# ANALYSIS OF HISTORICAL SEISMOGRAMS OF CENTRAL ASIA STATIONS TO PRECISE THE PARAMETERS OF NUCLEAR TESTS AT LOP NOR TEST SITE

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[O2.5-298]

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ORAL PRESENTATION

# Analysis of historical seismograms of Central Asia stations to precise the parameters of nuclear tests at Lop Nor Test Site

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## INTRODUCTION

**At the present time, researchers in the field of seismic and infrasound monitoring show increasing interest in the records of historical nuclear explosions conducted in different medium, including those taking place at the surface and in the atmosphere. There is a desire to reanalyze the historic data to shed light on the current regional monitoring regime. This interest is, first of all, due to the task of detection and discrimination of nuclear explosions under the Comprehensive Nuclear-Test-Ban Treaty (CTBT), creation of the database for ground-truth (GT) events for calibration of stations included in the International Monitoring System (IMS) network, and to provide a better understanding of natural atmospheric explosions such as the Chelyabinsk bolide of 2013 for which the seismic and infrasound records are similar to nuclear explosions conducted at high altitude.**

**The Lop Nor Test Site (LNTS) is located in the Xinjiang province, in the north-west of the People's Republic of China (PRC), about 600 km south-eastward from Kazakhstan-PRC border. Between 1964 and 1996 there were 48 nuclear tests, including 3 surface, 19 atmosphere and 26 underground explosions (Johnston, 2005). The underground nuclear explosions were conducted in boreholes and horizontal tunnels. The maximum yield of atmosphere explosions reached a yield (Y) of 4 Mt – for the explosion on November 17, 1976; for underground nuclear tests the maximum yield was Y=660 kt for the explosion conducted on May 21, 1992 (Johnston, 2005).**

**It should be noted that the explosions conducted at the LNTS have not been studied completely, the International Seismological Centre (ISC) bulletins, for instance, contain information on 28 nuclear tests conducted at Lop Nor Test Site (ISC, accessed 2020). Until 1990, the bulletins were compiled mainly from data of distant seismic stations more than 1500 km from the Test Site. Until 1990, the ISC did not receive the nuclear explosion seismic bulletins of the stations installed in Central Asia and Kazakhstan. Therefore, the creation of the seismic bulletin using legacy seismograms from the Kazakhstan archives improves the quality of the nuclear explosion catalogue from the LNTS region, encourages calibration of contemporary seismic stations, and allows creation of regional travel-time curves for the territories of Dzhungariya and Eastern Tien Shan.**

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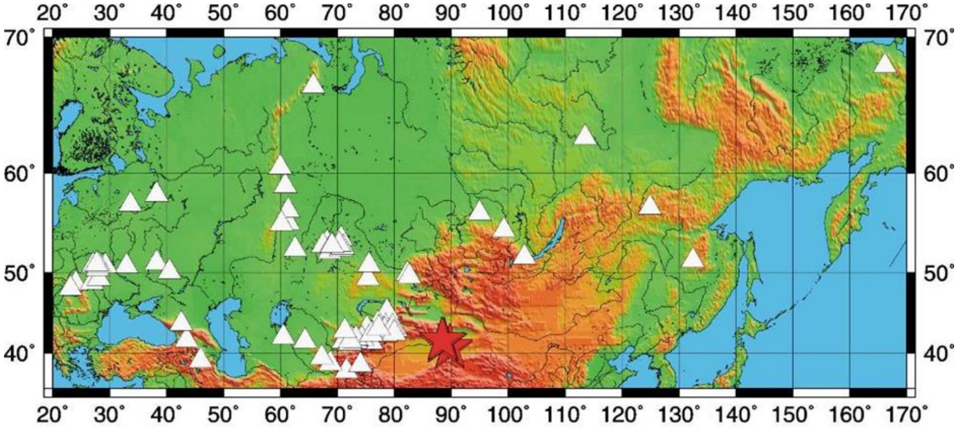
## Seismic Networks: Talgar CSE

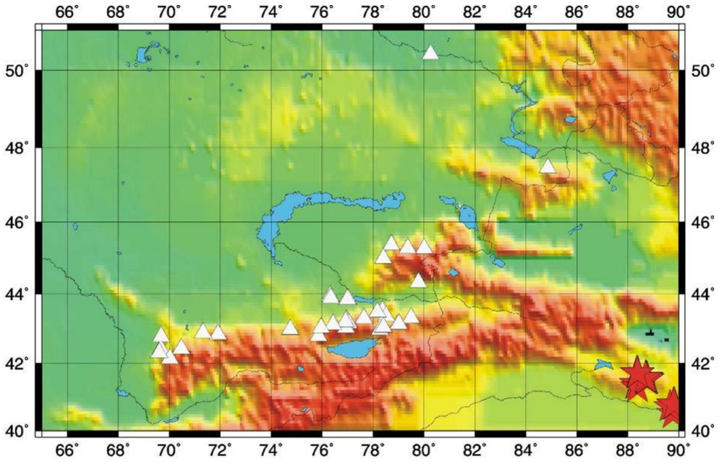
**In 1961 the Institute of the Physics of the Earth established the Complex Seismological Expedition (CSE) in Talgar. The main tasks of the CSE were study of the lithosphere structure, monitoring of dams, and monitoring of nuclear tests using seismic and other methods. The CSE installed a lot of seismic stations on the territory of the former Soviet Union. Most deployed stations used high sensitivity short period sensors.**




