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The Refined USSR Peaceful Nuclear Explosions Database for Borovoye Geophysical Observatory

Kseniia Nepeina [1,*] and Vadim An [2]

[1] Research Station of the Russian Academy of Sciences (RS RAS), Bishkek 790049, Kyrgyzstan
[2] Institute of Geosphere Dynamics of the Russian Academy of Sciences (IDG RAS), Moscow 119334, Russian; vadiman33@gmail.com
* Correspondence: nepeina.k@mail.ru; Tel.: +996-(312)-611158

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Abstract: This paper shows the results of the refined locations for underground Peaceful Nuclear Explosions (PNEs). Peaceful nuclear explosions (PNEs) were made for industrial applications in the Soviet Union. This study is based on a comparison of PNEs' parameters. These explosions were recorded by seismographic stations in Kazakhstan from 1966 to 1988. The monitoring/verification community generally utilizes PNE locations from Sultanov et al. (1999). In reality, there are errors and some PNEs are poorly located. Our locations were determined using an integrated approach encompassing published open literature sources and archive seismogram analysis from Borovoye Geophysical Observatory. Treated PNEs seismograms have been available to researchers since 2001. They became available after the cooperation between Russian and U.S. organizations. The first one was the Institute of Geosphere Dynamics of the Russian Academy of Sciences (IDG RAS), the organization that operated the Observatory in the Soviet era. The second one was the National Nuclear Center of the Republic of Kazakhstan (NNC since 1992). The third one, from the U.S. side, was the Lamont-Doherty Earth Observatory of Columbia University (LDEO). We present two digital seismograms of old-style seismograms from a digitized archive in ASCII format. We provide travel times for P-waves, some seismograms, and additional source parameters.

Keywords: digital seismograms; seismic instruments; Soviet era; nuclear testing

1. Introduction

Peaceful Nuclear Explosions (PNEs) were carried out for non-military purposes during the 20th century. Over a period of 23 years, the Soviet Union carried out 122 USSR PNEs, 81 of which were on Russian territory. Soviet PNEs can be divided into three types of "underground" nuclear explosions: those that were effectively on the surface, those that were sub-surface, and truly deep underground explosions. Most Soviet PNEs took place at depths of 500–2000 m. The power of the charges was usually between 2 and 20 kilotons. One hundred twenty-four USSR PNEs were conducted: 80 in Russia, 39 in Kazakhstan, and five altogether in Ukraine, Uzbekistan, and Turkmenistan. [1]. The former Soviet Union conducted 39 PNEs for seismological purposes. PNEs are powerful controlled sources. Among the seismological community, PNEs are considered so-called Ground Truth (GT) events. Information of Earth's structure can now be gathered from PNEs travel times. The data help us to define continental platform borders and obtain new data about the size of sediments on those platforms. This is still important in term of the Comprehensive Nuclear-Test-Ban Treaty verification and estimating Earth structure models. Kazakhstan (formerly the Kazakh Soviet Socialist Republic) was chosen as Training Test Site No. 2 of the USSR's Ministry of Defense. Kazakhstan is the right place for acquiring teleseismic (long-distance) and regional (short-distance) seismic signals to monitor the Asian region [2,3]. The geological structures, particularly in Northern Kazakhstan, allow seismic waves to propagate very efficiently, with minimal attenuation and minimal scattering [4]. The Borovoye Geophysical Observatory (BRVK) is located at 53.05806° N, 70.28278° E coordinates. The Observatory was built in the Soviet era in Kazakhstan, near Lake Borovoye. The observations began operating in 1960 by the forces of Special Sector of the Schmidt Institute of Physics of the Earth of the USSR Academy of Sciences (SS IPE). Borovoye Observatory obtained the first digital recordings of PNEs.

It is important to understand the historical context. During the 1950s there was no digital registration of seismic signals. The first prototypes of digital-to-analog and analog-to-digital converters (ADC) for the seismic station were prepared in 1961 by the SS IPE group engineers. The first field test of a 10-channel digital system layout was carried out in October 1961 at the “Mikhnevo” seismic station (MHV), located at 54.960° N 37.766° E in the Moscow region. For the first time, a seismic signal from an underground nuclear explosion at the Semipalatinsk test site (STS) was recorded in digital format. The following field test of a 25-channel digital system layout was carried out at Ili station (ILI), located at 49.933° N 77.067° E in Kazakhstan (February 1962). The next field experiment took place at Borovoye station in October-November 1962. The final check of the digital layout was carried out at the Lovozero station, located at 67.58° N 33.05° E (the Kola Peninsula), in November-December 1963. As a result of laboratory and field tests, the five-channel digital system KOD was designed. After that, KOD started operating in Kyrgyzstan (also an Asian country). In 1964 KOD was installed at “Talgar” station (TLG), located at 43.267° N 77.383° E. Later, in 1965–1966, it was installed at “Frunze” seismic station (Bishkek, FRU), located at 42.833° N 74.617° E, and “Naryn” (NRN), located at 41.433° N 76.000° E [3].

Thus, after this work at the Borovoye Geophysical Observatory in 1966, continuous seismic signal recording on magnetic tapes started in a digital format. The digital system KOD at the Borovoye seismic station operated from 23 July 1966 to 13 November 1973. Digital system KOD operated with different types of seismometers depending on the gain levels [4]. There were two modifications: three-component high-gain (multiple by 10 times) and a vertical-component low-gain (KODb); three-component low-gain and a vertical-component high-gain system (KODm). The three components consisted of the vertical (Z), North-South, and East-West planes.

