The Earthquake of 22 III 1928

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(With 2 figures.)

Summary: In the earthquake of 22 III 1928 the observations of P for distances from about 30 to 45° and from about 80 to 90° follow the BYERLY-JEFFREYS time-curve very closely. For distances from 78 to 94° from the epicentre, where the European stations are, the S phase has been studied more particularly. S_n is found to be a strong phase which is very well defined; up to 90° the equation of the time-curve is:

$$S_n - O = 22\text{ m }28\text{ s} + (\varDelta - 80°) \times 10.7\text{ s}.$$

$\overline{S_cP_cS}$ precedes S_n from a distance of 81.7°. Its time-curve can not be determined with much certainty since the beginning of the phase is weak and there are irregularities in its appearance.

Zusammenfassung: Die Beobachtungen der P-Phase des Bebens vom 22 III 1928 zeigen gute Übereinstimmung mit der Kurve von BYERLY-JEFFREYS für Entfernungen von ca. 30—45° und von ca. 80—90°. Die S-Phase ist für Epizentraldistanzen von 78—94°, was der Lage der europäischen Stationen entspricht, genauer untersucht worden. S_n ist eine ausgeprägte starke Phase, für deren Laufzeitkurve die obenstehende Gleichung gefunden wurde. S_cP_cS, die von einer Entfernung von 81.7° vor S_n gefunden worden ist, hat einen schwachen Anfang, und es kommen derartige Unregelmäßigkeiten bei ihrem Auftreten vor, daß die Laufzeitkurve nicht genau bestimmbar ist.

In a previous paper[1]) I have tried to determine mean values of the phase-difference $\overline{S_cP_cS}—P$ for distances from the epicentre between 85 and 95° by means of material drawn from the International Seismological Summary. Difficulties were found to arise from the fact that it is not always possible to identify the phase $\overline{S_cP_cS}$ in the material presented by the bulletins.

As a rule one S phase only is read in a diagram; in some cases this phase seems to be $\overline{S_cP_cS}$, in other cases S_n, and the separation of the two phases cannot be done with much certainty when the records are not available.

Therefore I wished to study the S phase directly from the records of a large earthquake, and I have chosen the earthquake of 22 III 1928

[1]) $\overline{S_cP_cS}$, Gerlands Beiträge zur Geophys. XXIII, 4, 1929.

which took place in Mexico and produced strong records in Europe at distances from the epicentre where $\overline{S_c P_c S}$ is to be found.

On request a great number of seismological stations have sent their records of this earthquake, originals or copies, to the Geodetic Institute in Copenhagen, and we gratefully acknowledge their courtesy.

The first problem to be solved was the determination of the epicentre of the earthquake.

In the seismological bulletin of the "Bureau central séismologique de Strasbourg" readings of P and S from a great number of seismological stations are collected and the epicentre 19° N 95.5° W has been determined. From American records the Jesuit Seismological Association determines the epicentre 14.5° N 95.8° W and the United States Coast and Geodetic Survey 14° N 95° W. The first determination deviates largely from the other two, but this is not very surprising as the European stations are at too great a distance from the epicentre for a good determination.

On a special request for data which could contribute to a determination of the epicentre, we received in the first place from the seismological station Tacubaya the readings of P, S and L from a number of seismological stations in Mexico. Later we received from the Instituto de Geologio in Mexico an extensive communication, and we are much indebted to the Institute for the pains they have taken in preparing it. It contained fuller information about the records of the different stations and also copies of the Tacubaya and Guadalajara records. In addition it was communicated that the epicentre had been determined to 15° 54′ N 96° 23′ W, a point which had also previously been an active earthquake centre. The position of this point gave good agreement between the times observed and those which had been calculated from the Omori and Wiechert-Zoeppritz tables.

The distances calculated from these tables are very different from those calculated by the tables of Mohorovičić or other tables which are due to recent studies of near earthquakes, and it does not seem possible to find a position of the epicentre to fit such distances. The absolute times of the Mexican stations are not in good agreement.

Before the communication was received from Mexico an epicentre had been determined by means of other data, and as it may be of some interest, I shall describe the proceeding.

An approximate epicentre near those determined by the American stations was adopted.

Using this epicentre the times observed for P were compared with those of the different tables commonly in use. They were found not to follow any of them, whereas there was good agreement with the Byerly-Jeffreys[1]) curve.

An attempt to smooth the observed data on this curve might therefore be justified; but I preferred another procedure which is less dependent on this particular time-curve. For distances between 30 and 45° the P curve of Macelwane and that of Byerly have very nearly the same course though their height is different; therefore, if we use the tables for these distances only, we do not make a choice of either of them. At these distances there are the American stations, sufficient in number and sufficiently widely distributed to make a good determination of the epicentre possible.

