REGIONAL FEATURES IN THE UPPER MANTLE, BASED ON THE RELATION BETWEEN APPARENT POISSON'S RATIO AND THE MECHANICAL STRUCTURE

著者	KAKUTA Toshiki, Institute of Earth Sciences Faculty of Science
journal or publication title	鹿児島大学理学部紀要. 地学・生物学
volume	2
page range	103-125
別言語のタイトル	みかけポアソン比と力学的構造の関係にもとづく上部マントルの地域的特徴
URL	http://hdl.handle.net/10232/00001691

Rep. Fac. Sci., Kagoshima Univ., (Earth Sci., Biol.), No. 2, (1969) p. 103-125.

REGIONAL FEATURES IN THE UPPER MANTLE, BASED ON THE RELATION BETWEEN APPARENT POISSON'S RATIO AND THE MECHANICAL STRUCTURE

By

Toshiki KAKUTA
Institute of Earth Sciences, Faculty of Science,
Kagoshima University

Abstract

It is generally believed that the upper mantle and the crust are heterogeneous and laterally anisotropic. What pattern the heterogeneity or anisotropy in the upper mantle or the crust shows has never been established though many studies have been made.

Spatial distributions of apparent Poisson's ratios near and in Japan are showing rather systematic patterns, which are in good agreement with the patterns of the mechanical structures of the crust obtained by Mogi (1963 b). This is reasonably expected because apparent Poisson's ratio may also be concerned with the state of media.

Although the data are not enough, it can be provisionally said that apparent Poisson's ratio decreases with the increasing of the degree of fracturing. This relation seems to be interpreted physically. So-called Fuji and Kirishima volcanic zones, where anomalously high Poisson's ratios have frequently been stated in connection with the existence of magma chamber, have not relatively high apparent Poisson's ratios. This may show that effects of fracturing on seismic waves are more predominant than those of the existence of magma chamber in these zones.

1. Introduction

It is known that the formula

$$t_s - t_p = \alpha(t_p - t_0) \tag{1}$$

can approximate the observed relation between the arrival time of ***P*** wave, t_p, and the one of ***S*** wave, t_s, in an arbitrary range of epicentral distance, where t_0 is the time at which ***P*** and ***S*** waves have been emitted simultaneously at the focus. α is a constant and can be related to the ratio between apparent velocities of ***P*** wave, $\bar{v}_p$, and ***S*** wave, $\bar{v}_s$, in the relation $\bar{v}_p/\bar{v}_s = 1+\alpha$. Hence, apparent Poisson's ratio can be defined as

$$\bar{\sigma} = \frac{(1+\alpha)^2-2}{2(1+\alpha)^2-2} \tag{2}$$

for the media through which seismic waves have passed.

Strictly speaking, the formula (1) holds only when the media have the same value of Poisson's ratio, while it may be a reasonable expectation that Poisson's ratio varies with the locality and depth in the earth. In order to deal with Poisson's ratio, it may be necessary to determine the velocity distributions of *P* and *S* waves, but it is very laborious to do this iteslf. Apparent Poisson's ratio obtained from observations is thought to be concerned with Poisson's ratio and to express conditions in media in spite of containing the effects of the difference in wave path between *P* and *S* waves. In contrast to determination of velocity distributions, it is a far simpler work to deal with apparent Poisson's ratio, of which accuracy depends only on the one of phase determination.

Yoshiyama (1957) has determined apparent velocity ratios, $\bar{v}_p/\bar{v}_s$, for the earthquakes occurred in Kinki and Shikoku districts, using the data from the network of the Japan Meteorological Agency (JMA). He has said that Poisson's ratio in the crust in the districts is nearly equal to that in America in spite of different wave velocities and inferred from the increasings of apparent velocity ratios for deep earthquakes that Poisson's ratio in the mantle must be higher than that in the crust.

Kamitsuki (1959) and Nishimura *et al.* (1960) have found that crustal Poisson's ratio in the Kyushu district is anomalously high and thought that this may be due to the existence of magma chamber in the crust. They have also used the data from a broad network.

Watanabe and Kuroiso (1967) have compiled the data obtained from the co-operative observations by the Research Group for Ultramicroearthquakes, of which stations spread over the Wakayama district. They have obtained the mean value of $\bar{v}_p/\bar{v}_s$, 1.716 ± 0.021, for 268 earthquakes. The values of $\bar{v}_p/\bar{v}_s$, however, extend over a fairly broad range. And they thought this is not due to observational errors. The network of the Research Group is considerably smaller than that of JMA. Hence, the data from the former network tend to be strongly influenced by local features and concern mainly the crust, while the data from the latter have connection with features of a rather wide scale and, mainly, of the upper mantle.

Kakuta (1968 b) has calculated apparent Poisson's ratios for 50 earthquakes occurred in southwestern Japan. He has recognized the differences in apparent Poisson's ratio among three regions, that is, the region including the Kinki district and the eastern part of Shikoku, the region corresponding to the so-called "Kirishima volcanic zone" and the region of Hyuga-nada. He has thought that these differences must show the regional differences in the upper mantle among these three regions.

This paper relates the regional features in the upper mantle and the crust, mainly based on spatial distributions of apparent Poisson's ratios and the relation of Poisson's ratio to the mechanical structure of media.

Heterogeneity or anisotropy in the upper mantle or the crust is generally believed. However, what kind of heterogeneity or anisotropy exists is not necessarily sure because of lack of data. Apparent Poisson's ratio is obtained with a rather equal accuracy for a comparatively broad area and adequate to compare regional features.

Though it is difficult to determine exactly how observed apparent Poisson's ratio reflects Poisson's ratio of the media, the former may be closely concerned with the latter. On the other hand, Poisson's ratio is largely influenced by the mechanical state of media, and, therefore, distributions of apparent Poisson's ratios can be compared with those of the mechanical structures, such as that obtained by Mogi (1963 b).

The mechanical structure in the upper mantle or the crust has an important meaning for the earthquake prediction because it is closely connected with the pattern of earthquake occurrence. Hence, if the relation between apparent Poisson's ratio and the mechanical structure can be established, the study on the distribution of apparent Poisson's ratio must also be useful for the earthquake prediction.

2. Spatial distributions of apparent Poisson's ratios

The earthquakes, of which focal depths are shallower than 160 km and which are observed at numerous observatories located within 1000 km of their epicenters, are selected from the Seismological Bulletin published by JMA, because apparent Poisson's ratio is utilized as an information on the upper mantle and the crust. Earthquakes occurred in Japan and adjacent area from 1961 through 1967 are used.

A linear relation of (1) for each earthquake is assumed and the method of least squares is carried on to determine coefficient α, from which apparent Poisson's ratio $\bar{\sigma}$ is calculated by using (2). Velocity ratios with their probable errors and apparent Poisson's ratios obtained in this way are tabulated in Table 1. Explanations on the regions in the table will be offered later.

Apparent Poisson's ratios in Table 1 are also shown in Fig. 1 and Fig. 3, classified into 8 groups according to their magnitude and plotted to their respective epicenters. For the earthquakes in Fig. 1 their focal depths are shown in Fig. 2. The earthquakes in Fig. 3 are almost the same used by Kakuta (1968 a). Values of apparent Poisson's ratio in these figures are medians for respective earthquakes and observational errors are not taken into considerations. However, it will be possible to diminish effects of errors by increasing the number of earthquakes.

In Fig. 4, apparent Poisson's ratio as a function of focal depth is shown for three regions in southwestern Japan. Strictly, it will be necessary to determine the velocity distributions of ***P*** and ***S*** waves in order to investigate its relation

Table 1. Parameters of earthquakes, apparent velocity ratios with their probable errors, and apparent Poisson's ratios. N is the total number of earthquakes in a region.

