ANALYSIS OF MANIFESTATION OF JOINT ACOUSTIC AND ELECTRIC RESPONSES OF NEAR-SURFACE SEDIMENTARY ROCKS ON THE DEFORMATION BY EARTHQUAKE SEISMIC WAVES IN THE SOUTH OF KAMCHATKA

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Introduction

Transmission of seismic waves, generated by earthquake sources, causes rock deformation and is accompanied by different co-seismic effects [Kisin, 2015]. These effects can manifest strongly enough as long as rock deformation occurs with the rate higher than that during the background regime. Among them, seismoelectric effect of the second kind [Ivanov, 1940] and geoacoustic effect [Marapulets, Shevtsov, 2012], observed in sedimentary rocks, are known.

Disturbances of geoelectric and geoacoustic fields occurring during seismic wave transmission though the near-surface sedimentary rocks have their own features of genesis but common deformation nature. Joint seismoelectric and seismoacoustic responses of these rocks were firstly discovered in 2018 at Karymshina site of IKIR FEB RAS [Muratov et al., 2018]. Investigation of these responses was continued in 2019–2020 [Muratov et al., 2019; Mishchenko et al., 2020].

Based on drilling results, the near-surface rocks at the observation site region are sedimentary with the layer thickness of about 50 m [Kuptsov et al., 2005]. The distance between the electrodes for geoelectric signal recording is 10 m and the depth of electrodes in the ground is 1 m. According to the estimates in the paper [Marapulets, Shevtsov, 2012], the sources of acoustic signals, generated in sedimentary rocks at the frequencies from the first hundreds of hertz to the first tens of kilohertz, are located at the distances up to 37 m from the hydrophone. Taking all that into account, we can say that the observed seismoelectric and seismoacoustic signals occur in the near-surface sedimentary rocks having the volume up to 10^5 m^3. This volume of rocks can be considered as two operating simultaneously natural seismometer, that transform the seismic wave energy into the energy of electric and acoustic signal.

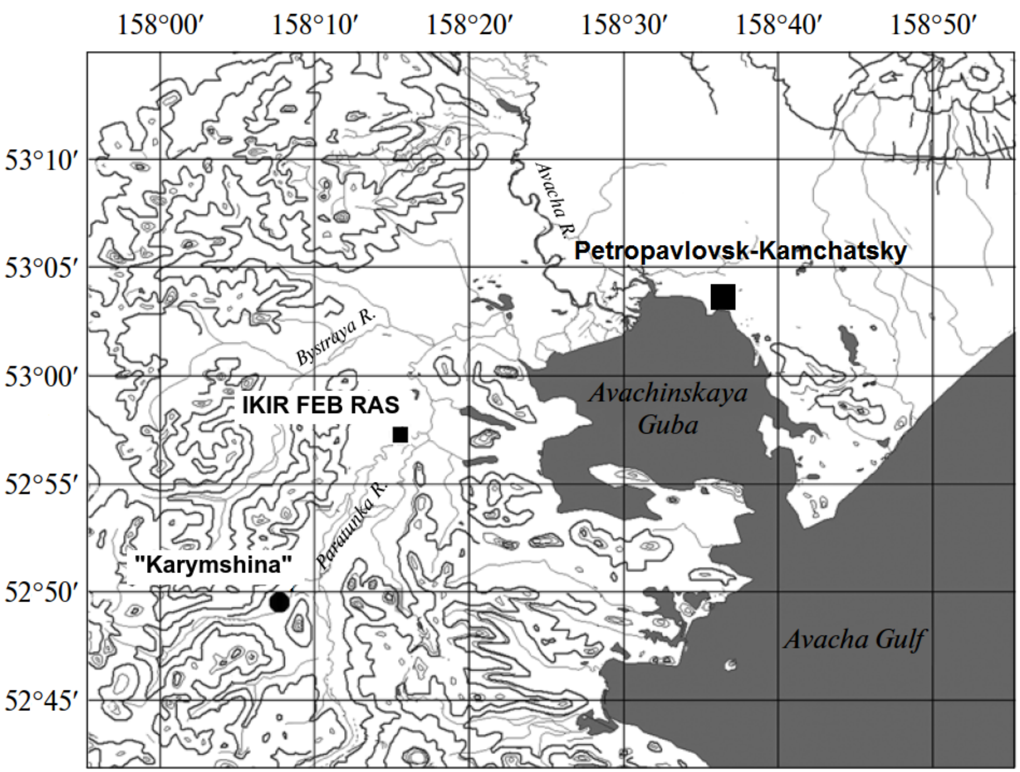
In the previous investigations we considered the features of manifestation of joint seismoelectric and seismoacoustic responses for five [Muratov et al., 2019] and six [Mishchenko et al., 2020] earthquakes of different energy, which occurred in Kamchatka region. In the paper, 52 earthquakes of this region are considered during the investigation of such responses.