**Map of CSE IPE AS USSR seismic station locations from which seismograms were used for bulletin compilation (white triangles). Red stars show locations of nuclear explosions conducted on the territory of LNTS.**

## SEME

**The Seismological Experimental Methodological Expedition (SEME) of the Kazakhstan Ministry of Science and Education and its predecessor organizations in Soviet times, retain a large archive of seismograms from the era of Lop Nor testing. Most of SEME's stations are in the southeastern part of Kazakhstan, relatively close to Lop Nor, and recorded explosions well.**




**Map of the SEME MES RK seismic stations location from which seismograms were used for the bulletin compilation. The stars show the places of nuclear explosions conducted on the territory of Lop Nor Test Site.**

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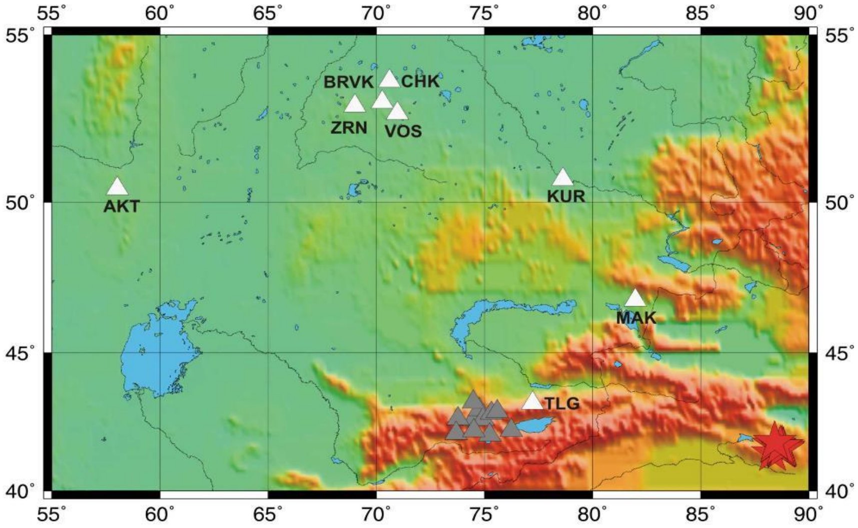
## KNET and KZNET

**In 1991, the contemporary digital seismic network KNET was established in Kyrgyzstan, consisting of 11 broadband seismic stations. Starting from 1994 the digital seismic network KZNET opened in Kazakhstan.**




**Location map of explosion epicenters and seismic stations from which records were used for processing. White triangles are the stations of the IGR NNC RK (KZNET), and grey triangles are KNET network stations. Red stars are the places of nuclear tests conducted at the LNTS.**

## Microbarograph observations

**The observatory at Talgar, Kazakhstan operated a microbarograph that recorded atmospheric explosions from the Lop Nor test site between 1962 and 1976. The microbarograph signals were recorded on photopaper. The microbarograph recordings are interpretable as infrasound signals within the response of the sensor and are analyzed in this study.**

**The entry to the tunnel at station Talgar**


**Soviet era microbarograph sensors. The Talgar Observatory, for which we have records, utilized the EDMB-IV sensor at left.**

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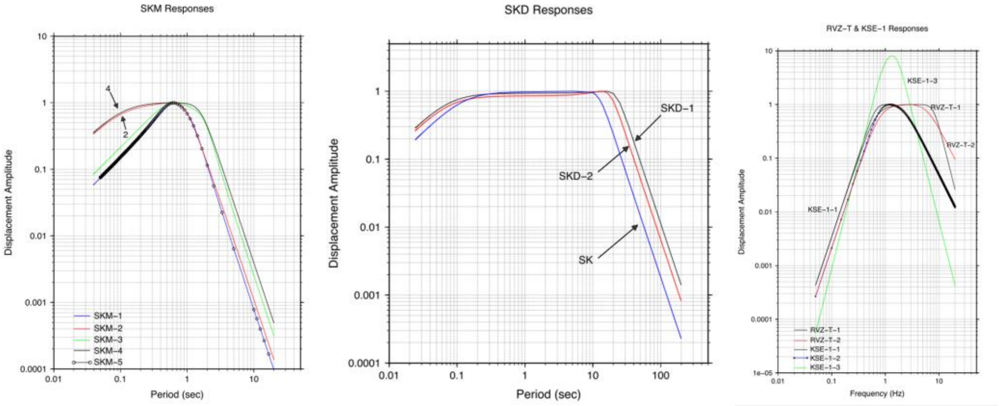
## Seismic Sensors

