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On the Mechanisms of the Earthquakes and the Stresses Producing Them in Japan and its Vicinity

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1. Introduction

The statistical investigation of the mechanisms of the earthquakes, basing on the study of the patterns of compressions and dilatations of the initial motions of the seismic waves recorded at stations close to the epicenter, enables us to estimate the state of the stresses which have been working in the earth crust and generating the earthquakes occasionally. The researches in this line have been carried out in Japan by many seismologists, *e.g.* H. HONDA (1932 b, 1934 c), T. HUKUTOMI (1933) and T. MINAKAMI (1935).

B. GUTENBERG (1941) investigated the patterns of compressions and dilatations in local earthquakes and obtained some conclusions respecting the mechanism of faulting in southern and central California. The methods which permit the use of data from distant stations have been evolved by P. BYERLY (1926 - 1950), and J. H. HODGSON and W. G. MILNE (1951).

The purpose of the present paper is to investigate statistically the mechanisms of the earthquakes occurred in Japan and its vicinity during 23 years from 1927 to 1949, and draw conclusions respecting the state of the stresses in the earth crust, and to find some relations which may exist between them and other geophysical phenomena, such as the form of the geoid and the trend of the active volcanic zone. Some of the results of the investigation covering the period 1927 to 1939, were published (H. HONDA and A. MASATSUKA, 1940), being written in Japanese. The research for the period 1940 to 1949 is rather preliminary, and it must be noted that careful considerations of the individual earthquake would occasionally cause some shifts.

2. The Distribution of the Earthquakes from 1927 to 1949

The earthquakes occurred in Japan and its vicinity during the period 1927 to 1949, and classed as remarkable earthquakes and moderate earthquakes in the Seismological Bulletin and Kishô-Yôran published by the Central Meteorological Observatory, were investigated. For determining the depths of foci, references were made sometimes to the papers by H. HONDA (1934 c), K. WADATI (1934), and B. GUTENBERG and C. F. RICETER (1938, 1939, 1949). The earthquakes are classed, throughout the present paper, as *shallow* when the depth does not exceed 100 km; *intermediate* when the depth is from 100 km to 250 km; *deep* when it exceeds 250 km. There occurred 87 deep earthquakes, 58 intermediate earthquakes and 841 shallow earthquakes during the period.

The geographical distribution of the deep and intermediate earthquakes and of shallow earthquakes are shown in the figures 1 and 2, respectively. As is well known, most deep earthquakes occur along two zones which run

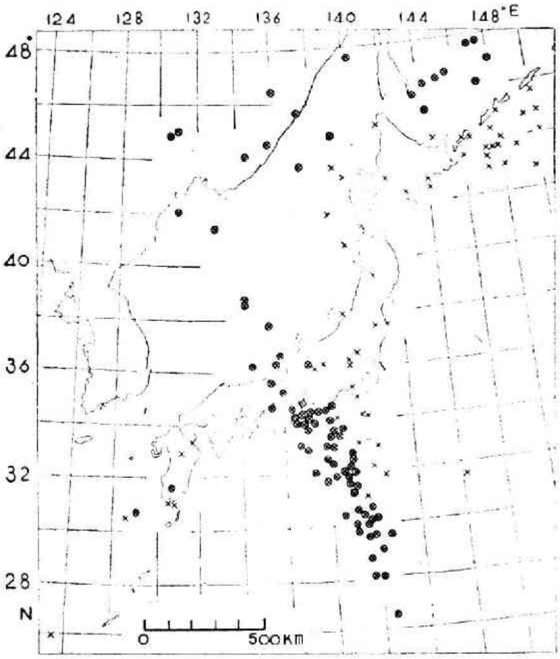


Figure 1. Epicenters of the Deep and Intermediate Earthquakes, 1927-1949.
⊗ ; Deep Earthquake. H≧250 km
× ; Intermediate Earthquake. 250 km>H≧100 km.
H ; Focal Depth.

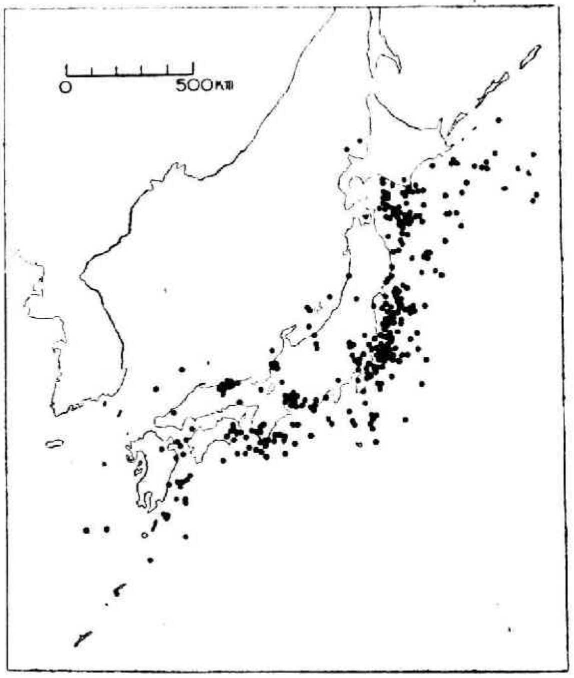


Figure 2 (b). 1940—1949

Figure 2. Epicenters of the Shallow Earthquakes, 1927-1949. H<100 km.

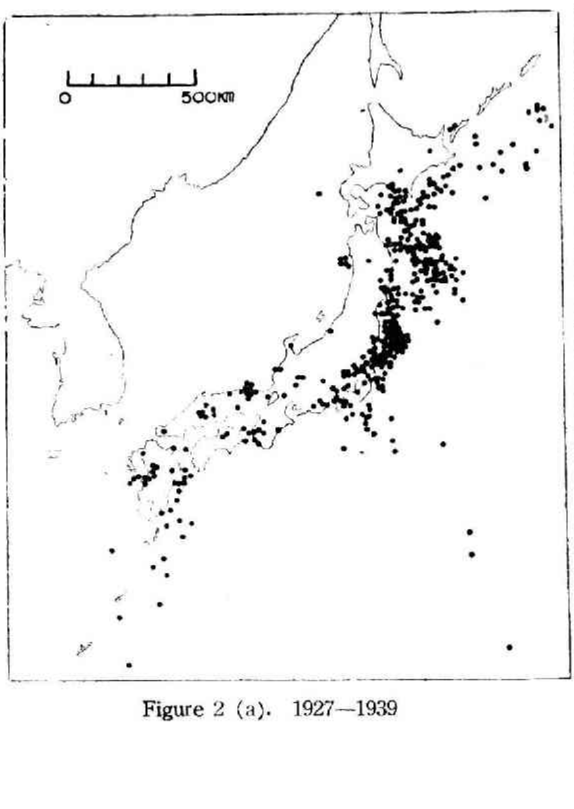


Figure 2 (a). 1927—1939

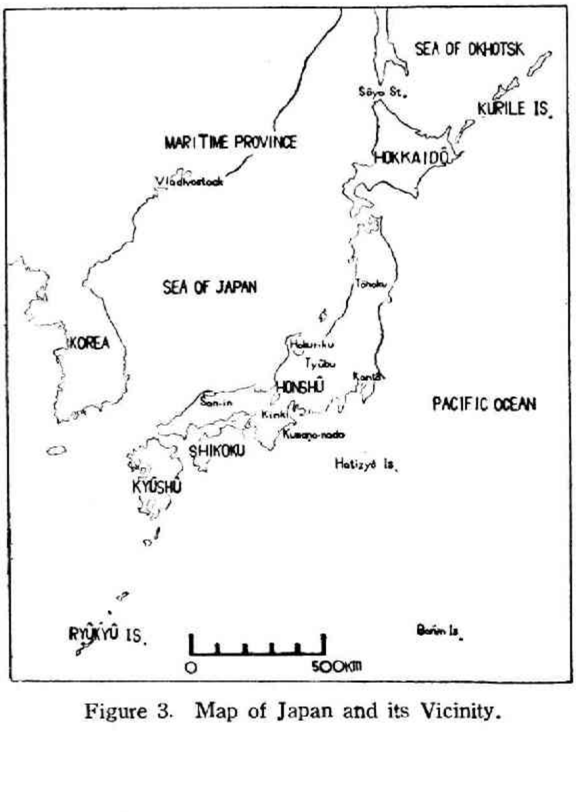


Figure 3. Map of Japan and its Vicinity.

roughly SSE and ENE from near Vladivostok; one of them crosses Honshû and extends to the Bonin Is., and the other passes through the Sôya St. and extends to the Sea of Okhotsk. But these two deep earthquake zones should rather be considered to be a single zone, which extends from the Bonin Is. to the Sea of Okhotsk and is curved strikingly almost at right angle near Vladivostok. Numerous shallow earthquakes occur in the eastern coast of Honshû, and most intermediate earthquakes occur in the zone between here and the deep earthquake zone. A few deep and intermediate earthquakes occur in Kyûshû, independently with the former ones. A more detailed discussion on the configuration of the seismic zones will be stated in later paragraphs.

