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24. *Rayleigh Wave Dispersions across the Oceanic Basin around Japan (Part II).*

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1. Introduction

In the previous paper,[1] the writer investigated the dispersion of Rayleigh waves which passed through the various oceanic paths around Japan.

Fig. 1. Epicenters and travelling paths of Rayleigh waves across the oceanic basin. The epicenters newly added and of the previous ones are represented by black and white circles respectively.

1) T. A. SANTÔ, "Observation of Surface Waves by Columbia-type Seismograph Installed at Tsukuba Station, Japan (Part I).—Rayleigh Wave Dispersions across the Oceanic Basin—," *Bull. Earthq. Res. Inst.*, **38** (1960), 237.

Table 1.

No.	District	Epicenter (λ, φ)		Date		Origin Time (G.M.T.)			Mag.
						h	m	s	
78	Kamchatka	63N,	160E	Oct.	10,58	08	30	19	
* 120	Mariana Is.	19.5N,	145.5E	Aug.	14,58	02	28	25	
* 117	〃	21.5N,	143.5E	Jan.	31,60	03	34	42	
* 118	〃	22N,	144E	Jan.	30,60	18	38	10	
* 119	〃	21.5N,	142.5E	〃	〃	17	56	05	
* 104	Galapagos Is.	4.5S,	104.5W	Aug.	27,58	02	25	32	
* 124	Peru	15S,	75W	Jan.	15,60	09	30	24	6.5
27	Northern Chile	21S,	69W	July	11,58	19	10	20	6.5
18	Pacific Ocean	5S,	106.5W	July	12,58	00	48	30	
30	Chile-Argentin	33.5S,	69.5W	Sept.	4,58	21	51	08	7
10	Kermadec Is.	29S,	176.5W	Sept.	29,59	15	41	57	6.5
* 127	Loyality Is.	22.5S,	174E	Mar.	30,60	15	19	30	
* 128	Fiji Is.	19.5S,	174.5E	Nov.	28,59	02	45	45	
56	Molluca Passage	2N,	126.5E	July	22,59	20	15	33	
77	Mindanao I.	7N,	126.5E	Sept.	11,58	18	01	45	
* 101	Celebes I.	1S,	123E	Dec.	02,59	09	34	00	6.55
* 125	Helmahera I.	1N,	129E	Mar.	06,60	02	22	06	
* 112	South Pac. Ocean	54S,	136W	Nov.	22,59	16	26	34	
* 113	〃	57S,	147.5W	Nov.	29,59	19	17	40	
* 105	Drake Passage	58S,	67W	Feb.	08,60	12	45	34	
* 116	Santa Cruz Is.	11.5S,	166.5E	Feb.	11,60	20	56	08	
* 111	New Zealand	42S,	173E	Feb.	21,60	00	46	56	
* 121	Solomon Is.	7.5S,	156E	Feb.	24,60	21	37	05	
* 114	Ceram Is.	4S,	127.5E	Jan.	23,60	04	40	56	6.5
* 115	〃	〃	〃	〃	〃	17	56	30	6.5
33	Antarctic Ocean	57S,	147E	Oct.	01,58	09	29	43	7
* 90	Balleny Is. region	63S,	154E	Dec.	01,59	14	59	40	
21	New Guinea	3.5S,	135.5E	May	01,59	07	19	16	
* 126	〃	3S,	138E	Mar.	19,60	19	15	37	
20	Ecuador-Peru border	3S,	77W	May	25,58	21	11	45	6.5
* 92	Costa Rica	8N,	85W	June	06,58	09	11	18	6.75
* 105	〃	5.5N,	82.5W	〃	〃	19	15	28	6
* 122	Panama	7.5N,	82W	Mar.	28,60	00	13	38	
* 123	Jalisco	20N,	105.5W	May	28,60	20	15	46	

* Newly added shocks.

Through the previous investigations, two important facts were observed. The first one was that the dispersions of Rayleigh waves with the paths across northern and eastern Pacific Ocean were quite the same as each other, while they gradually became continental when the path shifts from southern to western part. The second fact was that the dispersion of Rayleigh waves which passed near or over the series of volcanic islands beside trenches showed remarkable difference from the dispersion with the other ordinary oceanic paths. We called the former dispersive feature "B type" and the latter "A type."

After the first paper was written, the writer was able to study the dispersion of Rayleigh waves due to twenty-four shocks which also passed across the various regions of oceanic basin and reaffirm these conclusions.

As before, the vertical component records of Columbia type seismographs at Tsukuba Station were used. The epicenters, dates and other data of shocks used in this second paper are given in Table 1. The locations of the epicenters, the travelling paths of Rayleigh waves used in the present paper are shown in Fig. 1 together with those of the former ones.

2. Dispersions of Rayleigh waves due to the shocks of Mariana Islands

In the previous paper, the writer investigated the dispersion of Rayleigh waves which partly passed through the series of volcanic islands region such as Mariana Islands, Volcano Islands and Bonin Islands, and suggested that the dispersion curve of Rayleigh waves through the path from Mariana Islands to central Japan would belong to the "B type" and be the same as that from eastern coast of Kamchatka to central Japan. Recently, the writer was able to obtain the dispersion curve of Rayleigh waves due to four Mariana Islands shocks and reaffirm the previous suggestion.

