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# CHARACTERISTIC EARTHQUAKE RECORDS

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## Characteristic earthquake records.

The earthquake records here presented are from the long period seismographs, *Galitzin-Wilip* and *Wiechert*, of the København, Scoresby-Sund and Ivigtut observatories. Only two Benioff short period records have been included. The diagrams are arranged according to increasing epicentral distance and they exhibit the characteristic features of the various ranges of distance.

It is the conspicuous phases that lend to the diagram its characteristic appearance. A new phase may be taken to begin wherever there is a marked change in the recorded movement. Minor phases sometimes occur in great number, but they are not repeated in all diagrams of earthquakes from the same epicentral distance and focal depth; the general appearance of the diagrams varies greatly. However, a small number of conspicuous phases are usually found. They may separate distinctly sections of the diagram in which amplitudes and periods differ, or they may simply rise from the general background movement as a marked group of oscillations of greater amplitude and often also of different period. These phases are repeated in records in which the movement otherwise differs greatly. Time-curves have been constructed for them and interpretation made.

Whereas there will be few exceptions from the rule that the conspicuous phases can be identified, the well known phases are not equally conspicuous or not even always present in the entire range of distance for which their time-curves have been constructed. The amplitudes of the waves vary with distance and in some ranges the corresponding phases are much more prominent than in others. Thus the pattern formed by the conspicuous phases varies more markedly than would be the case if all the known phases were always equally prominent. Actually patterns are formed that are often so easily recognised by the experienced observer as to enable him to say to what range of distance they belong merely by inspection, without measuring the diagram.

In the diagrams here selected the phases characteristic of the respective distances appear very clearly. Actually in most diagrams they are not quite so clear. They may be less well developed, less clearly separated or masked by background movement, but if attention is directed towards the most prominent phases of the diagram they are usually refound. Interpretation becomes easier when this is realised. When several more or less important phases are read it may be possible to fit them on to existing time-curves in various ways and mistakes of interpretation are much more easily incurred. It is believed that the present work will be of use to the inexperienced observer in not simply describing the various phases characteristic of epicentral distance, but in actually placing before him diagrams in which they are clearly seen.

It is also believed that the most useful observations are obtained if attention is directed primarily towards the conspicuous phases and preference given to them when the bulletins are worked out. When numerous data are obtained for them it will be possible to determine their time-curves with greater accuracy. The readings of other phases are less useful since they are not so consistently repeated. Great interest attaches to the more detailed analysis of earthquake records, but special studies are needed for it.

The fact that conspicuous phases form patterns easily recognised as appertaining to various ranges of distance is in itself a proof of the existence of these phases and also of the reality of the variation of their amplitudes with epicentral distance.

It is much less easy to prove the existence of other phases or of the same phases outside the ranges in which they are conspicuous, for it will depend on the agreement of observed travel times with those calculated. And this agreement cannot be expected always to be very close since it is known that there is a considerable spreading of the travel times of most phases. The interpretation of minor phases meets with particular difficulty if they follow each other closely. Under such circumstances the idenfication of conspicuous phases may also be uncertain, but otherwise they may be identified with confidence even if their travel times are not in very perfect agreement with those calculated.

The variation of the appearance of earthquake diagrams is due to many causes such as the mechanism of the shock and secondary occurrences in the focal region, differences of structure along the path, more specially in the vicinity of the recording observatory. The phases themselves develop differently under varying conditions and the background movement varies, sometimes attaining such strength as to seriously mask the phases. When in spite of all this the features characteristic of epicentral distance usually are apparent, the corresponding variation of amplitudes with distance evidently is not only real, but very considerable.

It is the forerunners only that have been considered here while the surface waves have not been dealt with. This is because the speed and the appearance of their first arrivals differ too much for them to form part of a pattern characteristic of epicentral distance. Differences of crustal structure affect surface waves strongly. In a few cases attention has been drawn to surface waves characteristic of oceanic structure.

The differences in the forerunners due to other factors than distance have purposely been neglected, but one exception has been made. Differences in regional structure are responsible for such striking and interesting differences between the records obtained at small epicentral distances at København and at the Greenland observatories that it seemed natural to point them out.

The work does not claim to be complete. It will undoubtedly be possible to supplement it with other characteristic records especially from very great distances where there were only few records to chose from. Most of the diagrams are from shallow shocks or shocks of small depth. There are a few of really deep shocks. They have been included to show deep focus reflections well recorded. It could obviously not be attempted to present records of earthquakes of various depth from all ranges of epicentral distance.

In the second part of "On Seismic Waves" by B. Gutenberg and C. F. Richter (Gerl. Beitr. vol. 45, 1935) there is a chapter headed: "Appearance of normal seismograms at various distances", written "with a view to facilitating the determination of epicentral distance from the seismograms of a single station, and the identification of the phases recorded". It goes into considerable detail about the variation of amplitudes with distance and considers more phases than I have done, while the features that to me seem particularly characteristic not always have been emphasized. There are, however, no important discrepancies.

I wish to express my best thanks to Mr. Erik Møller for the excellent assistance rendered and for the interest he has taken in the work. My thanks are also due to Miss L. Balle, civ. eng., who has kindly helped to prepare the records.

## The diagrams.

The epicentral distances quoted are mainly from the International Seismological Summary. Where it was not available distances from the epicentres either of the International Central Bureau at Strasbourg or of the United States Coast and Geodetic Survey were taken. *G-W* stands for the Galitzin-Wilip seismograph, *Wi* for the Wiechert 1000 kg horizontal and 1300 kg vertical seismographs, *M-S* for the Milne-Shaw seismograph. For their constants reference is made to the bulletins of the observatories. All the diagrams except the one in fig. 1 have been reduced in the ratio 1:2.

*Fig. 1* presents the Wiechert records, amplified $2^1/_2$ times, of the only local shock recorded at the København observatory during the 27 years of its existence. There is the characteristic short-period movement, too swift to be well recorded. *P* and *S* are very clear. The surface waves are quite small and the shock evidently is deeper than normal.

At distances smaller than about 15° *P* of shallow shocks is usually quite small. *S* is also small if present at all; it is often late as compared with the tables. This is illustrated in *figs. 2, 4, 5,* and *7.* The forerunners are quite small as compared with the surface waves also in the component records not shown here, and this is due to the epicentral distance being small, for the *P*'s of these shocks are clearly recorded at much greater distances. *P* of the Yugoslavian shock of fig. 5 is recorded in California at an epicentral distance of 90° and *P* of the Italian shock of fig. 7 is recorded beyond 90°. *S* is not clearly present in figs. 2 and 5. The onset of the larger movement may be due to *L*. In figs. 4 and 7 *S* is quite small and in the latter the onset is 12 sec. late.

In the North Sea earthquake of *fig. 3* *P* and *S* are comparatively large and they are both clearly marked. No depth of focus has been assumed for this earthquake, but it may have had its focus below the crust. It is presented here because it is the only earthquake well recorded at København at about this epicentral distance and it was desired to make a comparison with Greenland records obtained at small distances, such as those of figs. 2 and 4. There is a striking contrast. In the Greenland records forerunners as well as surface waves are regular waves of long period whereas in the North Sea earthquake the movement is irregular, short period waves being superposed on long ones.

The Rumanian earthquake of *fig. 6* was about 100 km deep and here, at an epicentral distance smaller than that of the Italian earthquake, *P* and *S* are large and clearly recorded.

From distances of about 15° *P* and *S* increase quickly and are large at about 18°–19° as in the Iceland earthquake of *fig. 8*. Beyond 20° *P* usually decreases while *S* for some degrees onwards remains large or even increases. In *fig. 9* at a distance of 22°.2 *S* is very large. The surface waves of the Iceland shock are early arriving, long period, regular "oceanic" waves, whereas those of the Anatolian shock are irregular, waves of short period being superposed on longer ones.

*PP* is rarely well recorded at distances smaller than 30°, but it is usually a conspicuous phase at distances double those at which *P* is large. In *fig. 10*, at a distance of 37°.0, *PP* is large as compared with all the other movement recorded. In *fig. 11*, an Ivigtut record from a distance of 40°.8, there is a large *PP* and also a large *SS*.

*Fig. 12* is a record of the Benioff short period vertical seismograph. The strong earthquake recorded occurred at a distance of 41°.4 from København. The Benioff records of distant earthquakes have few conspicuous phases, but they record *P* very well. The phase usually consists of a group of short period oscillations and has a sharp onset; it is often visible when there is no trace of it in the records of the long period instruments. In fig. 12 a number of small groups of oscillations mark *P's* of repetitions of the main shock, and they were not recorded on the other instruments. These on the other hand record *PP* better. It is present in the Benioff record of the strong shock of fig. 12, but it is rather inconspicuous and it has no clear onset. It seems to be the general rule, applying also to other epicentral distances, that *PP* as recorded on the Benioff instrument has a somewhat blurred appearance. This may sometimes help to distinguish it from *P*.

The Hindu Kush deep shocks, so often repeated, give highly characteristic records at København at epicentral distances of 43°–44°. *Fig. 13* is the *E* component record of an exceptionally strong shock from this region, *fig. 14* the *E* and *Z* records of a smaller one (the recording speed is double that of fig. 13). In both there is a number of very clear phases, some of them deep focus reflections. The interpretation of the largest phases in the longitudinal and transverse sections of the forerunners is somewhat uncertain, since more than one phase is due at approximately the same time.

At distances of about 50° *ScS* becomes conspicuous. Here it arrives about $2^1/_2$ min. after *S* and is clearly separated from it, but with increasing epicentral distance the interval between the phases decreases, and *ScS* is often masked by the movement that continues after *S* and *PS*. In the Scoresby-Sund *E* record of *fig. 15* *ScS* is exceptionally large and clear. It is missing in the *N* record.

