https://doi.org/10.52676/1729-7885-2022-2-53-61
УДК 550.834

PAHUTE MESA TRAVEL TIMES AT KURIL–KAMCHATKA SEISMIC STATIONS

K.S. Nepeina[1], V.A. An[2]

[1] ***Research Station RAS in Bishkek, Bishkek, Kyrgyzstan***
[2] ***Sadovsky Institute of Dynamics of Geospheres of the Russian Academy of Sciences, Moscow, Russia***

E-mail for contacts: nepeina.k@mail.ru

This research fulfills additional information about the lithosphere below Southeastern Asia and the northern Pacific. The area is interesting for researchers because of the Kuril–Kamchatka subducted lithosphere. The availability to study an underground structure is complicated, because of Pacific Ocean. The significance of this research concerns epicentral distances ~54°–70° or ~6000–7000 km. During the Cold War of the 20th century and the classification of information between the largest nuclear states the Soviet Union (USSR) and the United States of America (USA), data on the registration of nuclear explosions were not published, however, underground nuclear explosions (UNE) were recorded. Thanks to an employee of the laboratory 5-s of the Institute of Physics of the Earth named after O.Yu. Schmidt of the USSR Academy of Sciences Kh.D. Rubinstein is kept at the Institute for the Dynamics of Geospheres of the Russian Academy of Sciences named after Academician M.A. Sadovsky (IDG RAS). Only after 1985 reports from some seismic stations of the former USSR began to be published in the operational reports of the United Geophysical Survey of the Russian Academy of Sciences (GS RAS). As it has not been yet published anywhere, we collect them and obtain the travel times were by revising seismograms from the archives IDG RAS and GS RAS for five Kuril–Kamchatka seismic stations (Bering, Esso, Severo-Kurilsk, Kurilsk). The 48 Unites States UNE at Pahute Mesa (at Nevada Test Site) from 1968 to 1990 are used for travel time curve building. We measure P waves travel times (t_p) on historical seismograms for the ray travel path between Pahute Mesa tests and Kuril–Kamchatka stations. The body-waves magnitudes (m_b) vary from 5.3 to 6.5. We obtain arrivals for: 1 UNE at Bering station, 7 UNE at Esso station, 45 UNE at Petropavlovsk, 18 UNE at Severo-Kurilsk and 12 at Kurilsk. We build a travel time function using linear regression algorithm as $t_p=k\cdot\Delta°+b$, where $\Delta°$ is the epicentral distance, k and b are arbitrary constants. We show that travel time deviations, associated with nonlinearity of the Earth. We estimate the effective velocities of P waves for the Pahute Mesa – Kuril–Kamchatka travel path as coefficient k in the linear equation. Effective velocity is equal to 7.5 km/s.

Keywords: *P wave, velocity, travel-time, teleseismic distance, NTS, Kuril–Kamchatka.*

INTRODUCTION

The study of the structure of the Earth based on the results of the travel times of body seismic waves is relevant at the present time, since the observational data are still being refined (for example, the coordinates of the sources, the parameters of the charge, the magnitudes). Of particular interest is the study of such data for teleseismic ray paths with source-receiver distances of ~6000–7000 km (epicentral distances Δ~54°–70°, where 1°~111 km) or further distances, e.g. 90° [1]. The archives of the Sadovsky Institute of Geosphere Dynamics of the Russian Academy of Sciences (IDG RAS) and United Geophysical Survey of the Russian Academy of Sciences (GS RAS) contain seismograms of historical underground nuclear explosions (UNE) recordings.

Most of the recordings were not analyzed, and the parameters of the related events still are not determined. In this case, the historical seismograms have been reviewed. For this reason, we need to develop an approach for travel time curves. Also, this information could be helpful for velocity models improvement. As P waves velocity values in the AK135 earth model [2] for better locating earthquakes in complex velocity models [3].

Velocity heterogeneity and anisotropy below Southeastern Asia and the northern Pacific are practically unknown. Especially the side, where is the Pacific Ocean. The research for Kuril Islands with earthquake travel times from stations in Western Europe (between 73° and 95° of epicentral distance) was studied before by Freybourger, Krüger and Achauer [4]. Concerning the east side of Eurasia, the most eastern stations of the former Soviet Union (USSR) were located in the Kuril–Kamchatka zone. They recorded some United States (US) nuclear tests. At the same time, the sources (US UNE) and receivers (Kuril seismic stations) are separated by the Pacific Ocean, where practically there were no seismic stations. The ocean borehole broadband observation beneath the deep seafloor in the Japan Sea started only after 1989 [5, 6]. The area is interesting for researchers because of the Kuril–Kamchatka subducted lithosphere. Since the Aleutian Arc is also a part of the Pacific “Ring of Fire”. However, there are some seismic tomography studies for these subduction zones below the Kuril–Kamchatka and the Aleutian arcs by Koulakov, Dobretsov, Bushenkova, and Yakovlev [7], which prove density heterogeneity. Thereby this research is a continuation and resumption of our previous works for teleseismic distances, e.g. for Aleutian arc [8].

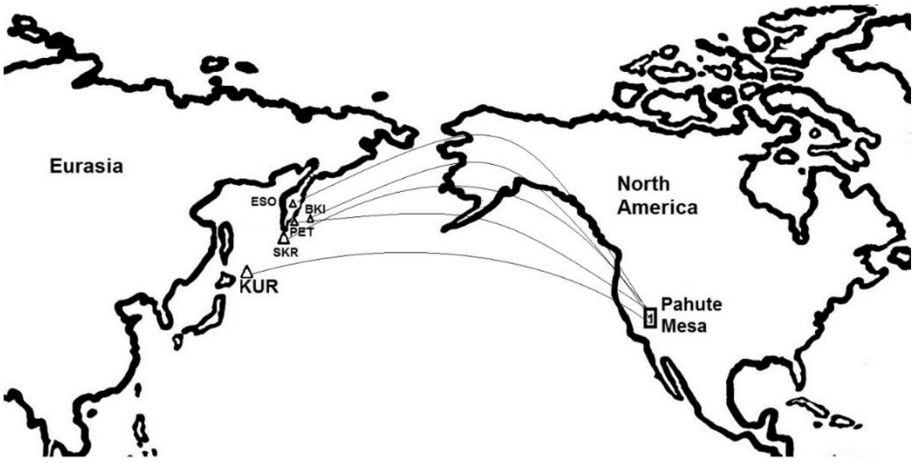

Figure 1. The relative position for travel path between seismic stations at the Kuril–Kamchatka zone and tests at Pahute Mesa (Nevada Test Site)