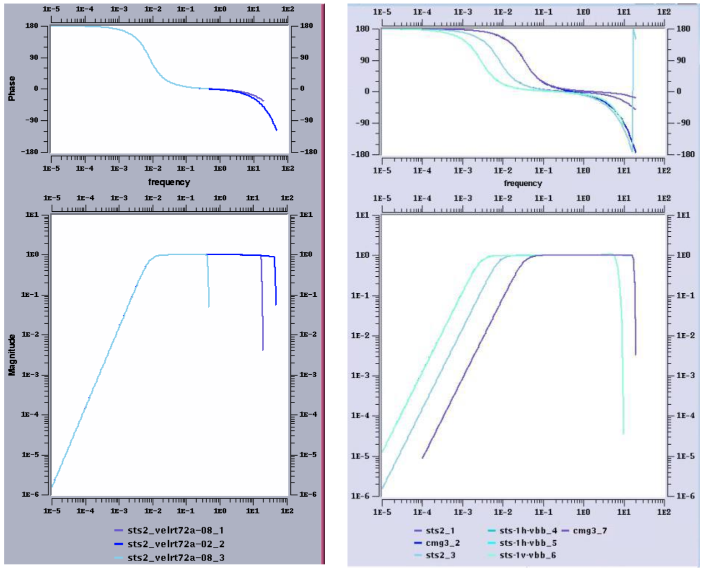
### ANALOG STATIONS

**Most of the permanent stations in Central Asia during Soviet time produced analog seismograms recorded on photopaper by three-component short- and long-period seismographs known as a SKM or SKD respectively. The seismographs had various standard configurations for seismometer and galvanometer settings. The RVZ-T and KSE-1 equipment was also widely used for permanent and field stations.**




**Typical responses of analog seismic stations in Central Asia**

### DIGITAL STATIONS




a) b)

**Amplitude-frequency characteristics of the seismic stations 1991-1996 a) KNET, b) KZNET.**

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## Measurements and Magnitude Calculations

**Each seismogram collected was analyzed for phases, arrival times, periods and amplitudes. Phases identified are Pn, P, Pg (from vertical component), Sn, S, Lg, and LR (from horizontal components). In all cases, analysis was conducted only on the original photopaper seismograms or original digital data from the contemporary networks. Digital data was emulated to an SKM instrument for correct calculation of Energy Class (K) and magnitudes. Magnitudes calculated are mpv, mb and MS. All analyses are original to this study to provide consistency; earlier measurements were not considered.**

**The Equation used for K-class determination:** $K=1.8 \lg(A_p + A_s) + \sigma_K(\Delta)$, **(1)**

**Where $A_p$ and $A_s$ are maximum amplitudes of the P and S waves respectively, and $\sigma_K(\Delta)$ is a distance correction.**

**The Equation used for MPV determination:** $MPV= \lg (A/T) + \sigma_{reg}(\Delta)$, **(2)**

**Where A is amplitude, T is period, and $\sigma_{reg}(\Delta)$is a distance correction.**

**mb magnitudes were computed using the procedure of Veith and Clawson (1972).**

## Origin Times

**Origin times are generally taken from Johnston (2005). However, often the published time was of low accuracy (only to the hour or minute) or inconsistent with the phase arrivals. In this case, the epicentral distance for each station was measured; the travel time for each station was calculated by the travel-time curve; the time of first Pn wave arrivals measured in seismograms were analyzed. Calculated $t_0$ values were then determined for each station and averaged to determine the origin time for the explosion.**

**Note that for air explosions $t_0$ is actually $t_0$ of impact, not the time of explosion as the velocity of the shock wave propagation in the atmosphere and accurate altitude of many explosions are unknown.**

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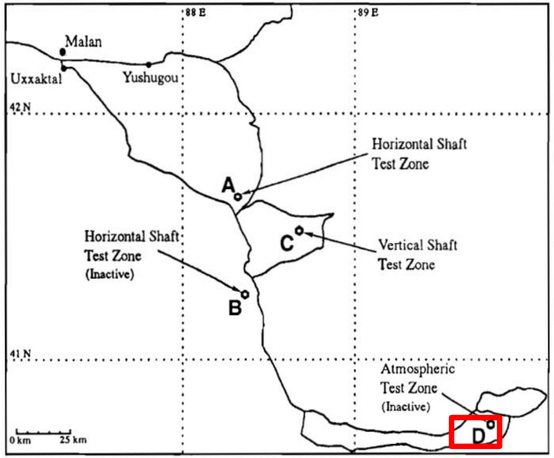
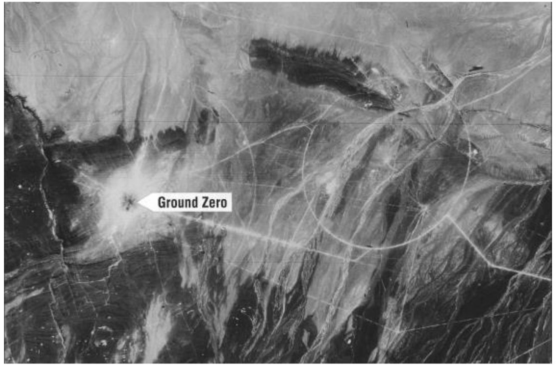
## Lop Nor Test Site

**Following convention of Gupta (1995), the Lop Nor Test Site is divided into four main areas. The original atmospheric test zone (D) is in the southeast. A vertical shaft test zone (C) and two zones for horizontal tunnel testing to the northwest.**

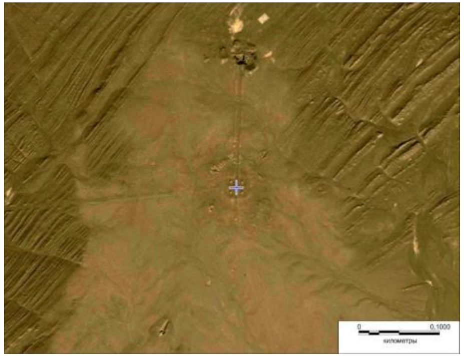
**As a part of this study, we compiled different analyses of the event locations from Lop Nor. Many published locations were seismically determined and not accurate. When possible, we adjusted the coordinates to correspond to reasonable features visible on satellite imagery. Revised coordinates are used for distance calculations to generate travel time curves and calculate new magnitudes.**