The results are shown in Fig. 2, in which the dispersion data of Rayleigh waves due to the Kamchatka shock (78) are represented by white circles. This figure shows that the Rayleigh wave dispersion due to the Mariana Islands shock (120) resembles well that due to the Kamchatka shocks. Further, it is interesting that the dispersive character of these four Mariana Islands shocks shows the same nature as those due to the Kurile Islands shocks. That is, just as was the case of the Kurile Islands shocks,[2] the dispersive character due to each shock

2) *loc. cit.* 1). p. 232.

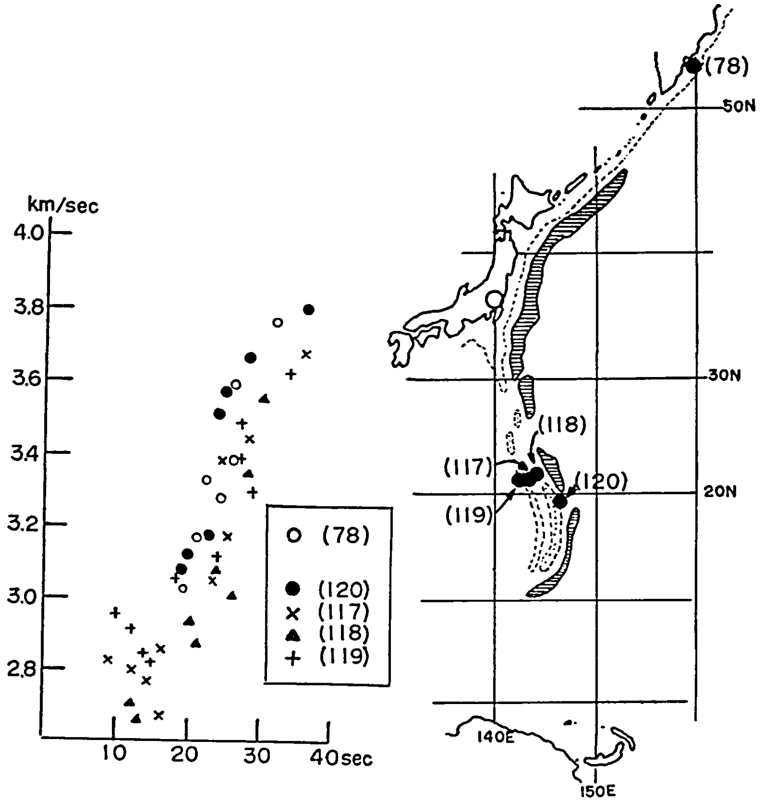


Fig. 2. Epicenters of the Mariana Islands shocks and group velocities of Rayleigh waves due to them. The dispersion data due to the Kamchatka shock (78) are also represented for comparison.

differs very much in spite of rather compact distribution of their epicenters. Though research into the cause of these facts has to be postponed to the future, it must be remarked here that this fact was obtained for the same condition when the epicenters and the travelling paths of Rayleigh waves are both located closely beside the trenches.

3. Additional dispersion data for the paths across the northern, central and eastern Pacific Ocean

Adding the new dispersion data due to the shocks of Galapagos Islands (104) and Peru (124), the dispersion of Rayleigh waves through the northern, central and eastern Pacific Ocean can be summarized in Fig. 3. As is well recognized in this figure, they lie on one smooth

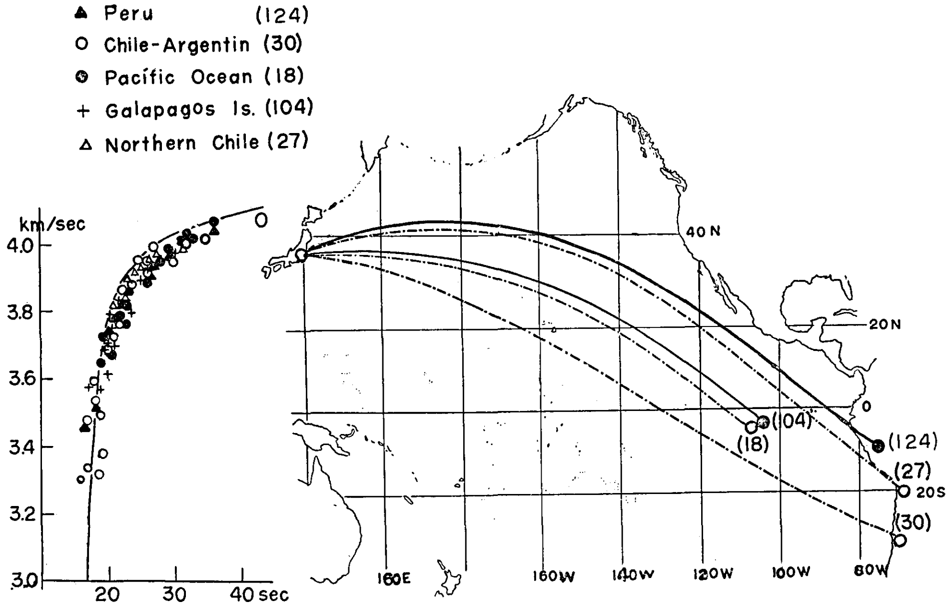


Fig. 3. Left: Dispersive characters of Rayleigh waves for the paths in the northern Pacific Ocean.

