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ON THE TRAVEL OF SEISMIC WAVES
FROM THE BAFFIN BAY EARTHQUAKE
OF NOVEMBER 20, 1933

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TABLE OF CONTENTS

SECTION	PAGE
1. INTRODUCTION	3
2. DETERMINATION OF EPICENTRE AND DEPTH OF FOCUS	3
3. ANALYSIS OF THE RECORDS	5
4. MULTIPLICITY OF THE PHASES	7
5. DISTRIBUTION OF RESIDUALS OF <i>P</i> AND <i>S</i> ACCORDING TO EPICENTRAL DISTANCE AND BEARING	9
6. COMPARISONS BETWEEN OBSERVED TIMES OF <i>P</i> AND <i>S</i> AND TABLES OF TRAVEL-TIMES ..	10
7. SUMMARY	13
BIBLIOGRAPHY	14
APPENDIX—Table II	15

LIST OF ILLUSTRATIONS

FIG.	
1. Map of regions around Baffin Bay	4
2. Time distance diagram for onsets tabulated from the records of the earthquake in Baffin Bay on November 20, 1933 (Plate I)	
3. Records obtained at Ivigtut ($\Delta=14.6^\circ$), and at Oak Ridge ($\Delta=30.5^\circ$) (Plate II)	
4. " " " Abisko ($\Delta=26.9^\circ$) (Plate III)	
5. " " " Kew ($\Delta=35.8^\circ$) (Plate IV)	
6. " " " De Bilt ($\Delta=36.8^\circ$), and at Ottawa ($\Delta=28.0^\circ$) (Plate V) }	between 6 and 7
7. Number of occurrences of specified residuals for various waves	7
8. Comparisons of observed onsets of <i>P</i> and <i>S</i> with the travel-times of Jeffreys and Bullen (Plate VI)	<i>facing</i> 10
9. Comparisons of grouped observations with various tables of travel-times (Plate VI)	<i>facing</i> 10

ON THE TRAVEL OF SEISMIC WAVES FROM THE BAFFIN BAY EARTHQUAKE OF NOVEMBER 20, 1933

§ 1—INTRODUCTION

A large earthquake which occurred late on November 20, 1933, was recorded by seismographs in all parts of the world. Provisional determinations of the epicentre showed that it was located in Baffin Bay. No information was immediately forthcoming from the surrounding regions, which are very thinly populated, but about a week later it was learned that the shock had been felt in western Greenland. The report* states that "tremors were felt from Upernivik to southern Upernivik, 40 miles to the south, but the colonies on Disko Bay, 300 miles or so to the south, and the more southern colonies, as well as Thule, 350 miles north from Upernivik, did not observe anything."

The earthquake is one of considerable interest since there is no record of any large shock having previously been experienced in the locality. Also, with most of the seismological observatories of the world clustered in Europe, in North America and in Japan, the shock is particularly suitable for investigation of the travel of earthquake waves to moderate distances. For these reasons it was decided to collect the seismograms from all the available observatories, and to analyse the records at Kew Observatory. In response to the circulars requesting the loan of the seismograms, suitable records for this investigation were received from 99 observatories; it is interesting to note that 90 per cent of these observatories were at epicentral distances from 25° to 100° , and that over two-thirds of the total number were between 25° and 50° .

The observing stations being well distributed the epicentre could be determined with considerable accuracy. There was ample material for a critical examination of the travel-time tables for angular distances between 25° and 50° . It was found that the closest representation of the travel of the P waves to these distances was given by a table based upon that published by B. Gutenberg and C. F. Richter (1)† but it was necessary to construct a new table for S .

The earthquake appears to have been one in which the initial waves of compression were very small, but the interval between the true P and the much larger sP (the wave generated by reflexion of a distortional wave), could be recognised on most of the seismograms. The multiplicity of other phases could also be studied.

§ 2.—DETERMINATION OF EPICENTRE AND DEPTH OF FOCUS

An examination was made of the Kew seismograms immediately after the records were developed on November 21, and served for preliminary determination of the epicentre. According to these measurements the shock occurred near latitude 75° N., longitude 65° W., at about 23h. 21½m., G.M.T. Later determinations, each based on the data from a number of observatories, were:—

Strasbourg, Central Seismological Bureau	..	75° N.,	65° W.
United States, Coast and Geodetic Survey	..	73° N.,	67° W.
Jesuit Seismological Association	..	72° N.,	70° W.

The travel-times of the P and S waves from this earthquake have been discussed in a paper (2) by N. Rajko and N. Linden; the epicentre computed in their investigation is 73.3° N., 72.0° W.

The computations of the epicentre to be adopted for this investigation were based solely upon the first onsets of the condensational waves. A selection was made of 14 observatories in different azimuths and at epicentral distances from

* Extracted from *The Times*, November 28, 1933.

† The numbers in brackets refer to the bibliography given on p. 14.

about 27° to 92° , for which the times of arrival of P , as published in the bulletins or communicated from the observatories, did not differ by more than one second from the measurements by the author. The distances between the selected observatories and each of the above tentative epicentres were computed, and the appropriate travel-times of P were obtained from the tables of H. Jeffreys and K. E. Bullen* (3). In these tables the times are reckoned from the "time of origin" of the waves, defined as the point at which the travel-time curve intersects the time axis for zero epicentral distance; these times are not the same for the P and S waves, but both are later than the actual time of the shock at the focus. In the present discussion T_0 (the "time of origin") refers to the P waves; the difference between this time and the time of occurrence of the earthquake† is determined in § 6. Subtraction of the travel-times from the observed times of arrival of P yields 14 values of T_0 for each epicentre. Adopting for each epicentre the mean value of T_0 , the differences between the observed times and calculated times ($O-C$) are obtained.

A method of successive approximations was then followed, and on repeating the computations for several localities in the region 72° — 73° N., 67° — 72° W., it was found that the P residuals were very small with the epicentre at 73° N., 70° W. The observed times of P at all the observatories were then compared with the theoretical times for this epicentre with T_0 at 23h. 21m. 38s. The residuals were on the average about +2 seconds for the observatories in North America and -2 seconds for those in Japan; for the European observatories the residuals did not show any systematic positive or negative tendency. To eliminate the systematic residuals the epicentre must be shifted about 0.2° further from North America and 0.3° nearer to Japan, without appreciably altering the distances from the European observatories. These conditions are approximately satisfied for the

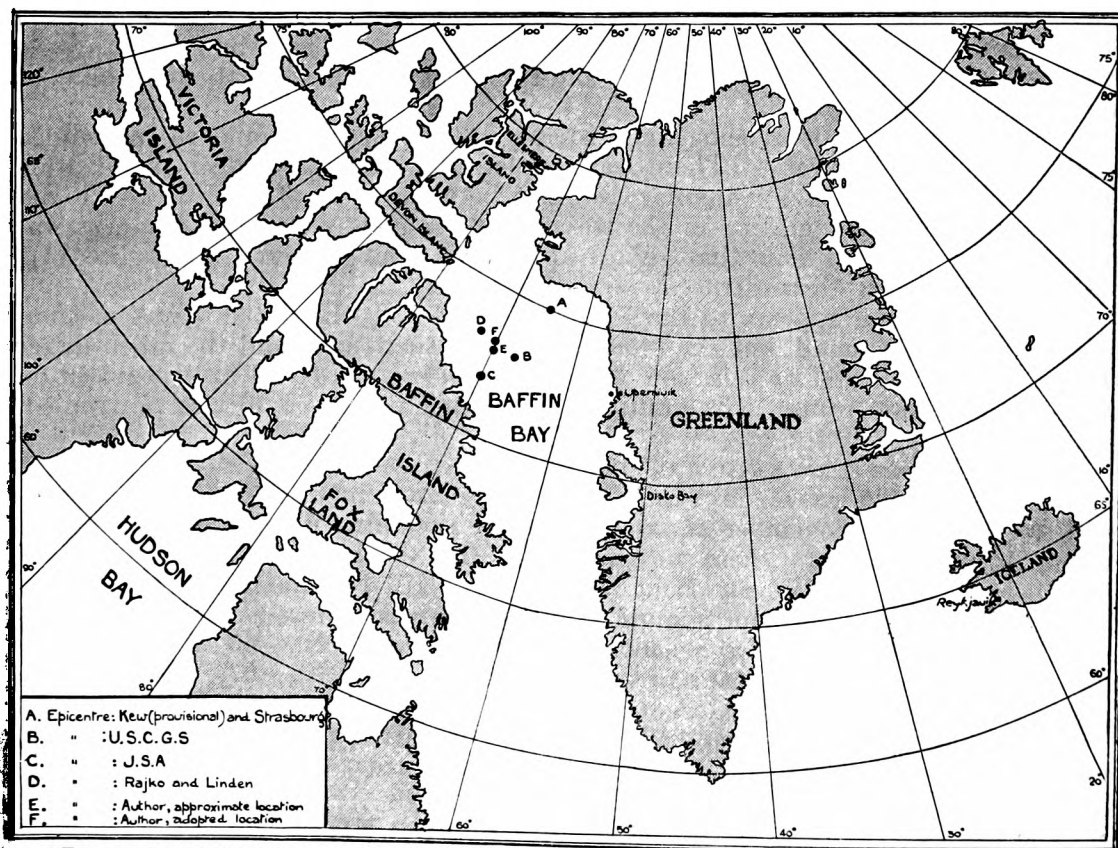


FIG. 1—MAP SHOWING REGIONS ROUND BAFFIN BAY AND POSITIONS SUGGESTED FOR THE EPICENTRE OF THE EARTHQUAKE OF NOVEMBER 20, 1933

* These are the tables used in preparation of the International Seismological Summary.
 † The "time of occurrence" indicates the time of the shock at the focus.

epicentre 73.3° N., 70.2° W., the location which has been finally adopted; the "time of origin" with this epicentre is 23h. 21m. 38s., G.M.T.

The various determinations of the epicentre may be identified by the letters:—A, Kew (provisional) and the International Seismological Association at Strasbourg; B, the United States Coast and Geodetic Survey (U.S.C.G.S.); C, the Jesuit Seismological Association (J.S.A.); D, Rajko and Linden; E, approximate location for present investigation; F, adopted location. The data for the 14 observatories and for the different epicentres are set out in Table I. The epicentres are shown in the accompanying map of the regions around Baffin Bay (Fig. 1).

TABLE I—COMPARISON OF VARIOUS EPICENTRES

Observatory	Time of first <i>P</i> movements (G.M.T.)	A		B		C		D		E		F	
		Δ	O-C	Δ	O-C	Δ	O-C	Δ	O-C	Δ	O-C	Δ	O-C
	h m s	°	sec.	°	sec.	°	sec.	°	sec.	°	sec.	°	sec.
Abisko ..	23 27 17	24.8	20	26.3	7	27.6	-4	27.3	-2	27.0	1	26.9	2
Fordham ..	23 28 4	34.4	-19	32.3	1	31.2	11	32.4	0	32.1	2	32.5	-1
Charlottesville	23 28 30	37.5	-20	35.4	-1	34.2	11	35.4	-1	35.2	1	35.5	-1
Copenhagen ..	23 28 34	33.9	16	34.9	8	36.1	-2	36.2	-4	35.8	0	35.7	1
Pulkovo ..	23 28 44	34.7	19	36.1	7	37.5	-4	37.2	-2	36.9	0	36.8	1
Ukiah ..	23 29 31	44.3	-15	43.1	-5	41.9	6	41.9	5	42.3	2	42.4	1
Pasadena ..	23 29 57	47.9	-17	46.5	-6	45.2	6	45.4	3	45.7	1	45.8	0
Tashkent ..	23 32 0	59.9	17	61.8	5	63.1	-3	62.4	1	62.3	2	62.1	3
Vladivostok ..	23 32 1	61.3	8	63.1	-3	63.8	-7	62.4	2	62.9	-2	62.6	1
Honolulu ..	23 32 41	70.2	-10	69.9	-7	69.1	-1	68.4	2	69.0	-2	69.0	-2
Hong Kong ..	23 34 7	82.7	6	84.7	-3	85.6	-6	84.3	-1	84.6	-2	84.3	-1
Colaba ..	23 34 8	82.5	8	84.4	0	85.7	-6	84.9	-3	84.9	-3	84.7	-2
La Paz ..	23 34 31	91.5	-12	89.5	-2	88.5	4	89.8	-3	89.5	-2	89.8	-3
Manila ..	23 34 43	90.3	5	92.3	-3	93.1	-6	91.7	0	92.1	-2	91.8	-1
Mean T_0 23h. +		21m. 39s.		21m. 38s.		21m. 37s.		21m. 38s.		21m. 38s.		21m. 38s.	

