

Figure 7. Seismograms of underground nuclear explosion of October 14, 1978, t0=00-59-58.01, φ=41.523°, λ=88.722°.

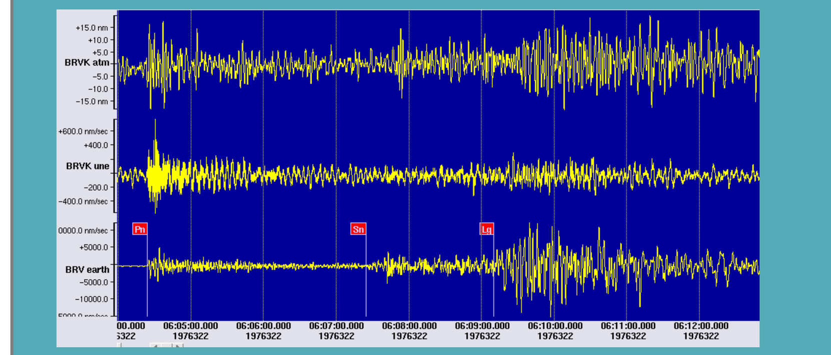

Figure 8. Seismograms up – down: atmospheric explosion of November 17, 1976, t0=06:00:12.7, φ=40.696°, λ=89.627°, mb=4.7, Underground nuclear explosion of July 29, 1996, t0=01:48:57.8, φ=41.82°, λ=88.42°, mb=4.9, tectonic earthquake of January 30, 1999, t0=03:51:05.00 φ=41.586°, λ=88.455°, mb=5.8. Z-components, BRVK station.

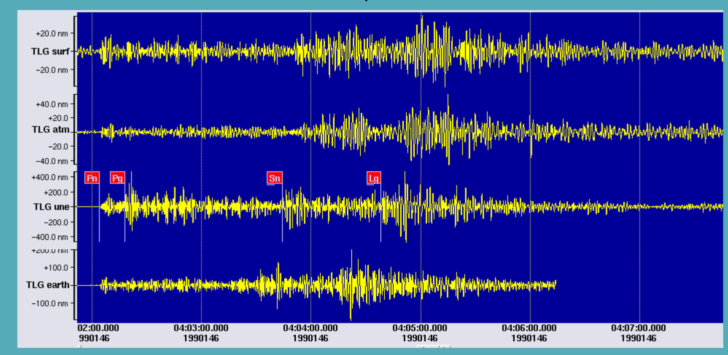

Figure 9. Seismograms up – down: surface explosion of December 28, 1966, t0=04:00, φ=41.5°, λ=88.5°, atmospheric explosion of June 17, 1973, t0=03:59:46.3, φ=40.7985°, λ=89.8091°, mb=4.8, underground nuclear explosion of May 26, 1990, t0=07:59:57.9, φ=41.569°, λ=88.701°, mb=5.5, tectonic earthquake of March 9, 1975, t0=14:04:42.5 φ=41.135°, λ=87.366°, mb=4.6. Z-components, TLG station.

Recording of atmospheric nuclear explosions at the LNTS by microbarograph.

Since 1962, on the territory Talgar seismic observatory a standard microbarograph with recording on photo paper was installed; the microbarograph recorded several atmospheric nuclear explosions conducted at LNTS. The archive of CSE contained 6 records of acoustic signals from LNTS recorded by Talgar station. The microbarograph records were collected and analyzed; Figure 10 shows the analog record of the nuclear explosion of November 17, 1976, t0=06-00-12.7, φ=40.696°, λ=89.627°, Δ=1065 km, blasting altitude is unknown, explosion yield was Y=4000 Kt, digitized record and spectrum are also shown.

The explosions yield for which acoustic signals were found varied from 0.3-4 Mt. Signals are long-period, maximum period is 120 s, average travel-time to the station is ~58 min.