**Zones of the Lop Nor Test Site (Gupta, 1995)**




**Satellite image of Site D showing the disturbed ground zero zone following the first nuclear explosion of 16 October, 1964 (NRO, 2021).**



**A modern satellite image of the site of China's first nuclear explosion that took place on 16 October, 1964, at coordinates 40.81248$^0$ N; 89.79010$^0$ E. This image is attributed to Bing Maps via SASPlanet.**

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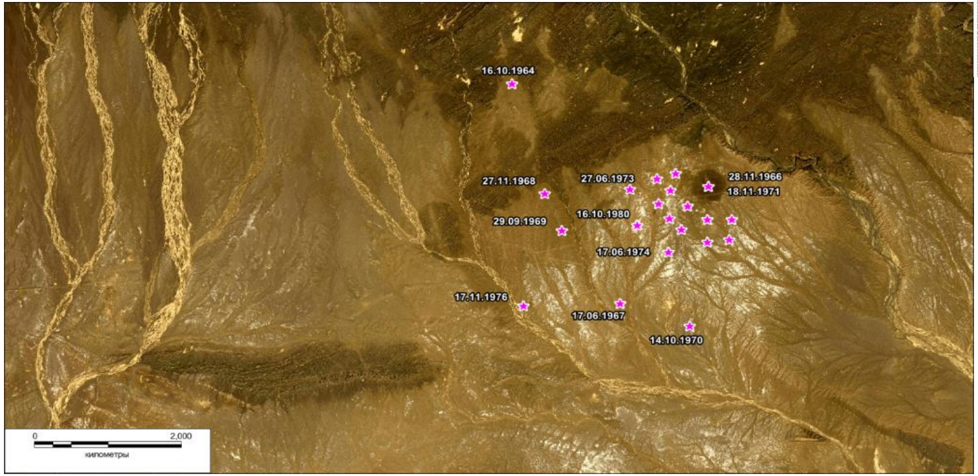
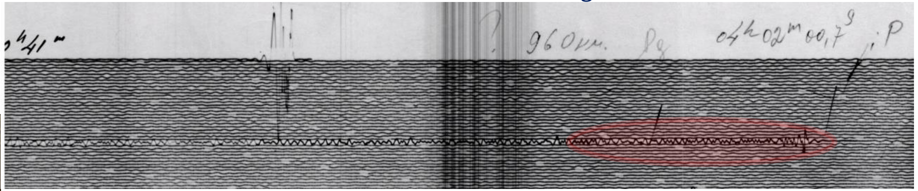
## Atmospheric Test Zone

**22 nuclear tests were conducted at the Lop Nor atmospheric test range (Zone D). Three were surface tests and 19 were at elevation, with many being air dropped. The locations are shown in the image. We generally cannot independently adjust locations as there is no associated surface signature. Locations shown are from Gupta (1995).**



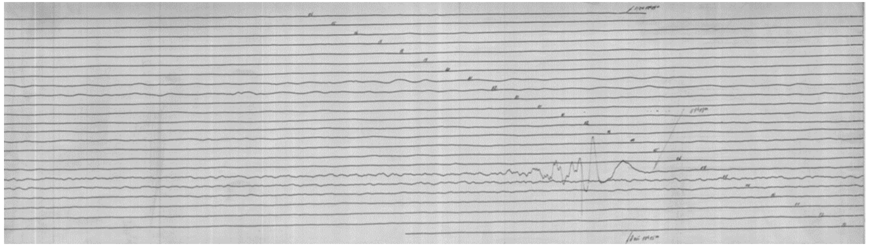

**Satellite image showing the locations of nuclear tests at the Lop Nor atmospheric test range (Zone D; Gupta, 1995). The first PRC test on 16/10/1964 is the northern-most star (SasPlanet displaying Bing Maps imagery).**

**Of the 22 Lop Nor atmospheric tests, we recovered original seismograms from 19, representing both the CSE and SEME networks. Distances of recorded seismic waveforms range from 827 to 4792 km. Data are shown here from the 300 kt test on 28 December, 1966 test. Elevation was 102 m above ground.**



**Scan of the vertical component seismogram from the Short period SKM sensor at Charyn, Kazakhstan. This seismogram reads right to left. An clear P wave is marked at 04:02:00.7.**

**8 of the Lop Nor atmospheric tests were recorded by microbarograph systems in Talgar. Data were analyzed in this study. The figures below show the data from the 17 November, 1976 4 Mt test.**



**Microbarograph record of the atmospheric nuclear explosion of November 17, 1976 by station Talgar, Kazakhstan , Δ=1065 km (reads right to left).**

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## Horizontal Tunnel Test Range (Zone B)

**4 nuclear tests were conducted at the Lop Nor Zone B horizontal test range. The northern two locations are clear on satellite imagery to the north of Gupta's (1995) coordinates, though identification of the southern two locations are suspect. Both northern locations and the 5/10/1982 southern event were well recorded by the Kazakhstan/Kyrgyzstan stations.**

