SnT 2023

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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19 TO 23 JUNE

Spatio-temporal variations of short-period S wave attenuation field in the region of Semipalatinsk Test Site (using recordings of nuclear and chemical explosions)

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O2.5-417

Presentation Date: 20 June 2023

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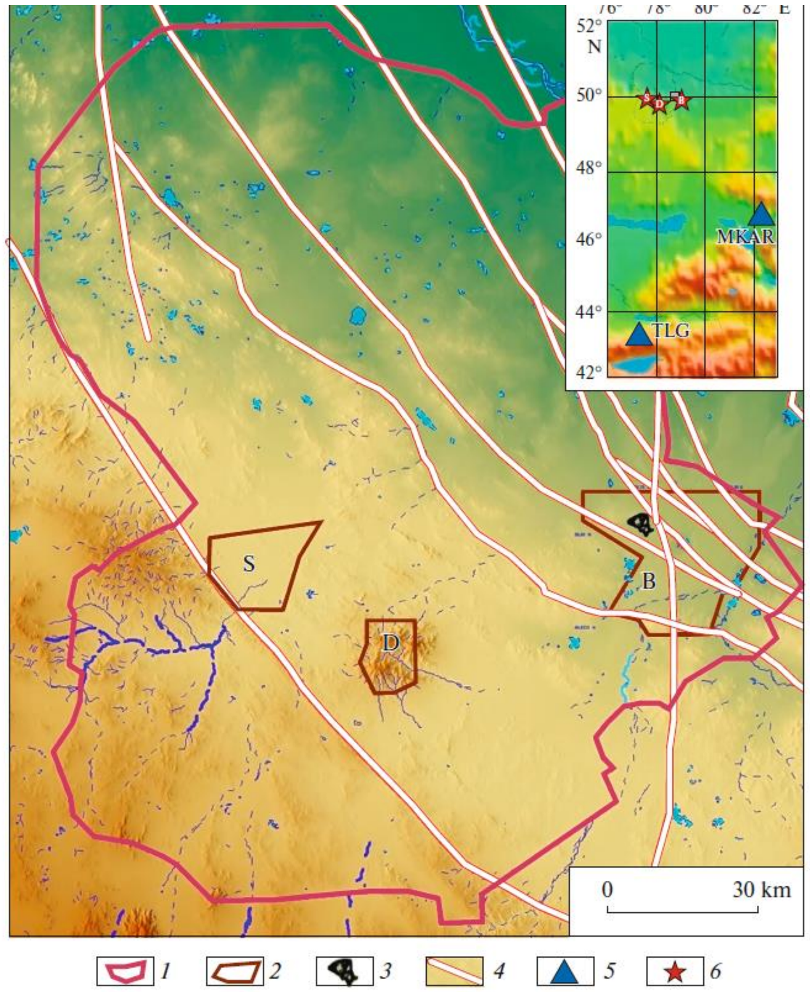
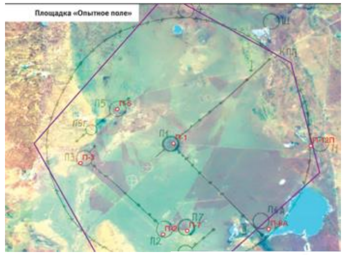
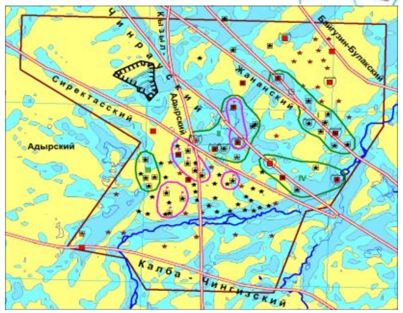


Map of the study area. (*1*) STS territory; (*2*) explosion sites: Sary-Uzen (S), Degelen (D), and Balapan (B); (*3*) Kara-Zhyra quarry; and (*4*) fault zones. Inset: (*5*) remote stations and (*6*) main explosion sites on the STS territory.

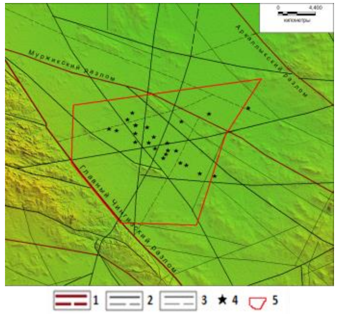


Opytnoye pole

Degelen



Balapan



Sary-Uzen

This presentation considers the spatiotemporal variations in the structure of the attenuation field in the region of the Semipalatinsk test site. It is known that there were 466 nuclear tests in the STS region for 40 years (from 1949 to 1989), including 30 surface, 88 atmospheric, and 348 underground nuclear explosions (UNEs). UNEs have been conducted since 1961 with a maximum yield of about 150 kt.

In this regard, the STS territory is a unique natural laboratory allowing one to study the effects associated with an intense and sufficiently long-term anthropogenic impact on the geological environment in a tectonically “quiet” region (unlike the territories of the other two large nuclear test sites of Nevada and LopNor).

It should be noted that temporal variations in the attenuation field can also be considered after the largest series of UNEs, since a significant number of relatively strong calibration and quarry blasts have been carried out in the STS region since the late 1990s.

It is significant that the Balapan area includes the large Kalba-Chingiz and Chinrau faults. There are only small fractures in the Degelen and Sary-Uzen areas. The large Main Chingiz fault is located just south of these areas. The average thickness of the STS crust is 44 km.

