On the Surface Waves of Aleutian, Alaska and Philippine Earthquakes

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On the Surface Waves of Aleutian, Alaska and Philippine Earthquakes

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Abstract

As a continuation of the previous study on Kamchatka and Formosa earthquakes, the dispersion of surface waves of earthquakes with larger epicentral distances are studied. The surface waves of Philippine earthquakes gives the crustal structure similar to the case of Formosa earthquakes. Aleutian earthquakes indicate a rather oceanic feature, although it is slightly different from the perfectly oceanic structure. This is in striking contrast to the Kamchatka earthquakes, which gives the continental crust with slightly less thickness than that of the perfect continent. The difference is due to the slight difference in the propagation path. Therefore the regions concerned are located just in the transient area from the continent to the ocean.

L_3 waves with a Love type orbit and a lower velocity than that of fundamental Love waves might be the Airy phase of higher mode of Love waves. No L_g waves are seen in every case even when the path is continental.

1 Introduction

In the previous paper (SUZUKI and ISHIDA, 1961) the surface waves of Kamchatka earthquakes were studied to elucidate the crustal structure in the boundary region between the continent and the ocean. Both the dispersions of the fundamental Rayleigh and Love waves of the above earthquakes were explained fairly well by NAGAMUNE's theoretical curve (NAGAMUNE, 1956), which was computed for the crust with the thickness of 22 Km. As well known, the crustal structures in various regions of the world can be generally classified into two types, i.e., the oceanic type characterized by a very thin, less than 10 Km, crust and the continental one corresponding to the crust of about 35 Km thick. According to the classification, the structure in the region from Kamchatka to Japan has a continental feature, although the thickness of the crust is comparatively less than that in the perfectly continental regions. The surface waves of the Formosa earthquake, which was also studied in the previous paper, indicated that the region from Formosa to Japan is also continental. A similar investigation will be made in this paper for the earthquakes with larger epicentral distances from Sendai, Japan, than those in the previous cases.

2 Materials used

The data of this study are based on the IGY observations by the long period electromagnetic seismograph at the Seismological Observatory, Tôhoku University, Sendai, Japan. The characteristics of the instrument and the exact location of the

Observatory were stated in the previous paper.

Five earthquakes are selected for the present purpose. Two of them are located in Aleutian region, one in Alaska and the other two are Philippine earthquakes. The minute data of these earthquakes are listed in Table I, in which the column "No." indicates the serial number assigned in the "List of earthquakes of IGY" published by the Japanese Meteorological Agency.

Table 1 Selected earthquakes.

No.	Date			Origin Time (GMT)			Epicenter	Epicentral Distance
85	1957	9	24	08	21	05	Near south coast of Mindanao, 5.5N. 127E.	35.0°
198	1958	2	27	23	27	49	Batan Is. region, 21N. 120E.	24.5°
257	1958	6	12	20	52	57	Fox Island, 53N. 167W.	38.5°
294	1958	8	14	14	55	10	Andreanof Island, 52N. 175W.	33.5°
209	1958	4	7	15	30	38	Alaska, 66.5N. 157 W.	44.5°

The locations of epicenters and the Observatory are seen in the geographical map of Fig. 1. The great circle paths for these earthquakes, together with those for the Kamchatka and Formosa earthquakes, are also given in Fig. 1. The surface waves of all the earthquakes in concern traverse the boundary region between the continent and the ocean, as is directly seen in the map. Exactly speaking, the paths for the Aleutian and Philippine earthquakes are slightly deflected towards the oceanic side in comparison with the paths for the Kamchatka and Formosa earthquakes respectively. On the other hand, the nearer portion of the path for the Alaska