Another digital system was called STcR-SS. There were two modifications: STcR-SS and STsR-TSG [4]. STcR-SS was a 10-channel digital station. This system began operating in Borovoye on 7 March 1973. STsR-TSG was a 24-channel digital station. It began operating later, on 18 July 1974. STcR operated with three-component seismometers. The three components consisted of the vertical (Z), North-South, and East-West planes.

In the late 1990s, the digital recordings from about 8000 magnetic tapes of the Borovoye Observatory were reformatted into a modern format [2,5,6]. This work was part of a program sponsored by the USA-based Natural Resources Defense Council and the Soviet Academy of Sciences [2,3]. Currently, they are stored at the Institute of Geospheres Dynamics of the Russian Academy of Sciences (IDG RAS) and the Lamont-Doherty Earth Observatory of Columbia University (LDEO).

2. Data Description

At the Borovoye Observatory (BRVK), from over 122 PNEs [7] 98 of them were registered in digital format (according to the archive of Expedition No. 4 SS IPE). However, when reformatting the archive of digital seismograms BRVK at the end of the last century, only 79 seismograms were saved [8]. These PNE tests convey information about different source conditions because they represent various regions and directions [9,10]. Table 1 presents the data of the 79 PNEs database from the Institute of Geosphere Dynamics (IDG RAS) of photographic recordings. The waveforms are available for the research community at IDG RAS database and at the LDEO site www.ldeo.columbia.edu/res/pi/Monitoring/Arch/BRV_arch_deglitched.html. The PNEs archive, described by Kim et al. (2010), is available today via www.ldeo.columbia.edu/Monitoring/Data/Brv_arch_ex/brv_text_table.pdf [11].

Table 1. Time corrections for USSR PNEs at Borovoye Geophysical Observatory (BRVK: ϕ ° N = 53.05806, λ ° E = 70.28278) after [8,12].

(1) Test No.	(2) Date Year-Month-Day	(3) m_b	(4) Instrument Type	(5) Time Corrections (δT), Sec	(1) Test No.	(2) Date Year-Month-Day	(3) m_b	(4) Instrument Type	(5) Time Corrections (δT), Sec
1	1967-10-06	4.7	KODb	−0.02	**41**	1978-10-17	5.5	SS	+0.190
2	1968-05-21	5.4	KODb	+0.28	**42**	1978-12-18	5.9	SS TSG	−0.233 −0.102
3	1969-09-02	4.8	KODb	+0.27	**43**	1979-01-17	6.0	SS TSG	+0.396 −0.332
4	1969-09-08	4.8	KODm	+0.52	**44**	1979-07-14	5.6	SS TSG	+0.138 −0.063
5	1969-09-26	5.6	KODm	+0.29	**45**	1979-08-12	4.9	SS TSG	−0.153 −0.029
6	1969-12-06	5.8	KODm	−0.37	**46**	1979-09-06	4.9	SS TSG	+0.205 −0.028
7	1970-06-25	4.9	KODb	+0.11	**47**	1979-10-04	5.4	SS TSG	+0.004 −0.003
8	1970-12-12	6.0	KODm	−0.31	**48**	1979-10-07	5.0	SS TSG	+0.060 −0.019
9	1970-12-23	6.0	KODm	−0.35	**49**	1979-10-24	5.8	SS TSG	+0.059 −0.013
10	1971-03-23	5.5	KODm	−0.08	**50**	1980-10-08	5.2	SS	+0.242
11	1971-07-02	4.7	KODb	+0.33	**51**	1980-11-01	5.2	TSG	+0.002
12	1971-09-19	4.5	KODb	+0.15	**52**	1981-05-25	5.5	SS	−0.094
13	1971-10-04	4.6	KODb	+0.064	**53**	1981-09-02	4.4	TSG	−0.011
14	1971-12-22	6.0	KODm	+0.095	**54**	1981-09-26	5.2	TSG	−0.028
15	1972-04-11	4.9	KODb	+0.030	**55**	1981-09-26	5.3	TSG	−0.028
16	1972-07-09	4.8	KODb	−0.018	**56**	1981-10-22	5.1	TSG	−0.009
17	1972-08-20	5.7	KODm	+0.352	**57**	1982-07-30	5.0	TSG	−0.033
18	1972-09-04	4.6	KODb	−0.087	**58**	1982-09-25	5.2	TSG	0.000
19	1972-09-21	5.0	KODb	−0.188	**59**	1983-07-10	5.3	SS	+0.025
20	1972-10-03	5.6	KODb	+0.214	**60**	1983-07-10	5.3	SS	+0.025
21	1972-11-24	4.5	KODb	+0.375	**61**	1983-07-10	5.3	SS	+0.025
22	1973-08-15	5.3	KODm SS	+0.169 −0.139	**62**	1983-09-24	5.2	SS	+0.003
23	1973-08-28	5.2	KODm SS	+0.217 +0.055	**63**	1983-09-24	5.1	SS	+0.003
24	1973-09-19	5.1	KODm SS	+0.117 +0.148	**64**	1983-09-24	5.0	SS	+0.003
25	1973-09-30	5.2	KODb	−0.065	**65**	1983-09-24	5.2	SS	+0.003
26	1973-10-26	4.8	KODb	+0.105	**66**	1983-09-24	5.4	SS	+0.003
27	1974-08-29	5.0	SS	+0.130	**67**	1983-09-24	5.3	SS	+0.003
28	1975-09-29	4.8	SS	+0.272	**68**	1984-07-21	5.4	SS	+0.009
29	1976-03-29	4.3	SS TSG	0.000 −0.017	**69**	1984-07-21	5.3	SS	+0.009