Right: Epicenters (black circles) and travelling paths (solid curves) newly studied and those for the previous ones (white circles and broken curves respectively).

curve which lies quite near the theoretical curve (O) of oceanic ones,[3] which fact tells us that the average crustal structures of these regions are all the same and typically oceanic.

4. Dispersion of Rayleigh waves due to the South Pacific Ocean shocks

Dispersion of Rayleigh waves due to two shocks in South Pacific Ocean (112, 113) shows, as is seen in Fig. 4, a slight difference from those due to the Central Pacific Ocean shocks. These are similar to the dispersion curve due to the shocks of Samoa Islands, which was given in the previous paper. It must be noticed that they are also similar to the dispersion obtained by M. Ewing and F. Press[4] for the path

3) W. S. JARDETZKY, F. PRESS, "Crustal Structure and Surface Wave Dispersion, Part III; Theoretical Dispersion Curves for Suboceanic Rayleigh Waves," *Bull. Seis. Soc. Amer.*, **43** (1953), 137.

4) M. EWING, F. PRESS, "Crustal Structure and Surface-Wave Dispersion Part II: Solomon Islands Earthquake of July 29 1950," *Bull. Seis. Soc. Amer.*, **24** (1952), 315.

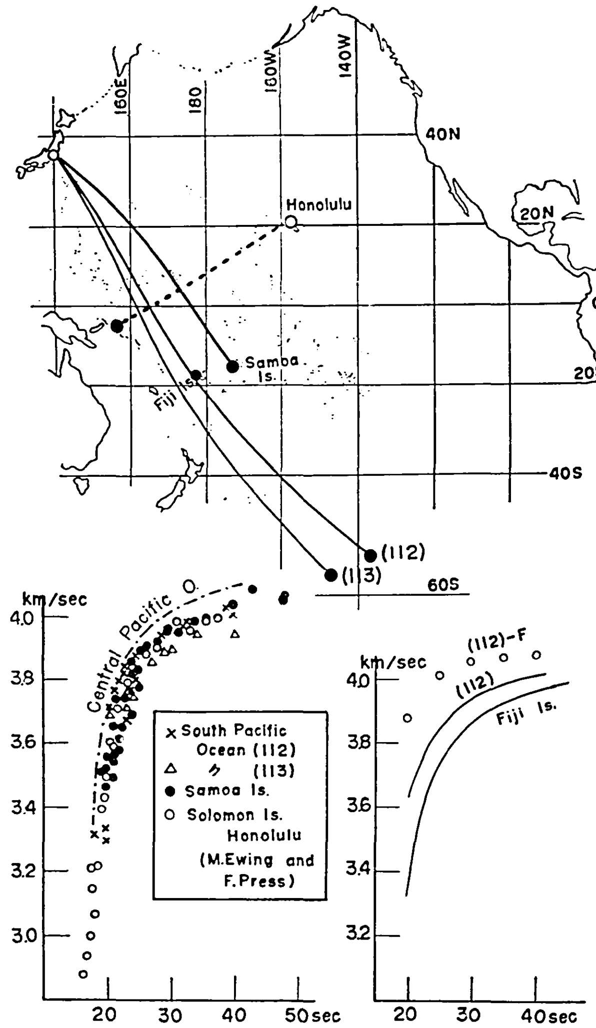


Fig. 4. Dispersive characters of Rayleigh waves due to two South Pacific Ocean shocks (112) and (113). Dispersion data and travelling paths for the Solomon Islands shock and for the Samoa Islands shock are also shown for comparison. White circles in the right figure mean the group velocities obtained by subtracting the travel times for the Fiji Islands shock from those for the shock (112).

from Solomon Islands to Honolulu. From these results, we may suggest that the slight departure of these dispersions from the Central Pacific ones may be caused by the different crustal structure beneath the small islands region (Micronesia, Melanesia and Polynesia) from other Pacific basins. Taking the difference of the travel times of Rayleigh waves from the epicenter (112) and that from the Fiji Islands to Tsukuba Station, we can find a dispersion curve along the remainder part, from (112) to the Fiji Islands. The result is given by white circles in the right figure of 4, which resembles those of the Central Pacific Ocean. Considering that this remainder part does not contain any small islands, this result supports our suggestion given above.

5. Dispersion of Rayleigh waves for the southern Pacific Ocean

The Drake Passage shock (105) gave us information about the crustal structure beneath the southern Pacific Ocean. As is seen in Fig. 5, the dispersion along the path from the epicenter (105) to Tsukuba lies

