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FEATURES OF THE WAVE PATTERN OF HISTORICAL ATMOSPHERIC NUCLEAR EXPLOSIONS ACCORDING TO THE DATA OF CENTRAL ASIAN STATIONS

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INTRODUCTION AND MAIN RESULTS

A large number of records of nuclear tests conducted in different environments at various test sites around the world has been accumulated in the historical archives of the Seismological Agencies of Central Asia countries. At the same time, not enough attention has been paid to the study of the features of the wave pattern of atmospheric nuclear explosions in comparison with underground nuclear explosions. The available legacy records are extremely important in connection with the task of nuclear tests detection and discrimination within the framework of the CTBT- related activity, creation and calibration of a database of reference events for the current IMS stations, and other tasks. An analysis of the dynamic and kinematic parameters, using historic seismic and infrasound records, of atmospheric nuclear explosions conducted at the Lop Nor, the Semipalatinsk, and the Novaya Zemlya test sites, is presented in the presentation.

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INTRODUCTION

The seismic technology of detection and discrimination of nuclear explosions can be used for all types of tests (except for nuclear tests in space and in the atmosphere at high altitudes, over several tens of kilometers). This type of investigation is most effective for underground and underwater nuclear explosions. Currently, there are a large number of digital seismic records of underground nuclear explosions, registered both at regional and teleseismic distances, and at the same time sufficiently reliable methods for discrimination of nuclear explosions and tectonic earthquakes have been developed. However, the number of digital and analogue seismic records of atmospheric tests is very limited. They are unique and represent a great value. This is due to the fact that mainly air and contact nuclear explosions were carried out from 1945 to 1962, before the signing of the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, или Partial Test Ban Treaty (PTBT) by Great Britain, the Soviet Union and the United States in 1963. During this period, only a small number of highly sensitive seismic stations were operating in the world. In addition, atmospheric explosions are poorly documented, many parameters are missing from catalogs or are given with large errors.

In the world, during the period of 1945-1980, 521 atmospheric explosions were carried out, their total yield was Y=479.1 Mt, and Table 1 demonstrates the distribution by countries that conducted nuclear tests in the atmosphere. In the territory of Northern Eurasia, atmospheric tests were carried out mainly at the Semipalatinsk test site (STS, USSR), the Novaya Zemlya test site (USSR) and Lop Nor test site (China).

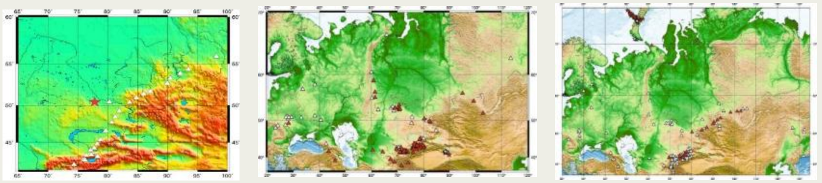
Table 1. Summary of listed detonations.

Country	Number of above ground detonations	Years	Total Yield, Mt
United States	216	1945-1962	153.8
USSR	214	1949-1962	281.6
United Kingdom	21	1952-1958	10.8
France	46	1960-1974	11.4
China	23	1964-1980	21.5

The study of the characteristics of atmospheric nuclear explosions is extremely important for solving several scientific problems: studying the parameters of fireballs, recognizing the nature of the source, modeling seismic impacts, etc.

FEATURES OF THE WAVE PATTERN OF ATMOSPHERIC NUCLEAR EXPLOSIONS AT THE STS

On the territory of the STS, the greatest number of atmospheric explosions were produced in 1961-1962, at the same time during this period powerful explosions were produced at the Novaya Zemlya test site, and at the STS low-power explosions were produced generally. The maximum yield for this period was Y = 23 Kt for the explosion of 08/21/1962, produced at an altitude of 590 m. In this regard, atmospheric explosions at the STS could be recorded by stations at regional distances, equipped with sensitive instruments (figure 1).