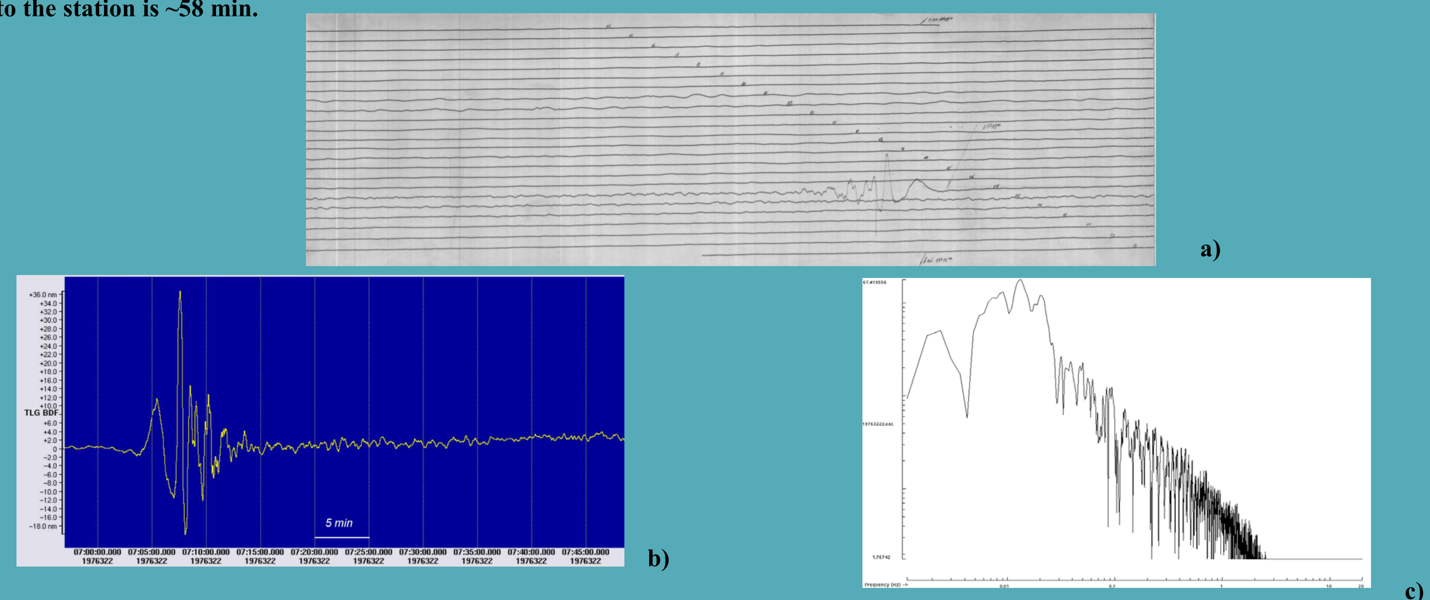

Figure 10. The record of atmospheric nuclear explosion by the microbarograph, November 17, 1976, t0=06-00-12.7, φ=40.696°, λ=89.627°, TLG station, Δ=1065 km, a) analog record, b) digitized record, c) spectrum.

Figure 11 shows mb magnitude dependence for nuclear explosions conducted in different media on explosion yield. It shows that seismic effect of explosions differs significantly depending on a source type – seismic effect of underground nuclear explosions is much higher than of atmospheric ones.

For underground nuclear explosions:
mb=4,40+0,77*lg(Y(kt)), correlation coefficient R=0.94.
For atmospheric nuclear explosions:
mb=3,48+0,33*lg(Y(kt)), correlation coefficient R=0.54.

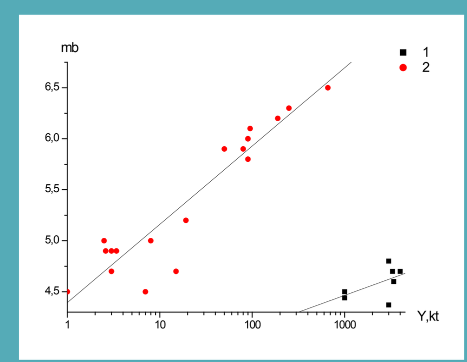

Figure 11. Dependence of mb magnitudes for nuclear explosions conducted in different media on explosion yield. 1 – mb magnitudes of atmospheric explosions, 2 –that of underground nuclear explosions.