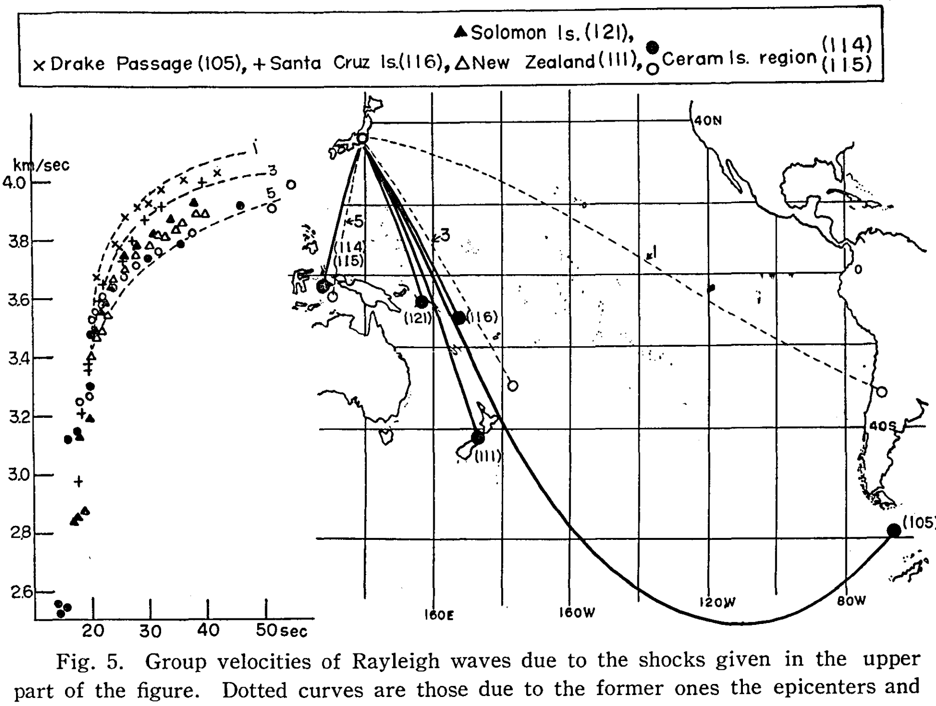


Fig. 5. Group velocities of Rayleigh waves due to the shocks given in the upper part of the figure. Dotted curves are those due to the former ones the epicenters and travelling courses of which are represented in the right map.

quite near the curve 1 (for central or northern Pacific Ocean). On the other hand, the dispersive character due to the Santa Cruz Islands shock (116) resembles the dispersion curve 3 which was obtained previously by the Kermadec Islands shocks. (The path is represented by a broken line in the map.) From these facts, we can suggest that the dispersion curve along the path from the epicenter (105) to (116) must be as oceanic as the curve 1. It means that the crust of the earth along the path from the epicenter (105) to (116) is as thin as northern or central Pacific Ocean.

The Ceram Island shocks (114) and (115) show the same dispersive character of Rayleigh waves as the Banda Sea shocks, the path of which is represented by a broken line 5. The New Zealand shock (111) and the Solomon Islands shock (121), however, show the dispersive characters between the curves 3 and 5, which well obey the tendency previously reported.

Fig. 6 shows the following two facts. That is:

1) The dispersive character of Rayleigh waves as well as Love waves due to the Balleny Islands region shock (90) resembles very well those due to the Antarctic shock (33) which was previously obtained, and further, Rayleigh wave dispersions are both nearly equal to the rather continental curve 6 corresponding to that due to the Java Island shock. As these paths run through the continental part of New Guinea and Australia, these results are reasonable.

2) The new dispersion data of Rayleigh waves due to the New Guinea shock (126) also resembles those due to the shock (21) obtained previously, and both lie near the curve 4. Fig. 7 was drawn for the same purpose as Fig. 6. In this figure, we can also recognize that the dispersion curves of Rayleigh waves due to the Fiji Islands shock (128) and the Loyality Islands shock (127) lie both on the curve due to the Kermadec Islands shock (10), and that due to the Selebes Island shock (101) lies on the curve due to the Molluca Passage shock (56). Another fact must be noticed here on the dispersion data due to the Helmahera Island shock (125). That is, if the dispersive character due to this shock obeys the general tendency that the dispersive character gradually becomes a continental one with the shift of travelling paths to the west, the dispersion data due to the shock (125) must be similar to those due to the shocks (56) or (101). Nevertheless, they lie on a rather oceanic curve due to the shocks of (127) or (128) which are much more eastward. A similar fact was previously observed for the Mindanao Island shock (77).[5]

5) *loc. cit.* 1). p. 228.