Table 1. *Cont.*

(1) Test No.	(2) Date Year-Month-Day	(3) m_b	(4) Instrument Type	(5) Time Corrections (δT), Sec	(1) Test No.	(2) Date Year-Month-Day	(3) m_b	(4) Instrument Type	(5) Time Corrections (δT), Sec
30	1976-07-29	5.9	SS TSG	+0.217 +0.248	**70**	1984-07-21	5.4	SS	+0.009
31	1976-11-05	5.3	SS	+0.128	**71**	1984-08-25	5.3	SS	+0.015
32	1977-07-26	5.0	SS TSG	−0.025 −0.021	**72**	1984-09-17	5.0	TSG	−0.020
33	1977-08-20	5.0	TSG	+0.019	**73**	1984-10-27	5.0	SS TSG	+0.013 −0.006
34	1977-09-10	4.8	SS TSG	+0.124 −0.002	**74**	1984-10-27	5.0	SS TSG	+0.013 −0.006
35	1977-09-30	5.0	SS	−0.002	**75**	1987-07-24	5.1	SS	+0.001
36	1978-08-09	5.6	SS	+0.226	**76**	1987-08-12	5.0	SS	−0.008
37	1978-08-24	5.1	SS TSG	+0.520 −0.012	**77**	1987-10-03	5.3	SS TSG	−0.008 0.000
38	1978-09-21	5.2	SS TSG	+0.189 −0.048	**78**	1988-08-22	5.3	SS TSG	−0.007 0.000
39	1978-10-08	5.2	SS	+0.049	**79**	1988-09-06	4.8	SS TSG	0.000 −0.006
40	1978-10-17	5.8	SS	+0.185					

Three different sets of recording systems were operated at Borovoye, each using several different seismometers and different gain levels. Digital data were recorded by three Russian different systems, called KOD, STsR-SS, and STsR-TSG; Inst. Type = instrument used; KODb = three-component high-gain and a vertical-component low-gain KOD; KODm = three-component low-gain and a vertical-component high-gain system; a 10-channel channel seismic station SS = STsR-SS system; "typical" a 24-channel seismic station TSG = STsR-TSG system [6].

Refined coordinates of Soviet Peaceful Nuclear Explosions are given in [8,11]. With regard to this, in the article, new epicentral distances and azimuths from the Borovoye Geophysical Observatory (BRVK), which has been digitally recorded during earthquakes' monitoring since 1966, have been calculated [12,13]. KOD and STcR systems have errors in time registration. This happened because of the magnetic tapes' replacement every 8 and 12 h. That is why we apply time corrections (δT). Time correction is calculated as follows: $\delta T = t_{(GMT)} - t_{(BRVK)}$, where $t_{(GMT)}$ is the exact time of the USSR PNEs in Greenwich Mean Time, and $t_{(BRVK)}$ is the BRVK registration time. All time corrections are listed in Table 1. For example, the accuracy in time is ±0.001 s for the STcR-SS and STcR-TSG stations, within a ±0.5 s time window.

Table 2 gives information about PNEs' distance (Δ°) and azimuth from BRVK and P-wave travel times (t_{p0} time of occurrence of primary body wave in solid earth after explosion origin time) to BRVK from [8], taking into account the time corrections (δT) of the digital registration stations [12]. PNE sites in Kazakhstan were visited in 2015, allowing GPS coordinates to be obtained in the field. The coordinates of 79 Peaceful Underground Explosions as a result of the analysis of satellite images (Google Earth images and a high resolution images was used from Geoportal Roscosmos), regional seismic data, and visits to epicenters (with radioactivity reports), are specified in [13]. PNEs locations after [13] are presented in Figure 1. Table 2 gives the following information about PNEs: (1) index number, (2) test name, (3) magnitude, calculated by body waves, m_b, (4) date in Year-Month-Day format, (5) origin source time in hour:minute:second format, (6) geographical coordinates in degrees, (7) distance between source and BRVK in degrees (where 1 degree ≈ 111 km), (8) azimuth—angle between direction to the source and BRVK in degrees, (9) travel time tp_0, registered at BRVK after time from row (5) in seconds, (10) instrument type [8]. The accuracy in geographical coordinate locations (row #6 in the table) differs because of the registration system and data quality. Bold type is used from [8], underlined text from IDG RAS database, plain type text from [13]. Refined PNEs locations are shown in Figure 2. All coordinates are available in KLM format in the Supplementary Materials.