3. The Model Representing the Mechanism of the Earthquake

i) The Mechanism of the Deep or the Intermediate Earthquake.

The amplitude and the direction of motion of P and S emitted from the origin of deep or intermediate earthquake are explained by the assumption, that the radial force of the shock type as can be expressed in spherical coordinates (r, θ, φ) by the following formulae

$$(F_r)_{r=a} = F \sin 2\theta \cos \varphi, \quad (F_\theta)_{r=a} = o,$$
$$(F_\varphi)_{r=a} = o, \qquad F;\ a\ constant.$$

acts on the surface of a small sphere $r = a$, constructed around the origin of the earthquake. The detail of the theory and some examples of its practical application have been given *e.g.* by H. HONDA (1932 b, 1933, 1934 a, b, c, d.) H. HONDA and T. MIURA (1938), H. HONDA and Y. HASAYA (1940), H. HONDA and A. MASATSUKA (1940) and H. HONDA and H. ITÔ (1951). The variation of the velocity of the seismic waves with the depth from the earth's surface is of course taken into account.

Let the sphere $r = a$ be divided into four parts by two planes

$$\theta = \frac{\pi}{2} \text{ and } \varphi = \frac{\pi}{2} - -\frac{\pi}{2},$$

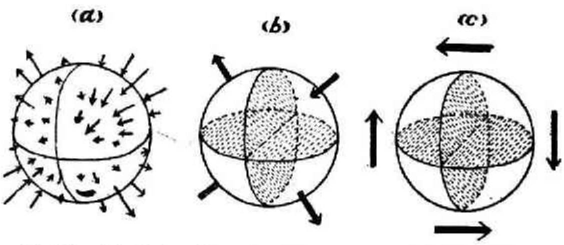
which pass throhgh the origin and are perpendicular each other. Then the force given above can be considered to act as pressure on two parts which are opposite each other, and as tension in the other two parts. We will denote the direction

$$(\theta = \frac{\pi}{4}, \varphi = 0) - (\theta = \frac{3\pi}{4}, \varphi = \pi)$$

as the direction of "*the maximum tension*" and the direction

$$(\theta = \frac{3\pi}{4}, \varphi = 0) - (\theta = \frac{\pi}{4}, \varphi = \pi)$$

as the direction of "*the maximum pressure*", for the sake of convenience of further investigation.



(a) The Radial Force, F_r. (b) The Maximum Pressure and the Maximum Tension. (c) The Shearing Stresses.

Figure 4. The Mechanism of the Deep or Intermediate Earthquake.

It should be noticed that the effect of pressure and tension, as shown in the figure 4 (b), is equivalent to that of two pairs of shearing stresses which are perpendicular each other as shown in the figure 4 (c).

The mechanism of each individual deep or intermediate earthquake can be illustrated *e.g.* as is shown in the figure 5, or may be represented by the expression *e. g.* such as

S 55°E (60°)- —
N 55°W (120°).

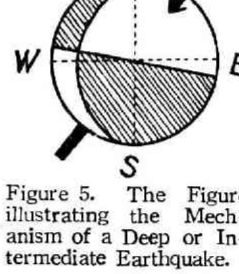


Figure 5. The Figure illustrating the Mechanism of a Deep or Intermediate Earthquake.

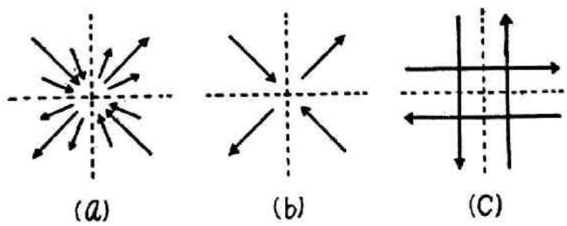
The figure 5 shows the pattern of the distribution of pressure and tension on the model sphere, when it is viewed from vertically above the origin; the hatched area represents the part of the sphere on which acts the tension, and the other area represents the part on which acts the pressure; the arrows show the projection of the maximum pressure on the horizontal plane.

The expression S 55° E (60°) — N 55° W (120°) means that the direction of the maximum pressure acting at the hypocenter, lies in the vertical plane directing S 55°E—N 55°W through the origin, and it is inclined in the vertical plane directing to S 55°E by the angle 60° from the vertical drawn upward, and it is inclined in the vertical plane directing to N 55°W by the angle 120° from the vertical drawn upward.

ii) The Mechanism of Very Shallow Earthquake.

The mechanisms of especially very shallow earthquakes which occur inland, whose focal depths are less than about 10 or 15 km, have been known to be comparatively simple in many cases. When the earth's surface is divided into four quadrants by two straight nodal lines, which pass through the epicenter and are perpendicular each other, the initial motions of P are dilatational in two quadrants lying opposite each other, and are condensational in the other quadrants. The amplitudes and the directions of the motions of P, S and surface waves of very shallow earthquakes, have been explained by the assumption, that the radial and horizontal force of the shock type as can be expressed by the expression $F\sin 2\varphi$ acts in the epicentral region; where φ is the azimuth with respect to the epicenter and measured from the nearest nodal line, and F is a constant. (H. HONDA, 1931, 1932 a).

The radial and horizontal force $F\sin 2\varphi$ can be represented by the maximum pressure and the maximum tension, or by two pairs of



(a) The Radial Force. (b) The Maximum Pressure and the Maximum Tension. (c) The Shearing Stresses.

Figure 6. The Mechanism of Very Shallow Earthquake.

shearing stresses which are perpendictcular each other, as are shown in the figure 6.

iii) The mechanisms of ordinary shallow earthquakes whose focal depths are not very shallow, seem generally not to be so easily elucidated as those of very shallow or deep or intermediate earthquakes. The reason lies probably in the facts, that the effects of the earth's surface and the variation of the velocity of the seismic waves with the depth, manifest themselves too conspicuously in comparatively narrow region, to be able to determine the mechanism of the shallow earthquake accurately by the mesh of the seismological stations. The problem on the mechanisms of most shallow earthquakes and the stresses producing them, except those of very shallow earthquakes, are left untouched in our present investigation.

4. The Mechanisms of the Deep and the Intermediate Earthquakes and the Stresses producing Them

The deep earthquakes and the intermediate earthquakes occurred in Japan and its vicinity during the period 1927 to 1949, are tabulated in the tables 1 and 2, respectively. The mechanisms of 34 deep earthquakes and 10 intermediate earthquakes out of them, have been exnlained by our model. The pattern of compressions and dilatations of each earthquake is shown in the figures 7 and 8, and the mechanism of the earthquake is illustrated in the same figure, in the way as is exemplified in the figure 5.