*ScS* is also well recorded in *fig. 16* at a distance of 56°.3. It is distinct in the *N* record of *fig. 17* from a distance of 59°.0, whereas in the *E* record it is masked by the preceding movement.

At distances three times the distances at which *P* is large *PPP* is usually conspicuous. In fig. 17 *PPP* is seen to be larger than both *P* and *PP*. In the shock of *fig. 18*, 130 km deep, recorded at nearly the same epicentral distance, *PPP* is very large in the *N* component record (the azimuth of the epicentre is nearly *N*), and in the *E* component record *SSS* is exceedingly large.

In *fig. 19* at a distance of 61°.9 *PPP* is no longer large. *ScS* is prominent and it is clear because the *S* movement subsides quickly.

*Fig. 20* is the record of a shock 560 km deep. There are several very clear phases, some of them marking deep focus reflections. The identification of two of the large phases is doubtful because more than one wave is due at practically the same time.

*Figs. 21, 22* and *23* are from a range of epicentral distance in which a great many earthquakes are recorded at København. They are those of the Kamchatka region, the Aleutians, the Kurile Islands and Japan. The diagrams are quite simple with *P* and *S* well recorded, *PS* following upon *S*, but rarely so clearly separated from it as in fig. 22, sometimes with clearly recorded *P* and *S* reflections as in figs. 21 and 23, sometimes without or with quite small reflections. (It may be remarked that no depth has been assigned to the shock of fig. 21 in which the forerunners are very large while the surface waves are not particularly large, whereas the *I.S.S* assigns a depth of 0.01 to the shock of fig. 23 in which the surface waves are exceptionally large and the forerunners small.)

*Fig. 24* is one of many records of strong Mexican shocks recorded at København at a distance where *SKS* just appears in front of *S*, but rarely is clearly separated from it. In *fig. 25* recorded at Scoresby-Sund at a slightly greater distance the separation of the phases is not yet very clear, but the earlier of the two phases, *SKS*, is larger in the *N* record (the azimuth of the epicentre is nearly south) and the later, *S*, is larger in the *E* record.

In *fig. 26*, the København record of the same shock at a ten degree greater distance, *SKS* and *S* are very clearly separated. Here the azimuth of the epicentre is nearly west and *SKS* is recorded only in the *E* record, whereas *S* is recorded in both horizontal component records. *PS* is conspicuous in the *E* record. The group of the three phases *SKS, S* and *PS*, usually clear and well separated, is very characteristic of records from about this epicentral distance.

In the large Celebes earthquake of *fig. 27* they are, however, less clearly separated because strong movement continues after each phase. In this record we notice that *PP* is large as compared with *P* as it mostly is at this and greater distances. *P* and *PP* sometimes remain about equally large up to and somewhat beyond 105°, but as a rule *P* decreases at distances of about 100° and becomes quite small while *PP* increases.

In the record of *fig. 28* from a distance of 108° *P* is still well marked, but *PP* is much larger. *P'* has now appeared in front of *PP*. In the *S* group an additional phase, *SKKS*, is present and large while *S* is comparatively small. It is clear only in the *E* component record (the azimuth of the epicentre is nearly north). *PPS* is now a prominent phase, clearly separated from *PS* in the vertical component record.

*Fig. 29* from a distance of 115° exhibits the features characteristic of vertical component records from about this distance. There is a small *P* and a *P'* very similar to it followed by a large *PP*. The next clear phase is the large *PS* followed by *PPS* which in this case is much smaller. Below is the first part of the long period, regular, "oceanic" surface waves. There are no *S* phases in this vertical component record. At greater distances they are small or absent also in the horizontal component records and we then have records as the one of *fig. 30* from a distance of 119°.2 where *PP* and *PS* are sometimes mistaken for *P* and *S*. In this case *P* and *P'* are just visible, but easily escape attention and often these two phases are not present at all.

Beyond 130° *PKS* appears and becomes very conspicuous, especially in the horizontal component records where the preceding *PP* is not so large. *Fig. 31* is a characteristic record from a distance of 135°. The first phase is the small *P'*, about $2^1/_2$ min. later *PP* arrives and about 1 min. later the very much larger *PKS*.

At the focal distance *P'* is usually the largest phase in the record. *Figs. 32* and *34* are examples of this; the latter is from a very deep earthquake.

*Fig. 33* is the Benioff *Z* short period record of the *P'* of which fig. 32 is the long period record. Short period movement is seen to be strong, and this is true for $P'$ also at other distances. The phase is often well recorded on the Benioff instrument when it is small or absent in the records of the others. At distances smaller than the focal distance where $P$ and $P'$ as recorded on the Galitzin-Wilip $Z$ often are similar in appearance as in fig. 29, Benioff $Z$ will usually record $P'$ clearly, but not $P$. Short period movement fades out of this latter phase beyond 100°.

At distances greater than 150° there are not many earthquakes well recorded at the København and Greenland observatories. The best records from great distances are those of the New Zealand shocks, but some of their phases are usually not very conspicuous because of strong background movement. However, the phases marked in *fig. 35* can be distinguished in most of the records. There are the two $P'$ phases, $P'_1$ and $P'_2$, present at distances greater than the focal distance and clearly separated at the distance here considered. $P'_2$ is much larger than $P'_1$ in the horizontal component records, but in the vertical component records they are both large. $PP$ is usually large and clearly marked and in the later part of the record $PPS$ is conspicuous.

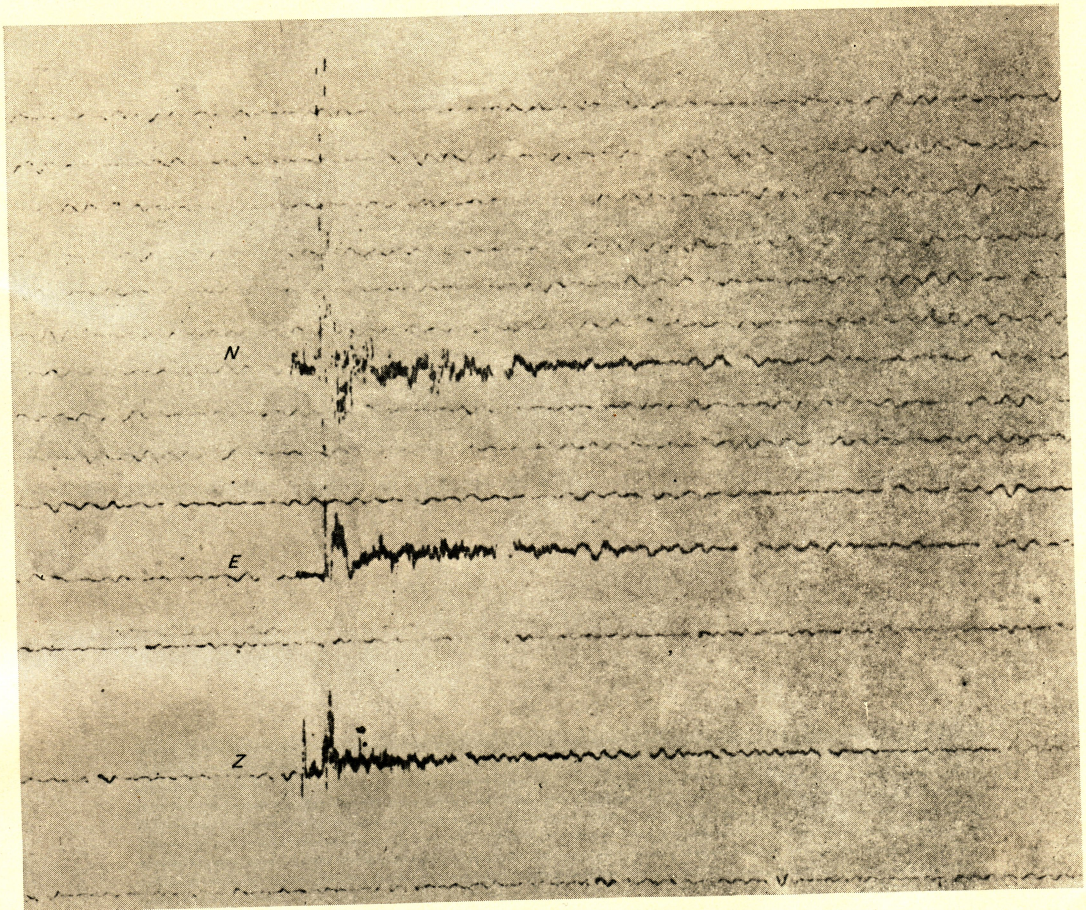


Fig. 1. 1930, Oct. 31. København Wi N, E, Z. Local shock.