Region I N=111

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$		$\bar{\sigma}$
		h.	m.	s.			km				
1961	I 23	13	48	18.1	146°24′E	43°17′N	120	(5.6)	1.748	±0.008	0.257
	II 13	6	53	45.2	147 53	43 13	80	(6.3)	1.742	0.009	0.246
	II 13	8	26	44.2	147 14	42 55	20	6.3	1.719	0.007	0.244
	II 14	1	27	27.2	147 47	42 59	60	6.1	1.763	0.008	0.263
	II 15	19	45	14.9	147 56	43 16	60	6.3	1.704	0.008	0.237
	II 16	22	54	53.3	147 41	43 12	40	(5.3)	1.713	0.014	0.241
	IV 20	1	12	34.3	148 13	43 21	80	(6.0)	1.746	0.008	0.256
	VII 29	0	19	36.3	147 10	43 14	60	(5.3)	1.759	0.013	0.261
	VIII 12	0	51	31.9	145 34	42 51	80	(6.6)	1.767	0.004	0.264
	VIII 12	8	33	49.6	145 34	42 49	60	5.8	1.761	0.005	0.262
	VIII 18	6	16	32.9	149 48	45 24	120	(6.4)	1.733	0.007	0.250
	VIII 19	11	42	56.4	145 33	42 53	100		1.752	0.008	0.258
	VIII 25	7	40	52.0	145 40	42 42	40		1.766	0.005	0.264
	VIII 28	1	22	9.7	154 48	46 02	100		1.773	0.013	0.266
	IX 30	1	50	32.2	145 51	42 44	60	5.6	1.760	0.006	0.261
	XI 15	16	17	9.9	145 34	42 39	60	6.9	1.762	0.003	0.262
	XII 13	8	6	18.9	146 40	42 56	80		1.775	0.004	0.267
	XII 24	15	50	53.3	144 29	43 05	120		1.751	0.005	0.258
1962	I 9	21	40	46.2	145 21	42 39	60	6.0	1.750	0.006	0.257
	II 21	1	5	41.6	145 13	42 46	80	(6.2)	1.744	0.005	0.255
	IV 23	14	58	11.8	143 55	42 14	60	7.0	1.771	0.004	0.266
	IV 30	11	26	21.0	141 08	38 44	0	6.5	1.772	0.004	0.266
	V 8	2	39	38.6	148 35	45 10	120	(6.1)	1.679	0.010	0.225
	VII 18	2	20	22.3	145 10	42 38	60	5.9	1.753	0.004	0.259
	IX 24	23	38	19.4	145 46	42 31	40	5.6	1.700	0.010	0.235
	XI 10	10	33	17.7	147 35	43 11	100	(6.2)	1.742	0.005	0.254
	XII 21	18	33	18.5	142 30	42 01	60	6.3	1.782	0.005	0.270
1963	II 11	6	35	54.4	147 58	43 49	100		1.766	0.008	0.264
	III 27	4	47	43.9	147 41	43 43	120		1.784	0.005	0.271
	III 31	1	52	0.2	148 10	43 14	60	6.0	1.733	0.006	0.250
	V 25	17	41	8.0	144 42	42 27	60	5.3	1.760	0.005	0.261
	X 12	20	26	58.1	148 54	43 53	0	6.3	1.733	0.010	0.250
	X 14	13	6	6.4	149 43	43 56	40	5.9	1.747	0.006	0.256
	X 20	20	52	25.8	149 25	43 36	0	5.9	1.768	0.006	0.265
	XI 11	2	17	44.2	149 04	43 36	40	6.0	1.712	0.007	0.241
	XI 16	6	6	34.4	149 04	43 32	60	6.2	1.764	0.007	0.263
	XII 30	22	29	31.7	150 17	44 11	20	5.8	1.713	0.023	0.241
1964	I 9	11	59	23.5	141 58	41 30	40	5.3	1.744	0.005	0.255
	I 10	3	31	52.4	151 24	44 46	120		1.788	0.006	0.272
	I 10	13	50	53.8	142 51	41 42	40	6.1	1.786	0.005	0.271
	II 7	21	58	51.8	142 53	39 47	40	5.7	1.820	0.010	0.283
	III 1	0	20	7.4	142 11	34 41	60	5.5	1.772	0.004	0.266
	III 6	11	36	33.8	142 31	40 55	20	5.0	1.793	0.025	0.274
	III 16	17	44	31.7	147 20	44 13	160		1.736	0.006	0.252
	III 27	4	37	21.3	143 41	39 04	20	5.2	1.736	0.016	0.251
	IV 16	10	4	24.9	143 07	36 56	0	6.0	1.810	0.009	0.280
	V 3	1	11	0.4	150 24	44 14	0	6.1	1.691	0.008	0.231
	V 3	10	54	32.2	142 15	40 08	40	5.0	1.748	0.007	0.256
	V 5	17	1	49.0	150 37	44 44	60	5.6	1.759	0.008	0.261
	V 24	19	31	19.2	141 00	34 20	0	5.7	1.736	0.012	0.251
	V 31	2	20	36.2	141 59	41 08	80		1.795	0.008	0.275
	V 31	9	40	35.7	147 14	43 16	60	6.7	1.769	0.004	0.265
	VI 21	1	59	9.5	142 25	40 08	40	5.0	1.827	0.010	0.286
	VI 23	10	26	34.9	146 28	42 59	80		1.804	0.003	0.278
	VII 6	8	35	58.7	149 45	43 45	60	6.0	1.764	0.008	0.263
	VII 9	21	2	9.6	141 07	34 09	80		1.767	0.007	0.264
	VII 24	22	25	21.6	153 53	45 49	80		1.775	0.007	0.267
	VII 25	2	2	55.3	153 13	45 24	0	6.0	1.762	0.008	0.262
	VIII 17	23	54	3.6	143 10	42 15	60	5.1	1.766	0.005	0.264

	IX 29	1	25	53.6	141 27	34 10	40	5.0	1.696	0.011	0.233
	X 5	12	35	8.2	143 12	42 02	40	5.3	1.728	0.005	0.248
	X 16	17	18	23.8	149 58	43 23	60	6.1	1.747	0.007	0.256
	XI 3	11	5	39.3	140 37	34 48	100		1.758	0.005	0.260
	XI 6	18	53	22.9	148 57	43 45	40	5.7	1.728	0.008	0.248
	XI 13	4	57	34.8	142 43	41 59	80		1.742	0.006	0.254
	XI 28	21	50	59.3	141 21	35 23	40	5.1	1.726	0.020	0.247
	XII 17	11	33	21.1	142 12	35 28	60	4.9	1.774	0.007	0.267
	XII 29	12	30	42.8	144 01	37 58	80		1.741	0.009	0.254
1965	I 13	17	40	53.5	141 08	38 43	0	5.2	1.728	0.010	0.248
	I 24	6	51	11.8	141 04	36 35	60	5.2	1.717	0.013	0.243
	II 2	13	13	37.7	142 22	37 38	40	5.0	1.796	0.016	0.275
	II 16	21	24	6.9	142 11	38 52	60	5.7	1.811	0.006	0.280
	III 17	1	46	13.7	143 12	40 42	40	6.4	1.859	0.013	0.296
	III 29	19	47	35.7	143 09	40 39	40	6.4	1.933	0.005	0.317
	III 31	0	59	32.7	143 04	40 41	40	5.4	1.777	0.012	0.268
	IV 5	22	52	16.5	150 24	43 45	60	5.7	1.754	0.007	0.259
	VI 11	12	33	44.2	148 48	43 39	0	6.4	1.771	0.007	0.266
	VI 13	16	6	10.2	143 48	31 35	20	6.0	1.793	0.006	0.274
	IX 1	4	25	51.1	141 22	37 17	60	5.5	1.675	0.016	0.223
	IX 18	0	18	34.1	141 31	36 14	40	5.7	1.827	0.007	0.286
	IX 25	23	37	10.2	143 43	39 30	60	5.6	1.805	0.018	0.278
	IX 25	23	42	23.1	143 43	39 30	40	5.5	1.847	0.013	0.292
	IX 25	23	53	31.4	143 30	39 33	40	5.6	1.758	0.010	0.260
	X 9	22	23	39.2	141 26	34 21	80		1.781	0.009	0.269
	X 26	7	34	24.7	145 31	43 44	160		1.756	0.009	0.260
	XII 27	13	7	18.5	142 33	36 12	60	5.1	1.726	0.016	0.247
1966	II 18	9	27	51.8	140 39	36 27	60	5.1	1.821	0.010	0.284
	III 14	15	38	3.8	141 05	36 36	40	5.0	1.698	0.013	0.234
	IV 16	19	13	20.3	142 04	34 48	60	5.2	1.842	0.022	0.291
	IV 22	0	45	18.3	142 17	35 30	40	5.8	1.887	0.014	0.304
	VI 5	8	48	29.8	152 01	44 57	20	6.0	1.758	0.011	0.261
	VIII 19	21	46	20.9	141 58	36 17	40	5.7	1.790	0.009	0.273
	IX 18	9	35	19.4	140 46	37 05	80		1.769	0.009	0.265
	XI 1	16	1	1.0	143 26	43 06	120		1.786	0.004	0.271
	XI 12	21	49	40.8	144 26	41 37	40	5.9	1.781	0.008	0.270
	XI 19	14	19	53.2	141 35	37 27	60	5.3	1.807	0.012	0.279
	XII 27	10	22	15.8	141 12	37 04	40	5.5	1.800	0.008	0.276
1967	I 6	9	4	3.5	143 29	41 48	50	5.9	1.728	0.009	0.248
	I 17	20	59	30.4	142 05	38 15	30	6.3	1.814	0.006	0.281
	I 24	12	5	38.3	142 08	41 26	50	5.7	1.802	0.005	0.277
	IV 30	7	2	7.8	140 56	35 50	30	5.1	1.771	0.010	0.266
	V 18	20	22	26.2	145 12	41 44	40	5.4	1.773	0.009	0.266
	VII 9	4	18	19.1	143 54	37 43	80		1.743	0.012	0.254
	VIII 12	13	30	40.2	142 03	38 17	70		1.761	0.007	0.262
	VIII 17	23	31	54.8	142 43	39 17	60	5.2	1.773	0.007	0.266
	IX 15	9	28	36.0	140 55	35 36	40	5.6	1.840	0.014	0.290
	IX 19	12	28	54.0	141 53	37 19	40	5.0	1.744	0.012	0.255
	IX 19	19	56	7.6	145 33	42 46	90		1.822	0.005	0.284
	XI 2	4	17	21.1	141 34	37 07	50	5.0	1.807	0.011	0.279
	XI 4	22	26	45.0	141 54	37 17	50	5.8	1.820	0.007	0.283
	XI 19	21	6	59.2	141 13	36 26	50	6.0	1.812	0.006	0.281