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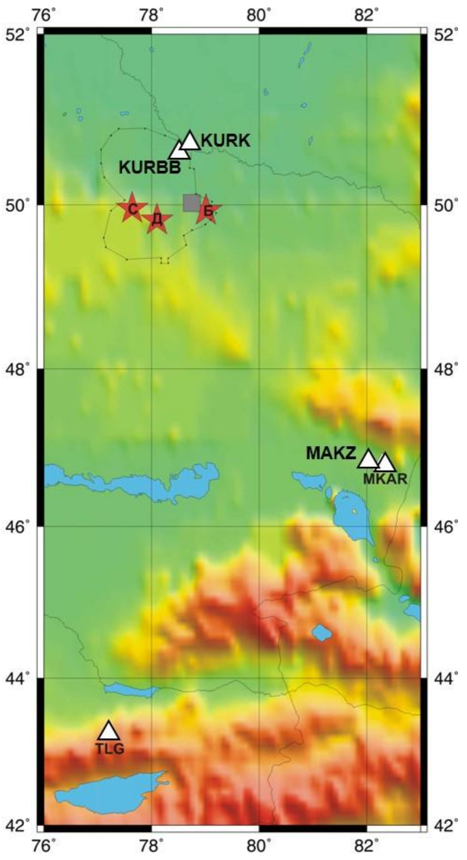
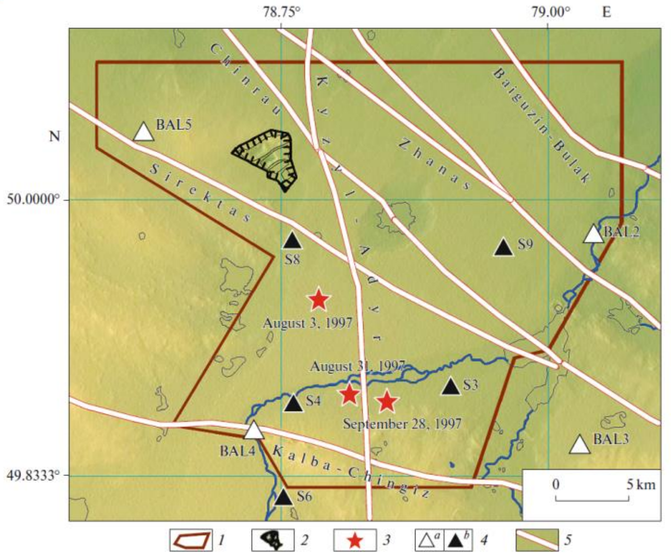
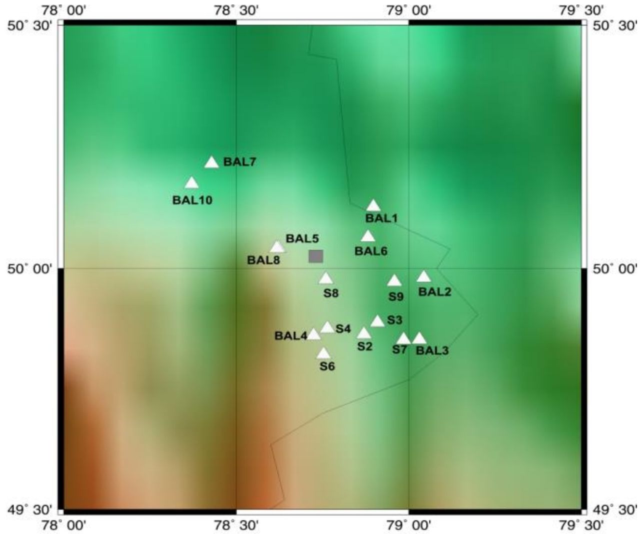


Maps of investigated regions. Triangles – permanent stations, square – Kara-Zhyra quarry. The STS borders are shown.



Map of the Balapan site. (*1*) Site boundaries, (*2*) Kara-Zhyra quarry, (*3*) epicenters of calibration explosions, (*4*) seismic stations recording (*a*) quarry explosions and (*b*) calibration explosions, and (*5*) deep-seated faults.