EPICENTRE

- A. 75° N., 65° W., Kew (provisional) and Strasbourg.
 B. 73° N., 67° W., U.S.C.G.S.
 C. 72° N., 70° W., J.S.A.
 D. 73.3° N., 72.0° W., Rajko and Linden.
 E. 73° N., 70° W., Author; approximate location.
 F. 73.3° N., 70.2° W., Author; adopted location.

The surface waves from the earthquake were very large, showing that the depth of focus was not abnormally great. This is confirmed by the agreement between the observed times of travel of the *P* waves from the epicentre to the observatories shown in Table I, and the times given in the tables for shocks of "normal" focal depth.

The occurrence of several pulses in the various phases of the seismograms is well known, and it was apparent that two onsets of the *P* phase were recorded systematically. These movements represent the arrivals of the normal condensational wave (*P*) and of the reflected wave (*sP*) which is transformed from a distortional to a condensational wave on reflection near the epicentre. The time interval between the onsets of *P* and *sP* is on the average about 4 seconds, which indicates a focal depth of some 10Km. below the surface; this depth is within the range encountered in "normal" earthquakes. In Europe there are several kilometres of sedimentary rocks over the granitic layer, which is about 14Km. in thickness and is superposed on the "intermediate" layers; the main discontinuity at the top of the lower layer lies about 45Km. below the surface. If the European structure extends beneath the regions around Baffin Bay the focus of the earthquake must have been located in the granite.

§ 3—ANALYSIS OF THE RECORDS

In tabulation of the records the times of all well-defined onsets were measured, and classified as *i* (impetus) or *e* (emersio) according to whether they were sharp or represented a gradual development. The movements entered as *i* were generally

timed with confidence to within one second, but for those marked e the uncertainties of measurement may amount to several seconds.

The times of the tabulated onsets (reckoned from the adopted time of origin as zero), are plotted against the epicentral distance in Fig. 2. The arrivals of the condensational and distortional waves, and to a lesser extent of the reflected waves, are clearly shown in the diagram; these movements can generally be identified from the characteristics of the individual records. There are observations which approximate to the theoretical times for other waves, but the identification of these points is less reliable. Points which do not agree with the travel-time curves of the known waves may possibly belong to new waves, be caused by interference phenomena, or be due to local peculiarities.

The waves discussed in this paper are of three types :—

(a) *Condensational Waves*.— P . The first movement to arrive. This is generally not very large and may be missed if the magnification of the seismograph is low or if the instrument is unfavourably orientated.

sP . The larger movement following a few seconds after P .

Px . Later onsets of the condensational waves. These movements are not shown as systematically as sP ; the time intervals between P and Px are irregular, so several pulses may be represented. The numbers of observations are not sufficient for the travel-times to be determined, so these later movements have for convenience all been tabulated under the one designation.

(b) *Reflected Condensational Waves*.—Examination of the seismograms and of the tabulations showed that the reflected condensational waves gave two groups of onsets, separated by 10 to 20 seconds,* which arrived at about the theoretical time for PP . At moderate epicentral distances it is difficult to discriminate between the second of these pulses and the onset of waves which have been reflected more than once between the epicentre and the recording station. The first two waves have been termed PPI and $PPII$, the subsequent ones PPx .

(c) *Distortional Waves*.—The difficulties of identification of S , the onset of the distortional waves, are well known. In this work S has been taken as the conspicuous large movement at the beginning of these waves. The smaller movement known as the "curtsey" sometimes precedes this, but the time interval between the "curtsey" and S is not uniform. Onsets following S have been classified as Sx .

A number of specimen records, showing the onsets selected in the analysis, are reproduced in Figs. 3–6.

Table II (Appendix) gives information relating to the observatories, to the types of seismographs and components recorded, together with the times of arrival of the waves and their departures from the times calculated from the Jeffreys-Bullen tables. The times of arrival are reckoned from the "time of origin" (23h. 21m. 38s., G.M.T.) as zero. In the table are shown :—

Columns

- | | |
|-------------|--|
| 1. | Identification number of the record. |
| 2, 3, 4. | Name of observatory, epicentral distance and bearing from epicentre to observatory. |
| 5, 6. | Type of seismograph and component recorded. |
| 7, 9. | Times of arrival of P and sP . |
| 8, 10. | Residuals P ($O-C$) and sP ($O-C$), the differences between the observed times of P and sP and the calculated times of P . |
| 12, 14. | Times of arrival of PPI and $PPII$. |
| 13, 15. | Residuals PPI ($O-C$) and $PPII$ ($O-C$), the departures from the calculated time for PP . |
| 17, 18. | Times of arrival and residuals of S . |
| 19. | Onset of the "curtsey" expressed as departure from the calculated time of S . |
| 11, 16, 20. | Onsets of Px , PPx and Sx expressed as departures from the calculated times of P , PP and of S respectively. |

* See, for example, the Kew vertical record reproduced in Fig. 5.

To face p. 6

Plate I

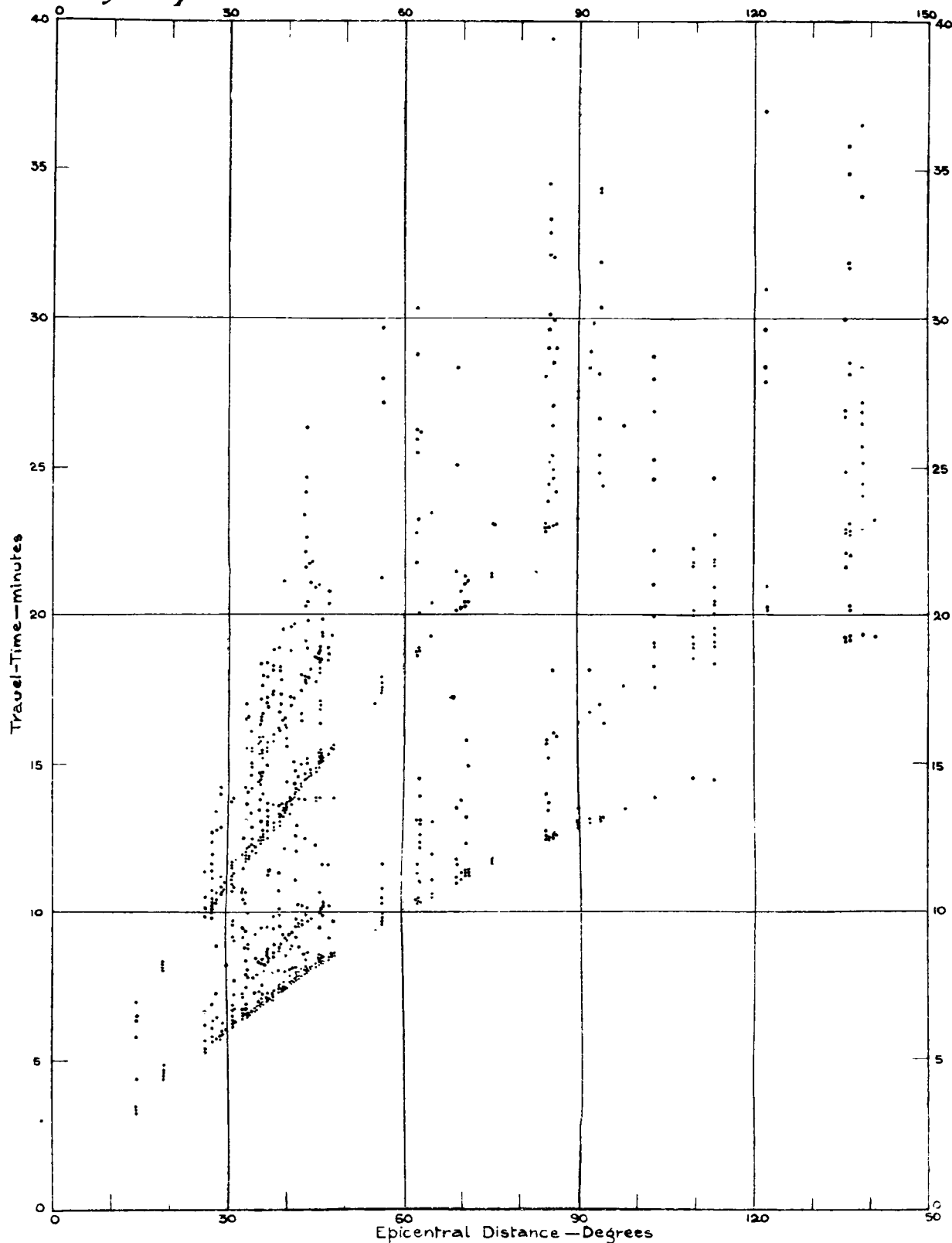


FIG. 2 - TIME-DISTANCE DIAGRAM FOR ONSETS TABULATED FROM THE RECORDS OF THE EARTHQUAKE IN BAFFIN BAY, NOVEMBER 20, 1933.

(2303)W*3445A,626,6'37Op921CBRL*

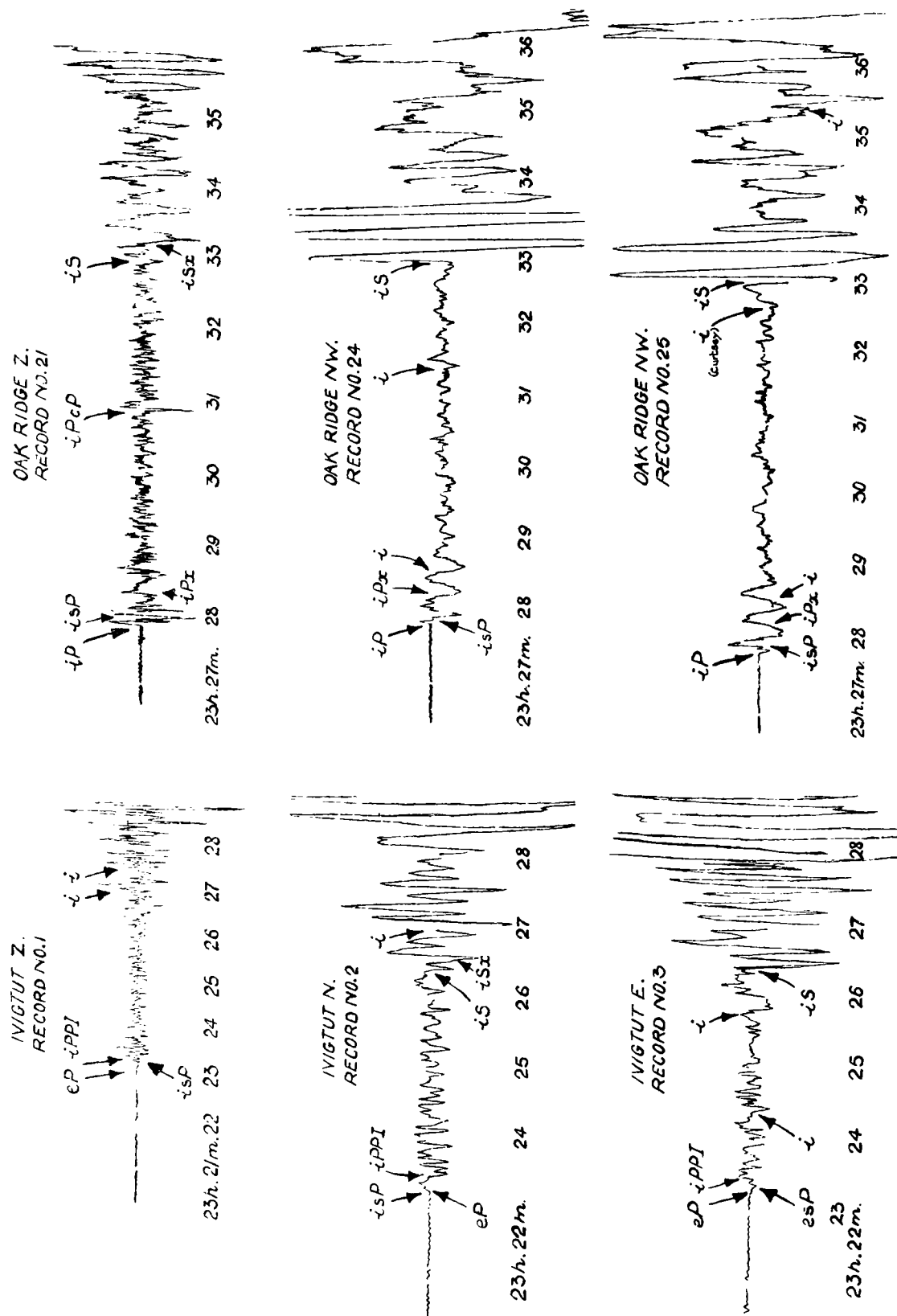


FIG. 3 RECORDS OBTAINED AT IVIGTUT ($\Delta = 14.6^\circ$) AND AT OAK RIDGE ($\Delta = 30.5^\circ$)
 Clock corrections: - IVIGTUT, + 1m 38s. OAK RIDGE, - 1s.