Region II N=21

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$		$\bar{\sigma}$
		h.	m.	s.			km				
1963	II 21	11	33	34.5	139°38′E	33°21′N	160		1.752	±0.007	0.258
	V 25	11	37	37.3	138 44	33 48	40	5.1	1.701	0.012	0.236
	VI 3	16	35	50.2	138 46	34 03	40	5.9	1.754	0.010	0.259
1964	IV 23	10	51	8.4	138 27	32 14	40	5.2	1.729	0.015	0.248
	IX 20	4	7	29.3	138 37	33 34	40	5.0	1.643	0.014	0.206
	XI 3	20	9	32.6	138 48	34 38	0	5.4	1.745	0.006	0.255
	XII 9	2	49	40.0	139 18	34 35	0	5.8	1.717	0.010	0.243

1965	I 6 5 45 13.5	139 17 34 38	20	5.1	1.775 0.010	0.267
	I 27 8 47 36.1	139 46 36 01	80		1.754 0.007	0.259
	IV 13 0 50 37.9	139 55 35 59	40	5.1	1.720 0.013	0.244
	VIII 3 17 30 38.4	139 18 34 16	0	5.0	1.766 0.016	0.264
1966	V 15 1 59 47.7	139 00 34 05	20	5.4	1.751 0.008	0.258
	V 15 2 3 53.1	139 00 34 04	20	5.5	1.712 0.010	0.241
	VII 14 15 18 40.7	140 23 35 13	40	5.1	1.771 0.009	0.266
	VIII 29 5 3 30.7	139 54 35 25	80		1.738 0.012	0.252
	X 28 22 20 28.1	140 13 35 45	60	5.0	1.701 0.007	0.236
1967	III 19 2 49 48.3	140 04 36 16	80		1.780 0.007	0.269
	III 21 6 54 49.0	139 50 36 09	50	5.1	1.756 0.017	0.260
	IV 6 15 17 26.9	139 09 34 13	10	5.3	1.809 0.010	0.280
	IV 6 17 49 36.2	139 10 34 19	0	5.2	1.786 0.007	0.271
	IV 7 8 28 49.9	139 09 34 15	10	5.2	1.809 0.010	0.280

Region III N=16

	Origin time (J. M. T.)	Epicenter	Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
	h. m. s.		km			
1961	V 7 21 19 58.5	134°30′E 35°02′N	20	5.2	1.711±0.016	0.240
	IX 1 17 20 53.5	135 01 53 51	0	4.5	1.716 0.020	0.242
	X 15 0 8 8.8	134 29 35 02	40	4.6	1.720 0.007	0.245
1962	XII 7 9 5 12.1	135 21 33 39	20	4.7	1.721 0.016	0.245
1963	I 9 0 14 17.6	134 43 33 34	20	4.4	1.733 0.020	0.250
	VII 30 17 27 50.7	134 59 33 50	20	5.2	2.117 0.020	0.356
1964	II 4 6 4 6.9	136 34 34 10	60	5.3	1.724 0.008	0.246
	IV 19 4 48 16.2	134 40 34 22	20	4.4	1.690 0.015	0.230
	VIII 2 20 20 44.5	135 13 33 54	0	4.4	1.670 0.008	0.220
1965	I 21 11 41 4.4	136 19 33 44	20	5.0	1.715 0.009	0.242
	VII 20 13 4 4.7	135 07 34 38	20	4.5	1.674 0.013	0.222
1966	I 11 23 6 15.0	137 14 33 44	20	5.4	1.666 0.009	0.218
	I 11 23 16 27.4	137 17 33 36	20	5.9	1.730 0.009	0.249
	III 10 12 48 40.8	135 44 35 10	20	4.6	1.732 0.027	0.250
	VI 29 21 21 56.8	135 24 34 47	0	4.7	1.730 0.015	0.249
	X 4 0 35 51.4	134 03 33 56	0	4.6	1.680	0.225

Region IV N=3

	Origin time (J. M. T.)	Epicenter	Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
	h. m. s.		km			
1964	XI 9 2 56 25.9	133°22′E 34°07′N	20	5.0	1.834±0.026	0.288
1967	I 1 3 3 10.4	133 19 33 30	10	4.7	1.904 0.027	0.309
	I 11 2 49 32.1	133 48 33 52	10	4.4	1.767 0.019	0.264

Region V N=7

	Origin time (J. M. T.)	Epicenter	Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
	h. m. s.		km			
1961	II 27 3 10 48.1	131°51′E 31°36′N	40	7.0	1.806±0.015	0.279
	VIII 11 13 27 15.0	132 07 31 40	0	5.2	1.779 0.036	0.269
	VIII 11 15 8 13.6	132 11 31 41	40	5.4	1.791 0.014	0.273
	VIII 15 7 4 55.5	131 50 31 27	0	5.2	1.769 0.026	0.265
	XI 27 14 57 10.7	131 33 31 18	40	6.0	1.833 0.016	0.288
1962	X 15 0 8 57.2	131 46 31 41	0	5.4	1.814 0.038	0.281
1965	IX 22 21 49 41.7	131 58 31 52	0	5.2	1.772 0.008	0.266

Region VI N=3

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
		h.	m.	s.			km			
1961	VII 19	15	33	20.2	131°50′E	29°44′N	60		1.711±0.017	0.240
	VII 20	18	2	42.1	131 49	29 50	60		1.708 0.007	0.239
1964	XII 24	4	47	59.2	131 14	30 14	40	5.1	1.715 0.015	0.242

Region VII N=11

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
		h.	m.	s.			km			
1961	III 16	7	16	32.2	130°42′E	32°00′N	0	5.5	1.754±0.019	0.259
	III 18	15	22	39.8	130 44	31 59	0		1.755 0.013	0.259
1962	IV 23	4	15	32.0	130 54	32 10	160		1.784 0.011	0.271
	VI 28	13	13	53.7	131 05	31 15	0	5.0	1.736 0.018	0.251
	VII 31	14	9	14.9	132 25	32 31	0	5.4	1.737 0.012	0.252
	IX 25	11	37	13.8	131 44	33 54	0	4.9	1.753 0.012	0.259
1963	I 9	0	46	44.2	130 32	31 11	160		1.744 0.010	0.255
1964	IV 12	21	14	51.1	132 06	33 30	80		1.730 0.009	0.249
	VIII 6	11	33	35.7	130 16	30 53	160		1.761 0.011	0.262
	XI 14	12	56	6.4	132 07	33 26	60	5.8	1.743 0.012	0.254
1966	XII 5	16	23	4.0	131 49	32 20	0	5.0	1.741 0.012	0.254

Reigon VIII N=4

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
		h.	m.	s.			km			
1964	IV 29	11	11	34.3	129°01′E	32°07′N	20		1.671±0.008	0.221
	VI 24	21	56	19.1	129 03	32 10	0	5.2	2.056 0.086	0.345
1965	XII 8	14	25	12.2	130 36	32 33	20	4.8	1.876 0.021	0.301
1966	XI 12	21	1	41.6	130 16	33 04	20	5.5	1.804 0.011	0.278

Region IX N=4

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
		h.	m.	s.			km			
1963	III 31	21	26	5.3	132°24′E	35°08′N	20	5.1	1.719±0.022	0.244
	IV 1	0	2	17.9	132 26	35 06	0	5.0	1.796 0.023	0.275
1965	II 26	15	42	53.4	132 44	35 16	20	5.1	1.688 0.011	0.230
1966	VIII 9	8	10	16.4	132 42	35 07	20	4.9	1.712 0.010	0.241

Region X N=19

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$	$\bar{\sigma}$
		h.	m.	s.			km			
1961	VIII 19	14	33	29.9	136°46′E	36°01′N	0		1.792±0.004	0.264
	VIII 19	17	7	15.6	136 35	36 00	0	5.2	1.741 0.015	0.254
1962	III 13	15	7	42.4	139 06	37 03	0	5.1	1.892 0.010	0.306
1963	II 9	12	53	0.8	137 42	36 22	0	5.5	1.685 0.013	0.228
	III 27	6	34	35.9	135 46	35 47	0	6.9	1.850 0.006	0.293
	III 27	12	27	47.1	135 48	35 48	0	5.2	1.841 0.012	0.290

	III 27	15	49	21.6	135 47	35 47	20	5,3	1.906	0.020	0.310
	III 28	1	13	14.0	135 47	35 44	0	5.2	1.763	0.018	0.263
	IV 21	22	2	37.4	137 38	35 15	20	4.9	1.697	0.007	0.234
1964	XI 12	22	57	54.2	139 13	36 37	0	4.9	1.869	0.010	0.299
1965	III 6	1	21	47.7	135 57	35 30	0	4.7	1.748	0.018	0.257
	IV 20	8	41	58.4	138 18	34 53	20	6.1	1.816	0.014	0.282
1966	I 9	7	39	17.6	138 33	37 09	0	5.2	1.782	0.012	0.270
	V 26	7	49	43.7	136 30	35 21	20	5.1	1.826	0.011	0.286
1967	II 3	17	17	1.5	138 04	36 26	0	5.4	1.836	0.010	0.289
	III 2	3	39	53.9	138 18	36 30	0	5.1	1.776	0.009	0.267
	V 5	8	25	33.4	138 03	36 24	10	5.2	1.784	0.008	0.271
	IX 14	19	38	32.3	138 09	36 26	10	5.1	1.800	0.012	0.277
	X 14	4	48	45.2	138 12	36 32	10	5.3	1.800	0.010	0.277