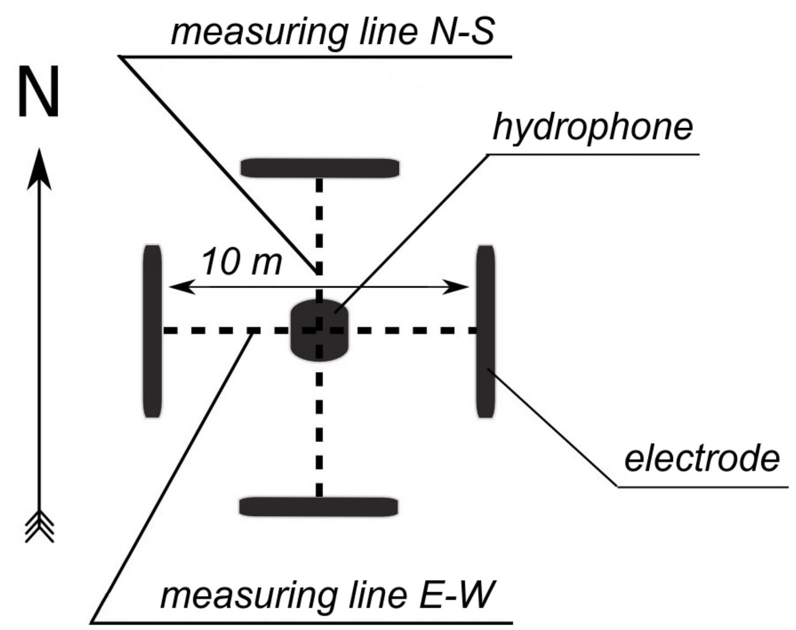
Observation

Seismoacoustic and seismoelectric observations were carried out at Karymshina site (52.83 N, 158.13 E) of IKIR FEB RAS. The observation method and the applied measuring-recording complex are described in the papers [Muratov et al., 2018; Muratov et al., 2019].