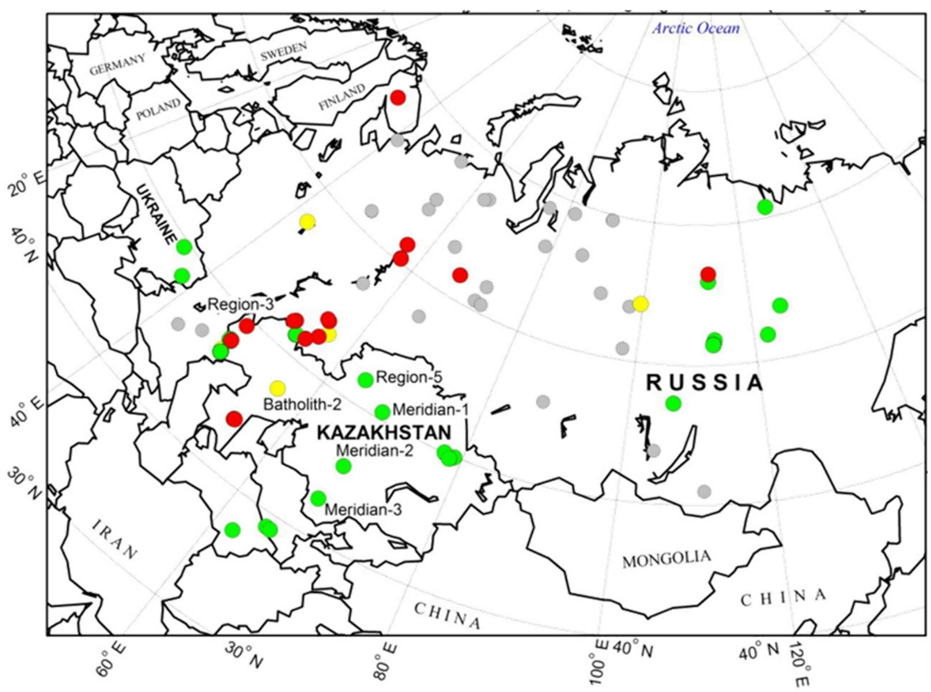


Figure 1. USSR PNEs locations. Green events represent locations determined or verified within 1 km accuracy; red events indicate GT0-1 locations determined where the new coordinates exceed the location errors published by [8]; yellow events were studied but the locations could not be determined or verified, or evidence exists that the true location error is greater than that published by [8]; gray events have not yet been investigated [13].

Table 2. Joint USSR Peaceful Nuclear Explosions database with additional information, registered by Borovoye Geophysical Observatory (BRVK: ϕ° N = 53.05806, λ° E = 70.28278) and included in the IDG RAS archive *.

(1) Test No.	(2) Test Name	(3) m_b	(4) Date Year-Month-Day	(5) Time h:min:s	(6) Coordinates		(7) Δ°, Grad from BRVK	(8) Az, Grad from BRVK	(9) t_{p0} BRVK, Sec	(10) Instrument Type [6]
					Lat. ϕ° (N)	Long. λ° (E)				
1	**Tawda**	**4.7**	**1967-10-06**	**06:59:57.50**	**57.70**	**65.20**	**5.4797**	**330.12**	84.26	KODb
2	Pamuk	**5.4**	1968-05-21	**03:59:11.98**	38.918	63.032	14.5991	196.45	202.70	KODb
3	**Grifon-1**	**4.8**	**1969-09-02**	**04:59:58.61**	**57.220**	**55.393**	**9.4861**	**301.99**	135.68	KODb
4	**Grifon-2**	**4.8**	**1969-09-08**	**04:59:58.70**	**57.220**	**55.417**	**9.4738**	**302.02**	135.28	KODb, KODm
5	**Stavropol**	**5.6**	**1969-09-26**	**06:59:58.14**	**45.848**	**42.600**	**19.3028**	**259.22**	263.83	KODb, KODm
6	Mangyshlak-1	**5.8**	1969-12-06	**07:02:59.85**	43.8625	54.7727	13.7771	234.31	192.71	KODb, KODm
7	Magistral	**4.9**	1970-06-25	**04:59:55.50**	52.3265	55.7238	8.8765	271.09	129.25	KODb
8	Mangyshlak-2	**6.0**	1970-12-12	**07:00:59.83**	43.9096	54.7937	13.7322	234.40	192.01	KODb, KODm
9	Mangyshlak-3	**6.0**	1970-12-23	**07:00:59.76**	43.8858	54.8973	13.6990	234.10	191.58	KODb, KODm
10	Taiga	**5.5**	1971-03-23	**06:59:58.38**	61.306	56.599	11.0884	323.58	157.57	KODb, KODm
11	**Globe-4**	**4.7**	**1971-07-02**	**17:00:01.13**	**67.283**	**63.467**	**14.6526**	**349.50**	202.91	KODb
12	**Globe-1**	**4.5**	**1971-09-19**	**11:00:01.08**	**57.508**	**42.643**	**16.3024**	**296.87**	225.87	KODb
13	**Globe-2**	**4.6**	**1971-10-04**	**10:00:00.14**	**61.358**	**48.092**	**14.5502**	**313.58**	203.719	KODb
14	Azgir A-3-1	**6.0**	1971-12-22	**06:59:59.00**	47.8980	48.1298	14.9938	258.76	207.405	KODb, KODm
15	Crater	**4.9**	1972-04-11	**06:00:01.92**	37.4158	62.0508	16.6626	203.43	230.459	KODb