Region XI N=14

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$		$\bar{\sigma}$
		h.	m.	s.			km				
1964	V 7	16	58	7.7	139°00′E	40°20′N	0	6.9	1.767±	0.010	0.264
	V 8	5	12	43.2	139 05	40 27	0	6.5	1.751	0.008	0.258
	VI 16	13	1	39.9	139 11	38 21	40	7.5	1.816	0.006	0.282
	VI 16	16	14	57.1	139 19	38 22	20	6.1	1.732	0.008	0.250
	VI 18	0	10	43.5	139 13	38 40	40	5.1	1.706	0.013	0.238
	VI 19	19	5	32.4	139 29	38 45	0	5.5	1.806	0.008	0.278
	VII 3	17	16	31.3	139 08	38 06	20	5.0	1.754	0.019	0.259
	VII 12	10	45	24.1	139 19	38 31	0	6.0	1.808	0.006	0.279
	XI 27	22	47	39.4	138 17	38 02	40	5.8	1.749	0.007	0.257
	XII 11	0	11	3.0	138 56	40 25	40	6.3	1.761	0.010	0.262
	XII 11	8	30	45.1	138 48	40 30	40	5.3	1.770	0.010	0.265
1966	I 20	10	44	45.1	138 07	37 53	0	5.3	1.701	0.011	0.236
	XII 2	3	56	25.8	140 05	41 27	160		1.774	0.005	0.267
	XI 4	23	30	34.8	144 16	43 29	20	6.5	1.842	0.006	0.279

Another regions N=2

	Origin time (J. M. T.)				Epicenter		Depth	M	$\bar{v}_p/\bar{v}_s$		$\bar{\sigma}$
		h.	m.	s.			km				
1963	VI 20	9	55	59.2	144°46′E	36°17′N	100		1.763±	0.012	0.263
1967	V 15	11	27	33.7	141 45	32 33	50	5.4	1.630	0.018	0.198

with depth. The depth penetrated with seismic rays arriving at some epicentral distance is concerned with the focal depth, and, therefore, it may be possible to utilize the focal depth as a parameter concerning depth. Standing on this point of view, we use the focal depth instead of the real depth in the following.

For the three regions in southwestern Japan, variations of apparent Poisson's ratio with the locality seems to be much larger than with the depth. In the case when Poisson's ratio in the mantle is different from that in the crust, apparent Poisson's ratio varies with the inclination of the Mohorovicic discontinuity. Differences in mean apparent Poisson's ratio among these three regions are, however, too large to be explained only on that reason. As the apparent Poisson's ratio dealt with in this paper is concerned mainly with the upper mantle, it may be reasonable to say that regional differences in the upper mantle explain differences in apparent Poisson's ratio.

Let us investigate Figs. 1 and 3, expecting regional differences in apparent Poisson's ratio.

If regularities in distributions of apparent Poisson's ratio in Fig. 1 and the focal depth in Fig. 2 are taken into consideration, some regions contoured with broken lines are separated as shown in Fig. 1. The region in Fig. 3 seems not to be separated any more and seems to belong to the same region as the one from off the south-east coast of Hokkaido to off the south coast of Chiba Prefecture. The separated regions are as follows:

Region I: the region from off the east coast of Hokkaido to off the south coast of Chiba Prefecture through off the east coast of Iwate Prefecture.

Region II: the region corresponding to the so-called "Fuji volcanic zone".

Region III: the Kinki district and the eastern part of Shikoku.

Region IV: the western part of Shikoku.

Region V: Hyuga-nada.

Region VI: the region off the south-east coast of Yakushima Island.

Region VII: the region corresponding to the so-called "Kirishima volcanic zone".

Region VIII: the region off the west coast and the northeastern part of Kyushu.

Region IX: the San-in district.

Region X: the region from the Bay of Wakasa through the Chubu district.

Region XI: the region from the northwestern part of Japan through the northern part of Hokkaido.

First, the region I is noticed. Earthquakes having higher apparent Poisson's ratio and those having lower one coexist in this region while regional differences in apparent Poisson's ratio are distinct in southwestern Japan. The main reason why regional differences become clear in southwestern Japan is thought that hypocenters are restricted in relatively narrow zones. On the other hand, zones of earthquakes occurring are comparatively broad in the region I. Therefore, it will be necessary to investigate the relation of apparent Poisson's ratio with depth in this region.

The relations between apparent Poisson's ratio and the focal depth are shown in Figs. 5 and 6, which exhibit the data for the region from off the east coast of Aomori Prefecture to off the south coast of Chiba Prefecture and the data for the region in Fig. 3 respectively. Because of scattered data, distinct relations of apparent Poisson's ratio with depth do not seem to be found out only from these figures. Scattering of data may be probably due to broadness of the region dealt with, errors in determinations of focal depths, etc., in addition to observational errors.

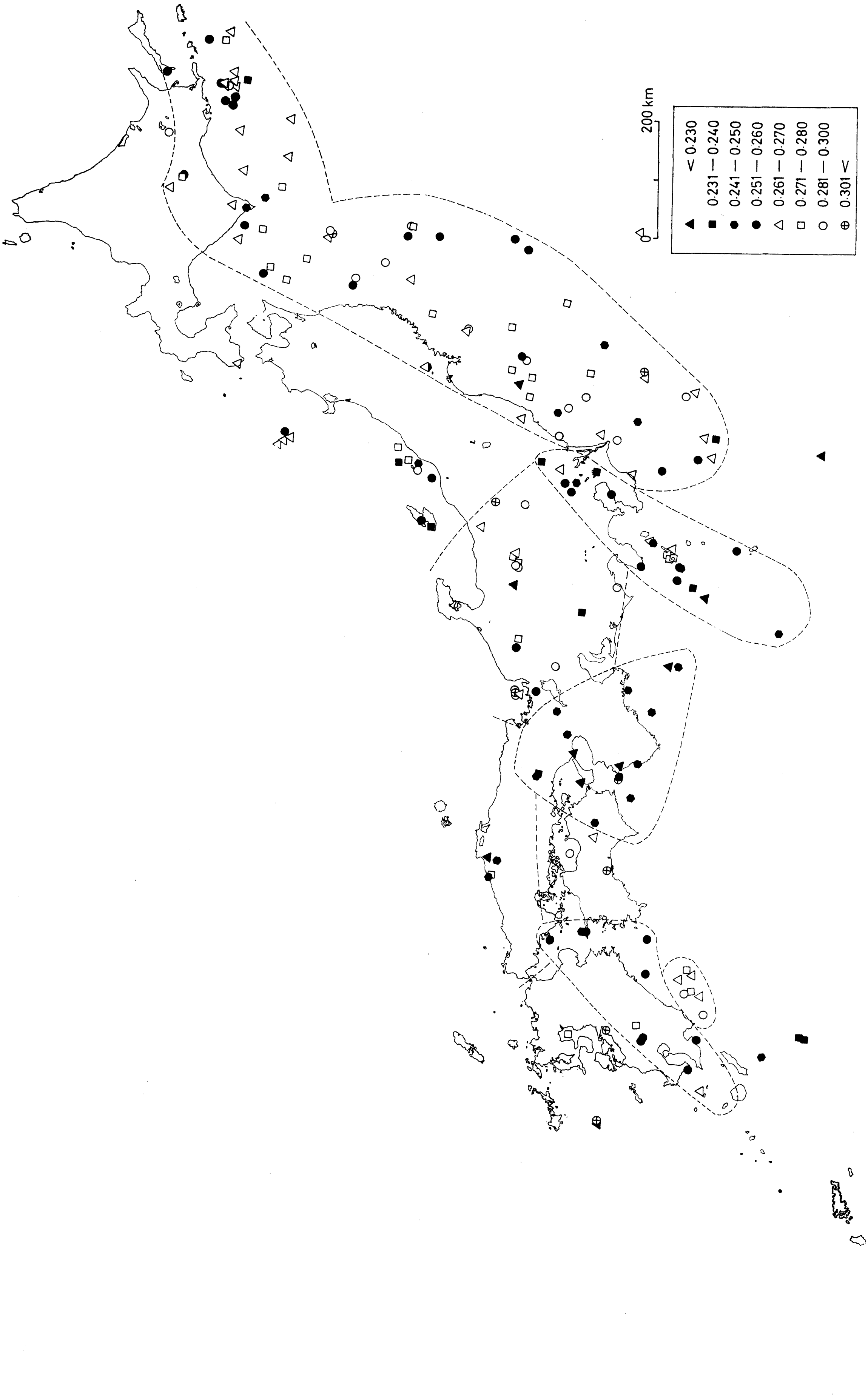

Fig. 1. Geographycal distributions of apparent Poisson's ratios plotted to respective epicenters. Broken lines indicate boundaries of blocks.