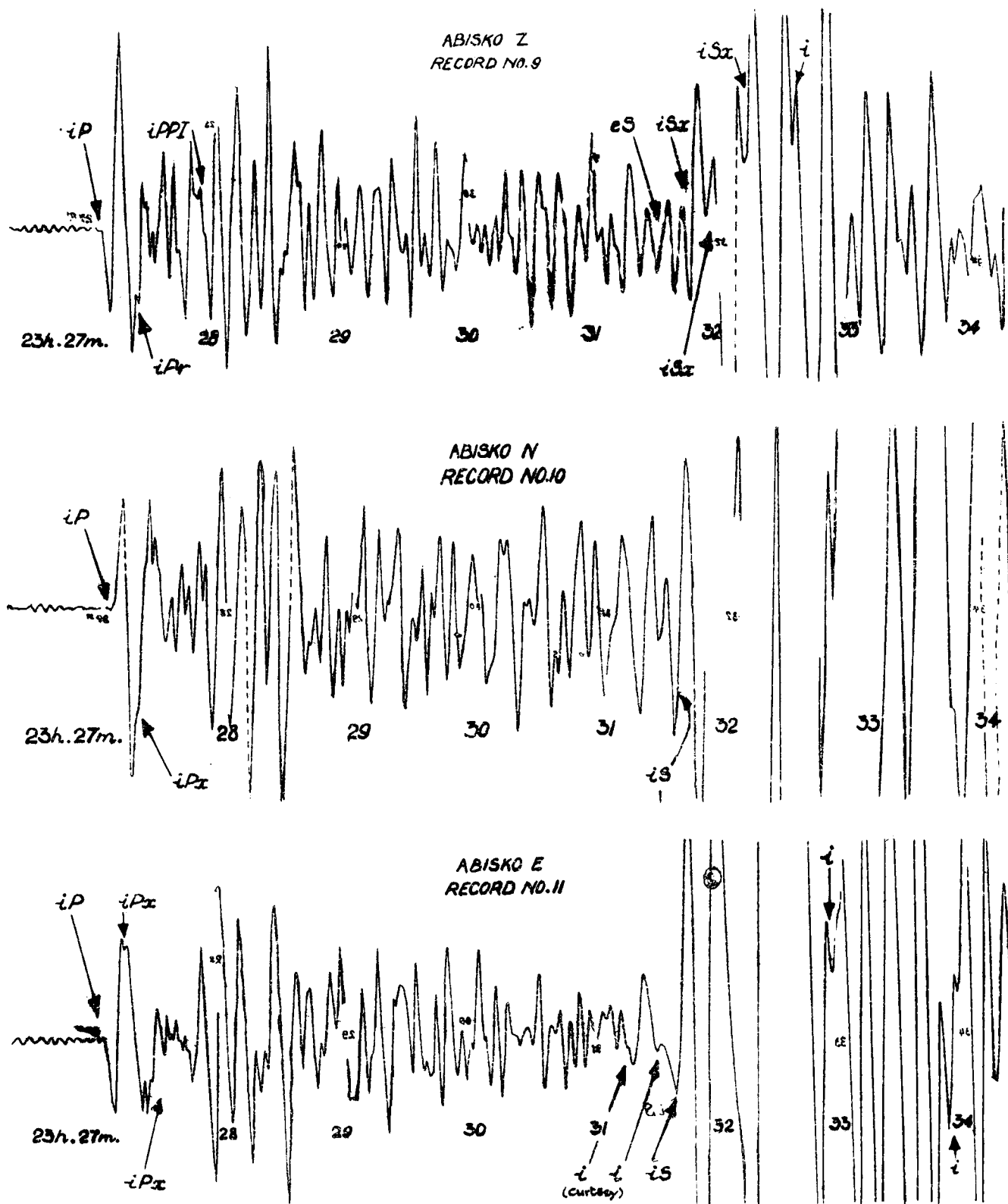


FIG. 4 RECORDS OBTAINED AT ABISKO ($\Delta = 26.9^\circ$)
Clock correction + 12s.

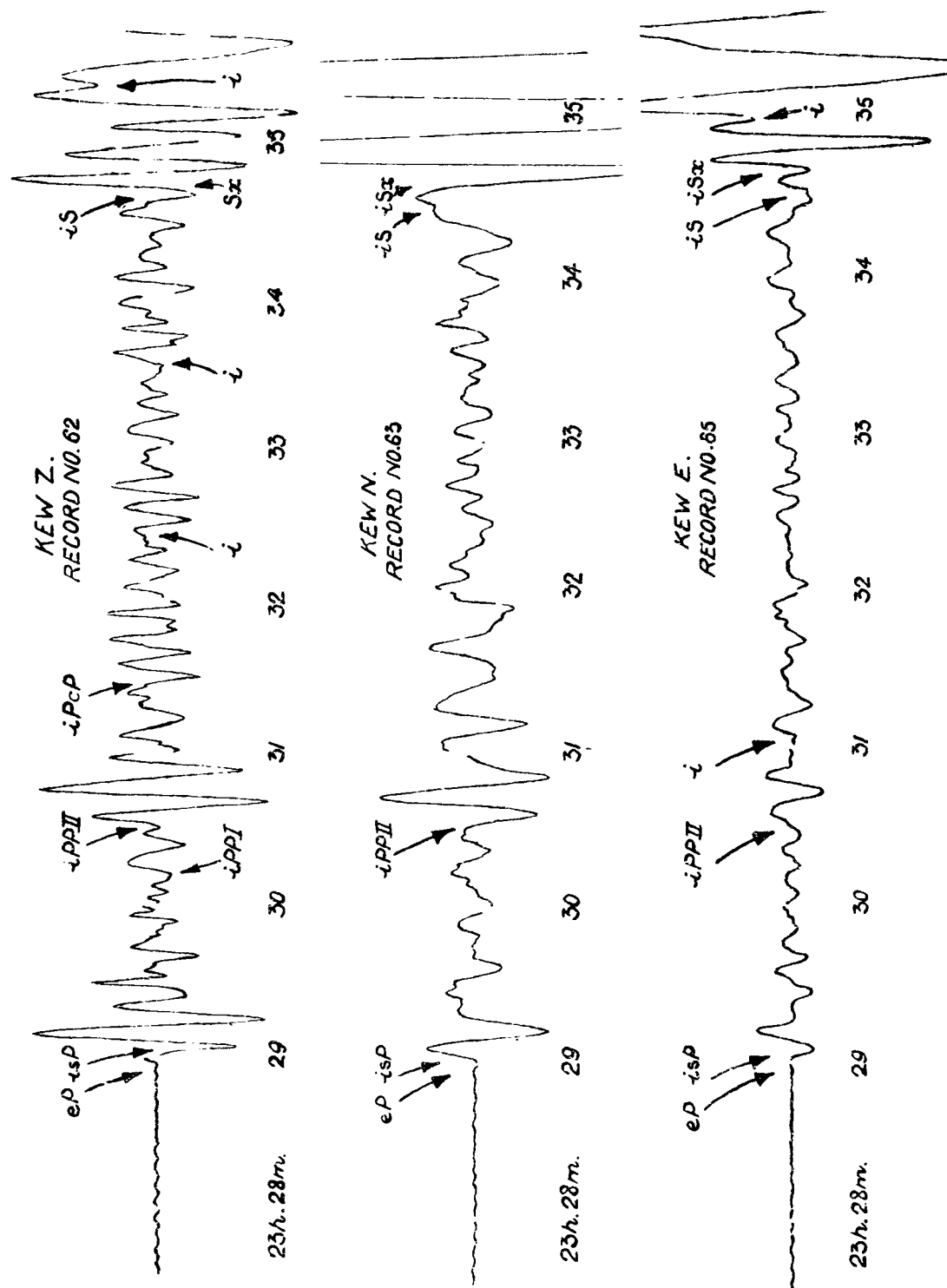


FIG.5 RECORDS OBTAINED AT KEW ($\Delta - 35.8^\circ$)
Clock correction - 24 s.

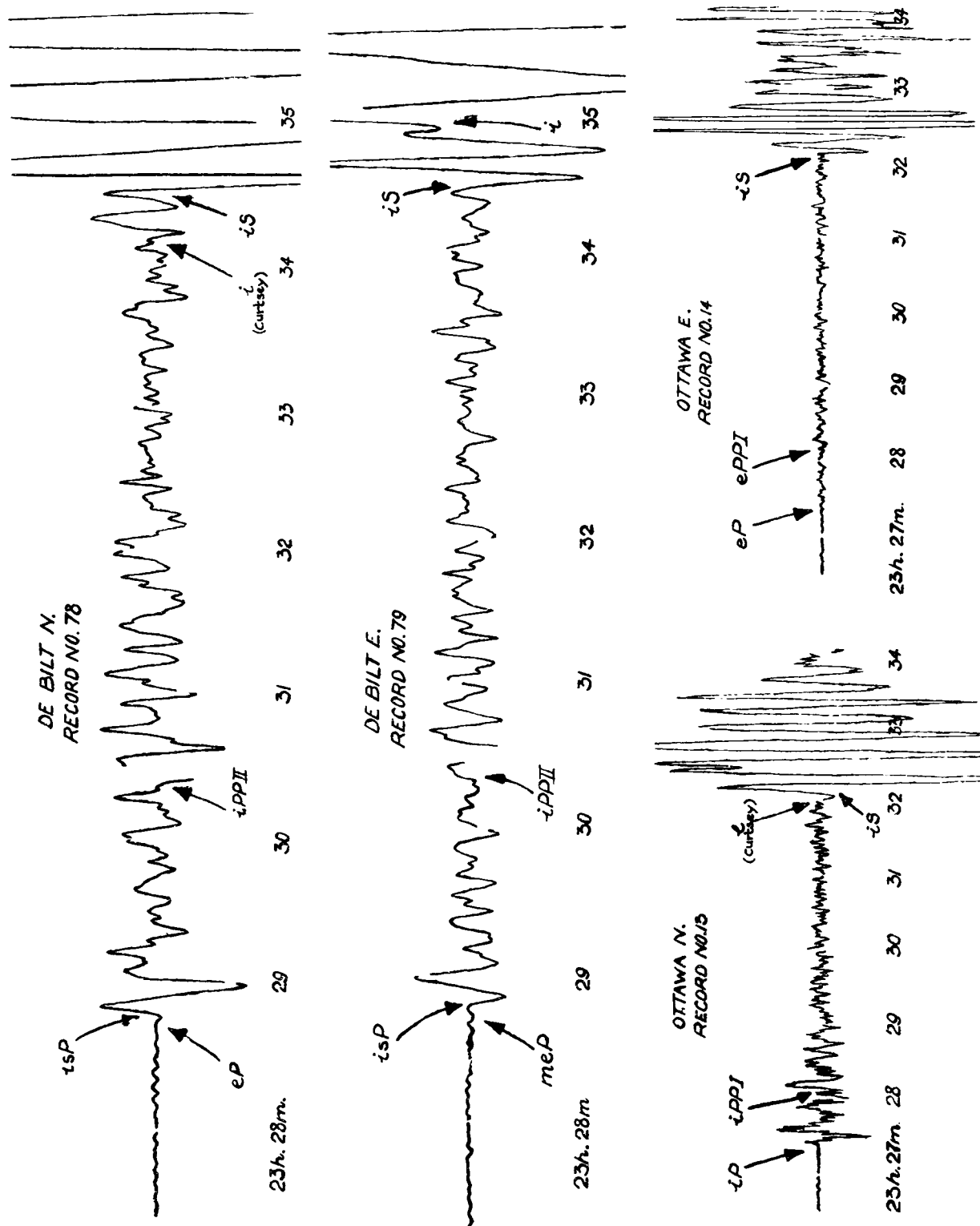


FIG 6. RECORDS OBTAINED AT DE BILT ($\Delta = 36.8$) AND AT OTTAWA ($\Delta = 28.0^\circ$)
Clock corrections:- DE BILT Os., OTTAWA - 1s.