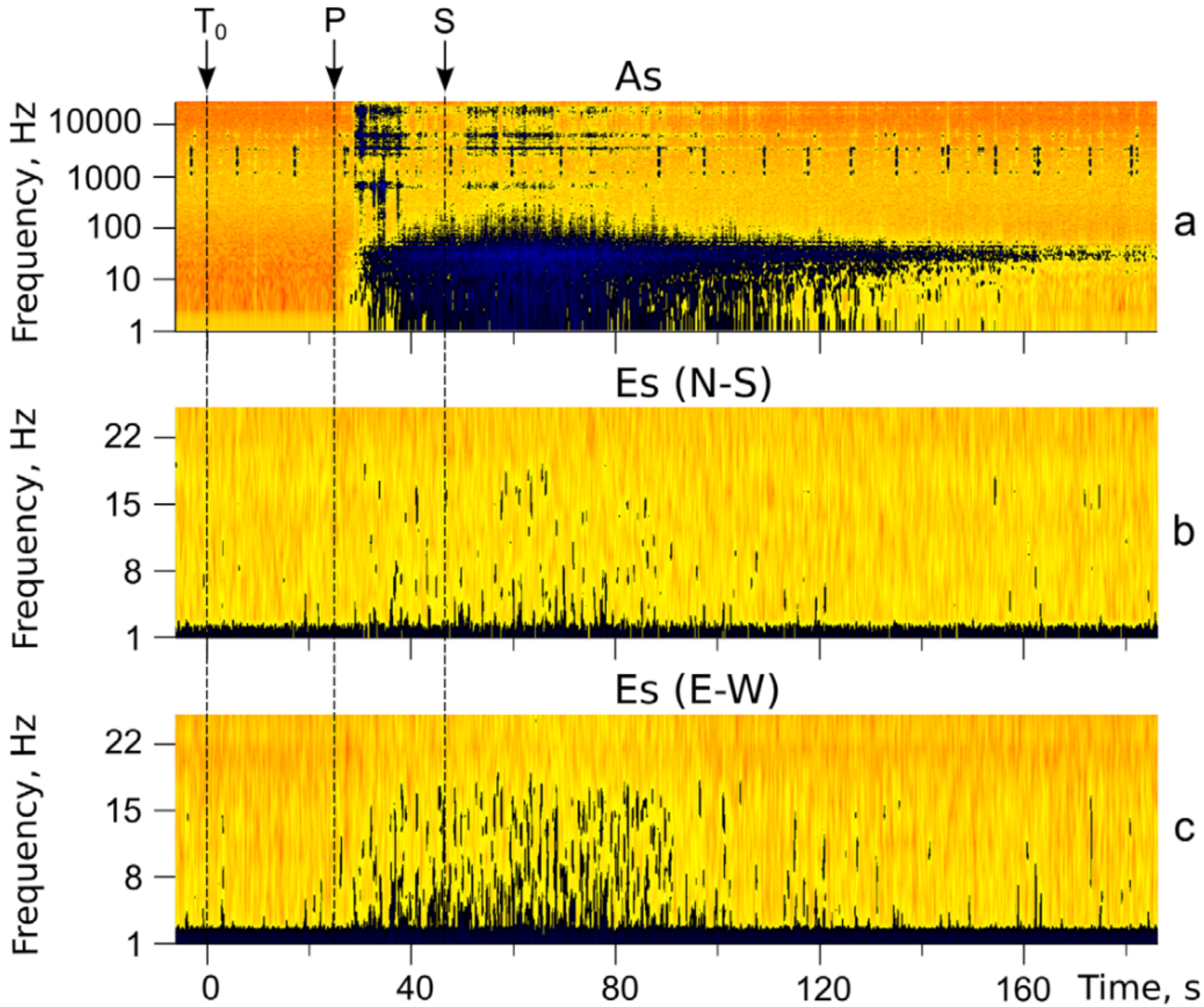
Electric field horizontal components were recorded by two orthogonal slotted lines of the length of 10 m oriented along the magnetic meridian (N – S) and perpendicularly to it (E – W). Buried into the ground at a depth of 1.0 m, lead plates with the dimensions of 0.25 × 1.0 m^2 were used as electrodes.The device was located near the slotted lines.

A broad-band piezoceramic hydrophone was used as an acoustic signal receiver. It was suspended in an artificial water pool of the size of 1 × 1 × 1 m^3 at the depth of 0.5 m. The hydrophone was oriented vertically downwards and was placed at the point of intersection of slotted lines for the electric field.





An example of a seismoacoustic and seismoelectric response to Zhupanovskoye earthquake 2016-jan-30 [*Mishchenko et al., 2020*]



Spectrograms of acoustic (As) and electric Es (N-S), Es (E-W) signals recorded during seismic wave propagation from earthquake (2016-01-30, 03:25:12 UT, Lat=53.9, Lon=158.5,M_w=7.2). Arrows indicate the times of earthquake T0 and longitudinal (P) and transversal (S) wave arrival to the seismic “Karymshina” station.

Initial data

To analyze the manifestation of rock joint response, we considered the earthquakes with the energy class $K_s > 11.0$. They occurred from June 2017 to May 2021 by the eastern coast of South Kamchatka in the latitude band of 51.7-54.0°N and had low-frequency, approximately up to 100 Hz, seismoacoustic response. The parameters of these earthquakes are taken from the catalogue of Kamchatka Branch of Geophysical Survey RAS (http://sdis.emsd.ru/info/earthquakes/catalogue.php) and are illustrated in Table 1.