16	Fakel	**4.8**	1972-07-09	**07:00:01.25**	49.552	35.471	21.9101	274.87	293.034	KODb
17	Region-3	**5.7**	1972-08-20	**03:00:00.01**	49.4169	48.16155	14.3130	264.13	199.142	KODb, KODm
18	Dnepr-1	**4.6**	1972-09-04	**07:00:00.00**	67.782	33.618	22.8505	324.21	308.013	KODb
19	Region-1	**5.0**	1972-09-21	**09:00:00.31**	52.1404	52.0929	11.1031	272.53	158.143	KODb
20	**Region-4**	**5.6**	**1972-10-03**	**09:00:00.18**	**46.853**	**44.938**	**17.3970**	**259.29**	238.325	KODb
21	Region-2	**4.5**	1972-11-24	**09:00:00.04**	51.9933	51.8826	11.2614	271.93	161.012	KODb
22	Meridian-3	**5.3**	1973-08-15	**02:00:00.02**	42.7740	67.40695	10.4688	191.73	149.359	KODb, KODm, SS
23	Meridian-1	**5.2**	1973-08-28	**03:00:00.04**	50.5279	68.32127	**2.8114**	206.45	46.643	KODb, KODm, SS
24	Meridian-2	**5.1**	1973-09-19	**03:00:00.18**	45.7588	67.82289	7.4800	193.35	109.022	KODb, KODm, SS
25	Sapphire-2	**5.2**	1973-09-30	**05:00:00.35**	51.6052	54.5991	9.7138	267.66	139.674	KODb
26	Kama-2	**4.8**	1973-10-26	**05:59:59.50**	53.5615	55.51436	8.8605	279.16	127.611	KODb
27	**Horizon-1**	**5.0**	**1974-08-29**	**15:00:00.39**	**67.085**	**62.625**	**14.5620**	**348.02**	203.400	SS
28	**Horizon-3**	**4.8**	**1975-09-29**	**11:00:00.43**	**69.578**	**90.337**	**18.9886**	**21.71**	259.782	SS
29	Azgir A-3-2	4.3	1976-03-29	07:00:00.23	47.8980	48.1298	14.9938	258.76	**207.43**	SS, TSG
30	Azgir A-4	**5.9**	1976-07-29	**05:00:00.50**	47.871	48.138	15.0018	258.65	207.158	SS, TSG
31	Oka	**5.3**	1976-11-05	**03:59:59.98**	61.4608	112.8592	24.1061	52.71	314.878	SS
32	**Meteorite-2**	**5.0**	**1977-07-26**	**17:00:00.22**	**69.575**	**90.375**	**18.9948**	**21.75**	258.899	SS, TSG
33	**Meteorite-3**	**5.0**	**1977-08-20**	**22:00:00.78**	**64.108**	**99.558**	**18.6478**	**42.18**	255.899	TSG
34	Meteorite-4	**4.8**	1977-09-10	**16:00:00.18**	57.2583	106.5565	20.9753	63.92	283.447	SS, TSG
35	Azgir A-5	**5.0**	1977-09-30	**06:59:58.43**	47.888	48.153	14.9848	258.69	207.838	SS
36	Kraton-4	**5.6**	1978-08-09	**18:00:00.79**	63.6773	125.5266	**29.8783**	47.33	367.406	SS
37	Kraton-3	**5.1**	1978-08-24	**18:00:00.35**	65.9254	112.3330	24.3581	41.77	317.681	SS, TSG
38	**Kraton-2**	**5.2**	**1978-09-21**	**15:00:00.19**	**66.598**	**86.210**	**15.6834**	**23.92**	215.752	SS, TSG
39	Vyatka	**5.2**	1978-10-08	**00:00:00.00**	61.5565	112.9922	24.1716	52.47	315.919	SS
40	Azgir A-7	**5.8**	1978-10-17	**04:59:59.06**	47.847	48.120	15.0239	258.60	207.710	SS