For the greater epicentral distances observations of *PKP* and the residuals appear in columns 7 to 10, with the corresponding data for *SKS* in columns 19 and 20. These data are too scanty for critical examination of the accuracy of the tables of travel-times for waves through the earth's core.

§ 4—MULTIPLICITY OF THE PHASES

The phenomenon of multiplicity, discussed by Gutenberg and Richter, is shown by the occurrence of the different onsets in the three main groups of waves. The high correlation between *P* and *sP* is evident from the specimen records, and there is an appreciable connexion between some of the other pulses. Frequently the α onsets could not be traced between stations at approximately the same distance from the epicentre, or even between the different records at the same observatory.

To investigate the definition of the onsets the departures of the observed from the calculated times have been summarised to show the numbers of occurrences of specified residuals. The resulting distributions for *P*, *sP*, *S*, *P α* , *S α* , *PPI* and *PPII* are plotted in Fig. 7.

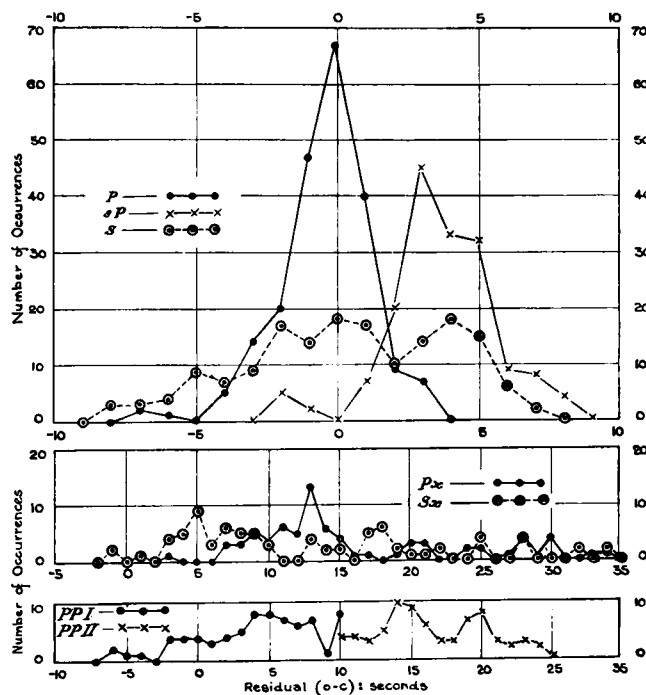


FIG. 7—NUMBER OF OCCURRENCES OF SPECIFIED RESIDUALS FOR VARIOUS WAVES

The distribution of residuals of *P* and of *sP* show well-marked maxima at 0 sec. and from 3 to 5 sec. respectively; the maximum frequency of *P α* onsets occurs from 11 to 14 seconds after *P*. The distribution of *S* is more uniform than that of *P*; residuals from -2 to +1 sec. and from +3 to +5 sec. are most frequent. The maxima of *S α* occur around 5 sec. and from 17 to 18 sec., consequently it appears probable that a movement occurs 5 sec. after the true *S* and that in some cases this movement may have been selected instead of *S*. The maximum of the *PPI* curve is for residuals from 4 to 8 sec.; *PPII* shows two maxima around 14–15 sec. and 19–20 sec. respectively.

The multiplicity of *PP* suggests that the *P* and *sP* pulses are both reflected from the base of the superficial layers as well as at the surface. On this hypothesis the onsets given as *PPII* represent the reflexions at the surface, the maximum frequency of residuals around 14–15 sec. indicating the onset generated from *P*, and that around 19–20 sec. the onset generated from *sP*. The earlier wave, *PPI*, being reflected at a depth, is weaker and most of the onsets selected would be generated from *sP* which is much larger than the true *P*.

The onsets of the "curtsey" most frequently occur from 4 to 11 sec. before the genuine *S*, the distribution of the residuals being as follows:—

Residual (sec.)	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	-(15 to 19)	-(20 to 24)	-(25 to 29)
Number of values	3	4	4	2	4	0	1	5	1	0	2	5	5	2

The movements are small and difficult to read owing to the presence of micro-seisms in most of the records, and also to the later oscillations of the condensational waves. The "curtsey" does not occur systematically before *S*, and its identification as part of the distortional waves has not been established.

TABLE III—RESIDUALS OF *P* AND *S*. SUMMARISED

Δ	Residuals of <i>P</i> (sec.)												Mean
	Bearing from epicentre to observatory (degrees)												
	350- 10	20- 40	50- 70	80- 100	110- 130	140- 160	170- 190	200- 220	230- 250	260- 280	290- 310	320- 340	
°													
25-30			2				0 0 0 -1 -2			3			0.3
30-35			0	-2 -3			0 -1 -1 -3	-1 -2	0 -1				-1.3
35-40			2 1 1 -2 -3	2 1 1 0 0 0 -1 -1			-1 -2	-4 -4					-0.6
40-45			0	2 1 0 0 -1 -1 0				-3	1 1 1 1 0 0				0.1
45-50			0	1 0 0 -1 -1					1 0 0 0 -1 -2				-0.3
50-60							-2	0					(-1.0)
60-70		3	0 -2							-2		1 0	(0.0)
70-80	0											1 -1	(0.0)
80-90	1 -1	-2					-1 -3						(-1.2)
90-100	-1	0		-4									(-1.7)
>100	-1											3	(1.0)
Mean	(-0.4)	(0.3)	-0.1	-0.3			-1.2	-2.3	0.1	(0.5)		(0.8)	

NOTE. 1. The component showing the earliest arrival of *P* or *S* is selected for observatories with more than one seismograph.

2. The following values have been omitted from the above table as abnormal :—

Observatory	Δ	Bearing	<i>P</i> Residual	<i>S</i> Residual
Ivigtut	°	°		
Reykjavik	14.6	130	-7	18
Saskatoon	19.0	90	..	19
	26.1	240	-0	..

ACCORDING TO EPICENTRAL DISTANCE AND BEARING

Residuals of <i>S</i> . (sec.)													Δ
Bearing from epicentre to observatory (degrees)													
350- 10	20- 40	50- 70	80- 100	110- 130	140- 160	170- 190	200- 220	230- 250	260- 280	290- 310	320- 340	Mean	
		-7				4 3 0 -3 -6		-6				-2.1	° 25-30
		-1	0 -1 -2 -7			-2 -2 -2 -4	-2 -3 -5	5 4 -3				-1.7	30-35
		2 0 0 -2 -3	6 4 3 1 1 0 -1 -2 -5			-1 -3	-5 -6					-0.6	35-40
		3 1	5 5 4 3 2 1 1				-4	6 6 5 5 0				2.9	40-45
		2	3 1 1 1 0					5 4 4 4 3 2				2.5	45-50
						-1	-1					(-1.0)	50-60
		4 -2							3		1 0	(1.2)	60-70
0											-3 -8	(-3.7)	70-80
-3	-4											(-3.5)	80-90
			-5									(-5.0)	90-100
													>100
(-1.5)	(-4.0)	-0.3	0.7			-1.4	-3.7	2.9	(3.0)		(-2.5)		Mean

§ 5—DISTRIBUTION OF RESIDUALS OF *P* AND *S* ACCORDING TO EPICENTRAL DISTANCE AND BEARING

The residuals of *P* and *S* are summarised in Table III according to epicentral distance and bearing from epicentre to observatory. In this table undue importance has not been attached to observatories having more than one seismograph, the

component showing the earliest arrival of P or S being selected for such stations. In addition to the residuals of P and S for each observatory the mean residuals for the different distances and bearings are included; the values are entered in brackets when the means have been obtained from a small number of observations.

On the average the residuals of P are slightly positive from 25° to 30° , more than a second negative from 30° to 35° , increasing at greater distances to zero round 40° to 45° and becoming negative once more from 45° to 50° ; those of S are negative by about two seconds from 25° to 30° , thence increasing and becoming positive by two to three seconds from 40° to 50° . Beyond 50° there are not many observations, but there is some indication that the residuals are negative by approximately one second for P at distances exceeding 80° and by about four seconds for S at those greater than 70° .

Negative residuals occur for both P and S in the bearings from 170° to 220° but from 230° to 250° P is approximately correct while S arrives late. The discrepancy of P from 170° to 220° could not be eliminated by a change of epicentre, since an error would be introduced in the adjacent bearing which includes some of the best equipped and most reliable stations in the world (the Californian group).

The distributions of residuals of different amounts for P and S , summarised from Table III without regard to distance or bearing, are:—

Residual ($O-C$). sec. ..	>+6	+6	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	<-6
Number of occurrences P .	0	0	0	0	3	4	14	27	18	10	5	3	0	0	2
.. .. S .	2	3	6	8	7	4	9	9	6	8	7	3	4	3	3

For P the distribution is approximately Gaussian with a sharp maximum in the frequency, the greatest value occurring near zero; the distribution for S is more scattered, but the numbers of occurrences of positive and negative residuals are nearly equal.

§ 6—COMPARISONS BETWEEN THE OBSERVED TIMES OF P AND S AND TABLES OF TRAVEL-TIMES

The mean residuals for P and S from Table III are set out in Table IV, together with the standard deviations, σ , the numbers of values, n , and the probable errors of the means. The formula used is:—Probable error of mean = $0.67 \sigma/n^{\frac{1}{2}}$.

TABLE IV—STANDARD DEVIATIONS, PROBABLE ERRORS AND MEANS FOR THE RESIDUALS OF P AND S

Epicentral distance	P			S		
	n	σ	Mean	n	σ	Mean
°		sec.	sec.		sec.	sec.
26—30	7	1.6	0.3 ± 0.4	7	4.2	-2.1 ± 1.1
30—35	11	1.1	-1.3 ± 0.2	15	2.6	-1.7 ± 0.5
35—40	18	1.8	-0.6 ± 0.3	18	3.1	-0.6 ± 0.5
40—45	14	1.2	0.1 ± 0.2	15	2.7	2.9 ± 0.5
45—48	12	0.8	-0.3 ± 0.2	12	1.8	2.5 ± 0.3

Comparisons between the observed times of P and S and the Jeffreys-Bullen tables appear in Fig. 8. To obtain a better representation of the data than can be obtained by plotting the departures of the observations from the travel-time curves, a novel method has been employed, the times being expressed as departures from the times which would correspond with constant velocities of P and of S from 25° to 50° . The mean travel-times for the Jeffreys-Bullen tables over this range are 8.46 sec. per degree for P and 15.20 sec. per degree for S . The curves of the diagram represent the travel-times of the tables; the observations are those used in Table III, only one component being taken for each observatory. The scatter of the observations on both sides of the curves is too great for corrections to the tables at

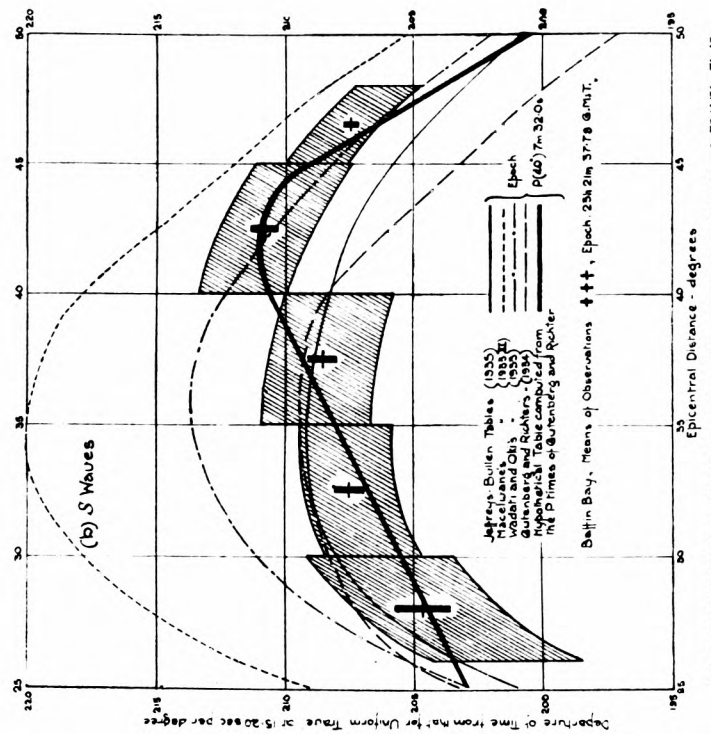
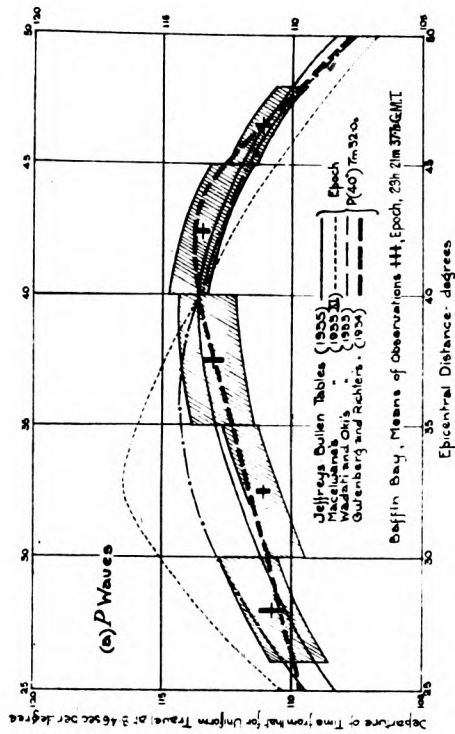