(a) (b) (c)

Figure 1. (a). The observation system for monitoring of the atmospheric nuclear explosions at the STS (1961-1962). Map of the location of epicenters of nuclear explosions, conducted at the Lop Nor test site: white stars – underground explosions, red stars – atmospheric and surface explosions, triangles - seismic stations, records of which were used for research: white triangles – stations that recorded only UNEs; red triangles – stations that recorded atmospheric, surface and underground explosions: (b) Lop Nor test site; (c) Novaya Zemlya test site.

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Figure 2 demonstrates seismograms of an atmospheric explosion on November 14, 1962, conducted at an altitude of 660 m, with yield of 12 Kt. Based on the records of analog seismograms, the parameters of the explosion were re-established: t_0=11-32-15.6, lat=50.4227°N, lon=77.7231°E, mpva=2.8. The records of air and contact explosions at the STS Experimental Field have all the characteristic features of atmospheric explosions, namely powerful surface waves that dominate in amplitude, unclear P arrival, the S/P ratio is greater than 1, and many seismograms show a record of an acoustic wave (figure 3).

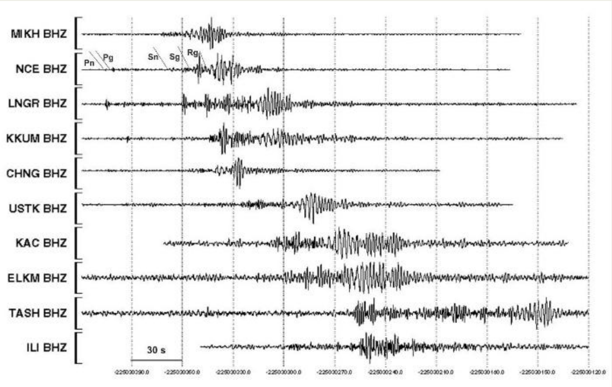
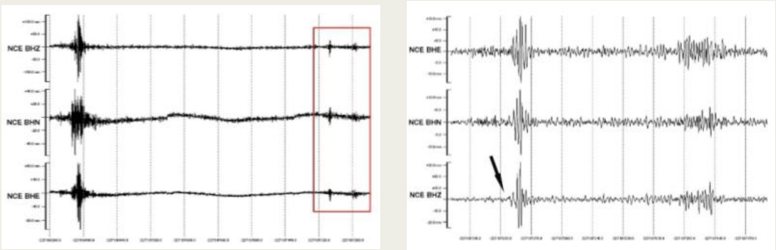


Figure 2. Seismograms of the atmospheric explosion on November 14, 1962, t_0=11-32-15.6, lat=50.4227°N, lon=77.7231°E, mpva=2.8. Z-component.

The acoustic wave was registered for many events, recorded by the regional stations. The acoustic wave records (figure 7 (b)) are clearly visible on both horizontal and vertical components and represent a «train» of oscillations with periods of 1-3 s.



(a) (b)

Figure 3. (a). Seismograms of the atmospheric explosion on October 20, 1962, t_0=09-21-45.6, lat=50.4227°N, lon=77.7231°E, NCE station (328 km). (b). Record of acoustic wave from the atmospheric explosion on October 20, 1962, t_0=09-21-45.6, lat=50.4227°N, lon=77.7231°E, NCE station (328 km).

Figure 4 demonstrates records of explosions produced in different environments at the STS, and recorded by one station, Kzyl-Agach (KAC), SKM seismometer. The upper record is the atmospheric nuclear explosion with an yield of 9.2 Kt, produced at the Experimental Field site of the STS on October 10, 1962, at a distance of 565 km; the second record from the top is a surface nuclear explosion with a yield of 9.9 Kt on August 7, 1962, produced at the Experimental Field site, the epicentral distance was 565 km; the third explosion from the top is an underground nuclear explosion on October 18, 1984 with a yield of less than 20 Kt, conducted in a tunnel at the Degelen site at an epicentral distance of 494 km from the station; the lower trace is a chemical explosion at the STS, an epicentral distance is 506 km.

It is evident from the figure that, despite the fact that the explosions are located practically in the same place, the waveform of event differs significantly depending on the type of source. Atmospheric and surface explosions have a number of similar features, surface waves dominated here, there are unclear Pn arrivals, but the record of a contact explosion has a higher frequency compared to an atmospheric explosion.