We choose five seismic stations, which recorded during the Soviet era with three-component seismometers [9, 10]: Severo-Kurilsk (SKR, φ=50.67°N, λ=156.117°E) and Kurilsk (KUR, φ=45.231°N, λ=147.873°E), Bering (BKI φ=55.194°N, λ=165.984°E), Esso (ESO, φ=55.9316°N, λ=158.6950°E), Petropavlovsk (PET, φ=53.0233°N, λ=158.653°E). The stations were opened: Severo-Kurilsk 01.03.1958 on the northern part of the Paramushir Island; Kurilsk 01.01.1950 on the Iturup Island; Bering 20.11.1962 on the Bering Island; Esso 24.11.1965 in Central part of the Kamchatka Peninsula; Petropavlovsk 18.03.1951 on shore of the Kamchatka Peninsula (Petropavlovsk-Kamchatsky city). All of these stations recorded US UNE. For the research purposes, as a teleseismic signal source, we chose Pahute Mesa tests. Pahute Flat (37.268547°N, 116.809234°W) is a plain area situated in the northeastern part of the NTS polygon. There were 827 documented atmospheric and underground nuclear tests conducted, accounting for nearly 80% of all US nuclear tests from 1951 to 1992, upon [11, 12]. The relative position of sources and receivers are presented in Figure 1.

Many researchers are still studying the legacy of nuclear explosions on the territory of the largest test sites – Semipalatinsk (STS) in Kazakhstan and Nevada (NTS) in the United States [13]. Locations of NTS and STS test areas are shown in An, Ovtchinnikov, Kaazik et al. [14]. Various researchers for NTS have constructed travel time curves for the propagation of body and shear waves and made estimates of attenuation [15, 16]. A detailed description of the geological and tectonic features is presented in publications [17, 18]. The results of the assessment of GIS surface effects of underground nuclear explosions carried out in Pahute Mesa are given in [12]. The results of processing the experimental data for ray traces below Southeastern Asia are presented in this work. The study shows the characteristics of the travel path– Pahute Mesa (NTS) – Kuril–Kamchatka. The non-linearity of geologic media gives a lot of deviations in seismic wave velocities for NTS UNE and, consequently, azimuths [19, 20].

METHODS AND DATA

In this study, we select 48 tests at Pahute Mesa (NTS), which occurred from 1968 to 1990. The test names and its' parameters (e.g. origin time) are known from [21, 22]. We search the first break peaks for P waves on historical seismograms and estimate deviations of travel time of seismic signals. We precisely measured arrival times (t_{arr}) of teleseismic P phases seismic stations based on the Kuril–Kamchatka arc. For the example of registration of underground nuclear explosions at the Pahute site of the Nevada Test Site (NTS), local travel time curves and linear trends in the P wave travel time in the range of epicentral distances ~54°–70° are investigated. The epicentral distances between Pahute polygon and Kuril seismic stations are: Bering Δ=54.1120° (BKI-Pah); Esso Δ=57.8442° (ESO-Pah); Petropavlovsk Δ=58.8831° (PET-Pah); Severo-Kurilsk Δ=61.2714° (SRK-Pah); Kurilsk Δ=68.6790° (KUR-Pah). The selected UNE have magnitudes m_b = 5.3–6.5.

After processing and analyzing all seismograms, we summarize all main UNE parameters in Tables 1 and 2. It shows the dates and origin time of the UNE tests, the yield, body wave magnitudes, depth of burial, surface elevation, and the calculated values of the teleseismic distances (Δ°) with the P wave arrival times (t_p). The total amount of underground nuclear explosions is 48 (Table 1). We especially note that the registration of US explosions by the Soviet stations is unique, because the distance is quite large. This fact indicates the high sensitivity of these selected stations. Although, some tests were missed. Hence, we obtain arrivals for: 1 UNE at Bering station, 7 UNE at Esso station, 45 UNE at Petropavlovsk, 18 UNE at Severo-Kurilsk and 12 at Kurilsk. An invisible small signal amplitude could explain the reason of the small amount of found arrivals for the analyst or any other error (e.g. time correction shift).

Table 1. The main parameters of Pahute Mesa tests at seismic stations (PET, SKR, KUR)