Table 1. Earthquake parameters based on which the manifestation of seismoacoustic and seismoelectric responses of near-surface sedimentary rock on the deformation by seismic waves were analyzed; K_s is the earthquake energy class; D is the hypocentral distance to Karymshina site; A is the presence of joint seismoacoustic and seismoelectric responses of rocks (♦) or only their seismoacoustic response (○); B is the presence of low-, mid- and high-frequency clusters (♦) or only of low-frequency cluster (○) in seismoacoustic response

Initial data

Table 1.

№	Earthquake		Epicenter coordinates		H, km	K_s	D, km	A	B
	Date, UTC	Time, UTC	Lat,° N	Long, ° E					
1	2017.06.27	02:23:18.1	52.58	160.80	40	12.1	186	○	○
2	2017.07.06	23:02:46.3	53.26	160.77	49	12.4	189	○	○
3	2017.07.25	16:24:51.5	53.85	159.74	124	11.1	199	○	○
4	2017.08.02	21:05:39.1	53.08	160.09	61	11.8	147	○	○
5	2017.08.19	00:59:56.4	52.90	160.25	87	11.1	167	○	○
6	2017.09.15	17:26:11.2	53.71	160.86	59	11.3	214	○	○
7	2017.09.16	21:00:54.7	52.82	160.00	53	12.8	136	♦	♦
8	2017.09.18	01:23:30.8	53.15	159.70	76	11.3	134	○	○
9	2017.09.29	19:24:59.1	53.10	160.33	51	13.4	159	♦	♦
10	2017.10.10	22:59:22.2	51.96	159.62	45	11.8	146	○	○
11	2017.12.02	15:11:38.1	52.54	159.88	44	11.3	130	○	○
12	2017.12.05	09:06:03.0	53.70	161.13	44	11.3	226	○	○
13	2017.12.22	14:44:16.2	53.68	160.88	69	14.2	217	♦	♦
14	2017.12.22	15:36:33.1	53.69	160.87	53	11.2	212	○	○
15	2017.12.22	22:28:22.6	53.72	160.78	61	12.4	211	○	○
16	2018.01.04	02:44:54.4	53.12	160.20	56	12.9	153	○	♦
17	2018.01.14	14:04:50.3	52.72	159.88	50	11.3	128	○	○
18	2018.01.17	18:58:04.6	53.13	160.99	52	11.2	201	○	○
19	2018.03.05	15:42:41.0	52.38	160.80	48	13.1	193	○	○
20	2018.04.06	16:13:13.0	52.45	159.17	86	11.5	119	○	○
21	2018.07.21	04:19:16.7	51.73	159.40	36	12.3	153	○	○
22	2018.10.15	01:32:11.1	53.95	159.86	125	12.8	210	○	○
23	2018.11.02	09:39:27.7	51.98	158.72	72	13.1	125	♦	♦
24	2019.01.03	17:57:43.5	53.14	160.05	58	12.2	145	♦	○
25	2019.01.12	11:18:58.4	52.79	159.80	60	12.4	127	♦	○
26	2019.02.08	17:08:35.2	52.42	159.05	59	12.0	97	♦	○