FIG. 9 - COMPARISONS OF GROUPED OBSERVATIONS WITH VARIOUS TABLES OF TRAVEL - TIMES

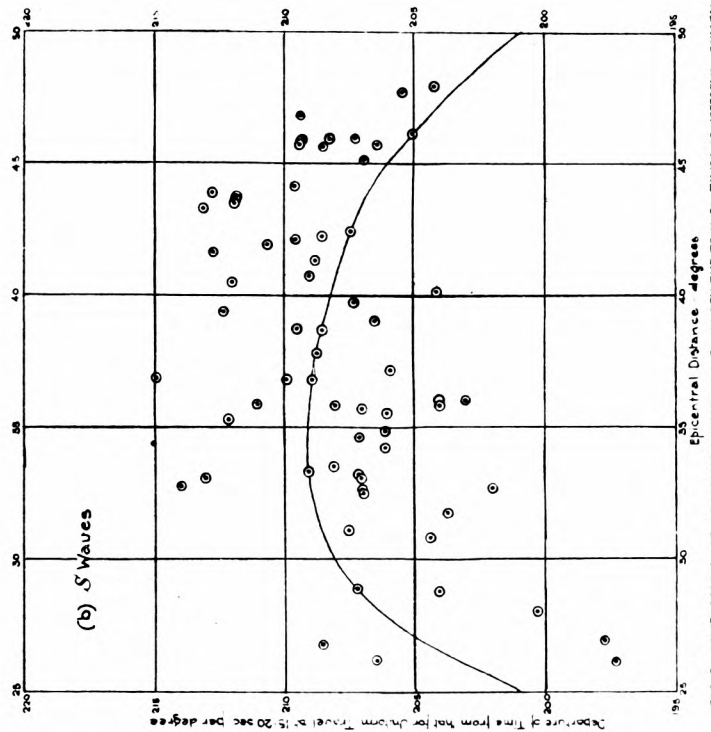
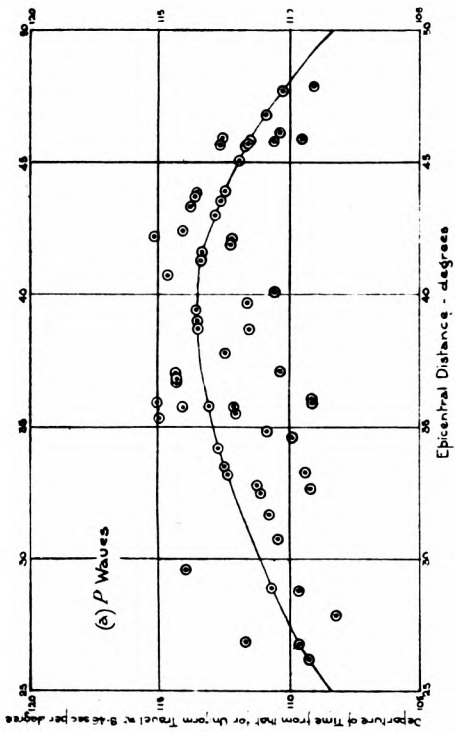


FIG. 8 - COMPARISONS OF OBSERVED ONSETS OF P & S WITH THE TRAVEL - TIMES OF JEFFREYS & BULLEN

various epicentral distances to be obtained directly from these diagrams. There is, however, a tendency for the observations of P and S both to be lower than the curves from 30° to 40° and above the curves from 40° to 45° .

On the whole there is better agreement between the observations of P and the Jeffreys-Bullen times if the "time of origin" is taken 0.3 sec. earlier than that determined in § 2. An adjustment of this amount is permissible, since the T_0 of § 2 was only determined to the nearest second, and the "time of origin" is therefore corrected to 23h. 21m. 37.7s. G.M.T. With this adjustment the mean residuals of P and S with respect to the Jeffreys-Bullen tables are:—

Epicentral distance	..	..	..	..	28°	32.5°	37.5°	42.5°	46.5°
Mean residual of P (sec.)	..	..	..	..	0.6	-1.0	-0.3	0.4	0.0
Mean residual of S (sec.)	..	..	..	..	-1.8	-1.4	-0.3	3.2	2.8

Other tables, which have been published recently and may be used for further comparisons with the observations, are:—

- Macelwane's tables. (November, 1933). (4).
- Wadati and Oki's tables. (1933). (5).
- Gutenberg and Richter's tables. (1934).

In the Jeffreys-Bullen tables times are given to a tenth of a second and Wadati and Oki have given their table of S to this order of accuracy. To utilise the other tables it was necessary to smooth the published times. The times of these tables are reckoned from the occurrence of the earthquake, and not from the Jeffreys-Bullen "time of origin" of the waves.

According to the Jeffreys-Bullen tables the arrival of P waves at 40° from the epicentre occurs 7m. 32.0s. after the "time of origin". For the comparison of the tables it is convenient to regard 7m. 32.0s. before the arrival of P waves at 40° as the "epoch" from which time is to be measured, all tables being adjusted to give 7m. 32s. at 40° . The adjustments required are:—Macelwane, -3.1 sec.; Wadati and Oki, -6.1 sec.; Gutenberg and Richter, -6.2 sec. The corresponding curves appear in Fig. 9; in the lower part of the figure S , referred to the same epoch, is graphed in the same way. In these diagrams are also shown the Baffin Bay observations grouped for epicentral distances 26° - 30° , 30° - 35° , 35° - 40° , 40° - 45° and 45° - 48° ; the probable deviations of an individual value are indicated by the shaded areas and the probable errors of the means by the heavy vertical lines.

For P the mean values of the observations agree best with the tables of Gutenberg and Richter. The Jeffreys-Bullen times are about half a second too great over the range 30° to 35° , the times of Wadati and Oki are over a second too large for these distances, and those by Macelwane are worse in this region as well as being too large from 26° to 30° and too small from 45° to 48° . The smoothed curve of P from Gutenberg and Richter is accordingly taken as giving the best representation of the travel of the waves from this earthquake. The zero of time for the Gutenberg and Richter table is 6.2 sec. earlier than the epoch of Fig. 9; the time adopted for the earthquake is therefore 23h. 21m. 31.5s. G.M.T.

TABLE V.—TRAVEL-TIMES OF P AND S WAVES FOR DISTANCES 25° TO 50°
 P from Gutenberg and Richter (1935); S proportional to P

Δ	P		S		Δ	P		S		Δ	P		S	
°	m	s	m	s	°	m	s	m	s	°	m	s	m	s
25	5	27.4	9	49.3	34	6	45.8	12	10.4	43	8	3.7	14	30.7
26	5	36.1	10	5.0	35	6	54.6	12	26.3	44	8	11.9	14	45.4
27	5	44.8	10	20.6	36	7	3.3	12	41.9	45	8	19.6	14	59.3
28	5	53.5	10	36.3	37	7	12.0	12	57.6	46	8	27.1	15	12.8
29	6	2.2	10	52.0	38	7	20.8	13	13.4	47	8	34.5	15	26.1
30	6	11.0	11	7.8	39	7	29.4	13	28.9	48	8	42.0	15	39.6
31	6	19.7	11	23.4	40	7	38.2	13	44.8	49	8	49.5	15	53.1
32	6	28.4	11	39.1	41	7	46.8	14	0.2	50	8	57.0	16	6.6
33	6	37.1	11	54.8	42	7	55.3	14	15.5					

NOTE.—The travel-times are reckoned from the time of occurrence of the earthquake.

The times of travel of P waves for distances from 25° to 50° are given in Table V, the epoch being the shock at the focus. It was noticed in preparing the table that, within the accuracy of the values, the time was a linear function of the distance from 25° to 40° and from 45° to 50° , the transition from one line to the other being continuous. Over the ranges of distance where the apparent velocity of P is constant the travel-times are 8.72 sec. per degree and 7.48 sec. per degree. The former figure is approximately the value (8.8 sec. per degree) found by Miss Lehmann from the observations of P at similar distances from the Azores earthquake of May 20, 1931, (6).

In his recent paper "The structure of the earth down to the 20° discontinuity" H. Jeffreys (7), has developed formulæ from which he has deduced tables of travel of P waves for earthquakes with foci at the earth's surface and at the base of the intermediate layer. In these tables the shock at the focus is taken as epoch. The depth of focus of the Baffin Bay earthquake is about a quarter of the depth to the base of the intermediate layer, and the travel-times for this earthquake can be obtained by interpolation. The travel-times, and the differences between the new tables, (J. 1936), and those of Jeffreys and Bullen, (J.B. 1935), are :—

	Epoch	Epicentral distance (degrees)					
		25	30	35	40	45	50
P . (J. 1936). Surface focus	Shock at focus	m s 5 28.5	m s 6 14.3	m s 6 58.3	m s 7 40.4	m s 8 21.0	m s 9 0.1
P . (J. 1936). Focus at base of intermediate layer ..	" "	5 22.7	6 8.3	6 52.2	7 34.3	8 14.8	8 53.9
P . (J. 1936). Interpolated for Baffin Bay focal depth	" "	5 27.1	6 12.8	6 56.8	7 38.9	8 19.5	8 58.5
P . (J. 1936). Interpolated for Baffin Bay focal depth	$P(40^\circ) - 7^m 32^s$	5 20.2	6 5.9	6 49.9	7 32.0	8 12.6	8 51.6
P . (J.B. 1935)	" "	5 19.9	6 5.0	6 49.1	7 32.0	8 12.7	8 51.4
(J. 1936).—(J.B. 1935) ..	" "	0.3	0.9	0.8	0.0	-0.1	0.2

It will be seen that the graph to represent the J. 1936 table would run above the curve in Fig. 8a between 25° and 40° , and would therefore be a worse representation of the Baffin Bay observations.

Considering now the lower part of Fig. 9 we notice that there are discrepancies between the observations of S and the times of arrival given by the tables. Below 40° , and especially from 30° to 35° , the tables generally give times which are too great, and beyond 40° the times are all too small. The maxima of the curves are all well below 40° , whereas the maximum of the observations is from 40° to 45° , agreeing with the P observations and the P curve from Gutenberg and Richter.

It was seen that fair representation of the S observations would be obtained from a hypothetical curve based upon the P times of Table V. The mean times reckoned from 23h. 21m. 31.5s. G.M.T., and the ratios between the travel-times of S and P , for the adopted ranges of epicentral distance, are given in the following table :—

Mean distance	28°	32.5°	37.5°	42.5°	46.5°
P sec. ..	354.0	392.3	436.6	479.2	510.8
S sec. ..	636.4	707.8	784.8	862.9	920.5
Ratio S/P ..	1.798	1.804	1.798	1.801	1.802

The hypothetical curve for S can therefore be computed on the assumption that the ratio between the S and P times is 1.800. The computed times for S are set out in Table V. From 25° to 40° the travel is uniformly 15.70 sec. per degree, which is slightly greater than the rate 15.6 sec. per degree obtained by Miss Lehmann for S at these distances from the Azores earthquake; over the distances from 45° to 50° the rate is 13.46 sec. per degree. The times of the new table have been plotted in Fig. 9b and show satisfactory agreement with the observations.

In Table VI are shown the differences between the times for *P* and *S* from Table V and those of Jeffreys and Bullen (J.B.), together with the departures of the observations from the tables. Allowance has been made in these comparisons for the 6.2 sec. discrepancy of zero between the two sets of tables.