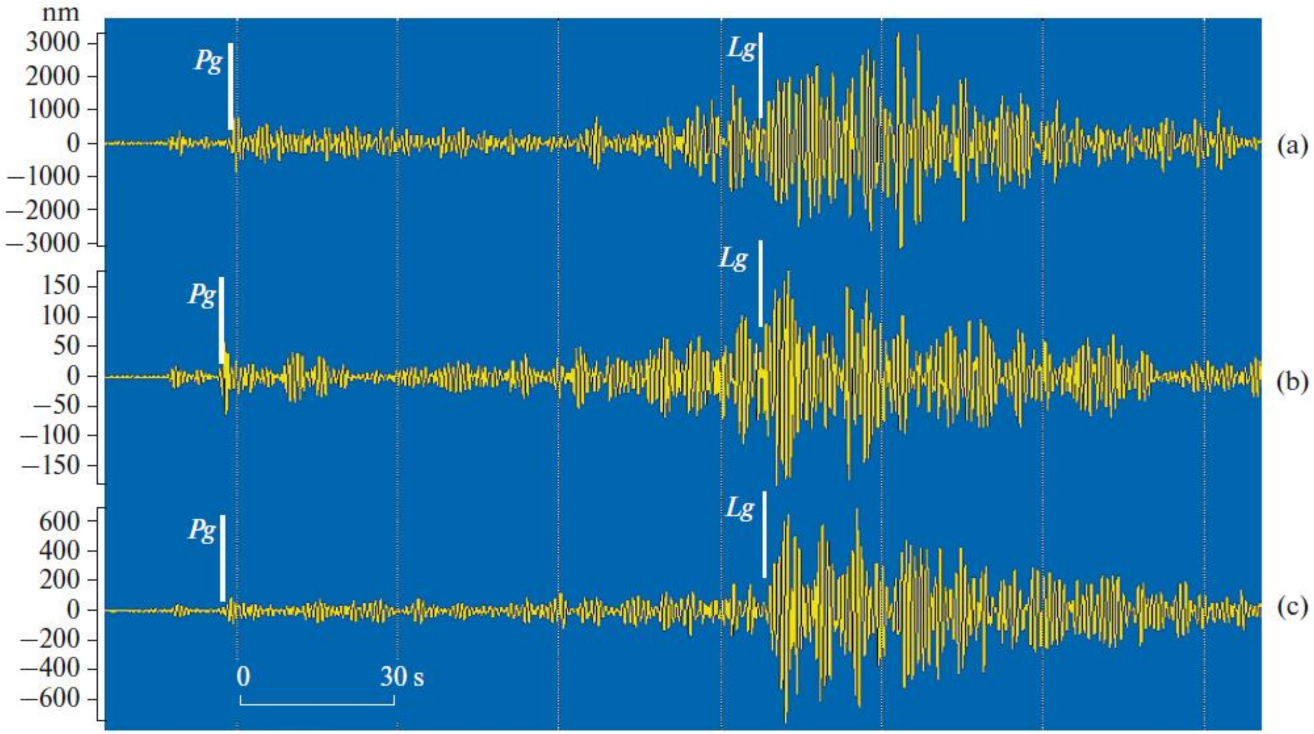


The map of seismic stations location at Balapan site. Triangles are stations, square is Kara-Zhyra quarry.

More than 260 UNE records obtained in 1964–1989 for the TLG station located in the Northern Tien Shan have been processed. The seismograms recorded by the SKM seismometer were previously digitized. We also considered records of three chemical calibration explosions with an yield of 25 t, which were conducted in 1997 in the area of the Balapan site. Seismograms were obtained by three-component digital narrow-band stations located in the near zone at epicentral distances from 2 to 18 km.

In addition, we analyzed records of chemical explosions conducted at the Balapan site since the early 2000s. The records were received by field stations located in the near zone from the quarry, as well as by the MKAR station installed on the border of Western Altai (Eastern Kazakhstan). A total of about 200 seismograms were processed.

Spatio-temporal variations of short-period S wave attenuation field in the region of Semipalatinsk Test Site (using recordings of nuclear and chemical explosions)



Examples of seismograms of underground nuclear explosions conducted at different STS sites. (a) Balapan (September 14, 1988, *t*0 = 03-59-57.4, Δ = 743 km); (b) Degelen (October 18, 1988, *t*0 = 03-40-06.6, Δ = 739 km); and (c) Sary-Uzen (February 16, 1979, *t*0 = 04-04-00.5, Δ = 750 km). TLG station, vertical component, 1.25 Hz filter. *Pg* and *Lg* wave arrivals are marked according to the travel-time curves.

RESEARCH METHODOLOGY

The records of regional stations (TLG and MKAR) were used to analyze the ratio of the maximum amplitudes in the *Lg* and *Pg* groups (parameter *lg*(*ALg*/*APg*)); for brevity, this ratio is denoted as *Lg*/*Pg*. The *Lg* group represents a set of shear waves reflected from crust boundaries; therefore, this parameter characterizes the integral attenuation of *S* waves along the entire source-to-station path.

In addition, we considered the characteristics of the short-period *S*-coda in the records of calibration and chemical quarry explosions obtained by nearby stations. At frequencies around 1 Hz, the *S*-coda is formed by shear waves reflected from multiple subhorizontal boundaries in the earth's crust and upper mantle; therefore, the record envelopes allow one to map in detail the attenuation field inhomogeneities at depths up to ~200 km. Different-slope sections were identified on the coda envelopes; the effective quality factor *Qs* for each section was determined by the formula

$$A(t) \sim \exp(-\pi t / Q_s T)/t,$$

where *t* is the lapse time from radiation onset in the source and *T* is the oscillation period.

The processing of digital seismograms was based on narrow-band frequency filtering by a filter with a central frequency of 1.25 Hz.

