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Earthquake Prediction Research by Means of Telluric Potential Monitoring

Progress Report No. 2: Preliminary Study on Teshikaga Channel 2 Signals and the Seismicity in the Region off Kushiro

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Abstract

The VAN-method for short-term earthquake prediction based on monitoring telluric potential changes, which has reportedly been successful in Greece, is now under testing in Japan. More than 20 local networks have been established and tested for about one year using existing electrodes and cables of the Nippon Telegraph and Telephone Corporation (NTT). Generally the records suffer from cultural noise much higher than in Greece, but some stations far from DC-powered rail-roads were found to be reasonably noise-free. Preliminary examination of data indicates that potential precursory signals in the sense of the VAN-method were recognized preceding earthquakes of $M \geqq 5$ at some stations. This report presents an example, i.e. the possible correspondence between a specific type of telluric potential change appearing in the channel 2 at Teshikaga station, Hokkaido, and seismicity in the region off Kushiro, Hokkaido.

1. Introduction

As has been described in our first report (Kinoshita *et al.*, 1989), a telluric potential monitoring network system has been operating in Japan under a cooperative program with the Nippon Telegraph and Telephone Corporation (NTT) since late 1987. It is aimed at testing the applicability of the VAN-method for earthquake prediction (Varotsos and Alexopoulos, 1984a, b, 1986, 1987, Varotsos *et al.*, 1986, 1988). Fig. 1 shows the distribution of monitoring stations. At all stations, except at KAK (Kakioka, Ibaraki pref.) and ERI (Earthquake Research Institute, Tokyo), electrodes already installed by NTT for grounding are used to form 6 dipoles with various lengths and azimuths. Self telluric

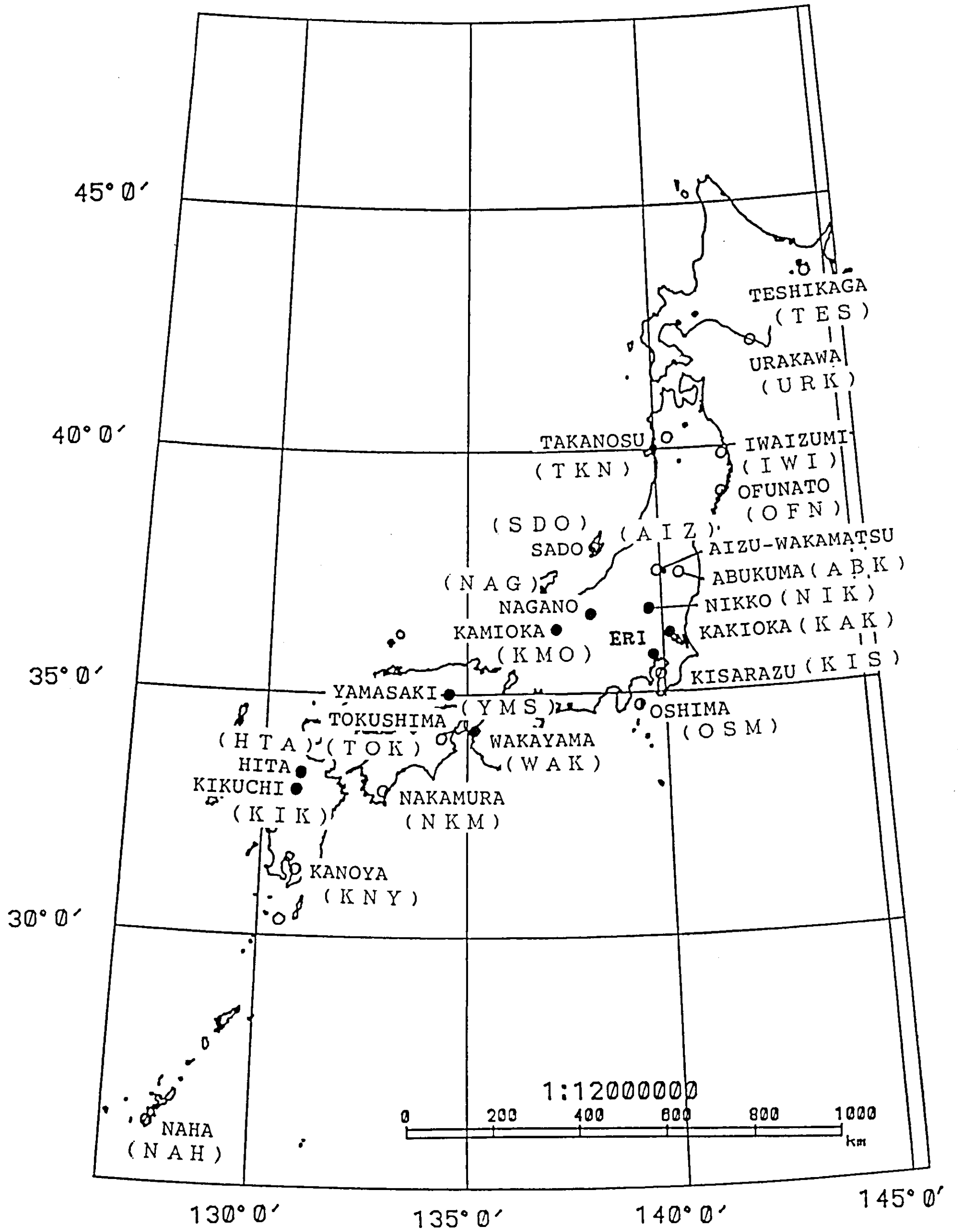

Fig. 1. The distribution of stations for telluric potential monitoring. Open circles: stations presently working, closed circles: stations aborted.

potentials on each dipole are digitally sampled every 20 seconds. In the present report, some preliminary results of examination of these data in relation to the occurrences of earthquakes are presented.

2. Method and Results of Examination

2.1. Identification of possible SES

Seismicity in Japan is much higher than in Greece, and probably due to also much higher human noise, there are many anomalous (which means non-geomagnetic in origin) disturbances in telluric potential. It is quite difficult to find one to one correspondence between many possible signals and many earthquakes. Therefore, we first examined if earthquakes greater than 5.0 in magnitude (M), which are not so many, were preceded by some characteristic signals. If VAN's empirical rule on the magnitudes of earthquake and seismic electric signals (SES) is valid (Fig. 2 which will be called the VAN diagram hereafter); i.e. if

$$\log(\Delta V \cdot R) = a \cdot M + b \ , \qquad (1)$$

we would have a better chance to find SES for larger earthquakes occurring at smaller focal distances. Here ΔV is the amplitude of SES per unit dipole length, R and M are the focal distance and magnitude of earthquakes, and 'a' and 'b' are constants. In the VAN system, the value of 'a' was found to be about 0.3. Also following VAN's experience, we carefully examined the telluric potential data backward

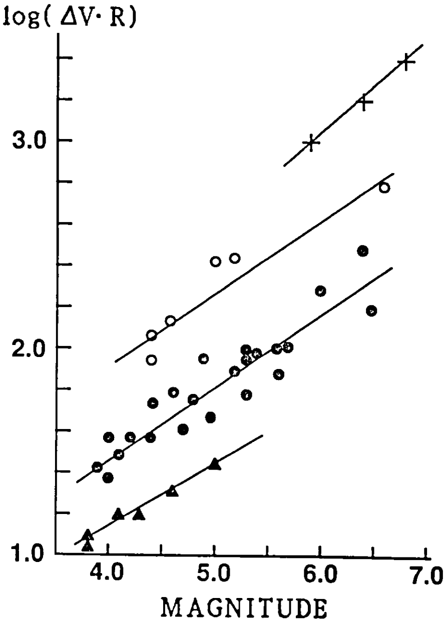

Fig. 2. VAN diagram showing VAN's empirical law on the correlation between the amplitude of SES (ΔV) times the epicentral distance (R) and the magnitude of earthquakes (reproduced from VAROTSOS and ALEXOPOULOS 1984a Fig. 18).

from the time of earthquake occurrence for 20 days for all earthquakes $M \geqq 5$ that occurred during the observation period (1988/1/1 to 1988/12/31) around Japan (20°N-50°N, 120°E-160°E, Fig. 3). We listed all anomalous disturbances on all channels at all stations which occurred during the 20 day period immediately preceding each earthquake $M \geqq 5$, with their characteristics such as time of appearance, polarity, amplitude, duration and form.

Here the anomalous disturbances are changes of telluric field that are not detected at all stations simultaneously and yet are clearly above the daily noise level. Changes detected at all stations simultaneously are most likely due to geomagnetic changes.

From the list of detected signals, were selected those which were detected on the same dipoles, had the same polarity and were commonly preceded all the earthquakes $M \geqq 5$ in the same seismic region. As can be seen in Fig. 3, regions where a significant number of $M \geqq 5$ events occurred during the period concerned are offshore of eastern Hokkaido (EH), offshore of Kushiro (KU), offshore of Fukushima (FU), southern Kanto area (KA), area around Torishima (TO), and the northeastern corner of the Philippine Sea (NP). Then, from these signals,

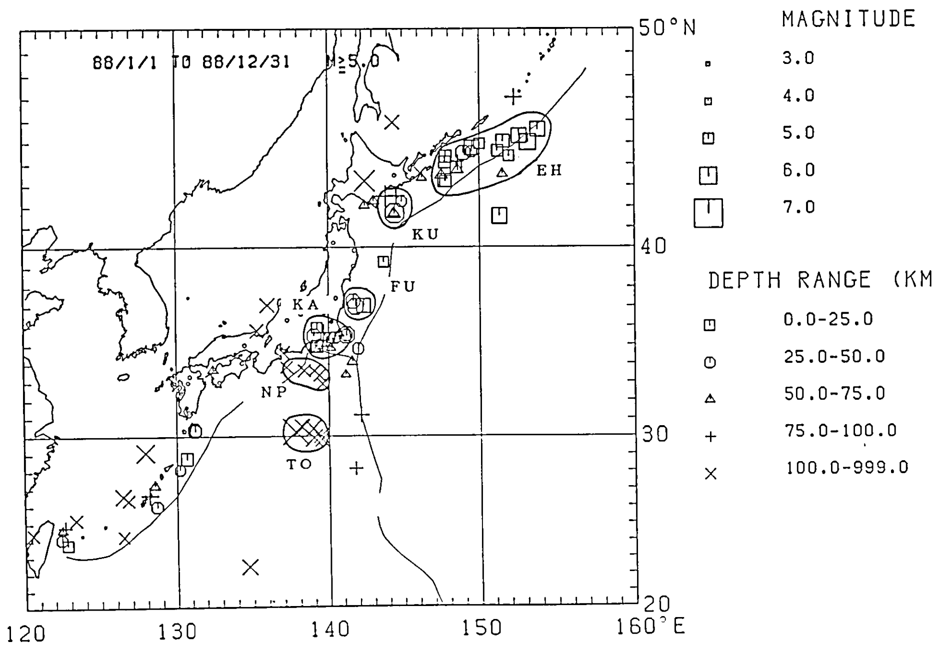

Fig. 3. Seismicity (magnitude greater than 5 in Japanese area for 1988/1/1-1988/12/31 after JMA's Preliminary Earthquake Origin). EH: off eastern Hokkaido region. KU: off-Kushiro region. FU: off-Fukushima region. KA: southern Kanto area. NP: northeastern corner of the Philippine Sea. TO: area around Torishima.

those detected at the same time of day (e.g. 8:00 a.m.) on many different days were suspected to be of artificial origin and were excluded. Several cases of potentially meaningful correlation between electric signals and earthquakes emerged from this process. In the present report, some result of further examination on the correspondence between the electric signals at Teshikaga (TES) station and seismicity in the region off Kushiro (KU), south of Hokkaido are presented.

