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ON LOCAL CHARACTER OF POISSON'S RATIO IN THE EARTH'S CRUST

BY

Akira KAMITSUKI

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ABSTRACT

Instead of the usual time-distance curve, the *P–S* diagram method is effectively employed to detect any area of anomalous value of Poisson's ratio, if existent, in the earth's crust. In the present article, the anomalous Poisson's ratio in the crust of Kyushu District is discussed in some detail, and it hints at the possibility of existence of local magmatic reservoir in the crust.

1. Introduction

It was found by the seismometric investigation that within the earth's crust, there exist two or more distinct layers which are characterized mainly by the seismic wave velocities. In the various regions of the world the seismic wave velocities transmitted through these layers, the thickness of each individual layer and the depth of the Mohorovičić discontinuity have been investigated. From the numerous results hitherto obtained, the earth's crust may be considered to have distinct local character.

Theoretically, the velocity of longitudinal wave V_p and the velocity of transverse wave V_s transmitted through the infinite homogeneous isotropic medium are related to the density and the elastic constants of the medium in the following forms:

$$V_p = \sqrt{\frac{k+\frac{4}{3}\mu}{\rho}} \quad \text{and} \quad V_s = \sqrt{\frac{\mu}{\rho}},$$

ρ being the density, and k and μ being the incompressibility and the rigidity of the medium respectively. The ratio of V_p to V_s is the function of the elastic constants only. Namely,

$$\frac{V_p}{V_s} = \sqrt{\frac{k+\frac{4}{3}\mu}{\mu}} = \sqrt{\frac{k}{\mu}+\frac{4}{3}} = \sqrt{1+\frac{1}{1-2\sigma}},$$

and

$$\sigma = \frac{1}{2}\left(1-\frac{1}{\left(\frac{V_p}{V_s}\right)^2-1}\right),$$

σ being Poisson's ratio. At relatively shallow depths σ is slightly less than 0.25 and in the lower layers of the crust it is about 0.25, and in the deeper parts of the mantle about 0.30. Inside the core, σ seems to be close to 0.50 (**1, 2**). For example, various values of Poisson's ratio were found in some regions (**3, 4, 5, 6**). Some recent results are tabulated below (**7**).

The velocities of *P*– and *S*–waves, velocity ratio and Poisson's ratio in some regions.

Region	Author	V_p km/sec	V_s km/sec	V_p/V_s	σ	Depth km	Remarks
Quincy granite	Don Leet and Maurice Ewing	4.96 ± 0.02	2.48 ± 0.03	2.00	0.33	Very shallow	Using the waves generated by dynamite explosion.
Rockport granite	Don Leet	5.08 ± 0.01 5.14 ± 0.05	2.70 ± 0.02	1.90_4	0.31	Shallow	
Sudbury norite		6.22 ± 0.003	3.49 ± 0.006	1.78_3	0.27		
Southern California	B. Gutenberg	5.55	3.23	1.70	0.24	0–14	Natural earthquakes
		6.05	3.39	1.79	0.27	14–26	
		6.83	3.66	1.86	0.30	26–30	
		7.6	4.24	1.80	0.27	30–39	
		7.9_4	4.45	1.78	0.27	>39	
Europe	H. Jeffreys	$P_g=5.57\pm0.02$	$S_g=3.36\pm0.01$	1.65_8	0.215		Natural earthquakes
		$P^*=6.50\pm0.03$	$S^*=3.74\pm0.03$	1.73_8	0.252		
		$P_n=7.76\pm0.03$	$S_n=4.36\pm0.02$	1.78_0	0.269		
Southern California	B. Gutenberg	$\bar{P}=5.58\pm0.01$	$\bar{S}=3.26$	1.71_2	0.241		Natural earthquakes
		$P_y=6.05$	$S_y=3.65$	1.65_8	0.215		
		$P_m=6.95\pm0.18$	$S_m=4.10$	1.69_5	0.233		
		$P_n=8.06\pm0.11$	$S_n=4.45$	1.81_1	0.280		

The values of Poisson's ratio in the weathering or sedimentary layers are determined to be very much complex from the observation of artificial explosions. This should be investigated in the near future, but in the present state, it is rather a difficult problem as the generation and identification of *S*–waves in the artificial explosion are comparatively difficult (**8**). Setting aside the problem of sedimentary layer, Poisson's ratio of the earth's crust as a whole is considered to have a nearly constant value from 0.23 to 0.27 as seen in the annexed tables.

On the other hand, numerous experiments have been made for the comparison of elastic properties of rock with those obtained from the seismometric observations. Elastic constants obtained by the laboratory experiments have the diverse values (see, e.g. **9, 10, 11**), but it is recently ascertained by the experiment of high pressure and temperture that the standard errors of these diversities become smaller with the increase of pressure and temperature. The average values of pressure and temperature within the crust can be reproduced in the laboratory and the variation of elastic properties under high pressure and temperature are discussed.

Some recent data based on natural earthquakes and artificial explosion.

Region	Author	V_p km/sec			V_s km/sec			V_p/V_s			σ			Depth km		
Based on natural earthquakes.																
SW. Germany	Hiller (1953)	5.6	6.4	8.1	3.3	3.7	4.7	1.69_7	1.73_0	1.72_3	0.23_4	0.25_0	0.24_5	10∼15	−30±	>30±
Italy, Cansiglio	Caloi (1952)	5.7	6.61	8.00	3.36	3.64	4.44	1.69_6	1.81_6	1.80_2	0.23_3	0.28_2	0.27_7	10∼15	−35±	>35±
Italy, NW Apennines	Caloi (1952)	5.25	6.63	8.16	3.06	3.57	4.44	1.71_5	1.85_7	1.83_8	0.24_3	0.29_5	0.29_0			
Italy, Gran Sasso	Fillippo and Marcelli (1952)	5.46	6.38	8.19	3.01	3.63	—	1.81_4	1.75_7	—	0.28_1	0.26_0	—	−25	−60±	>60±
S. California	Richter and Nordquist (1951)	6.34		8.15	3.67		4.55	1.72_7		1.79_1	0.24_7		0.27_4			
S. California	Gutenberg (1951)	6.35		8.1∼8.2	3.6		4.6_2	1.76_4		1.75_3∼1.77_5	0.26_3		0.25_9∼0.26_8	−28	−35	>35
Based on artificial explosions.																
Heligoland to S. Germany	Schulze and Förtsch (1950)	6.18	6.60	8.3	3.67	3.87	—	1.68_4	1.70_5	—	0.23	0.24	—	6− 9	9–27	>27
Black Forest	Förtsch (1951)	5.9+	6.55	8.34	3.4+	3.78	4.82	1.73_5	1.73_3	1.73_0	0.25	0.25	0.25	0–15	15–31	>31
Black Forest	Rothé and Peterschmitt (1950)	5.97	6.54	8.15	3.4±	3.65	—	1.75_5	1.79_1	—	0.26	0.27	—	2–20	20–30	>30
*N. New York toward W. and S.	Katz (1953)	6.4		8.2±	3.62		4.68	1.76_8		1.75_2	0.27		0.26±	0–35		>35
		6.3		8.07	3.60		4.7±	1.75_0		1.71_7	0.26		0.24	0–36		>36
*Pennsylvania	Katz (1953)	6.1		8.21	3.61		4.69	1.69_0		1.75_0	0.22		0.26	1–32		>32
*Canadian Shield	Hodgson (1953)	6.25		8.18	3.54		4.85	1.76_6		1.68_6	0.26		0.23	0–36		>36
		6.23		7.06	3.54		3.92	1.76_0		1.80_1	0.26		0.28	0–28±		28–40
Japan	Research Group for explosion seismology (1951, 52, 54)	6.1±	7.4	8.2	3.4	—	—	1.79_4	—	—	0.28	—	—	1–27	27–32±	>32±
*W. Transvaal	Willmore, Hales and Gane (1952)	6.09		8.22∼8.27	3.68		4.80∼4.83	1.65_5		1.71_2	0.21		0.24	5–34		>34
		6.09	6.83	8.22∼8.27	3.68	3.89	4.80∼4.83	1.65_5	1.75_6	1.71_2	0.21	0.26	0.24	5–23	23–38	>38

(Note: In regions marked with an asterisk the structure calculated by the analysis of P-waves is different from that of S-waves.)

Taking account of the constancy of Poisson's ratio in a certain limited region, the $P \sim S$ durations may linearly increase with the arrival times of P-wave (**12**). This method is emoloyed to research the origin time of deep earthquakes (**13**). In recent years, Yoshiyama (**14**) investigated the value of V_p/V_s and found that at the Mohorovičić discontinuity it increases abruptly from 1.67 to 1.78.