An underground nuclear explosion has a completely different waveform, the Lg wave dominates, the Pn arrival is clear, the record is high-frequency, the level of surface waves is very low. Lg waves are also dominated in the record of a chemical explosion, the Pn level is low, the arrival is unclear, Pg dominates among body waves, the record is high-frequency.

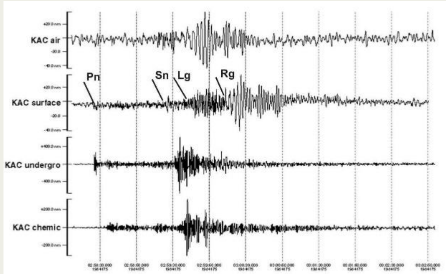


Figure 4. Records of different types of explosions at the STS, KAC station (Δ~ 500 km). The upper record is an air nuclear explosion, the second record from the top is a surface nuclear explosion, the third record from the top is an underground nuclear explosion, conducted in the tunnel at the Degelen site, the lower one is a chemical explosion at the STS. Z channel.

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Figure 5 presents records of explosions produced in different environments at the STS, registered by the Semipalatinsk (SEM) station, located in eastern Kazakhstan. The upper record is an atmospheric nuclear explosion with a yield of 13 Kt, produced at the Experimental Field site on October 4, 1961, distance is 166 km, the second record from the top is an underground nuclear explosion on December 14, 1980 with the yield of 20-150 Kt, conducted in a borehole at the Balapan site at an epicentral distance of 166 km from the station, the third record is an underground nuclear explosion on June 25, 1980 with a yield of less than 20 Kt, conducted in a tunnel at the Degelen site at an epicentral distance of 166 km from the station, the lower trace is a calibration chemical explosion, conducted at the STS on August 22, 1998, with a yield of 100 t, epicentral distance is 176 km.

It is evident from the figure that records of nuclear and chemical explosions have a number of similar features: the S-wave dominates in all records; for underground nuclear and calibration explosions, clear P-wave arrivals are observed, the S/P ratio is greater than 1; for an atmospheric explosion, the amplitude level of P-waves is significantly lower than that of underground explosions, and the amplitude level of surface waves is greater than that of an UNE and chemical explosion.

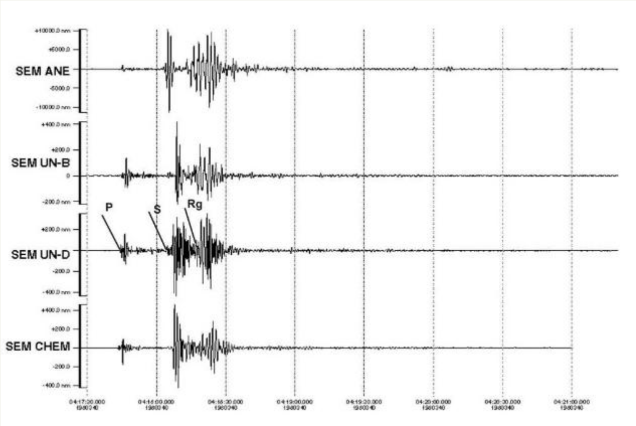

Figure 5. Records of explosions of different types at the Semipalatinsk test site, SEM station (Δ~170 km). From top to bottom: record of an air nuclear explosion, an underground nuclear explosion in a borehole at the Balapan site, an underground nuclear explosion in a tunnel at the Degelen site, a chemical explosion at the STS. SKM filter. Z-channel.

For research in the area of nuclear test monitoring, the dependences of nuclear explosion magnitudes on the yield and the features of tests represent a great interest. Figure 6 shows that the greatest seismic effect is caused by UNEs produced in boreholes, the seismic effect is slightly lower for UNEs produced in tunnels, and the lowest seismic effect is caused by atmospheric nuclear explosions.