The epicentre was determined by means of the times of P using the method of least squares as proposed by Geiger. Macelwane's tables were used and the times observed at American stations at distances from 30 to 45° from the approximate epicentre. The epicentre thus calculated was 16°.0 N 96°.0 W.

Calculating the distances from this point and also from the epicentre determined by Mexico, we find the differences shown in Table I between the times observed and those calculated by Macelwane's (Mac.), the Byerly-Jeffreys (B.-J.) and the Wiechert-Zoeppritz (W.-Z.) tables.

At distances greater than 30° the residues are small. Those calculated by Macelwane's table are naturally smaller than the others, as the smoothing has been done by means of these tables.

The difference found from the B.-J. tables are a little smaller when the calculated epicentre is adopted than when the one given by Mexico is used, and in the latter case the western stations have positive, the eastern negative residues, which seems to indicate that the epicentre is too far West.

It is of small importance in our further investigation, which of the two epicentres we use, and the one communicated by Mexico has been adopted.

Considering the residues for distances between 25 and 30° we see that, when the B.-J. tables are used, these are chiefly negative, whereas Macelwane's tables give positive values.

The greater number of the near Mexican stations have not been

[1]) See Harold Jeffreys: The Times of Transmission and Focal Depths of Large Earthquakes. (M. Not. R. Astron. Soc., Geoph. Suppl. 1928, I, 10.)

Table I.

Station	Δ_1	Δ_2	P obs.	B.-J. O_1-C_1	B.-J. O_2-C_2	Mac. O_3-C_2	W.-Z. O_4-C_2
	Degrees		m s	sec	sec	sec	sec
Oaxaca	1.2	1.3	17 7	— 8	— 11		5
Tacubaya	4.5	4.6	18 24	22	19		33
New Orleans	15.3	15.0	21 5	32	36		44
Tucson	21.0	21.1	51	9	7	15	15
St. Louis	23.4	23.2	22 8	0	1	8	7
Denver	25.0	24.8	59	32	33	41	41
Cincinnati	25.5	25.2	28	— 4	— 2	6	6
Chicago (W. B.)	27.0	26.8	40	— 5	— 4	0	2
Chicago (Loyola)	27.0	26.8	43	— 2	— 1	3	4
Milwaukee	28.6	28.4	57	— 2	— 2	1	3
Georgetown	28.6	28.3	23 3	4	5	8	10
Lick	30.9	31.0	24	5	3	3	4
Santa Clara	31.2	31.3	20	— 2	— 4	— 4	— 3
Toronto	31.3	31.0	14	— 9	— 7	— 7	— 6
Berkeley	31.7	31.8	29	3	1	1	2
Ottawa	34.2	33.9	45	— 3	— 1	— 1	— 1
Spokane	36.2	36.2	24 8	4	3	2	2
Saskatoon	36.8	36.8	4	— 4	— 5	— 6	— 6
Victoria	39.2	39.3	29	1	— 1	0	— 2
Halifax	40.1	39.8	33	— 2	0	0	— 2
La Paz	42.7	42.6	59	3	3	1	2
Sucre	46.4	46.3	25 22	— 3	— 3	0	— 2

Epicentre 1 = 15° 54′ N 96° 23′ W

Epicentre 2 = 16°.0 N 96°.0 W

h m s

O_1 = 4 16 58

O_2 = 4 16 59

O_3 = 4 16 45

O_4 = 4 16 42

included here as their absolute times are not correct. Even the time of Tacubaya seems doubtful.

Next we calculate the distances from the epicentre 15° 54′ N 96° 23′ W to the other observing stations. They are found in table II, col. 1. In col. 2 are the observed values of P and in col. 3 the differences between these and the values calculated by means of the B.-J. tables. The time of the earthquake has been taken as 4 h 16 m 58 s to fit the observations which have been used for the determination of the epicentre.

The European observations are seen to be in good agreement with the B.-J. tables. The main part of the residues are quite small. The po-

Table II.

O = 4 h 16 m 58 s.