In the present case, Poisson's ratio in the earth's crust is investigated using the seismic wave velocities of natural earthquakes, especially in relation to the local character of the earth's crust.

2. The method of *P-S* diagram

In order to find the values of V_p/V_s, especially their local anomaly, the P-S diagram method is effectively employed. In this case, the following must be reasonably assumed. Namely, each earthquake has only one origin time at the hypocenter, being common for P- and S-waves, and the hypocenter at which P- and S-waves are emitted has a negligibly small domain compared with those of the earth's crust to be investigated. In the P-S diagram, the arrival time of P-wave, T_p, is taken as abscissa and that of S-wave, T_s, as ordinate. Observed value obtained at one station corresponds to one point in this diagram. The velocity ratio of P-wave to S-wave is represented by the following formula:

$$\frac{V_p}{V_s} = \frac{T_s - T_0}{T_p - T_0},$$

where T_0 is the origin time at the hypocenter. The gradient of the straight line connecting the origin to each point directly represents the mean value of V_p/V_s along the seismic wave path between the hypocenter and each station. If some points show any particular or systematic deviations, those points represent immediately their local anomaly of V_p/V_s. Comparing this method with the time-distance curve method, the former has some merits as mentioned below.

1) In order to construct the time-distance curves, the position and depth of the hypocenter must be determined accurately and in this case some assumptions about the subterranean structure must necessarily be made. Moreover, the velocities must be estimated from these curves by the troublesome treatments. On the contrary, the P-S diagram method need not any assumption and treatment. The one time T_0 only should be computed, being easily determined by the graphical method. Speaking in detail, T_0 is given at the intersection of the mean straight line tentatively drawn through the observed points with the straight line of 45° gradient. The error which will be produced in the process of constructing the time-distance curves will be excluded and any local anomaly of Poisson's ratio in the earth's interior will be easily found out and checked immediately.

2) The absolute values of *P*- and *S*-wave velocities and the thickness of the earth's crust and others have no influence upon the results obtained by the *P-S* method, and so the *P-S* diagram method is more effectively and accurately applied compared with that of time-distance curves for the study of local character of the elastic properties of the earth's interior.

The value of V_p/V_s estimated by the present method is the mean one, being estimated along the seismic wave path from the hypocenter to each station and so it is necessary to determine through which layer the waves are transmitted. The *P-S* diagram method is more useful in such a case as many earthquakes of various focal depths are observed with high time accuracy. It should be remarked that the origin time at the hypocenter is assumed to be only one, as stated previously. Yashima (**15**) estimated the magnitude of the hypocentral region of an earthquake from the difference between two times, one being the origin time of *P*-wave in time-distance curve analysis, the other the time at which $P \sim S$ duration is zero. Though this is a very interesting problem, its discussion will be postponed to another opportunity.

3. Application of the *P-S* diagram method

As will be mentioned in the next section, some definite deviations in the *P-S* diagram were found in the Kyushu district. Reflecting upon this effect, the accuracy of arrival times of *P*- and *S*-waves must be carefully discussed. Recently the time correction in seismograms has become very accurate by using the J. J. Y.-time signal. In the case of *P*-wave, the identification of phase is easy and the measurement of arrival time is accurate if they are those of direct *P*-wave. According to this reason, most of the earthquakes investigated in the treatment are rather deep ones, foci of which are situated below the Mohorovičić discontinuity, and the few that are shallow are investigated in the distances ranging within about 100 km. In the case of *S*-wave, the identification and measurement must carefully be considered. Theoretically, the wave transformed from *S*-type to *P*-type at the Mohorovičić discontinuity may appear before the arrival of direct *S*-waves. But these transformed *SP*-wave are correctly and safely discriminated from the direct *S*-wave considering the time-distance and amplitude relation. The *S*-waves have generally larger amplitudes and periods than *P*-waves, and it may be probable that the arrival times of *S*-wave have errors of one or more seconds.

In the present case, the original seismograms at the observatories of Aso, Abuyama and Kamigamo were investigated and the copied ones at twenty-five stations of the Japan Meteorological Agency were examined concurrently.

4. Anomaly of Poisson's ratio in the Kyushu district

The twelve earthquakes which occurred in or near the Kyushu district were selected. The epicenters and observation stations are shown in Fig. 1, and tabulated in Table 1,

Table 1. The earthquakes used in section 4.

No.	Origin time	d	h	m	s	Epicenter: Location	Latitude	Longitude	Depth (km)
1	53 Jan.	23	11	47	59	Bungo Channel.	33.3°*N*	132.2°*E*	40
2	56 Oct.	5	19	34	11	*E* part of Oita Pref., Kyushu.	33.1	131.6	100 ca.
3	50 Sept.	16	21	48		*N* part of Miyazaki Pref., Kyushu.	32.7	131.5	110
4	54 Feb.	24	3	28	17	*SE* part of Miyazaki Pref., Kyushu.	31.8	130.9	30
5	58 May	15	5	32	3	Off *E* coast of Kyushu.	32.7_5	132.2	30
6	53 Nov.	27	4	25	55	Off *E* coast of Kyushu.	32.0	131.9	30
7	56 Sept.	7	7	45	28	Off *SE* coast of Kyushu.	31.0	132.0	40
8	51 Apr.	26	3	30		Off Satamisaki, Kagoshima Pref., Kyushu.	30.8	130.7	130
9	55 Mar.	28	18	12	20	Off *S* coast of Kyushu.	29.4	130.1	60 ca.
10	55 Apr.	17	10	13	32	Saga Pref., Kyushu.	33.3	130.1	0~10
11	58 June	19	22	49	48	*W* coast of Kyushu.	32.9	130.4	0~10
12	56 Nov.	2	20	34	22	*W* part of Setonaikai.	33.8	132.3	<30

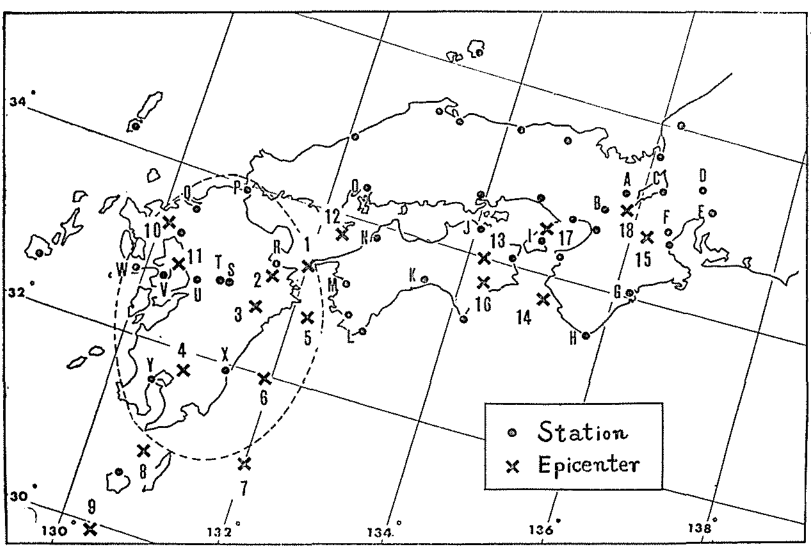


Fig. 1. The location of stations and epicenters.

Stations are as follows:

A: Kamigamo B: Abuyama C: Hikone D: Gifu E: Nagoya F: Kameyama G: Owashi H: Shionomisaki I: Sumoto J: Takamatsu K: Kochi L: Shimizu M: Uwazima N: Matsuyama O: Hiroshima P: Shimonoseki Q: Fukuoka R: Oita S: Aso-san T: Aso-obs. U: Kumamoto V: Unzendake W: Nagasaki X: Miyazaki Y: Kagoshima

Epicenters are listed in Tables 1 and 2.

Table of earthquake No. 1.
53 Jan. 23d 11h 47m 59s Bungo Channel.
(33.3°N, 132.2°E H=40 km)

Station		P-wave		S-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
R	Oita	iP	48 10.3	iS	48 17.6	53.7
L	Shimizu	iP	13.7	iS	24.1	107.5
N	Matsuyama	iP	14.6	iS	25.7	81.5
T*	Aso-obs.	iP	16.3	iS	30.3	122.3
K	Kochi	iP	18.2	iS	31.2	127.9
P*	Shimonoseki	iP	18.3	iS	33.9	137.1
U*	Kumamoto	iP	19.5	iS	36.6	148.3
Q*	Fukuoka	iP	23.5	iS	43.2	172.4
X*	Miyazaki	eP	24.1	iS	44.0	166.8
J	Takamatsu	eP	29.6	iS	50.9	205.7
W*	Nagasaki	P	30.8	S	57.4	226.1
Y*	Kagoshima	P	35.9	S	49 8.3	246.5

(Note: In the tables of earthquakes No. 1~No. 9 the stations marked with an asterisk have their deviations in the P–S diagram.)