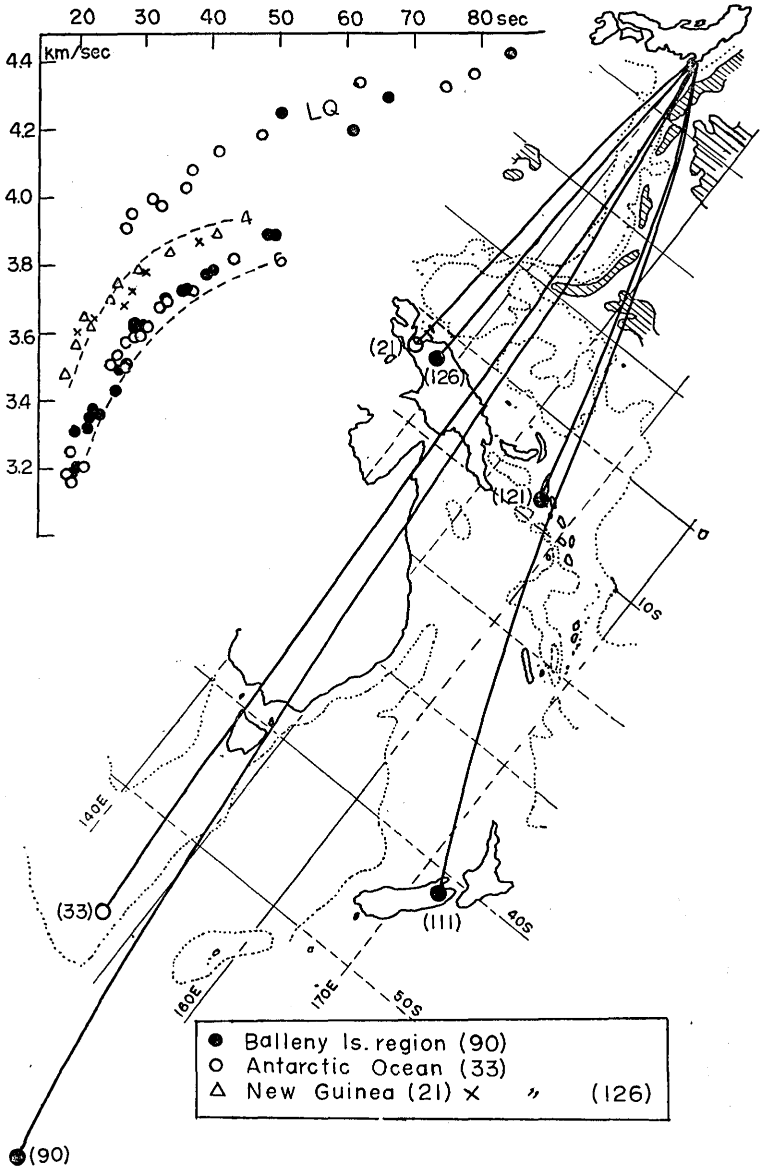


Fig. 6. Dispersions of Rayleigh waves due to two shocks (90) and (126). They are similar to the previous ones due to the shocks (33) and (21) respectively. Dispersion data of Love waves due to (33) and (90) are also represented for reference. In the map, hatched regions are the deep sea with more than 6km depth, and dotted curves mean the counter lines of 2km depth.

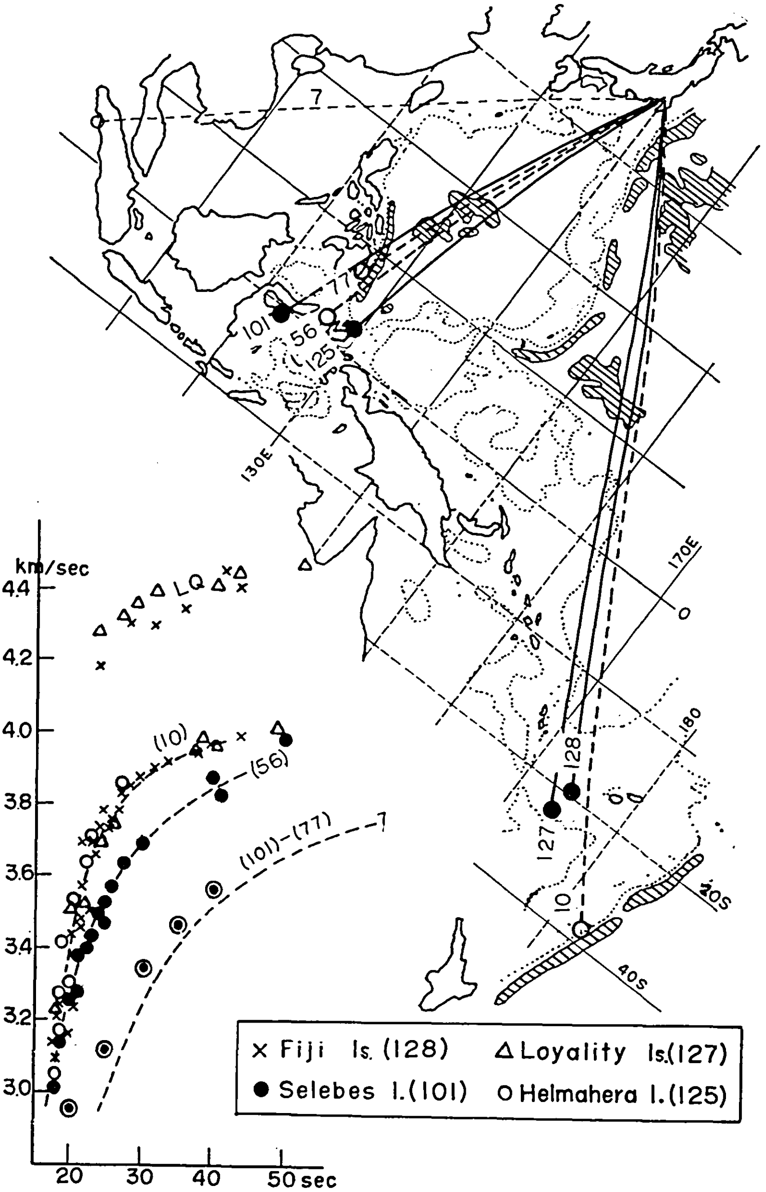


Fig. 7. Dispersions of Rayleigh waves due to two shocks (127) and (128), and those due to the shock (101). The former two resemble that due to the Kermadec Islands shock (10) and the last one resembles that due to the Molluca Passage shock (56).

The dispersion due to the shock (125) resembles those due to the shock 10 (uppermost broken curve) though the path lies western.

This feature is reasonable, because the travelling courses of Rayleigh waves due to these two shocks, as are seen in Fig. 7, contain a deep sea region more than any other courses in the same region.