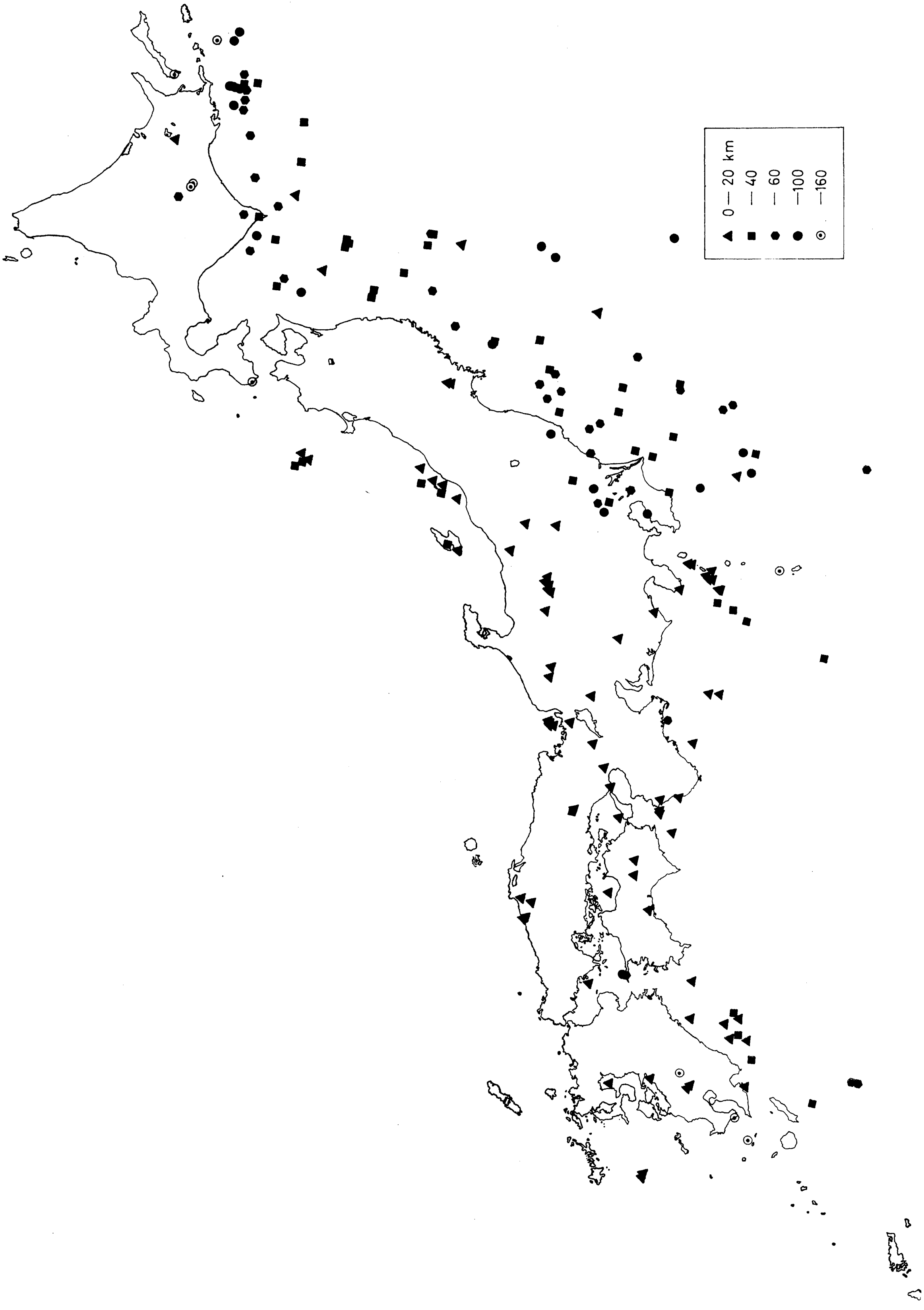

Fig. 2. Geographycal distributions of focal depths of earthquakes corresponding to those used in Fig. 1.

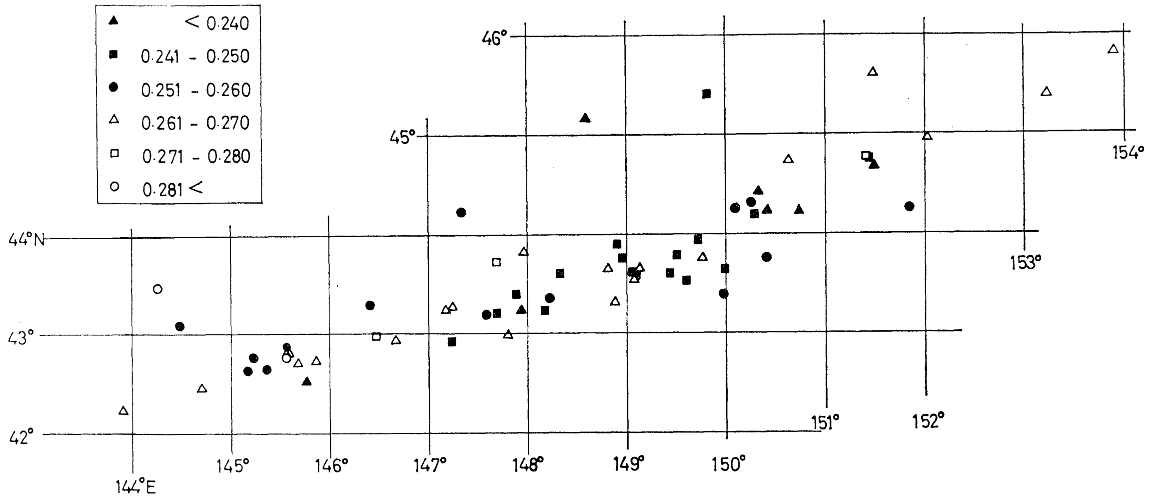

Fig. 3. Apparent Poisson's ratios plotted to respective epicenters of earthquakes in the region from off the southeast coast through off the east coast of Hokkaido.

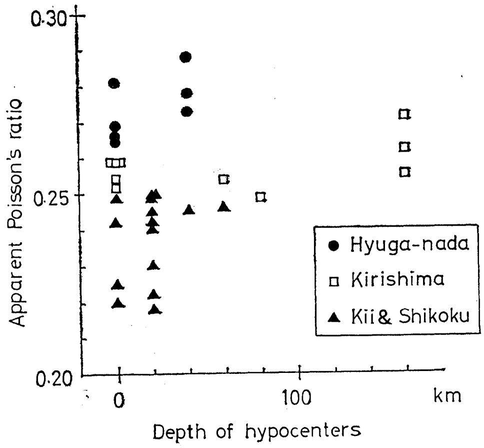

Fig. 4. Apparent Poisson's ratio as a function of focal depth for earthquakes in southwestern Japan.

Kakuta (1968 a) has studied S travel times from the earthquakes having occurred off the southeast and east coast of Hokkaido, and found that the epicentral distance Δ_c at which S travel times break out discontinuously relates to the focal depth. He has thought it a phenomenon due to the low velocity layer in the upper mantle. Δ_c as a function of focal depth is shown in Fig. 7 (a) with a theoretical curve based on the model of S wave velocity distribution inserted above. This model is the one after Kakuta (1968 a).

If the parameter concerning depth is removed out from the relation of Δ_c with depth and the relation of apparent Poisson's ratio with depth, it may be possible to take away the effect due to errors in determinations of focal depth by making a new relation between Δ_c and apparent Poisson's ratio. The new relation is shown in Fig. 7 (b). A broken line in the figure is an expected lower limit of Δ_c

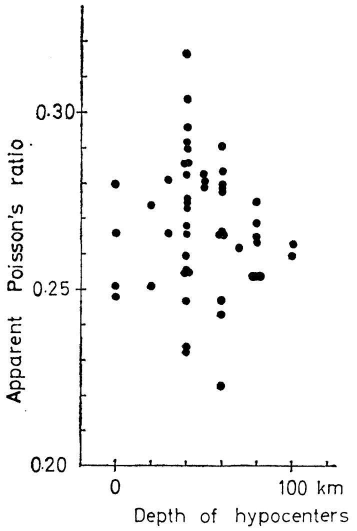

Fig. 5. Apparent Poisson's ratio as a function of focal depth for earthquakes in the region from off the east coast of Aomori Prefecture to off the south coast of Chiba Prefecture.

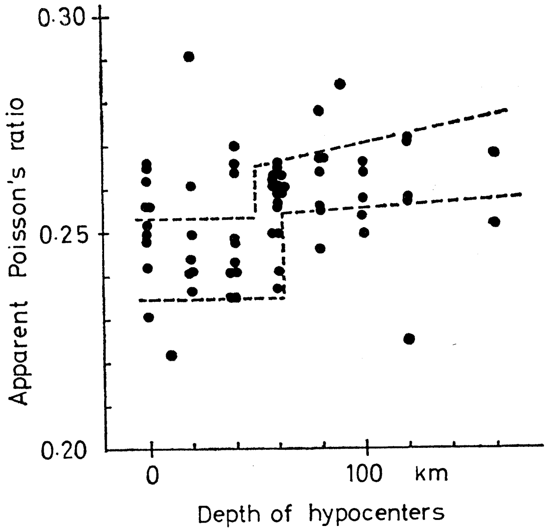

Fig. 6. Apparent Poisson's ratio as a function of focal depth for earthquakes used in Fig. 3.

as a function of $\bar{\sigma}$. In these figures, a closed circle corresponds to Δ_c obtained as a point and open circles combined with a line indicate Δ_c obtained as a range.