Table of earthquake No. 2.
56 Oct. 5d 19h 34m 11s E part of Oita Pref., Kyushu.
(33.1°N, 131.6°E H=100 km ca.)

Station		P-wave		S-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
R*	Oita	eP	34 26.9	iS	34 36.6	14.8
T*	Aso-obs.	iP	29.5	iS	41.1	61.2
M*	Uwajima	eP	31.1	eS	44.4	90.8
U*	Kumamoto	iP	31.7	iS	44.8	87.1
*	Saga	iP	34.2	iS	49.6	122.3
L*	Shimizu	eP	34.3	iS	50.4	135.3
Q*	Fukuoka	iF	35.1	iS	51.1	124.2
X*	Miyazaki	iF	36.2	iS	52.7	111.2
N	Matsuyama	eP	38.6	iS	55.7	105.6
K	Kochi	iP	41.2	eS	35 1.4	187.2
	Murotomisaki	eP	47.8	eS	13.5	242.8
J	Takamatsu	eP	50.1	iS	16.3	265.0
	Tokushima	iP	53.9	eS	22.6	296.5
*	Yaku-shima	eP	55.4	eS	30.1	309.5
I	Sumoto	eP	59.5	iS	31.4	337.3

Table of earthquake No. 3.
50 Sept. 16d 21h 48m *N* part of Miyazaki Pref., Kyushu.
(32.7°*N*, 131.5°*E* *H*=110 km)

	Station	*P*-wave		*S*-wave		*Δ*
		Phase	Time	Phase	Time	
			m s		m s	km
*U**	Kumamoto	*P*	49 2.6	*S*	49 17.5	74.1
*	Saga	*P*	4.7	*S*	22.8	127.9
X	Miyazaki	*iP*	6.0	*iS*	20.9	85.2
*Q**	Fukuoka	*iP*	6.1	*iS*	23.8	127.9
*Y**	Kagoshima	*iP*	4.0	*iS*	22.4	153.8
*L**	Shimizu	*iP*	8.1	*iS*	27.4	140.8
*P**	Shimonoseki	*P*	9.3	*S*	28.5	148.3
*N**	Matsuyama	*P*	11.2	*S*	32.8	176.1
*O**	Hiroshima	*P*	13.2	*iS*	36.0	203.8
K	Kochi	*P*	16.1	*S*	38.7	211.3
*	Izuhara	*P*	17.5	*S*	45.8	263.2
*	Tomie	*P*	18.9	*S*	45.7	255.8
*	Yoku-shima	*P*	19.2	*S*	46.9	265.0
	Murotomisaki	*P*	21.1	*S*	48.2	257.6
	Himeji	*P*	36.4	*S*	50 14.1	379.9
H	Shionomisaki	*iP*	38.7	*iS*	19.4	405.9
	Kobe	*P*	39.6	*S*	20.8	405.9
	Osaka	*P*	43.3	*S*	26.3	431.8
F	Kameyama	*eP*	52.7	*eS*	43.9	518.8
C	Hikone	*P*	55.2	*S*	47.9	522.5

Table of earthquake No. 4.
54 Feb. 24d 3h 28m 17s *SE* part of Miyazaki Pref., Kyushu.
(31.8°*N*, 130.9°*E* *H*=30 km ca.)

	Station	*P*-wave		*S*-wave		*Δ*
		Phase	Time	Phase	Time	
			m s		m s	km
X	Miyazaki	*iP*	28 28.0	*iS*	28 33.5	59.3
*Y**	Kagoshima	*eP*	29.3	*S*	39.0	40.8
*U**	Kumamoto	*iP*	35.8	*S*	50.8	114.9
*T**	Aso-obs.	*iP*	36.4	*iS*	52.2	120.5
*R**	Oita	*iP*	44.5	*eS*	29 6.9	174.2
	Yaku-shima	*P*	46.6	*S*	5.4	152.0
*Q**	Fukuoka	*eP*	49.2	*S*	11.8	203.8
*P**	Shimonoseki	*iP*	49.7	*S*	18.3	239.1
L	Shimizu	eP_E	53.2	S_{NE}	16.3	224.3
*	Tomie	*iP*	56.5	*S*	25.2	220.5
*N**	Matsuyama	*eP*	59.9	*iS*	32.9	289.1
*	Izuhara	*P*	29 4.7	*S*	43.8	305.8
*O**	Hiroshima	*eP*	6.—	*eS*	44.—	318.8
K	Kochi	*eP*	9.0	*eS*	41.4	315.0

Table of earthquake No. 5.

58 May 15d 5h 32m 3s Off *E* coast of Kyushu. (32.7$_5$°*N*, 132.2°*E* *H*=30 km)

	Station	*P*-wave Phase	*P*-wave Time	*S*-wave Phase	*S*-wave Time	*Δ*
			m s		m s	km
	Sukumo	*P*	32 17.0	*S*	32 23.0	50.0
*L**	Shimizu	*iP*	19.2	*S*	28.0	72.3
*R**	Oita	iP_Z	20.1	eS_{EZ}	30.0	76.0
*X**	Miyazaki	*P*	23.9	*S*	37.2	103.8
*S**	Aso-san	iP_E	25.3	S_N	40.4	105.6
*T**	Aso-obs.	*iP*	25.8	*iS*	41.4	113.0
N	Matsuyama	iP_E	26.6	eS_E	41.4	133.4
U	Kumamoto	iP_Z	31.4	*S*	49.1	139.0
K	Kochi	*iP*	34.4	*iS*	55.3	152.0
*P**	Shimonoseki	eP_N	34.4	eS_N	56.7	177.9
	Murotomisaki	*eP*	41.9	*iS*	33 8.4	194.6
J	Takamatsu	*eP*	46.5	*eS*	16.8	244.6

Table of earthquake No. 6.

53 Nov. 27d 4h 25m 55s Off *E* coast of Kyushu. (32.0°*N*, 131.9°*E* *H*=30 km)

	Station	*P*-wave Phase	*P*-wave Time	*S*-wave Phase	*S*-wave Time	*Δ*
			m s		m s	km
*X**	Miyazaki	*iP*	26 3.3	*S*	26 8.3	50.0
*S**	Aso-san	*iP*	16.4	*S*	30.9	127.9
*L**	Shimizu	iP_{NE}	16.6	*S*	32.1	137.1
*T**	Aso-obs.	*iP*	17.1	*iS*	33.2	133.4
*Y**	Kagoshima	*iP*	17.9	*S*	35.2	129.7
*U**	Kumamoto	iP_Z	18.5	*S*	35.9	148.3
*R**	Oita	*eP*	19.4	*S*	39.1	144.6
*V**	Unzendake	*P*	20.9	*S*	42.3	177.9
	Yaku-shima	*eP*	25.7	*S*	42.8	215.0
*Q**	Fukuoka	*iP*	28.7	*S*	56.3	229.8

Table of earthquake No. 7.

56 Sept. 7d 7h 45m 28s Off *SE* coast of Kyushu. (31.0°*N*, 132.0°*E* *H*=40 km)

	Station	*P*-wave Phase	*P*-wave Time	*S*-wave Phase	*S*-wave Time	*Δ*
			m s		m s	km
*X**	Miyazaki	P_Z	45 47.5	*S*	46 0.9	133.4
*Y**	Kagoshima	*P*	52.6	*eS*	11.4	152.0
	Yaku-shima	*P*	53.4	*S*	9.6	155.7
L	Shimizu	eP_{NE}	46 1.8	*eS*	22.9	220.5
*U**	Kumamoto	*eF*	2.7	*S*	32.3	235.4
*S**	Aso-san	eP_E	3.8	S_E	31.6	226.1
*T**	Aso-obs.	*iP*	4.7	S_Z	33.1	229.8
*W**	Nagasaki	eP_N	7.2	eS_N	34.0	278.0
*Q**	Fukuoka	eP_Z	14.4	S_E	49.6	324.3
N	Matsuyama	eP_E	17.8	eS_N	50.8	326.2

Table of earthquake No. 8.
51 Apr. 26^d 3^h 30^m Off Satamisaki, Kagoshima Pref., Kyushu.
(30.8° *N*, 130.7° *E* *H*=130 km)

	Station	*P*-wave		*S*-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
	Yaku-shima	*P*	31 25.3	*S*	31 41.6	53.7
Y	Kagoshima	*iP*	25.5	*iS*	41.8	87.1
X	Miyazaki	*iP*	29.4	*iS*	48.6	144.6
*V**	Unzendake	*iP*	32.2	*iS*	55.9	218.7
*W**	Nagasaki	*iP*	32.3	*iS*	55.4	228.0
*U**	Kumamoto	*P*	33.6	*S*	58.1	224.2
*R**	Oita	*P*	39.3	*S*	32 9.3	283.6
*Q**	Fukuoka	*P*	41.5	*S*	12.2	311.3
*P**	Shimonoseki	*P*	46.4	*S*	19.8	350.3
*N**	Matsuyama	*P*	50.0	*S*	27.5	387.3
K	Kochi	*P*	55.2	*S*	33.3	405.9
	Murotomisaki	*P*	58.5	*S*	40.6	426.2
*	Hamada	*P*	32 0.2	*S*	46.9	472.5
J	Takamatsu	*iP*	7.6	*iS*	54.9	500.3
I	Sumoto	*P*	13.5	*S*	33 6.7	555.9
	Osaka	*P*	23.2	*S*	23.1	622.6
	Toyooka	*P*	24.3	*S*	25.3	650.4
B	Abuyama	*eP*	24.5	*iS*	26.2	641.1

Table of earthquake No. 9.
55 Mar. 28^d 18^h 12^m 20^s Off *S* coast of Kyushu.
(29.4° *N*, 130.1° *E* *H*=60 km ca.)