2.2. Preliminary result on signals at TES and earthquakes $M \geqq 5$ in the region off Kushiro.

Five earthquakes $M \geqq 5$ occurred in the region off Kushiro (41°N-43°N, 143°E-145°E, region KU in Fig. 7) from the beginning of our measurement at TES, (1988/5/12 to 1989/1/15) (Table 2). The five earthquakes were all preceded by potential changes with negative polarity on channel 2 at TES. All these changes had duration longer than several minutes. The correspondence between the earthquakes and the electric potential variations is shown in Fig. 4. Three of these earthquakes occurred in one day (July 7, 1988) and hence are indicated by a single bar. At first glance, the correspondence shown in this figure appears quite encouraging. Actually, electric signals at some other stations also preceded these earthquakes such as positive changes on channels 2 and 6 (simultaneous) and negative changes on channel 4 at Urakawa (URK). However, these potential changes were not simultaneous with the ones at TES. VAN's empirical laws state that one earthquake is preceded by one SES and that earthquakes occurring

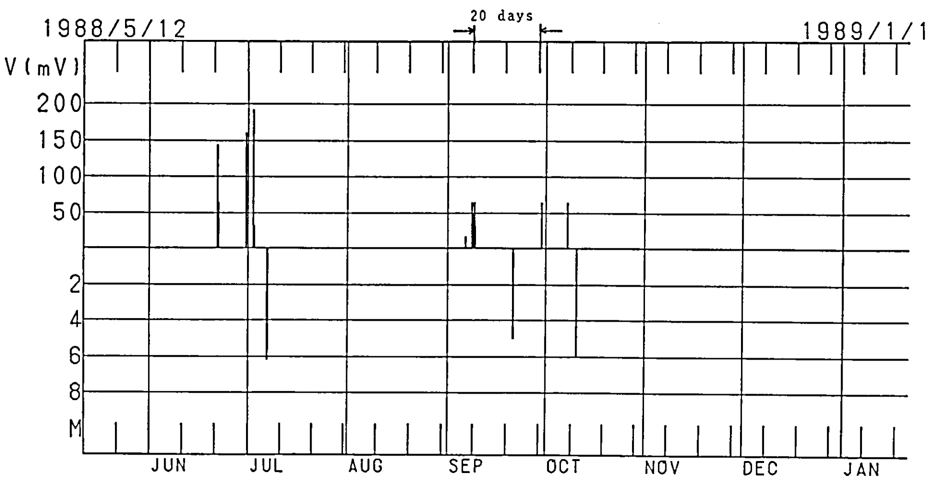

Fig. 4. Occurrence of earthquakes $M \geqq 5$ in region off Kushiro (lower diagram) and anomalous electric signals which appeared on ch. 2 of Teshikaga (TES) station during the 20-day period immediately preceding each earthquake (upper diagram) for 1988/5/12-1988/12/31.

Fig. 5. Distribution of NTT electrodes at telephone stations and measuring channels at Teshikaga (TES).

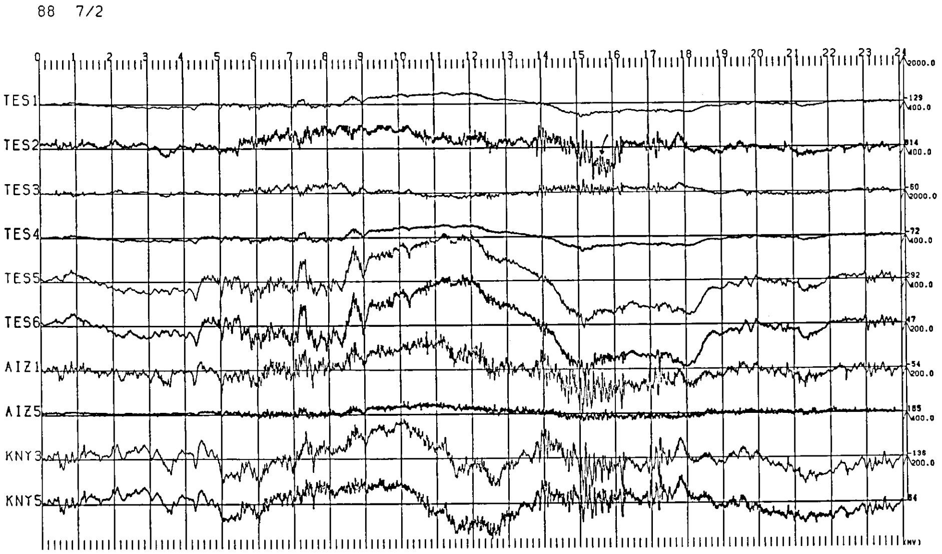

Fig. 6(a)

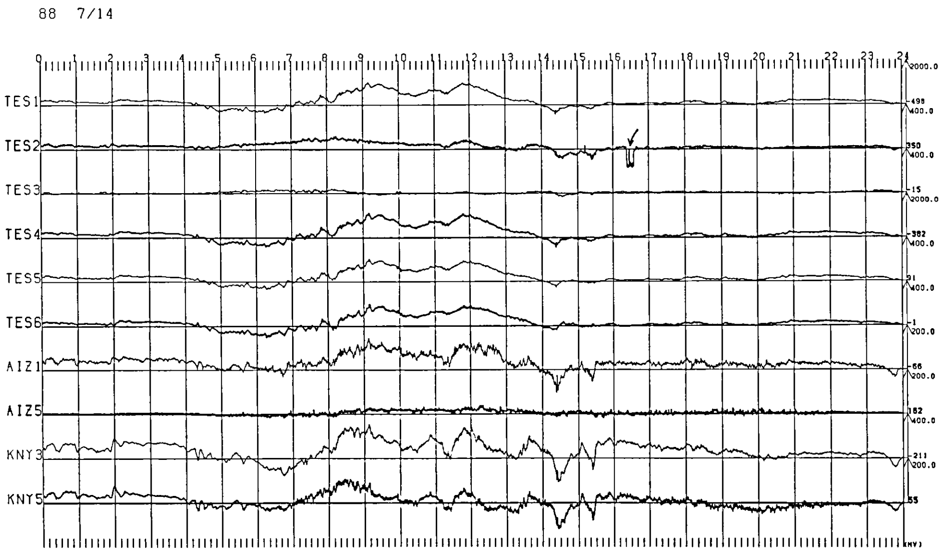

Fig. 6(b)

in one region are always preceded by the SES's detected at the same corresponding stations. If these laws are right, it is impossible that all these variations are true SES's for the earthquakes in question. We, then, examined all the simultaneous records at URK and TES for the whole period. It was found that at URK similar electric signals also

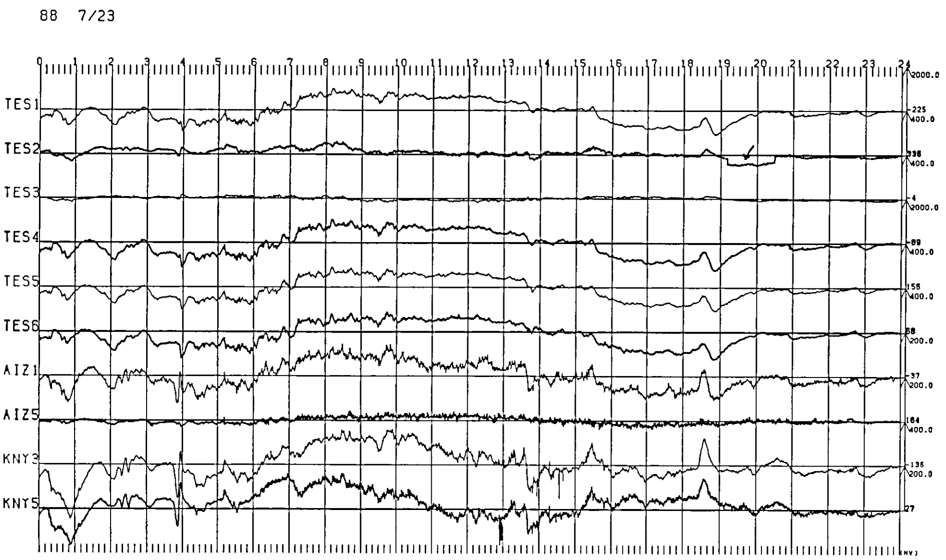

Fig. 6(c)

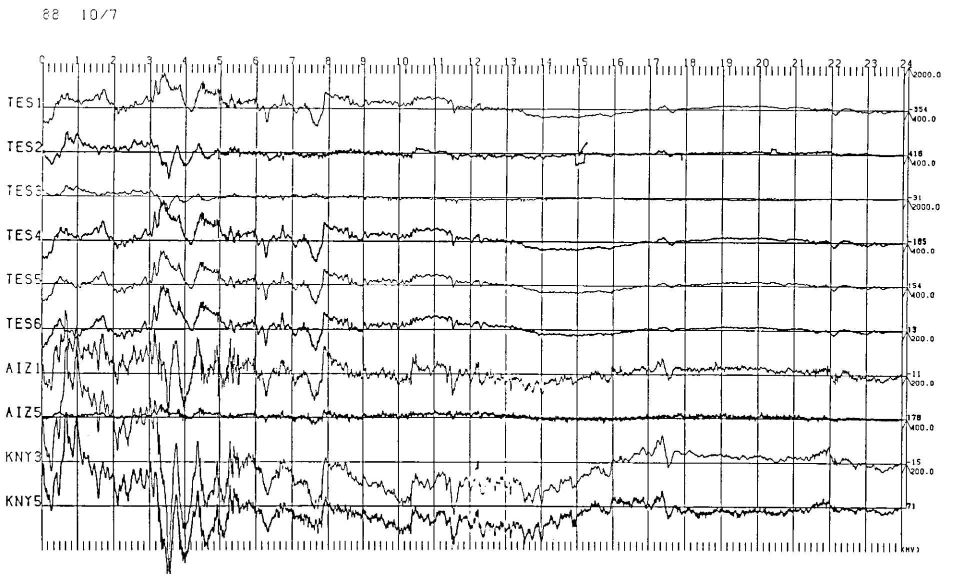

Fig. 6(d)

appeared frequently during periods preceding no earthquakes $M \geqq 5$ in the region off Kushiro, whereas signals on channel 2 at TES appeared much less frequently during the same periods. From this observation, we decided to proceed, at this stage, with further examination of the signals on TES channel 2 for their possible correlation with the off-Kushiro

Fig. 6(e)

Fig. 6. Examples of anomalous disturbances detected on Teshikaga channel 2 (indicated by small arrow). For the sake of comparison, the records of AIZ and KNY are also shown. Right most numbers are offset (lower) and full scale (upper) of each channel in millivolts. These are one-day data (Japan Standard Time). 6a: 1988/7/2. 6b: 1988/7/14. 6c: 1988/7/23. 6d: 1988/10/7. 6e: 1988/10/24.

seismicity. The URK signals will also be examined in due course.