TABLE VI—COMPARISONS BETWEEN THE GROUPED OBSERVATIONS AND TABLES OF TRAVEL-TIMES

Epoch. Tables, *P* (40°)—7m. 32.0s.; Observations, 23h. 21m. 37.7s. G.M.T.

Mean Δ (degrees)	28	30	32.5	35	37.5	40	42.5	45	46.5	50
<i>P</i> . (Table V—J.B.) sec. ..	0.1	-0.2	-0.6	-0.7	-0.5	0.0	0.7	0.7	0.0	-0.6
<i>S</i> . (Table V—J.B.) sec. ..	-1.9	-2.5	-2.3	-1.1	0.4	2.3	3.4	3.0	1.8	-0.5
<i>P</i> . (<i>O</i> - <i>C</i>) Table V, sec. ..	0.5	..	-0.4	..	0.2	..	-0.3	..	0.0	..
<i>P</i> . (<i>O</i> - <i>C</i>) J.B., sec. ..	0.6	..	-1.0	..	-0.3	..	0.4	..	0.0	..
<i>S</i> . (<i>O</i> - <i>C</i>) Table V, sec. ..	0.1	..	0.9	..	-0.7	..	-0.2	..	1.0	..
<i>S</i> . (<i>O</i> - <i>C</i>) J.B., sec. ..	-1.8	..	-1.4	..	-0.3	..	3.2	..	2.8	..

The *P* times of Table V are 0.5 to 0.7 sec. less than the J.B. times from 32.5° to 37.5°, and 0.7 sec. greater from 42.5° to 45°; the *S* differences (Table V—J.B.) increase from a minimum of -2.5 sec. at 30° to a maximum of 3.4 sec. at 42.5°. For *P* the residuals (*O*-*C*) when the observations are judged by Table V are less than when the standard tables of Jeffreys and Bullen are used, but the improvement is small except at 32.5°; in the case of *S* Table V gives much smaller residuals for all the distances except 37.5°. With the new tables the mean residuals of *P* do not exceed half a second, and those of *S* do not exceed one second.

The observations agree with those of Miss Lehmann and other investigators who have found that, within the accuracy of the measurements, the apparent velocities of the waves are constant for considerable ranges of epicentral distance. The geophysical significance of this result seems to have been overlooked, and the ordinary Wiechert solution for obtaining the variation of velocity with depth needs modification. A uniform velocity implies that the rays reaching the surface at different distances are inclined at the same angle to the vertical and the wave is diffracted along the surface of discontinuity. In the present case it appears that the *P* waves and *S* waves which emerge at epicentral distances between 25° and 40° all penetrate to the same depth, to a boundary between what Miss Lehmann calls the *r* layer and a lower layer which may be termed the *w* layer. Following Gutenberg and Richter the travel-times have been regarded as continuous at 40°, but it is likely that the waves which emerge just beyond 40°, and have penetrated the *w* layer, have an appreciably smaller angle of incidence on the surface than the diffracted waves. This implies that the two branches of the curve make an angle. If this surmise is verified, then the determination of the velocity of transmission of the waves by the method with which the names Herglotz, Bateman and Wiechert are associated, is not immediately applicable.

§ 7—SUMMARY

This earthquake was chosen for study because the epicentre was in such a position that the records at the numerous seismological stations of Europe and America would provide material for determining more precisely the travel-times for distances of the order 40°. The records of ninety-nine observatories were collected and examined at Kew Observatory; over two-thirds of these observatories are at epicentral distances between 25° and 50°.

The epicentre is located as in latitude 73.3° N., 70.2° W., and the focus at a depth of about 10 Km.; the time of occurrence of the shock is taken as 23h. 21m. 31.5s. G.M.T.

Comparisons have been made between the observed travel-times for P and S and the times calculated from various tables. The best representation of the travel of the P waves from 25° to 50° is given by a table based upon one published by Gutenberg and Richter; in this modified table the apparent velocity is uniform for epicentral distances from 25° to 40° and again from 45° to 50° , the velocity changing by 17 per cent from 40° to 45° . There are discrepancies between the observations of S and the tables of travel-times hitherto available. A new table for S at distances from 25° to 50° has been computed from the travel-times for P on the assumption that Poisson's ratio is constant for the rocks traversed by the waves. The agreement between the observations and this table is satisfactory.

ACKNOWLEDGMENTS

I should like to express my indebtedness to Dr. F. J. W. Whipple, Superintendent of Kew Observatory, who has always been willing to discuss the difficulties which have been encountered in this investigation and who has suggested a number of improvements which have been incorporated in the paper. I wish also to thank Mr. B. G. Brame of the Observatory staff for assistance in the computations of epicentral distances and bearings, and the directors of the observatories who have been so kind as to lend their seismograms.

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APPENDIX, TABLE II—DETAILS OF OBSERVATORIES AND INSTRUMENTS, EPICENTRAL DISTANCES AND BEARINGS FROM EPICENTRE TO OBSERVATORIES AND OBSERVED TIMES AND RESIDUALS FOR THE CONDENSATIONAL WAVES, REFLECTED CONDENSATIONAL WAVES AND DISTORTIONAL WAVES. The times of arrival of the waves are reckoned from the "time of origin" (23h. 21m. 38s. G.M.T.).

No. of record	Observatory	Δ	Bearing	epicentre	Type of seismograph	Component	P phases				Reflected P phases				S phases							
							P (O-C)	sP	sP (O-C)	P _x (O-C)	PP I (O-C)	PP II (O-C)	PP _x (O-C)	S (O-C)	S (O-C)	Curtsey (O-C)	S _x (O-C)					
1	2	3	4	5*	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20			
1	Ivigtut	14.6	130	{	W.	Z.	m. s.	-7	i 3 21	-2	i 3 28	1	..	..	..	..	m. s.	..	..	
2					W.	N.	e 3 16	-7	e 3 21	-2	e 3 28	1	i 6 23	18	..	
3					E.	e 3 17	-6	e 3 21	-2	i 3 28	1	i 6 23	18	..
4	Reykjavik	19.0	90	{	M.	N.	..	..	e 4 27	8	i 4 38	10	..	..	14, 24	..	..	..	..
5					M.	E.	i 4 27	8	i 4 38	10	16, 24	e 8 6	19	..	28	
6					N.	e 5 21	-9	i 5 24	-6	i 6 15	10	36	i 9 54	3	..	25, 34	
7	Seven Falls	26.2	180	M.S.	N.	i 5 31	0	i 5 34	3	13	..	..	..	..	..	i 10 5	4	..	14
8	Shawinigan Falls	26.8	180	W.A.	N.	i 5 36	0	i 5 42	6	20	..	..	..	..	..	i 10 16	3	..	..	
9	Abisko	26.9	50	{	G.	Z.	i 5 39	2	..	14	i 6 23	7	..	..	..	..	..	..	8, 15, 32
10					N.	i 5 39	2	
11					E.	i 5 39	2
12	Ottawa	28.0	190	{	W.	Z.	i 5 39	2	..	13	..	..	..	..	40	i 10 13	-1	..	14
13					M.S.	N.	e 5 45	-2	49	i 10 26	-6	..	8	
14					E.	e 5 45	-2	i 10 28	-4
15	Halifax	28.8	170	{	M.	N.	i 5 45	-2	..	..	e 6 30	-1	..	..	..	i 10 28	-4	..	..	
16					E.	e 5 53	-1	i 5 57	3	i 10 42	-3	..	3, 17	
17					N.	i 6 0	5	i 10 47	0	..	37
18	Burlington	28.9	180	M.S.	NW.	i 5 55	0	i 6 0	5	24	..	..	..	..	..	..	..	..	5
19	Sitka	29.6	270	{	Wn.	N.	i 6 4	3	..	..	..	..	..	..	..	..	..	..	5
20					E.	i 6 4	3
21					Bn.	i 6 11	-1
22	Oak Ridge	30.8	180	{	Bn.	Z. (II)	i 6 11	-1	i 6 15	3	25	..	..	..	..	i 11 15	-2	..	17
23					W.A.	N.	i 6 11	-1	i 11 19	-2	..	21
24					E.	i 6 11	-1	i 11 13	-4	..	28
25	Edinburgh	31.1	80	{	M.S.	NW.	i 6 11	-1	i 6 15	3	21	..	..	..	..	i 11 15	-2	..	..	
26					NE.	i 6 11	-1	i 6 20	5
27					E.
28	Ann Arbor	31.7	200	{	B.	N.	i 6 19	-1	..	..	..	..	..	..	..	e 11 26	-5	..	1
29					E.	i 6 19	-1
30					G.	i 6 26	-1	i 6 31	4	9
31	Fordham	32.5	190	{	Z.	N.	i 6 26	-1	i 6 31	4	9, 21	..	..	..	..	i 11 41	-2	..	..	
32					E.	i 6 26	-1	i 6 31	4
33					G.	i 6 26	-1	i 6 31	4
34	Chicago	32.6	200	M.S.	E.	e 6 30	2	i 6 30	2	28	..	..	..	..	..	i 11 43	-2	..	..	
35	Durham	32.7	90	M.S.	N.	e 6 26	-3	i 6 31	2	15	..	..	..	..	..	i 11 39	-7	..	..	
36	Spokane	32.8	240	{	W.	N.	e 6 29	-1	i 6 31	1	..	..	..	..	..	i 11 53	5	..	..	
37					E.	e 6 29	-1	i 6 31	1
38					Mc.R.	N.
39	Bozeman	33.1	240	Mc.R.	N.	..	..	i 6 36	4	15	..	..	..	..	..	i 11 56	4	..	8
40	Stonyhurst	33.1	90	{	Mc.R.	E.	..	..	..	..	..	..	..	..	..	i 11 50	-2	..	..	
41					M.S.	E.
42					E.
43	Pittsburg	33.2	190	Wn.	N60°E.	i 6 33	0	..	..	..	..	..	..	..	..	i 11 52	-2	..	..	

* See footnote on p. 21.