For works on seismic discrimination of source nature the records from the following digital seismic stations of the IGR RK were analyzed: BRVK, CHKZ, KURK, MAKZ, TLG, VOS, ZRNK. In addition, data of analog stations of the CSE JIPE RAS - CHK, ZRN, VOS, TLG (SKM-3, ACC-6/12, KSE), data of analog stations of the IGR RK archive – BRVK and KURK (SKM-3) were used; analog seismograms were preliminary digitized. Tectonic earthquakes were selected from the regions constrained by coordinates ±2° from the Test Site center.

Seismic records were previously filtered. Filters with central frequency of 0.6, 1.25, 2.5, 5 Hz and pass band of 2/3 octave at the level of 3 dB to maximum were used. Filtration was made with purpose to exclude the effects produced by different spectral characteristics of seismic records because of instrument frequency characteristics difference. General frequency range was determined by instrument characteristics, magnitude and epicentral distances, outside of this range signal/noise ratio did not allow conducting measurements [13,14].

Peak amplitudes in waves Pn(P), Pg, Sn(S), Lg were measured. Common logarithms of amplitudes ratio ASn/APn, ALg/APg (for LNTS), and AS/AP (for Pokharan and Chagay Test Sites) measured at the same component were used for analysis. Figure 12a shows the results of Sn/Pn values measurement for nuclear explosions and earthquakes from LNTS region for BRVK station; it is seen that good separation of parameters is observed at frequencies of 2.5 and 5.0 Hz. Figure 12b shows the results of Sn/Pn values measured for nuclear explosions and earthquakes from LNTS region for MAKZ station; good separation of parameters is also observed at frequencies of 2.5 and 5.0 Hz.

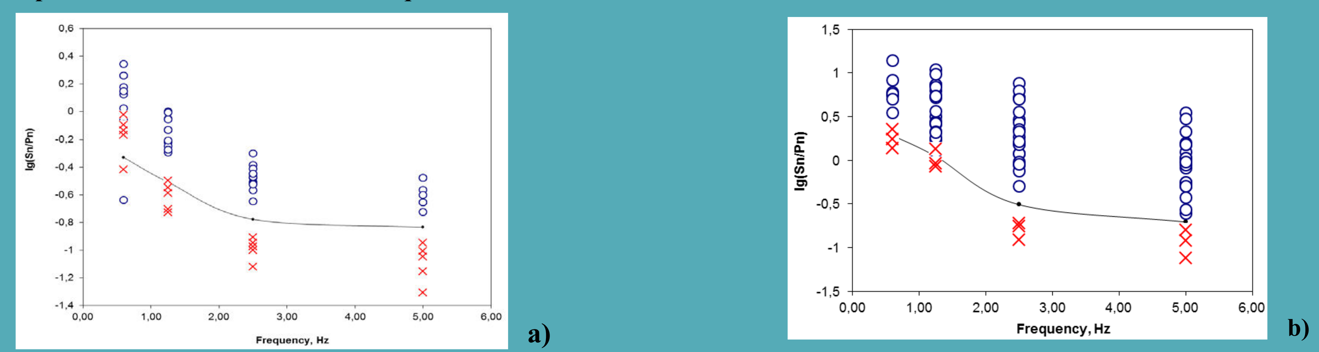

Figure 12 – Distribution of Sn/Pn values for explosions (crosses) and earthquakes (circles) from the region of LNTS, channel Z. a) BRVK station, b) MAKZ station.

Temporal variations of short-period S wave attenuation field in the area of LNTS

Earlier [15] significant temporal variations of short-period shear waves attenuation field were revealed at the region of the STS and were related to migration of deep fluids as a result of continuous intensive induced impact on geologic environment. The present work considers such variations at the region of LNTS.

We used 16 seismograms of UNEs conducted from 1969 to 1996, mb=4.5 – 6.5 (see Figure 1) [16]. The explosions yield did not exceed 700 kt. In addition, at the LNTS region and its vicinity 15 earthquakes (mb=4.5 – 5.9) have been recorded since 1969 (within the map borders shown in Figure 13). The UNE records conducted in 1969 – 1996 were processed as well as records of earthquakes occurred close to the Test Site and recorded by BRVK station located in the north of Kazakhstan (Figure 13). In total, 26 seismograms recorded in 1969-2010 at epicentral distance of ~1800-2000 km were processed.