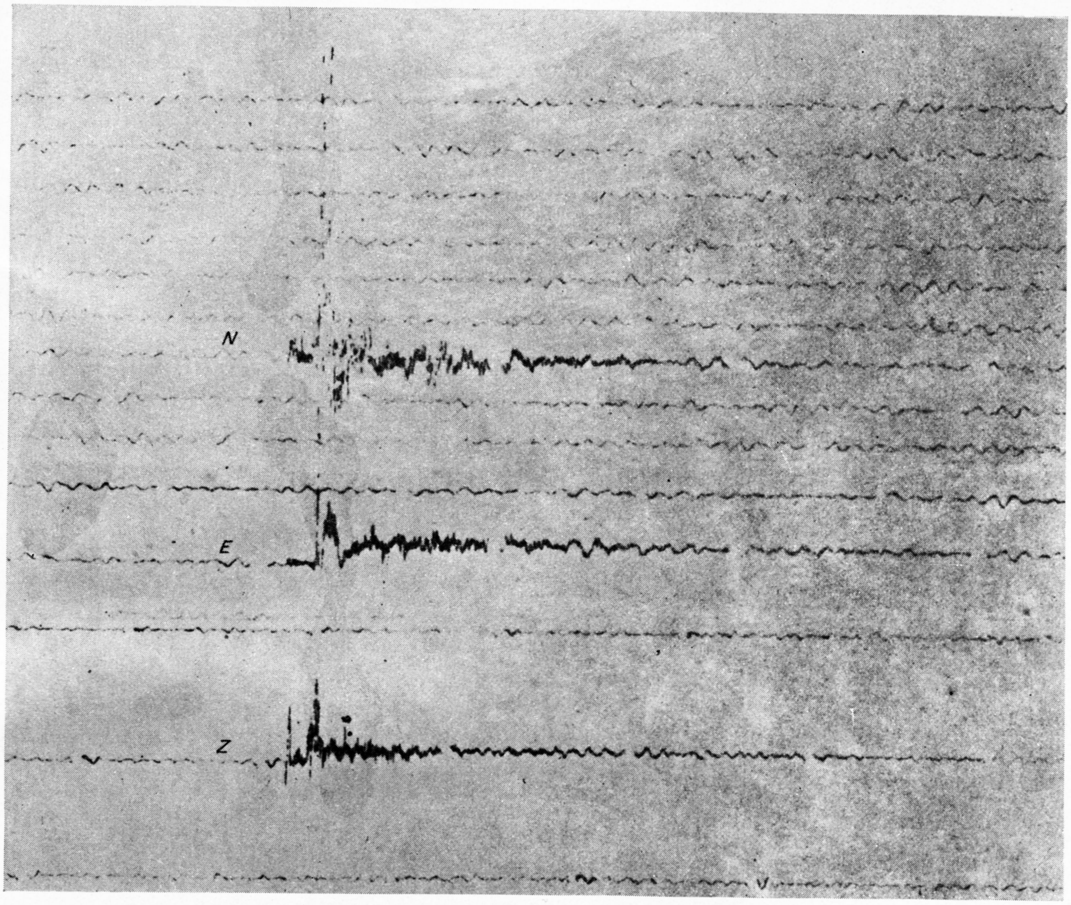


Fig. 1. 1930, Oct. 31. København Wi N, E, Z. Local shock.

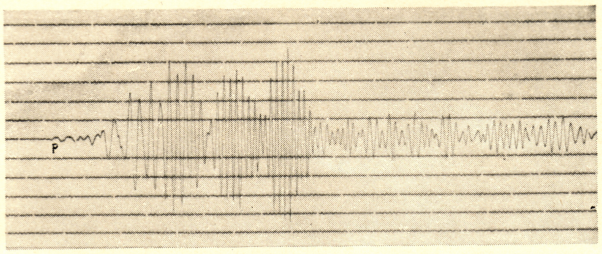


Fig. 2. 1929, Aug. 6. Near Jan Mayen. Scoresby-Sund G-W N. △ = 4°.6.

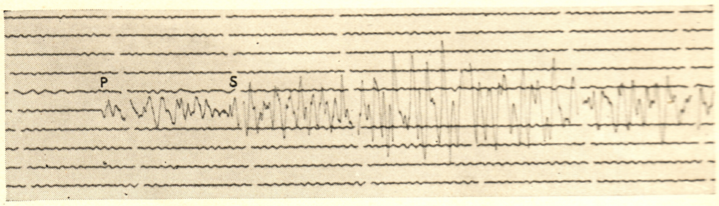


Fig. 3. 1931, June 7. North Sea. København G-W E. △ = 6°.7.

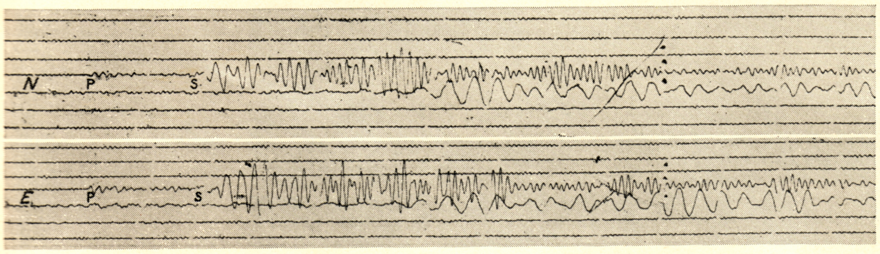


Fig. 4. 1937, April 29. Atlantic Ocean. Ivigtut Wi N, E. △ = 8°.7-

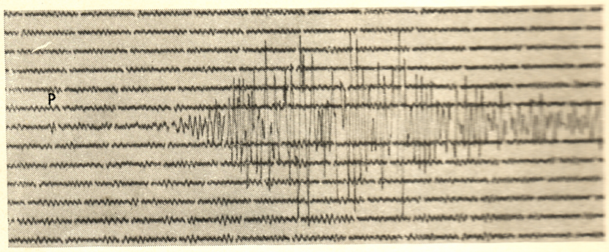


Fig. 5. 1938, March 27. Yugoslavia. København G-W N. △ = 9°.9.

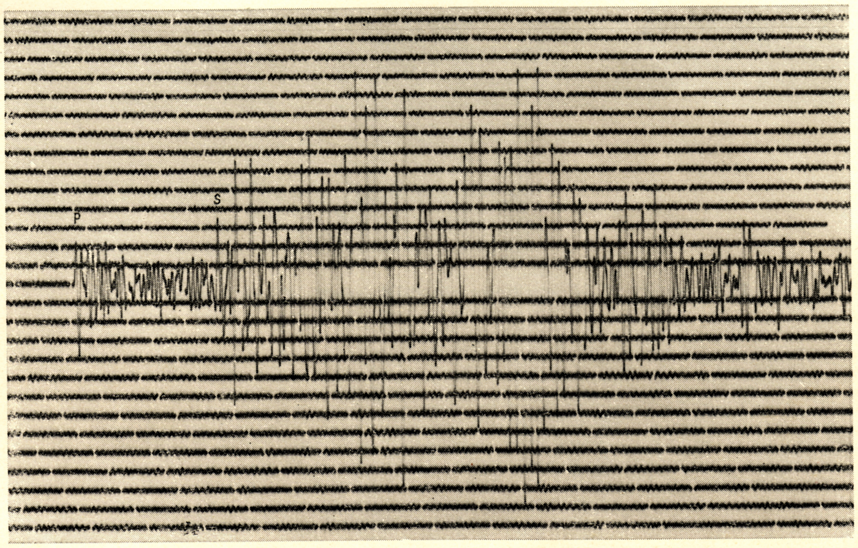


Fig. 6. 1940, Oct. 22. Rumania. København G-W N. △ = 13°.5. Depth about 100 km.

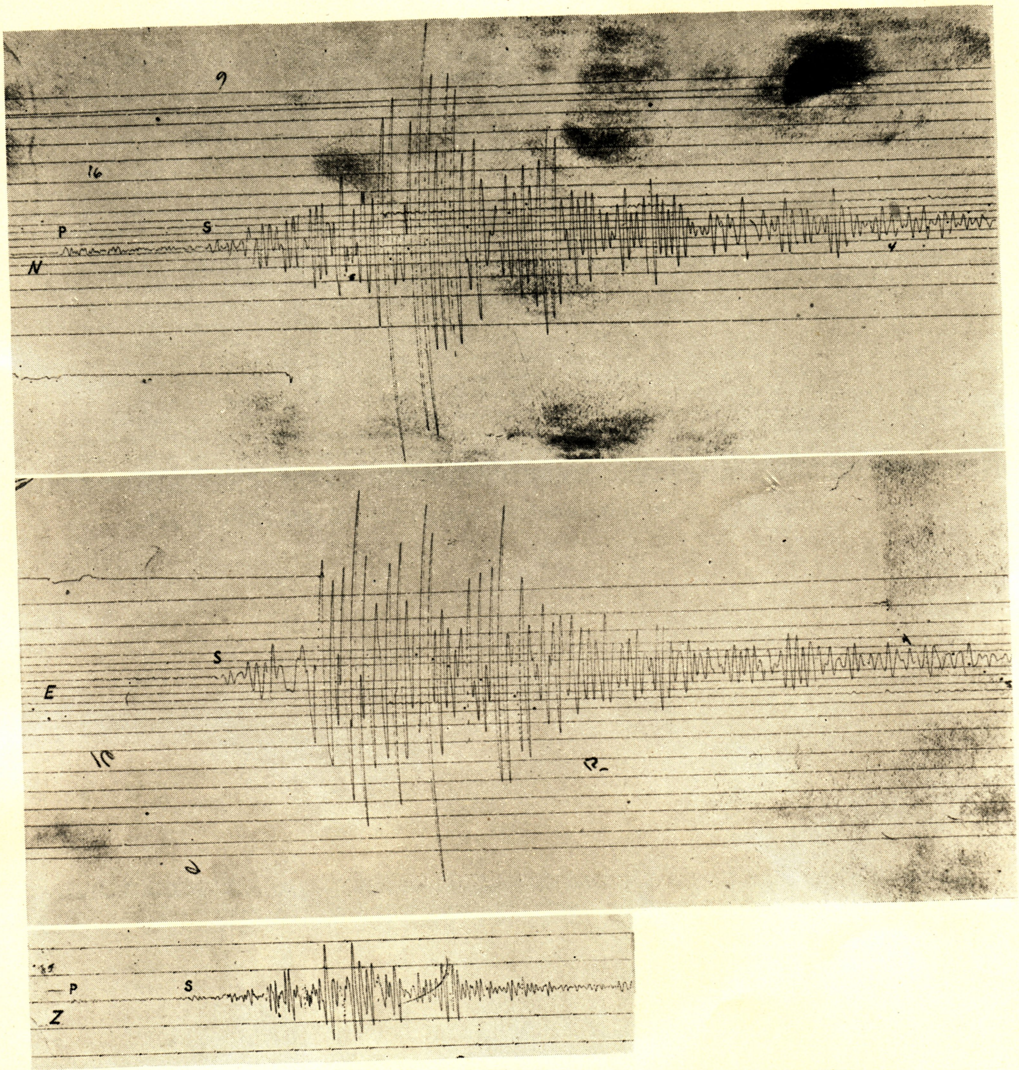


Fig. 7. 1930, July 23. Italy. København Wi N, E, Z. $\triangle = 14^\circ.7$.