By using the two dispersion curves due to the shocks (101) and (77) (they are approximately equall to the curves (56) and (10) respectively), we can obtain the new dispersion curve along the path from Selebes Island to Mindanao Island. The result is shown by a broken curve in Fig. 7, which lies near the most continental curve of 7 (from Sumatra Island to Tsukuba Station).

As will be understood by the above descriptions, all the data of Rayleigh wave dispersions newly obtained satisfy very well the conclusions given in the previous paper.

6. Dispersion of Rayleigh waves which traverse the Sierra Madre Mountains

Two shocks which took place off the coast of Costa Rica (92 and 100) offered us an interesting fact on the dispersion of Rayleigh wave which traverse the Sierra Madre Mountains region. The wave forms due to these two shocks are shown in Fig. 8. The beginnings of Love (LQ) and Rayleigh waves (LR), though somewhat disturbed, are represented together with other phases, PP, PPP, PKKP ··· etc.

Trying to make a dispersion curve of Rayleigh waves from these records, an interesting fact was found. That is, they contain the third dispersive wave trains remarkably later than the ordinary Rayleigh wave trains. These unexpected dispersion data are shown by the lowermost points in Fig. 9a, and the beginnings of these wave trains are marked by black circles on every record in Fig. 8.

As will be noticed in Fig. 9a, these dispersion data (the lowermost ones) lie more regularly than those of the ordinary Rayleigh waves (the middle dispersion data) in the same figure.

In order to affirm this peculiar fact, we examined the records of the same shocks which were obtained by a Galitzin type seismograph at Matsushiro Observatory, Meteorological Agency, Japan. The record of EW component for the shock (92) was also shown in Fig. 8. (Regrettable to say, the records of the other two components for this shock are missing on account of some defects on the instruments, and the traces for the shock (100) were too small). From this record, the same results were observed. The dispersion data by this record are also added

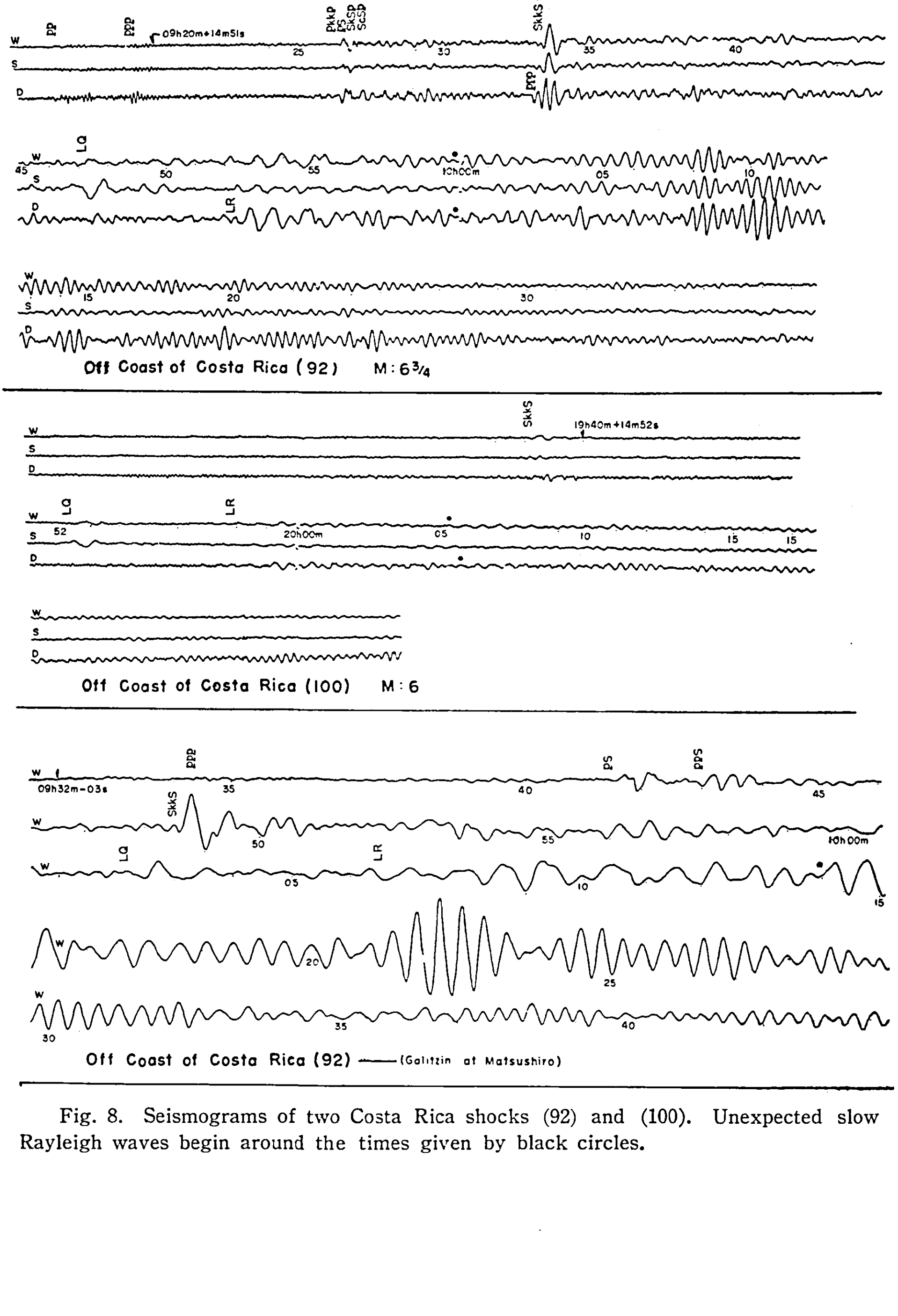
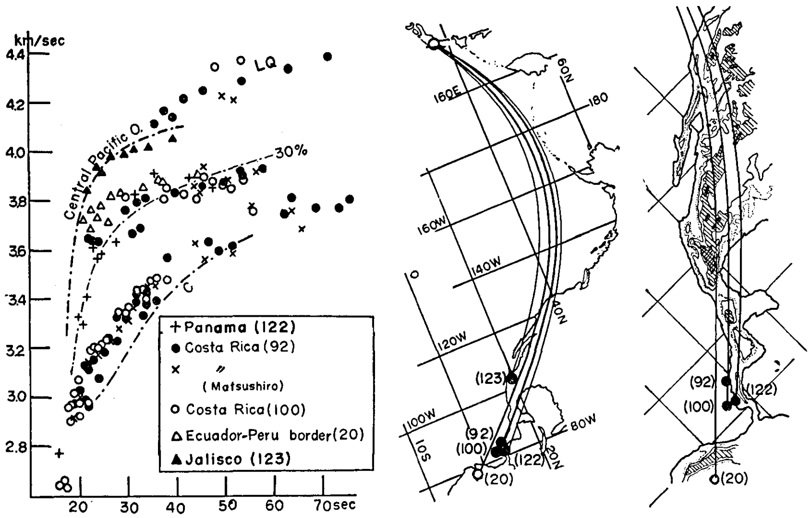