#	Date* DD.MM.YYYY	Origin Time* T_0 HH:MM:SS	Test Name*	Test Latitude*	Test Longitude*	Time t_{arr} PET Δ=58.8831°	Time t_{arr} SKR Δ=61.2714°	Time t_{arr} KUR Δ=68.6790°	Yield* kt	m_b*	Depth of Burial*, m	Surface Elevation*, m
1.	20.12.1966	15:30:00.08	Greeley	37.302	−116.409	15:39:58.0	–	–	870	6.3	1215	1945
2.	23.05.1967	14:00:00.04	Scotch	37.275	−116.371	14:09:57.0	–	–	155	5.7	977	2034
3.	26.04.1968	15:00:00.07	Boxcar	37.295	−116.457	15:09:57.0	15:10:13.5	–	1300	6.3	1158	1914
4.	15.06.1968	13:59:59.97	Rickey	37.265	−116.316	14:09:59.0	–	–	20–200	5.9	683	2116
5.	28.06.1968	12:22:00.08	Chaleaugay	37.245	−116.484	12:31:57.0	–	–	20–200	6.3	607	1876
6.	19.12.1968	16:30:00.04	Benham	37.231	−116.474	16:39:56.6	16:40:13.1	–	1150	6.3	1402	1887
7.	07.05.1969	13:45:00.04	Purse	37.283	−116.502	13:54:58.5	–	–	20–200	5.8	599	1828
8.	16.09.1969	14:30:00.04	Jorum	37.314	−116.462	14:39:52.3	14:40:14.3	14:41:02.2	<1000	6.2	1159	1898
9.	08.10.1969	14:30:00.14	Pipkin	37.257	−116.442	14:39:59.5	–	–	200–1000	5.5	624	1965
10.	26.03.1970	19:00:00.20	Handley	37.300	−116.535	19:09:57.4	19:10:14.8	19:11:00.4	>1000	6.5	1209	1772
11.	06.06.1973	13:00:00.08	Almendro	37.245	−116.347	13:09:58.0	13:10:14.5	–	200–1000	6.1	1064	2069
12.	14.05.1975	14:00:00.16	Tybo	37.221	−116.475	14:09:59.0	14:10:11.5	–	200–1000	6.0	765	1880
13.	03.06.1975	14:20:00.17	Stilton	37.340	−116.524	14:29:58.0	14:30:13.0	14:31:01.8	20–200	5.9	732	1667
14.	19.06.1975	13:00:00.09	Mast	37.350	−116.321	13:09:58.0	13:10:14.0	–	200–1000	6.1	911	2068
15.	26.06.1975	12:30:00.16	Camembert	37.279	−116.369	12:39:58.5	12:40:13.8	–	200–1000	6.2	1311	2033
16.	28.10.1975	14:30:00.16	Kasseri	37.290	−116.412	14:39:58.5	14:40:13.5	14:41:02.2	200–1000	6.4	1265	1957
17.	20.11.1975	15:00:00.09	Inlet	37.225	−116.368	15:09:58.5	–	–	200–1000	6.0	818	2025
18.	03.01.1976	19:15:00.16	Muenster	37.297	−116.334	19:24:59.0	19:25:14.0	–	200–1000	6.2	1452	2082
19.	12.02.1976	14:45:00.16	Fontina	37.271	−116.489	14:54:58.0	14:55:13.5	14:56:01.9	200–1000	6.3	1219	1837
20.	14.02.1976	11:30:00.16	Cheshire	37.243	−116.421	11:39:58.5	–	11:41:02.3	200–500	6.0	1167	1947
21.	09.03.1976	14:00:00.09	Estuary	37.310	−116.365	14:09:58.0	14:10:14.0	14:11:02.4	200–500	6.0	857	2025
22.	14.03.1976	12:30:00.16	Colby	37.306	−116.472	12:39:59.0	12:40:13.6	12:41:01.5	500–1000	6.3	1273	1904
23.	17.03.1976	14:15:00.09	Pool	37.256	−116.329	14:24:59.0	14:25:14.5	14:26:02.5	200–500	6.1	879	2076
24.	11.04.1978	15:30:00.16	Fondutta	37.300	−116.328	15:39:59.0	–	–	20–150	5.3	633	2072
25.	11.04.1978	17:45:00.07	Backbeach	37.233	−116.369	17:54:59.0	–	–	20–200	5.5	672	2040
26.	31.08.1978	14:00:00.16	Panir	37.276	−116.358	14:09:58.5	–	–	20–150	5.6	681	2013
27.	16.12.1978	15:30:00.16	Farm	37.273	−116.411	15:39:58.7	–	–	20–150	5.5	689	1979
28.	11.06.1979	14:00:00.17	Pepato	37.290	−116.456	14:09:59.0	–	–	20–150	5.5	681	1913
29.	26.04.1980	17:00:00.08	Colwick	37.248	−116.423	17:09:58.5	–	–	20–150	5.4	633	1946
30.	12.06.1980	17:15:00.09	Kash	37.282	−116.455	17:24:59.0	–	–	20–150	5.6	645	1911
31.	25.07.1980	19:05:00.08	Tafi	37.256	−116.478	19:14:58.4	–	–	20–150	5.5	680	1859
32.	06.06.1981	18:00:00.08	Harzer	37.303	−116.326	18:09:58.7	–	–	20–150	5.6	637	2073
33.	12.02.1982	14:55:00.08	Molbo	37.224	−116.464	–	–	15:06:02.6	20–150	5.4	638	1873
34.	12.02.1982	15:25:00.09	Hosta	37.348	−116.317	–	–	15:36:02.7	20–150	5.4	640	2076
35.	25.04.1982	18:05:00.01	Gibne	37.256	−116.423	18:14:58.4	–	–	20–150	5.4	570	1937
36.	24.06.1982	14:15:00.09	Nebbiolo	37.236	−116.371	14:24:59.0	–	–	20–150	5.6	640	2038
37.	01.09.1983	14:00:00.08	Chancellor	37.273	−116.356	14:09:58.0	14:10:14.2	–	143	5.5	624	2013
38.	25.07.1984	15:30:00.08	Kappeli	37.268	−116.412	15:39:59.0	–	–	20–150	5.4	640	1982
39.	09.12.1984	19:40:00.09	Egmont	37.270	−116.498	19:49:45.0	–	–	20–150	5.5	546	1839
40.	02.05.1985	15:20:00.08	Towanda	37.253	−116.326	15:29:59.5	–	–	20–150	5.7	660	2085
41.	12.06.1985	15:15:00.06	Salut	37.248	−116.490	15:24:58.0	–	–	20–150	5.5	608	1873
42.	17.07.1986	21:00:00.06	Cybar	37.279	−116.356	21:09:59.0	21:10:12.4	–	119	5.7	627	2017
43.	18.04.1987	13:40:00.00	Delamar	37.248	−116.510	13:49:59.0	–	–	20–150	5.5	544	1875
44.	30.04.1987	13:30:00.09	Hardin	37.233	−116.424	13:39:59.0	–	–	20–150	5.5	625	1943
45.	07.07.1988	15:05:30.07	Alamo	37.252	−116.378	15:15:29.0	–	–	<150	5.6	622	1964
46.	31.10.1989	15:30:00.09	Hornitos	37.263	−116.492	15:39:59.0	–	–	20–150	5.7	564	1846
47.	13.06.1990	16:00:00.09	Bullion	37.262	−116.421	–	16:10:13.3	16:11:02.7	20–150	5.7	674	1950
48.	12.10.1990	17:30:00.08	Tenabo	37.248	−116.495	17:39:59.0	–	–	20–150	5.6	600	1871

Note: * – Information from [21]

Table 2. The main parameters of Pahute Mesa tests (from Table 1) at seismic stations (BKI, ESO)

#	Date* DD.MM.YYYY	Origin Time* T_0 HH:MM:SS	Test Name*	Time t_{arr} BKI Δ=54.1120°	Time t_{arr} ESO Δ=57.8442°	m_b*
1.	07.05.1969	13:45:00.04	Purse	–	13:54:51.0	5.8
2.	08.10.1969	14:30:00.14	Pipkin	–	14:40:00.0	5.5
3.	26.03.1970	19:00:00.20	Handley	19:09:28.7	19:09:51.2	6.5
4.	06.06.1973	13:00:00.08	Almendro	–	13:09:48.0	6.1
5.	14.05.1975	14:00:00.16	Tybo	–	14:09:51.3	6.0
6.	03.06.1975	14:20:00.17	Stilton	–	14:29:50.7	5.9
7.	19.06.1975	13:00:00.09	Mast	–	13:09:51.1	6.1

Note: * – Information from [21]

Then we calculate the travel times (t_p) of the body P wave, as residual between arrival time (t_{arr}) and the origin time T_0, i.e. $t_p = t_{arr} – T_0$. When constructing the local travel time curve, we use the parameters of the P wave travel time (t_p) and plot the linear function, using regression algorithm $t_p=k·\Delta°+b$, where Δ° is the epicentral distance, k and b are arbitrary constants. Afterwards, we calculate differential travel time (δt) as residual between travel time (t_p) and predicted regression value. We observe differential travel time residuals (δt) for five seismic stations and get results (Table 3). For time travel curve estimation for ray path on Pahute Mesa – Kuril–Kamchatka we apply the methodology and results of our previous studies [8, 13, 22].