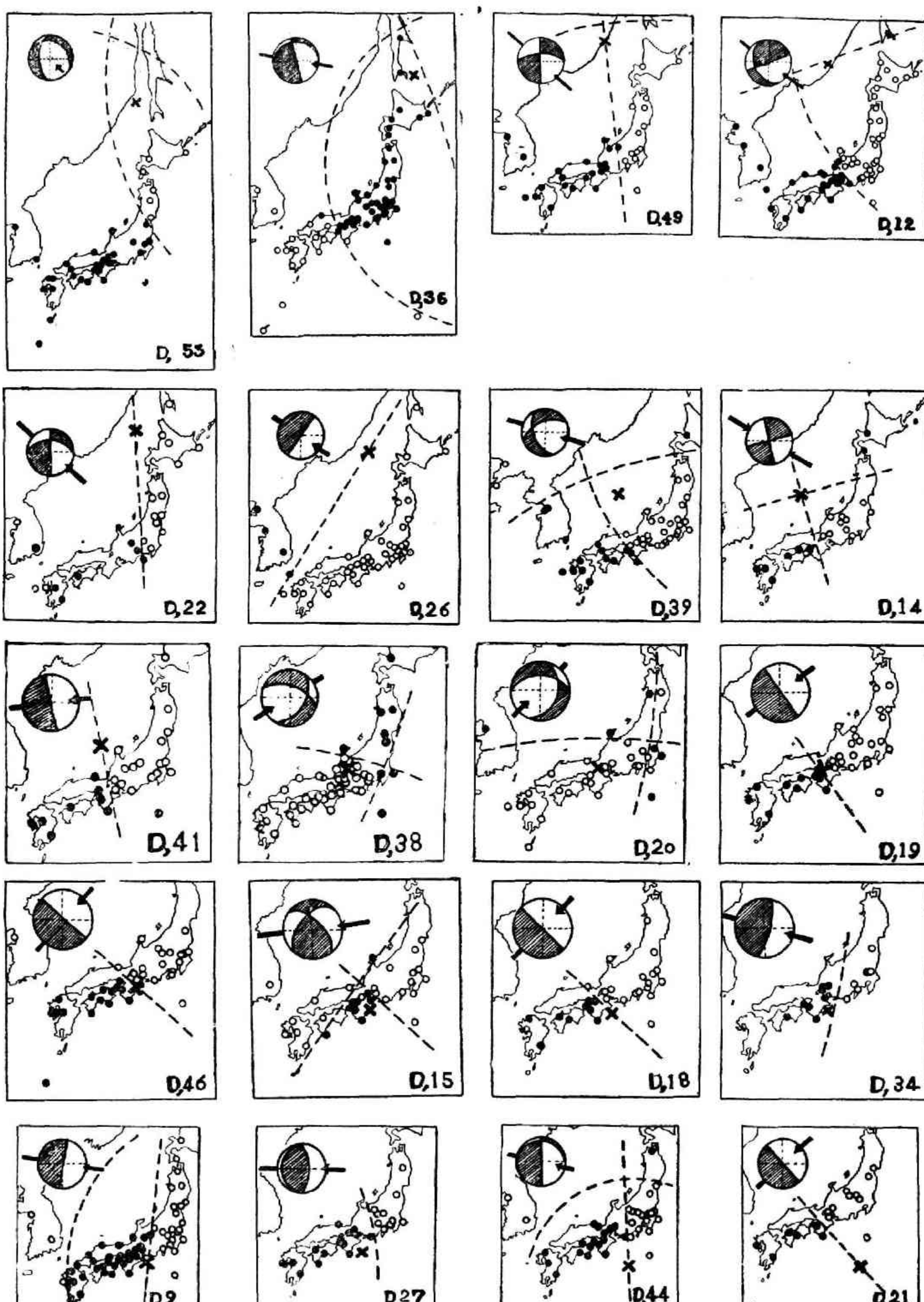

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Figure 7 (a).

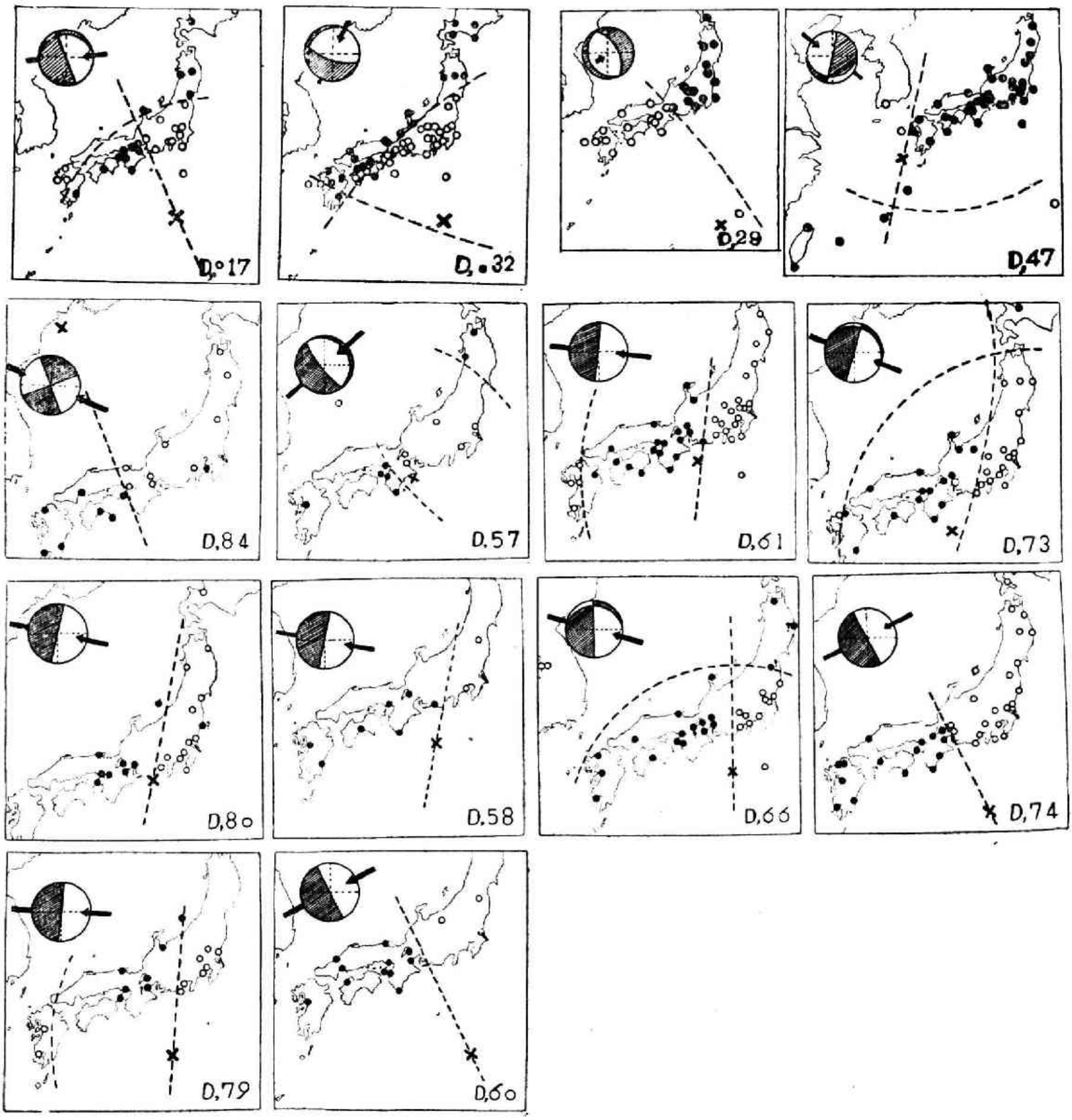


Figure 7 (b).

Figure 7. Patterns of Compressions (•) and Dilatations (∘) and the Mechanisms of the Deep Earthquakes. $H \geqq 250$ km

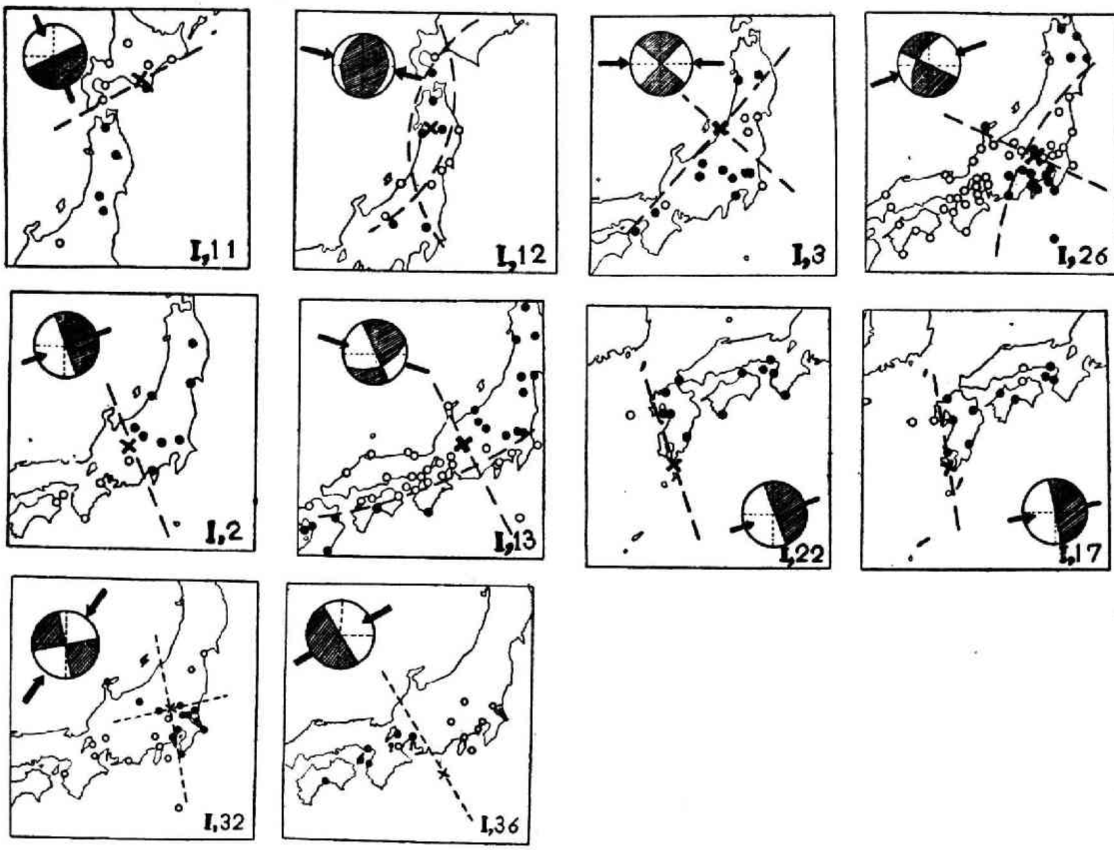


Figure 8. Patterns of Compressions (•) and Dilatations (∘) and the Mechanisms of the Intermediate Earthquakes. 250 km > H ≧ 100 km

Table 1. The Deep Earthquakes. (H ≧ 250 km.)