As seen in Fig. 7 (b), Δ_c decreases suddenly in the neibourhood of $\bar{\sigma}=0.265$. According to Kakuta (1968 a), Δ_c has its minimum when the earthquake has occurred at the top of the low velocity layer, which lies at the depth between 40 and 60 km in the region. If the data in Fig. 6 are reexamined with thinking of Fig. 7 (b) apparent Poisson's ratio as a function of focal depth is estimated as shown in Fig. 6 with the region enclosed with two broken lines. Though there are no data of Δ_c corresponding to Fig. 5, it will not be unreasonable that a similar

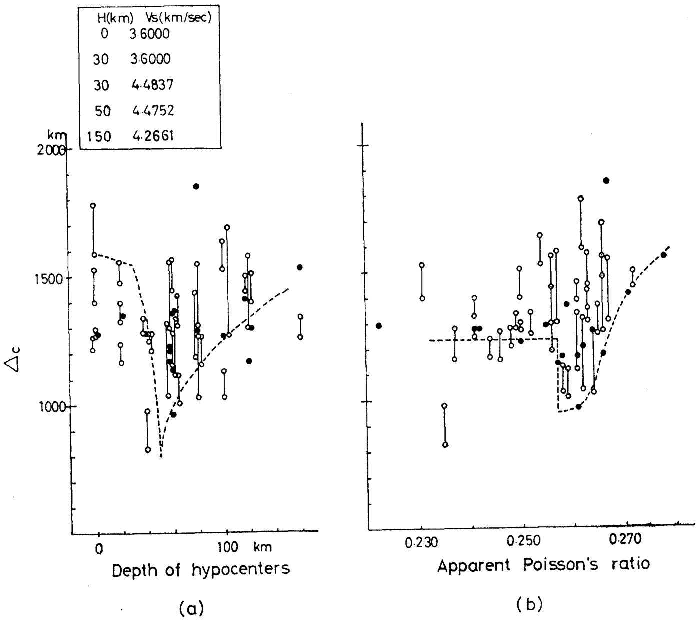

Fig. 7. (a) The relation of critical distance Δ_c to focal depth (reproduced after Kakuta (1968 a)). (b) The relation between critical distance and apparent Poisson's ratio. These data are ones for earthquakes in Fig. 3.

relation to Fig. 6 holds in the case of Fig. 5 because of analogous features of distributions of apparent Poisson's ratio. The depth at which Poisson's ratio increases abruptly seems, however, to be shallower than that in the region corresponding to Fig. 6 and lie between 20 and 40 km in this region.

If the variation of apparent Poisson's ratio with depth is disregarded and the normal distribution is assumed for the region I, the mean value of $\bar{\sigma}$ with its confidence interval can be obtained. In the case of the confidence coefficient 0.95, it is 0.263 ± 0.003.

Next, the regions II and VII are noticeable. In the region II, the mean apparent Poisson's ratio with its 95% confidence interval is 0.251 ± 0.008, except shallow earthquakes occurred near Kozushima Island in April of 1967. It is 0.256 ± 0.004 in the region VII. These regions correspond to the so-called "volcanic zones". And frequently these regions are thought to be concerned with anomalously high Poisson's ratio (Nishimura *et al.* (1960)). As there are few data in another volcanic zones, more detail discussions about them must be postponed to the future. It is, however, interesting that values of apparent Poisson's ratios are not relatively high in these volcanic zones.

It is remarkable that values of apparent Poisson's ratios near Matsushiro and Kozushima Island, where swarms of earthquakes have frequently occurred, and in Wakasa Bay are relatively high. If the normal distribution is assumed in spite of a few data, the mean values of $\bar{\sigma}$ with the 95 % confidence interval are 0.276 ± 0.010, 0.277 ± 0.013 and 0.289 ± 0.031 for the earthquake swarms near Matsushiro and Kozushima Island and in Wakasa Bay, respectively.

In the region III where earthquakes have been occurring in swarm since 1920, the mean value of $\bar{\sigma}$ with its 95 % confidence interval is 0.238 ± 0.006, which is considerably lower than those in any other regions near and in Japan and is, in tendency, in agreement with ones obtained by Yoshiyama (1957), 0.22, and Watanabe and Kuroiso (1967), 0.243.

In the region XI, any more separations of the region are not carried out because of a few data. In this region, especially off the north coast of Niigata Prefecture, scattering of values of $\bar{\sigma}$ is remarkable.

For aftershocks of the 1964 Niigata Earthquake, Kayano (1968) has compiled the observed data by parties of Hokkaido University, Tohoku University, the Earthquake Research Institute and the Japan Meteorological Agency. He has calculated v_p/v_s with another earthquake parameters from the data. Values of v_p/v_s he calculated are scattered widely. He has thought they come from observational errors. Geographycal distributions of v_p/v_s, however, show meaningful trends which are parallel to the structural trends in the region. Hence, they seem to express some features of the structure in the region. Accordingly, the scatterings of $\bar{\sigma}$ in the region XI seem also to have some physical meanings, but nothing about them is discussed here.

For the region IV, the mean value of $\bar{\sigma}$ with its 95 % confidence interval is 0.287 ± 0.056 though there are only three data. The mean value may not be reliable, but it must be relatively high. It is 0.274 ± 0.008 for the region V.

3. The mechanical structure and the degree of fracturing

Mogi (1962, 1963 a) has assumed that earthquakes are caused by brittle fracturing of the stressed crust or the upper mantle and carried out experimental studies on fracture phenomena. As the results of experiments, it has been clarified that the patterns of successive shock occurrences are remarkably influenced by the degree of heterogeneity of the structure of media. There are three typical patterns of shock occurrence:

First type: When the medium is homogeneous and the stress is uniformly applied, a main shock occurs suddenly without any preceding shock and many elastic shocks follow the main one. This is the type of a main shock——aftershocks.

Second type: When the medium has a rather heterogeneous structure and/or the applied stress is not uniform, small shocks occur prior to a main one which is in turn accompanied by many shocks. This is the type of foreshocks —— a main shock —— aftershocks.

Third type: When the structure of the medium is extremely heterogeneous and/or the applied stress is concentrated, elastic shocks begin to occur as soon as the stress is applied. This is the swarm type.

Applying the experimental results to natural earthquake occurrences, Mogi (1963 b) has decided mechanichal structures near and in Japan. The results are reproduced in Fig. 8, where numbers indicate the degree of fracturing. The smaller a number is, the larger the degree of fracturing is.

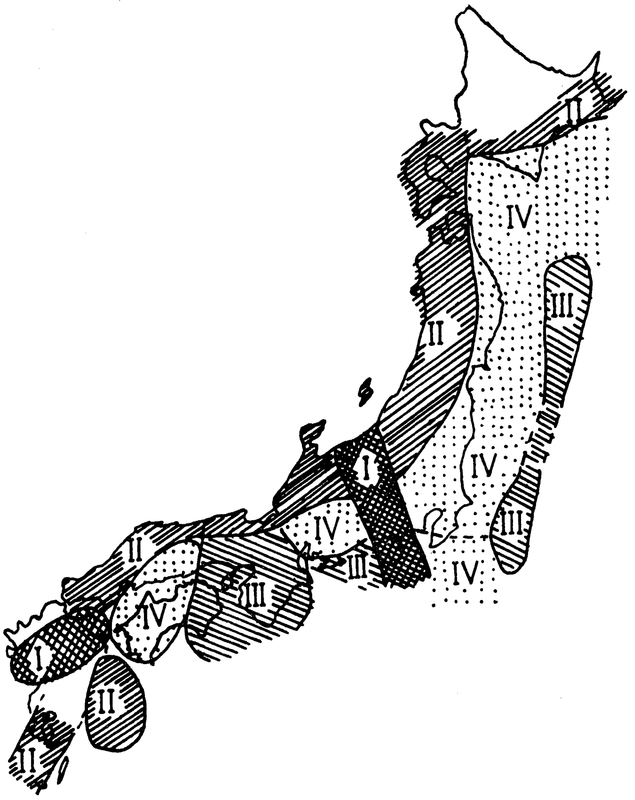

Fig. 8. The degree of fracturing near and in Japan (after Mogi (1963 b))

A comparison of Fig. 1 with Fig. 8 makes us be interested in the physical meanings of their relations.

Earthquakes used in Fig. 8 have occurred in the shallower part than 40 km while most of earthquakes in Fig. 1 have occurred in the upper mantle. However, the agreement between the respective regions in these figures is fairly good. It will not, therefore, be unreasonable to assume that the crust is in a close connection with the upper mantle and that the degree of fracturing is almost the same in the upper mantle as in the crust.

Mogi (1963 b) has designated the degree of fracturing for Hyuga-nada region as II, supposing that earthquake series of the second type have occurred in the region. In his original data, however, for most of earthquake series designated as the second type in the region, separation from the normal activity is more or less uncertain as the increase of the seismicity before the principal earthquake is not so remarkable or major earthquakes occur successively. It may, therefore, be probable to alter the Mogi's designation of the degree of fracturing. It may be smaller than that designated by Mogi.