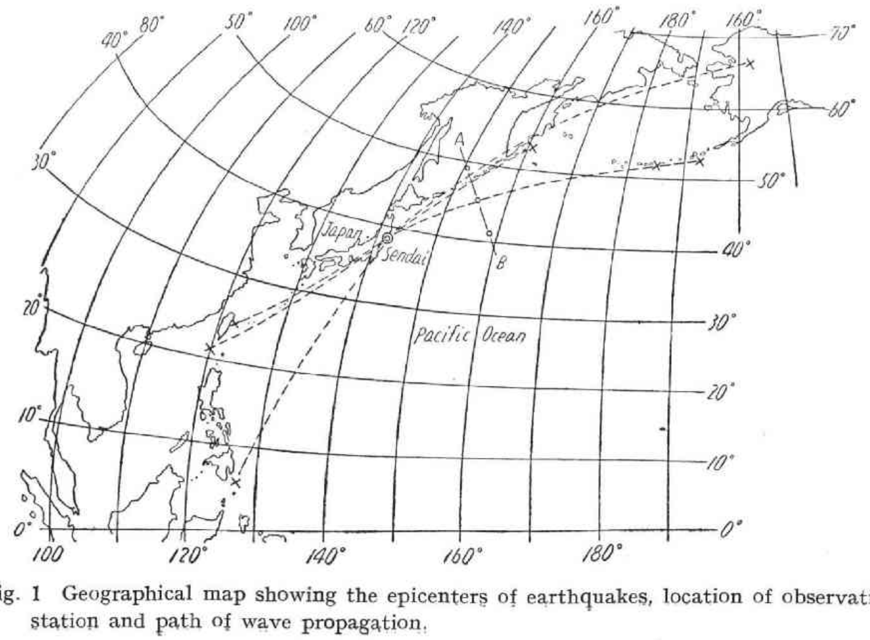

Fig. 1 Geographical map showing the epicenters of earthquakes, location of observation station and path of wave propagation.

earthquake is almost overlapped with that for the Kamchatka earthquake. The Alaska earthquake, therefore, is available for the examination of the difference in dispersion, if it be, according to this deflection of the path.

3 Philippine earthquakes

At first the surface waves of the Philippine earthquakes are discussed in the similar way to the previous cases. Three distinguished wave-groups of L_R, L_Q and L_3 are picked up from the seismograms. The examination of orbital motions for each group shows that L_R and L_Q are the fundamental Rayleigh and Love waves respectively. The group of L_3, which was found only in the case of the earthquake on Feb. 27, 1958, has an orbit of Love type but the velocity is lower than that of L_Q. Therefore, this group is taken to be the same type of waves as that noted by the same symbol in the case of the Kamchatka and Formosa earthquakes.

According to the procedure stated in the previous paper, the group velocities calculated for the three kinds of waves are plotted in Fig. 2 against the period of waves in abscissa. Full circles, hollow circles and crosses in the figure represent the data for L_Q, L_R and L_3 groups respectively. Some representative theoretical curves are also given in the figure for reference's sake. Curve (a) (EWING and PRESS, 1952) shows the dispersion of Rayleigh waves for the perfectly oceanic crust, curve (b) and (b') (BRILLIANT and PRESS, 1954) represent the Rayleigh and Love wave dispersions for

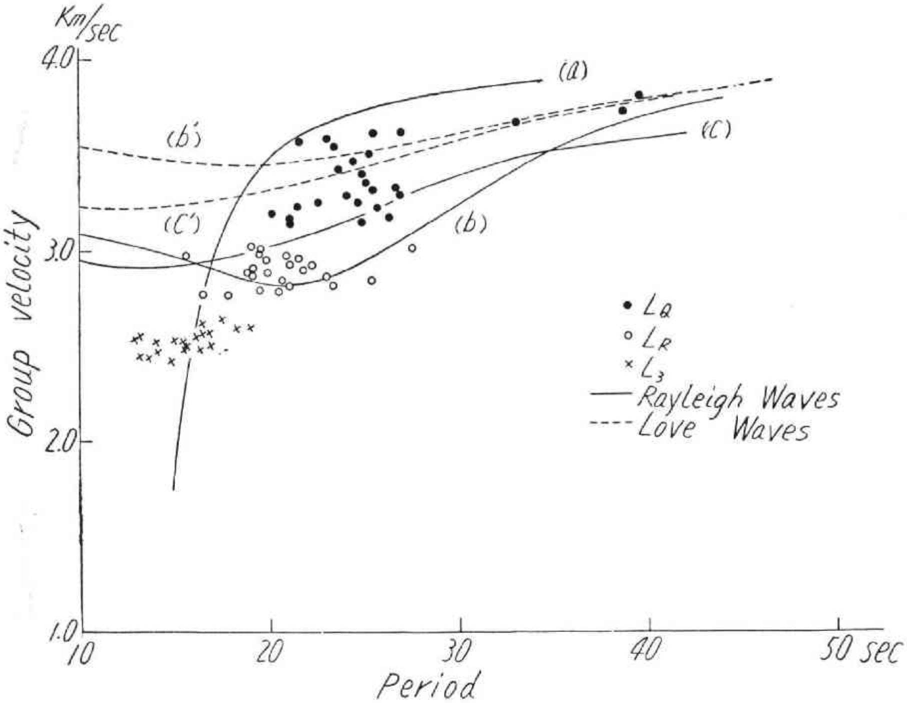

Fig. 2 The dispersion of surface waves of Philippine earthquakes.