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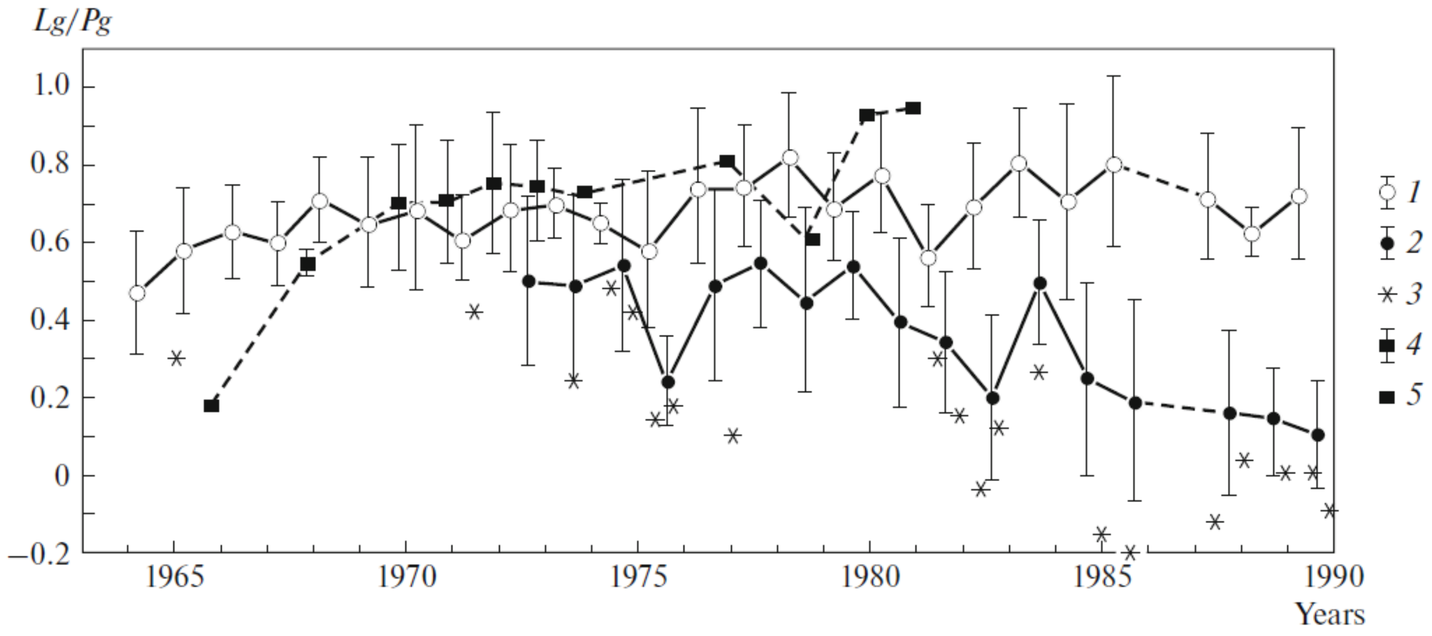
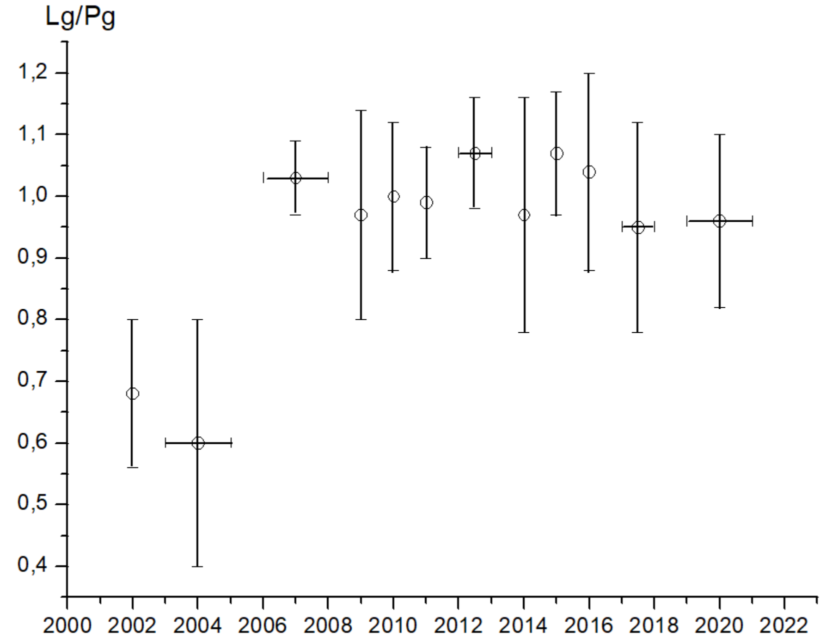


Variations in Lg/Pg for underground nuclear explosions conducted on the STS territory and recorded at TLG station. Average annual values and standard deviations for Degelen (*1*), Balapan (*2*), and Sary-Uzen (*4*) sites, as well as data for individual explosions at the Balapan site with epicenters close to fault zones (*3*) and for individual explosions at the Sary-Uzen site (*5*).

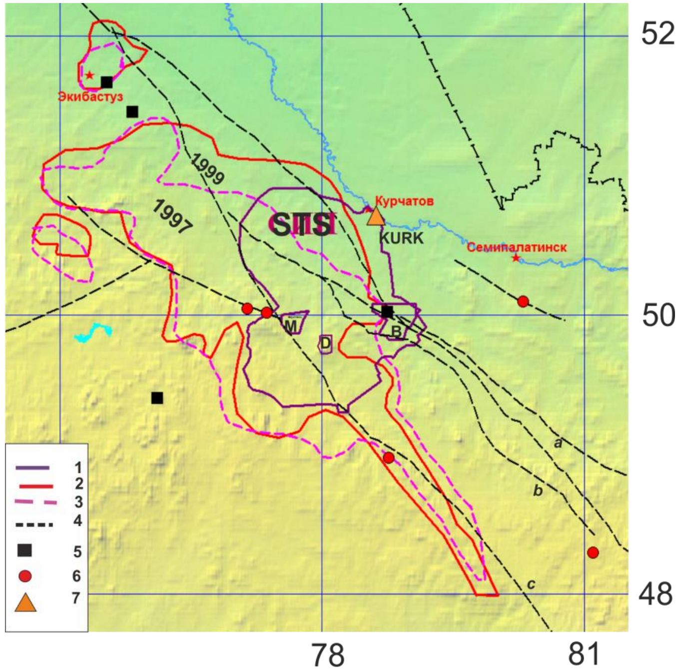
The analysis of the amplitude ratio of Lg and Pg waves from a few hundred UNEs records obtained by TLG station showed that crustal attenuation of S waves appreciably decreased in the Degelen and Sary-Uzen areas from the mid-1960s to the end of the 1970s and markedly increased in the Balapan area in the 1980s. The Lg/Pg averages over the Degelen area and particularly over Murzhik area (smaller amount of data) are considerably larger than in the Balapan area. The ratio significantly varies with time for all three areas.



Variations in Lg/Pg for explosions conducted in the Sary-Uzen quarry and recorded at MKAR station. Averages, standard deviations, and data averaging intervals (in other cases, annual averages).

Figure shows the temporal dependence of Lg/Pg constructed from records of explosions at the Kara-Zhyra quarry obtained at the MKAR station. For these explosions, the paths to the station pass through the Balapan site. It can be seen that this parameter increased significantly from 2002 to 2006 and, then, until 2021, they were approximately at the same level.