It is designated as III in the region III. In this region, as mentioned above, seismicity has increased abruptly in 1920 and high seismic activity continues even till now. This is such a special region that earthquakes of swarm type have been occurring. Hence, it may not be unreasonable that the degree of fracturing in this region is altered to I or II.

For regions I, II, III, IV, V and VII, where data of apparent Poisson's ratios are not relatively dispersive, the relation between the degree of fracturing and apparent Poisson's ratio with its 95 % confidence interval is shown in Fig. 9, where modified values of the degree of fracturing for regions III and V are also taken into consideration.

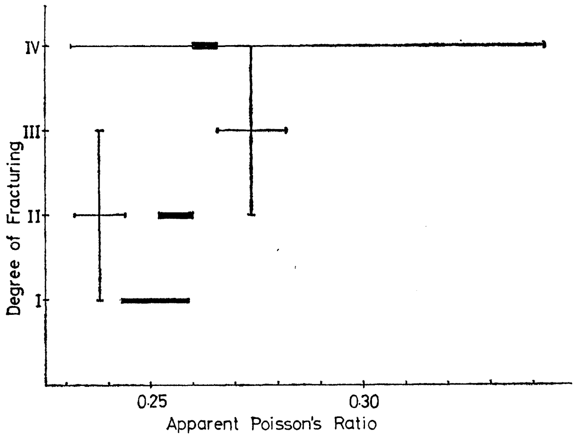

Fig. 9. The relation between the degree of fracturing and apparent Poisson's ratio with its 95 % confidence interval.

In the case of investigating the relation in Fig. 9, the fact that apparent Poisson's ratio depends on the depth is not taken care of.

It may be necessary to investigate it as a function of depth in a strict sense when regional features are compared among some regions. Earthquakes in one region, however, tend to be concentrated in the neibourhood of a certain depth. In this paper, earthquakes are chosen out accidentally and, hence, the mean value of apparent Poisson's ratio may be nearly equal to the peculiar one.

From Fig. 9, the tendency that the degree of fracturing decreases with the increasing of apparent Poisson's ratio seems to exist though there are only a few data.

In such regions as vicinities of Matsushiro, Kozushima Island and others, earthquakes of swarm type have been frequently occurred. That is, according to the Mogi's definition, these are such regions that the degree of fracturing is relatively high, whereas values of apparent Poisson's ratios are relatively high. For these regions, another causes in addition to fracturing, for example, phenomena associated with groundwater, magma chamber, etc., may be necessary to be considered.

4. On the relation between Poisson's ratio and the degree of heterogeneity

If the patterns of earthquake occurrence depend on the degree of fracturing of media, it is reasonably expected that apparent Poisson's ratio has connection with the degree of fracturing. Because, Poisson's ratio will be strongly affected by the state of media, that is, the mechanical structure.

From Fig. 9, the tendency that heterogeneity of medium increases with the decrease of Poisson's ratio seems to exist. If it is true, Poisson's ratio must increase with the increasing of wave velocity because wave velocity usually decreases with the increasing of the degree of heterogeneity. Is it possible?

Arranging the Kayano's data for aftershocks of the 1964 Niigata Earthquake (Kayano (1968)), we get a relation between v_p and v_s, which offers an information for the relation between Poisson's ratio and wave velocities. It is shown in Fig. 10, where it is evident that v_p/v_s increases with wave velocities.

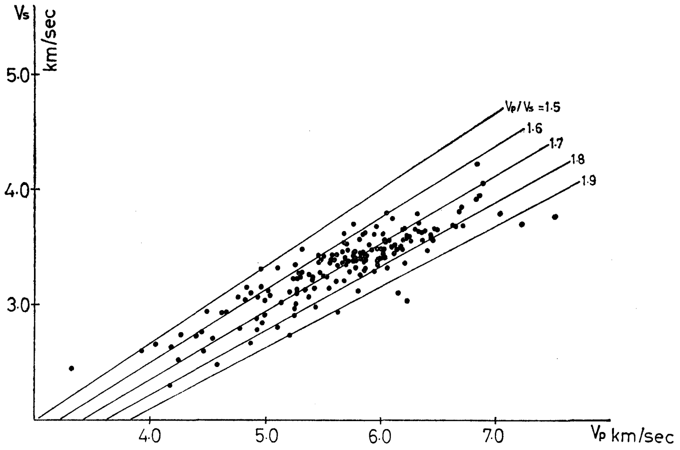

Fig. 10. The relation of shear wave velocity, v_s, to compressional wave velocity, v_p, for aftershocks of the 1964 Niigata Earthquake. These data are obtained after Kayano (1968).

Wave velocities are represented as follows:

$$v_p=\sqrt{3\frac{K}{\rho}\frac{1-\sigma}{1+\sigma}}, \quad v_s=\sqrt{3\frac{K}{\rho}\frac{1-2\sigma}{2(1+\sigma)}},$$

where ρ and σ are density and Poisson's ratio, respectively. K is bulk modulus and defined as $K=\rho\ (dP/d\rho)$. P is pressure.

Generally speaking, heterogeneity of media decreases with the increasing of confining pressure. This leads to the assumption that Poisson's ratio must increase with pressure.

Seismic wave velocities also increase with pressure. Thus $\partial v_s/\partial P>0$. Therefore, from the definition,

$$\frac{\partial v_s}{\partial P}=\frac{3}{2}\frac{1}{v_s}\left[\frac{1-2\sigma}{2(1+\sigma)}\frac{\partial}{\partial P}\left(\frac{K}{\rho}\right)-\frac{K}{\rho}\frac{3}{(1+\sigma)^2}\frac{\partial \sigma}{\partial P}\right]>0.$$

Accordingly, if such a condition as

$$\frac{\partial}{\partial P}\left(\frac{K}{\rho}\right)>\frac{K}{\rho}\frac{6}{(1+\sigma)(1-2\sigma)}\frac{\partial \sigma}{\partial P}>0$$

is satisfied, wave velocities and Poisson's ratio increase with pressure together.

If density is a function of only pressure, finally,

$$\frac{d^2P}{d\rho^2}>\left(\frac{K}{\rho}\right)^2\frac{6}{(1+\sigma)(1-2\sigma)}\frac{\partial \sigma}{\partial P}>0.$$

If $(\partial\sigma/\partial P)=$constant, then it is necessary that P is represented by a polynominal expression of ρ and the highest power needs to be more than the second and has a plus coefficient. Such a example is the Murnaghan-Birch's equation of state:

$$P=\frac{3}{2}K_0\left[\left(\frac{\rho}{\rho_0}\right)^{7/3}-\left(\frac{\rho}{\rho_0}\right)^{5/3}\right].$$

But it is uncertain that this equation is suitable to apply to the fractured medium.

Experimental results on the variation of Poisson's ratio with axial stress which is applied to specimens of granite have been cited in Matsushima (1962). These indicate that Poisson's ratio is low in the low stress range and increases with stress.

Hughes and Cross (1951) have studied velocities of elastic waves as a function of hydrostatic pressure for sandstone, etc., at some fixed temperatures. The relations of Poisson's ratio with hydrostatic pressure after them are reproduced in Fig. 11 for sandstone. For dry sandstone, the more pressure increases the more Pois-

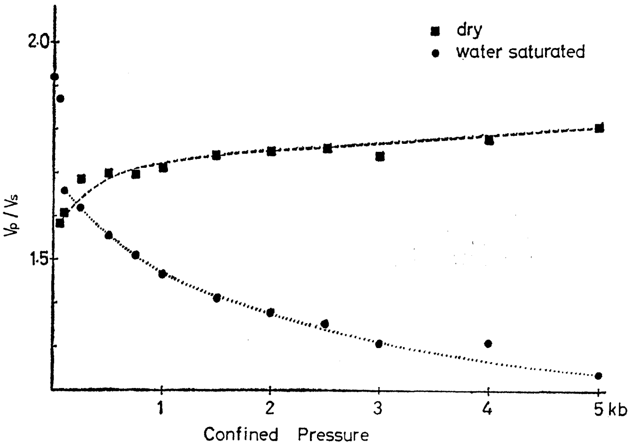

Fig. 11. Velocity ratio, v_p/v_s, as a function of pressure for dry and water-saturated sandstone (after Hughes and Cross (1951)). Temperature was fixed at 27°C.

son's ratio increases. For water-saturated sandstone, however, the tendency of the relation is contrary to the above case. In this case, internal pressure in pores in sandstone increases with the increasing of external pressure. And wave velocities are mainly controlled by differential pressure which means the difference between external and internal pressure. From these experiments, it may not be unreasonable to assume that fractures in the earth are in the state more similar to dry pores than water-saturated ones, that is, in a state of open pores.

These examples seem to support the possibility of the existence of the relation in Fig. 9.

On the other hand, for general rocks of which the crust and the upper mantle are thought to be composed, the effects of pressure on Poisson's ratio are little for high pressure ranges. What is worse, Poisson's ratio for them increases or decreases with the increases of pressure as the case may be. According to a finite strain theory, Poisson's ratio increases in the case of $\lambda>\mu$ and decreases in the case of $\lambda<\mu$ with the increase of pressure (Shimozuru (1963)), where λ and μ are Lame's constants. However, this may be the another case of fractured states of media.

As there are few data to study the relation of the mechanical structure with Poisson's ratio, the more detail investigations about them must be postponed to future. The relation in Fig. 9, however, seems to be useful to investigate the mechanical structures in media.