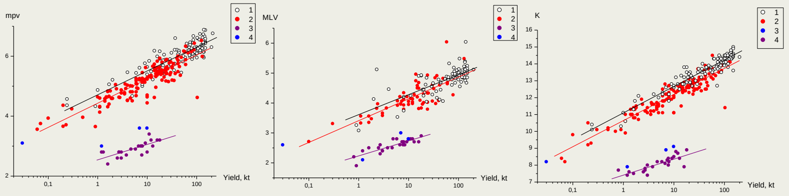

Figure 6. Dependence of nuclear explosion magnitudes on the yield: (a) mpv; (b) MLV; (c) energy class K. The graphs show: 1 – UNEs produced in boreholes at the Balapan and Sary-Uzen sites; 2 – UNEs produced in tunnels at the Degelen site; 3 – nuclear explosions produced on the surface (on towers) at the Experimental Field site; 4 – nuclear explosions produced in the atmosphere above the Experimental Field site. Regression lines are shown: purple line – for atmospheric explosions, red – for UNEs at the Degelen site, black – for UNEs at the Balapan and Sary-Uzen sites.

FEATURES OF THE WAVE PATTERN OF ATMOSPHERIC NUCLEAR EXPLOSIONS AT THE LOP NOR TEST SITE

To study the features of the wave pattern of atmospheric and underground nuclear explosions, conducted at the Lop Nor Test Site, both analog and digital records from the historical archives of the Seismological Agencies of Central Asia countries were used. In total, ~600 seismic records for 23 nuclear explosions were processed, including ~500 seismograms of UNE at distances of 710-2550 km and ~100 seismograms of air and surface NE at distances of 698-2003 km.

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The range of epicentral distances from the Lop Nor test site to the Central Asian stations corresponds to regional distances at which the wave pattern of the record is significantly affected by the structure of the S-wave absorption field. Nevertheless, a number of similar features can be identified for records of air nuclear explosions. Records of air nuclear explosions produced at the Lop Nor test site are low-frequency, have all the characteristic features of air explosions, the Lg wave dominates in amplitude on the seismograms, an unclear P arrival is observed, the S/P ratio is greater than 1. Surface waves are present on some seismograms. No acoustic signal records were found on the seismograms.

Figure 7 demonstrates records of events of various natures on the territory of the Lop Nor test site, registered by the Borovoe seismic station located in Northern Kazakhstan at epicentral distances of 1870-2000 km. The record of an atmospheric nuclear explosion has lower frequencies compared to an UNE, the Sn wave is clearly distinguished, its amplitude, as well as the amplitude of the Lg wave are close to the amplitude of Pn, the ratio of the amplitudes Sn(Lg)/Pn is close to 1, a surface wave is observed, the UNE seismogram is high-frequency, the amplitudes of the P wave dominate, Sn/Pn < 1, Lg/Pn < 1, the Lg wave dominates on the records of a tectonic earthquake with an epicenter close to the test site territory, Lg/Pn > 1.

Figure 8 presents records of events of various natures on the territory of the Lop Nor test site, recorded by the Talgar seismic station located in the Northern Tien Shan at epicentral distances of 945-1070 km. The record of a surface nuclear explosion is similar to the record of an atmospheric one, only the amplitude level Pn is higher than for an atmospheric one, Sn and Lg waves are clearly distinguished, their maximum amplitudes are close to each other, the amplitude ratio S/P > 1, the record of an UNE is high-frequency, the amplitudes of the P-wave dominate, Sn(Lg)/Pg is close to 1, in the records of a tectonic earthquake with an epicenter close to the test site territory the Lg-wave dominates, Lg/Pn > 1.

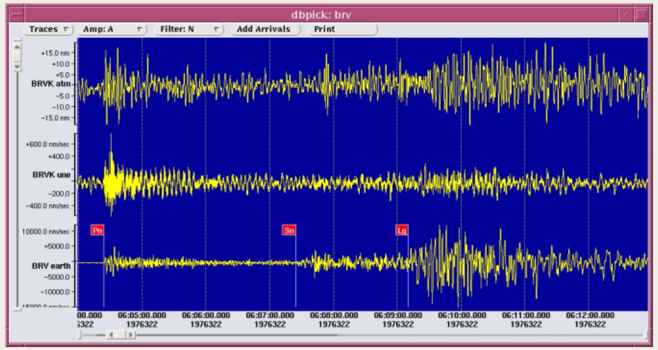

Figure 7. Records from top to bottom: atmospheric explosion of November 17, 1976, t_0=06:00:12.7, lat=40.696°N, lon=89.627°E, mb=4.7; underground nuclear explosion of July 29, 1996, t_0=01:48:57.8, lat=41.82°N, lon=88.42°E, mb=4.9; tectonic earthquake of January 30, 1999, t_0=03:51:05.00, lat=41.586°N, lon=88.455°E, mb=5.8. Z-components, BRVK station.