the perfectly continental structure, and (c) and (c') are the curves computed by NAGAMUNE (1956) for the crust of 22 Km thick. The last case corresponds to the continental structure with rather thin crust. The numerical data in each case is seen in Fig. 3.

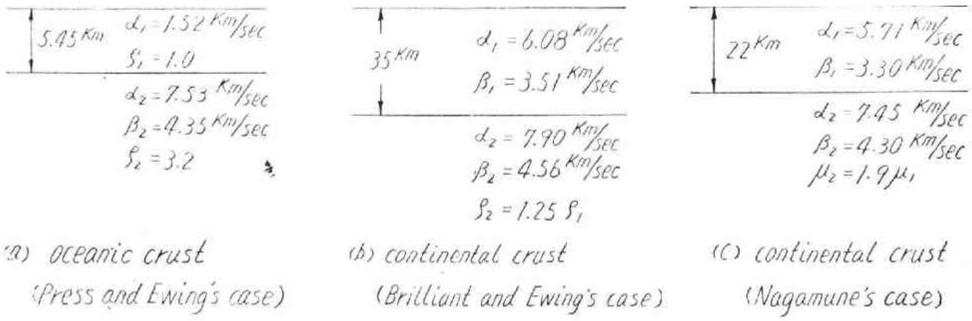

Fig. 3 The crutsal structures assumed in the computation of dispersion curves.

The comparison of observations with theoretical curves indicates that the Rayleigh waves of Philippine earthquakes are well explained by the typical continental curst of 35 Km in thickness. However, the dispersion of Love waves agrees with the NAGAMUNE's curve better than the perfectly continental one. It is possible to obtain the structure which gives the dispersion in accordance with the observation of both Rayleigh and Love waves. However, the tedious calculations are not attempted in this paper, because the data are so scattered that an accurate solution may not be expected.

Nevertheless, it is safely concluded that the region from the Philippines to Japan has a continental feature according to the general classification stated previously, the thickness of the crust being probably 30 Km of the order of magnitude. This is the case of the Formosa of earthquakes in the previous study. Although the Formosa and Philippine islands are geographically situated in the sea, this conclusion is reasonably accepted from the geological view point.

4 Aleutian earthquakes

The dispersion of Aleutian earthquakes is seen in Fig. 4, in which the full and hollow circles represent the Rayleigh and Love waves respectively. No L_3 waves are found in this case. The data for Kamchatka earthquakes studied in the previous paper are reproduced in Fig. 5 for comparison. The theoretical curves by EWING and PRESS (1952) and by NAGAMUNE (1956) are also shown by the curves of (a) and (b) respectively. The former corresponds to the typical occeanic structure and the latter to the continental structure with a rather thin crust.

As is seen in Fig. 4, the data for Rayleigh waves of Aleutian earthquakes are far apart from the NAGAMUNE's curve, which fits the observation in the case of the Kamchatka earthquakes. The typical oceanic dispersion can not sufficiently explain the