Spatio-temporal variations of short-period S wave attenuation field in the region of Semipalatinsk Test Site (using recordings of nuclear and chemical explosions)

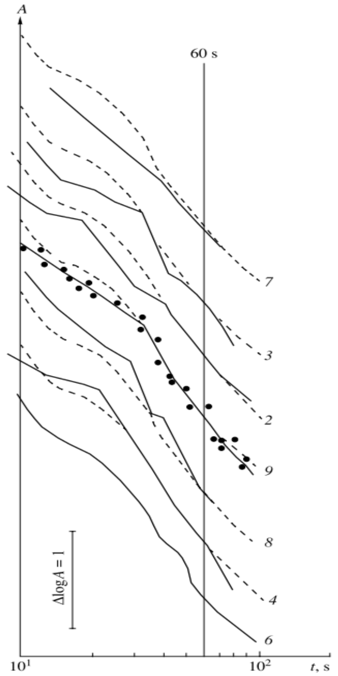


Map of the study region. 1 – the STS and STS sites: M - Murzhik, D – Degelen, B – Balapan. 2 – boundaries of the termal anomaly in 1997, 3 in 1999. 4 – main fault zones: a – Chinrau, b – Kalba-Chingiz, c – Main Chingiz. 5 - largest quarries in the vicinity of the STS, 6 - epicenters of local earthquakes, 7 – seismic station.

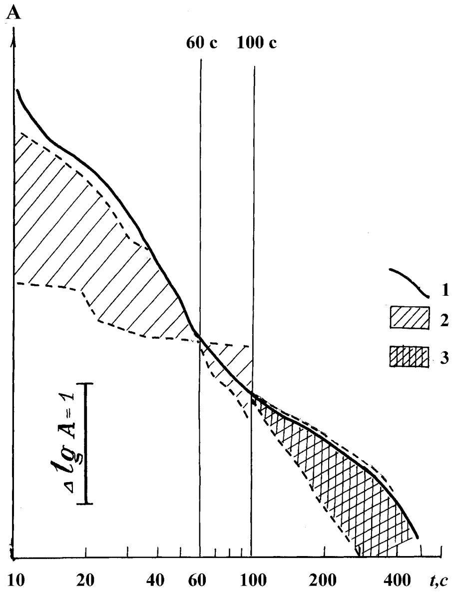
Abnormally strong attenuation of S waves is observed at depths of 10 to 120 km in the Balapan area, where two large fault zones are located. The attenuation in the Degelen area is much weaker at these depths. The Q factor sharply increases at depths greater than 200 km in the test site region.

For comparison, we shows the scatter range of data for the coda envelopes from local earthquakes and quarry blasts, calculated from the records of 40 digital stations in the Central Tien Shan region. As seen from the figure, if the envelopes are superposed at t = 60 s, all Tien Shan envelopes within the interval from 10 to 60 s (depths of about 20 to 120 km) attenuate considerably slower compared to the Balapan station 6.

It is important that, from 1997 to 1999, a relatively large STS-including region of northeastern Kazakhstan was characterized by an intense thermal anomaly. The snow cover was absent in this region in winter, and the surface temperature was higher than in the surrounding areas by about 10°C. The area of the thermal anomaly is nearly three times as large as the STS area.



Common coda envelopes from recordings of calibration explosions at Balapan site. 1.25 Hz. Digits are station number. Dashed line is the envelope for station 6. Dots show the data scatter for common envelope (station 9).



The data scatter range of coda envelopes constructed from records of 40 digital stations in the Central Tien Shan: (*1*) coda envelope from records of stations 6 (Balapan) and KUR; (*2*)–(*3*) envelopes are superposed at (*2*) *t* =60 s and (*3*) *t* = 100 s.