Initial data

Continuation of **Table 1.**

№	Earthquake		Epicenter coordinates		*H*, km	K_s	*D*, km	A	B
	Date, UTC	Time, UTC	Lat,° N	Long, ° E					
27	2019.02.14	18:24:27.6	52.39	159.13	58	11.2	101	♦	○
28	2019.04.16	15:22:50.8	53.69	160.94	55	12.1	217	○	○
29	2019.07.18	12:45:38.6	52.43	159.99	51	11.8	142	♦	○
30	2019.07.28	09:53:04.0	53.70	160.88	52	11.5	213	○	○
31	2019.07.31	12:56:36.9	52.36	159.81	47	11.1	133	○	○
32	2019.09.23	21:54:55.9	52.01	159.93	21	11.8	153	○	○
33	2019.10.05	16:18:36.6	51.69	158.89	63	11.4	150	○	○
34	2019.11.09	11:16:57.2	52.33	161.05	54	11.6	212	○	○
35	2020.01.01	03:53:26.2	52.50	159.40	46	12.4	104	♦	♦
36	2020.01.16	16:31:09.5	52.01	159.84	29	12.8	150	♦	♦
37	2020.01.16	21:50:56.4	51.98	159.93	30	11.1	157	○	○
38	2020.01.28	04:19:45.8	52.40	159.56	47	11.5	117	♦	○
39	2020.02.20	18:57:34.4	53.44	160.92	52	14.3	205	♦	♦
40	2020.03.12	05:20:10.0	52.40	159.11	56	12.2	99	♦	○
41	2020.05.17	19:26:31.5	52.02	159.98	42	11.4	160	○	○
42	2020.05.30	11:01:32.1	52.83	159.40	115	11.9	143	○	○
43	2020.08.07	03:41:09.3	52.20	159.27	63	12.0	121	♦	○
44	2020.08.25	21:53:43.7	52.86	160.24	50	11.4	150	○	○
45	2020.09.04	21:10:12.9	52.08	160.56	49	12.7	190	○	○
46	2020.09.04	21:14:22.3	52.08	160.43	18	11.8	177	○	○
47	2020.09.05	00:21:21.0	52.09	160.59	46	11.8	191	○	○
48	2020.10.05	09:04:29.8	52.22	158.98	100	11.5	133	○	○
49	2020.11.27	22:57:13.1	52.04	159.98	40	11.8	158	○	○
50	2021.01.11	12:56:39.3	52.46	159.22	61	11.4	104	♦	○
51	2021.04.11	13:48:49.0	52.08	158.88	60	11.9	114	♦	○
52	2021.05.05	14:08:42.4	51.98	159.19	66	11.2	135	♦	○