The method related to the analysis of peak amplitudes ratio in Sn and Pn waves (lgASn/APn parameter) [11] was used. The work [17] shows that Sn group is mainly formed by shear waves reflected from sub-horizontal boundaries of the upper mantle. The amplitudes ratio is used for normalization.

In addition, the slope of P-coda envelops was analyzed. As stated earlier, P-wave coda in the considered distance range is mainly formed by waves propagated near radial plane as a result of exchange scattering of S–P type at the source area [18]. In this case coda waves traverse the crust and upper mantle at the epicenter area at sharper angles than Sn group [17, 19]. The parameter lg(Ac/Ap) was considered; Ac – the level of coda envelop at fixed lapse time moment, tc. Thereinafter the described parameters will be referred as Sn/Pn and C/P, respectively.

Vertical components of the records were preliminary filtered by a narrow-band filter (filter with central frequency of 1.25 Hz and bandwidth of 2/3 octaves was used).

Figure 14 shows the examples of the LNTS UNEs records. For the record of explosion conducted in 27.10.1975, Sn group shows relatively large amplitudes. However, for UNE record obtained 20 years later (17.08.1995), Sn/Pn ratio decreased significantly, and amplitude attenuation velocity in P-coda increased.

Figure 15 shows the graphs of Sn/Pn dependence on time for UNEs and earthquakes. The Figure shows that Sn/Pn value in UNE records decreases with time, and in 1993 – 1996 its average value is lower than that in 1969-1978, by 0.26 log unit. It is interesting that after nuclear explosions ban, the same tendency is observed also for earthquakes records: in 2007-2010 in comparison with 1994-1995 the indicated parameter decreases in average by 0.13 log units. Note that in 1993 – 1996, Sn/Pn value for earthquakes was higher than for UNEs, by 0.29 log units.

Figure 16 shows common P coda envelops for UNEs and earthquakes in different periods of time. The slope of envelops for UNE records increases significantly with time, and average values C/P at tc=380 sec decrease from -0.54 in 1969-1978 to -0.74 in 1994-1996. For earthquakes records, C/P parameter decreases from -0.62 in 1994-1999 to -0.72 in 2007-2010. Note that this parameter decreases less with time than Sn/Pn for both, UNEs and earthquakes.

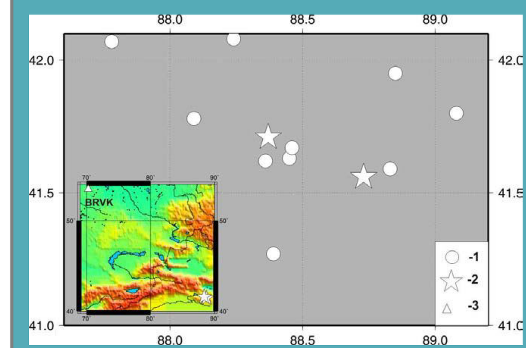

Figure 13. The map of the LNTS region. 1 – earthquake epicenters, 2 – main sites where UNE were conducted. The inset shows the Test Site location (2), and BRVK stations (3).

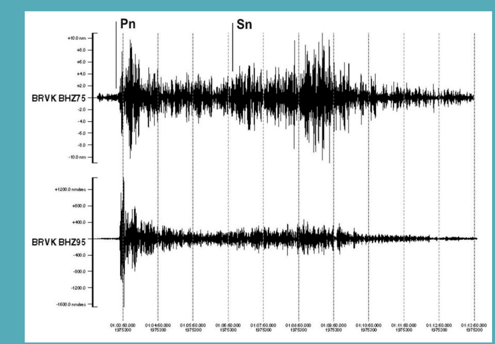

Figure 14. Examples of UNE records from the LNTS. Upper trace – explosion of 27.10.1975, lower trace – 17.08.1995. BRVK station, 1.25 Hz channel. Arrows – moments of Sn and Pn waves arrivals.

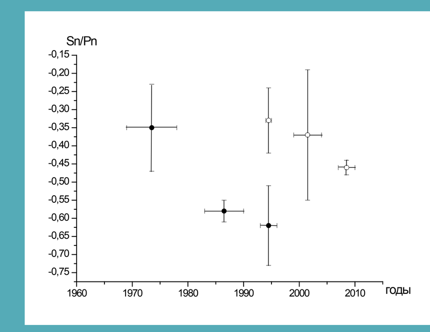

Figure 15. Dependence of average values Sn/Pn on time for the LNTS. Average values and standard deviations for UNEs (solid signs) and earthquakes are shown. Horizontal lines – intervals of data averaging.