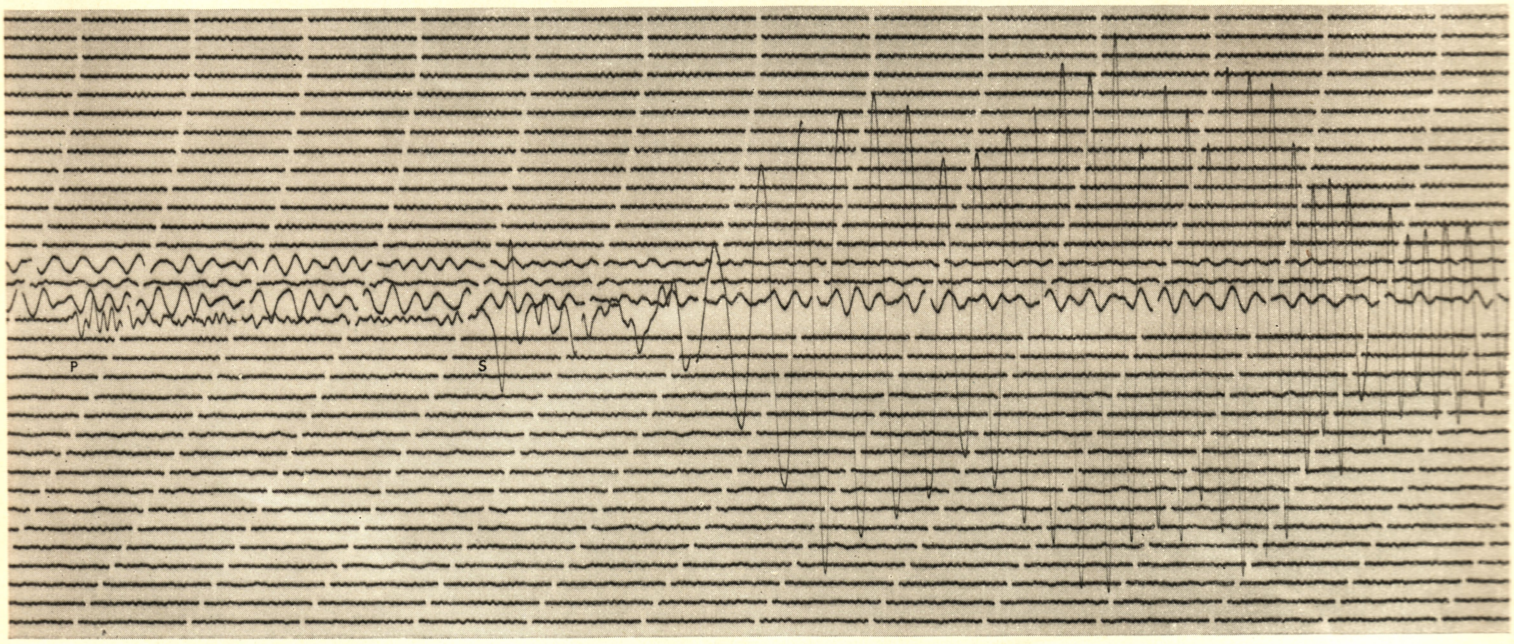


Fig. 8. 1929, July 23. Off Iceland. København G-W N. △ = 18°.6.

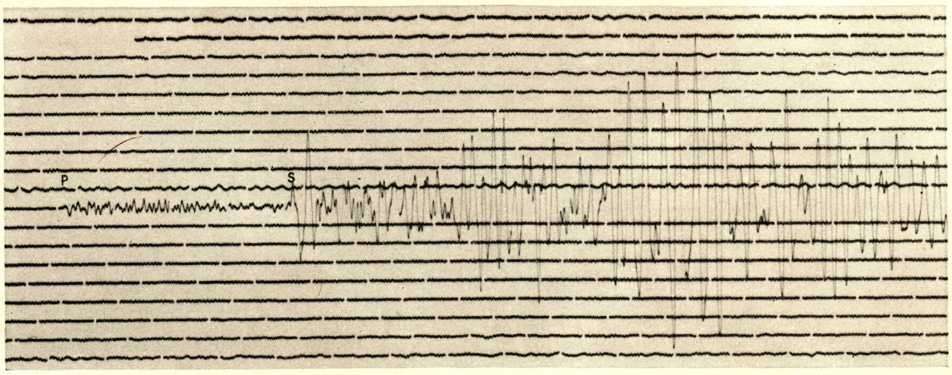


Fig. 9. 1940, July 30. Anatolia. København G-W N. △ = 22°.2.

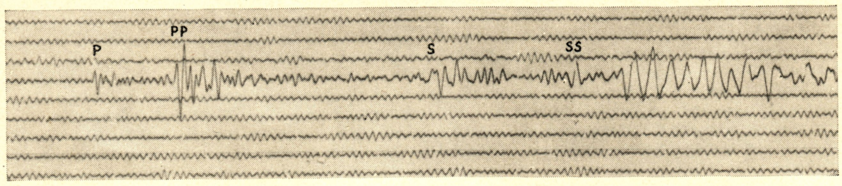


Fig. 10. 1931, March 8. Yugoslavia. Scoresby-Sund G-W E. △ = 37°.0.

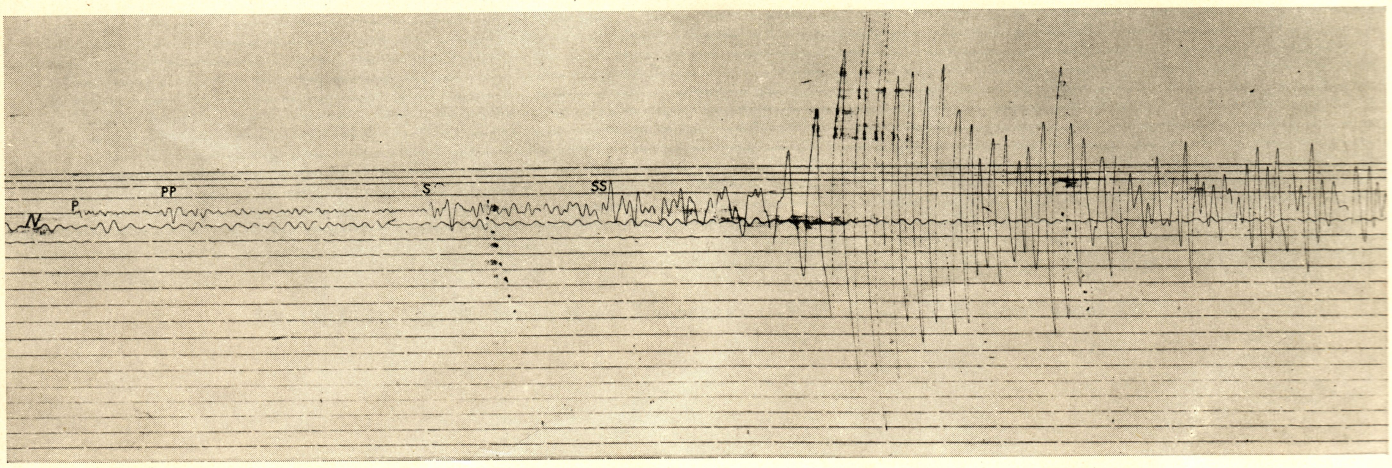


Fig. 11. 1937, July 22. Alaska. Ivigtut Wi N. △ = 40°.8.

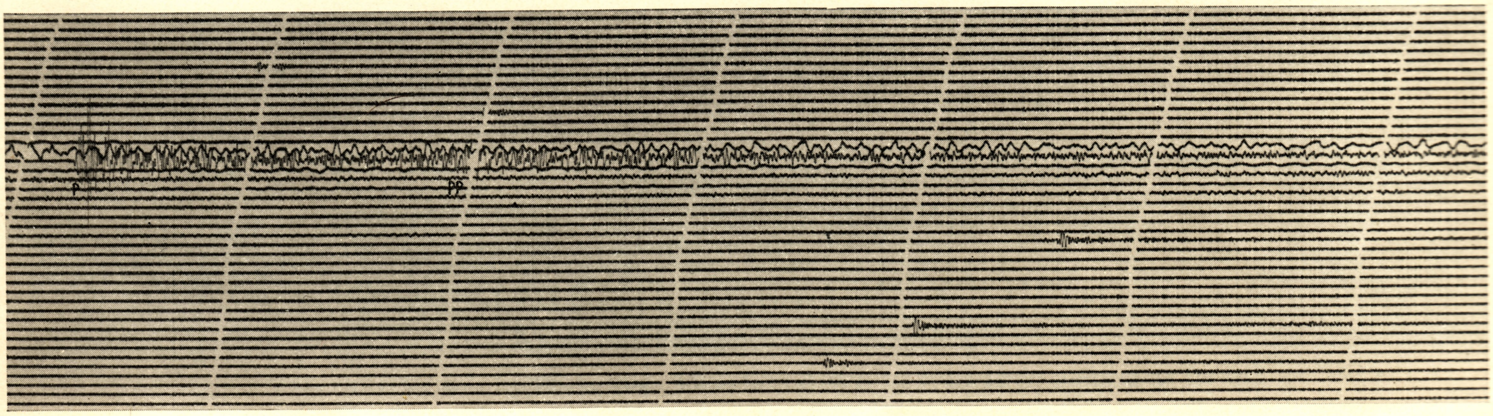


Fig. 12. 1949, July 10. Turkestan. København Benioff Z. △ = 41°.4.