TABLE II—continued

No. of record	Observatory	Δ	Bearing of observatory	Type of seismograph	Component	P phases					Reflected P phases					S phases				
						P	P (O-C)	sP	sP (O-C)	P*	PPI	PPI (O-C)	PPII	PPII (O-C)	PP*	S	S (O-C)	S	Curtsey (O-C)	S*
1	2	3	4	5*	6	m. s.	s.	m. s.	s.	s.	m. s.	s.	m. s.	s.	s.	m. s.	s.	s.		
40	Bidston	33.3	90	M.S.	N.	i 6 32	-2	i 6 37	3	..	..	..	i 7 52	13	28	i 11 55	0	..	..	18
41	Uppsala	33.5	70	W.	N.	e 6 36	0	i 6 38	2	..	..	..	..	..	..	i 11 57	-1	-4	..	18
42	Seattle	34.2	250	B.	N.	e 6 36	0	..	..	..	..	..	..	..	..	i 11 57	-1	..	..	18
43	Seattle	34.2	250	B.	N.	e 6 42	0	..	..	..	..	..	..	..	..	..	..	..	..	10, 22
44	Seattle	34.2	250	B.	N.	e 6 42	0	..	..	..	..	..	..	..	..	..	..	..	..	10, 22
45	Georgetown	34.6	190	G.	N.	i 6 43	-3	i 6 48	2	..	..	..	..	..	32	i 12 6	-3	..	..	..
46	Georgetown	34.6	190	G.	N.	i 6 43	-3	..	..	..	..	..	..	..	..	i 12 14	-1	..	..	..
47	Cincinnati	34.8	200	G.	N.	i 6 44	-2	i 6 49	3	..	..	..	..	..	28	i 12 13	-2	..	..	..
48	Cincinnati	34.8	200	G.	N.	i 6 45	-2	..	..	..	..	..	..	..	..	..	..	..	..	..
49	Cincinnati	34.8	200	G.	N.	i 6 45	-2	i 6 51	4	33	..	..	..	..	..	i 12 15	-3	..	..	..
50	Oxford	35.3	90	M.S.	N.	e 6 54	2	i 6 59	7	30	..	..	i 8 23	19	..	i 12 29	3	..	..	..
51	Oxford	35.3	90	M.S.	N.	e 6 54	2	i 6 59	7	30	..	..	i 8 23	19	..	i 12 29	3	..	..	..
52	Charlottesville	35.5	190	Wd.	N.	i 6 52	-1	i 6 57	4	..	..	..	i 8 21	14	..	e 12 26	-3	..	..	5
53	Charlottesville	35.5	190	Wd.	N.	i 6 52	-1	..	..	..	..	..	i 8 21	14	..	e 12 26	-3	..	..	5
54	Charlottesville	35.5	190	Wd.	N.	i 6 52	-1	..	..	..	..	..	i 8 21	14	..	e 12 26	-3	..	..	5
55	Copenhagen	35.7	70	G.	N.	i 6 56	1	i 7 0	5	41	..	..	i 8 27	18	..	i 12 30	-2	..	..	..
56	Copenhagen	35.7	70	G.	N.	i 6 56	1	i 7 0	5	41	..	..	i 8 27	18	..	i 12 30	-2	..	..	..
57	Copenhagen	35.7	70	G.	N.	i 6 56	1	i 7 0	5	41	..	..	i 8 27	18	..	i 12 30	-2	..	..	..
58	Copenhagen	35.7	70	G.	N.	i 6 56	1	i 7 0	5	41	..	..	i 8 27	18	..	i 12 30	-2	..	..	..
59	Heligoland	35.8	80	W.	N.	i 6 55	-1	i 6 59	3	..	..	..	..	..	..	i 12 35	3	..	..	..
60	Heligoland	35.8	80	W.	N.	i 6 55	-1	i 6 59	3	..	..	..	..	..	..	..	..	..	..	..
61	Heligoland	35.8	80	W.	N.	i 6 55	-1	i 6 59	3	..	..	..	..	..	..	..	..	..	..	..
62	Heligoland	35.8	80	W.	N.	i 6 55	-1	i 6 59	3	..	..	..	..	..	..	..	..	..	..	..
63	Kew	35.8	90	G.	N.	e 6 56	0	i 7 1	5	28	..	..	i 8 30	19	..	i 12 33	0	..	..	7
64	Kew	35.8	90	G.	N.	e 6 56	0	i 7 1	5	28	..	..	i 8 30	19	..	i 12 33	0	..	..	7
65	Kew	35.8	90	G.	N.	e 6 56	0	i 7 1	5	28	..	..	i 8 30	19	..	i 12 33	0	..	..	7
66	Kew	35.8	90	G.	N.	e 6 56	0	i 7 1	5	28	..	..	i 8 30	19	..	i 12 33	0	..	..	7
67	Florissant	35.9	210	G.	N.	i 6 54	-3	i 6 58	1	19	..	..	..	..	52	..	..	..	..	..
68	Florissant	35.9	210	G.	N.	i 6 54	-3	..	..	..	..	..	..	..	..	..	..	..	..	..
69	Florissant	35.9	210	G.	N.	i 6 54	-3	..	..	..	..	..	..	..	..	..	..	..	..	..
70	Lund	35.9	70	W.	NW.	i 6 53	-4	i 6 55	-2	..	..	..	i 8 27	15	..	i 12 30	-5	..	..	..
71	Lund	35.9	70	W.	NW.	i 6 53	-4	i 6 55	-2	..	..	..	i 8 27	15	..	i 12 30	-5	..	..	..
72	Lund	35.9	70	W.	NW.	i 6 53	-4	i 6 55	-2	..	..	..	i 8 27	15	..	i 12 30	-5	..	..	..
73	St. Louis	36.0	210	W.A.	N. (I)	i 6 54	-4	..	..	..	..	..	..	..	..	i 12 34	-1	..	..	..
74	St. Louis	36.0	210	W.A.	N. (II)	i 6 55	-3	i 7 1	3	..	..	..	..	..	..	i 12 37	2	-28	..	..
75	St. Louis	36.0	210	W.A.	N. (II)	i 6 55	-3	..	..	..	..	..	..	..	..	i 12 37	2	..	..	..
76	St. Louis	36.0	210	W.A.	N. (II)	i 6 55	-3	..	..	..	..	..	..	..	..	i 12 37	2	..	..	..
77	St. Louis	36.0	210	W.A.	N. (II)	i 6 55	-3	..	..	..	..	..	..	..	..	i 12 37	2	..	..	..
78	De Bilt	36.8	80	G.	N.	i 7 6	1	i 7 10	5	..	..	..	..	..	..	i 12 31	-5	..	..	..
79	De Bilt	36.8	80	G.	N.	i 7 6	1	i 7 10	5	..	..	..	..	..	..	i 12 31	-5	..	..	..

* See footnote on p. 21.

TABLE II—continued

No. of record	Observatory	Δ	Bearing; epicentre-observatory	Type of seismograph	Component	P phases					Reflected P phases					S phases				
						P (O-C)	sP	sP (O-C)	P _x (O-C)	PP I (O-C)	PP II (O-C)	PP II (O-C)	PP _x (O-C)	S	S (O-C)	Curtsey (O-C)	S _x (O-C)			
1	2	3	4	5*	6	m. s.	s.	m. s.	s.	s.	m. s.	s.	m. s.	s.	m. s.	s.	s.	s.	s.	
80	Pulkovo	36.8	60	G.	Z.	i 7 6	1	i 7 8	3	13	i 8 37	14	..	i 12 48	0	
81					N.	i 7 6	1	i 7 8	3	..	..	i 8 37	14	..	i 12 48	0	..	..
82					E.	i 7 6	1	i 7 8	3	i 8 37	14	..	i 12 48	0	-20	
83					G.	i 7 7	1	i 7 12	6	20	-15	
84	Hamburg	36.9	80	W.	Z.	..	..	i 7 11	5	..	..	..	..	..	i 12 56	6	..	..
85					E.	i 7 8	1	3	
86	Tartu	37.1	60	G.	N.	e 7 4	-3	i 7 8	1	..	..	..	..	..	i 12 50	-3	..	..
87					E.	i 7 12	-1	i 7 16	3	11	i 8 31	4	..	i 13 4	1	
88	Uccle	37.8	80	G.	Z.	i 7 12	-1	i 7 16	3	..	..	i 8 56	21	..	i 13 4	1	..	..
89					W.	i 7 12	-1	i 7 16	3	..	..	i 8 58	23	..	i 13 4	1	..	..
90					N.	i 7 12	-1	i 7 16	3	i 13 5	2	-8	
91					W.	i 7 12	-1	i 7 16	3	i 13 4	1	-8	
92	Göttingen	38.7	80	G.	E.	i 7 12	-1	i 7 16	3	..	..	i 8 56	21	..	i 13 3	0	-7	..
93					W.	e 7 12	-1	i 7 16	3	i 13 3	1	-8	
94	Konigsberg	38.7	70	W.	Z.	i 7 21	0	i 7 25	4	14	..	..	..	..	..	..	..	..
95					N.	i 7 21	0	i 7 25	4	i 8 49	4
96	Parc Saint Maur	39.0	90	W.	E.	e 7 21	0	i 7 25	4	..	..	i 8 58	13	..	i 13 21	4	-14	..
97					Z.	i 7 19	-2	i 7 24	3	i 13 17	0
98	Tannus	39.4	80	M.	N.	..	..	i 7 24	3	..	..	..	..	..	i 13 17	0	..	..
99					E.	e 7 24	3	15	i 13 17	0
100	Columbia	39.7	190	McR.	N.	i 7 23	0	i 7 26	3	..	..	i 8 59	10	..	i 13 19	-2	..	..
101					E.	i 7 23	0	i 7 26	3	i 8 59	10	..	i 13 19	-2
102	Little Rock	40.1	210	W.A.	N.	i 7 27	0	i 7 31	4	13	..	..	..	..	i 13 31	4	-11	..
103					E.	e 7 27	0	i 13 31	4
104	Karlsruhe	40.5	80	M.	N.	e 7 27	0	i 7 31	4	..	..	..	..	..	e 13 31	4	..	..
105					E.	i 7 27	-2	i 7 31	2	34	i 13 31	-1	-6
106	Strasbourg	40.7	80	G.	Z.	e 7 27	-2	i 7 31	2	..	..	..	..	..	i 13 31	-1	-6	..
107					N.	i 7 30	-3	i 13 34	-4
108	Prague	41.3	70	W.	N.	e 7 31	-2	..	..	..	..	i 9 4	4	..	i 13 42	4	..	..
109					E.	e 7 31	-2	i 9 4	4	..	i 13 48	4	..
110	Basle	41.6	80	Q.P.	Z.	..	..	i 7 42	6	..	..	..	..	..	..	..	..	..
111					N.	i 7 39	1	i 7 43	5	17	i 13 48	1	-6
112	Neuchatel	41.9	80	Q.P.	E.	i 7 39	1	i 7 43	5	30	..	..	..	..	..	..	..	..
113					N.	i 7 39	1	i 7 43	5	30	i 13 57	1
114	5,25	5,25	13	49	32	

* See footnote on p. 21.

TABLE II—continued

No. of record	Observatory	Δ	Bearing: epicentre	Type of seismograph	Component	P phases					Reflected P phases					S phases				
						P	P	sP	sP	sP	PP I (O-C)	PP II (O-C)	PP II (O-C)	PP II (O-C)	PP II (O-C)	S	S (O-C)	S	Curtsey (O-C)	Sx (O-C)
1	2	3	4	5*	6	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.	m. s.
121	Zurich	42.1	80	O.P.	Z.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
122					N.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
123					N.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
124					E.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
125	Munich	42.2	80	M.	E.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
126					N.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
127					E.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
128					N.	7 48	-1	7 52	3	..	..	..	..	..	..	..	..	..	..	..
129	Ukiah	42.4	250	McR.	N ₁₀ W	7 53	1	7 55	5	..	..	..	..	..	..	..	..	..	..	..
130					N ₃₀ E	7 53	1	7 55	5	..	..	..	..	..	..	..	..	..	..	..
131					Bn.	7 53	1	7 55	5	..	..	..	..	..	..	..	..	..	..	..
132					W.A.	7 53	1	7 55	5	..	..	..	..	..	..	..	..	..	..	..
133	Berkeley	43.0	240	W.A.	Z.	7 57	0	8 3	6	..	..	..	..	..	..	..	..	..	..	..
134					E.	7 57	0	8 3	6	..	..	..	..	..	..	..	..	..	..	..
135					N.	7 57	0	8 3	6	..	..	..	..	..	..	..	..	..	..	..
136					E.	7 57	0	8 3	6	..	..	..	..	..	..	..	..	..	..	..
137	Vienna	43.3	250	W.A.	Z.	8 0	1	8 4	5	..	..	..	..	..	..	..	..	..	..	..
138					N.	8 0	1	8 4	5	..	..	..	..	..	..	..	..	..	..	..
139					E.	8 0	1	8 4	5	..	..	..	..	..	..	..	..	..	..	..
140					N.	8 0	1	8 4	5	..	..	..	..	..	..	..	..	..	..	..
141	Branner	43.5	80	W.	E.	8 1	0	8 6	5	..	..	..	..	..	..	..	..	..	..	..
142					N.	8 1	0	8 6	5	..	..	..	..	..	..	..	..	..	..	..
143					E.	8 1	0	8 6	5	..	..	..	..	..	..	..	..	..	..	..
144					N.	8 1	0	8 6	5	..	..	..	..	..	..	..	..	..	..	..
145	Lick	43.7	240	W.A.	Z.	8 3	1	8 5	3	..	..	..	..	..	..	..	..	..	..	..
146					N.	8 3	1	8 5	3	..	..	..	..	..	..	..	..	..	..	..
147					E.	8 3	1	8 5	3	..	..	..	..	..	..	..	..	..	..	..
148					N.	8 3	1	8 5	3	..	..	..	..	..	..	..	..	..	..	..
149	Haitwee	43.9	240	Bn.	Z.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
150					N.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
151					E.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
152					N.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
153	Lemberg	44.1	70	B.	E.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
154					N.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
155					E.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
156					N.	8 4	0	8 8	4	..	..	..	..	..	..	..	..	..	..	..
157	Trieste	45.1	80	A.	Z.	8 13	0	8 17	4	..	..	..	..	..	..	..	..	..	..	..
158					N.	8 13	0	8 17	4	..	..	..	..	..	..	..	..	..	..	..
159					E.	8 13	0	8 17	4	..	..	..	..	..	..	..	..	..	..	..
160					N.	8 13	0	8 17	4	..	..	..	..	..	..	..	..	..	..	..
161	Zagreb	45.6	80	W.	NW	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
162					E.	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
163					N.	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
164					E.	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
165	Ebro	45.7	90	M.	NW	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
166					E.	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
167					N.	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
168					E.	8 17	0	8 21	4	..	..	..	..	..	..	..	..	..	..	..
169	Mount Wilson	45.7	240	Bn.	Z.	8 18	0	8 22	5	..	..	..	..	..	..	..	..	..	..	..
170					N.	8 18	0	8 22	5	..	..	..	..	..	..	..	..	..	..	..
171					E.	8 18	0	8 22	5	..	..	..	..	..	..	..	..	..	..	..
172					N.	8 18	0	8 22	5	..	..	..	..	..	..	..	..	..	..	..