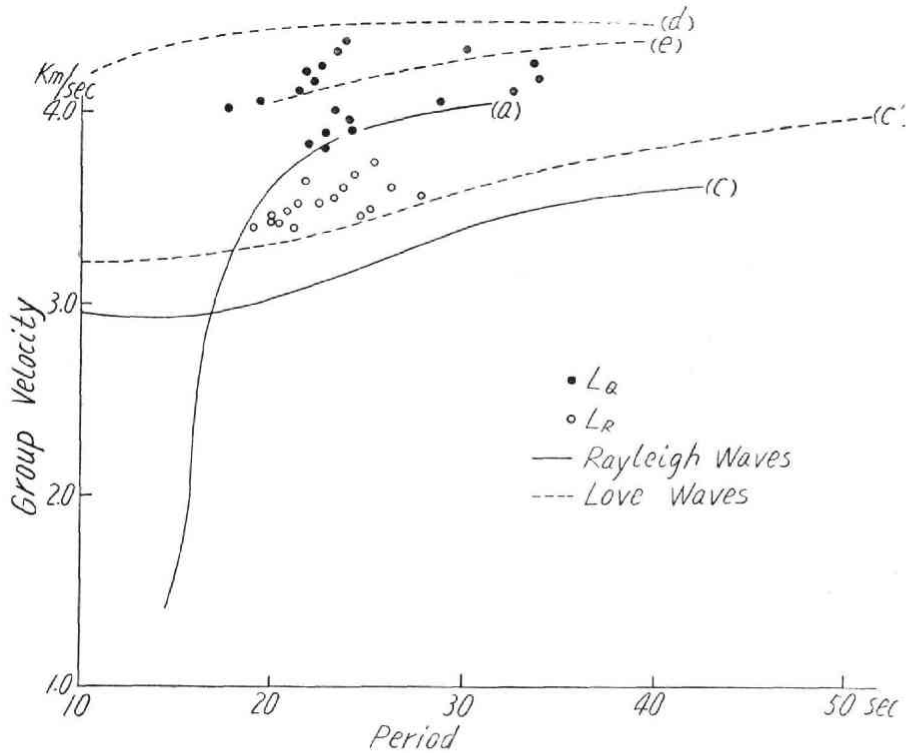

Fig. 4 The dispersion of surface waves of Aleutian earthquakes.

observations but the discrepancy between the observation and the theoretical curve is smaller than that in the above cases. The structure in the region from the Aleutians to Japan, therefore, is indicated to be oceanic but to be slightly different from the perfectly oceanic one. The similar result was pointed out also by SANTO (1960), who studied the Rayleigh waves of many earthquakes observed at Mt. Tsukuba. He stated in his paper "All of the dispersion curves for the paths over or near the series of volcanic islands beside trenches show remarkable different character form those for the paths over the other oceanic basin." This is the case of the present study.

Two dashed curves (d) and (e) in Fig. 4 represent the oceanic dispersion of Love waves through the structure shown in Fig. 6. It is clear that the observed Love waves has a more oceanic feature than in Nagamune's case (curve (b')), although the thickness of the crust cannot be definitely determined because of the scattered data.

From the above considerations it is reasonably concluded that the structure from the Aleutians to Japan is characterized by the rather oceanic crust, its thickness being presumably 10 Km of the order of magnitude. This is in the striking contrast to the former result on the Kamchatka earthquakes, considering the discrepancy of the paths in the two cases is as slight as 15° in azimuth at Sendai. (cf. Fig. 1)

If we tentatively adopt the standpoint that the difference in the paths mentioned above is so slight to cause no difference in wave dispersion, the result of the present