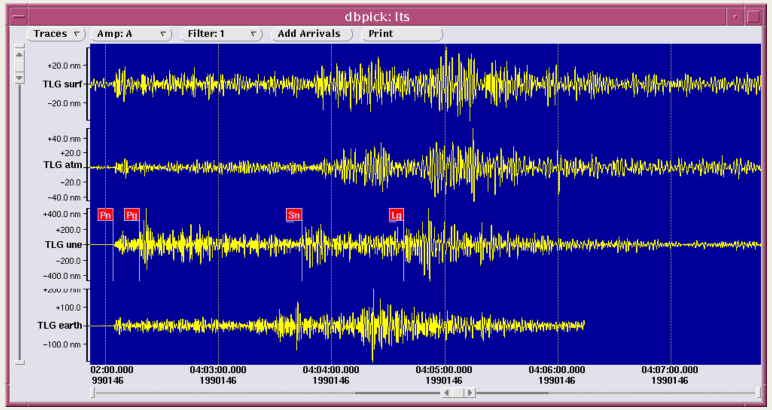

Figure 8. Records from top to bottom: surface explosion on December 28, 1966, t_0=04:00, lat=41.5°N, lon=88.5°E; atmospheric explosion on June 17, 1973, t_0=03:59:46.3, lat=40.7985°N, lon=89.8091°E, mb=4.8; underground nuclear explosion on May 26, 1990, t_0=07:59:57.9, lat=41.569°N, lon=88.701°E, mb=5.5; tectonic earthquake on March 9, 1975, t_0=14:04:42.5 lat=41.135°N, lon=87.366°E, mb=4.6. Z-components, TLG station.

Figure 9 demonstrates the dependence of the magnitudes mpv, mb and K_R for nuclear explosions conducted in different environments on the explosion's yield. It is evident that the seismic effect of explosions differs significantly depending on the type of source - for underground nuclear explosions the seismic effect is significantly higher than for air explosions.

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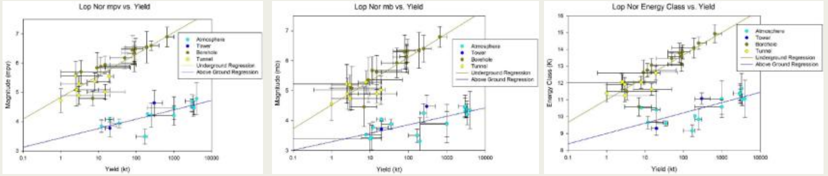

Figure 9. Dependence of magnitudes and energy classes of nuclear explosions conducted in different environments as a function of explosion's yield: (a) mpv; (b) mb; (c) K_R-class. Uncertainties for K_R-class represent one standard deviation of individual station determinations. Uncertainties for yield represent the min/max range.

FEATURES OF THE WAVE PATTERN OF ATMOSPHERIC NUCLEAR EXPLOSIONS CONDUCTED ON NOVAYA ZEMLYA

Eighty-five atmospheric nuclear tests were conducted on Novaya Zemlya from September 24, 1957 to December 25, 1962, with a total yield of 239.6 Mt. The distance from the area of atmospheric nuclear tests to the Central Asian stations was 2600–3800 km. At such distances, only atmospheric explosions with the yield range of 0.4–58 Mt were recorded. The records of air nuclear explosions produced at the Novaya Zemlya test site are low-frequency and have all the characteristic features of air explosions: powerful surface waves that dominate in amplitude, unclear arrival of the P-wave, the value of the S/P ratio is greater than 1. Figure 10 shows an example of a seismic record of an air nuclear explosion produced at an altitude of 3230 m on October 22, 1962, t_0=09- 06-10.1, lat=73.4°N, lon=54.9°N, the explosion yield is Y=8200 Kt. It is noted that a feature of seismic records of atmospheric and contact nuclear explosions, recorded by standard long-period seismometers, is the presence of characteristic oscillations on the seismograms that coincide in arrival time and waveform, especially in the initial section, with the corresponding records of microbarographs.