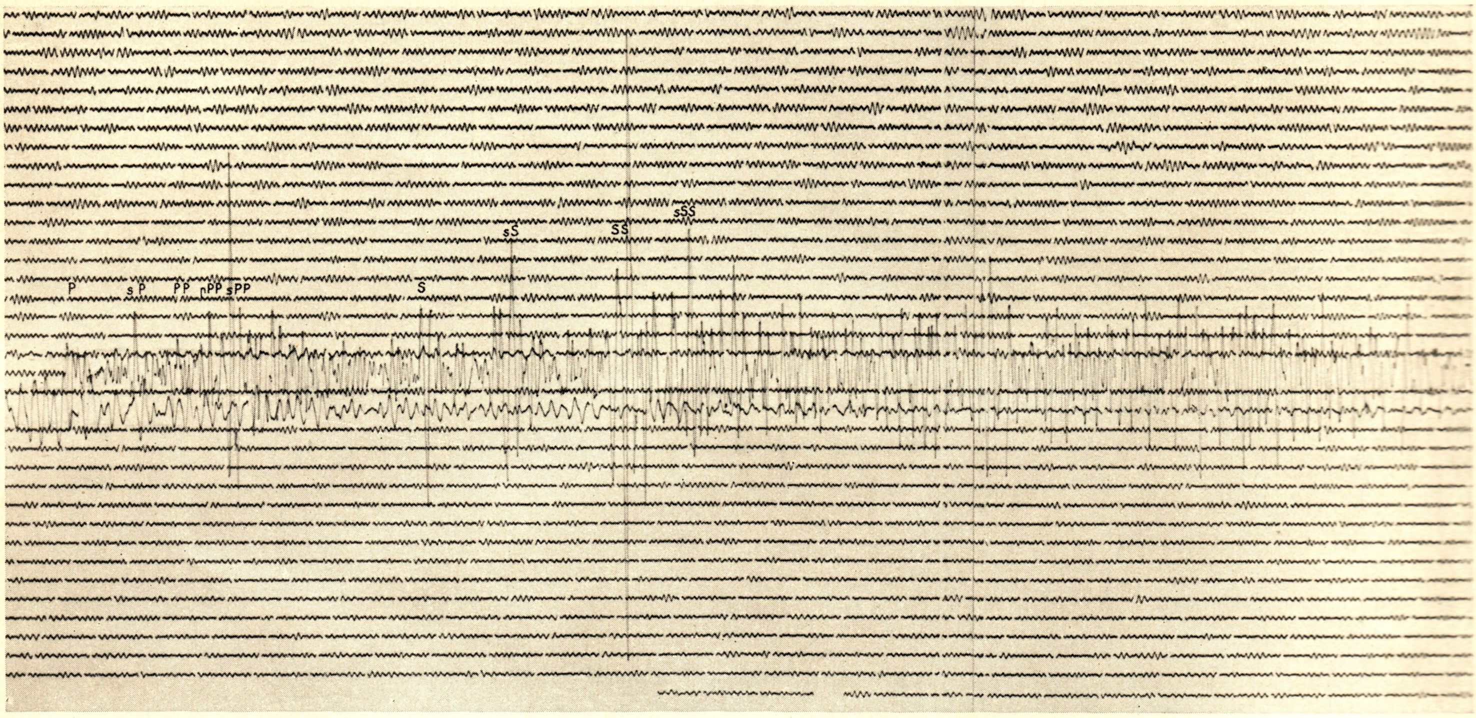


Fig. 13. 1939, Nov. 21. Hindu Kush. København G-W E. △ = 43°.6. Depth about 220 km.

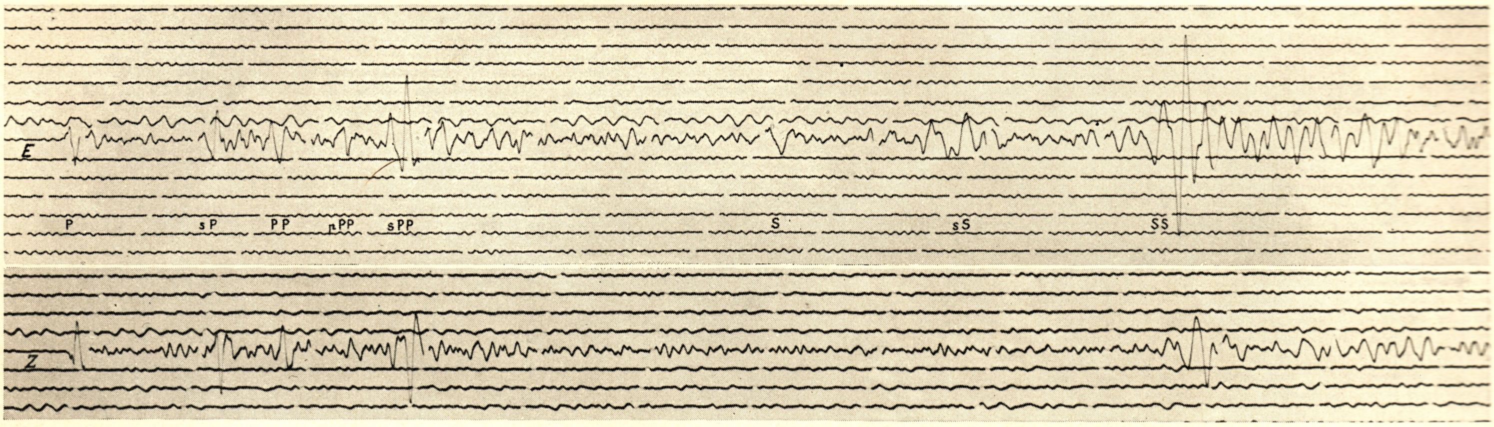


Fig. 14. 1936, June 29. Hindu Kush. København G-W E, Z. △ = 43°.3. Depth about 220 km.

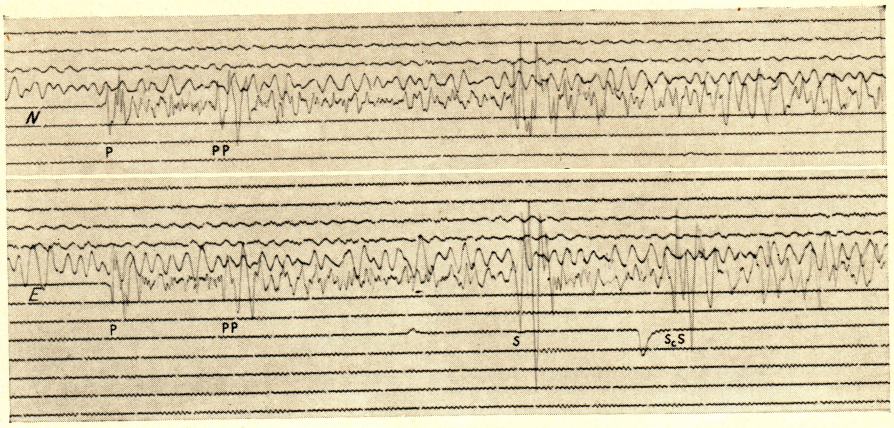


Fig. 15. 1951, Febr. 13. Gulf of Alaska. Scoresby-Sund G-W N, E. $\triangle = 50°.6$.

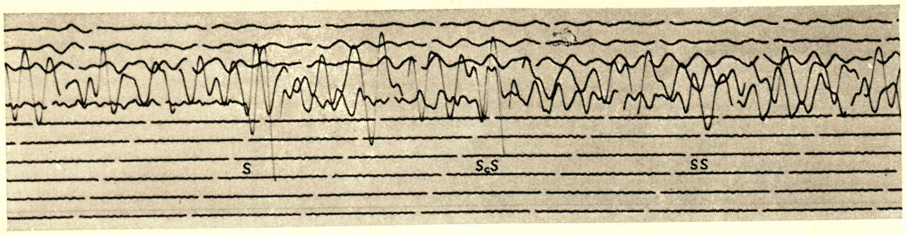


Fig. 16. 1936, May 27. China. København G-W N. $\triangle = 56°.3$.