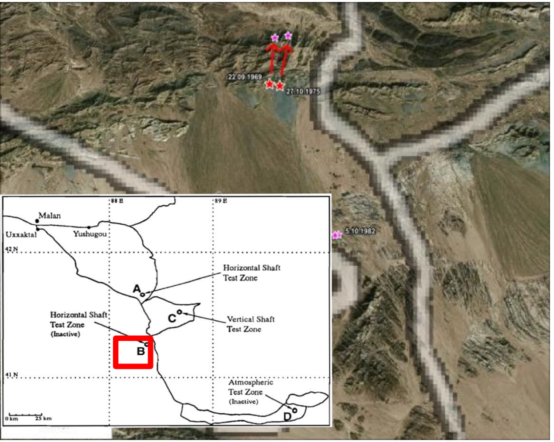
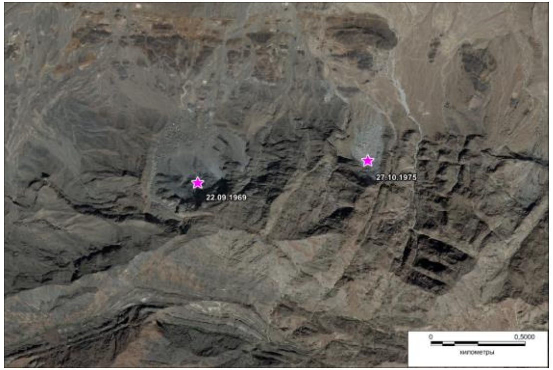


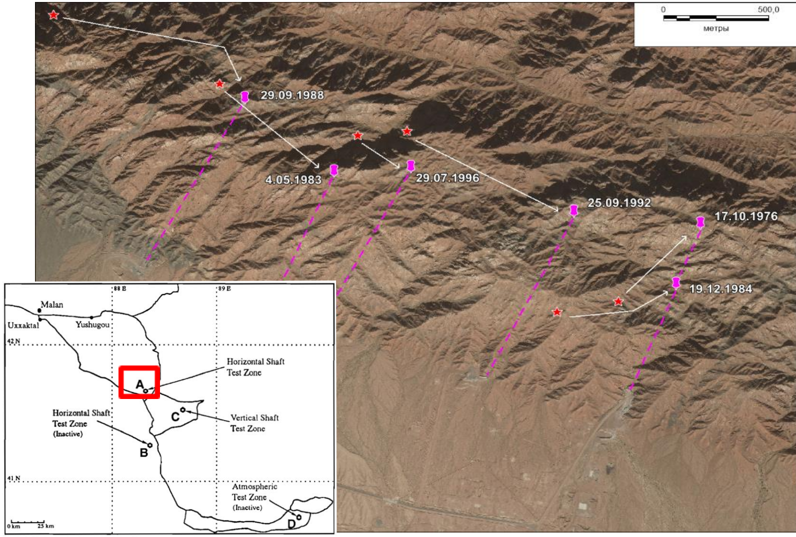

**Image of the Zone B horizontal tunnel test range of Lop Nor (SasPlanet displaying Bing Maps imagery).**




**Northern region of Zone B showing slope failures associated with the 22/09/1969 and 27/10/1975 tests (SasPlanet displaying Bing Maps imagery).**

## Horizontal Tunnel Test Range (Zone A)

**6 nuclear tests were conducted at the Lop Nor Zone A horizontal tunnel test range.**




**Zone A of the Lop Nor Test Range showing the locations of nuclear explosions. Red stars indicate locations of Waldhauser et at. (2004). Purple locations show adjustments of locations to correlate with visible tunnel entrances and to maximize topographic overburden. (SasPlanet displaying Bing Maps Imagery)**

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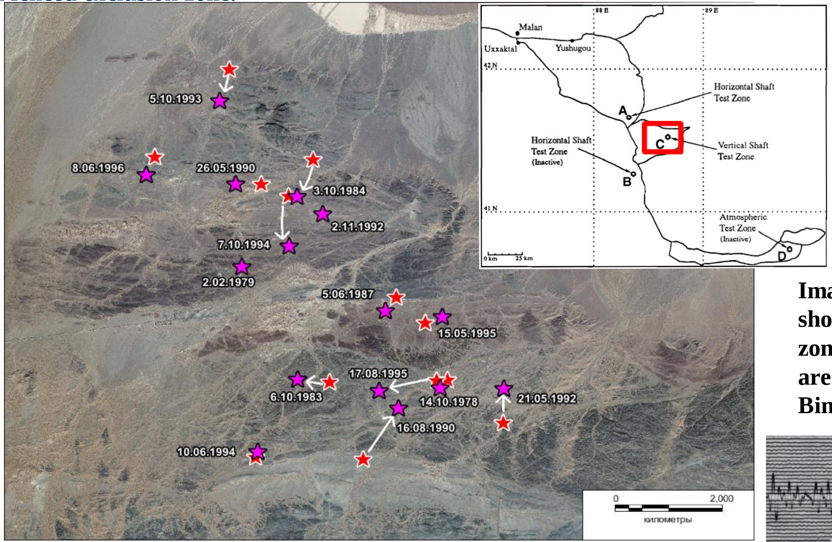
## Borehole Test Range (Zone C)