Table 2. *Cont.*

(1) Test No.	(2) Test Name	(3) m_b	(4) Date Year-Month-Day	(5) Time h:min:s	(6) Coordinates Lat. ϕ° (N)	Long. λ° (E)	(7) Δ°, Grad from BRVK	(8) Az, Grad from BRVK	(9) t_{p0} BRVK, Sec	(10) Instrument Type [6]
41	**Kraton-1**	**5.5**	**1978-10-17**	**14:00:00.16**	**63.185**	**63.432**	**10.7732**	**343.18**	152.487	SS
42	Azgir A-9	**5.9**	1978-12-18	**07:59:58.50**	47.857	48.161	14.9949	258.58	207.855	SS, TSG
43	Azgir A-8	**6.0**	1979-01-17	**07:59:58.50**	47.919	48.124	14.9872	258.83	207.860	SS, TSG
44	Azgir A-11	**5.6**	1979-07-14	**04:59:58.00**	47.882	48.120	15.0072	258.71	207.254	SS, TSG
45	Kimberlite-4	**4.9**	1979-08-12	**18:00:00.21**	61.7997	122.4161	28.6462	51.47	355.658	SS, TSG
46	**Kimberlite-3**	**4.9**	**1979-09-06**	**18:00:00.31**	**64.110**	**99.562**	**18.6502**	**42.18**	257.024	SS, TSG
47	**Kimberlite-1**	**5.4**	**1979-10-04**	**16:00:00.03**	**60.675**	**71.455**	**7.6641**	**4.33**	107.615	SS, TSG
48	Sheksna	**5.0**	1979-10-07	**21:00:00.22**	61.7679	113.1554	24.2540	51.96	316.473	SS, TSG
49	Azgir A-10	**5.8**	1979-10-24	**05:59:59.00**	48.852	48.143	15.0079	258.58	208.281	SS, TSG
50	Vega-1	**5.2**	1980-10-08	**06:00:00.29**	46.7565	48.2738	15.4846	254.81	213.473	SS
51	**Batholith-1**	**5.2**	**1980-11-01**	**13:00:00.42**	**60.80**	**97.55**	**16.6751**	**51.53**	231.578	TSG
52	**Pyrite**	**5.5**	**1981-05-25**	**05:00:00.32**	**68.20**	**53.50**	**17.1684**	**338.57**	236.342	SS
53	Helium-1	**4.4**	1981-09-02	**03:59:59.99**	60.2751	57.2991	10.1514	320.56	145.379	TSG
54	Vega 2-1	**5.2**	1981-09-26	**05:00:00.28**	46.7936	48.3088	15.4445	254.88	212.732	TSG
55	Vega 2-2	**5.3**	26-09-1981	**05:03:59.94**	46.7760	48.3012	15.4583	254.84	214.682	TSG
56	**Shpat-2**	**5.1**	**22-10-1981**	**14:00:00.36**	**63.80**	**97.55**	**17.7117**	**41.95**	244.801	TSG
57	**Rift-3**	**5.0**	**30-07-1982**	**21:00:00.00**	**53.80**	**104.15**	**20.0877**	**74.25**	273.192	TSG
58	**Rift-4**	**5.2**	**25-09-1982**	**18:00:00.18**	**64.35**	**91.80**	**15.8005**	**35.89**	218.070	TSG
59	Lira 1-1	**5.3**	10-07-1983	**03:59:59.99**	51.3627	53.306	10.5577	267.54	150.648	SS
60	Lira 1-2	**5.3**	10-07-1983	**04:04:59.94**	51.3660	53.3258	10.5449	267.54	151.245	SS
61	Lira 1-3	**5.3**	10-07-1983	**04:09:59.85**	51.3802	53.3388	10.5332	267.61	149.695	SS
62	Vega 4-1	**5.2**	24-09-1983	**05:00:00.03**	46.7812	48.3197	15.4447	254.83	212.555	SS
63	Vega 4-2	**5.1**	24-09-1983	**05:05:00.03**	46.7872	48.2966	15.4550	254.88	212.964	SS
64	Vega 4-3	**5.0**	24-09-1983	**05:10:00.08**	46.7671	48.3079	15.4591	254.80	212.417	SS
65	Vega 4-4	**5.2**	24-09-1983	**05:15:00.14**	46.7500	48.3006	15.4724	254.76	213.059	SS
66	Vega 4-5	**5.4**	24-09-1983	**05:19:59.93**	46.7538	48.2877	15.4779	254.79	213.677	SS
67	Vega 4-6	**5.3**	24-09-1983	**05:25:00.00**	46.7657	48.2740	15.4796	254.84	213.489	SS
68	Lira 2-1	**5.4**	21-07-1984	**02:59:59.81**	51.3584	53.3198	10.5506	267.51	150.022	SS
69	Lira 2-2	**5.3**	21-07-1984	**03:04:59.71**	51.3717	53.3357	10.5374	267.56	149.769	SS
70	Lira 2-3	**5.4**	21-07-1984	**03:09:59.85**	51.3916	53.3497	10.5235	267.66	151.319	SS
71	**Quartz-3**	**5.3**	**25-08-1984**	**19:00:00.33**	**61.90**	**72.10**	**8.9200**	**5.56**	123.723	SS
72	**Quartz-4**	**5.0**	**17-09-1984**	**21:00:00.03**	**55.834**	**87.526**	**10.4174**	**67.65**	149.494	TSG
73	**Vega 5-1**	**5.0**	**27-10-1984**	**06:00:00.10**	**46.90**	**48.15**	**15.4811**	**255.44**	213.594	SS, TSG
74	**Vega 5-2**	**5.0**	**27-10-1984**	**06:05:00.00**	**46.95**	**48.10**	**15.4842**	**255.67**	214.404	SS, TSG
75	Neva 2-2	**5.1**	24-07-1987	**02:00:00.00**	61.4172	112.8927	24.1215	52.81	314.981	SS
76	Neva 2-3	**5.0**	12-08-1987	**01:30:00.50**	61.4266	112.8879	24.1193	52.79	315.097	SS
77	**Batholith-2**	**5.3**	**03-10-1987**	**15:15:00.03**	**47.60**	**56.20**	**10.5241**	**244.37**	149.077	SS, TSG
78	**Ruby-2**	**5.3**	**22-08-1988**	**16:20:00.07**	**66.280**	**78.491**	**13.8757**	**13.94**	**192.197**	SS, TSG
79	**Ruby-1**	**4.8**	**06-09-1988**	**16:19:59.94**	**61.361**	**48.092**	**14.5515**	**313.60**	202.637	SS, TSG

* In the table, the parameters according to [8] are marked in bold, according to [13] in plain text, and underlined text according to the Institute of Geosphere Dynamics (IDG RAS). Three different sets of recording systems were operated at Borovoye, each using several different seismometers and different gain levels. Digital data were recorded by three Russian different systems, called KOD, STsR-SS, and STsR-TSG; Inst. Type = instrument used; KODb = three-component high-gain and a vertical-component low-gain KOD; KODm = three-component low-gain and a vertical-component high-gain system; a 10-channel channel seismic station SS = STsR–SS system; "typical" a 24-channel seismic station TSG = STsR–TSG system [6].