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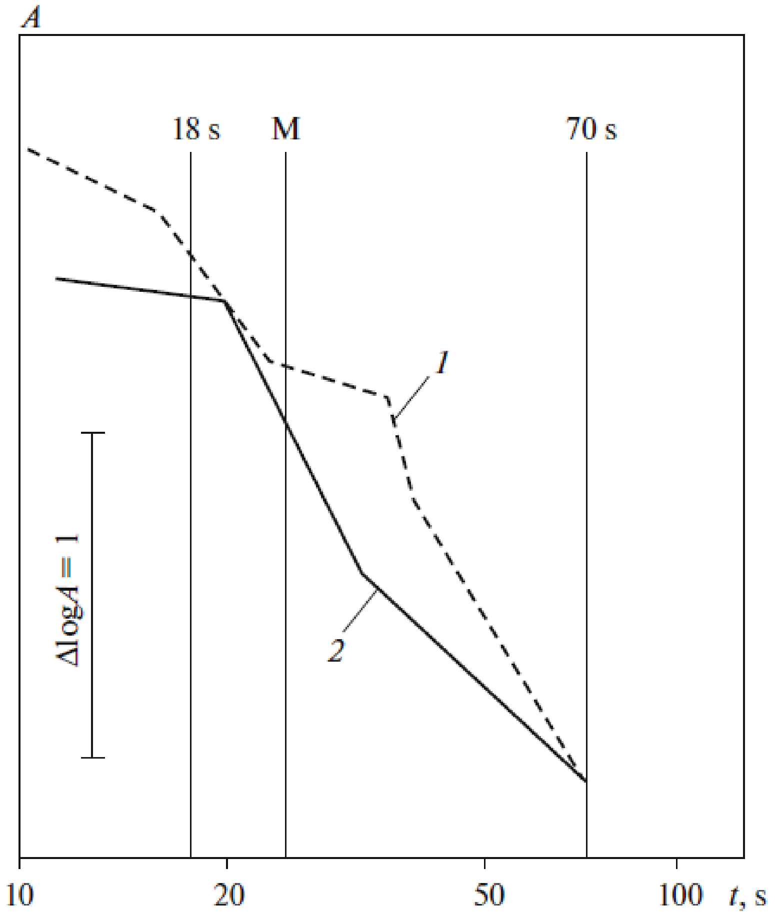
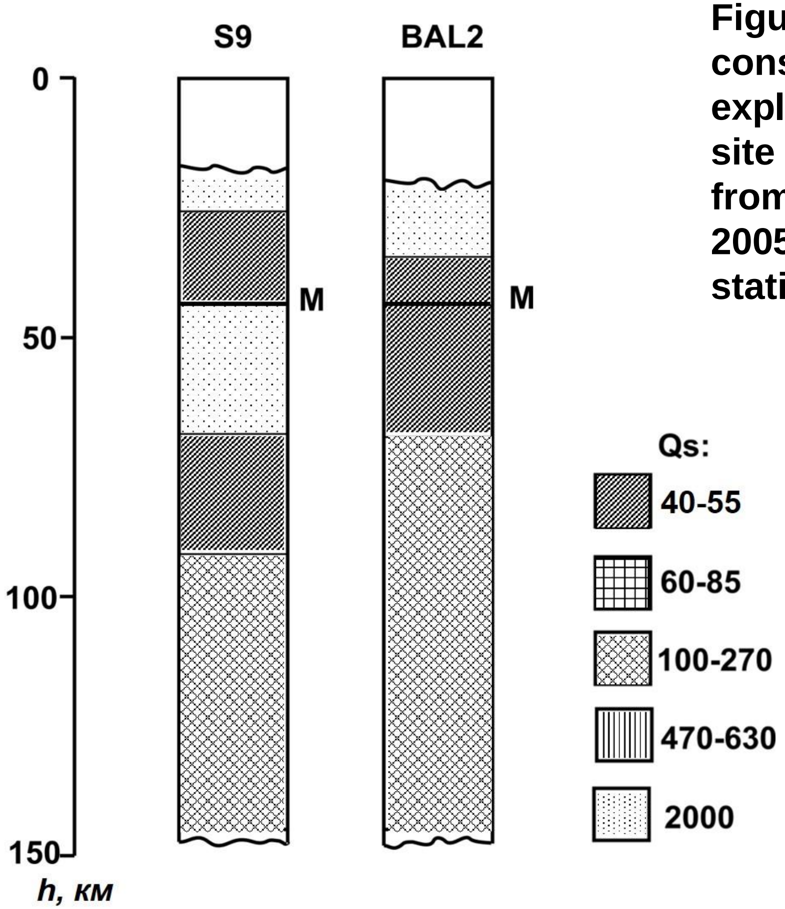


Coda envelopes for explosions recorded at stations (1) S9 and (2) BAL2. M corresponds to Moho.



Attenuation field sections by data of st. S9 and BAL2.

Figure shows the general *S*-coda envelopes constructed from the records of calibration explosions conducted in 1997 at the Balapan site and the coda envelopes constructed from the records of explosions conducted in 2005–2021 at the Karazhyra quarry for stations S9 and BAL2.