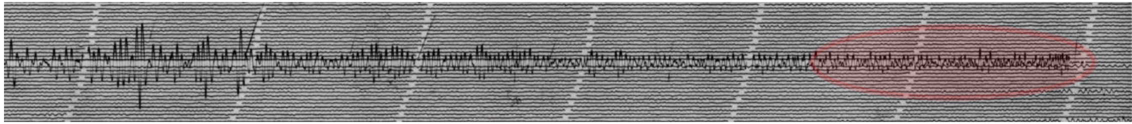
**16 nuclear tests were conducted at the Lop Nor borehole tunnel test range (Zone C). Boreholes generally have a surface infrastructure of buildings and a fenced exclusion zone.**




**Zone C of the Lop Nor Test Range showing the locations of nuclear explosions. Red stars indicate locations of Waldhauser et at. (2004). Purple stars show adjustments of locations to correlate with closest identified borehole. (SasPlanet displaying Bing Maps Imagery)**


**Image of the nuclear explosion site of 7/10/1994 showing typical infrastructure and circular exclusion zone around the borehole. Coordinates for this site are 41.56475 $^{0}$ N; 88.71926 $^{0}$ E. (SasPlanet displaying Bing Maps Imagery)**

**Of the 26 Lop Nor underground tests, we recovered original seismograms from 23, representing all analyzed networks. As seismic coupling is better with underground explosions, data quality is typically better than that from atmospheric explosions. Data shown here is from the 8 kt test of 25 September, 1992. All data were analyzed from analog records.**



**Scan of the vertical component seismogram from the short period SM-2 sensor at Talgar, Kazakhstan. This seismogram reads right to left. A clear Pn wave is marked at right.**

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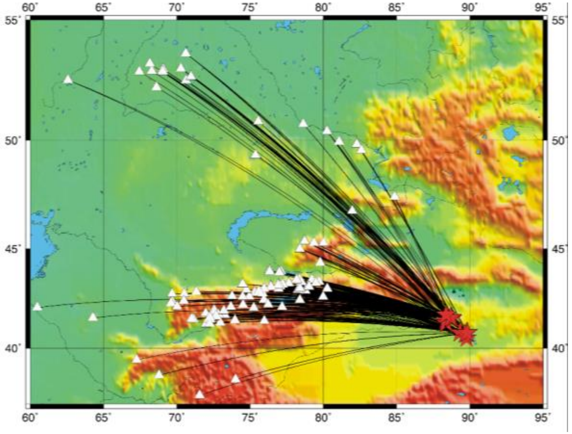
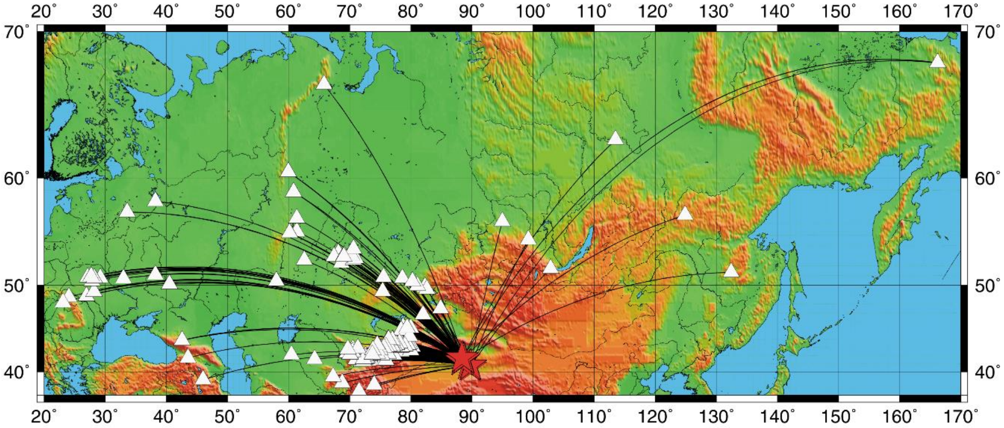
## Data Distribution




Raypath distribution of regional seismic phases from stations in Central Asia analyzed in this study.




Raypath distribution of regional and teleseismic seismic phases analyzed in this study. Several Talgar CSE stations in Russia and Ukraine were included.

**Phases and numbers of measurements taken in this study**

| phase | number of measurements |
|---|---|
| t(Pn) | 715 |
| t(P) | 70 |
| t(Pg) | 252 |
| t(Sn) | 521 |
| t(S) | 7 |
| t(Lg) | 581 |
| t(LR) | 39 |

**All analysis from seismograms are combined into a seismological bulletin. Approximately 2200 phases and their analyzed parameters are included. The vast majority of the resulting data are new and not found in the ISC or other sources.**