No.	Date and Time (G. M. T.)			Epicenter E	Epicenter N	Focal Depth	Maximum Pressure
			d h m	°	°	km	
D. 1	1927	Jan.	15 14 32	134.5	36.2	420	
2	1927	June	18 2 27	138.5	33.6	300	
3	1927	Aug.	20 22 13	138.4	33.6	300	
4	1927	Sept.	12 15 30	138.0	34.0	300	
5	1927	Dec.	18 19 50	132.8	41.3	350	
6	1928	Mar.	29 5 07	138.2	31.8	410	
7	1928	Aug.	27 17 59	139.0	32.5	300	
8	1929	Mar.	17 12 15	147.0	47.7	260	
9	1929	June	2 21 39	137.2	34.3	320	S 82° E (58°) - N 82° W (122°)
10	1930	Mar.	6 3 32	139.5	28.7	250	
11	1930	Sept.	29 4 53	130.6	31.6	260	
12	1931	Feb.	20 5 34	135.7	44.5	350	S 55° E (60°) - N55° W (120°)
13	1931	Mar.	1 14 23	143.7	46.0	250	
14	1931	Apr.	21 0 03	134.2	38.5	350	S 60° E (90°) - N 60° W (90°)
15	1931	June	29 16 43	136.5	34.2	360	N 84° E (81°) - S 84° W (99°)

No.	Date and Time (G. M. T.)			Epicenter E	Epicenter N	Focal Depth	Maximum Pressure
			d h m	°	°	km	
D. 16	1932	Feb.	3 7 35	140.1	29.0	400	
17	1932	Apr.	4 19 17	139.1	30.5	410	N 85° E (47°) - S 85° W (133°)
18	1932	Apr.	28 3 43	136.8	34.0	320	N 45° E (45°) - S 45° W (135°)
19	1932	May	5 4 11	135.3	34.6	360	N 55° E (45°) - S 55° W (135°)
20	1932	July	25 8 25	135.9	35.2	360	S 45° W (38°) - N 45° E (142°)
21	1932	July	27 0 30	139.0	31.2	300	N 50° E (45°) - S 50° W (135°)
22	1932	Sept.	23 14 23	139.0	44.7	330	S 50° E (70°) - N 50° W (110°)
23	1932	Oct.	1 15 09	140.5	29.5	420	
24	1932	Oct.	14 12 37	138.8	31.6	300	
25	1932	Oct.	25 17 03	145.0	46.5	360	
26	1932	Nov.	13 4 48	137.3	43.6	320	S 55° E (45°) - N 55° W (135°)
27	1932	Dec.	5 0 20	137.0	33.7	350	N 90° E (65°) - S 90° W (115°)
28	1933	Feb.	9 3 57	138.8	31.7	300	
29	1933	Mar.	11 19 33	140.5	26.5	500	S 60° W (15°) - N 60° E (165°)
30	1933	May	24 4 36	145.6	46.7	450	
31	1933	May	28 23 40	138.0	32.4	300	
32	1933	Sept.	2 16 42	139.4	30.3	380	N 25° E (34°) - S 25° W (146°)
33	1933	Sept.	6 14 05	137.8	34.4	250	
34	1933	Sept.	20 3 57	136.6	34.1	330	S 75° E (55°) - N 75° W (125°)
35	1933	Nov.	19 1 34	139.0	32.6	250	
36	1933	Dec.	4 19 34	144.3	46.4	350	S 78° E (62°) - N 78° W (118°)
37	1934	Apr.	19 16 14	139.5	30.0	350	
38	1935	Apr.	15 11 15	137.1	36.2	280	S 58° W (45°) - N 58° E (135°)
39	1935	May	31 8 19	134.2	38.6	450	S 74° E (57°) - N 74° W (123°)
40	1935	July	26 8 04	147.5	47.7	360	
41	1935	Oct.	15 14 35	135.4	37.7	280	N 80° E (45°) - S 80° W (135°)
42	1935	Dec.	14 12 49	145.0	22.0	360	
43	1936	Mar.	1 10 23	148.0	47.0	360	
44	1936	June	25 16 52	137.9	32.5	320	S 77° E (46°) - N 77° W (134°)
45	1936	Oct.	19 19 56	135.8	36.5	350	
46	1936	Oct.	26 9 34	136.3	34.5	340	N 40° E (45°) - S 40° W (135°)
47	1936	Dec.	1 6 10	129.0	30.7	270	N 53° W (52°) - S 53° E (128°)
48	1937	Jan.	5 11 10	139.6	28.0	500	
49	1937	Apr.	29 20 20	137.3	45.7	370	S 47° E (76°) - N 47° W (104°)
50	1937	May	28 19 57	142.5	24.0	450	
51	1937	July	21 0 08	144.3	45.4	360	
52	1938	Mar.	18 2 09	147.1	46.2	320	
53	1939	Apr.	21 4 30	140.2	47.6	530	S 43° E (28°) - N 43° W (152°)
54	1940	Mar.	9 10 48	140.0	28.0	520	
55	1940	July	10 5 01	130.6	44.8	560	
56	1940	Nov.	7 13 59	138.5	30.3	480	
57	1940	Dec.	30 20 52	136.8	34.2	360	N 50° E (40°) - S 50° W (140°)
58	1941	Feb.	4 20 06	137.8	33.0	300	N 80° W (135°) - S 80° E (45°)
59	1941	Mar.	22 22 06	138.0	33.4	320	
60	1941	Oct.	30 7 11	139.7	30.6	300	N 65° E (45°) - S 65° W (135°)
61	1942	Apr.	20 8 41	137.3	33.9	350	S 80° E (45°) - N 80° W (135°)
62	1942	May	15 16 18	135.6	36.2	300	
63	1942	June	27 2 45	139.0	29.8	420	
64	1943	Sept.	2 13 41	136.9	34.7	340	
65	1943	Sept.	27 4 41	135.4	35.5	360	
66	1943	Nov.	17 14 58	138.0	33.0	320	S 75° E (45°) - N 75° W (135°)
67	1944	June	3 4 11	139.6	30.2	330	
68	1944	Oct.	14 15 16	136.0	46.5	—	
69	1945	Jan.	24 9 32	139.5	29.5	250	
70	1945	Oct.	9 10 57	137.0	34.1	360	

No.	Date and Time (G. M. T.)			Epicenter E	Epicenter N	Focal Depth	Maximum Pressure
			d h m	°	°	km	
D. 71	1946	Jan.	11 1 35	131.0	45.0	600	
72	1946	Mar.	12 15 29	136.9	32.9	340	
73	1947	Feb.	18 13 31	136.8	33.0	400	S 70° E (50°) - N 70° W (130°)
74	1947	Oct.	3 6 22	139.0	31.5	350	N 65° E (45°) - S 65° W (135°)
75	1947	Nov.	30 21 18	137.5	34.4	300	
76	1948	Jan.	23 8 36	139.0	32.0	350	
77	1948	Feb.	23 17 00	139.0	32.0	350	
78	1948	Mar.	15 2 17	138.6	32.0	300	
79	1948	Apr.	11 15 57	137.8	31.7	250	N 85° W (135°) - S 85° E (45°)
80	1948	June	20 0 33	138.0	34.5	300	S 80° E (45°) - N 80° W (135°)
81	1948	Sept.	5 10 01	139.8	29.6	300	
82	1948	Nov.	15 4 50	139.0	29.8	370	
83	1948	Nov.	28 12 50	138.4	33.6	250	
84	1949	Apr.	5 9 28	131.0	42.0	600	N 67° W (90°) - S 67° E (90°)
85	1949	July	14 23 22	139.8	30.2	350	
86	1949	Sept.	23 8 13	134.5	44.0	300	
87	1949	Nov.	17 22 29	137.3	32.0	320	

(D. 9) K. SAGISAKA; *K. Z.* 6: 15-42. H. HONDA; *G. M.* 8: 153-164.