Table 3. Result table for P wave travel times and differential travel time residuals

Date DD.MM.YYYY	Epicentral distance Δ°	Travel time t_p, s	Station name	Differential time δt, s
26.03.1970	54.1120	568.50	BKI	6.72
07.05.1969	57.8442	590.96	ESO	1.01
08.10.1969	57.8442	599.86	ESO	9.91
26.03.1970	57.8442	591.00	ESO	1.05
06.06.1973	57.8442	587.92	ESO	−2.03
14.05.1975	57.8442	591.14	ESO	1.19
03.06.1975	57.8442	590.53	ESO	0.58
19.06.1975	57.8442	591.01	ESO	1.06
20.12.1966	58.8831	597.92	PET	0.13
23.05.1967	58.8831	596.96	PET	−0.83
26.04.1968	58.8831	596.93	PET	−0.86
15.06.1968	58.8831	599.03	PET	1.24
28.06.1968	58.8831	596.92	PET	−0.87
19.12.1968	58.8831	596.56	PET	−1.23
07.05.1969	58.8831	598.46	PET	0.67
16.09.1969	58.8831	592.26	PET	−5.53
08.10.1969	58.8831	599.36	PET	1.57
26.03.1970	58.8831	597.2	PET	−0.59
06.06.1973	58.8831	597.92	PET	0.13
14.05.1975	58.8831	598.84	PET	1.05
03.06.1975	58.8831	597.83	PET	0.04
19.06.1975	58.8831	597.91	PET	0.12
26.06.1975	58.8831	598.34	PET	0.55
28.10.1975	58.8831	598.34	PET	0.55
20.11.1975	58.8831	598.41	PET	0.62
03.01.1976	58.8831	598.84	PET	1.05
12.02.1976	58.8831	597.84	PET	0.05
14.02.1976	58.8831	598.34	PET	0.55
09.03.1976	58.8831	597.91	PET	0.12
14.03.1976	58.8831	598.84	PET	1.05
17.03.1976	58.8831	598.91	PET	1.12
11.04.1978	58.8831	598.84	PET	1.05
11.04.1978	58.8831	598.93	PET	1.14
31.08.1978	58.8831	598.34	PET	0.55
16.12.1978	58.8831	598.54	PET	0.75
11.06.1979	58.8831	598.83	PET	1.04
26.04.1980	58.8831	598.42	PET	0.63
12.06.1980	58.8831	598.91	PET	1.12
25.07.1980	58.8831	598.32	PET	0.53
06.06.1981	58.8831	598.62	PET	0.83
25.04.1982	58.8831	598.39	PET	0.60
24.06.1982	58.8831	598.91	PET	1.12
01.09.1983	58.8831	597.92	PET	0.13
25.07.1984	58.8831	598.92	PET	1.13
09.12.1984	58.8831	584.91	PET	−12.88
02.05.1985	58.8831	599.42	PET	1.63
12.06.1985	58.8831	597.94	PET	0.15
17.07.1986	58.8831	598.94	PET	1.15
18.04.1987	58.8831	599.00	PET	1.21
30.04.1987	58.8831	598.91	PET	1.12
07.07.1988	58.8831	598.93	PET	1.14
31.10.1989	58.8831	598.91	PET	1.12
12.10.1990	58.8831	598.92	PET	1.13
26.04.1968	61.2714	613.43	SKR	−2.39
19.12.1968	61.2714	613.06	SKR	−2.76
16.09.1969	61.2714	614.26	SKR	−1.56
26.03.1970	61.2714	614.6	SKR	−1.22
06.06.1973	61.2714	614.42	SKR	−1.40
14.05.1975	61.2714	611.34	SKR	−4.48
03.06.1975	61.2714	612.83	SKR	−2.99
19.06.1975	61.2714	613.91	SKR	−1.91
26.06.1975	61.2714	613.64	SKR	−2.18
28.10.1975	61.2714	613.34	SKR	−2.48
03.01.1976	61.2714	613.84	SKR	−1.98
12.02.1976	61.2714	613.34	SKR	−2.48
09.03.1976	61.2714	613.91	SKR	−1.91
14.03.1976	61.2714	613.44	SKR	−2.38
17.03.1976	61.2714	614.41	SKR	−1.41
01.09.1983	61.2714	614.12	SKR	−1.70
17.07.1986	61.2714	612.34	SKR	−3.48
13.06.1990	61.2714	613.21	SKR	−2.61
16.09.1969	68.6790	673.16	KUR	1.44
26.03.1970	68.6790	670.84	KUR	−0.88
03.06.1975	68.6790	672.63	KUR	0.91
28.10.1975	68.6790	673.04	KUR	1.32
12.02.1976	68.6790	672.74	KUR	1.02
14.02.1976	68.6790	673.14	KUR	1.42
09.03.1976	68.6790	673.31	KUR	1.59
14.03.1976	68.6790	672.34	KUR	0.62
17.03.1976	68.6790	673.41	KUR	1.69
12.02.1982	68.6790	673.52	KUR	1.80
12.02.1982	68.6790	673.61	KUR	1.89
13.06.1990	68.6790	673.61	KUR	1.89

RESULTS

We plot travel times versus epicentral distance from Table 3 in Figure 2. Following, we apply regression and get a linear function for the local travel time curve for epicentral distance (54<Δ°<70°). The interpretation of travel time observations, however, helps investigate the wave velocity propagation and derive varying velocity structures below selected traces.

The deviations of travel times of seismic signals are called differential travel time residuals (δt). The δt values (seconds) from Table 3 slightly vary in average segment: for Esso −2.03<δt<1.19; for Petropavlovsk −1.23<δt <1.63; for Severo-Kurilsk −4.48<δt<−1.22; for Kurilsk −0.88<δt<1.89. Nevertheless, some travel times are anomalous: at ESO station too long for Pipkin UNE (08.10.1969) with δt=9.91 s; at PET station too fast – Egmont UNE (09.12.1984) with δt= −12.88 s and Jorum UNE (16.09.1969) with δt= −5.53 s. For Bering station, we could not provide this analysis, as we have only one registration. In Figure 3, we give a graphical estimation for the travel time trend in calendar time.