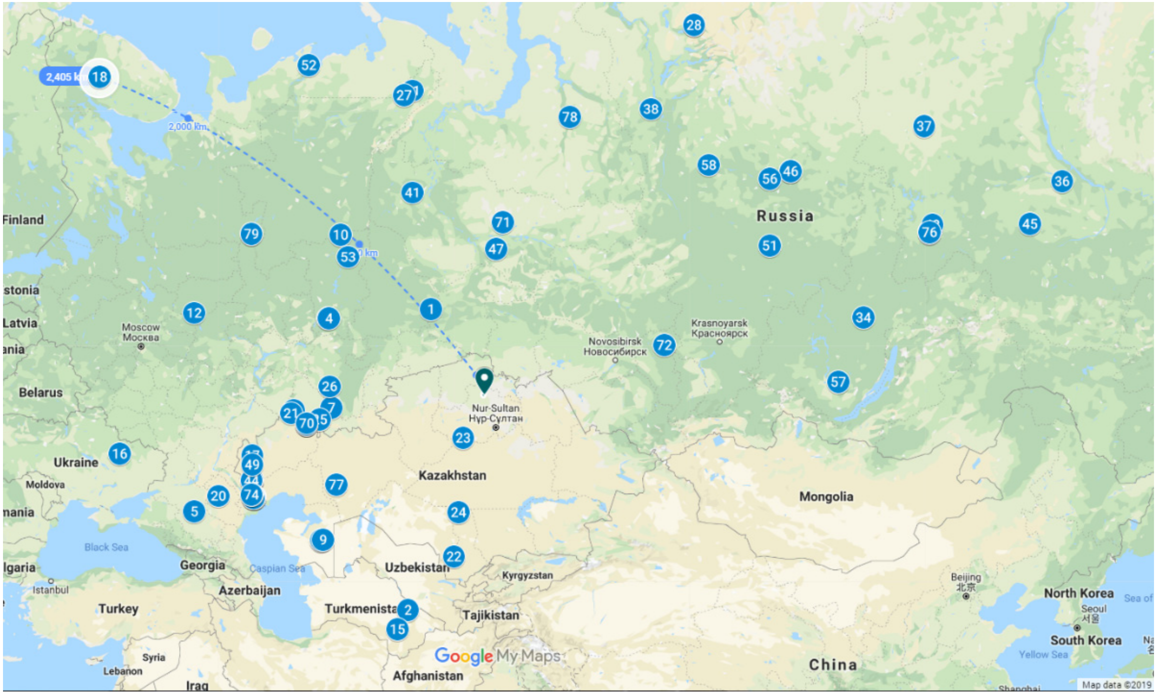


Figure 2. USSR PNEs locations from Table 2 with Google Maps Tools. The numbers are related to column #(1) Test No. from Table 2.

An error was found in [8] in the travel time of the 22 August 1988 test named Ruby-2 (corrected in the table by the bold underline). In addition, we lined up travel-time curves for all epicentral distances from Table 2, shown below.

3. Seismograms

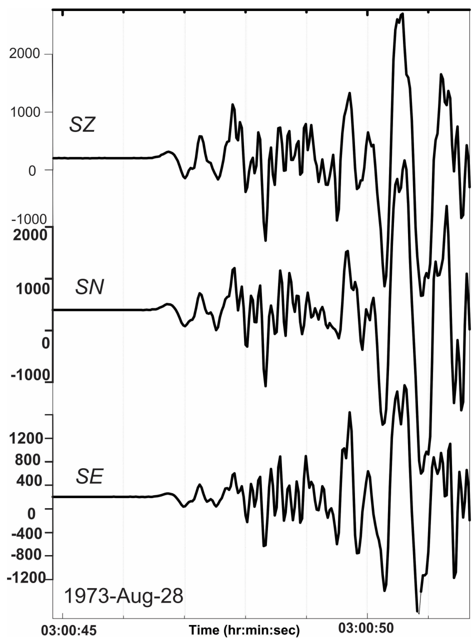
The information restoration from magnetic tapes is a complex task. At Los Alamos National Laboratory, an automated algorithm was designed. It is an algorithm to repair wave form [10,11,13]. Timing information comes from the extraction and de-multiplexing. The information tag inside magnetic tape provides information on channel number, digitizing interval, date, record start time (to the nearest ms) and time correction. There are some signals of good quality and others that are badly clipped. Bad quality means that raw waveforms (traces) are contaminated with glitches on all seismometer channels and different gain levels. The following algorithms are applied to identify the glitches' edge points at the poor data trace: trace differentiation, high pass Butterworth filtering, a fourth-order polynomial L1 minimization fit, the median removal and 10-point tapers to the beginning and end of the entire waveform (with a corner set to two-thirds the Nyquist frequency). The procedure matches five waveform points exactly. As a fine adjustment, this algorithm add a linear function to the polynomial to ensure that those edge points are matched exactly. Finally, we can obtain absolute values. The original glitch and repaired waveform are then displayed, whereupon the user may:

1. accept the repair;
2. pick one or more of the glitch edge points and window endpoints, and refit the waveform;
3. expand the window, pick as above, and refit the waveform;
4. skip the repair of that segment.

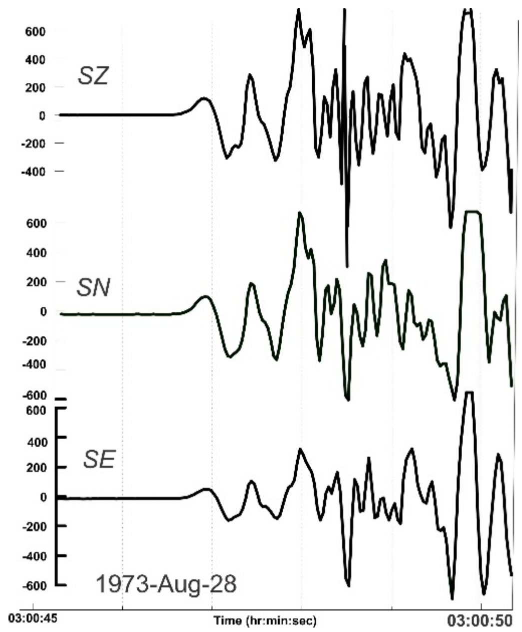
Due to this LDEO script, the seismograms were stored. Digital data from the magnetic tapes were mass stored on the hard drive in the IDG RAS archive as PostScript files. These files were converted into images (TIFF, JPEG, or BMP format). Then we applied the GetData Graph Digitizer program (http://www.getdata-graph-digitizer.com/index.php) for digitizing independent traces. GetData Graph Digitizer is a program for digitizing graphs and plots. We adjusted the X and Y axis in the image plot.

GetData Graph Digitizer allows us to get the values in different formats (TXT (ASCII), XLS (MS Excel), XML, DXF (AutoCAD), or EPS (PostScript)). Because of that, we obtain ASCII files (Supplementary files S1–S6).