The configuration of dipoles using NTT electrodes at TES is shown in Fig. 5. The arrows attached to dipoles indicate the polarity of the records. For example, TES channel 2 measures the telluric potential difference 'Teshikaga minus Nijibetsu'. Typical examples of records showing the signals in question on TES channel 2 can be seen in Fig. 6a, b, c, d and e, together with records at some other stations shown for reference. The Teshikaga electrode, which is the plus side of TES channel 2, is also shared with channel 1, 4 and 5, which do not show any simultaneous changes. Therefore, the signals in question, detected only on channel 2, should be due to the potential changes (rises) at Nijibetsu electrode alone. The shapes of the changes are rectangular wave type than gradual. On this ground one may suspect that these signals may be caused by local noise around Nijibetsu, noise produced by instability of the Nijibetsu NTT electrode or noise produced in the measuring system. However, some of the SES reported by VAN have the same rectangular wave shape as ours. In fact, it is one of the VAN's typical shapes. Thus, we considered that they should be examined further before being rejected as noise. As will be mentioned later in section 3, a short-span network at Nijibetsu has recently shown that these signals are not noise specific to the NTT electrode or the NTT measuring system.

Table 1. List of all the anomalous signals detected on channel 2 of Teshikaga station from 1988/5/12 to 1988/12/31.

Number	:	year	date	hour	:	amplitude (mV)
1	:	1988	5/21	10	:	144.0
2	:	1988	5/25	16	:	128.0
3	:	1988	6/ 1	17	:	48.0
4	:	1988	6/ 4	9	:	48.0
5	:	1988	6/21	16	:	48.0
6	:	1988	6/21	16	:	144.0
7	:	1988	6/21	23	:	64.0
8	:	1988	6/30	10	:	160.0
9	:	1988	7/ 2	15	:	192.0
10	:	1988	7/ 3	1	:	32.0
11	:	1988	7/14	16	:	160.0
12	:	1988	7/23	19	:	64.0
13	:	1988	8/ 5	19	:	64.0
14	:	1988	8/ 8	18	:	48.0
15	:	1988	9/ 6	12	:	16.0
16	:	1988	9/ 8	15	:	64.0
17	:	1988	9/ 8	16	:	48.0
18	:	1988	9/ 9	8	:	48.0
19	:	1988	9/ 9	9	:	64.0
20	:	1988	9/ 9	11	:	32.0
21	:	1988	9/29	19	:	64.0
22	:	1988	10/ 7	15	:	64.0
23	:	1988	10/18	7	:	48.0
24	:	1988	10/24	11	:	32.0
25	:	1988	10/24	14	:	96.0
26	:	1988	10/24	14	:	112.0
27	:	1988	10/24	15	:	112.0
28	:	1988	10/25	13	:	96.0
29	:	1988	10/26	12	:	96.0
30	:	1988	10/26	13	:	96.0
31	:	1988	11/ 1	13	:	48.0
32	:	1988	11/ 3	18	:	64.0
33	:	1988	11/ 4	11	:	64.0
34	:	1988	11/17	19	:	32.0
35	:	1988	12/ 2	3	:	16.0
36	:	1988	12/14	11	:	64.0
37	:	1988	12/14	12	:	80.0
38	:	1988	12/17	0	:	64.0
39	:	1988	12/21	16	:	32.0
40	:	1988	12/22	3	:	48.0
41	:	1988	12/22	8	:	48.0
42	:	1988	12/26	20	:	64.0

Table 2. List of all the earthquakes which occurred off Kushiro (41°N-43°N 143°E-145°E) from 1988/5/12/ to 1989/1/15 after JMA's Preliminary Earthquake Origin reports. *; $M \geqq 5.0$, +; $M \geqq 3.0$, −; $M \geqq 3.0$ and $D \leqq 67.5$ km.

number	:	year	date	hour	:	latitude	longitude	:	magnitude	:	depth (km)
1	:	1988	5/12	9	:	42.57°N	143.98°E	:		:	40.1
2	:	1988	5/12	23	:	41.14°N	143.14°E	:		:	73.0
3	:	1988	5/15	12	:	42.54°N	144.17°E	:	2.7	:	53.1
4	:	1988	5/17	20	:	42.92°N	143.46°E	:		:	92.0
5	:	1988	5/25	9	:	42.89°N	144.30°E	:	2.7	:	45.9
6 +−	:	1988	5/29	14	:	42.50°N	144.33°E	:	3.3	:	39.8
7	:	1988	6/ 1	11	:	42.70°N	143.62°E	:		:	104.9
8 +−	:	1988	6/ 3	8	:	42.49°N	143.83°E	:	3.7	:	56.5
9 +−	:	1988	6/ 3	8	:	42.50°N	143.85°E	:	3.1	:	45.5
10	:	1988	6/ 7	23	:	42.53°N	144.82°E	:	2.9	:	29.6
11 +−	:	1988	6/10	7	:	42.48°N	144.68°E	:	3.0	:	31.0
12	:	1988	6/11	16	:	42.53°N	143.04°E	:		:	107.2
13	:	1988	6/12	14	:	42.73°N	143.62°E	:		:	116.5
14	:	1988	6/14	7	:	41.83°N	143.74°E	:		:	64.0
15	:	1988	6/25	11	:	41.66°N	143.29°E	:		:	62.0
16 +−	:	1988	6/26	4	:	42.71°N	144.71°E	:	3.5	:	50.7
17 +−	:	1988	6/26	16	:	42.34°N	144.73°E	:	3.0	:	24.0
18	:	1988	7/ 1	4	:	41.20°N	144.96°E	:		:	44.0
19 +−	:	1988	7/ 2	9	:	42.79°N	144.84°E	:	3.2	:	41.6
20	:	1988	7/ 2	16	:	42.71°N	143.41°E	:		:	113.5
21*+−	:	1988	7/ 7	0	:	41.68°N	144.48°E	:	6.2	:	48.5
22*+	:	1988	7/ 7	1	:	41.66°N	144.45°E	:	5.2	:	73.0
23 +−	:	1988	7/ 7	1	:	41.49°N	144.22°E	:	4.2	:	21.0
24*+	:	1988	7/ 7	1	:	41.63°N	144.44°E	:	5.7	:	68.0
25	:	1988	7/ 7	3	:	41.44°N	144.19°E	:		:	85.0
26	:	1988	7/ 7	5	:	41.68°N	144.34°E	:		:	18.0
27	:	1988	7/ 7	6	:	41.56°N	144.31°E	:		:	79.0
28	:	1988	7/ 7	12	:	41.51°N	144.38°E	:		:	70.0
29 +−	:	1988	7/ 7	13	:	41.59°N	144.62°E	:	3.9	:	41.0
30	:	1988	7/ 7	18	:	41.51°N	144.40°E	:		:	80.0
31 +−	:	1988	7/ 9	19	:	41.90°N	144.56°E	:	3.3	:	0.0
32 +−	:	1988	7/10	15	:	42.49°N	143.71°E	:	3.2	:	49.7
33	:	1988	7/11	0	:	41.62°N	143.19°E	:		:	62.0
34 +−	:	1988	7/11	2	:	41.64°N	144.56°E	:	3.7	:	56.0
35	:	1988	7/13	4	:	41.80°N	144.61°E	:		:	65.0
36 +−	:	1988	7/15	17	:	42.80°N	144.90°E	:	3.5	:	44.8
37	:	1988	7/16	4	:	42.34°N	143.24°E	:		:	69.0
38	:	1988	7/17	6	:	42.32°N	144.08°E	:		:	33.4
39	:	1988	7/18	10	:	41.67°N	144.46°E	:		:	71.0
40 +−	:	1988	7/19	21	:	42.51°N	143.95°E	:	3.0	:	33.0
41	:	1988	7/20	22	:	41.70°N	144.47°E	:		:	64.0
42	:	1988	7/21	0	:	42.65°N	144.53°E	:		:	38.0
43	:	1988	7/21	4	:	42.76°N	143.50°E	:		:	107.0
44	:	1988	7/26	12	:	42.07°N	144.14°E	:		:	38.0
45	:	1988	7/30	9	:	42.80°N	143.38°E	:		:	95.7
46	:	1988	8/ 1	21	:	42.97°N	144.42°E	:		:	110.6
47	:	1988	8/ 3	20	:	41.77°N	143.46°E	:		:	71.0