Manifestation of joint acoustic and electric response of rocks

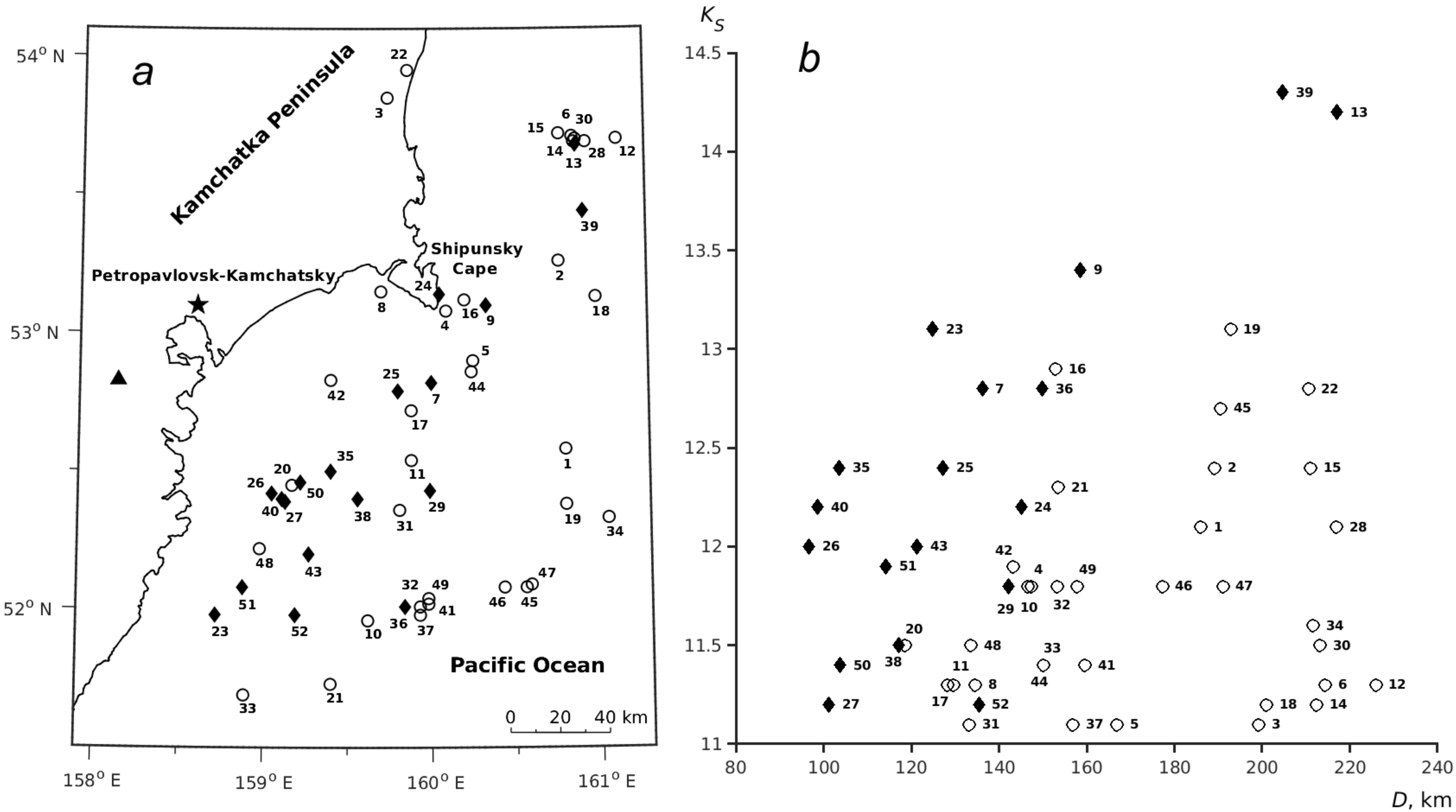


Figure 1. Map of the considered earthquakes epicenters (a) and comparison of their energy class K_s with the distance from the hypocenter D to Karymshina site (b). Designations: ▲ is the location of Karymshina site; ♦ are the earthquakes in which a joint seismoacoustic and seismoelectric response of rocks was observed; ○ are the earthquakes in which there was only a seismoacoustic response.