We show an example of seismic signals for Meridian-1 Test on 28 August 1973 (Figure 3). We mentioned that there were two registration systems, KOD and STsR, with different gain levels. In Figure 3a the KODm seismic station and in Figure 3b the STsR-SS seismic station data are shown. Both systems have spatially orientated components recorded at separate channels: SZ—vertical; SN, SE—horizontal.



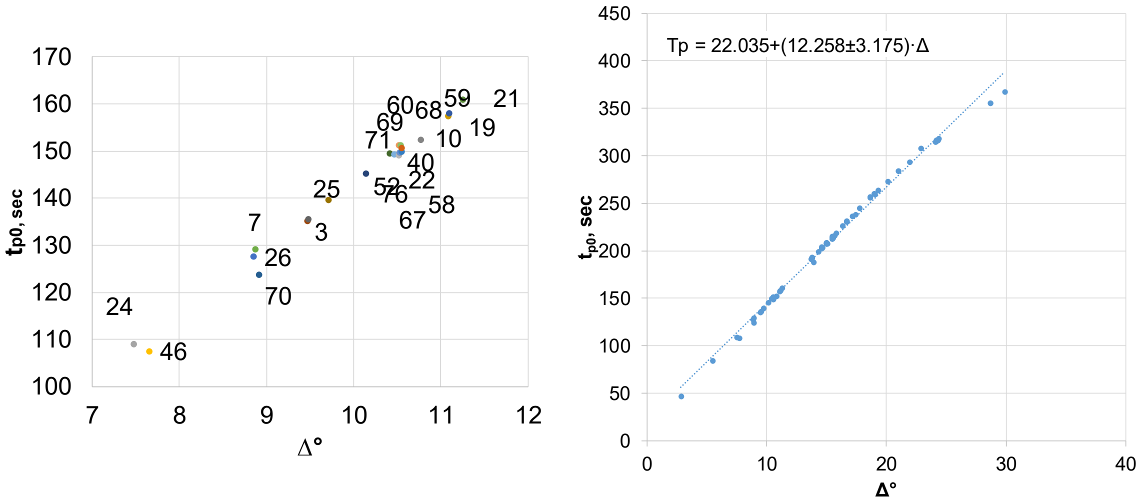
(**a**)



(**b**)

Figure 3. Meridian-1 test on 28 August 1973: seismic traces that present primary body wave arrivals, detected from the paper recordings. Channels SZ—vertical; SN, SE—horizontal registered by: (**a**) KODm seismic station. Time correction is $\delta T = +0.217$ s [7]; (**b**) STsR-SS seismic station, 28 August 1973. Channels SZ—vertical; SN, SE—horizontal. Time corrections is $\delta T = +0.055$ s [8].

Figure 3 illustrates the signal from the primary body wave (P-wave arrival). The registration time is the same, 03:00:46.78. The signal shape is also similar to Figure 3a,b. P-arrivals are quite impulsive. Afterwards, the data from Table 2 could be used for P-wave velocity estimation. With the travel-time P-wave, it is simple to construct a velocity propagation model. For this reason, we draw a plot. The distance between PNE and Borovoye is shown on the X axis ($\Delta°$ in degrees). The travel time is shown on the Y axis (t_{p0}). This is called the travel-time curve plot $t_{p0} = F(\Delta°)$. It helps us to find the local or regional velocity as a function of distance. Local and regional travel-time curves are shown in Figure 4. If we put all the dots together, we obtain the full curve. This curve is suitable for linear equations. We approximate it with the equation $Tp = 22.035 + (12.258 \pm 3.175)\cdot\Delta$.



(**a**) (**b**)

Figure 4. Local (Δ° = 7–12) (**a**) and regional (Δ° = 0–30) (**b**) P-wave travel-time curves (t_{p0} = F(Δ°)) for the traces from USSR Peaceful Nuclear Explosions locations to observatory Borovoye.

4. Conclusions

We described the PNEs database from the IDG RAS archive. We compared PNEs' parameters from different literature sources. We found some mistakes in the PNEs' locations, time delays, and shifts according to the distance–explosion magnitude dependence. In addition, we corrected the information and made a refined table. Then, we made a map with the PNEs' coordinates in KML format. We use P-wave travel-time from the seismograms to plot travel-time curves. Propagating wave travel times make it possible to construct deep Earth models. PNEs' locations are widespread across the Eurasian continent. Providing refined information is useful for Earth modeling within Eurasia. There are many more seismograms in the IDG RAS database, but there are no confirmed and controlled seismic events like explosions. We encourage scientists to work with such data.

Supplementary Materials: The following are available online at http://www.mdpi.com/2306-5729/4/2/56/s1, Files S1–S6 Meridian-1 Test seismic trace recorded by: File S1: channel (SZ) of KODm seismic station, File S2: channel (SN) of KODm seismic station, File S3: channel (SE) of KODm seismic station; File S4: channel (SZ) of STsR-SS seismic station, File S5: channel (SN) of STsR-SS seismic station, File S6: channel (SE) of STsR-SS seismic station; File S7: PNEs coordinates; Files Figure 3a KOD and Figure 3b SS seismogram Meridian-1 test in PostScript format.

Author Contributions: Head of Expedition No. 4 of the Special Branch of the Institute of Physics of the Earth of the USSR Academy of Sciences, participant in digital recording designing and restoration process, conceptualization, methodology, resources V.A.; formal analysis, data curation, visualization, K.N.; writing—original draft preparation, K.N.

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