(D. 12) K. WADATI and T. ISIKAWA; *G. M.* 7: 291-305. H. HONDA and H. ITÔ; *Science Rep. Tôhoku. Univ.* Ser. 5. 3: 144-155.

(D. 15) M. MORITA; *K. Z.* 9: 231-251.

(D. 17) H. HONDA; *G. M.* 5: 301-326.

(D. 18) H. HONDA; *G. M.* 8: 153-164.

(D. 19) H. HONDA; *G. M.* 8: 327-332.

(D. 20) M. TAKEHANA; *K. Z.* 9: 261-264.

(D. 26) H. HONDA; *G. M.* 8: 165-177.

(D. 36) M. KIZIMA; *K. Z.* 9: 171-199.

(D. 39) M. TAKEHANA; *K. Z.* 9: 253-264.

(D. 46) T. KADOWAKI, S. TAKAHASHI and H. WADA; *K. Z.* 10: 78-85.

(D. 47) H. HONDA and Y. HASAYA; *G. M.* 13: 219-230.

(D. 49) H. ITÔ; *K. Z.* 11: 28-40.

(D. 53) H. HONDA and H. ITÔ; *K. Z.* 11: 1-27. *Science Rep. Tôhoku Univ.* Ser. 5. 3: 144-155.

(D. 61) K. IMADA, N. MIYOSHI and Y. TANAKA; *K. Z.* 12: 55-58.

G. M.; *Geophysical Magazine*. *K. Z.*; *Kenshin Zihô*.

Table 2. The Intermediate Earthquakes. 250 km > H ≧ 100 km.

No.	Date and Time (G. M. T.)			Epicenter E	Epicenter N	Focal Depth	Maximum Pressure
			d h m	°	°	km	
I. 1	1927	July	12 21 08	146.0	43.5	100	
2	1927	Nov.	10 19 48	137.8	36.2	190	S 70° W (45°) - N 70° E (135°)
3	1927	Dec.	10 2 44	139.0	38.0	130	N 90° E (90°) - S 90° W (90°)
4	1927	Dec.	31 5 50	139.2	36.1	120	
5	1929	Jan.	13 0 05	154.8	49.7	120	
6	1929	Oct.	5 19 01	146.0	44.2	150	
7	1929	Oct.	9 19 45	131.1	32.9	120	
8	1930	May	23 16 38	139.6	34.2	120	
9	1930	July	22 19 26	147.8	43.7	120	
10	1930	Aug.	29 20 02	146.5	44.2	150	

No.	Date and Time (G. M. T.)			Epicenter E	Epicenter N	Focal Dapth	Maximum pressure
			d h m	°	°	km	
I. 11	1931	Jan.	6 3 23	142.8	42.4	100	N 25° W (45°) – S 25° E (135°)
12	1931	Jan.	9 1 46	140.6	39.8	130	N 75° W (90°) – S 75° E (90°)
13	1931	June	2 2 38	137.5	36.0	240	N 73° W (70°) – S 73° E (110°)
14	1931	Nov.	12 13 10	139.4	34.8	100	
15	1932	Feb.	19 13 25	140.3	32.9	150	
16	1932	Sept.	2 12 57	145.0	24.0	240	
17	1932	Nov.	17 20 11	130.4	31.1	100	S 80° W (45°) – N 80° E (135°)
18	1932	Dec.	26 21 15	125.5	26.0	160	
19	1933	Mar.	18 15 51	140.0	32.2	120	
20	1934	Feb.	1 0 16	139.3	35.3	100	
21	1934	Oct.	29 17 23	140.3	41.3	140	
22	1935	Oct.	2 9 28	130.7	31.0	120	S 70° W (45°) – N 70° E (235°)
23	1936	Nov.	12 20 05	148.0	45.0	240	
24	1937	Jan.	23 8 50	131.6	33.3	100	
25	1937	June	8 18 01	150.0	45.6	240	
26	1938	Feb.	7 14 43	139.2	36.3	100	N 70° E (73°) – S 70° W (107°)
27	1938	Aug.	17 1 46	147.6	43.7	100	
28	1938	Oct.	17 15 27	140.0	44.4	200	
29	1938	Nov.	13 13 14	149.4	44.7	100	
30	1939	Dec.	16 10 47	147.2	43.7	120	
31	1940	July	4 9 01	144.5	44.3	200	
32	1940	Nov.	26 22 25	139.5	36.5	120	N 35° E (90°) – S 35° W (90°)
33	1941	Mar.	15 19 08	139.3	40.6	160	
34	1941	Apr.	2 18 05	138.6	41.8	150	
35	1941	July	6 0 34	140.5	31.8	200	
36	1941	Aug.	3 7 26	138.2	34.0	240	N 60° E (45°) – S 60° W (45°)
37	1941	Nov.	14 6 49	148.8	43.7	—	
38	1942	Mar.	5 19 48	141.7	43.0	—	
39	1942	Apr.	14 20 39	128.5	30.5	—	
40	1942	July	27 11 05	147.2	43.0	120	
41	1942	Nov.	26 14 28	150.2	44.8	120	
42	1943	Apr.	29 15 25	147.2	43.4	180	
43	1943	Nov.	9 11 48	148.0	43.0	120	
44	1944	July	10 12 30	144.0	42.8	100	
45	1945	Apr.	24 14 36	139.5	31.0	240	
46	1945	Nov.	17 16 07	139.5	43.2	240	
47	1946	Mar.	2 12 50	148.0	44.0	150	
48	1946	Mar.	6 13 11	147.5	44.4	100	
49	1946	June	26 19 29	139.3	33.1	—	
50	1946	Dec.	10 7 23	139.0	43.5	100	
51	1946	Dec.	10 10 20	141.2	37.5	100	
52	1947	Aug.	16 14 55	149.6	42.8	100	
53	1948	May	8 2 47	141.5	45.0	150	
54	1948	Nov.	10 12 59	144.2	31.5	100	
55	1949	July	30 6 30	150.1	44.1	180	
56	1949	Aug.	23 21 42	140.7	37.5	100	
57	1949	Oct.	1 16 18	139.7	34.1	150	
58	1949	Oct.	11 9 05	144.0	42.6	100	

(I. 12) Y. Oka; *G. M.* **6**: 213-221.

(I. 13) K. Tanahashi; *Umi to Sora* **11**: 277-288.

(I. 26) *K. Z.* **10**: 248-265.

When the directions of the horizontal components of the maximum pressure of the deep earthquakes and the intermediate earthquakes are shown by arrows on a map (the figure 9), it is seen that there exist close relations between them, and they are directed nearly perpendicularly to the deep earthquake zone and the intermediate earthquake zone, respectively.

5. The Mechanisms of the Very Shallow Earthquakes and the Stresses producing Them

The very shallow earthquakes occurred in or near the inland of Japan and caused damage more or less during the period 1927 to 1949, are tabulated in the table 3. The mechanisms of 27 earthquakes out of them have been explained by our model. The pattern of compressions and dilatations of each earthquake is shown in the figure 10, and the directions of the maximum pressure and the maximum tension are also illustrated by arrows in the same figure.