	Station	*P*-wave		*S*-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
	Yaku-shima	*iP*	12 40.5	*iS*	12 53.0	124.2
*Y**	Kagoshima	*iP*	55.7	*S*	13 23.3	246.5
*X**	Miyazaki	*iP*	13 3.9	*iS*	38.6	326.2
*	Tomie	P_H	9.6	S_H	57.2	379.9
*W**	Nagasaki	*eP*	11.8	*iS*	57.6	370.7
*V**	Unzendake	*P*	13.3	S_H	52.3	370.7
*U**	Kumamoto	*iP*	14.4	*iS*	58.0	385.5
*S**	Aso-san	*P*	16.5	*S*	14 3.7	398.5
*R**	Oita	iP_N	21.7	iS_H	11.7	450.3
*Q**	Fukuoka	*iP*	25.6	*S*	19.7	465.1
L	Shimizu	eP_{NH}	26.1	*eS*	8.0	465.1
*P**	Shimonoseki	*iP*	32.4	*S*	26.8	511.4
*N**	Matsuyama	*P*	34.9	*S*	31.2	555.9
K	Kochi	*eP*	35.9	*eS*	30.4	565.2
*O**	Hiroshima	*eP*	39.3	eS_Z	38.4	594.8
*	Hamada	*eP*	44.1	*eS*	58.1	639.3
J	Takamatsu	*eP*	49.5	*S*	51.8	796.8

Table of earthquake No. 10.
55 Apr. 17d 10h 13m 32s Saga Pref., Kyushu.
(33.3°N, 130.1°E H=0~10 km)

Station		P-wave		S-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
Q	Fukuoka	iP	13 40.5	iS	13 44.8	40.8
V	Unzendake	iP	43.9	eS	53.1	64.9
	Saga	iP_N	44.1	iS_N	47.0	18.5
W	Nagasaki	iP_Z	44.4	iS_Z	53.0	66.7
U	Kumamoto	iP_Z	47.2	iS	2.0	77.8
P	Shimonoseki	iP	50.9	S	2.0	105.6
S	Aso-san	P	52.5	S	4.1	103.8
	Izuhara	iP	55.1	S_N	8.4	124.2
	Tomie	iP	59.5	S	18.4	146.4
R	Oita	eP_N	14 0.1	eS_E	14.9	140.8
X	Miyazaki	P_Z	7.9	S_Z	35.9	181.6
Y	Kagoshima	P_N	12.7	S^N	39.0	194.6

Table of earthquake No. 11.
58 June 19d 22h 49m 48s W coast of Kyushu.
(32.9°N, 130.4°E H=0~10 km)

Station		P-wave		S-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
V	Unzendake	iP	49 56.7	S	49 59.4	24.1
U	Kumamoto	iP	57.9	S	50 2.4	31.5
	Saga	iP	58.1	iS	2.2	38.9
W	Nagasaki	iP	59.9	iS	6.7	51.9
S	Aso-san	iP	50 2.5	S	9.9	64.9
Q	Fukuoka	iP_Z	2.8	S_Z	10.6	76.0
P	Shimonoseki	iP	11.4	iS_N	24.9	126.0
R	Oita	iP_Z	11.4	eS_{NE}	27.8	120.5
X	Miyazaki	P_Z	15.7	S	34.0	129.7
Y	Kagoshima	P	16.3	eS	35.3	146.4
	Tomie	P_Z	16.3	S_{NZ}	35.6	157.5
	Izuhara	eP_{NE}	16.7	iS_N	37.9	176.1

Table of earthquake No. 12.
56 Nov. 2d 20h 34m 22s W part of Setonaikai.
(33.8°N, 132.3°E H<30 km)

Station		P-wave		S-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
N	Matsuyama	iP_E	34 32.1	iS_E	34 39.1	44.5
	Uwajima	iP	34.1	iS	42.0	66.7
O	Hiroshima	P	35.8	S	44.8	64.9
R	Oita	iP_Z	38.1	eS_E	47.9	88.9
	Sukumo	eP	38.3	S	45.3	103.8
K	Kochi	iP	40.9	iS	52.8	116.8
L	Shimizu	eP	41.0	eS	57.4	127.9
T	Aso-obs.	{ iP { i	(48.3 (49.0	iS	35 4.9	157.5

((Note: At Aso the refracted wave is observed 0.7 sec before the direct wave.)

Most of these earthquakes have the foci situated below the Mohorovičić discontinuity. Three earthquakes Nos. 10, 11 and 12 are shallow ones.

No. 1) In the P–S diagram, the points are separated into two groups. The lower group points are of the stations situated eastward from the epicenter (Shikoku and Chugoku districts) and upper group points are all of the stations situated west- and southwest-ward (Kyushu district). The lower group poitns are arrayed nearly on a straight line, the gradient of which is calculated as 1.70, being the normal value of V_p/V_s for the focal depth 40 km. The upper group points deviate upward from this straight line, thus re-

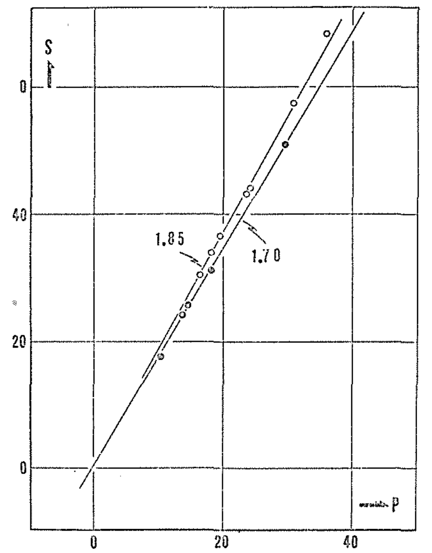


Figure for erathquake No. 1.

presenting the anomalously large value of V_p/V_s of nearly 1.85. The phases of P– and S–waves are tabulated in Table (No. 1) and it is favourable that all are sharp iP and iS.

Furthermore, the amplitudes and periods of P– and S–waves are measured. As

The amplitude ratio of S-wave to P-wave and their half periods.

Station		Amplitude ratio $\frac{S}{P}$	Half period	
			P-wave	S-wave
R	Oita	1.2 (*V*)	0.4 (*V*)	0.3 (*V*)
L	Shimizu	50.0 (*V*)	0.5 (*V*)	0.5 (*V*)
N	Matsuyama	3.7 (*V*)	0.6 (*N*) 0.7 (*E*)	0.4 (*V*) 0.7 (*N*) 0.7 (*E*)
T	Aso-obs.	3.0 (*V*)	0.4 (*V*)	0.6 (*V*)
K	Kochi	10.0 (*V*)	0.6 (*V*) 0.7 (*N*) 0.7 (*E*)	0.5 (*V*) 0.7 (*N*) 0.7 (*E*)
P	Shimonoseki	——	0.3 (*N*) 0.2 (*E*)	0.2 (*N*) 0.3 (*E*)
U	Kumamoto	——	0.7 (*N*) 0.8 (*E*)	0.8 (*N*) 0.8 (*E*)
Q	Fukuoka	2.2 (*V*)	0.4 (*V*) 0.3 (*E*)	1.0 (*V*) 0.4 (*E*)
X	Miyazaki	12.5 (*V*)	0.2 (*V*)	0.4 (*V*)
J	Takamatsu	20.0 (*V*)	0.9 (*N*)	1.0 (*N*)
Y	Kagoshima	6.2 (*V*)	0.9 (*V*)	0.9 (*V*)

the general tendency, the amplitude ratio of S-wave to P-wave and the period of S-phase seem to be slightly larger concerning to the upper group points than to the lower group ones. As this problem is very essential in nature, a detailed study will be made after collection of exact data concerning suitable earthquakes.