The reason for the registration of acoustic waves from nuclear explosions by a seismometer is the ground movement caused by a change in the loading of the earth's surface when an acoustic wave passes over the location of the seismometer.

For atmospheric explosions, 6 acoustic wave records were found on the seismograms of the Alma-Ata (AAA) and Talgar (TLG) stations. Figure 11 presents a record of an air explosion with the yield of 8.2 Mt on October 22, 1962, t_0=09:06:10.1, lat=73.4°N, lon=54.9°E, registered by the AAA station at a distance of 3550 km. The acoustic wave record (AAA station) is visible only on the vertical component and is a «train» of oscillations with large periods, reaching of 3 minutes.

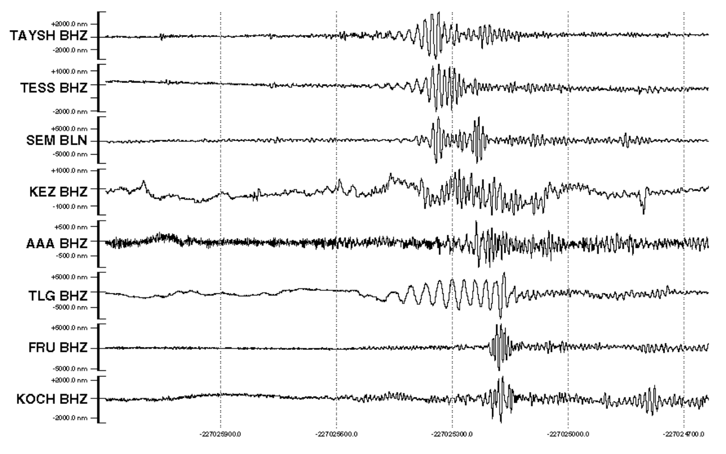

Figure 10. Seismograms of the air nuclear explosion of October 22, 1962, t_0=09-06-10.1, lat=73.4°N, lon=54.9°E.

(a)

(b)

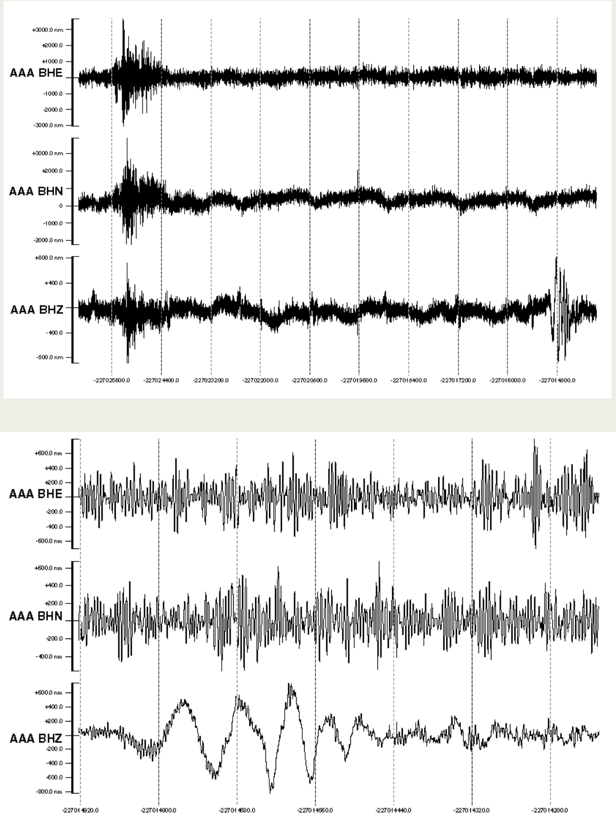

Figure 11. Seismograms and acoustic wave record of the atmospheric nuclear explosion of October 22, 1962: t_0=09:06:10.1, lat=73.400°N, lon=54.900°E: (a) full record of the nuclear explosion; (b) specification of acoustic wave. Alma-Ata station (AAA). Epicentral distance is 3550 km.