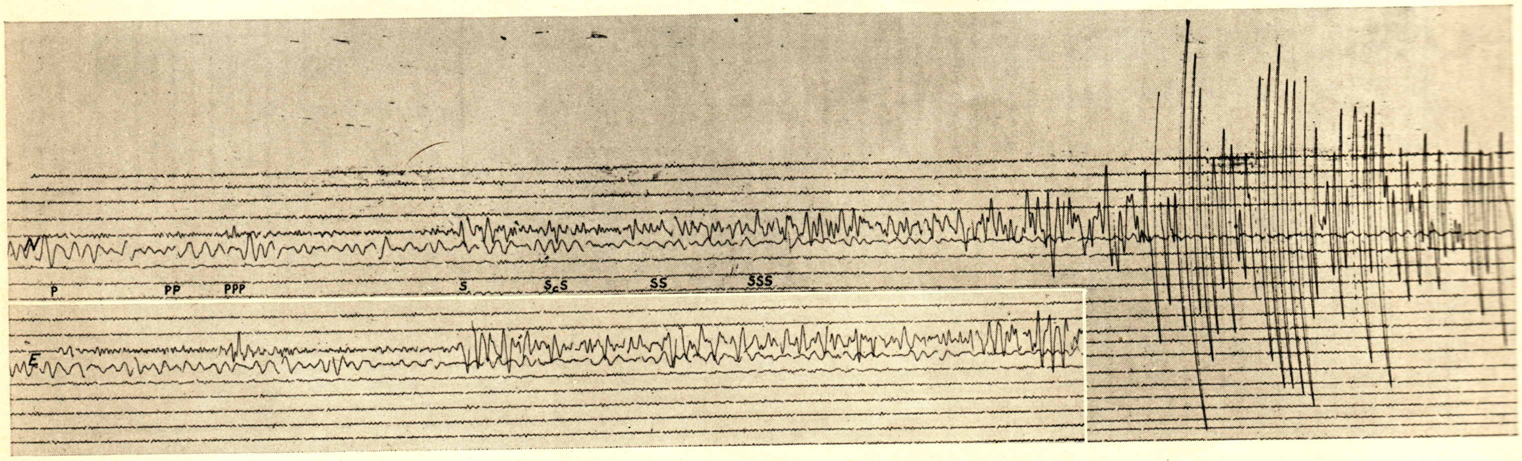


Fig. 17. 1937, Jan. 7. China. København Wi N, E. $\triangle = 59°.0$.

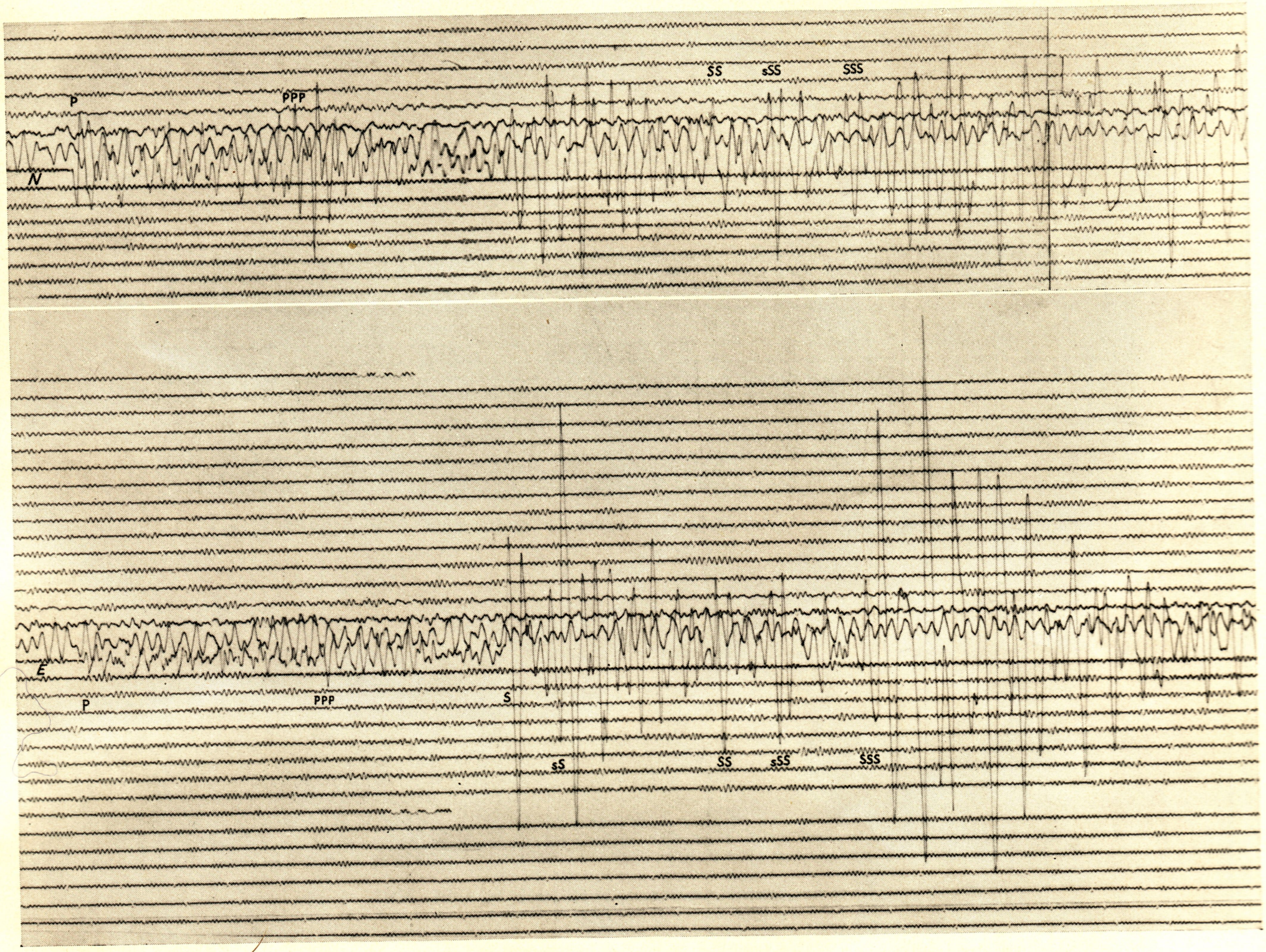


Fig. 18. 1929, Jan. 13. Kurile Islands. Scoresby-Sund G-W N, E. $\triangle = 59°.8$. Depth about 130 km.

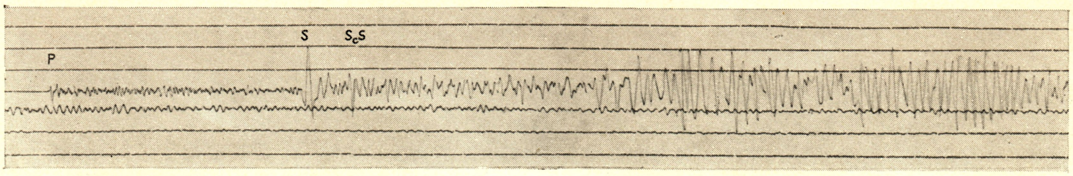


Fig. 19. 1929, Febr. 22. Atlantic Ocean. København M-S E. $\triangle$ = 61°.9.

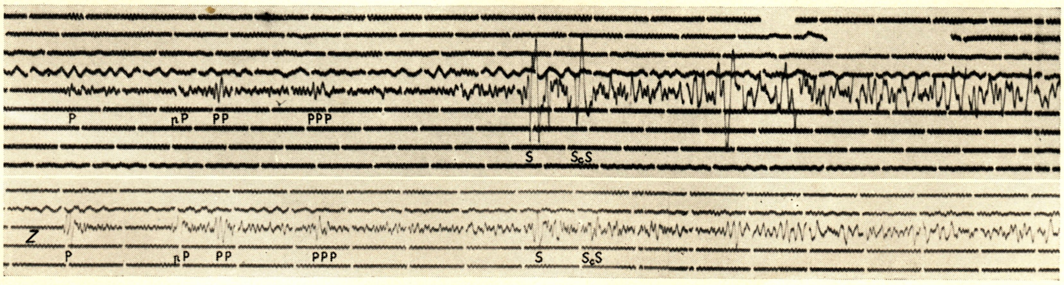


Fig. 20. 1940, July 10. Manchukuo. København G-W N, Z. $\triangle$ = 67°.0. Depth about 560 km.

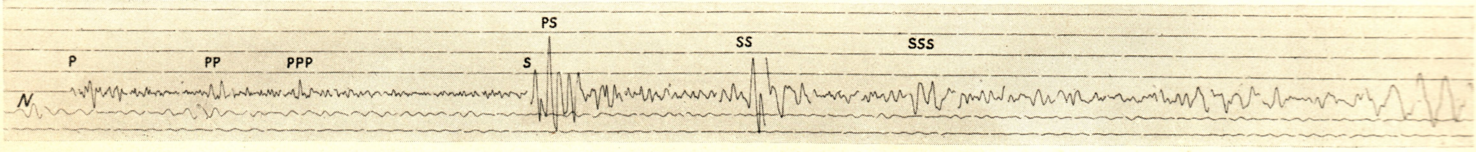


Fig. 21. 1936, June 30. East of Kamchatka. København Wi N. $\triangle$ = 70°.1.

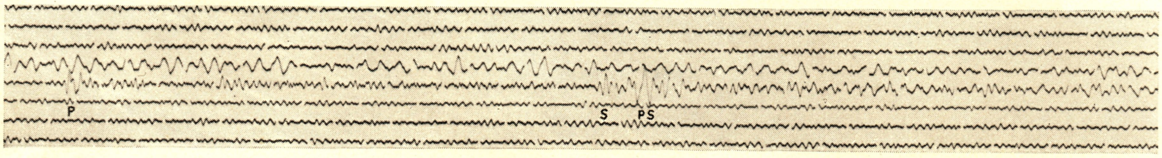


Fig. 22. 1940, Febr. 7. Aleutian Islands. København G-W N. $\triangle$ = 72°.4.