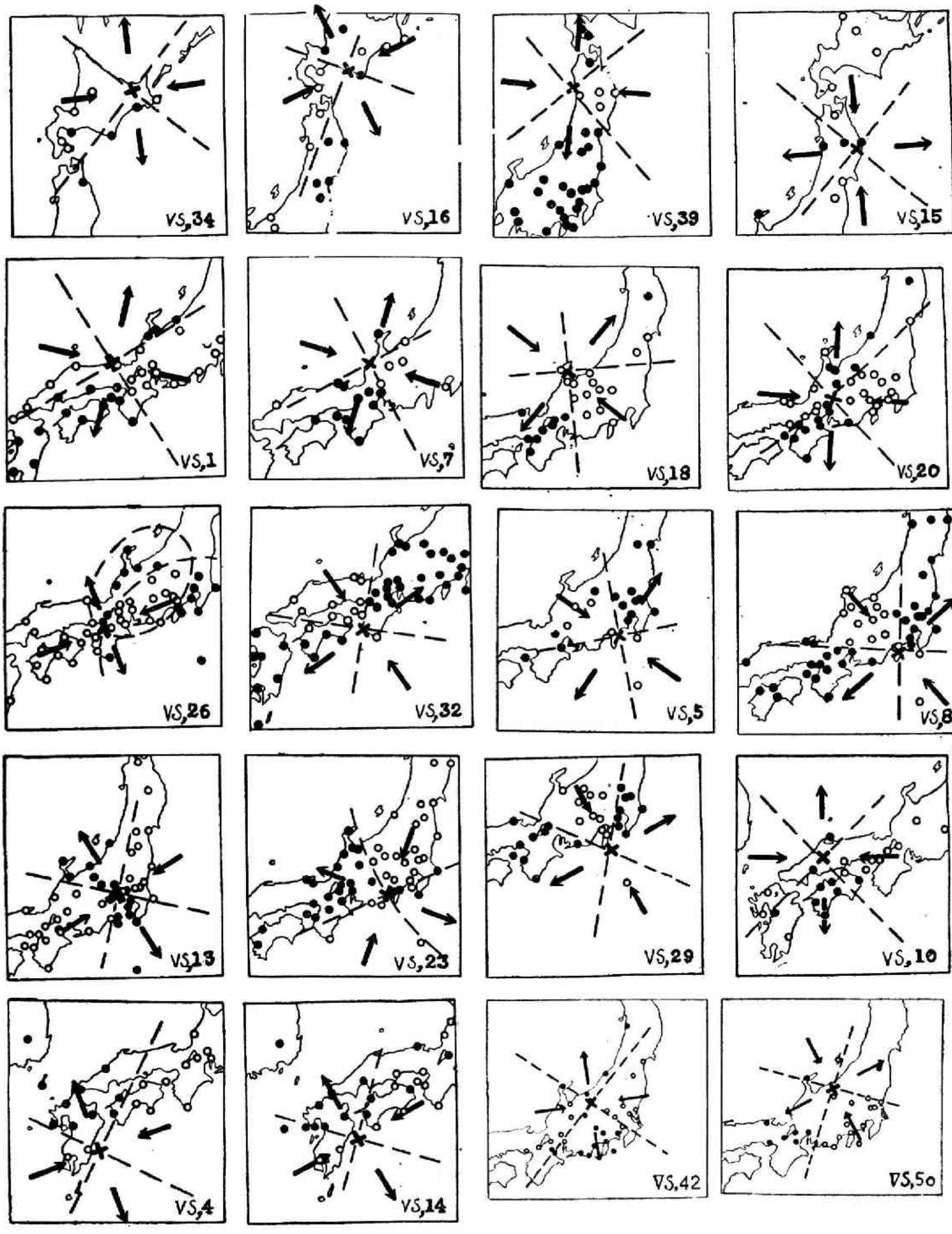
Figure 9. The Direction of the Horizontal Components of the Maximum Pressure for the Deep (⊗) and Intermediate (×) Earthquakes.

Table 3. The Very Shallow Earthquakes, which occurred in or near the Inland and caused Damage more or less.

No.	Date and Time (G. M. T.)			Epicenter E	Epicenter N	Maximum Pressure
			d h m	°	°	
VS. 1	1927	Mar.	7 9 28	135.1	35.7	N 75° W - S 75° E
2	1927	Aug.	5 21 14	141.6	37.7	
3	1927	Aug.	24 18 09	120.5	23.1	
4	1929	May	21 16 35	131.8	31.8	N 70° E - S 70° W
5	1930	Mar.	22 8 50	139.1	35.0	N 50° W - S 50° E
6	1930	May	31 17 58	140.4	36.4	
7	1930	Oct.	16 21 36	136.3	36.3	N 70° W - S 70° E
8	1930	Nov.	25 19 03	139.0	35.1	N 38° W - S 38° E
9	1930	Dec.	8 8 01	120.5	23.4	
10	1930	Dec.	21 12 14	132.9	34.8	E - W
11	1931	Feb.	16 18 48	142.6	42.3	
12	1931	Mar.	9 3 49	141.9	40.6	
13	1931	Sept.	21 2 20	139.3	36.0	N 60° E - S 60° W
14	1931	Nov.	2 10 03	132.1	32.4	N 60° E - S 60° W (?)
15	1931	Nov.	3 16 20	141.7	39.5	N - S
16	1932	Nov.	26 4 24	142.3	42.4	N 70° E - S 70° W
17	1933	Mar.	2 17 31	144.7	39.1	
18	1933	Sept.	21 3 14	136.97	37.07	N 50° W - S 50° E
19	1934	Aug.	11 8 18	121.8	24.7	
20	1934	Aug.	18 2 38	137.03	35.72	N 85° W - S 85° E

No.	Date and Time (G. M. T.)			Epicenter E	Epicenter N	Maximum Pressure
			d h m	°	°	
VS. 21	1935	Feb.	9 19 19	121.8	24.7	
22	1935	Apr.	20 22 02	120.82	24.35	E - W
23	1935	July	11 8 24	138.44	34.98	N 25° E - S 25° W
24	1935	July	16 16 19	120.9	24.6	
25	1935	Sept.	4 1 37	121.6	22.4	
26	1936	Feb.	21 1 08	135.67	34.52	N 70° E - S 70° W (?)
27	1936	Aug.	22 6 51	121.2	22.1	
28	1936	Nov.	2 20 46	142.0	38.4	
29	1936	Dec.	27 0 14	139.17	34.42	N 25° W - S 25° E
30	1937	July	26 19 56	141.97	38.23	
31	1937	Dec.	8 8 32	121.5	22.9	
32	1938	Jan.	11 15 12	135.17	33.72	N 35° W - S 35° E
33	1938	May	23 7 18	141.45	36.70	
34	1938	May	28 16 42	144.3	43.6	E - W
35	1938	Sept.	7 4 03	121.7	23.9	
36	1938	Nov.	5 8 43	141.65	37.10	
37	1938	Dec.	6 23 01	121.5	22.9	
38	1939	Mar.	20 3 22	131.8	32.4	
39	1939	May	1 5 58	139.82	39.95	N 80° W - S 80° E
40	1940	Aug.	1 15 08	139.1	44.3	
41	1941	Apr.	5 16 49	131.7	34.6	
42	1941	July	15 14 45	138.2	36.7	N 79° E - S 79° W
43	1941	Nov.	18 16 46	132.4	32.3	
44	1941	Dec.	16 19 20	120.6	23.4	
45	1942	Feb.	21 7 08	141.8	37.7	
46	1943	Mar.	4 10 13	134.2	35.6	N 62° W - S 62° E
47	1943	Mar.	4 19 50	134.2	35.6	N 68° W - S 68° E
48	1943	Aug.	12 4 50	139.8	37.3	N 83° E - S 83° W
49	1943	Sept.	10 8 37	134.2	35.5	N 67° W - S 67° E
50	1943	Oct.	13 5 42	138.2	36.8	N 27° W - S 27° E
51	1943	Dec.	2 5 09	121.6	22.9	
52	1944	Dec.	7 4 35	136.2	33.7	
53	1945	Jan.	12 18 38	137.0	34.7	
54	1945	Feb.	10 4 58	142.1	40.9	
55	1946	Dec.	20 19 19	135.6	33.0	
56	1947	May	9 14 05	131.1	33.3	
57	1947	Nov.	4 0 09	141.0	43.8	
58	1948	June	15 11 44	135.5	33.8	
59	1948	June	28 7 13	136.2	36.1	N 57° W - S 57° E
60	1949	Jan.	20 13 25	134.6	35.6	N 50° W - S 50° E
61	1949	July	11 16 10	132.5	34.0	N 28° W - S 28° E
62	1949	Dec.	25 23 25	139.7	36.7	

(VS. 1) S. Kunitomi; *G. M.* 2: 65-89.
(VS. 4) K. Hayata; *K. Z.* 3: 339 365.
(VS. 5) H. Honda; *G. M.* 4. 185-213.
(VS. 8) H. Honda; *G. M.* 4: 185-213.
(VS. 13) H. Honda; *G. M.* 5: 69-88.
(VS. 18) *K. Z.* 7: 393-397.
(VS. 20) H. Honda and T. Miura; *K. Z.* 8: 123-128.
(VS. 22) H. Honda and T. Miura; *K. Z.* 10: 61-64.
(VS. 23) *K. Z.* 9: 65-70.
(VS. 26) M. Takehana and M. Morita; *K. Z.* 9: 91-104.
(VS. 29) T. Miura; *K. Z.* 10: 65-77.
(VS. 32) *K. Z.* 10: 266 276.
(VS. 42) A. Masatsuka; *K. Z.* 12: 153-161.


VS,34
VS,16
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VS,1
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VS,26
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VS,4
VS,14
VS,42
VS,50

Figure 10 (a).