Station	1	2	3	4	5	6	7	8
	Distance Degrees	P m s	$O-C$ sec	S m s	$O-C$ sec	$\overline{S_cP_cS}$ m s	$\overline{S_cP_cS\text{-}P}$ m s	PS m s
Oaxaca	1.2	17 7	— 8					
Tacubaya	4.5	18 24	22					
New Orleans	15.3	21 5	32	24 15	59			
Tucson	21.0	51	9	25 48	17			
St. Louis	23.4	22 8	0	26 22	5			
Denver	25.0	59	32	27 37	50			
Cincinnati	25.5	28	— 4	26 54	— 2			
Chicago (W. B.)	27.0	40	— 5	27 36	16			
Chicago (Loyola)	27.0	43	— 2	28	8			
Milwaukee	28.6	57	— 2	37	— 9			
Georgetown	28.6	23 3	4	49	3			
Lick	30.9	24	5	—	—			
Santa Clara	31.2	20	— 2	28 31	5			
Toronto	31.3	14	— 9	31	3			
Berkeley	31.7	29	3	48	14			
Ottawa	34.2	45	— 3	29 7	— 6			
Spokane	36.2	24 8	4	54	10			
Saskatoon	36.8	4	— 4	52	— 1			
Victoria	39.2	29	1	30 39	7			
Halifax	40.1	33	— 2	32	— 12			
La Paz	42.7	59	3	31 19	— 5			
Sucre	46.4	25 22	— 3	32 13	— 5			
Honolulu	58.4	26 55	3	35 10	13			
La Plata	62.6	27 27	0	44	— 8			
Scoresby-Sund	69.8	28 14	6	37 24	2			38.1
Edinburgh	78.7	29 6	4	39 8	— 4			39 43
Stonyhurst	79.5	29.3	(11)	24	4			40 4
Oxford	80.7	29 17	3	37	4			32
San Fernando	80.8	16	1	31	— 4			—
Kew	81.4	17	— 1	41	0			27
Toledo	81.7	18	— 2	48	4	39 32	10 14	—
Cartuja	82.6	25	0	56	2	48	23	36
Parc St. Maur	83.8	31	— 1	40 14	7	54	33	46
Abisco	84.1	32	— 1	8	— 2	54	22	43
Uccle	84.3	33	— 1	10	— 2	40 3	30	50
De Bilt	84.4	33	— 2	11	— 2	39 59	26	58
Tortosa	84.8	38	1	—	—	40 4	26	—
Barcelona	85.7	46	2	24	— 3	—	—	41 20
Hamburg	86.6	44	— 3	40	3	16	32	31
København	87.0	47	— 2	48	7	40.4	(37)	30

Station	1 Distance Degrees	2 P m s	3 $O-C$ sec	4 S m s	5 $O-C$ sec	6 $\overline{S_cP_cS}$ m s	7 $\overline{S_cP_c}S-P$ m s	8 PS m s
Strasbourg . . .	87.1	29 47	— 2	40 48	6	40 20	10 33	41 38
Karlsruhe . . .	87.4	55	3	46	1	25	30	36
Göttingen . . .	87.4	49	— 2	52	7	25	36	42
Lund	87.5	51	— 1	49	3	34	45	34
Upsala	87.7	51	— 1	46	— 3	34	—	30
Alger	87.9	56	0	48	— 3	34	38	41
Hohenheim . .	88.0	58	4	54	2	37	34	45
Zürich.	88.1	53	— 2	55	2	21	23	43
Jena	88.5	55	— 2	53	— 4	30	35	48
Nördlingen. . .	88.7	59	1	41 2	3	28	29	55
Potsdam. . . .	88.7	57	— 1	40 57	— 2	43	46	42
Chur	88.9	30 2	2	41.0	(0)	34	32	58
München . . .	89.7	29 54	— 10	41 7	— 3	35	41	49
Firenze	91.2	30 10	— 1	14	— 12	42	41	42 21
Graz	92.5	11	— 7	20	— 11	37	26	37
Wien	92.5	10	— 8	29	— 11	41	31	41
Pulkovo	93.0	14	— 7	—	—	46	32	44
Zagreb	93.4	19	— 4	42	— 7	53	34	42
Kucino	98.7	30.7	(— 8)			41.2	10.5	43.5
Sverdlovsk. . .	106.0	31 18						
Irkutsk	111.0	31						
Baku	116.6	32 0						
Zi-ka-wei . . .	122.0	23						
Tachkent . . .	122.6	26						

sitive residues are due to the fact that the movement begins faintly, and the less sensitive instruments do not render the first beginning. An examination of the records confirms this beyond doubt. Therefore these need not be considered and from 78 to 90°, we can take the B.-J. values minus 1 sec. as the smoothed values of our observations. For larger distances the observed values show negative deviations from the tables.