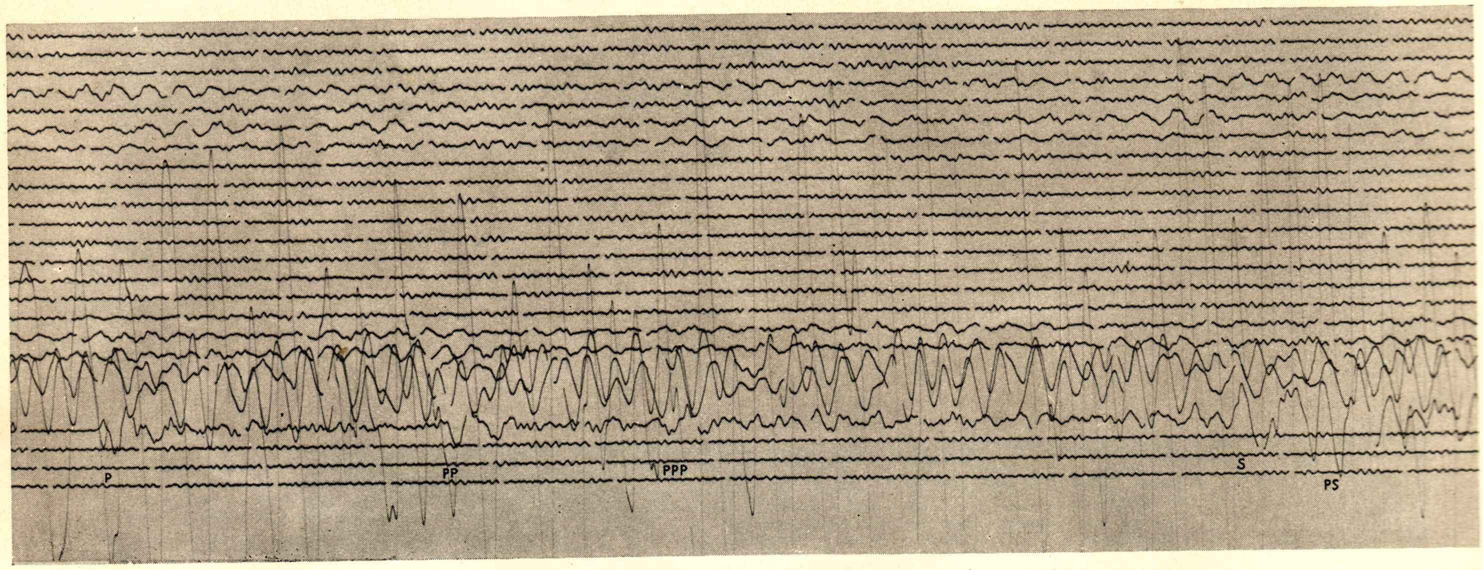


Fig. 23. 1931, Nov 2. China Sea. København G-W E. $\triangle = 78^{\circ}.0$.

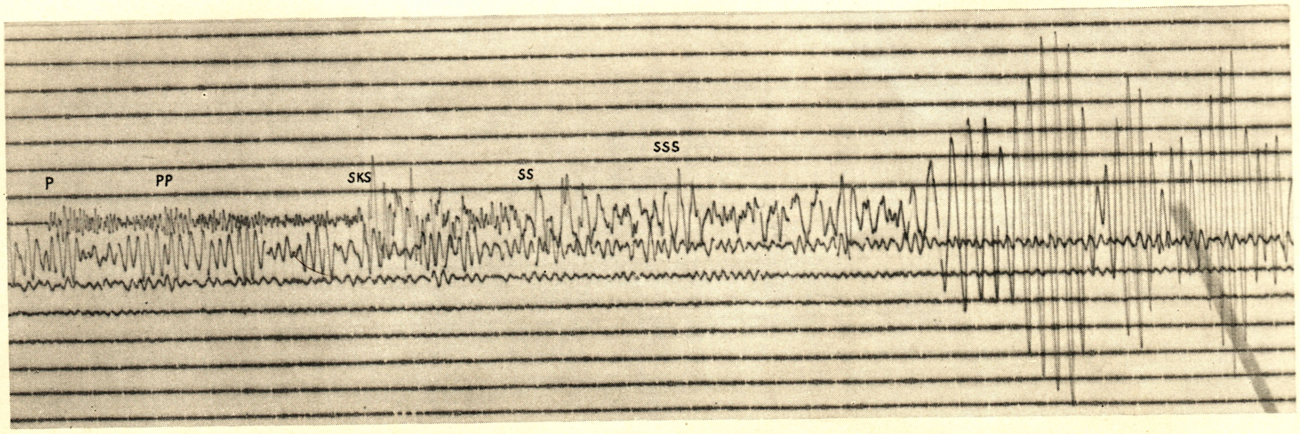


Fig. 24. 1931, Jan. 15. Mexico. København M-S E. $\triangle = 86^{\circ}.6$.

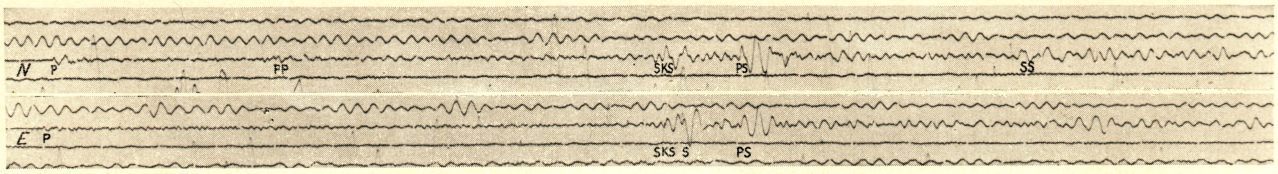


Fig. 25. 1940, May 24. Peru. Scoresby-Sund G-W N, E. △ = 88°.9.

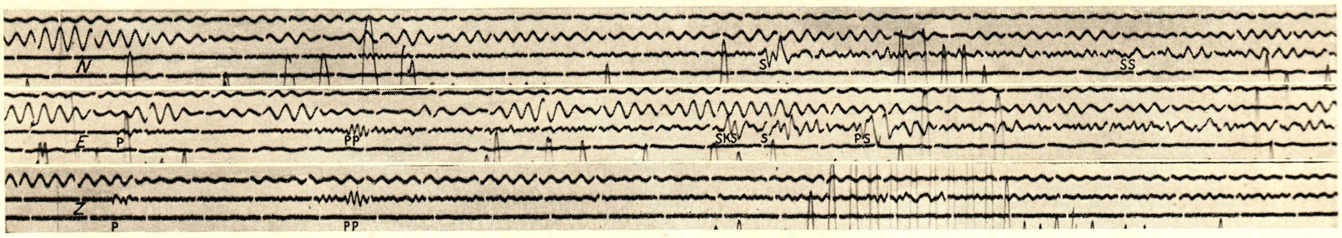


Fig. 26. 1940, May 24. Peru. København G-W N, E, Z. △ = 98°.3.

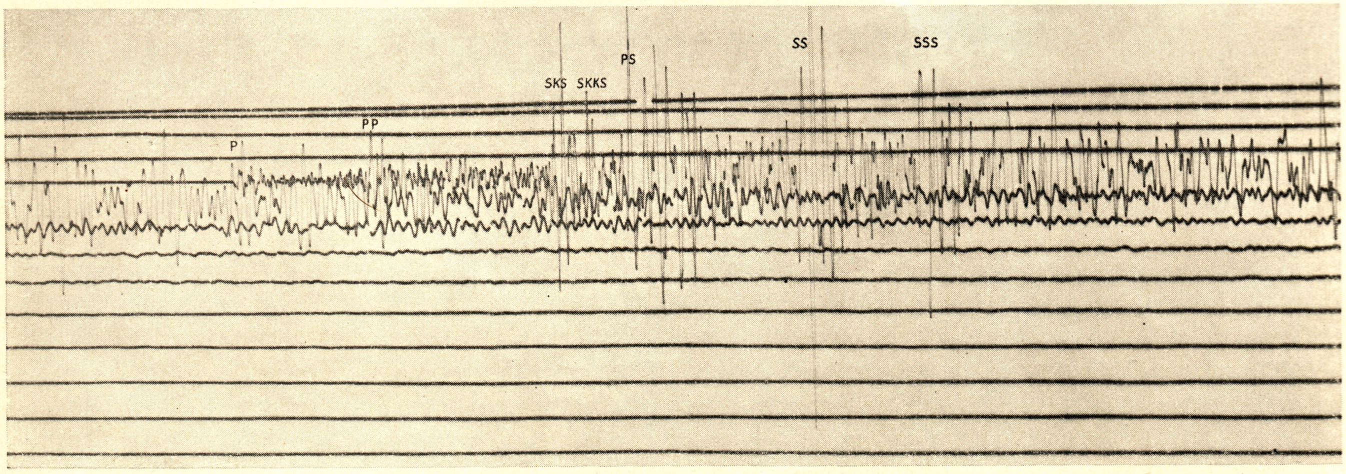


Fig. 27. 1932, May 14. Celebes. København M-S E. △ = 102°.6.