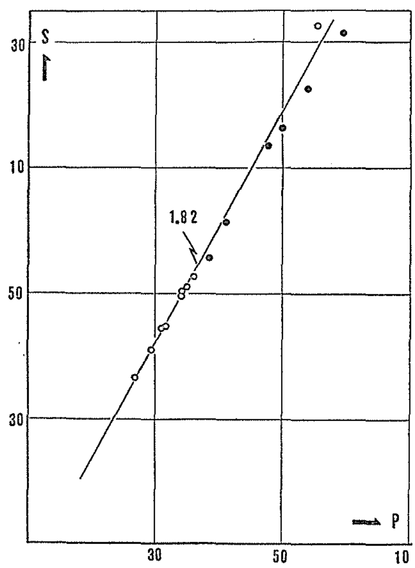


Figure for earthquake No. 2.

The seismograms recorded at Matsuyama and Kumamoto are shown in Figs. 2 and 3.

No. 2) The epicenter is situated on land in Kyushu. The value of V_p/V_s is calculated as 1.82 by drawing a straight line through the six stations in Kyushu and of Uwajima, Shimizu and Yaku-shima. The points of other stations deviate downward from this straight line.

No. 3) The epicenter of this earthquake is situated also on land. Excluding the points of stations in and near Kyushu, remaining points are arrayed on a straight line, the gradient of which is 1.76, being normal value for the focal depth of 110 km.

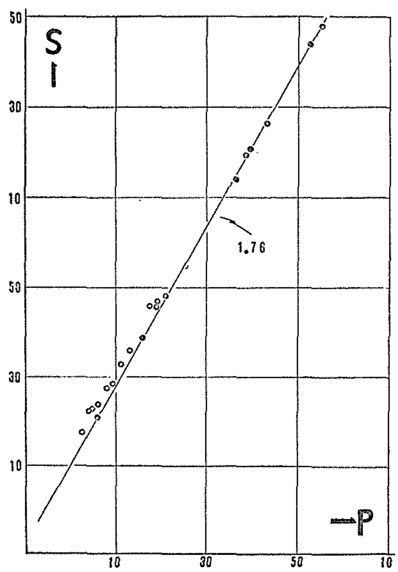


Figure for earthquake No. 3.

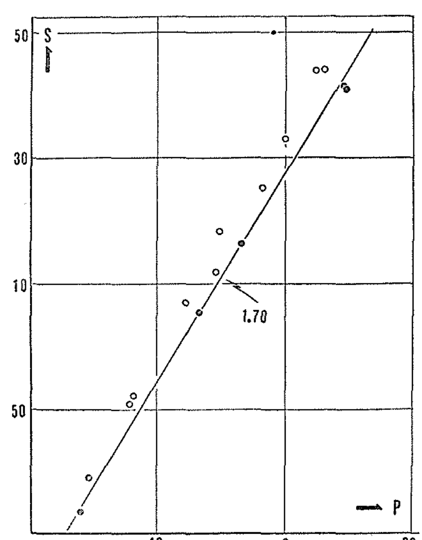


Figure for earthquake No. 4.

No. 4) The epicenter is situated more southward and the focal depth is shallower than that of No. 3. A straight line whose gradient is 1.70 is tentatively drawn. The points of stations in the Kyushu district deviate largely upward and the other points deviate downward.

No. 5) The epicenter is situated off the E coast of Kyushu. The mean straight line is drawn through the points of stations in and near Kyushu. The gradient of 1.83 is anomalously large for the focal depth of 30 km. The points of stations in Shikoku deviate downward.

No. 6) The epicenter is situated also off the E coast of Kyushu and more southward than that of No. 5. The mean straight line is drawn through the points of stations in Kyushu. The gradient of 1.86 is anomalously large for the focal depth of 30 km.

Because of the scantiness of nearer stations, drawing of time-distance curve is difficult. In the cases of earthquakes Nos. 4, 5 and 6, the apparent velocity is approximately 7 km/sec up to the distances of about 200 km, indicating that the focus is situated in the lower layer of the crust. At further distances the time-distance curve is largely diversed.

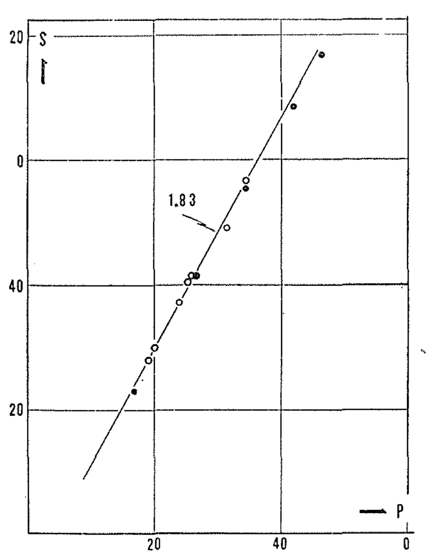


Figure for earthquake No. 5.

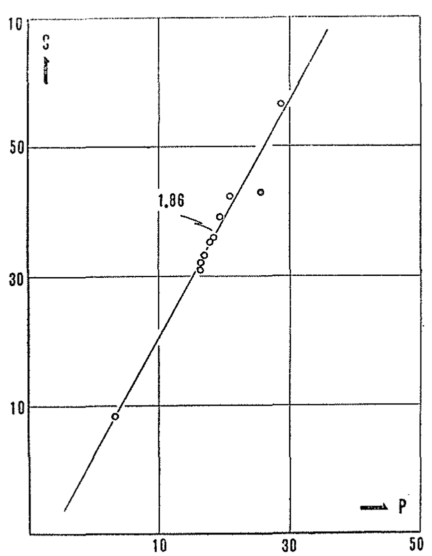
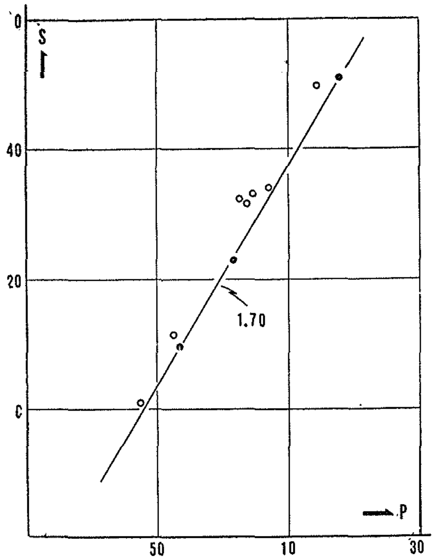


Figure for earthquake No. 6.

No. 7) The epicenter is situated more southward than that of No. 6 and below the Mohorovičić discontinuity. The points of stations in Kyushu deviate upward from the mean straight line whose gradient is 1.70.

No. 8) The epicenter of this earthquake is situated near off the *S* coast of Kyushu and the focal depth is 130 km. Excluding the points of stations in and near Kyushu, a straight line is drawn through the remaining points, its gradient being 1.76.



igure for earthquake No. 7.

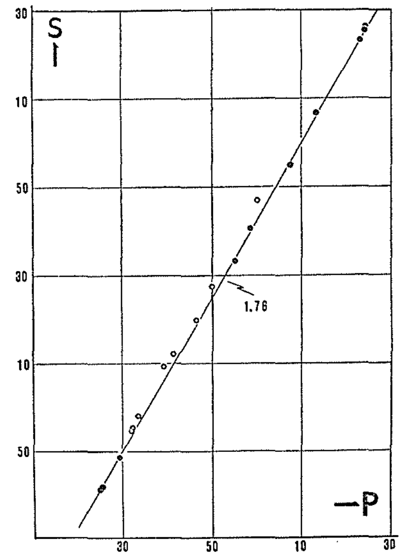


Figure for earthquake No. 8.

No. 9) The epicenter is situated far off the *S* coast of Kyushu and the focal depth is 60 km ca. The points deviate upward at first and then gradually return to the mean straight line, its gradient being 1.75.

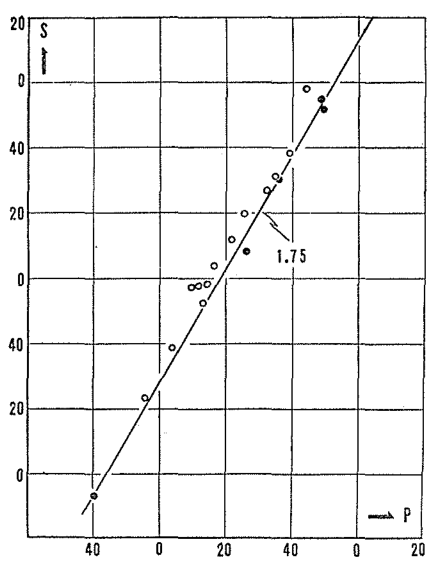


Figure for earthquake No. 9.