* See footnote on p. 21.

TABLE II—continued

No. of record	Observatory	Δ	Bearing: epicentre	Type of seismograph	Component	P phases					Reflected P phases					S phases				
						P (O-C)	sP (O-C)	ΔP (O-C)	P_s (O-C)	P_s (O-C)	PP I (O-C)	PP I (O-C)	PP II (O-C)	PP II (O-C)	$P'x$ (O-C)	S (O-C)	S (O-C)	S (O-C)	Curtsey (O-C)	S_x (O-C)
1	2	3	4	5*	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
161	Pasadena	45.8	240	Bn.	Z.	8 19	0	8 24	5	10	10 8	9	..	..	..	15 6	4	..	7	..
162				W.A.	N.	8 19	0	8 21	2	11.43	10 8	9	..	..	..	15 6	4	..	..	..
163				Bn.	E. (I)	8 19	0	8 21	2	11.43	10 8	9	..	..	..	15 6	4	..	..	..
164				W.A.	E. (II)	8 19	0	8 21	2	11.43	10 8	9	..	..	..	15 6	4	..	..	..
165				W.A.	E. (II)	8 19	0	8 21	2	11.43	10 8	9	..	..	..	15 6	4	..	..	..
166	Riverside	45.8	240	Bn.	Z.	8 18	-1	..	..	12	..	..	..	..	..	15 6	4	..	..	..
167				W.A.	E.	8 18	-1	..	..	12	..	..	..	..	..	15 6	4	..	..	..
168				Bn.	Z.	8 21	1	..	..	11	..	..	..	..	..	..	..	..	..	..
169	Santa Barbara	45.9	240	W.A.	N.	8 21	1	8 23	3	..	..	..	..	..	..	15 5	2	..	..	..
170				W.A.	E.	8 21	1	8 23	3	..	..	..	..	..	..	15 5	2	..	..	..
171				W.A.	N.	8 18	-2	8 23	3	..	..	..	..	..	..	15 6	3	..	..	..
172	Tucson	45.9	230	W.A.	N.	8 18	-2	8 23	3	..	..	..	..	..	..	15 6	3	..	..	..
173				W.A.	E.	8 18	-2	8 23	3	..	..	..	..	..	..	15 6	3	..	..	..
174				W.A.	E.	8 20	-1	8 24	3	12	9 57	-5	..	..	..	15 6	0	..	..	..
175	Florence	46.1	80	W.A.	Z.	8 20	..	8 23	2	12	10 7	5	..	..	..	15 11	5	..	..	..
176				A.	NW.	..	..	8 23	2	12	10 7	5	..	..	..	..	..	..	..	..
177				Bn.	N.E.	8 27	0	8 27	..	..	10 17	8	..	..	..	15 21	5	..	..	..
178	La Jolla	46.8	240	W.A.	N.	8 27	0	8 29	2	45	10 17	8	..	..	..	15 21	5	..	..	..
179				W.A.	E.	8 27	0	8 29	2	..	10 17	8	..	..	..	15 31	2	..	..	..
180	Belgrade	47.7	70	W.	Z.	8 34	0	8 37	3	..	..	..	..	..	..	15 32	3	..	..	..
181				W.	NW.	8 34	0	8 37	3	..	..	..	..	..	..	15 32	3	..	..	..
182				W.	N.E.	8 34	0	8 37	3	..	..	..	..	..	..	15 32	3	..	..	..
183	San Fernando	47.9	100	Bf.	N.	8 34	-1	8 39	4	..	..	..	..	..	..	15 32	3	..	..	..
184				Wn.	E.	8 34	-1	8 39	4	..	..	..	..	..	..	15 32	3	..	..	..
185	San Juan	55.0	180	Wn.	N.	8 34	-1	8 39	4	..	..	..	..	..	..	15 32	3	..	..	..
186				Wn.	E.	8 34	-1	8 39	4	..	..	..	..	..	..	15 32	3	..	..	..
187				W.	Z.	8 38	0	9 41	3	11.43	11 36	-1	..	..	..	17 8	-1	..	..	..
188	Tacubaya	50.3	210	W.	N.	9 39	1	9 41	3	7	11 36	-1	..	..	..	17 8	-1	..	..	..
189				W.	E. (I)	9 39	0	9 42	4	..	11 35	-2	..	..	..	17 26	-1	..	..	..
190				W.	E. (II)	9 38	0	9 42	4	..	11 35	-2	..	..	..	17 26	-1	..	..	..
191				W.	E.	10 22	3	10 26	7	..	..	..	..	..	..	..	..	..	..	..
192	Tashkent	62.1	30	G.	N.	10 22	3	10 26	7	..	..	..	..	..	..	..	..	..	..	..
193				G.	E.	10 22	3	10 26	7	..	..	..	..	..	..	..	..	..	..	..
194	Ksara	62.2	60	M.	N.	10 20	0	10 24	4	..	..	..	..	..	..	..	..	..	..	..
195				M.	E.	10 20	0	10 24	4	..	..	..	..	..	..	..	..	..	..	..
196	Vladivostok	62.6	340	G.	Z.	10 23	1	..	..	..	12 37	4	..	..	..	18 43	-2	..	..	..
197				G.	N.	10 23	1	..	..	..	12 39	6	..	..	..	18 43	-2	..	..	..
198				G.	E.	10 23	1	..	..	..	12 24	-6	..	..	..	18 50	0	..	..	..
199	Helwan	64.7	70	M.S.	E.	10 23	-2	10 27	5	..	..	..	..	..	..	18 50	0	..	..	..
200	Honolulu	69.0	270	M.S.	N.	11 3	-2	10 40	3	8	13 32	3	..	..	..	19 20	4	..	..	..

* See footnote on p. 21.

TABLE II—continued

No. of record	Observatory	Δ	Bearing	epicentre	Type of seismograph	Component	P' phases					Reflected P phases					S phases										
							P	P (O-C)	sP	sP (O-C)	P*	P* (O-C)	PP I	PP I (O-C)	PP II	PP II (O-C)	PP*	PP* (O-C)	S	S (O-C)	S Curtsey (O-C)	S* (O-C)					
1	2	3	4	5*	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20								
201	Toyooka	69.8	340	W.	Z.	i 11 9	0	..	..	13	..	..	e 13 48	12	..	..	..	..	..			
202					N.	i 11 9	0	..	..	13	..	..	e 20 20	1	..	..	..	..	..	..	
203					E.	i 11 9	0	..	..	..	..	..	..	..	..	..	..	..	..	..	..
204					W.	i 11 15	1	i 11 20	6	13	..	..	..	..	..	..	..	..	..	..	..
205	Kobe	70.6	340	W.	Z.	e 11 15	1	i 11 20	6	13	..	..	..	..	..	e 20 20	-8	..	..						
206					N.	e 11 15	1	..	..	..	..	..	..	..	..	..	..	..	e 20 20	-8	..	..			
207					E.	i 11 15	1	..	..	..	..	..	..	..	..	..	..	..	e 20 20	-8	..	..			
208					W.	i 11 16	-1	i 11 21	4	12	..	..	..	..	..	..	..	..	..	..	..	..
209	Sumoto	71.0	340	W.	N.	e 11 16	-1	i 11 22	5	13	..	..	..	..	..	e 20 30	-3	..	..						
210					E.	e 11 16	-1	i 11 22	5	..	..	..	..	..	..	..	..	..	..	..	..
211					W.	e 11 41	0	i 11 44	3	8	..	..	..	..	..	..	..	..	e 21 22	0	..	..			
212					E.	..	..	e 11 44	3	..	..	..	..	..	..	..	..	..	..	..	..	..
213	Hong Kong	84.3	0	M.S.	N.	i 12 29	-1	i 12 34	4	..	i 15 44	4	..	..	..	i 22 58	-3	..	..						
214					E.	i 12 29	-1	i 12 34	4	..	i 15 48	8	..	..	..	..	..	..	i 22 58	-3	..	..			
215					N.	e 12 30	-2	i 12 34	2	i 23 1	-4				
216					E.	e 12 30	-2	i 12 34	2				
217	Huangyao	85.4	190	Bn.	Z.	i 12 34	-1	i 12 37	2	9	..	..	..	..	..	..	..	..	..
218					N.	i 12 34	-1	i 12 37	2	9	..	..	..	..	..	..	..	..	..	..	..	..
219					E.	i 12 34	-1	i 12 37	2	9	..	..	..	..	..	..	..	..	..	..	..	..
220					Wn.	i 12 39	1				
221	Phu Lien	85.9	0	M.	N.	e 12 39	1	..	..	..	..	..	..	..	..	..	..	..	..
222					E.	e 12 39	1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
223					N.	i 12 53	-3	i 12 57	1	7, 38	..	..	..	..	..	..	..	..	..	..	..	..
224					E.	e 12 53	-3	i 12 57	1	7				
225	La Paz	91.8	350	Bf.	N.	e 13 5	-1	i 13 10	4	..	..	..	..	..	..	..	..	..	..
226					E.	e 13 5	-1	i 13 10	4	..	..	..	..	..	..	..	..	..	..	..	..	..
227					W.	i 13 10	-4	i 13 13	-1	..	i 16 47	7	..	..	..	..	..	..	..	..	..	..
228					M.S.	i 13 10	-4	i 13 13	-1	..	e 17 1	8	i 24 24	-5				
229	Entebbe	93.5	80	M.S.	N.	e 13 15	0	..	..	..	i 16 53	0	..	..	..	i 24 25	-4	..	..						
230					E.	e 13 15	0				
231					N.	e 13 32	-1				
232					E.	e 13 32	-1			
233	Kodiakanal	93.9	30	M.S.	N.	e 13 32	-1	..	..	..	..	..	..	..	..	..	..	..	..
234					E.	e 13 32	-1				
235					N.	e 13 55	-1				
236					E.	e 13 55	-1			
237	Colombo	97.6	30	M.S.	N.	e 14 32	3	..	..	..	..	..	..	..	..	..	..	..	..
238					E.	e 14 32	3				
239					N.	e 14 32	3			
240					E.	e 14 32	3			
241	Medan	102.8	10	W.	N.	PKP	PKP (O-C)	..	..	..	..	..	..	..	..	..	..	..	..
242					E.	PKP	PKP (O-C)				
243					N.	i 18 25	-1			
244					E.	i 18 25	-1			
245	Amboina	109.5	340	W.	N.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
246					E.			
247					N.			
248					E.		
249	Batavia	112.9	0	W.	N.	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
250					E.		
251					N.		
252					E.	
253	Cape Town	122.0	100	M.S.	N.				
254					E.	
255					N.
256					E.

* See footnote on p. 21.

TABLE II—continued

No. of record	Observatory	4	Bearing: epicentre	Type of seismograph	Com- ponent	P phases				Reflected P phases				S phases			
						PKP (O-C)	sP (O-C)	sP (O-C)	P* (O-C)	PP I (O-C)	PP I (O-C)	PP II (O-C)	PP II (O-C)	S (O-C)	S (O-C)	SKS (O-C)	SKS (O-C)
237	Riverview	3	°	°	6	7	m. s.	s.	s.	m. s.	s.	m. s.	s.	m. s.	s.	s.	s.
238		3	135.4	310	Z.	e 19 16	1	..	..	..	..	..	..	..	..	..	..
239		3	..	..	N.	e 19 10	1	..	..	..	..	..	..	..	..	..	..
240		3	..	..	E.	..	..	..	..	..	..	..	..	..	..	..	..
241	Wellington	3	136.3	280	Z.	i 19 14	..	i 19 22	5	i 22 4	..	..	..	..	..	..	..
242		3	..	..	N.	e 19 14	-3	..	..	..	..	..	..	..	..	..	..
243	Perth	3	138.5	350	E.	e 19 14	-3	i 19 20	3	..	..	..	..	..	..	..	..
244	Melbourne	3	140.6	310	N.	i 19 24	4	..	..	i 22 18	..	..	..	..	..	i 26 51	8
					E.	e 19 19	-3	..	..	..	..	..	..	..	..	..	..

* The abbreviations for the various types of seismographs are:—

A. Alfani	Bf. Bifilar	Bn. Benioff
G. Galitzin	Mc.R. McComb-Romberg	M.S. Milne-Shaw
Q.P. Quervain-Piccard	W.A. Wood-Anderson	Wd. Weed
Wn. Wenner		