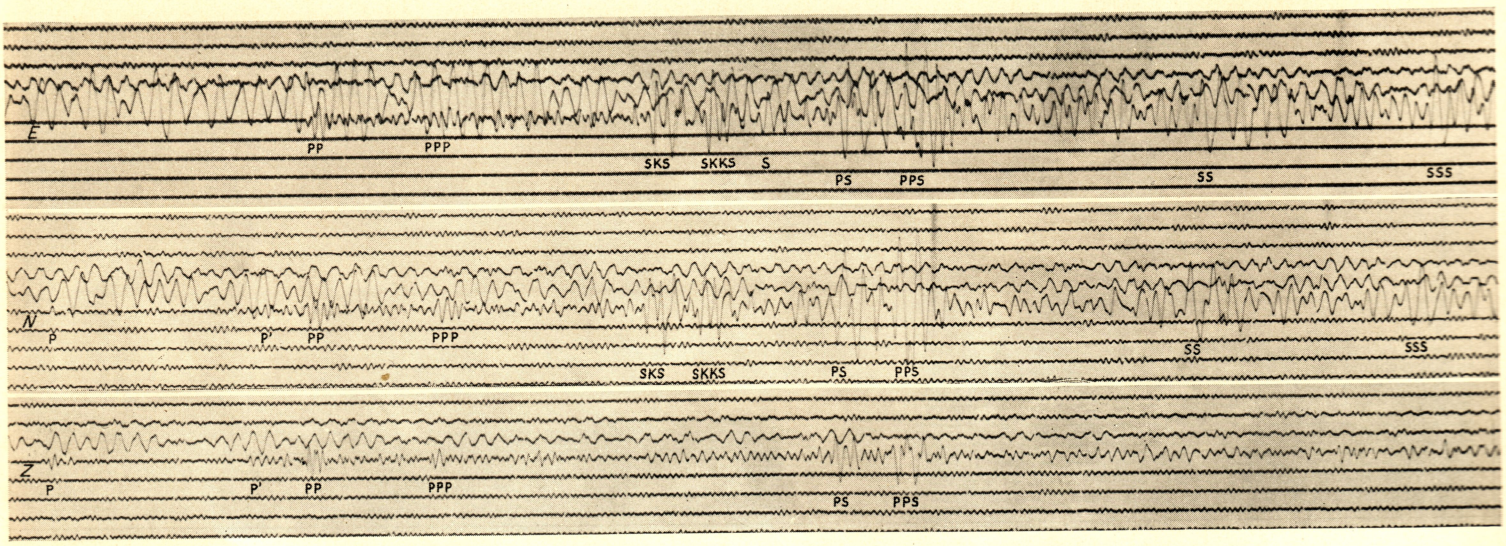


Fig. 28. 1948, March 1. Off west coast of New Guinea. Scoresby-Sund G-W E, N, Z. $\triangle = 108°$.

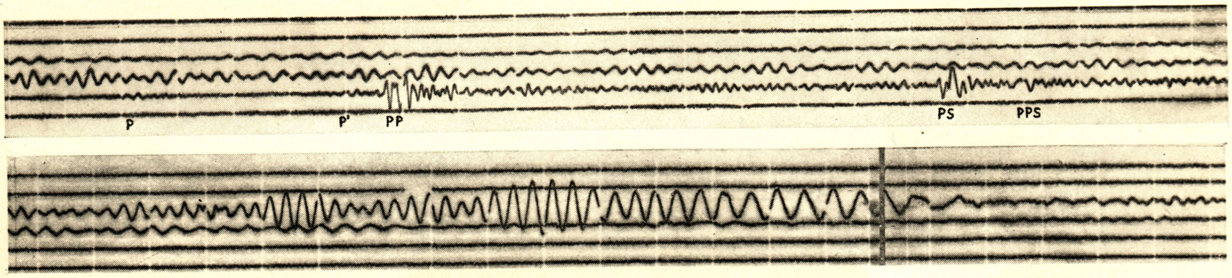


Fig. 29. 1930, Aug. 18. South Atlantic Ocean. København G-W Z. $\triangle = 115°.4$.

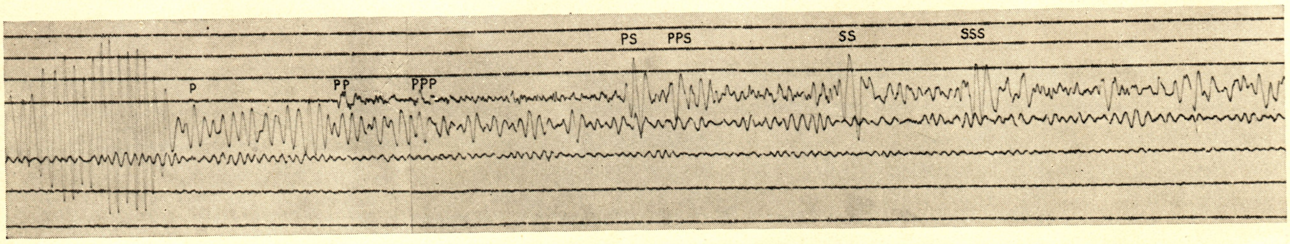


Fig. 30. 1938, May 12. North of New Britain. København M-S E. $\triangle = 119°.2$.

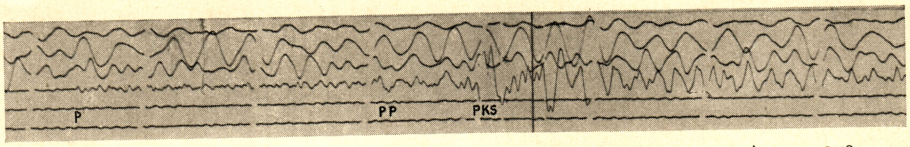


Fig. 31. 1935, June 24. New Hebrides region. København G-W N. △ = 135°.

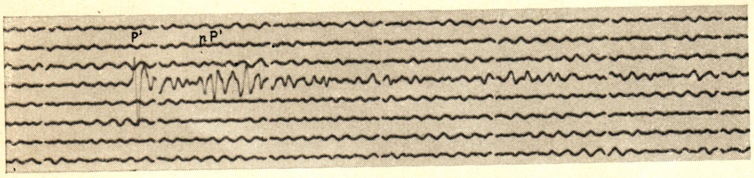


Fig. 32. 1948, Jan. 22. Tonga Islands. København G-W Z. △ = 146°. Depth about 140 km.

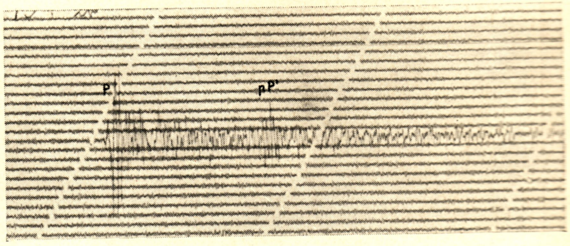


Fig. 33. 1948, Jan. 22. Tonga Islands. København Benioff Z. △ = 146°. Depth about 140 km.

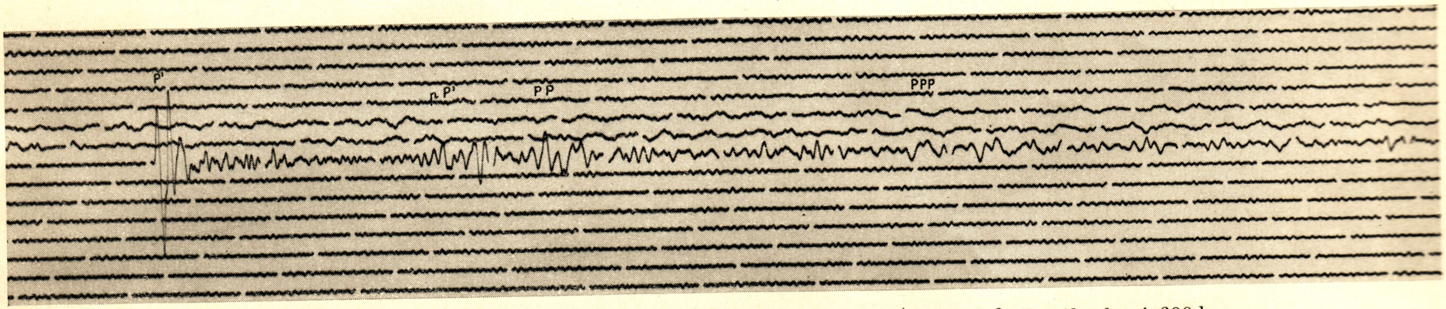


Fig. 34. 1944, May 25. South of Fiji Islands. København G-W Z. △ = 145°. Depth about 600 km.

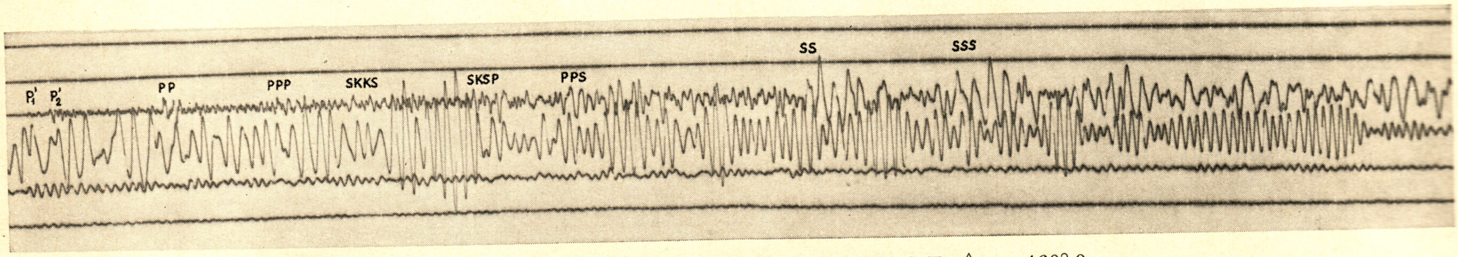


Fig. 35. 1929, June 16. New Zealand. København M-S E. △ = 160°.9.