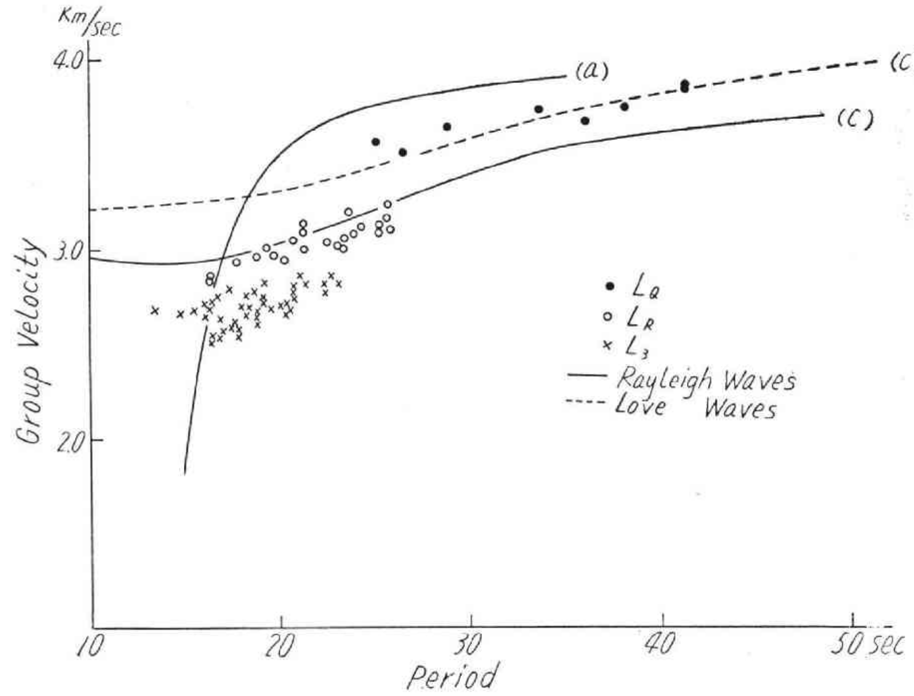

Fig. 5 The dispersion of surface waves of Kamchatka earthquakes. (reproduced from the previous paper)

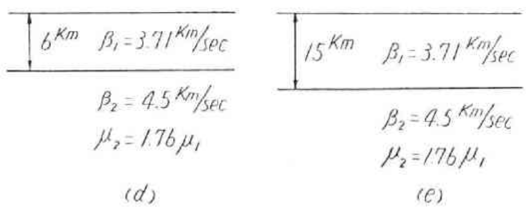

Fig. 6 The crustal structures assumed in the calculation of dispersion curves (d) (e) in Fig. 4.

observation may lead us to the conclusion that the region from Japan to Kamchatka is continental, while that from Kamchatka to the Aleutians is oceanic, and consequently the observed dispersion represent a rather oceanic feature. The similar consideration is sometimes taken in the analysis of surface waves travelling along a partly continental and partly oceanic path. However, the deduction in this direction is easily proved that this is not valid in the present case. If a part of the path is continental, while the other is oceanic, the ratio of the two parts can be estimated from the observation. The calculation of the ratio shows that the boundary between the two parts should be located far nearer to Japan than the Kamchatka Islands. This is obviously incompatible with the former conclusion that the region from Kamchatka to Japan is continental.

It is concluded, therefore, that the region from the Aleutians to Japan has a different structure from the Kamchatka-Japan region, although the two are situated adjacently to each other. This also implies that the regions in concern are located just in the boundary area between the continent and the ocean.

A cross section, which is perpendicular to the path at the Kurile Islands, is taken into consideration. The location of the section is shown by the chain line AB in Fig. 1. The submarine topography in this section is seen in Fig. 7. in which the location of the path in each case is given by an arrow. This figure indicates that the depth of the sea varies suddenly in the region concerned. Although the change in sea depth does not directly correspond to that of Moho there, this fact may support the reasonableness of our conclusion.

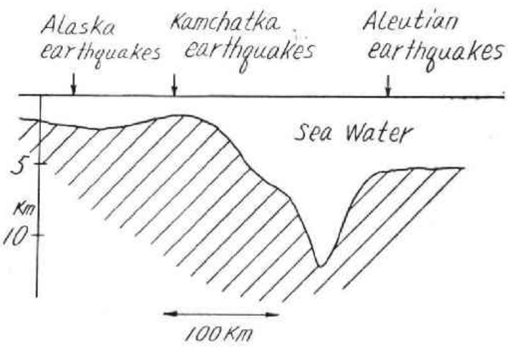

Fig. 7 The submarine topography in the cross section shown by AB in Fig. 1. Arrows represent the locations of paths for earthquakes concerned.

5 Alaska earthquake

The surface waves of the Alaska earthquake on Apr. 7, 1958 are studied here in the similar way to the former earthquakes. In this case about a half of the path almost coincides with that for the Kamchatka earthquakes, as is seen in Fig. 1.

The dispersion for this earthquake is given in Fig. 8, together with some theoretical curves. The notations of the curves mean the same as those in the previous figures. Fig. 8 shows that the present dispersion, except a group of plots corresponding to Love waves with the period of 20–25 sec, is well explained by Nagamune's curve (b'), as in the case of the Kamchatka earthquakes.

It is concluded from the above data that the Aleutian-Kamchatka region has the structure similar to Kamchatka-Japan. This fact gives a strong support to the conclusion in the previous paragraph.

6 On L_3 waves

L_3 waves, which have a nature of Love type orbit and a lower group velocity than that of fundamental Love waves, were observed in most earthquakes treated in the previous paper. In the present study, however, they are found only in the case of the Philippine earthquake, Feb. 27, 1958. Even in the case of another Philippine earthquake, they are hardly seen.