Fig. 8. Seismograms of two Costa Rica shocks (92) and (100). Unexpected slow Rayleigh waves begin around the times given by black circles.



a b c

Fig. 9a. Dispersions of Rayleigh waves which passed the mountain region in Mexico. Dispersion of Love waves and two kinds of Rayleigh waves due to two Costa Rica shocks are respectively shown as the uppermost, middle and lowermost dispersion data marked by circles. Ordinary Rayleigh wave dispersions for these shocks together with those for other shocks, are reasonably distributed around a 30% continental curve.

Fig. 9b. Travelling paths of Rayleigh waves which passed around the mountain region in Mexico.

Fig. 9c. Detail map of Sierra Madre Mountains region and three travelling paths. Hatched and double hatched regions respectively mean those of more than 2km and 4km in height.

in Fig. 9a by X marks.

In Fig. 9b, three other travelling paths of Rayleigh waves due to three shocks of Jalisco (123), Ecuador-Peru border (20) and Panama (122) are shown. As is seen, these paths lie near the ones for the Costa Rica shocks.

Along the first path for (123) which mostly passes through northern Pacific Ocean, dispersion data of Rayleigh waves (black triangles) lie just on the purely oceanic one. Along the latter two paths for (20) and (122) which run on both sides of the path for the Costa Rica shocks, the dispersion data of Rayleigh waves (white triangles and crosses) are distributed around the curve for 30% continental and 70% oceanic crustal structure. (This curve was calculated in the previous paper.[6]). The Costa Rica shocks also give the dispersion data on the same curve. These

6) *loc. cit.* 1). p. 238.

results are all easily expected. Here is, however, an unexpected fact that only the Costa Rica shocks show, as is seen in Fig. 9a, other dispersion curve of Rayleigh waves which lie near a rather continental one in spite of their 70% oceanic paths.

One explanation for this fact is to consider that these slow waves did not travel along the shortest path, but along other paths due to some causes, for instance being diffracted by the abrupt change of crustal structure in the high Mountain region. If this was the case, along what path did they travel? One method to obtain information on this problem is to examine the direction of the ground movement due to these waves. As these waves are dispersive and appeared well on vertical records, they are surely Rayleigh type. Therefore, the directions of ground movement must show the coming direction of these waves. This was examined in two horizontal records. However, the ground movement changes its direction from time to time and the writer could not obtain any decisive conclusions on this point. It can be recognized for instance, by the phase relations of two horizontal records due to the shock (92) in Fig. 8, that their directions are approximately EN–WS around 10h 04m, 10m to 11m, while ES–WN around from 10h 07m to 09m.

Fig. 9c was drawn to find some special conditions, if any, along the paths for the Costa Rica shocks. From this map, however, it is hard to find any special condition about the travelling paths. Two neighboring paths for the shocks (20) and (122) were also added, and the path for the shock (20) showed a special feature in traversing the steep inclined region beside the Sierra Madre Mountains. The dispersive character of Rayleigh waves due to this shock (20) is shown in Fig. 9a by white triangles, from which we can see some departure from others in short period range. At present, it is also difficult, to explain this special character.