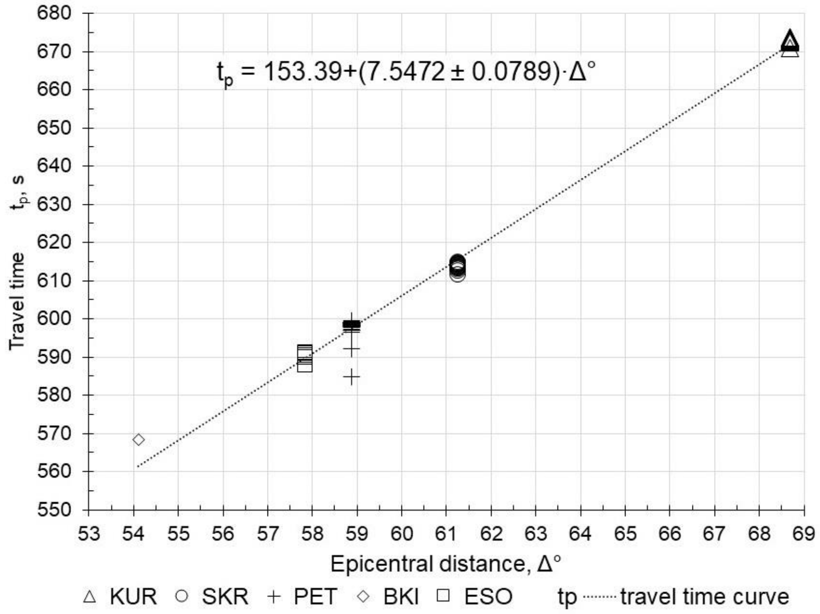

Figure 1. Travel times (t_p) versus epicentral distance (54<Δ°<70°) of seismic stations (KUR, SKR, PET, BKI, ESO) and local approximation for travel time curve

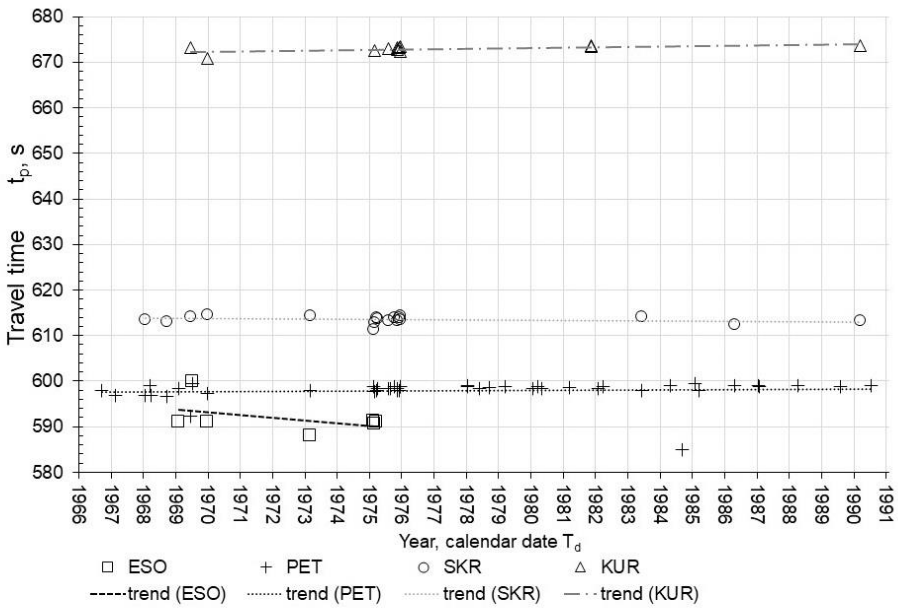

Figure 2. Travel time (t_p) plot versus calendar date (T_d, years) with trends for four Kuril–Kamchatka seismic stations (ESO, PET, SKR, KUR)

CONCLUSIONS

We analyzed historical seismograms of five Soviet era seismic stations:

− Severo-Kurilsk (SKR, φ=50.67°N, λ=156.117°E);
− Kurilsk (KUR, φ=45.231°N, λ=147.873°E);
− Bering (BKI, φ=55.194°N, λ=165.984°E);
− Esso (ESO, φ=55.9316°N, λ=158.6950°E).
− Petropavlovsk (PET, φ=53.0233°N, λ=158.653°E).

We prepared the P wave travel times table for 48 artificial seismic events (Pahute Mesa texts). We construct functional dependencies, which satisfies the equation for the travel time curve (in seconds):

$$t_p = 153.39 + (7.5472 \pm 0.0789)\cdot\Delta°,$$

where Δ is the epicentral distance in degrees between 54° and 70°.

We estimate the effective velocities of P waves equal to 7.5 km/s for the Pahute Mesa – Kuril–Kamchatka travel path as coefficient k in the linear regression equation. However, assessing the trend t_p along the calendar date (T_d) in years instead of the epicentral distance (Δ°) show the absence of tendency. Luckily, it notes the reasonable and stable choice of seismic station locations.

Our results prove velocity anomalies existence beneath selected paths. Thus these conclusions fully match with density jump observations from [23–25]. This effect is also noted by Zheng and Lay [26]. We also take into account the opinion about "… unusually low Vp/Vs ratios in the range 1.6–1.7 for the uppermost mantle under the Sea of Okhotsk and comparably low average Vp/Vs ratios for the crust in several regions. The presence of fluids and extensive silica enrichment, possibly involving low-temperature veining, are viable explanations for the anomalous Vp/Vs ratios" [26].

ACKNOWLEDGEMENTS

The authors are grateful to Taisiya Chelyubeeva from IDG RAS for her assistance in carrying out this study and United Geophysical Survey of the Russian Academy of Sciences (GS RAS) staff for cooperation. All requests were initiated to GS RAS by Vadim An (IDG RAS) personally.

The work was carried out within the framework of the state assignment of the Research Station of the Russian Academy of Sciences in Bishkek 1021052806454-2-1.5.1.