Comparing the earthquakes having predominant L_3 waves with those of no L_3 waves, it is seen that the waves are found only when the epicentral distance is near 20° and they are scarcely observed in the case of larger epicentral distance. It was

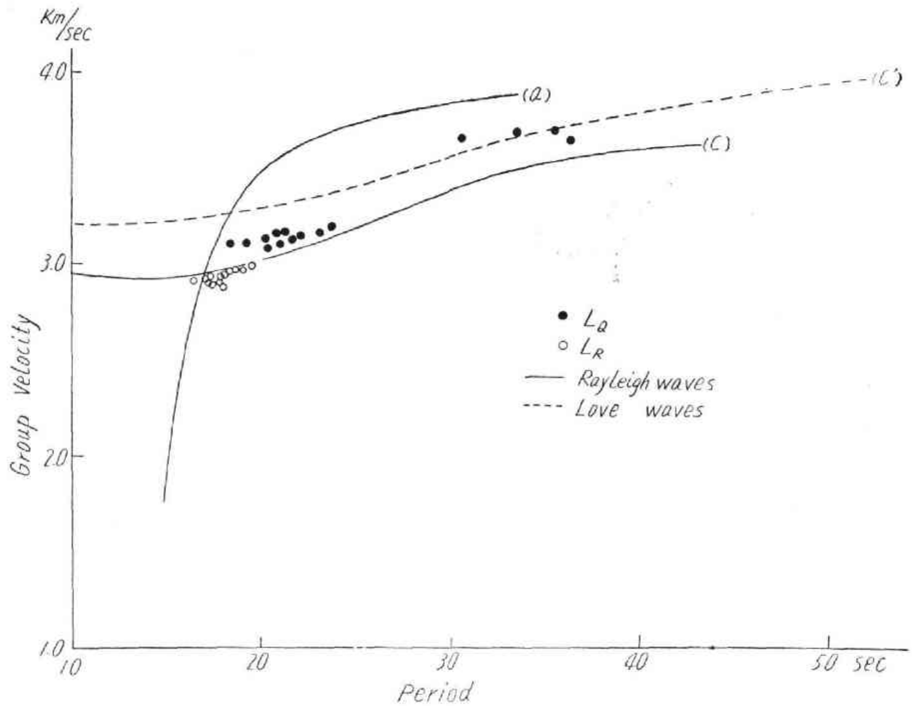

Fig. 8 The dispersion of surface waves of Alaska earthquake.

sometimes reported by several authors (OLIVER and EWING, 1958, OLIVER and others, 1959, and KOVACH, 1959) that the higher modes of Rayleigh waves were observed only at a specific epicentral distance range. Accordingly the L_3 waves in our study are suggested to be a higher mode of Love waves.

The plots of L_3 waves in every figure exhibit a tendency of gathering within a small domain in the velocity-period diagram. This indicates that the observed waves correspond to the Airy phase. According to the theoretical investigations, the higher mode of surface waves has a sharper minimum of dispersion curve than that of fundamental one, and the waves with an amplitude large enough to be observable are considered to be limited within a small range of period. Therefore the observation does not conflict with the theoretical consideration. Moreover, Airy phase of higher mode has a lower velocity than that of the fundamental one. It is also compatible with the observation. From these considerations L_3 waves may probably be identified as the second mode of Love waves.

7 Discussion

The study in the foregoing paragraphs shows that the structure from Kamchatka to Japan is rather continental, although that in the Aleutian-Japan region is oceanic. This implies that the dispersion of surface waves is mainly controlled by the crustal structure just below the path of wave propagation. It is not self-evident a priori considering the circumstances that the structure in our study is inclined in the direction perpendicular to the path, though it is almost horizontal in the direction of wave propagation. The wave-length in concern is of the order of 100 Km, and the change in the thickness of the crust is considerably sudden in comparison with the wave-length. Nevertheless, the change in dispersion follows, at least in its main part, the structure just below the path. Such a property of surface waves will be experimentally verified in the next paper.

Another important result should be noted. No Lg waves are propagated along the continental path in our cases. Utsu (1960) reported that the Lg waves were hardly seen in the Kamchatka and other earthquakes, while they were clearly predominat in the Siberian and Chinese earthquakes. His conclusion agrees with ours fairly well. This may be in some relation to the rather thin crust in the regions concerned.

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