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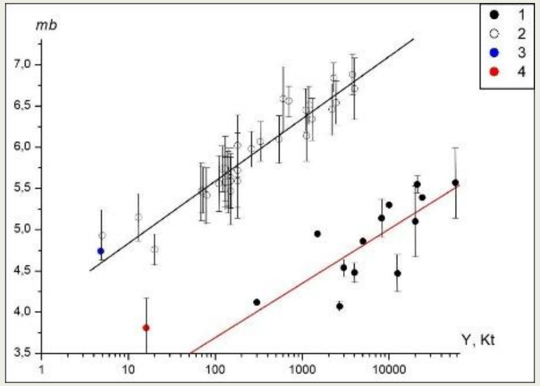
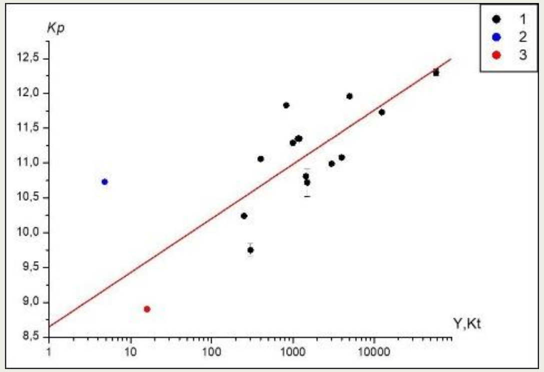
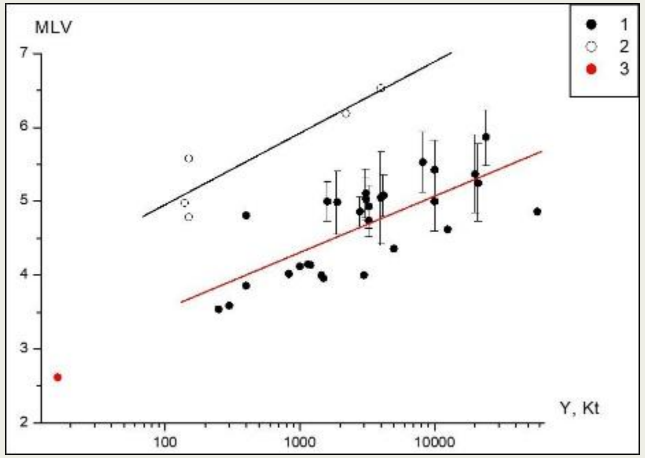
Figure 12 demonstrates the dependence of the magnitudes mb, MLV, K_R for nuclear explosions conducted in different environments on the yield of the explosion. It is evident that the seismic effect of explosions differs significantly depending on the type of source- the seismic effect of underground nuclear explosions is significantly higher than of air explosions.



(a)



(b)



(c)

Figure 12. Dependence of the magnitude of nuclear explosions on the yield: (a) mb; (b) MLV; (c) energy class K_R. On the graph: (a) 1 - atmospheric nuclear explosions, 2 - UNE, 3 - underwater nuclear explosion, 4 - above-water nuclear explosion; (b) 1 - atmospheric nuclear explosions, 2 - underwater nuclear explosion, 3 - above-water nuclear explosion; (c) 1 - atmospheric nuclear explosions, 2 - UNE, 3 - above-water nuclear explosion.

CONCLUSION

Seismic bulletins of nuclear explosions conducted in different environments have been created: atmospheric, surface, underground nuclear explosions for the Lop Nor, Semipalatinsk and Novaya Zemlya test sites. In total, several thousand seismograms at regional and teleseismic distances have been processed. Dynamic parameters of records of nuclear explosions conducted in different environments have been studied, characteristic features of the wave pattern of each type of events have been found, magnitudes mb and MLV and energy class K_R have been calculated, that allowed to re-establish the missing parameters of the catalog of nuclear explosions at these test sites. Dependences of magnitudes on the yield of explosions for each test site have been found. It is shown that for STS, the seismic effect of UNEs produced in boreholes is higher than UNEs conducted in tunnels. The seismic effect of atmospheric explosions is significantly lower than the seismic effect of UNEs.