REFERENCES

1. An V. A., Lyuke E. I., Pasechnik I. P. Variatsii parametrov seysmicheskikh voln pri prosvechivanii Zemli na rasstoyanii 90° // Dokl. AN SSSR. – 1985. – T. 285(4). – P. 836–840.
2. Zhang F.-X., Wu Q.-J., Pan J.-T., Zhang G.-C., Feng Q.-Q. The computation of a finite-frequency travel time sensitive kernel for P waves in the AK135 earth model // Appl. Geophys. – 2011. – Vol. 8 (2). – pp. 158–163. https://doi.org/10.1007/s11770-011-0280-6.
3. Zhao A., Ding Z. An intersection method for locating earthquakes in complex velocity models // Appl. Geophys. – 2007. – Vol. 4 (4). – pp. 294 – 300. https://doi.org/10.1007/s11770-007-0036-5.
4. Freybourger M., Krüger F., Achauer U. A 22° long seismic profile for the study of the top of D' // Geophys. Res. Lett. – 1999. – Vol. 26 (22). – pp. 3409 – 3412. https://doi.org/10.1029/1999GL010827.
5. Suyehiro K., Araki E., Shinohara M., Kanazawa T. Deep sea borehole observatories ready and capturing seismic waves in the western Pacific // Eos, Trans. Am. Geophys. Union. – 2002. – Vol. 83 (53). – pp. 621–625. https://doi.org/10.1029/2002EO000420.
6. Webb S. C. Broadband seismology and noise under the ocean // Rev. Geophys. – 1998. – Vol. 36 (1). – pp. 105–142. https://doi.org/10.1029/97RG02287.
7. Kulakov I. Yu., Dobretsov N. L., Bushenkova N. A., Yakovlev A. V. Forma slebov v zonakh subduktsii pod Kurilo-Kamchatskoy i Aleutskoy dugami po dannym regional'noy tomografii // Geologiya i geofizika. – 2011. – T. 52 (6). – P. 830–851.
8. Nepeina K. S., An V. A. Godografy seysmicheskikh voln ot podzemnykh vzryvov na ostrove Amchitka // Akusticheskiy zhurnal. – 2021. – T. 67. – No. 6. – P. 650–658. http://dx.doi.org/10.31857/s0320791921060125.
9. Nepeina K. S., An V. A. Historical seismic stations in USSR and registration underground nuclear explosions // NNC RK Bulletin. – 2021. – Issue. 2. – P. 47–52. https://doi.org/10.52676/1729-7885-2021-2-47-52. (in Russ.)
10. Tsifrovaya baza seysmicheskikh stantsiy na territorii Rossii i SSSR // FGBUN FITs Edinaya Geofizicheskaya sluzhba RAN. http://eqru.gsras.ru/stations/index.php?inc=stalist [Data obrashcheniya 02.02.2022].
11. Patton H. J. Characterization of spall from observed strong ground motions on Pahute Mesa // Bull. Seismol. Soc. Am. – 1990. – Vol. 80 (5). – pp. 1326–1345. https://doi.org/10.1785/BSSA0800051326.
12. Grasso D. N. GIS surface effects archive of underground nuclear detonations conducted at Yucca Flat and Pahute Mesa, Nevada Test Site, Nevada // U.S. Geol. Surv. Open-File Rept. – 2001. – 2001-272.
13. Nepeina K. S., An V. A. Travel time curves and isochron maps from the Borovoye digital archive for the Nevada and Semipalatinsk Nuclear Test Sites // Results Geophys. Sci. – 2021. – Vol. 6. – 100014. https://doi.org/10.1016/j.ringps.2021.100014.
14. An V. A. , Ovtchinnikov V. M., Kaazik P. B., Adushkin V. V., Sokolova I. N., Aleschenko I. B., Mikhailova N. N., Kim W-Y., Richards P. G., Patton H. J., Phillips W. S., Randall G., Baker D. A digital seismogram archive of nuclear explosion signals, recorded at the Borovoye Geophysical Observatory, Kazakhstan, from 1966 to 1996 // GeoResJ. – 2015. – Vol. 6. – pp. 141–163. https://doi.org/10.1016/j.grj.2015.02.014.
15. Gupta I. N., Blandford R. R. A study of P waves from Nevada Test Site explosions: Near-source information from teleseismic observations? // Bull. Seismol. Soc. Am. – 1987. – Vol. 77 (3). – pp. 1041 – 1056. https://doi.org/10.1785/BSSA0770031041.
16. Kopnichev Yu. F., Sokolova I. N., Sokolov K. N. Prostranstvenno-vremennye variatsii struktury polya pogloshcheniya S voln v rayone Nevadskogo yadernogo poligona // Fizika Zemli. – 2013. – No. 6. – P. 39–48. https://doi.org/10.7868/S0002333713060082.

17. Liverman J. L. Nevada Test Site. Nye County, Nevada // Final Environmental Impact Statement. 1977. https://inis.iaea.org/collection/NCLCollectionStore/_Public/09/362/9362842.pdf.
18. Sinnock S. Geology of the Nevada test site and nearby areas, southern Nevada // Sandia Report. SAND82-2207. 1982.
19. Lynnes C. S., Lay T. Effects of lateral velocity heterogeneity under the Nevada Test Site on short-period P wave amplitudes and travel times // Pure Appl. Geophys. PAGEOPH. – 1990. – Vol. 132 (1-2). – pp. 245–267. https://doi.org/10.1007/BF00874365.
20. Kopnichev Yu.F., Pavlova O.V. Azimutal'nye magnitudnye otkloneniya dlya yadernykh vzryvov na poligonakh Semipalatinsk i Nevada // Fizika Zemli. – 1997. – No. 4. – P. 34-45.
21. Springer D. I., Pawloski G. A., Ricca J. L., Rohrer R. F., Smith D. K. Seismic source summary for all U. S. below-surface nuclear explosions // Bull. Seism. Soc. Am. – 2002. – Vol. 92 (5). – pp. 1808–1840. https://doi.org/10.1785/0120010194.
22. An V. A., Godunova L. D., Kaazik P. B., Mikhailova N. N., Ovtchinnikov V. M. Travel time change of seismic body wave in calendar time // Bulletin NNC RK. – 2005. – Issue 2. – pp. 41–45. (in Russ.)
23. Ovchinnikov V.M., Kaazik P.B., Krasnoshchekov D.N. Slabaya anomaliya skorosti vo vneshnem yadre iz seysmicheskikh dannykh // Fizika Zemli. – 2012. – № 3. – S. 34-45.
24. Liu X., Zhao D., Li S. Seismic heterogeneity and anisotropy of the southern Kuril arc: insight into megathrust earthquakes // Geophys. J. Int. – 2013. – Vol. 194 (2). – pp. 1069–1090. https://doi.org/10.1093/gji/ggt150.
25. Krasnoshchekov D., Kaazik P., Kozlovskaya E., Ovtchinnikov V. Seismic Structures in the Earth's Inner Core Below Southeastern Asia // Pure and Applied Geophysics. – 2016. – Vol. 173 (5). – pp. 1575–1591. https://doi.org/10.1007/s00024-015-1207-6.
26. Zheng Y., Lay T. Low Vp / Vs ratios in the crust and upper mantle beneath the Sea of Okhotsk inferred from teleseismic p_MP, s_MP, and s_MS underside reflections from the Moho // J. Geophys. Res. – 2006. – Vol. 111. – B01305. https://doi.org/10.1029/2005JB003724.