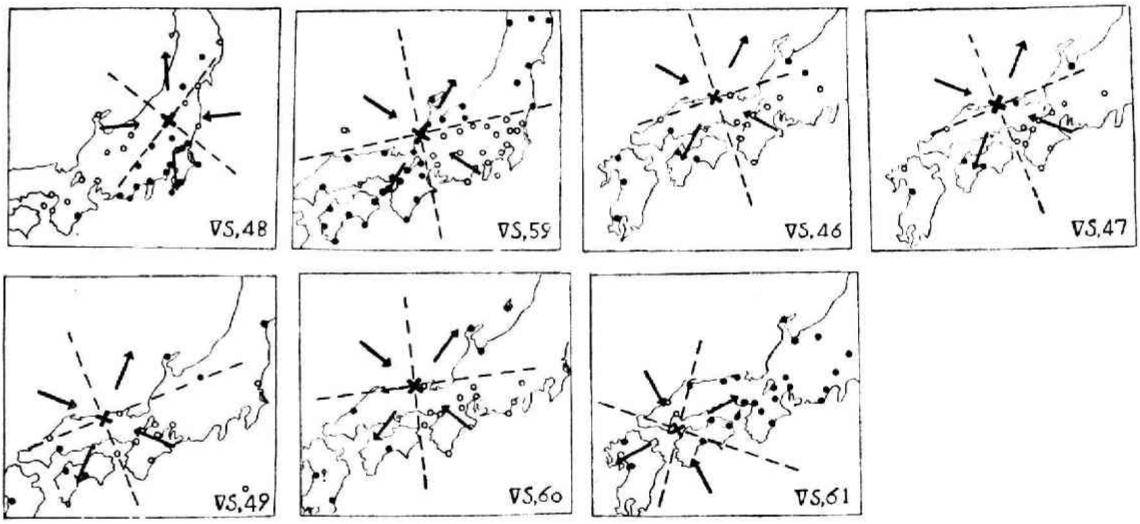

Figure 10 (b).

Figure 10. Patterns of Compressions (•) and Dilatations (∘) and the Mechanisms of the Very Shallow Earthquakes.

When the directions of the horizontal maximum pressure of the very shallow earthquakes are shown by arrows on a map (the figure 11), it may be seen that there exist some relations between them. Especially in Hokuriku and San-in, they are almost parallel each other and directed nearly NW-SE, and we may be able even to predict the probable direction of the maximum pressure of any very shallow earthquake which may occur in this region.

Anyhow, all these facts indicate the persistence of displacements or the stresses producing the earthquakes in the same sense in each individual region, not only in the deep layer but also in the superficial layer of the earth crust.

The mechanisms of the numerous ordinary shallow earthquakes and especially of those of large magnitudes which occur in the Pacific coast of Honshû, have almost not been known accurately, and are left for future investigation.

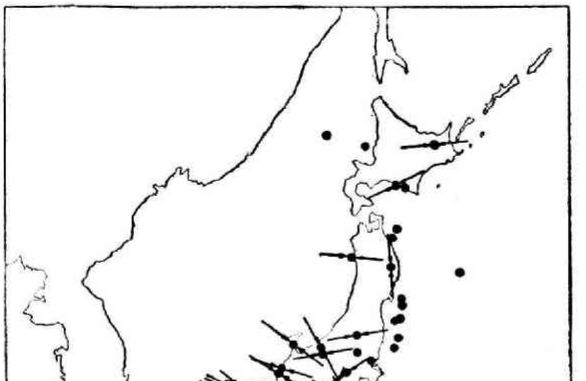

Figure 11. The Direction of the Maximum Pressure for the Very Shallow Earthquakes.

6. The Stresses producing the Earthquakes and Their Relations to Other Geophysical Phenomena

The deep and the intermediate earthquake zones and the region in which numerous shallow earthquakes occur most frequently, are shown in the figure 12. The horizontal components of the maximum pressure producing the deep and the intermediate earthquakes are directed nearly perpendicularly to each earthquake zone respectively, as are shown schematically in the same figure. The positions of the volcanoes ever erupted in the historical time are also entered in the figure. The trend of the active volcanoes, in the sense stated above, is nearly coincident with that of the

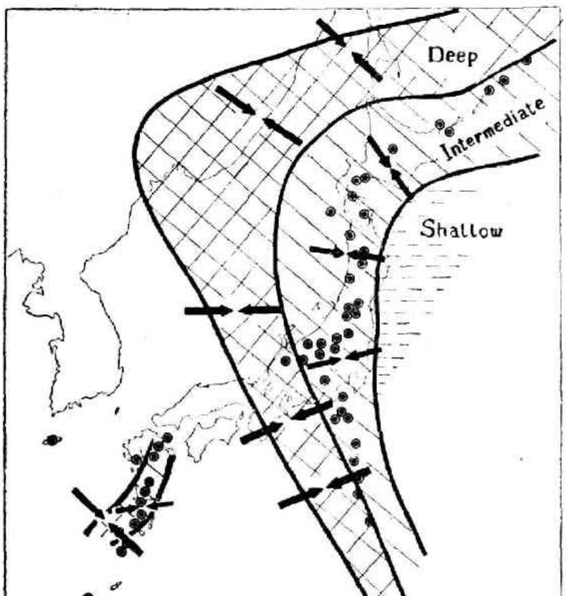

Figure 12. The Deep and the Intermediate Earthquake Zones and the Active Volcanoes.
☷; The Region in which Shallow Earthquakes occur most frequently.
⊙; The Volcanoes ever erupted in the Historical Time.
→←; The Direction of the Horizontal Component of the Maximum Pressure.

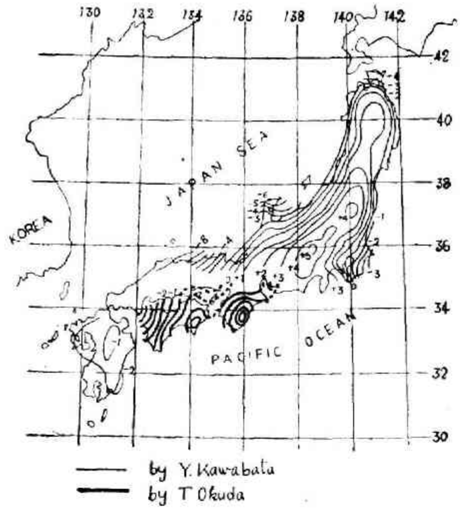

Figure 13. The Geoid in Japan (in meter). (After T. Okuda)

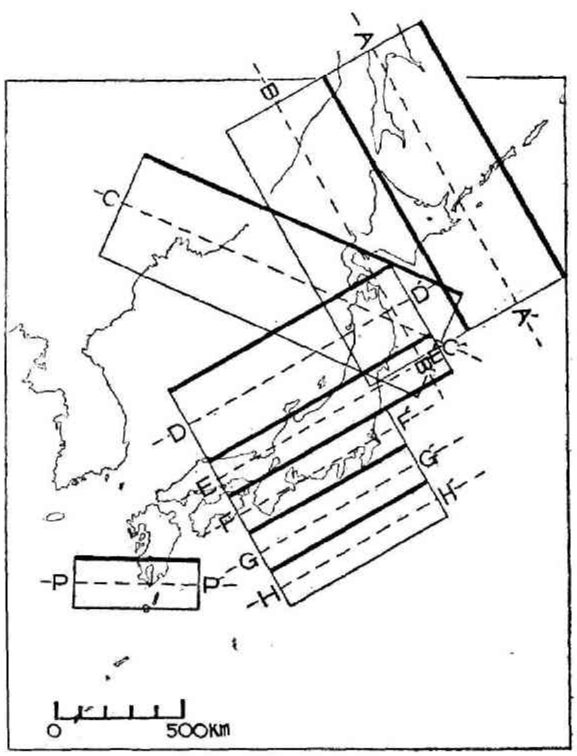

Figure 14. The Positions of the Sections for the Profiles illustrated in the Figure 15.