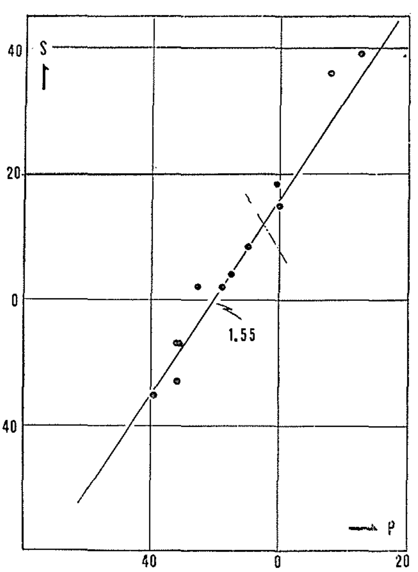


Figure for earthquake No. 10.

Nos. 10, 11 and 12) These earthquakes are shallow ones. Through the points of stations at the distances within about 100 km the mean straight lines are drawn. Their gradients are 1.55, 1.68 and 1.55 respectively. These values are normal for the shallow earthquakes whose foci are situated in the upper layer of the earth's crust.

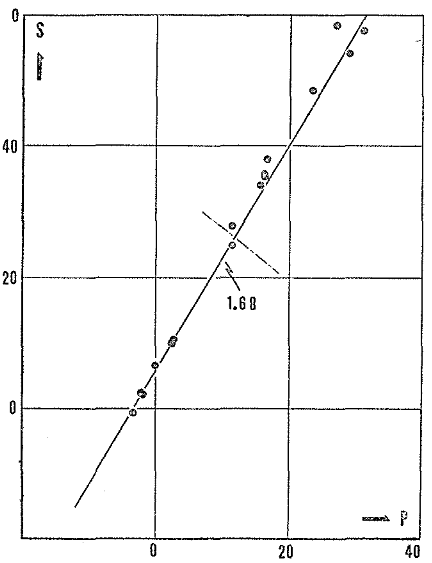


Figure for earthquake No. 11.

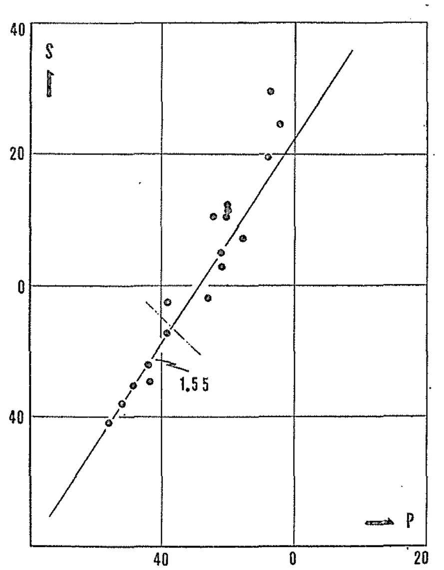


Figure for earthquake No. 12.

The values of V_p/V_s estimated in such a manner as mentioned above are compared with those of earthquakes discussed in the following sections and it is found that the points of the stations in and near the Kyushu district must be excluded owing to their deviation from the mean straight line and the correlation of the value of V_p/V_s to the focal depth is valid.

Putting together the results obtained above, the anomaly of the value of V_p/V_s, namely Poisson's ratio in the Kyushu district including the sea parts off the E and SE coast of Kyushu, is clarified. The horizontal contour of anomalous region is roughly represnted by the chain line shown in Fig. 1. The shallow earthquakes do not show any anomalous effect. The earthquakes whose foci are situated in the lower layer of the crust and immediately below the Mohorovičić discontinuity show the anomalously large values of V_p/V_s and rather deeper ones a little larger value. After all, the upper and lower boundaries of the domain in which Poisson's ratio is anomalously large are roughly estimated to be situated at depths from about 20 km and 40 km.

5. Poisson's ratio obtained in the Shikoku, Chugoku and Kinki districts.

The investigations by the same method are carried out in the adjacent region and the anomaly of Poisson's ratio found in the Kyushu district will be more clarified. The earthquakes used are tabulated in Table 2 and shown in Fig. 2.

Table 2. The earthquakes used in section 5.

No.	Origin time						Epicenter			
							Location	Latitude	Longitude	Depth
			d	h	m	s		°*N*	°*E*	km
13	57	Nov.	14	22	29	9	*E* part of Shikoku.	34.0	134.2	40
14	55	Dec.	18	15	27	42	Kii Channel, *W* Honshu.	33.7_5	135.1	40~50
15	57	Nov.	27	14	24	47	*NW* part of Mie Pref., *W* Honshu.	34.7	136.2	70
16	56	July	18	0	42	37	*S* part of Tokushima Pref., Shikoku.	33 3/4	134 1/4	0~10
17	58	June	17	16	20	12	Awaji-shima, *W* Honshu.	34.5	134.9	0~10
18	54	Dec.	21	19	31	58	Near Kyoto, *W* Honshu.	35.1	135.7	<20

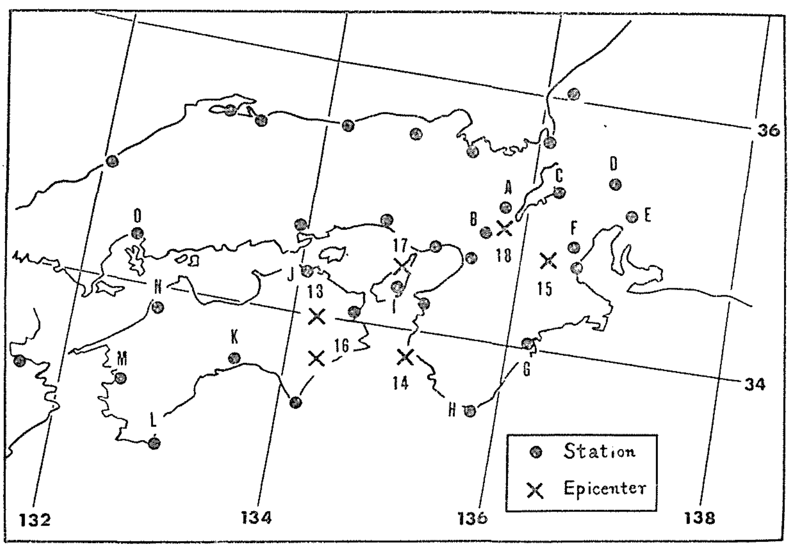


Fig. 2. The location of stations and epicenters:
Stations are as follows:
A: Kamigamo B: Abuyama C: Hikone D: Gifu E: Nagoya F: Kameyama
G: Owashi H: Shionomisaki I: Sumoto J: Takamatsu K: Kochi
L: Shimizu M: Uwazima N: Matsuyama O: Hiroshi
Epicenters are listed in Table 2.

In these regions, no conspicuous anomaly can be found. All points in the *P-S* diagrams are arrayed on a straight line within the time accuracy. The obtained values of V_p/V_s are 1.74, 1.76 and 1.75 in the cases of earthquakes Nos. 13, 14 and 15 respectively, whose foci are situated immediately below the Mohorovičić discontinuity. And in the cases of shallow earthquakes Nos. 16, 17 and 18, the values of V_p/V_s are 1.70, 1.68 and 1.70 respectively.

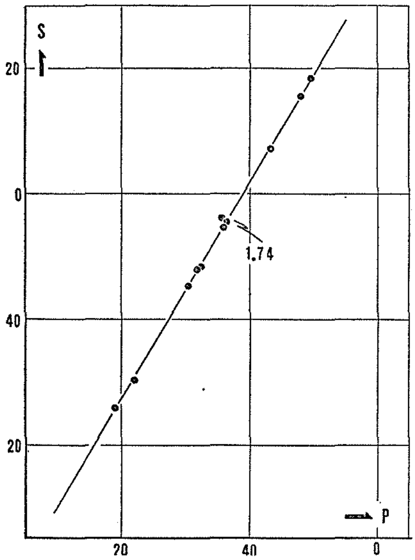


Figure for earthquake No. 13.