Table 2. (Continued)

number	year	date	hour	latitude	longitude	magnitude	depth (km)
48 +−	1988	8/ 6	4	42.70°N	144.86°E	3.3	40.7
49	1988	8/ 8	9	42.97°N	143.26°E		105.6
50 +−	1988	8/10	14	42.29°N	143.83°E	3.7	55.6
51 +−	1988	8/11	20	42.41°N	143.75°E	3.5	52.7
52 +−	1988	8/13	5	42.36°N	144.11°E	3.0	36.0
53	1988	8/14	17	41.77°N	144.15°E		29.3
54	1988	8/15	8	42.88°N	143.85°E		69.2
55	1988	8/16	18	41.99°N	144.23°E		51.0
56	1988	8/16	20	42.89°N	144.31°E		108.3
57 +−	1988	8/17	11	41.61°N	143.59°E	3.8	33.7
58 +	1988	8/18	7	42.65°N	144.01°E	4.1	113.6
59	1988	8/18	23	42.66°N	143.01°E		114.3
60	1988	8/19	4	42.73°N	143.48°E		110.0
61	1988	8/23	20	42.36°N	143.86°E		36.0
62	1988	8/24	0	41.68°N	143.66°E		0.0
63 +−	1988	8/24	5	41.53°N	143.93°E	4.0	24.0
64	1988	8/29	4	42.79°N	143.09°E		141.0
65	1988	8/29	9	42.70°N	143.70°E		62.0
66	1988	9/ 5	9	42.73°N	144.34°E		77.0
67	1988	9/ 7	8	42.77°N	144.62°E	2.9	52.7
68	1988	9/ 7	20	42.25°N	143.17°E		65.9
69	1988	9/10	17	42.54°N	143.05°E		121.0
70	1988	9/10	20	42.54°N	144.23°E	2.8	58.7
71 +−	1988	9/15	5	42.23°N	143.08°E	4.9	66.3
72	1988	9/15	5	42.22°N	143.10°E		68.5
73	1988	9/18	4	42.85°N	144.77°E		52.4
74*+−	1988	9/21	7	42.25°N	144.95°E	5.0	47.0
75 +−	1988	9/21	7	42.42°N	144.89°E	4.0	32.0
76 +−	1988	9/21	12	42.34°N	144.93°E	3.1	6.3
77	1988	9/27	5	42.55°N	143.12°E		43.0
78	1988	9/27	10	42.47°N	144.15°E		62.9
79 +−	1988	9/27	19	41.54°N	144.79°E	3.3	7.0
80	1988	10/ 1	11	42.34°N	143.01°E		69.0
81 +	1988	10/ 1	15	42.73°N	143.34°E	4.2	75.0
82	1988	10/ 1	18	42.85°N	144.83°E		65.4
83 +−	1988	10/ 4	6	41.51°N	143.92°E	4.0	57.0
84	1988	10/ 4	21	41.14°N	143.19°E		66.0
85	1988	10/ 6	3	42.80°N	143.35°E		116.0
86	1988	10/ 7	11	42.86°N	144.42°E		54.6
87	1988	10/ 7	13	42.73°N	143.62°E		99.0
88	1988	10/ 8	8	42.07°N	143.25°E	2.4	57.0
89*+	1988	10/10	14	42.51°N	144.58°E	6.0	78.1
90 +−	1988	10/10	15	42.47°N	144.59°E	3.0	32.0
91	1988	10/10	18	42.64°N	144.50°E		64.0
92	1988	10/11	6	42.96°N	143.58°E		132.6
93	1988	10/19	21	41.99°N	143.11°E	2.8	47.0
94	1988	10/19	23	42.85°N	143.35°E		9.0
95	1988	10/23	19	42.73°N	143.34°E		68.3
96	1988	10/26	1	42.62°N	143.27°E		113.1

Table 2. (Continued)

number	:	year	date	hour	:	latitude	longitude	:	magnitude	:	depth (km)
97	:	1988	11/ 5	5	:	43.00°N	144.83°E	:	2.1	:	55.8
98	:	1988	11/11	19	:	41.75°N	144.55°E	:		:	7.0
99 +	:	1988	11/13	19	:	42.68°N	143.51°E	:	3.9	:	101.4
100 +−	:	1988	11/14	17	:	42.33°N	144.15°E	:	3.3	:	18.0
101	:	1988	11/17	1	:	41.71°N	143.99°E	:		:	12.0
102	:	1988	11/18	11	:	43.00°N	143.12°E	:		:	131.0
103 +−	:	1988	11/24	1	:	41.98°N	144.38°E	:	3.6	:	52.0
104	:	1988	11/25	14	:	41.92°N	144.95°E	:		:	0.0
105	:	1988	11/27	3	:	42.80°N	144.07°E	:		:	107.1
106 +−	:	1988	11/30	18	:	42.64°N	144.30°E	:	3.7	:	52.6
107	:	1988	12/ 6	13	:	42.35°N	143.30°E	:		:	188.0
108	:	1988	12/13	22	:	42.34°N	143.00°E	:		:	75.3
109	:	1988	12/18	11	:	42.91°N	144.49°E	:		:	115.3
110	:	1988	12/18	13	:	42.27°N	143.08°E	:		:	63.3
111 +−	:	1988	12/20	9	:	42.53°N	144.96°E	:	4.2	:	36.3
112 +−	:	1988	12/22	16	:	41.72°N	143.23°E	:	3.6	:	37.9
113	:	1988	12/23	11	:	42.24°N	143.18°E	:		:	65.6
114	:	1988	12/23	20	:	42.38°N	143.13°E	:		:	62.6
115 +−	:	1988	12/25	0	:	42.40°N	144.69°E	:	4.3	:	40.9
116 +−	:	1988	12/25	0	:	42.44°N	144.68°E	:	3.2	:	30.0
117	:	1988	12/26	21	:	41.76°N	143.76°E	:		:	68.1
118 +−	:	1988	12/28	7	:	42.54°N	144.23°E	:	3.3	:	59.2
119	:	1988	12/31	0	:	41.73°N	144.77°E	:		:	2.0
120 +−	:	1988	12/31	4	:	41.77°N	144.53°E	:	3.8	:	44.0
121 +−	:	1989	1/ 2	23	:	42.52°N	144.74°E	:	3.0	:	24.0
122	:	1989	1/ 4	5	:	42.65°N	143.57°E	:		:	69.5
123	:	1989	1/ 5	3	:	42.59°N	144.45°E	:		:	65.9
124	:	1989	1/10	0	:	42.53°N	144.41°E	:		:	77.1
125	:	1989	1/10	3	:	42.49°N	143.26°E	:		:	72.0
126	:	1989	1/12	23	:	42.73°N	143.43°E	:		:	93.5

2.3. TES channel 2 signals and seismicity of off-Kushiro region

The negative changes on channel 2 at TES as shown in Figs. 6(a–e) appear more frequently, i.e. not only within 20-day periods preceding $M \geqq 5$ events in the region off Kushiro. The total number of this type of signal which appeared from 1988/5/12 (beginning of TES station) to 1988/12/31 was 42 as listed in Table 1. If the TES channel 2 signals are true SES's, signals not corresponding to earthquakes $M \geqq 5$ should correspond to earthquakes occurring in the same region but with smaller magnitudes. According to the Preliminary Earthquake Origin reports of Japan Meterological Agency (JMA), during the period from 1988/5/12 to 1989/1/15 (20 days after the appearance of the last signal at TES), 126 earthquakes were observed in the region off Kushiro as listed in Table 2, whereas the number of electric signals was 42. Earthquakes without magnitude values in Table 2 were too small to be given exact values. The distribution of epicenters in the Hokkido region for the period concerned is shown in Fig. 7. In Fig. 8, all 42 signals and 126 earthquakes are shown. Now the correspondence does not look so promising as in Fig. 4.

In order to examine the possibility that the two time series shown in Fig. 8 have a corresponding relationship in the sense of the VAN-method, three kinds of success rates, namely SRE (success rate of

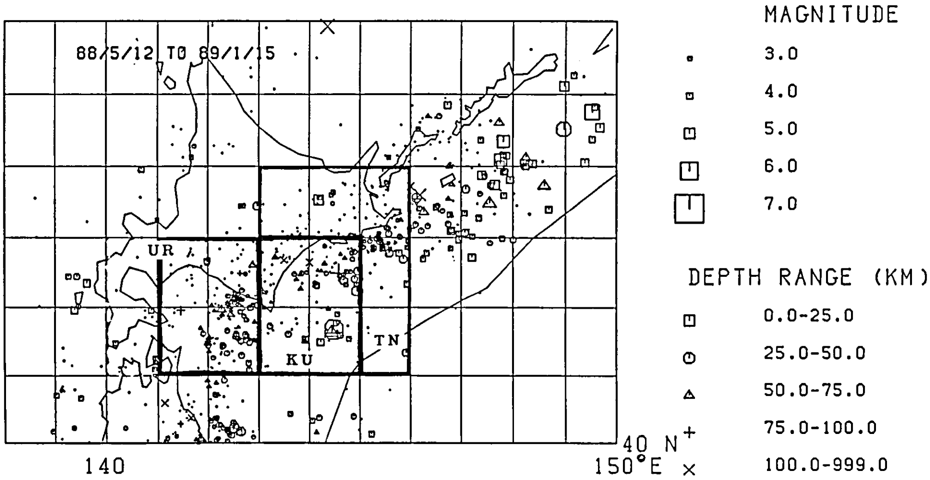

Fig. 7. Seismicity in Hokkaido region for 1988/5/12–1988/1/15 (after JMA's Preliminary Earthquake Origin reports). KU: region off Kushiro (41°N–43°N, 143°E–145°E).UR: region off Urakawa (41°N–43°N, 141°E–143°E). TN: Teshikaga plus region off Nemuro (43°N–44°N, 143°E–145°E plus 41°N–44°N, 145°E–146°E).

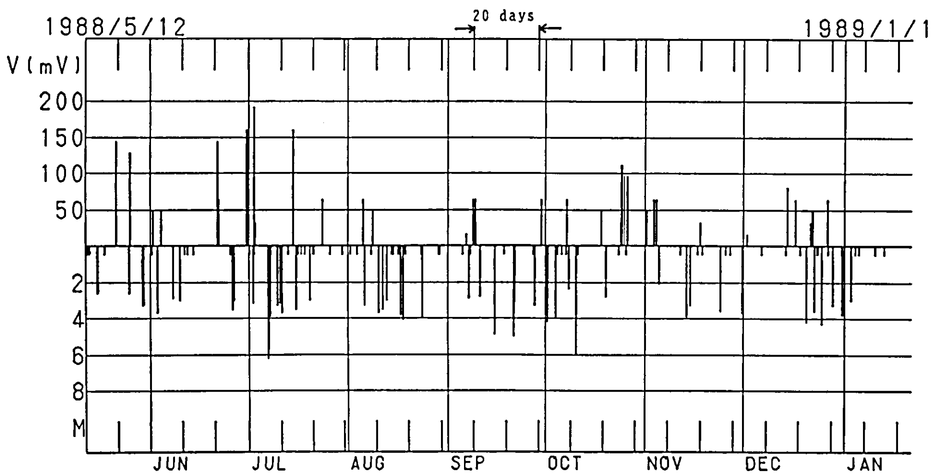

Fig. 8. Occurrence of anomalous electric signals on ch. 2 of Teshikaga station (upper diagram) and all reported earthquakes (lower diagram) in region off Kushiro for 1988/5/12–1988/1/15.