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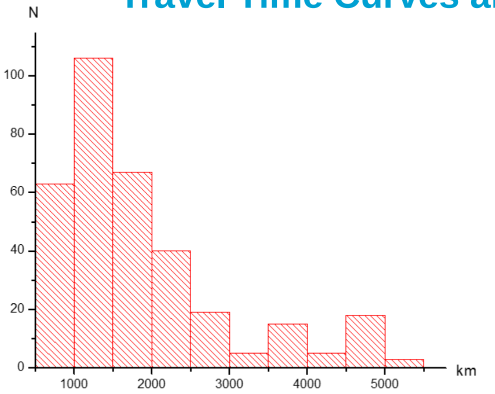
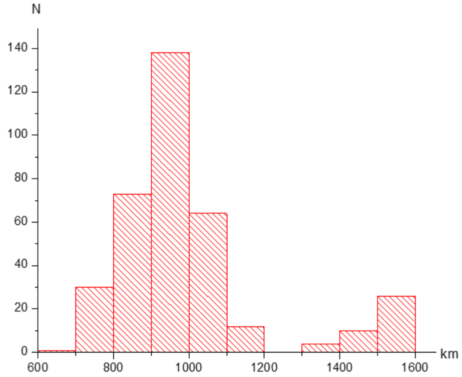
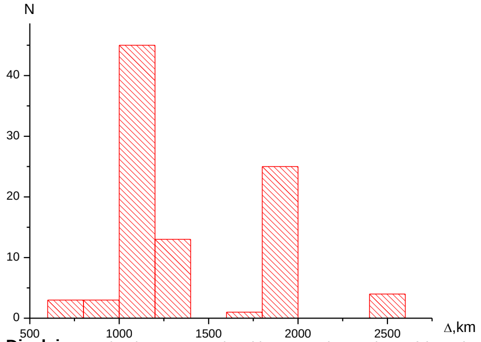
## Travel Time Curves and Raypaths




**Talgar CSE – 340 Seismograms.**

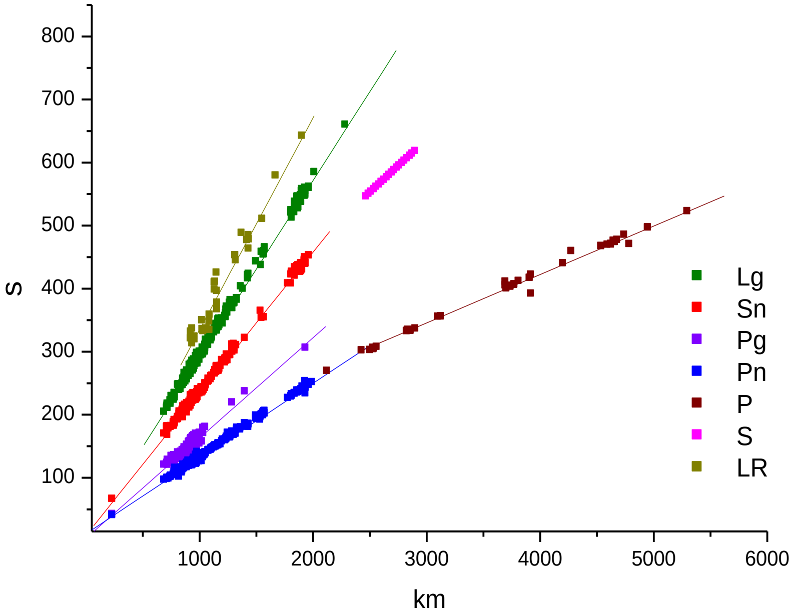



**SEME ~350 Seismograms.**




**KNET and KZNET – 94 Seismograms.**

## See Poster P2.5-297 for more detailed information




**Composite travel time curve for Lop Nor explosions analyzed in this study. Velocities are similar to those determined from calibration explosions for the Semipalatinsk Test Site.**

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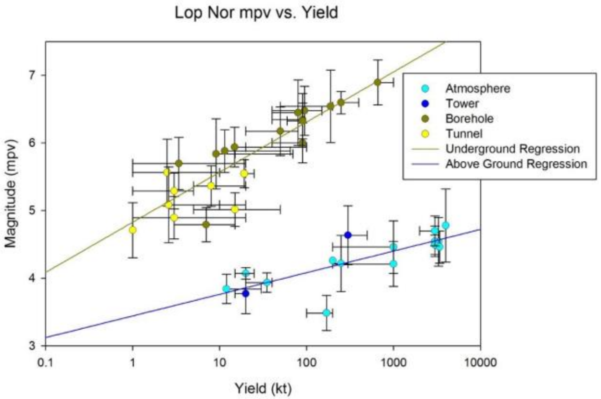
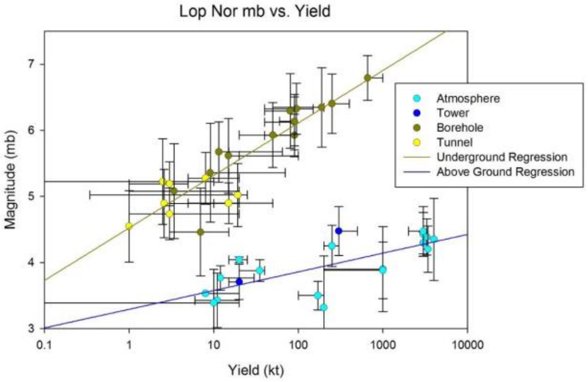
## Magnitude Relations

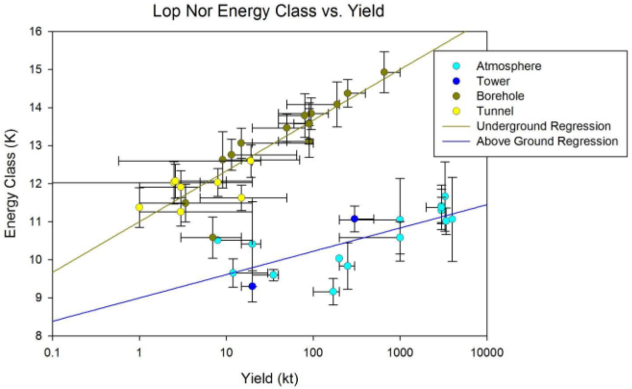
**Magnitudes and Energy Class were calculated for both atmospheric and underground tests from Lop Nor. There is sufficient data to correlate yield with magnitudes for both types of tests. As would be expected with poor seismic coupling, for a given yield, magnitudes values are reduced.**




a)




b)




c)