Литература

1. Ан В. А., Люкэ Е. И., Пасечник И. П. Вариации параметров сейсмических волн при просвечивании Земли на расстоянии 90° // Докл. АН СССР. – 1985. – Т. 285(4). – С. 836–840.
2. Zhang F.-X., Wu Q.-J., Pan J.-T., Zhang G.-C., Feng Q.-Q. The computation of a finite-frequency travel time sensitive kernel for P waves in the AK135 earth model // Appl. Geophys. – 2011. – Vol. 8 (2). – pp. 158–163. https://doi.org/10.1007/s11770-011-0280-6.
3. Zhao A., Ding Z. An intersection method for locating earthquakes in complex velocity models // Appl. Geophys. – 2007. – Vol. 4 (4). – pp. 294 – 300. http://dx.doi.org/10.1007/s11770-007-0036-5.
4. Freybourger M., Krüger F., Achauer U. A 22° long seismic profile for the study of the top of D' // Geophys. Res. Lett. – 1999. – Vol. 26 (22). – pp. 3409 – 3412. https://doi.org/10.1029/1999GL010827.
5. Suyehiro K., Araki E., Shinohara M., Kanazawa T. Deep sea borehole observatories ready and capturing seismic waves in the western Pacific // Eos, Trans. Am. Geophys. Union. – 2002. – Vol. 83 (53). – pp. 621–625. https://doi.org/10.1029/2002EO000420.
6. Webb S. C. Broadband seismology and noise under the ocean // Rev. Geophys. – 1998. – Vol. 36 (1). – pp. 105–142. https://doi.org/10.1029/97RG02287.
7. Кулаков И. Ю., Добрецов Н. Л., Бушенкова Н. А., Яковлев А. В. Форма слэбов в зонах субдукции под Курило-Камчатской и Алеутской дугами по данным региональной томографии // Геология и геофизика. – 2011. – Т. 52 (6). – С. 830–851.
8. Непеина К. С., Ан В. А. Годографы сейсмических волн от подземных взрывов на острове Амчитка // Акустический журнал. – 2021. – Т. 67. – № 6. – С. 650–658. http://dx.doi.org/10.31857/s0320791921060125.
9. Непеина К. С., Ан В. А. Сейсмические станции Советского Союза и регистрация подземных ядерных взрывов // Вестник НЯЦ РК. – 2021. – Вып. 2. – С. 47–52. https://doi.org/10.52676/1729-7885-2021-2-47-52.
10. Цифровая база сейсмических станций на территории России и СССР // ФГБУН ФИЦ Единая Геофизическая служба РАН. http://eqru.gsras.ru/stations/index.php?inc=stalist [Дата обращения 02.02.2022].
11. Patton H. J. Characterization of spall from observed strong ground motions on Pahute Mesa // Bull. Seismol. Soc. Am. – 1990. – Vol. 80 (5). – pp. 1326–1345. https://doi.org/10.1785/BSSA0800051326.
12. Grasso D. N. GIS surface effects archive of underground nuclear detonations conducted at Yucca Flat and Pahute Mesa, Nevada Test Site, Nevada // U.S. Geol. Surv. Open-File Rept. – 2001. – 2001-272.
13. Nepeina K. S., An V. A. Travel time curves and isochron maps from the Borovoye digital archive for the Nevada and Semipalatinsk Nuclear Test Sites // Results Geophys. Sci. – 2021. – Vol. 6. – 100014. https://doi.org/10.1016/j.ringps.2021.100014.
14. An V. A. , Ovtchinnikov V. M., Kaazik P. B., Adushkin V. V., Sokolova I. N., Aleschenko I. B., Mikhailova N. N., Kim W-Y., Richards P. G., Patton H. J., Phillips W. S., Randall G., Baker D. A digital seismogram archive of nuclear explosion signals, recorded at the Borovoye Geophysical Observatory, Kazakhstan, from 1966 to 1996 // GeoResJ. – 2015. – Vol. 6. – pp. 141–163. https://doi.org/10.1016/j.grj.2015.02.014.
15. Gupta I. N., Blandford R. R. A study of P waves from Nevada Test Site explosions: Near-source information from teleseismic observations? // Bull. Seismol. Soc. Am. – 1987. – Vol. 77 (3). – pp. 1041 – 1056. https://doi.org/10.1785/BSSA0770031041.
16. Копничев Ю. Ф., Соколова И. Н., Соколов К. Н. Пространственно-временные вариации структуры поля поглощения S волн в районе Невадского ядерного полигона // Физика Земли. – 2013. – № 6. – С. 39–48. https://doi.org/10.7868/S0002333713060082.
17. Liverman J. L. Nevada Test Site. Nye County, Nevada // Final Environmental Impact Statement. 1977. https://inis.iaea.org/collection/NCLCollectionStore/_Public/09/362/9362842.pdf.
18. Sinnock S. Geology of the Nevada test site and nearby areas, southern Nevada // Sandia Report. SAND82-2207. 1982.

19. Lynnes C. S., Lay T. Effects of lateral velocity heterogeneity under the Nevada Test Site on short-period P wave amplitudes and travel times // Pure Appl. Geophys. PAGEOPH. – 1990. – Vol. 132 (1-2). – pp. 245–267. https://doi.org/10.1007/BF00874365.
20. Копничев Ю.Ф., Павлова О.В. Азимутальные магнитудные отклонения для ядерных взрывов на полигонах Семипалатинск и Невада // Физика Земли. – 1997. – № 4. – С. 34-45.
21. Springer D. I., Pawloski G. A., Ricca J. L., Rohrer R. F., Smith D. K. Seismic source summary for all U. S. below-surface nuclear explosions // Bull. Seism. Soc. Am. – 2002. – Vol. 92 (5). – pp. 1808–1840. https://doi.org/10.1785/0120010194.
22. Ан В. А., Годунова Л. Д., Каазик П. Б., Михайлова Н. Н., Овчинников В. М. Изменения времени пробега продольной сейсмической волны в календарном времени // Вестник НЯЦ РК. – 2005. – Вып. 2. – С. 41–45.
23. Овчинников В.М., Каазик П.Б., Краснощеков Д.Н. Слабая аномалия скорости во внешнем ядре из сейсмических данных // Физика Земли. – 2012. – № 3. – С. 34–45.
24. Liu X., Zhao D., Li S. Seismic heterogeneity and anisotropy of the southern Kuril arc: insight into megathrust earthquakes // Geophys. J. Int. – 2013. – Vol. 194 (2). – pp. 1069–1090. https://doi.org/10.1093/gji/ggt150.
25. Krasnoshchekov D., Kaazik P., Kozlovskaya E., Ovtchinnikov V. Seismic Structures in the Earth's Inner Core Below Southeastern Asia // Pure and Applied Geophysics. – 2016. – Vol. 173 (5). – pp. 1575–1591. https://doi.org/10.1007/s00024-015-1207-6.
26. Zheng Y., Lay T. Low Vp / Vs ratios in the crust and upper mantle beneath the Sea of Okhotsk inferred from teleseismic p_MP, s_MP, and s_MS underside reflections from the Moho // J. Geophys. Res. – 2006. – Vol. 111. – B01305. https://doi.org/10.1029/2005JB003724.