earthquakes), SRS (success rate of signals), and SR (overall success rate) were defined as follows:

$$\mathrm{SRE}=E_c/E\ , \tag{2}$$

$$\mathrm{SRS}=S_c/S\ . \tag{3}$$

Here E_c is the number of the earthquakes which have 1 to 1 correspondence with the signals and E is the total number of earthquakes considered. Similarly, S_c is the number of signals which have 1 to 1 correspondence with earthquakes and S is the total number of signals. Since E_c is equal to S_c by definition, this number will be denoted by ES_c hereafter. Then, the overall success rate SR is defined as,

$$\mathrm{SR}=\mathrm{SRE}\cdot\mathrm{SRS}=\frac{(ES_c)^2}{E\cdot S} \tag{4}$$

The total number of signals, S, in the present case is 42, whereas the total number of earthquakes considered, E, is variable as explained below. First, earthquakes with $M<3$ and those with no magnitude values were excluded from consideration, because such small earthquakes are hardly expected to generate sizable signals. This reduced E from 126 to 44. Then earthquakes with too large focal depths were excluded

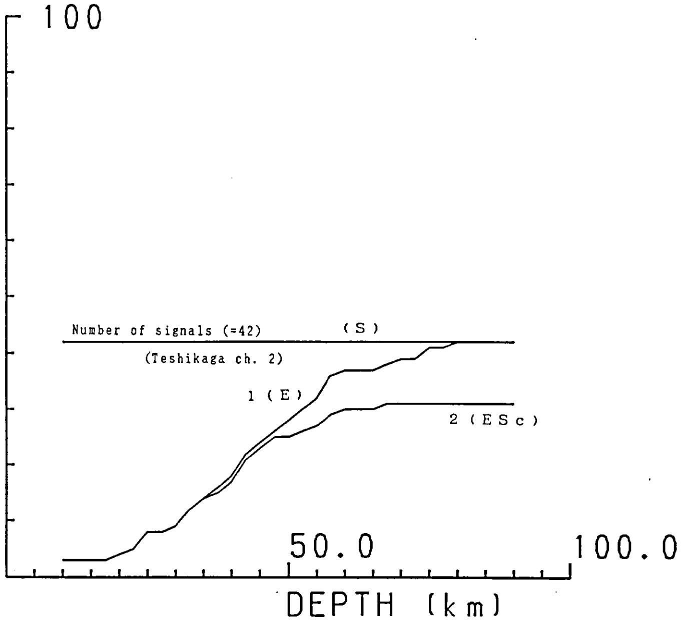

Fig. 9. line 1: Number of $M\geqq 3$ earthquakes (cumulative), E vs. focal depth: region off Kushiro.
line 2: Number of $M\geqq 3$ earthquakes correlated with signals, ES_c vs. focal depth: region off Kushiro.

in view of the fact that the VAN-method has not been reported effective in Greece for deep earthquakes and there seems to be some theoretical basis for this fact (VAROTSOS and ALEXOPOULOS, 1986). The threshold focal depth may be related to the depth where a sufficient amount of piezoelectric minerals such as silica exist. In our case, however, it was considered appropriate to estimate the threshold focal depth empirically as follows: in Fig. 9 are plotted the number of signals, S, the number of earthquakes (cumulative), E, and the number of possible one to one correspondence between signals and earthquakes, ES_c, vs. focal depth. The number of signals, S, is constant (42 in the present case). As the number of earthquakes, E, increases (line 1) with focal depth, the number of possible correspondence, ES_c also increases (line 2). Beyond about 50 km focal depth, however, ES_c does not increase as E does with focal depth. From this figure, the success rates, SRS, SRE and SR, defined above, were computed as shown in Fig. 10 by line 2, line 3 and line 1. The overall success rate, SR, seems to have a maximum value at 67.5 km, where E is 38 and ES_c is 31. This depth was tentatively adopted as the threshold for the earthquakes to be considerdd, although its exact value obviously carries little importance. Thus, further examination was conducted to see if a VAN-type

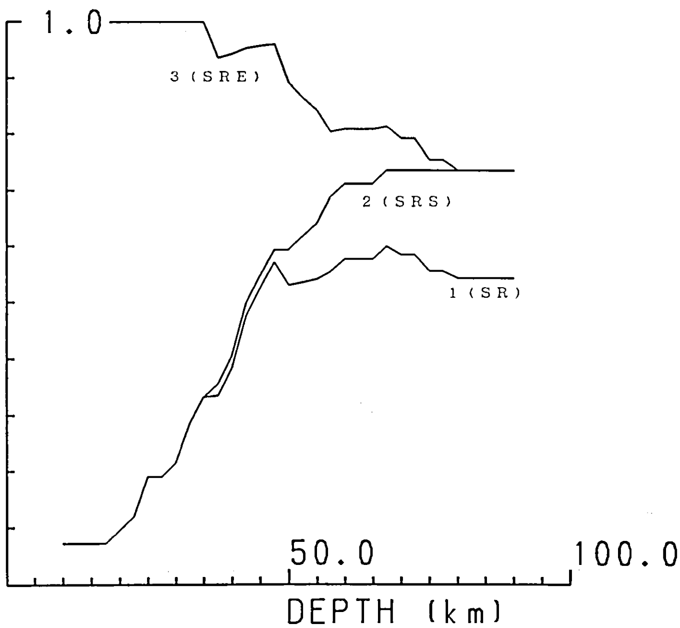

Fig. 10. Success rates vs. focal depth: region off Kushiro. line 1: Success rates, $SR=SRS\cdot SRE$. line 2: Success rates of signals, $SRS=ES_c/S$. line 3: Success rates of earthquakes, $SRE=ES_c/E$.

Table 3. List of all the anomalous electric signals on ch. 2 of Teshikaga Station during 1988/5/12–1988/12/31, with the values of $\log(\Delta V \cdot R)$ of the candidate earthquakes which followed within 20 days. The numbers of the signals and earthquakes are same as those in Tables 1 and 2, respectively. *: earthquakes used for correlation shown in Figs. 12, 14. +: earthquakes used for correlation shown in Figs. 13, 15.

signal number	candidate earthquake number, magnitude $\log(\Delta V \cdot R)$								
	6: *M* 3.3	8: *M* 3.7	9: *M* 3.1	11: *M* 3.0					
1	4.23*	4.31 +	4.29	4.21					
2	4.18 +	4.26*	4.24	4.16					
3		3.83	3.81*+	3.74					
4				3.74*+					
	16: *M* 3.5	17: *M* 3.0	19: *M* 3.2	21: *M* 6.2	23: *M* 4.2	29: *M* 3.9	31: *M* 3.3	32: *M* 3.2	34: *M* 3.7
5	3.67*	3.79	3.62	3.99	4.03	4.01	3.92	3.84	4.00 +
6	4.15	4.26	4.10	4.47*	4.51	4.49 +	4.40	4.31	4.48
7	3.80 +	3.91	3.75	4.12	4.16*	4.13	4.05	3.96	4.13
	36: *M* 3.5	40: *M* 3.0							
8	4.15	4.30	4.14	4.52	4.55 +	4.53*	4.45	4.36	4.53
9	4.23	4.38		4.60 +	4.63	4.61	4.53*	4.44	4.61
10	3.45	3.61		3.82	3.86	3.83	3.75 +	3.66	3.83*
11	4.15*+	4.30							
	48: *M* 3.3	50: *M* 3.7	51: *M* 3.5	52: *M* 3.0	57: *M* 3.8	63: *M* 4.0			
12	3.79	4.01*+	3.98						
13	3.79	4.01	3.98	3.94	4.16*	4.16 +			
14		3.88	3.85	3.82	4.04 +	4.03*			
	71: *M* 4.9	74: *M* 5.0	75: *M* 4.0	76: *M* 3.1	79: *M* 3.3				
15	3.51*	3.36	3.29	3.31 +					
16	4.11 +	3.97*	3.89	3.91	4.14				
17	3.98	3.84	3.77*+	3.79	4.01				
18	3.98	3.84	3.77	3.79*	4.01				

Table 3. (Continued)

signal number	candidate earthquake number, magnitude log($\Delta V \cdot R$)						
19	4.11	3.97 +	3.89	3.91	4.14*		
20	3.81	3.67	3.59	3.61	3.84 +		
	83: M 4.0	90: M 3.0					
21	4.17*+	3.87					
22		3.87*+					
23							
24							
25							
26							
27							
28							
	100: M 3.3	103: M 3.6	106: M 3.7				
29	4.11*						
30	4.11						
31	3.81 +						
32	3.94						
33	3.94	4.05*+					
34		3.75	3.55*+				
	111: M 4.2	112: M 3.6	115: M 4.3	116: M 3.2	118: M 3.3	120: M 3.8	121: M 3.0
35	3.25						
36	3.86*+	4.17	3.91	3.88	3.90	4.09	3.84
37	3.95	4.27*	4.00 +	3.98	4.00	4.19	3.93
38	3.86	4.17 +	3.91*	3.88	3.90	4.09	3.84
39		3.87	3.60	3.58*	3.60	3.79	3.54 +
40		4.04	3.78	3.75 +	3.78*	3.97	3.71
41		4.04	3.78	3.75	3.78 +	3.97*	3.71
42					3.90	4.09 +	3.84*

correspondence can be established between the 42 electric signals on TES channel 2 and the 38 earthquakes with $M \geqq 3$ and focal depth $\leqq 67.5$ km in the region off Kushiro.

2.4. Possible correspondence

Table 3 lists all 42 signals with all of their potentially correlatable earthquakes, namely earthquakes with $M \geqq 3$ and focal depth $\leqq 67.5$ km that occurred within 20 days after each signal in the region off Kushiro. The table also lists the values of $\log(\Delta V \cdot R)$. As can be seen in Fig. 9, the number of the cases of one to one correspondence, ES_c, is less than both the number of earthquakes E, and the number of signals S, because, there are some earthquakes and signals that are not correlatable. The contents of Table 3 can be illustrated in a $\log(\Delta V \cdot R)$ vs. M diagram (VAN-diagram) as in Figs. 11a and b. In Figs. 11a and b, which simply correspond to different time periods to avoid overcrowding, one earthquake is indicated by the same symbol and the earthquakes having possible correspondence to the same signal are linked by lines. This situation occurs because both an earthquake and a signal often have a few candidates for correspondence.

If the signals are true SES's, one to one correspondence is hidden in Figs. 11a and b, but we know of no unique way to discover it. Therefore, two different criteria were employed to search for one to one correspondence between electric signals and earthquakes. One is to keep the order of occurrence of signals and earthquakes.