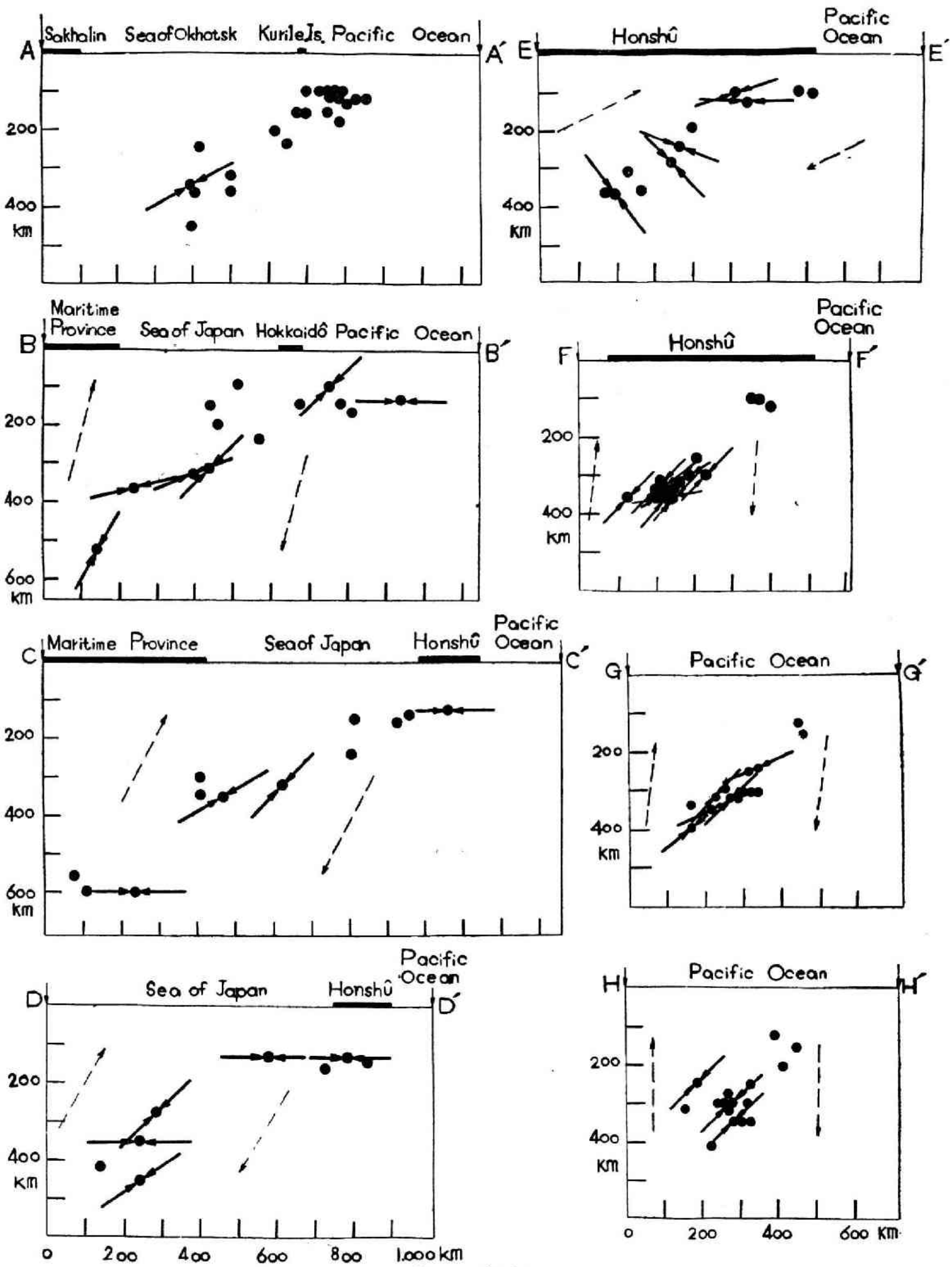
A
Sakhalin
Sea of Okhotsk
Kurile Is.
Pacific Ocean
A′
200
400
km
E
Honshû
Pacific Ocean
E′
200
400
km
B
Maritime Province
Sea of Japan
Hokkaidô
Pacific Ocean
B′
200
400
600
km
F
Honshû
Pacific Ocean
F′
200
400
km
C
Maritime Province
Sea of Japan
Honshû
Pacific Ocean
C′
200
400
600
km
G
Pacific Ocean
G′
200
400
km
D
Sea of Japan
Honshû
Pacific Ocean
D′
200
400
km
0
200
400
600
800
1,000 km
H
Pacific Ocean
H′
200
400
km
0
200
400
600 km

Figure 15 (a).

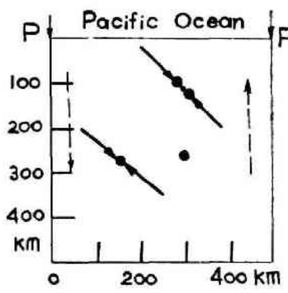

Figure 15 (b).

Figure 15. The Profiles showing the Origins of the Deep and Intermediate Earthquakes, the Directions of the Maximum Pressure and the Probable Shearing Stress. →←; The Maximum Pressure ⇄; Shearing Stress.

intermediate earthquake zone. The form of the geoid in Japan, determined by Y. KAWABATA (1939) and T. OKUDA (1951) is shown in the figure 13. The ridge of the geoid is also nearly coincident with the active volcanic zone.

It may be especially to be noticed that the active volcanic zone as well as the ridge of the geoid are directed nearly perpendicularly to the direction of the horizontal components of the maximum pressure of the stresses producing the deep and the intermediate earthquakes. The relation between the active volcanic zone and the ridge of the geoid and the directions of the maximum pressure of the stresses in the superficial layer of the earth crust producing the very shallow earthquakes, can not be found so evidently as in former case.

Projecting the origins of the deep and the intermediate earthquakes (the figure 15), on the vertical sections A-A′, B-B′, ···, P-P′, shown in the figure 14, respectively, we see that they are restricted nearly on the inclined and curved surface (ABC-A'B'C', the figure 16), which dips toward the Asiatic Continent from the eastern coast of Honshû, the slope being steep in the southeastern part of the surface. Thus it appears likely that an inclined surface or huge "*fault*" extending to a depth of 400 km to 600 km, beneath the outermost margin or the boundary toward the continent of the deep earthquake zone, can exist in the earth crust, and that the origins of the deep and the intermediate earthquakes lie on such surface. Numerous shallow earthquakes occur near where the inclined surface approaches the earth's surface in the eastern coast of Honshû. The dirtribution of the earthquakes as stated here, has been studied by many seismologists, among whom H. HONDA (1934 c), K. WADATI (1934) and B. GUTENBERG and C. F. RICHTER (1949) should be referred to.

The directions of the maximum pressure of the stresses producing the deep and the intermediate earthquakes, and the probable direction of a pair of shearing stresses estimated from them and the figures 7 and 8, though not accurately, are shown in the figure 15. From the figures 15 and 16, it may be seen that the block of the crust deeper than about 100 km from the earth's surface and is beneath and bounded by the inclined and curved surface ABC-A'B'C' seem to be, generally speaking, under shearing stress such that its tendency is directed approximately down-

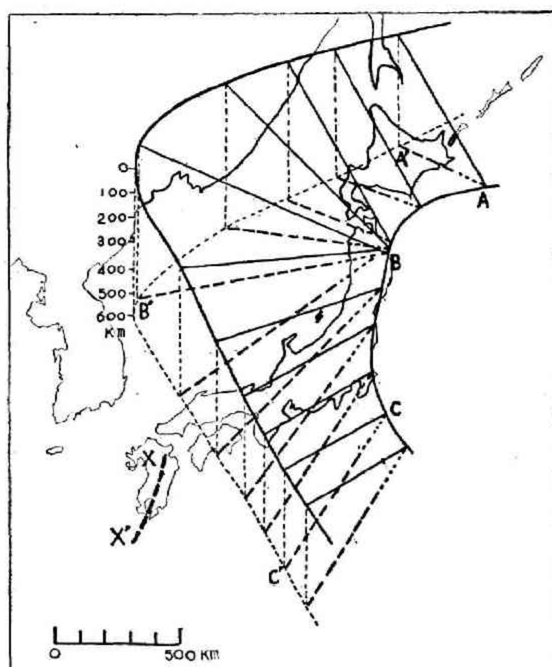

Figure 16. The Inclined Surface near which the Deep and Intermediate Earthquakes occur.

ward and toward the continent, relatively to the block above the surface, which is forced upward and toward the eastern offing of Honshû.

For a few deep and intermediate earthquakes occuring near Kyushû, other than those stated above, the eastern side of the surface (XX', the figure 16) near which they occur, seems to be forced upward relatively to the western side which is forced downward.

7. The Summary

The main results of the present investigation are summarized as follows: ——

i) The distributions and the mechanisms of the deep, the intermediate and the shallow earthquakes occurred in Japan and its vicinity during the period 1927 to 1949, are investigated.

ii) The directions of the horizontal components of the maximum pressure of the stresses producing the deep and the intermediate earthquakes are perpendicular to the deep and the intermediate earthquake zone respectively.

iii) The trends of the zone of the volcanoes which ever erupted in the historical time, and of the ridge of the geoid in Japan, are nearly coincident with that of the intermediate earthquake zone, and are perpendicular to the direction of the horizontal component of the maximum pressure of the stresses producing the deep and the intermediate earthquakes.

iv) Most deep and intermediate earthquakes occur on the inclined and curved surface which slopes downward from the eastern coast of Honshû toward the Asiatic Continent, and extends to a depth of 400 km or to 600 km, beneath the boundary toward the continent of the deep earthquake zone. Numerous shallow earthquakes occur in the eastern coast of Honshû.

v) The block of the crust beneath and bounded by the inclined surface seems to be forced downward and toward the continent relatively to the block above the surface which is forced upward and toward the eastern offing of Honshû.

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