КУРИЛЬ-КАМЧАТКА СЕЙСМИКАЛЫҚ СТАНЦИЯЛАРЫНДАҒЫ PAHOTE MESA САЯХАТ УАҚЫТЫ

К.С. Непеина[1], В.А. Ан[2]

[1] Бішкек қаласындағы РҒА ғылыми станциясы, Бішкек, Қырғызстан
[2] Садовский РҒА Геосфералар динамикасы институты, Мәскеу, Ресей

Бұл зерттеу Оңтүстік-Шығыс Азия мен Тынық мұхитының солтүстігінен төмен литосфера туралы қосымша ақпаратты орындайды. Бұл аймақ зерттеушілер үшін Курил-Камчатка суасты литосферасына байланысты қызықты. Тынық мұхитына байланысты жер асты құрылымын зерттеудің қолжетімділігі қиын. Бұл зерттеудің маңыздылығы эпицентрлік қашықтыққа ~54°–70° немесе ~6000–7000 км қатысты. 20 ғасырдағы қырғи-қабақ соғыс кезінде және ең ірі ядролық мемлекеттер Кеңес Одағы (КСРО) мен Америка Құрама Штаттары (АҚШ) арасындағы ақпараттың жіктелуі кезінде ядролық жарылыстарды тіркеу туралы мәліметтер жарияланбады, алайда жерасты ядролық жарылыстары (UNE) жазылды. О.Ю. атындағы Жер физикасы институтының 5-с зертханасының қызметкеріне рахмет. Шмидт КСРО Ғылым академиясының Х.Д. Рубинштейн Академик М.А. Садовский атындағы Ресей ғылым академиясының Геосфера динамикасы институтында (РҒА ИДГ) сақталады. 1985 жылдан кейін ғана бұрынғы КСРО-ның кейбір сейсмикалық станцияларының есептері Ресей Ғылым академиясының Біріккен геофизикалық қызметінің (ГС РҒА) жедел есеп берулерінде жариялана бастады. Ол әлі еш жерде жарияланбағандықтан, біз оларды жинаймыз және жол жүру уақытын бес Курил-Камчатка сейсмикалық станциясы (Беринг, Эссо, Северо-Курильск, Курильск) үшін IDG RAS және GS RAS мұрағаттарынан сейсмограммаларды қайта қарау арқылы аламыз. 1968 жылдан 1990 жылға дейін Пахуте Месадағы (Невада сынақ алаңында) 48 Америка Құрама Штаттарының UNE ұйымы саяхат уақытының қисығын құру үшін пайдаланылады. Пахуте-Меса сынақтары мен Курил-Камчатка станциялары арасындағы сәуленің жүру жолы үшін тарихи сейсмограммаларда P толқындарының жүру уақытын (t_p) өлшейміз. Дене толқындарының магнитудасы (m_b) 5.3-тен 6.5-ке дейін өзгереді. Біз келушілерді аламыз: Беринг станциясында 1 UNE, Эссо станциясында 7 UNE, Петропавлда 45 UNE, Северо-Курильскте 18 UNE және Курильскте 12. $t_p=k\cdot\Delta°+b$ ретінде сызықтық регрессия алгоритмін пайдаланып саяхат уақыты функциясын құрастырамыз, мұндағы Δ° – эпицентрлік қашықтық, k және b – ерікті тұрақтылар. Біз Жердің сызықты еместігімен байланысты саяхат уақытының ауытқуын көрсетеміз. Пахуте-Меса – Курил – Камчатка жүру жолы үшін P толқындарының тиімді жылдамдықтарын сызықтық теңдеуде k коэффициенті ретінде бағалаймыз. Тиімді жылдамдық 7,5 км/с тең.

Түйін сөздер: *P толқыны, жылдамдық, жүру уақыты, телесейсмикалық қашықтық, НТС, Курил–Камчатка.*

ГОДОГРАФЫ ОТ ВЗРЫВОВ ПЛОЩАДКИ ПАХЬЮТ ПО ДАННЫМ КУРИЛО-КАМЧАТСКИХ СЕЙСМИЧЕСКИХ СТАНЦИЙ

К.С. Непеина[1], В.А. Ан[2]

[1] Научная станция РАН в г. Бишкеке, Бишкек, Кыргызстан
[2] Институт динамики геосфер РАН им. академика М.А. Садовского, Москва, Россия

Исследование дает дополнительную информацию о литосфере под Юго-Восточной Азией и северной частью Тихого океана. Район интересен для изучения зоны субдукции литосферы в районе Курило-Камчатской дуги. Доступность для изучения подземной структуры затруднена наличием Тихого океана. Значение этого исследования касается эпицентральных расстояний ~54°–70° или ~6000–7000 км. В годы холодной войны 20 века и засекречивания информации между крупнейшими ядерными государствами Советским Союзом (СССР) и Соединенными Штатами Америки (США) данные о регистрации ядерных взрывов не публиковались, однако подземные ядерные взрывы (ПЯВ) были записаны сейсмическими станциями. Благодаря сотруднику лаборатории 5-й Института физики Земли им. О.Ю. Шмидта АН СССР Х.Д. Рубинштейна хранится в Институте динамики геосфер Российской академии наук имени академика М.А. Садовского (ИДГ РАН). Лишь после 1985 г. отчеты с некоторых сейсмических станций бывшего СССР стали публиковаться в оперативных сводках Объединенной геофизической службы Российской академии наук (ГС РАН). Так как она еще нигде не публиковалась, мы собираем их и получаем времена пробега путем ревизии сейсмограмм из архивов ИДГ РАН и ГС РАН для пяти Курило-Камчатских сейсмостанций (Беринг, Эссо, Северо-Курильск, Курильск и Петропавловск). 48 ПЯВ Соединенных Штатов в Пахьют Меса (на испытательном полигоне в Неваде) с 1968 по 1990 год используются для построения годографа продольных волн. Мы измеряем времена пробега P-волн (t_p) на исторических сейсмограммах для трассы между испытаниями на Пахьют Меса и станциями Курило-Камчатского региона. Магнитуда объемных волн (m_b) варьируется от 5.3 до 6.5. Получено: 1 ПЯВ на ст. Беринг, 7 ПЯВ на ст. Эссо, 45 ПЯВ на ст. Петропавловск, 18 ПЯВ на ст. Северо-Курильск и 12 ПЯВ на ст. Курильск. Мы строим функцию времени пробега, используя алгоритм линейной регрессии как $t_p=k\cdot\Delta°+b$, где $\Delta°$ – эпицентральное расстояние, k и b – произвольные константы. Показано, что отклонения времени пробега связаны с нелинейностью Земли. Оценены эффективные скорости продольных волн для трассы Пахьют Меса – Курилы – Камчатка как коэффициент k в линейном уравнении. Эффективная скорость равна 7,5 км/с.

Ключевые слова: *P волна, скорость, время пробега, телесейсмическое расстояние, Невадский испытательный полигон, Курило-Камчатка.*