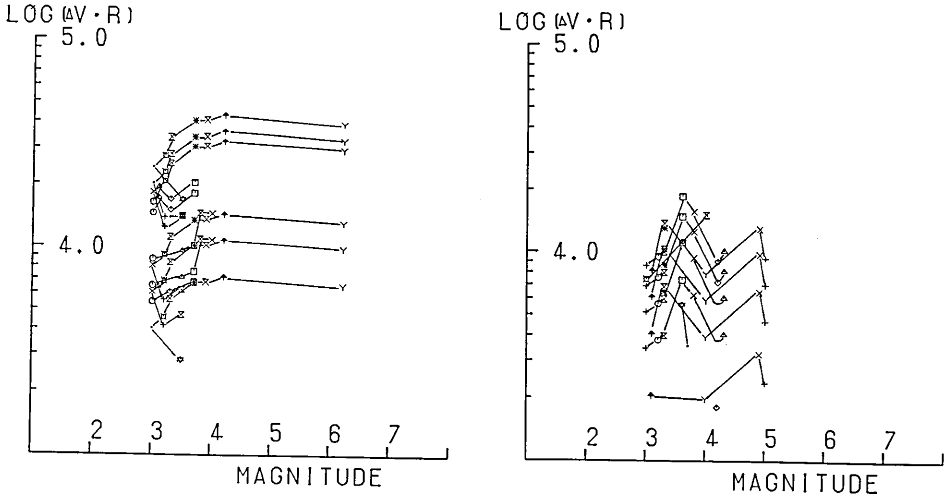

Fig. 11. Graphical representation of possible correlations between electric signals and earthquakes listed in Table 3. Candidate earthquakes for the same signals are linked by a line. a: for 1988/5/12–1988/8/8. b: for 1988/8/9–1988/12/31.

This gives an almost unique set of correspondence as shown in Fig. 12. The other is to assign correspondence to conform to the VAN's proportional relationship between M and $\log(\Delta V \cdot R)$ as closely as possible with the condition that the precursory time is shorter than 20 days, i.e. earthquakes with larger M are to be correlated with larger $\log(\Delta V \cdot R)$. This also resulted in an almost unique set of correspondence as shown in Fig. 13. In applying both criteria, when there were still

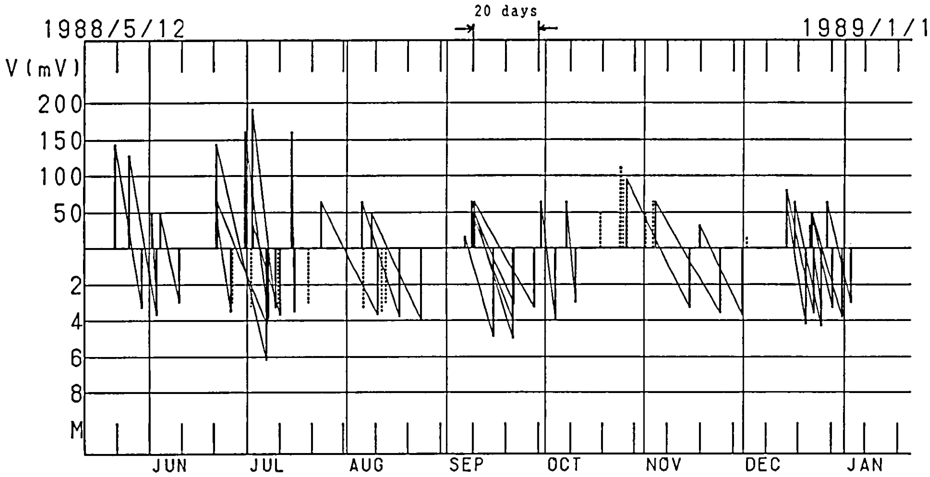

Fig. 12. One possible set of correspondence between electric signals and earthquakes ($M \geqq 3$, $D \leqq 67.5$ km). Correspondence was assigned with the rule that the order of events should not be reversed. Dotted bars represent uncorrelated events.

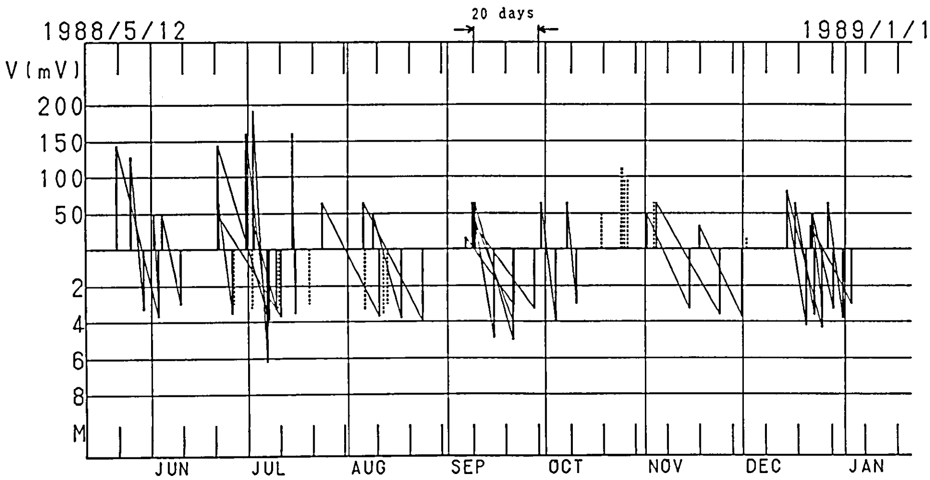

Fig. 13. One possible set of correspondence between electric signals and earthquakes ($M \geqq 3$, $D \leqq 67.5$ km). Correspondence was assigned to agree as much as possible with VAN's empirical law for $\log(\Delta V \cdot R)$ and M. Dotted bars represent uncorrelated events.

several candidate earthquakes for one electric signal, the earthquake with the largest magnitude was chosen. In a few cases, the signal corresponding to an aftershock had to be placed before that of the signal for the main shock. According to P. VAROTSOS (personal communication) such a situation has also been experienced in Greece, although it is somewhat difficult to envisage that an aftershock occurrence is determined before the main shock. The earthquakes used

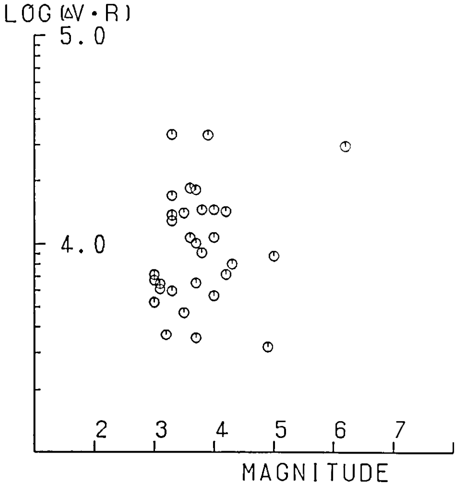

Fig. 14. VAN-diagram for the set of correspondence shown in Fig. 12.

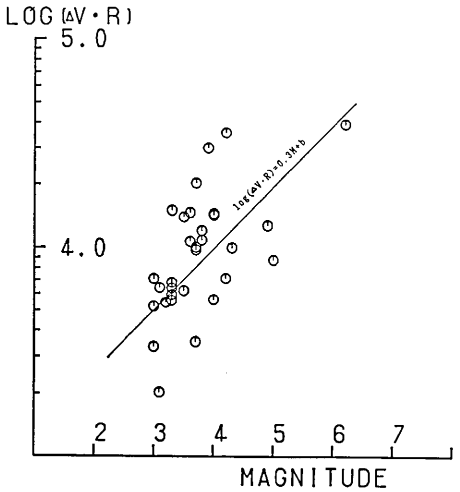

Fig. 15. VAN-diagram for the set of correspondence shown in Fig. 13.

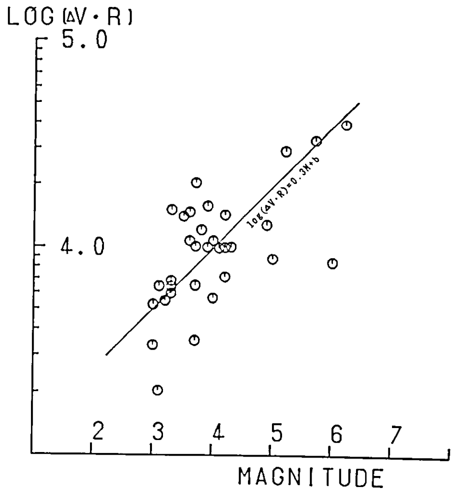

Fig. 16. VAN-diagram for the set of correspondence between electric signals and all the $M \geqq 3$ earthquakes. Correspondence was assigned to agree as much as possible with VAN's empirical law for $\log(\Delta V \cdot R)$ and M.

in the sets of correspondence shown in Figs. 12 and 13 are marked by * and + respectively in Table 3. In both Figs. 12 and 13, earthquakes and signals that could not be correlated are shown by dotted bars. A cluster of uncorrelatable signals is noticeable in October.

The sets of correspondence shown in Figs. 12 and 13 are plotted in the form of VAN-diagrams as shown in Figs. 14 and 15. The former set of correspondence does not conform to the VAN relation but, as expected, the second set does better. In constructing Fig. 15, the value of "a" in the VAN relation $\log(\Delta V \cdot R)=a \cdot M+b$ was not assigned but the result does not seem to conflict with $a=0.3$ as given by VAN. In the above analysis, three earthquakes $M \geqq 5$ are omitted