Manifestation of high-frequency acoustic response of rocks

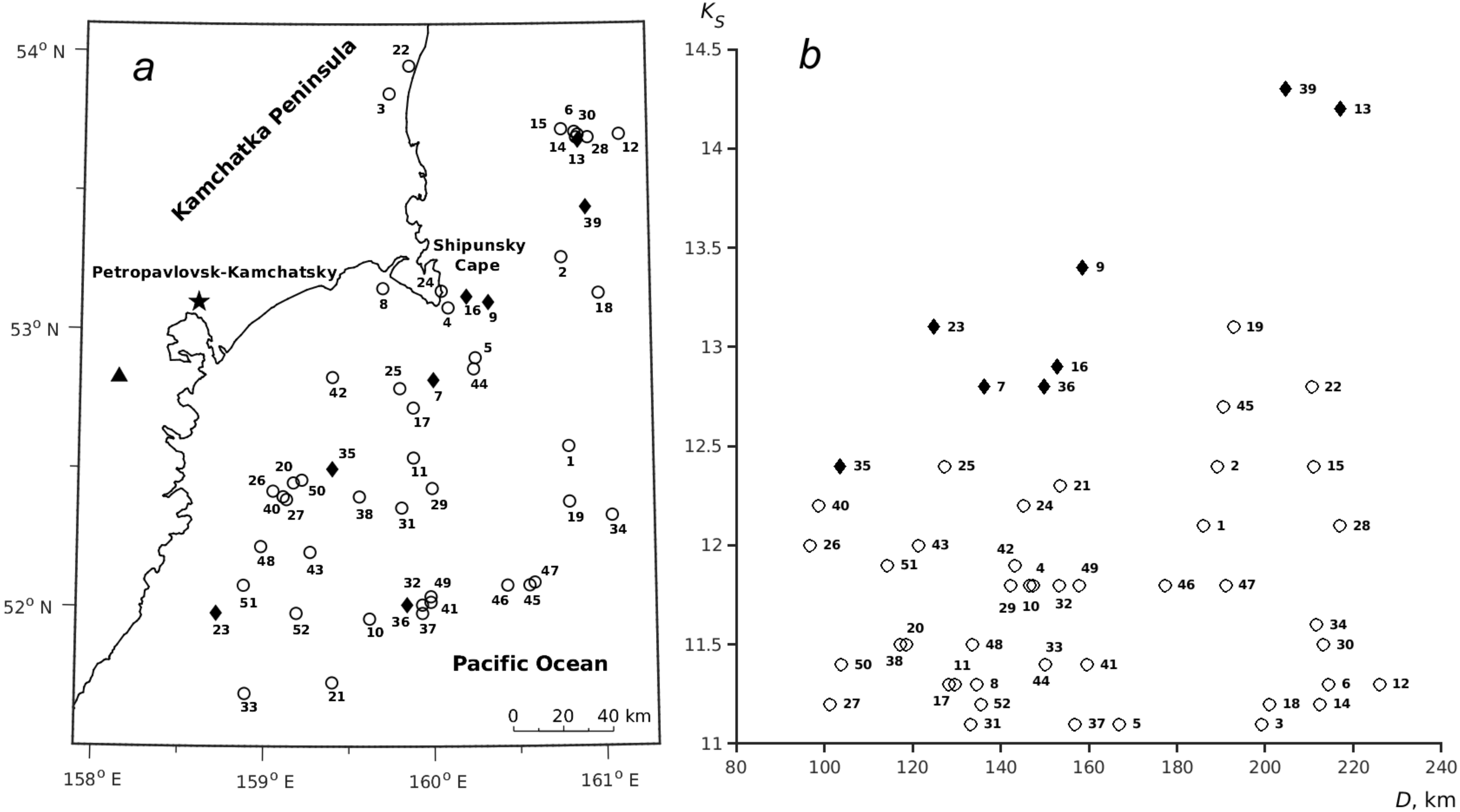


Figure 2. Map of the considered earthquakes epicenters (a) and comparison of their energy class K_s with the distance from the hypocenter D to Karymshina site (b). Designations: ▲ is the location of Karymshina site; ♦ are the earthquakes in which, in addition to a low–frequency cluster up to about 100 Hz, there was a medium-frequency cluster at frequencies of 0.1-1 kHz and even a high-frequency cluster of ~ 1-11 kHz in the seismic-acoustic response of rocks; ○ are the earthquakes in which there was only a low-frequency cluster.

Correlation

Table 2. Estimates of correlation Spearman coefficient r s and its significance level *p* between earthquake energy class K_s and distance from a hypocenter *D* to Karymshina site for each group of the detected earthquakes, *n* is the number of earthquakes in a group. Symbols (♦) and (○) are the same as for Table 1.

Parameter	Earthquake designation in figures			
	Fig . 1b		Fig . 2b	
	♦	○	♦	○
r_s	0.597	0.129	0.826	0.031
p	0.009	0.468	0.017	0.841
n	18	34	8	44

Conslusion

We have continued the investigation of earlier discovered joint acoustic and electric responses of the near-surface sedimentary rocks on the deformation by earthquake seismic waves. Occurrences and absence of such responses for 52 earthquakes with the energy class of more than 11.0 were considered. These events which took place from June 2017 to May 2021 by the eastern coast of South Kamchatka. We discovered the statistically significant relation between the energy class of the earthquakes, during which joint seismoacoustic and seismoelectric responses of rocks were observed, and between the distance from hypocenter to the observation site. Such a relation was discovered for rock acoustic response on seismic waves from the earthquakes, during which besides the low-frequency cluster of about up to 100 Hz, the cluster at the frequencies of ~0.1–1 kHz and even higher-frequency cluster at the frequencies of ~1–11 kHz were also observed. These clusters are likely to be generated by rocks during intensive deformations, formation of relative microdisplacements and interaction of small fragments. When there was no seismoelectric response of rocks and only low-frequency cluster was presented in the seismoacoustic response, we did not detect any statistically significant relation between earthquake energy class and distance from hypocenter.

The work was carried out within the framework of the State Task AAAA-A21-121011290003-0. We applied the data, obtained at a unique scientific unit "Seismo-infrasonic complex to monitor arctic cryolithic zone and a complex for continuous seismic monitoring of the Russian Federation, cross-border regions and the world" (https://ckp-rf.ru/usu/507436/).

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