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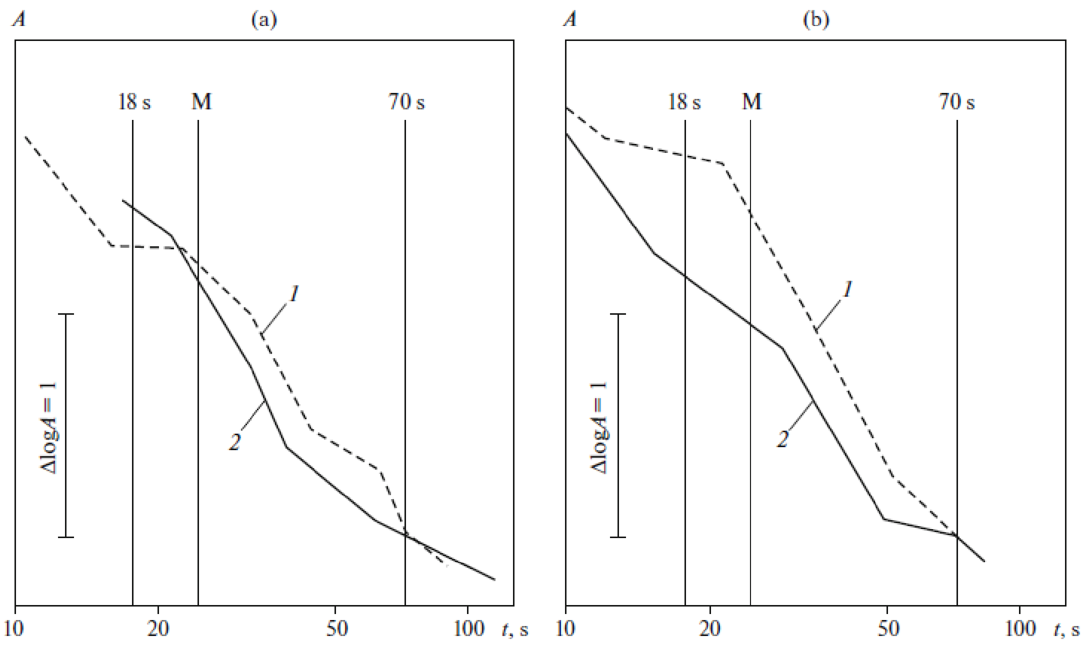
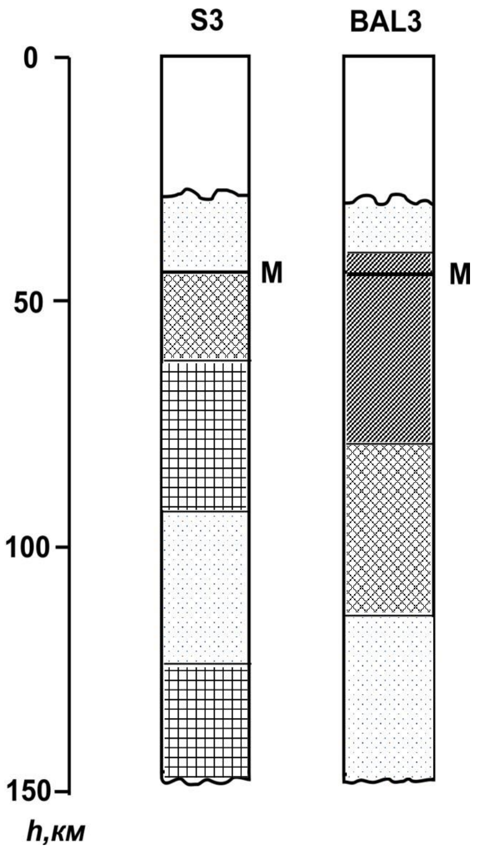
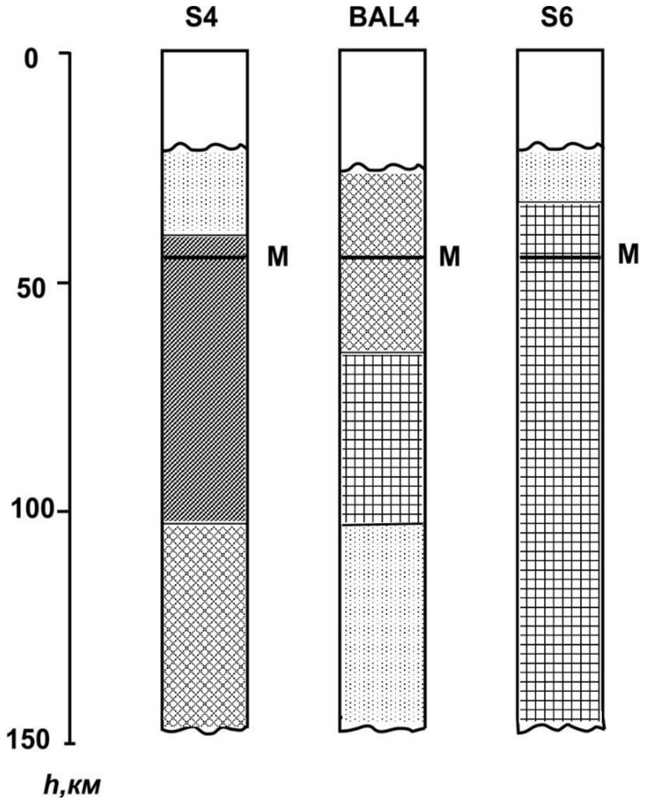


Coda envelopes for explosions recorded at stations (*1*) S3 and (*2*) BAL3 (a) and (*1*) S4 and (*2*) BAL4 (b). Channel 1.25 Hz. M - Moho border.

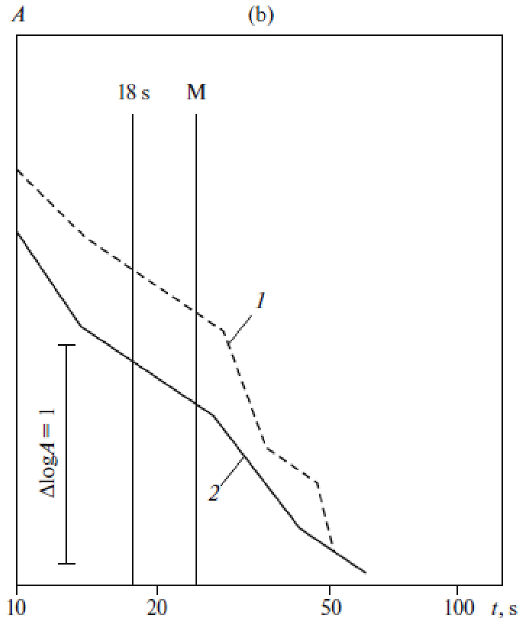


Attenuation field sections by data of st. S3 and BAL3.

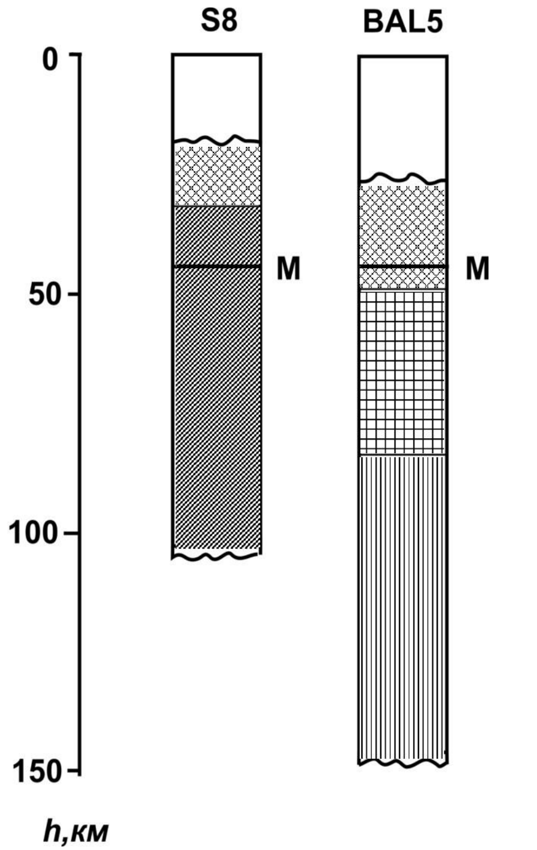


Attenuation field sections by data of st. S4, BAL4 and S6.