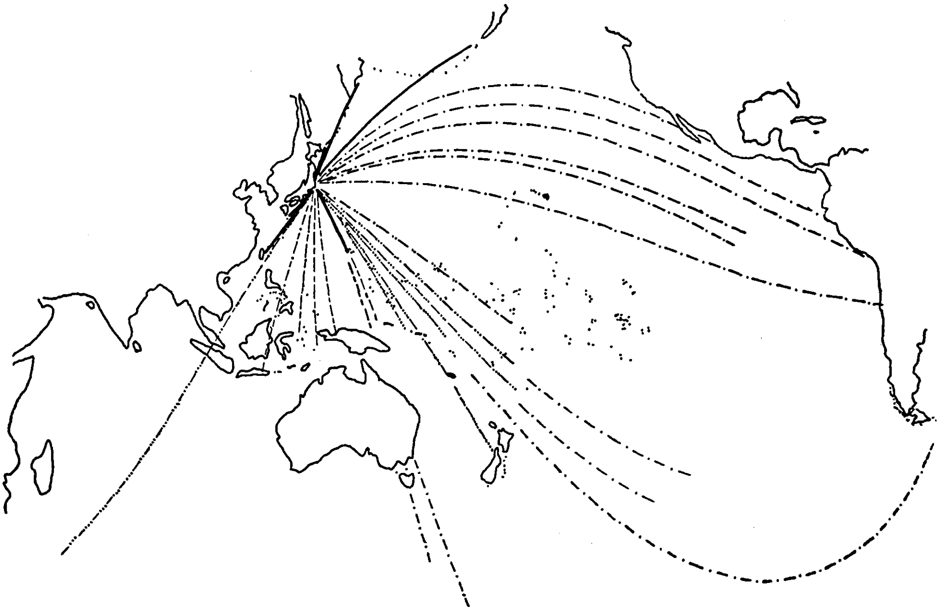
In any case, we may say that Rayleigh waves take some peculiar travelling path when they traverse high mountain regions.

7. Conclusions

Dispersion of Rayleigh waves due to twenty-four shocks across the oceanic basin were added to the previous study.

We found two important conclusions in the previous paper, that is:

1) The dispersions of Rayleigh waves across the northern, central



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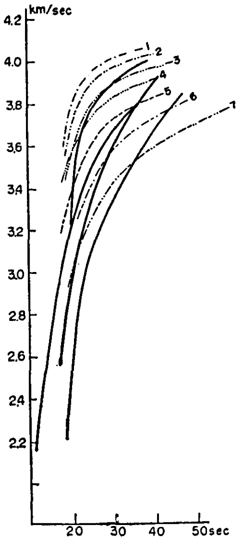

b

Fig. 10. Classification of the travelling paths of Rayleigh waves across the oceanic basin according to the dispersive character along them. (a). The dispersion curves corresponding to each kind of path are represented in (b) by the same marks as in (a). Solid curves correspond to "B type".

and eastern part of the Pacific Ocean were all quite the same as each other, while they gradually became continental ones when the paths shift to the west.

2) The dispersive character of Rayleigh waves which traverse the volcanic islands regions beside trenches showed remarkable difference from others which passed across the ordinary oceanic basins.

These conclusions are all well satisfied by the newly added data of Rayleigh wave dispersions. (They are summerized in Fig. 10.)

Moreover, it is suggested in the present study that the departure of dispersion curves for the southern Pacific Ocean from purely oceanic ones may be influenced by the thicker crustal structures beneath the Micronesia, Polinesia and Melanesia regions.

Other interesting facts as follows, are added:

1) The dispersive feature of Rayleigh waves due to four shocks which took place in Mariana Islands beside Mariana Trench shows the same feature as those due to eighteen shocks in Kurile Islands beside Kurile Trench. This feature is that the dispersive characters differ much from one another in spite of the rather compact distribution of their epicenters. These peculiar phenomena seem to be caused from their paths whether they lie closely to the trenches or not.

2) Two Costa Rica shocks show the slow Rayleigh wave trains which cannot be considered to have travelled along the shortest course.

3) The group velocities of Rayleigh waves which traverse the sharp slope region beside Sierra Madre Mountains are much higher, in the shorter period range, than those with neighboring paths.

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24. 海洋底を伝わるレーリー波の分散 (第二報)

地震研究所　三　東　哲　夫

前論文で，筆者は種々の海洋径路をとつて日本にやつてくるレーリー波の分散の相異を約 60 ケの地震について調べた．その結果，

1) 北部および中部太平洋を通つてくるレーリー波の分散にはお互いにほとんど差が見られないが，径路が段々西に移つて，ポリネシヤ，ミクロネシヤ等の小群島地域を通るようになると，だんだん変化が生じ，更に径路が西に移るにつれて，分散は次第に陸的なものに近づいてゆくこと．

2) 海溝にそつた火山列島の附近を縦走するレーリー波は，それ以外の普通の海洋底を通るそれ

らとは著しく様子のちがつた分散を示すこと．

等を発見した．

今回，更にその後の 24 ケの地震についてのレーリー波の分散を調べたが．やはり，上に述べた観測事実に間違いのないことが分つた．

更に，今度新しく得られた注目すべき結果は，メキシコのシエラマドレ山脈の近くを縦走してくるレーリー波の分散のうち，コスタ・リカ地方で起つた二つの地震の場合（第 8 図）に，通常の大圏コースを通つて来たとして話が合うレーリー波とは別に，これよりもかなりおくれて，むしろより以上きれいな分散性を示すレーリー波が記録された（第 9a 図）ということである．これらのレーリー波は，その走時から考えると，大圏コース以外の径路を通つてやつて来たものと考えざるをえないが，どんな路を，そして何故に，という点は今の段階では分らない．