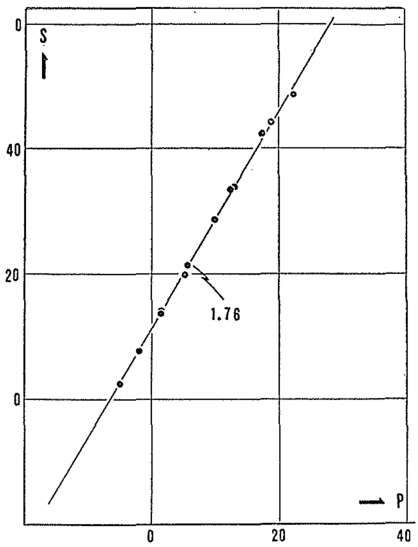


Figure for earthquake No. 14.

Table of earthquake No. 13.
57 Nov. 14^d 22^h 29^m 9^s *E* part of Shikoku.
(34.0°*N*, 134.2°*E* *H*=40 km)

	Station	*P*-wave		*S*-wave		*Δ*
		Phase	Time	Phase	Time	
			m s		m s	km
J	Takamatsu	*iP*	29 19.1	*iS*	29 25.9	37.1
I	Sumoto	*iP*	22.1	*iS*	30.3	76.0
N	Matsuyama	*P*	30.5	*S*	45.3	131.6
H	Shionomisaki	*iP*	31.9	*iS*	48.0	157.5
B	Abuyama	*iP*	32.5	*S*	48.4	157.5
O	Hiroshima	*eP*	35.9	*eS*	54.6	166.8
A	Kamigamo	*iP*	36.4	*iS*	55.5	187.2
G	Owashi	*eP*	35.7	*iS*	56.2	185.3
C	Hikone	*iP*	43.3	*S*	30 7.1	235.4
D	Gifu	*eP*	48.0	*iS*	15.5	283.6
E	Nagoya	*iP*	49.6	*iS*	18.5	285.4

Table of earthquake No. 14.
55 Dec. 18^d 15^h 27^m 42^s Kii Channel, *W* Honshu.
(33.7_5°*N*, 135.1°*E* *H*=40∼50 km)

	Station	*P*-wave		*S*-wave		*Δ*
		Phase	Time	Phase	Time	
			m s		m s	km
I	Sumoto	*iP*	27 55.1	*iS*	28 2.6	66.7
H	Shionomisaki	*iP*	58.1	*iS*	7.7	70.4
G	Owashi	*iP*	28 1.4	*iS*	13.7	107.5
J	Takamatsu	*iP*	1.4	*iS*	14.1	114.9
A	Kamigamo	iP_{NS}	5.3	iS_{NS}	19.8	159.4
K	Kochi	*iP*	5.7	*iS*	21.3	146.4
F	Kameyama	*iP*	9.9	*iS*	28.6	176.1
C	Hikone	*iP*	12.4	*iS*	33.4	200.1
N	Matsuyama	*iP*	13.0	*iS*	33.8	215.0
E	Nagoya	*eP*	17.4	*eS*	42.3	233.5
O	Hiroshima	*iP*	18.8	*iS*	44.2	255.8
	Fukui	*iP*	22.4	*S*	48.6	276.1

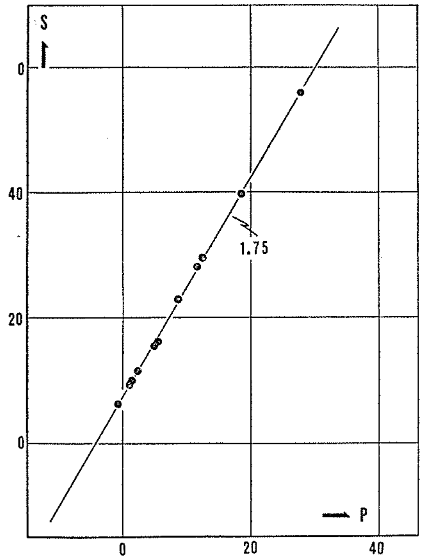


Figure for earthquake No. 15.

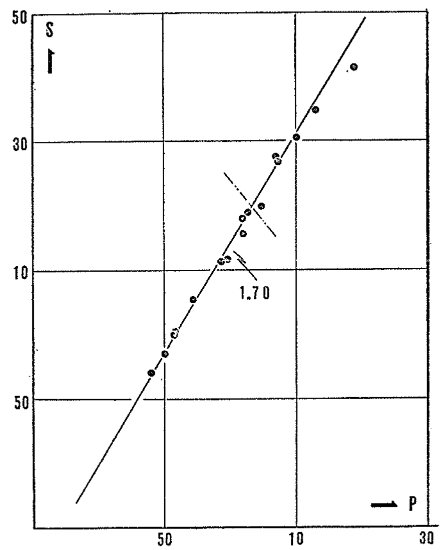


Figure for earthquake No. 16.

Table of earthquake No. 15.
57 Nov. 27ᵈ 14ʰ 24ᵐ 47ˢ *NW* part Mie Pref., *W* Honshu.
(34.7°*N*, 136.2°*E* *H*=70 km)

	Station	*P*-wave		*S*-wave		*Δ*
		Phase	Time	Phase	Time	
			m s		m s	km
F	Kameyama	*iP*	24 59.3	*iS*	25 6.3	29.6
A	Kamigamo	*iP*	25 1.2	*iS*	9.4	57.4
B	Abuyama	*iP*	1.5	*iS*	10.0	61.2
C	Hikone	*iP*	2.4	*iS*	11.5	64.9
E	Nagoya	*eP*	5.0	*iS*	15.4	87.1
D	Gifu	*iP*	5.4	*iS*	16.1	94.5
I	Sumoto	*iP*	8.7	*iS*	22.8	124.2
H	Shionomisaki	iP_Z	11.7	*iS*	28.1	144.6
	Fukui	*iP*	12.5	*iS*	29.4	150.1
J	Takamatsu	*iP*	18.7	*S*	39.6	202.0
K	Kochi	*eP*	27.9	*iS*	55.9	278.0
N	Matsuyama	*iP*	34.0	*iS*	26 6.5	328.0
O	Hiroshima	eP_Z	36.7	*iS*	12.0	348.4

Table of earthquake No. 16.
56 July 18ᵈ 0ʰ 42ᵐ 37ˢ *S* part of Tokushima Pref., Shikoku.
(33 3/4°*N*, 134 1/4°*E* *H*=0~10 km)

	Station	*P*-wave		*S*-wave		*Δ*
		Phase	Time	Phase	Time	
			m s		m s	km
	Tokushima	*iP*	42 48.2	*iS*	42 54.1	46.3
	Murotomisaki	*eP*	50.2	*iS*	57.0	55.6
J	Takamatsu	iP_N	51.6	*iS*	43 0.0	48.2
K	Kochi	*iP*	51.8	*iS*	0.5	70.4
I	Sumoto	*P*	54.5	*iS*	5.4	88.9
	Okayama	*eP*	58.8	*iS*	11.4	107.5
	Wakayama	*eP*	59.7	*eS*	11.7	100.1
N	Matsuyama	*iP*	43 1.9	eS_H	17.9	135.3

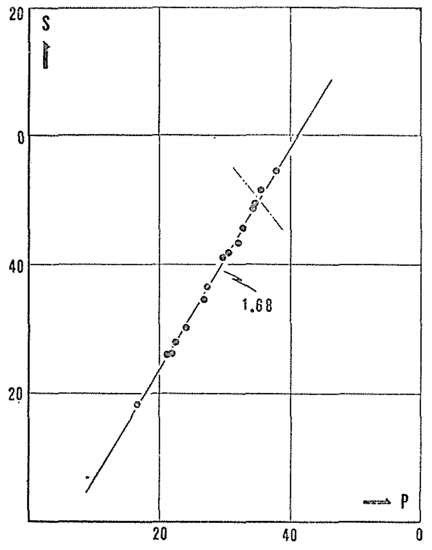


Figure for earthquake No. 17.

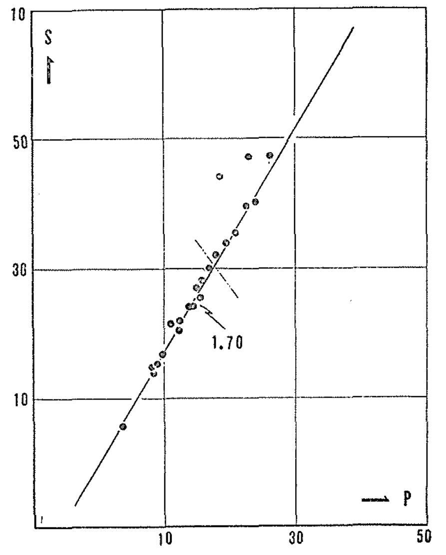


Figure for earthquake No. 18.

Table of earthquake No. 17.