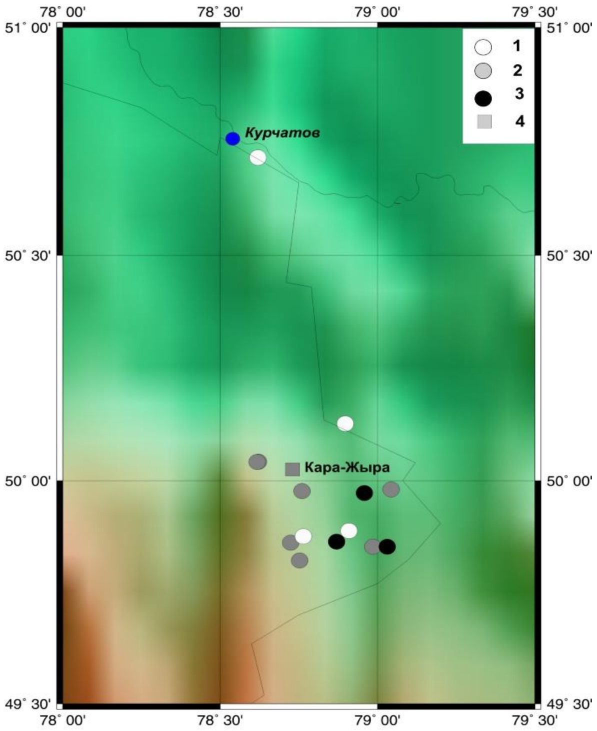
Spatio-temporal variations of short-period S wave attenuation field in the region of Semipalatinsk Test Site (using recordings of nuclear and chemical explosions)



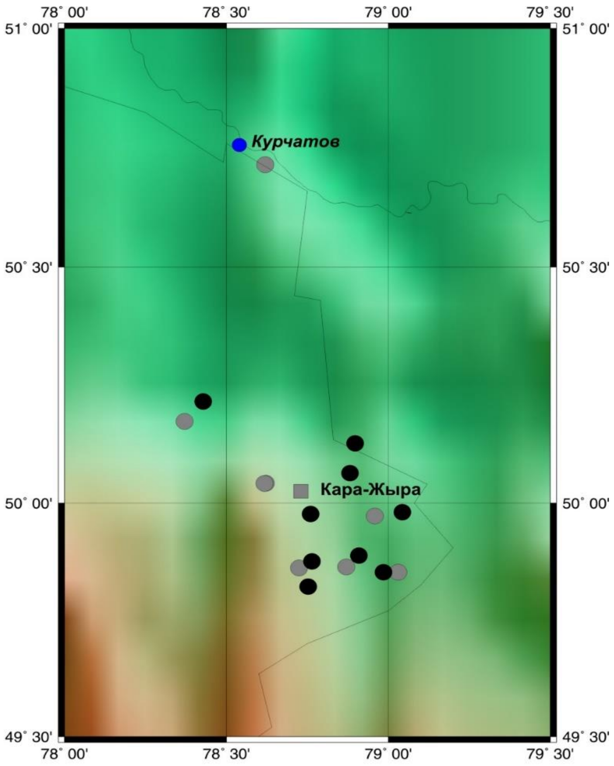
Coda envelopes for explosions recorded at stations (*1*) S8 and (*2*) BAL5 (b). Channel 1.25 Hz. Moho border (M).



Attenuation field sections by data of st. S8 and BAL5.



Attenuation field heterogeneities in the lower crust. Attenuation: 1 – low, 2 – middle, 3 – high. 4 – Kara-Zhyra quarry.



Attenuation field heterogeneities in the uppermost mantle.

The attenuation field heterogeneities mapping was done for the lower crust (h=25-44 km) and uppermost mantle (h=44-80 km) of the east Kazakhstan. Very low Q-factor values (Qs~40-55) correspond to several stations installed at the area of Balapan Test Site where the most powerful UNEs were conducted.

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CONCLUSIONS

The research considers the spatio-temporal variations of short-period shear waves attenuation field in the east Kazakhstan lithosphere including the region of the Semipalatinsk Test Site where a lot of underground nuclear explosions were conducted in the past. Big temporal variations of the attenuation field in the STS region were found using data of distant stations recorded UNEs and quarry blasts.

The common S-wave coda envelops were obtained by the records of close calibration and mining explosions as well as local earthquakes by data of 20 permanent and temporary stations. The obtained data allowed us to create attenuation field sections in the lithosphere of the considered region. The attenuation field heterogeneities mapping was done for the lower crust and uppermost mantle of the east Kazakhstan. Very low Q-factor values (Qs~40-55) correspond to several stations installed at the area of Balapan Test Site where the most powerful explosions were conducted. These values are lower than minimum values corresponding to large number of stations installed at seismically active region of the Northern Tien Shan.

It is supposed that the effect is due to the uplift of deep-seated fluids along the active fault zones under the long intensive vibration effect. According to our data, the zone of high attenuation of S waves in the region of the Balapan site could extend to depths of ~150 km.

Earlier we have found similar spatio-temporal variations in the attenuation field structure in the regions of the other two largest nuclear test sites, Nevada and LopNor. Thus, a long-term intensive man-made impact on the geological environment can lead to a significant change in its characteristics up to sufficiently large depths not only in the earth's crust, but also in the uppermost mantle.