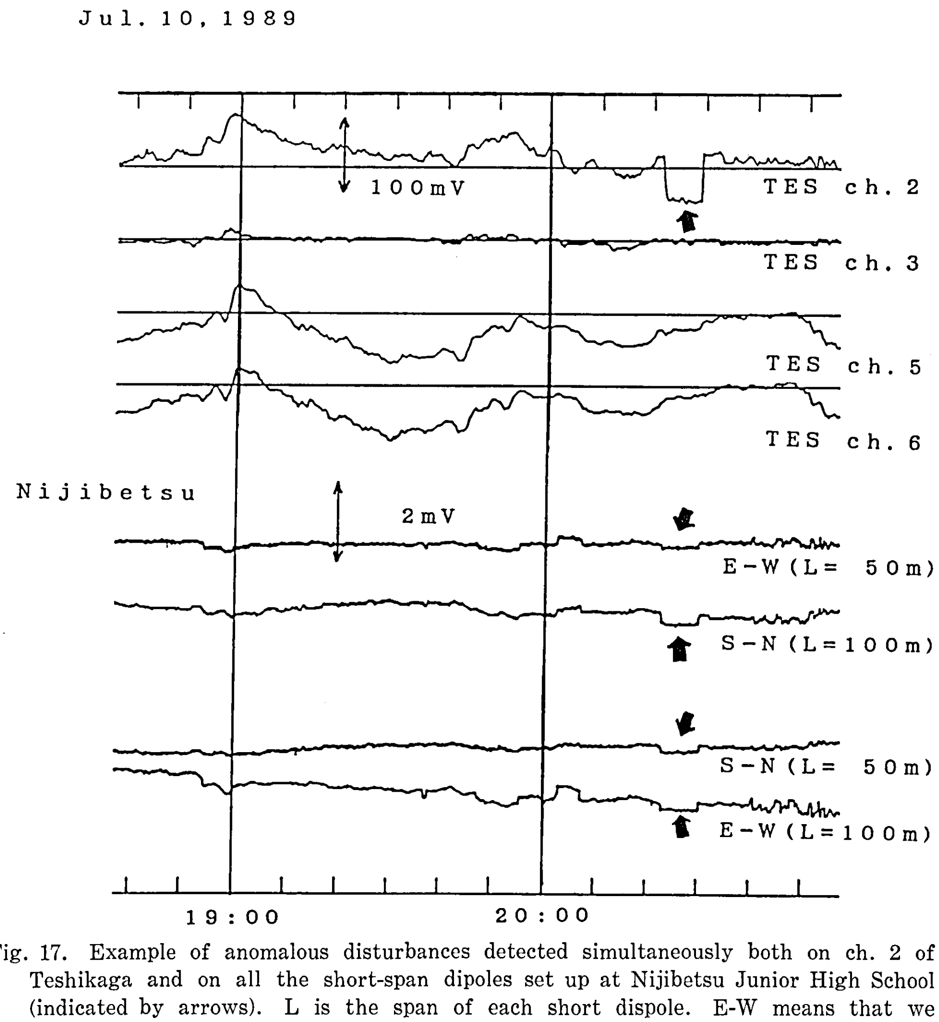

Fig. 17. Example of anomalous disturbances detected simultaneously both on ch. 2 of Teshikaga and on all the short-span dipoles set up at Nijibetsu Junior High School (indicated by arrows). L is the span of each short dispole. E-W means that we measure the potential difference of the eastern electrode minus the western one.

because their focal depth are greater than 67.5 km. If we try to find the 1 to 1 correspondence between 42 signals and 44 earthquakes, which are the earthquakes $M \geqq 3$ of all the focal depths, the result corresponding to Fig. 15 becomes as shown in Fig. 16, which seems to conform to VAN's empirical rule somewhat better than Fig. 15.

3. Discussion

From the above consideration, it is concluded that the signals on TES channel 2 may be SES's of earthquakes which occur in the region off Kushiro. Although the possibility remains that the signals are some kind of noise unrelated to seismicity, it seems improbable that such a set of correspondences, which somewhat conform the VAN-relation as shown in Fig. 15 and 16, can be obtained entirely from random noise.

There are, however, problems. First, it is somewhat strange that the signals appear on only one channel, which means that the electric potential changes only on the single electrode at Nijibetsu. Since June,

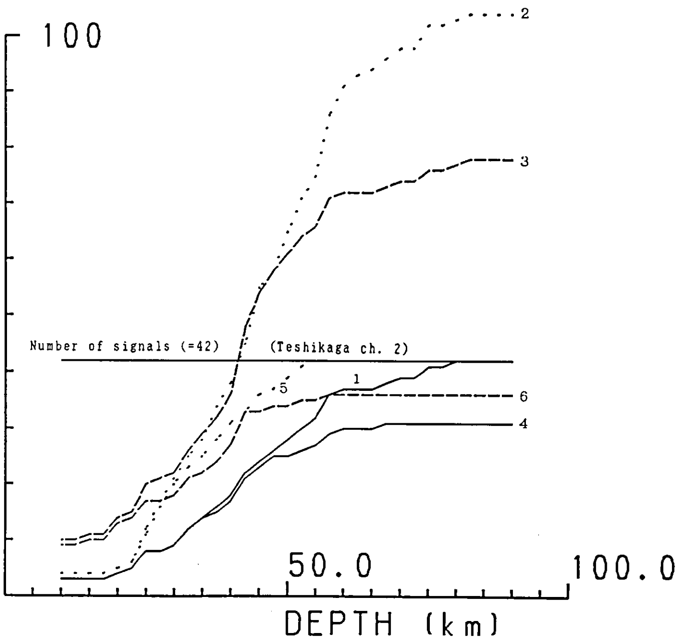

Fig. 18. Number of $M \geqq 3$ earthquakes (cumulative) vs. focal depth. line 1: off-Kushiro region. line 2: off-Kushiro+off-Urakawa region. line 3: off-Kushiro+off-Numuro+Teshikaga region.
Number of $M \geqq 3$ earthquakes correlated with signals vs. focal depth. line 4: off-Kushiro region. line 5: of-Kushiro+off-Urakawa region. line 6: off-Kushiro+off-Nemuro+Teshikaga region.

1989, a short-spanned network has been operating on the ice skating rink (unused except in winter) of Nijibetsu Junior High School, using home-made electrodes. At this network, two dipoles with 50 m and 100 m lengths are installed in both the NS and EW directions and their telluric potentials are recorded at the site both on analog and digital recorders. The site is several hundred meters away from that of the NTT electrode used for the TES channel 2 dipole, and the system is completely independent from the NTT measuring system. It has been observed that most of the TES channel 2 signals are accompanied by simultaneous changes on short spanned dipoles which satisfy the $\Delta V/L$ test. This shows that the TES channel 2 signals are not noise inherent to the NTT electrode or the NTT measuring system. Fig. 17 shows an example of such signals.

Second, the precursory time in the correspondence seems to be considerably longer than in the VAN's case (peaks at about 7 hours and 45-57 hours). The average precursory times for the cases of Figs. 12 and

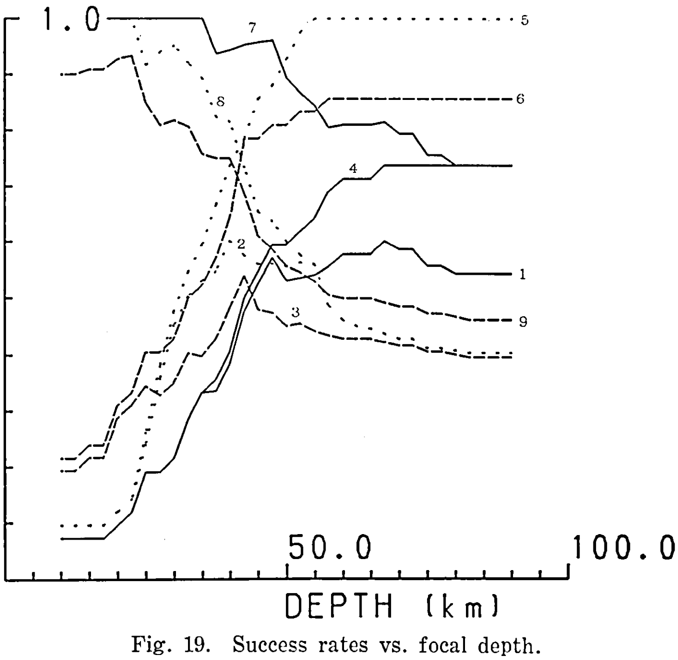

Fig. 19. Success rates vs. focal depth.

Success rates, $SR=SRS\cdot SRE$. line 1: off-Kushiro region. line 2: off-Kushiro+off-Urakawa region. line 3: off-Kushiro+off-Nemuro+Teshikaga region.

Success rates of signals, $SRS=ES_c/S$. line 4: off-Kushiro region. line 5: off-Kushiro+off-Urakawa region. line 6: off-Kushiro+off-Nemuro+Teshikaga region.

Success rates of earthquakes, $SRE=ES_c/E$. line 7: off-Kushiro region. line 8: off-Kushiro+off-Urakawa region. line 9: off-Kushiro+off-Nemuro+Teshikaga region.

13 are 231 and 227 hours, and the standard deviations are 123 and 136 hours, respectively.

Third, as can be seen from Table 1, the signals concerned appeared more frequently during day-time than in night-time. This gives us reasons to suspect that some, if not all, signals may be due to man-made noise.

Fourth, what are the signals without corresponding earthquakes? Are they related to earthquakes in other region(s)? This possibility was examined by applying the same procedures to the seismicity of expanded regions as shown in Figs. 18 and 19. In both figures, dotted lines are for the region (41°N-43°N, 141°E-145°E, namely the off-Kushiro region plus off-Urakawa region, KU+UR in Fig. 7) and broken lines are for the region (41°N-44°N, 143°E-146°E, the off-Kushiro region plus Teshikaga region and off-Nemuro region, KU+TN in Fig. 7). For expanded regions, both the numbers of earthquakes (lines 2 and 3) and correspondence (lines 5 and 6) are naturally increased compared to the case for the off-Kushiro region only as shown in Fig. 18. The case for the off-Kushiro region only is represented by solid lines

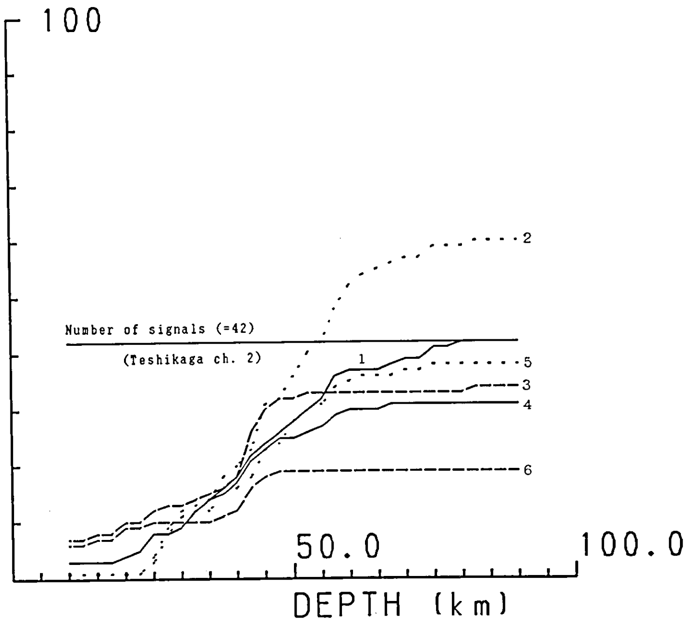

Fig. 20. Number of $M \geqq 3$ earthquakes (cumulative) vs. focal depth. line 1: off-Kushiro region. line 2: off-Urakawa region. line 3: off-Nemuro+Teshikaga region.