5. On travel times in the case of the laterally discontinuous mantle

In the preceding sections, apparent Poisson's ratio has been dealt with and it has been clarified that it varies with the locality. This seems to imply lateral variations of the structure and wave velocities in the upper mantle.

From Fig. 1, a model composed of some blocks is immediately thought of for the upper mantle. As a simplified model, the mantle is assumed to consist of two adjacent blocks which contact with each other. Wave velocities are laterally isotropic but vertically anisotropic in the respective blocks. For convenience, the crust is supposed to be uniform.

When the structure of media is represented by such a model, travel time curves manifest peculiar features. Tazime (1963) has built up formulae to calculate travel times for a flat earth model in the case of the existence of some lateral discontinuities. According to him, if a hypocenter lies on the side of the lower wave velocity and waves are transmitted toward the higher velocity side, a travel time curve breakes out and a shadow zone where direct waves do not arrive comes out. The area of the shadow zone increases with velocity contrast between both blocks.

For a spherical earth model, a travel time curve is influenced by some more parameters.

Wave velocity in the mantle is assumed to vary with the depth according to the formula $v=v_m(r/r_m)^\nu$, where r is the radius from the earth's center and ν is a constant. A suffix m concerns the parameter at the uppermost part of the mantle, that is, the Mohorovicic discontinuity. If a hypocenter lies at the Mohorovicic discontinuity on the lower velocity side, the area of the shadow zone Δ_s is represented as follows:

$$\Delta_s=\Delta_b-\Delta_e,$$

where
$$\Delta_b=\alpha+[(\pi/2)-\arcsin(p_b/\eta_{hm})]/(1-\nu)+(\Delta_c)_{p=p_b},$$
$$\Delta_e=\alpha+(\Delta_c)_{p=p_e},$$
$$\Delta_c=\arcsin(p/\eta_{cd})-\arcsin(p/\eta_{cu}),$$
$$p_b=\eta_{ml}\sin[\arcsin(v_{mh}/v_{ml})-\alpha(1-\nu)],$$
$$p_e=\eta_{ml}\cos\alpha(1-\nu),$$
$$\eta=r/v.$$

α is the angular distance from the epicenter to the boundary between two blocks and represents the scale of area of the lower velocity side. Suffixes l and h concern the lower and the higher velocity side of the mantle. Suffixes c, u and d indicate parameters concerning the crust, the uppermost and the lowermost part of the crust respectively.

Thus the area of the shadow zone depends on the scale of the lower velocity side α and velocity gradient ν in addition to velocity contrast v_{mh}/v_{ml}. It increases with the increase of α or the decrease of ν. If a numerical estimation is performed, based on a probable assumption of numerical values, the area of the shadow zone reaches to 100 km or more in the case of $\alpha=1°$ even if the maximum ν is assumed. Therefore, if the boundary is sharp, observable waves in the neibourhood of the boundary on the higher velocity side may be scattered or diffracted waves. When the boundary is not so sharp that wave velocities vary laterally gradually, another interpretation of the observed waves may be possible.

To our disappointments, patterns of distributions of wave velocities near and in Japan are insufficient. The investigations about the distribution of apparent Poisson's ratio may, however, contribute to studies on travel times or phases.

6. Discussions

It has been clarified by the comparison of Fig. 1 with Fig. 8 that Poisson's ratio varies in block with the locality and seems to be concerned with the mechanical structure of media.

Poisson's ratio also varies with depth in one block. The relation between apparent Poisson's ratio and focal depth changes discontinuously at a certain depth.

This means that the upper part of the earth is composed of two kinds of media which have different Poisson's ratios with each other and that the main part of wave path in the case when a focus lies shallower than the boundary differs far from the one in the case of a deeper focus. The latter is possible when the condition $dv/dr > v/r$ is satisfied, which means the condition of the low velocity layer. Consequently, it is concluded that Poisson's ratio increases abruptly at the upper boundary of the low velocity layer.

Many authors (for example, Lehmann (1953), Kakuta (1963)) have thought that the low velocity layer for P wave is not so dominant as the one for S wave or does not exist. The abrupt increase of Poisson's ratio at the upper boundary of the low velocity layer does not contradict the above assumptions.

Low S_n velocity near and in Japan has frequently been reported. This may be led from the low velocity layer or fracture phenomena. The author thinks from the above investigations that high Poisson's ratio may be related to the low velocity layer and low one may be related to fracture phenomena. More data will, however, be required to confirm the assumption.

Generally speaking, Poisson's ratio is influenced largely by temperature (Shimozuru (1962)) and anomalously high Poisson's ratio has been reported for the so-called "volcanic zone" (Nishimura *et al.* (1960)). However, it is not recognized from Fig. 1. In both of regions II and VII, values of apparent Poisson's ratios are not so high as in the region I or V. For these regions, the author thinks, it will be better to think that the mantle will be in a state of fractured media and this state influences Poisson's ratio more strongly than the existence of magma chamber does. Apparent Poisson's ratios for such earthquakes as in the vicinity of Kozushima Island are relatively high. This may be the case that the effect of the existence of magma chamber etc. is more dominant than the effect of fractured media.

Mogi (1963 b) has designated the degree of heterogeneity for the crust in the region I as IV, which means according to his definition that occurrence of foreshocks will not be expected in the region. Poisson's ratio seems, however, to be relatively low in the shallower part than the low velocity layer in the region. Accordingly, if the author's assumption is true, foreshocks must occur in the shallower part. Nagumo *et al.* (1968) has reported abnormal seismic activities before the 1968 Tokachi-Oki Earthquake. These may be the evidence for the above expectation.

Acknowledgment

The author thanks the Kagoshima District Meteorological Observatory for allowing him to make use of the Seismological Bulletin of JMA.

References

Hughes, D. S. and J. H. Cross, 1951, Elastic wave velocities in rocks at high pressures and temperatures, Geophysics, 16, 577-593.

Kakuta, T., 1963, The low vleocity layer in Japan (Part I), Geophys. Bull. Hokkaido Univ., 11, 67-75, (in Japanese).

Kakuta, T., 1968a, The structure of the upper mantle—In the vicinity of the low velocity layer —, Zisin (J. Seism. Soc. Japan), 21, 202-221, (in Japanese)

Kakuta, T., 1968 b, On the apparent Poisson's ratios in the southwestern part of Japan, Rep. Fac. Sci., Kagoshima Univ., 1, 79-88, (in Japanese).

Kamitsuki, A., 1959, On local character of Poisson's ratio in the earth's crust, Mem. Coll. Sci., Kyoto Univ., A, 29, 163-185.

Kayano, I., 1968, Determination of origin times, epicenters and focal depths of aftershocks of the Niigata Earthquake of June 16, 1964. —A preliminary report of the cooperative study of aftershocks of the Niigata Earthquake—, Bull. Earthq. Res. Inst., 46, 223-269.

Lehmann, I., 1953, *P* and *S* at small distance than 25°, Trans. Amer. Geophys. Union, 34, 477-483.

Matsushima, S., 1962, The mechanical properties of rocks under high pressure, Bull. Volcanol. Soc. Japan, 7, 61-74, (in Japanese).

Mogi, K., 1962, The fracture of a semi-infinite body caused by an inner stress origin and its relation to the earthquake phenomena (First paper), Bull. Earthq. Res. Inst., 40, 815-829.

Mogi, K., 1963 a, The fracture of a semi-infinite body caused by an inner stress origin and its relation to the earthquake phenomena (Second paper). — The case of the materials having some heterogeneous structures —, Bull. Earthq Res. Inst., 41, 595-614.

Mogi, K., 1963 b, Some discussion on aftershocks, foreshocks and earthquake swarms — The fracture of a semi-infinite body caused by an inner stress origin and its relation to the earthquake phenomena (Third paper), Bull. Earthq. Res. Inst., 41, 615-658.

Nagumo, S., H. Kobayashi and S. Koresawa, 1968, Foreshock phenomena of the 1968 Tokachi-Oki Earthquake observed by ocean-bottom seismographs off Sanriku, Bull. Earthq. Res. Inst., 46, 1355-1368, (in Japanese).

Nishimura, E., A. Kamitsuki and Y. Kishimoto, 1960, Some Problems on Poisson's ratio in the earth's crust, Tellus, 12, 236-241.

Shimozuru, D., 1962, Elasticity of rocks at high temperature with special reference to the nature of the low velocity layer in the crust and the upper mantle of the earth, Bull. Volcanol. Soc. Japan, 7, 45-60, (in Japanese).

Shimozuru, D., 1963, The low velocity zone and temperature distribution in the upper mantle of the earth, J. Phys. Earth, 11, 19-24.

Tazime, K., 1963, Refraction shooting on the experimental field for small explosions in the neibourhood of the city of Mitsuke, Niigata Prefecture, Geophys. Bull. Hokkaido Univ., 11, 113-168, (in Japanese).

Watanabe, H., and A. Kuroiso, 1967, Some properties of microearthquakes in the west of Kii Peninsula, Central Honshu, Japan, Zisin(J. Seism. Soc. Japan), 20, 180-191, (in Japanese).

Yoshiyama, R., 1957, The ratio of the velocity of *P* and *S* waves, Bull. Earthq. Res,. Inst., 35, 627-640.