58 June 17^d 16^h 20^m 12^s Awaji-shima, *W* Honshu.

(34.5°*N*, 134.9°*E* $H=0\sim10$ km)

	Station	*P*-wave		*S*-wave		Δ
		Phase	Time	Phase	Time	
			m s		m s	km
I	Sumoto	iP_{NE}	20 16.7	iS_{NEZ}	20 18.3	18.5
	Kobe	eP_{NEZ}	21.2	iS_{NEZ}	26.0	33.4
	Wakayama	iP	21.9	iS	26.2	38.9
	Himeji	iP_{NE}	22.5	iS_{NE}	28.0	40.8
	Tokushima	iP	24.1	iS	30.2	57.4
	Osaka	iP	26.9	iS	34.5	59.3
J	Takamatsu	iP	27.3	iS	36.5	81.5
	Okayama	iP	29.7	eS	41.1	92.6
	Nara	eP	30.6	iS	41.8	94.5
	Kyoto	eP	32.0	S	43.3	96.4
A	Kamigamo	iP_Z	32.8	iS_Z	45.7	100.1
	Toyooka	P_{NEZ}	34.3	iS_{NEZ}	48.6	105.6
	Maizuru	iP	34.7	iS	49.4	116.8
G	Owashi	P_{NE}	35.5	S_{NE}	51.4	127.9
H	Shionomisaki	eP_Z	37.8	eS_Z	54.4	142.7

Table of earthquake No. 18.
54 Dec. 21d 19h 31m 58s Near Kyoto, *W* Honshu.
(35.1°*N*, 135.7°*E* $H=20$ km)

	Station	*P*-wave		*S*-wave		Δ
		Phase	Time	Phase	Time	
			m s			km
	Kyoto	*eP*	32 3.7	*iS*	5.7	9.6
C	Hikone	*P*	7.9	*iS*	14.9	54.5
	Osaka	*eP*	8.2	*iS*	14.8	52.2
	Nara	*iP*	8.4	*iS*	13.6	47.9
	Maizuru	*iP*	8.9	*iS*	15.3	50.0
	Kobe	*eP*	9.8	*iS*	16.8	65.9
	Ibukiyama	eP_N	11.2	iS_N	21.6	69.7
	Tsuruga	*P*	12.3	*iS*	20.4	69.6
F	Kameyama	*iP*	12.6	*iS*	21.9	75.1
	Tsu	*P*	13.9	*S*	24.2	86.6
	Himeji	*iP*	14.6	iS_B	24.2	95.6
	Wakayama	*eP*	15.1	*eS*	27.1	107.7
	Toyooka	*eP*	15.7	*iS*	25.6	93.8
I	Sumoto	*P*	15.8	*iS*	28.2	111.0
D	Gifu	*P*	17.0	*S*	30.0	102.7

6. Poisson's ratio obtained in other districts

The estimations of Poisson's ratio are carried out in other districts. Some earthquakes tabulated below are examined. The data of the second earthquake are those observed by S. Omote (**16**). The epicenter of the third earthquake is located near Yakedake Volcano in central Honshu.

Origin Time	Location of Epicenter	Focal Depth	V_p/V_s
57 Dec. 31d 22h 30m 27s	Fukui Pref., Central Honshu.	20 ca km	1.65
48 July 29 16 1	One of the Aftershocks of the Fukui Earthquake	Shallow	1.68
58 June 24 4 51	Local Earthquake near Yakedake, Central Honshu.	Very shallow	1.58
55 Mar. 2 7 17 16	E part of Yamanashi Pref., Central Honshu.	20 ca	1.76

The values of V_p/V_s are normal in the cases of the first three earthquakes, but that of the fourth is considered to be anomalously large, being similar to the case of the Kyushu district. Namely, in the Yamanashi Prefecture, the value of V_p/V_s is larger than in the neighbouring region. It should be pursuited by a more detailed test using more abundant seismic data.

7. Some considerations on the low-velocity layer

Recently, Gutenberg stated that there are so-called low-velocity layers in the earth's crust and the upper mantle. In these layers, the *P*-velocity variation with depth is considerably different from the *S*-velocity variation and the rate of decrease in *S*-velocity is larger than in *P*-velocity (**7**).

In some regions, the depth of discontinuity estimated from the *S*-velocity is found to be greater than that estimated from the *P*-velocity. Katz represented the alternative explanation that the existence of layer with an increase of Poisson's ratio results in the different depths of discontinuity as mentioned above (**17**).

By the present investigation, it is ascertained that the layer with an anomalously large Poisson's ratio exists in the particular regions such as the Kyushu district. But the correlation between such anomaly of Poisson's ratio and the velocity variation with depth should be more investigated in future.

8. Summary

Poisson's ratio in the earth's crust is investigated, especially in relation to their local character. The *P*-*S* diagram method is effectively employed. Considering the correlation of the value of V_p/V_s with the focal depth of each earthquake, the mean straight lines in this diagram are drawn respectively and the anomalously large value of V_p/V_s which is calculated as from about 1.80 to 1.85 was found in the Kyushu district. The anomalous domain is considered to be situated at depths from about 20 km to 40 km in the earth's crust. The amplitude and period of seismic waves transmitted through this anomalous domain, the velocity variation with depth in this domain and others should be investigated in near future.

Moreover, the secular variation of seismic wave velocities are reported by some investigators. The value of V_p/V_s may probably vary with time. From those stand-points of view, further research of V_p/V_s is considered to be one of the effective and important methods to increase our knowledge on the nature of the earth's crust.

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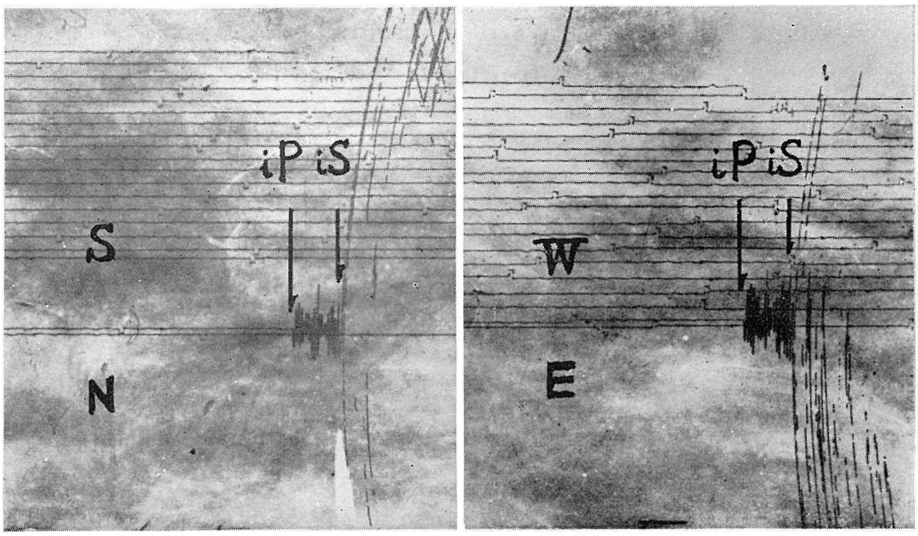

Fig. 3. The horizontal seismograms of earthquake No. 1 recorded at Matsuyama ($\triangle$=81.5 km, in Shikoku). The constants of Wiechert seismograph are as follows (Magnification=70, Period=5.0 s Damping ratio=5).

(By the courtesy of the Matsuyama Meteorological Observatory)

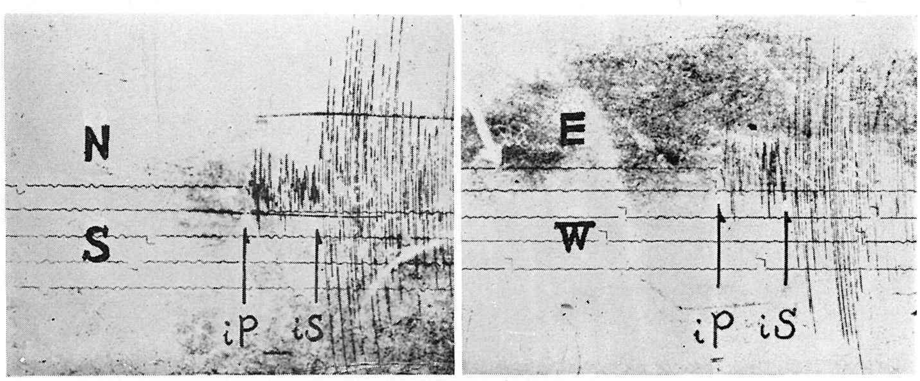

Fig. 4. The horizontal seismograms of earthquake No. 1 recorded at Kumamoto ($\triangle$=148.3 km in Kyushu). The constants of Wiechert seismograph are as follows (Magnification=80, Period=4.8 s, Damping ratio=6).

(By the courtesy of the Kumamoto Meteorological Observatory)