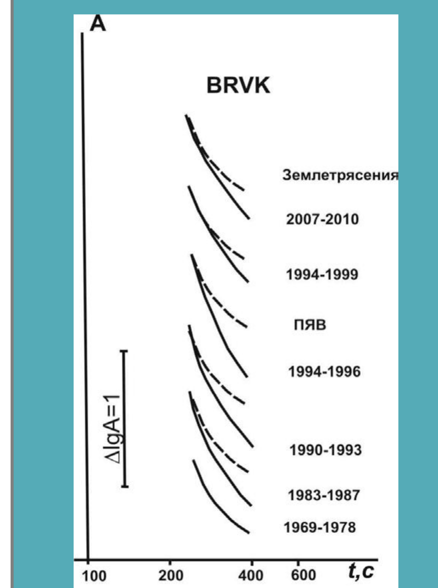

Figure 16. General envelops of P coda for UNEs and earthquakes (LNTS) in different time intervals. Dashed line – envelop for 1969-1978. t is the lapse time.

The data obtained testifies the significant increase of S-waves attenuation with time at traces propagating from the Test Site to BRVK stations. As the station is located at low seismicity area characterized by relatively weak attenuation of S-waves [20], the main variations of the attenuation field should occur within the earth crust and upper mantle of the Test Site region.

The analysis of crustal phase Lg attenuation at the east Tien Shan region described in work [21], shows that attenuation of S-waves in the earth crust at the LNTS region is relatively weak. Therefore, the main changes of the attenuation field are observed here in the upper mantle.

The most appropriate explanation of the revealed effects is connected with migration of deep fluids in the lithosphere [15, 21, 19] (partially melted material that also leads to high attenuation of S-waves cannot rise relatively quickly due to very high viscosity in comparison to fluids). Migration of fluids, probably, is a result of sharp increase of rocks permeability at vibration effects that was revealed even during model experiments [22] (and at depths corresponding to the lower crust and upper mantle the effect strengthens significantly due to buoyant force that "pushes" fluids up). In this regard, we would like to note that enlarging a lower crust permeability that led to accelerated uplift of mantle fluids was observed at the south-west region of Japan during propagation of low-frequency Rayleigh waves after large earthquakes, even at epicentral distances of ~4-5 thousand km [23].

Figure 15 shows that at the LNTS region, fluids uplift continued even after UNEs cease, despite that seismic energy of the earthquakes occurred at the region was significantly lower than that of UNEs. Earlier, the same effect was noted for the STS region ([15, 24]). This can be explained by fluids uplift process inertia after equilibrium distortion caused by intensive induced impact.

The data obtained provide new evidences that continuous induced impact is able to change the medium characteristics at quite large depths of the earth crust and upper mantle. Earlier, such evidences were obtained for the regions of Semipalatinsk, Nevada, and Novaya Zemlya Test Sites [15, 24]. It also should be noted that existence of temporal variations of shear wave attenuation field should be considered during works conducted on discriminating of UNEs and earthquakes [14].

Conclusion

Historical seismograms of nuclear explosions and earthquakes on the territory of LNTS were collected and digitized by the Complex Seismological Expedition of the IPE RAS and by the Institute of Geophysical Research of RK; the database of event records at epicentral distances of 700-2550 km from the Test Site was created. The database includes seismic records of atmospheric, surface, and underground nuclear explosions as well as tectonic earthquakes. In addition, infrasound records of waves from powerful atmospheric explosions recorded by the microbarograph Talgar seismic station at distance of~1050 km from the Test Site were collected and analyzed.

By digitized and digital records of events from LBTS we have studied dynamic parameters of conducted in different media nuclear explosion records (in the atmosphere, and underground), and found specific features of the wave pattern of each events class, and compared with earthquakes records.

We identified also temporal variations of short-period shear wave attenuation field in the LNTS region, connected with deep-seated fluid migration as a result of long intense artificial influence on geological medium.

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