**The dependence of magnitudes and Energy Class for nuclear explosions conducted in different mediums on the explosion yield. a) mpv, b) mb, c) K-class. Error bars for K-Class represent one standard deviation of individual station determinations. Error bars for yield represent the min/max range from Johnston (2005).**

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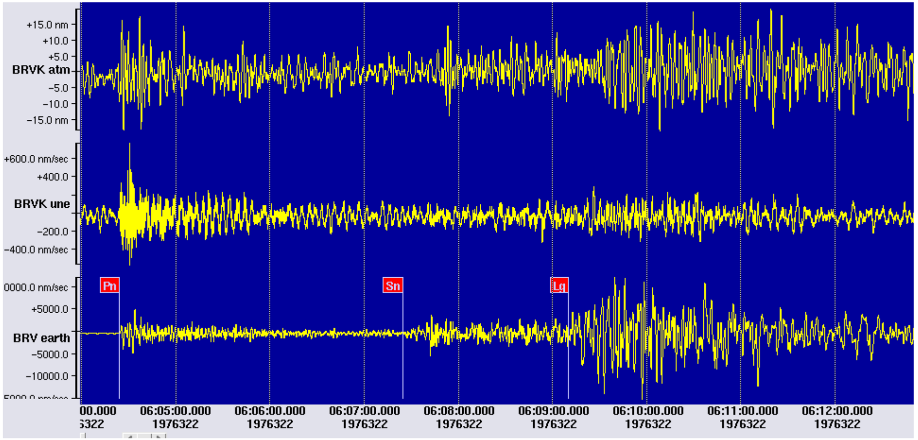
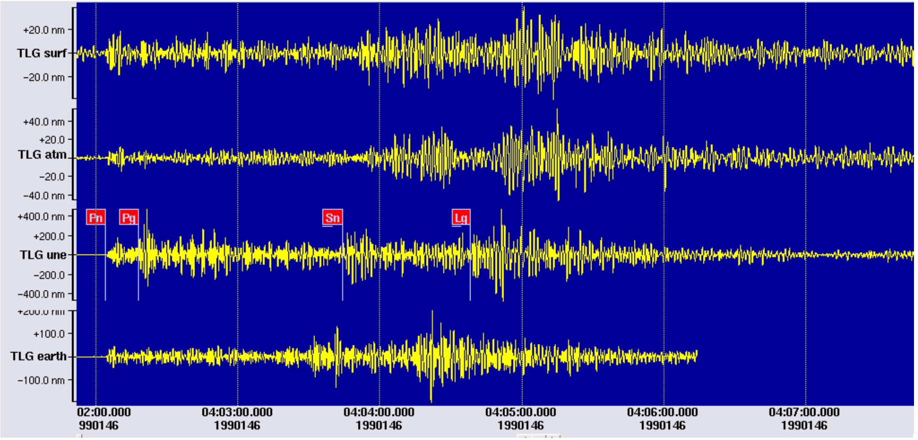
## Wave Patterns From Explosions Conducted in Different Media

**The epicentral distance range from the LNTS to the Central Asia stations corresponds to regional distances over which the recorded wave pattern is significantly affected by the structure of the S-wave attenuation field. Nevertheless, several similar peculiarities can be determined for seismograms of atmospheric nuclear explosions.**




**Comparison of station BRVK vertical component seismograms. From top to bottom: atmospheric nuclear explosion of 17 November 1976, mb=4.7; underground nuclear explosion of 29 July 1996, mb=4.9; tectonic earthquake of 30 January 1999, t0=03:51:05.00 φ°=41.586, λ=88.455°, mb=5.8.**




**Comparison of station TLG vertical component seismograms. From top to bottom: surface explosion of 28 December 1966; atmospheric nuclear explosion of 17 June 1973, mb=4.8; underground nuclear explosion of 26 May 1990, mb=5.5; tectonic earthquake of 9 March 1975, mb=4.6.**

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## Conclusions

**A seismic bulletin for nuclear explosions conducted at the LNTS was created through analysis of analog seismograms from the archives of the CSE IPE AS USSR and SEME MES RK, and on digital records of KNET and KZNET. The bulletin contains approximately 2200 newly analyzed phase picks. This bulletin significantly increases the regional data available for the LNTS nuclear explosions. This study produced phase and time picks for several nuclear explosions, both atmospheric and underground, that previously were not known to be seismically recorded. Epicentral distances range from 700-5300 km. Amplitudes are included in the bulletin and multiple station and event magnitudes were calculated. Magnitudes for atmospheric explosions were also calculated, allowing a comparison of magnitude/yield relationships between atmospheric and underground detonations. We find that correlations with yield are of similar quality among mb, MPV, and K. We recognize that the published and available yield estimates have large errors. We also note comparative differences in waveforms between atmospheric and underground nuclear tests and tectonic earthquakes.**

**The infrasound records of waves from powerful atmosphere nuclear explosions recorded by the microbarograph installed at the seismic station in Talgar at a distance of ~1070 km from the Test Site were collected and analyzed.**

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