Number of $M \geqq 3$ earthquakes correlated with signals vs. focal depth. line 4: off-Kushiro region. line 5: off-Urakawa region. line 6: off-Nemuro+Teshikaga region.

reproduced from Fig. 9. However, the number of uncorrelated earthquakes (the difference between line 2 and line 5, and the difference between line 3 and line 6) increases, so that the maximum success rates, SR, indicated in Fig. 19 by line 2 and line 3 are not higher than the maximum values for the region off Kushiro only (line 1, reproduced from Fig. 10). This means that the earthquakes in the added region(s) do not help to improve the success rate. Then what are the uncorrelated signals? The uncorrelated signals may be some kind of noise. But at the present stage, it is difficult to prove this.

Fifth, are the TES channel 2 signals really best correlated with the off-Kushiro seismicity? The possible correspondence was noticed first for earthquakes $M \geqq 5$, but it is still possible that the signals are better correlated with the seismicity in some other regions where a sufficient number of earthquakes $M \geqq 5$ did not occur during the observation period. In order to check this point, the correspondence of TES channel 2 signals with earthquakes in the region off Urakawa (41°N-43°N, 141°E-143°E, UR in Fig. 7) and Teshikaga plus the region

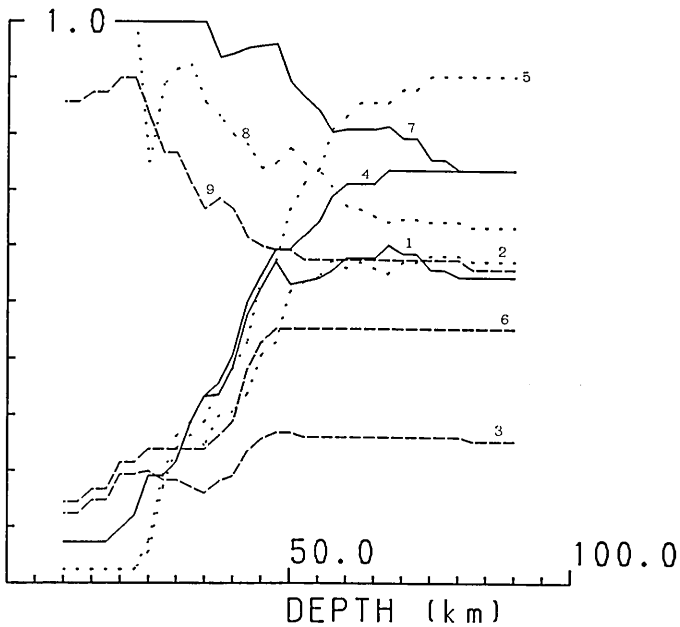

Fig. 21. Success rates vs. focal depth.

Success rates, $SR=SRS \cdot SRE$. line 1: off-Kushiro region. line 2: off-Urakawa region. line 3: off-Nemuro+Teshikaga region.

Success rates of signals, $SRS=ES_c/S$. line 4: off-Kushiro region. line 5: off-Urakawa region. line 6: off-Nemuro+Teshikaga region.

Success rates of earthquakes, $SRE=ES_c/E$. line 7: off-Kushiro region. line 8: off-Urakawa region. line 9: off-Nemuro+Teshikaga region.

off Nemuro (43°N-44°N, 143°E-145°E plus 41°N-44°N, 145°E-146°E, TN in Fig. 7) were examined separately. The results are shown in Figs. 20 and 21. Again in these figures, the case for the region off Kushiro is represented by solid lines. The number of uncorrelatable earthquakes is greater for these regions (difference between lines 2 and 5, and between lines 3 and 6 in Fig. 20) than for the region off Kushiro (difference between lines 1 and 4). The overall success rate, SR, for the Teshikaga plus off-Nemuro region (line 3 in Fig. 21) is definitely lower but SR for the region off Urakawa (line 2) is almost the same as SR for the region off Kushiro (line 1). A correlation between earthquakes in the off-Urakawa region ($M \geqq 3$, $D \leqq 75$ km in the region UR in Fig. 7) and TES channel 2 signals has been found following the second criterion described in section 2.4. The resulting VAN-diagram is as shown in Fig. 22. The least square coefficients are $a=0.25 \pm 0.31$ (95% confidence limit), $b=3.04$ with correlation coefficient $\rho=0.59$ for Fig. 15 and $a=0.17 \pm 0.17$, $b=3.59$, $\rho=0.32$ for Fig. 22 respectively. (Note that the straight lines in Figs. 15, 16, 22 are not least square fitted lines, but lines with VAN's empirical coefficient $a=0.3$ for reference.) One may say that the VAN relationship ($a=0.3$)

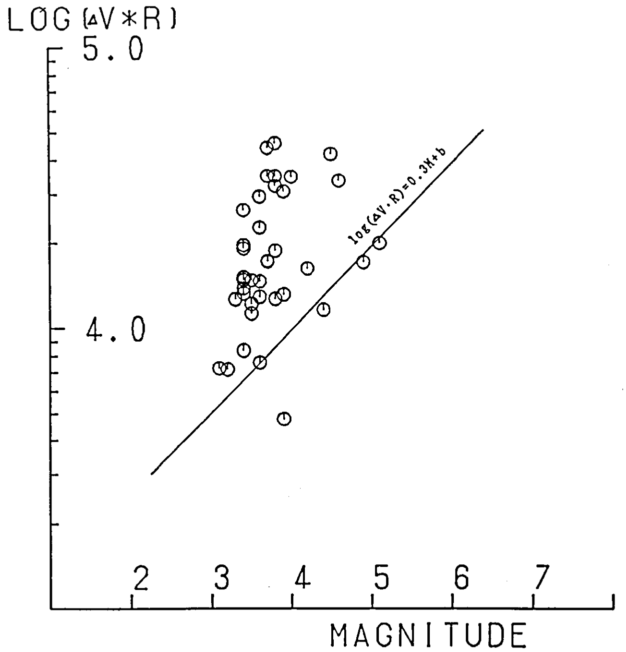

Fig. 22. VAN-diagram for the set of correspondence between electric signals detected on ch. 2 Teshikaga and earthquakes ($M \geqq 3$, $D \leqq 75$ km) which occurred off Urakawa. Correspondence was assigned to agree as much as possible with VAN's empirical law for $\log(\Delta V \cdot R)$ and M.

is better satisfied for seismicity in the region off Kushiro than in the region off Urakawa. Thus, although the seismicity off-Urakawa is an almost equally qualified candidate as far as the overall success rate is concerned, it seems less qualified when the VAN-relationship is taken into consideration. A definite conclusion will have to be waited until more earthquakes of greater magnitude occur in the regions concerned.

4. Conclusion and Acknowledgments

There seems to be a possibility that a specific type of short duration change of the electric potential which appears on channel 2 at Teshikaga network is the SES of earthquakes occurring in the off-Kushiro region, Hokkaido. There are, however, problems such as too long precursory time and too frequent day-time appearance of the electric changes. In order to check if the above possibility is a real one or just an illusion resulting from sheer coincidence between two random time series of events, much further work is required.

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References

KINOSHITA, M., M. UYESHIMA and S. UYEDA, 1989, Earthquake prediction research by means of telluric potential monitoring, Progress Report No. 1: Installation of monitoring network, *Bull. Earthq. Res, Inst. Univ. Tokyo*, **64**, 255-311.

VAROTSOS, P. and ALEXOPOULOS, 1984a, Physical properties of the variations of the electric field of the earth preceding earthquakes, I, *Tectonophysics*, **110**, 73-98.

VAROTSOS, P. and K. ALEXOPOULOS, 1984b, Physical properties of the variations of the electric field of the earth preceding earthquakes, II, Determination of epicenter and magnitude, *Tectonophysics*, **119**, 99-125.

VAROTSOS, P. and K. ALEXOPOULOS, 1986, Stimulated current emission in the earth; piezo-stimulated currents and related geophysical aspects, in *Thermodynamics of Point Defects and their Relation with Bulk Properties*, pp. 410-412, 417-420, North-Holland, Amsterdam.

VAROTSOS, P. and K. ALEXOPOULOS, 1987, Physical properties of the variations of the electric field of the earth preceding earthquakes, III, *Tectonophysics*, **136**, 335-339.

VAROTSOS, P., K. ALEXOPOULOS, K. NOMICOS and M. LAZARIDOU, 1986, Earthkuake prediction and electric signals, *Nature*, **322**, 120.

VAROTSOS, P., K. ALEXOPOULOS, K. NOMICOS and M. LAZARIDOU, 1988, Official earthquake prediction procedure in Greece, In: O. Kulhanek (Editor), Seismic Source Physics and Earthquake Prediction Research, *Tectonophysics*, **152**, 193-196.

地電位差同時連続観測による地震予知研究報告 II

——弟子屈の地電位差異常変化と釧路沖の地震との対応について——

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ギリシャにおける地電位差の短期的（数分-数時間）変化を利用した地震予知法（VAN 法）を検討すべく，1987 年より日本電信電話株式会社（NTT）との共同研究により，日本全国で同社の通信用アースを用いた地電位差同時連続モニターを行ってきた．得られたデータを検討した結果，弟子屈の 2 チャンネルに出現する地電位差異常変化と釧路沖で起こる地震との間に VAN 法の要請を満たす対応関係が成り立っている可能性が認められた．

まず，日本付近で起こったマグニチュード（M）5 以上の地震の発生前 20 日間の全国のデータを詳細に検討し異常変化をリストアップすることにより，各震源域と対応する可能性のあるシグナルがいくつか抽出された．それらのうち，弟子屈の 2 チャンネル（弟子屈-虹別）のみに 1988 年 5 月 12 日から 1988 年 12 月 31 日の間に現れたすべてのシグナル（42 個）と釧路沖（41°N-43°N, 143°E-145°E）で起こったすべての M 3 以上の地震（44 個）との対応関係をさらに詳しく調べてみた．その結果，予知率が最大となる 67.5 km 以浅の地震（38 個）と問題のシグナルとの間で，VAN 法の経験則，$\log(\Delta V\cdot R)=a\cdot M+b$（$\Delta V$ はシグナルの大きさ，R は震央距離，a, b は定数）を満たすような 1 対 1 対応関係（31 個）を見いだすことができた．しかし，VAN 法の場合に比べて先行時間が長いこと，シグナル発生時刻が日中に偏っていることなど問題点も多い．

問題のシグナルが本当に釧路沖の地震の地震先行シグナル（SES）であるか否かを検証するには，さらに観測を継続すると共に短基線観測を併用する必要がある．