The observations of P between 80 and 90° can also be made to fit MACELWANE's tables which for these distances have about the same course as those used; but whereas MACELWANE's tables give greater values of P for distances from 30 to 45°, they give smaller values for distances from 80 to 90°. The difference in P at 35° and at 85° is in the case of MACELWANE's tables 5 m 25 s, in the case of BYERLY-JEFFREYS' 5 m 44 s, and this latter difference has been confirmed by the observations of this earthquake.

It has also been observed in the Californian earthquake of 31 I 1922 studied by MACELWANE[1]) and considered by JEFFREYS in the paper previously referred to. The earthquake of 22 I 1923[2]) seemed to have approximately the same epicentre and the observations of P had the same course.

In the WIECHERT-ZOEPPRITZ tables which are used for the International Seismological Summary the difference in P at 35 and 85° is greater than in MACELWANE's tables but smaller than in BYERLY-JEFFREYS' by 9 s. In his statistical treatment of the material of the International Summary for the years 1918—22[3]), TURNER deduces negative corrections to the tables at 35° and the difference in height with which we are concerned is, with the corrections introduced, increased by 6 s, so that it nearly reaches that of the B.-J.'s tables.

The BYERLY-JEFFREYS tables are based on BYERLY's study of the Montana earthquake[4]). It was observed at several near stations so that the epicentre was well determined. The propagation of the waves near the epicentre was found to be the same as in the case of European earthquakes. The earthquake was strong enough to be recorded also at distant stations, and therefore an unusual opportunity was here afforded for the determination of a time-curve.

JEFFREYS introduced minor corrections to the original tables of BYERLY and with these he recommends the tables as being probably the best yet constructed.

Possible this is so. They are, as we have seen, in good agreement with this and other earthquakes; but they are based on the observations of a single earthquake only, and it does not seem very certain that one time-curve can be made to fit all cases, even with the assumption of differences of focal depth at our disposal. There is, however, no doubt that the tables deserve attention.

The chief object of this investigation is, as previously said, the S phase recorded at distances where $\overline{S_cP_cS}$ may be expected.

Considering the data of the bulletins of the European stations which are at distances between 78 and 94° from the epicentre, we see that all stations, with the exception of but two, give one S phase only.

[1]) Bull. Seism. Soc. America XIII, 2. 1923.

[2]) See the International Seismological Summary.

[3]) H. H. TURNER: Revised Seismological Tables and the Earth's Liquid Core. (M. Not. R. Astron. Soc., Geoph. Suppl. I, 8. 1926.)

[4]) P. BYERLY: The Montana Earthquake of June 28, 1926. (Bull. Seism. Soc. Amer. XVI, 1926.)

This, however, can not be taken to indicate that only one S phase is to be found, as it is not customary to read all the phases of the diagrams.

We shall now examine the diagrams to see what S phases can be read and whether it is possible to identify the phases.

Let us consider the diagrams of Hamburg (86.6°), shown in fig. 1. We see that the S movement begins rather feebly, but that, a little later, a very strong movement sets in on both components. Still later, most prominent on the E component, is another phase, *PS*.

If we try to read all the phases of a diagram I think that, perhaps, it is natural to read both the beginning of the weaker movement and of the strong movement. Still, there may be some doubt as to whether we are concerned with a new phase, since the strong movement forms the continuation of the weaker movement and the two are not clearly separated.

If we consider the records of stations at about the same distance from the epicentre, we see that they have, more or less marked, the characteristics of these records: a weaker beginning of the phase, followed by a strong movement.

Now the S phase might have this appearance at all distances; but that is not the case. Considering the E record of Oxford (80.7°) we see that the phase is not divided as in the former cases, but begins abruptly with a very large movement; later follows *PS*.

In the records of Parc St. Maur (83.8°), Uccle (84.3°) and De Bilt (84.4°) a division begins to be visible; in Uccle and De Bilt it is only seen on the E record where the S phase has an earlier beginning than on the N record; simultaneously with the beginning on the N record, the movement on the E record increases strongly.

With increasing distances from the epicentre the duration of the fainter beginning of the S phase increases; the strongest movement is always in the later part of the phase.

As a rule, the phases are more clearly separated on the E component than on the N component. The first beginning of the phase is stronger on the E component, but on the N component the movement often shows a steady increase which makes it difficult to separate the phases. The epicentre is very nearly to the West.

In the Wien (92.5°) E record (see fig. 1) we find two clearly separated phases; they are moreover equally strong; it is no longer the latter part of the phase which is the stronger.

At Kučino (98.7°) the phase is strong and begins with a strong movement; it has some duration and may be composed of more than one phase; but a phase corresponding to the later part of the S phase at

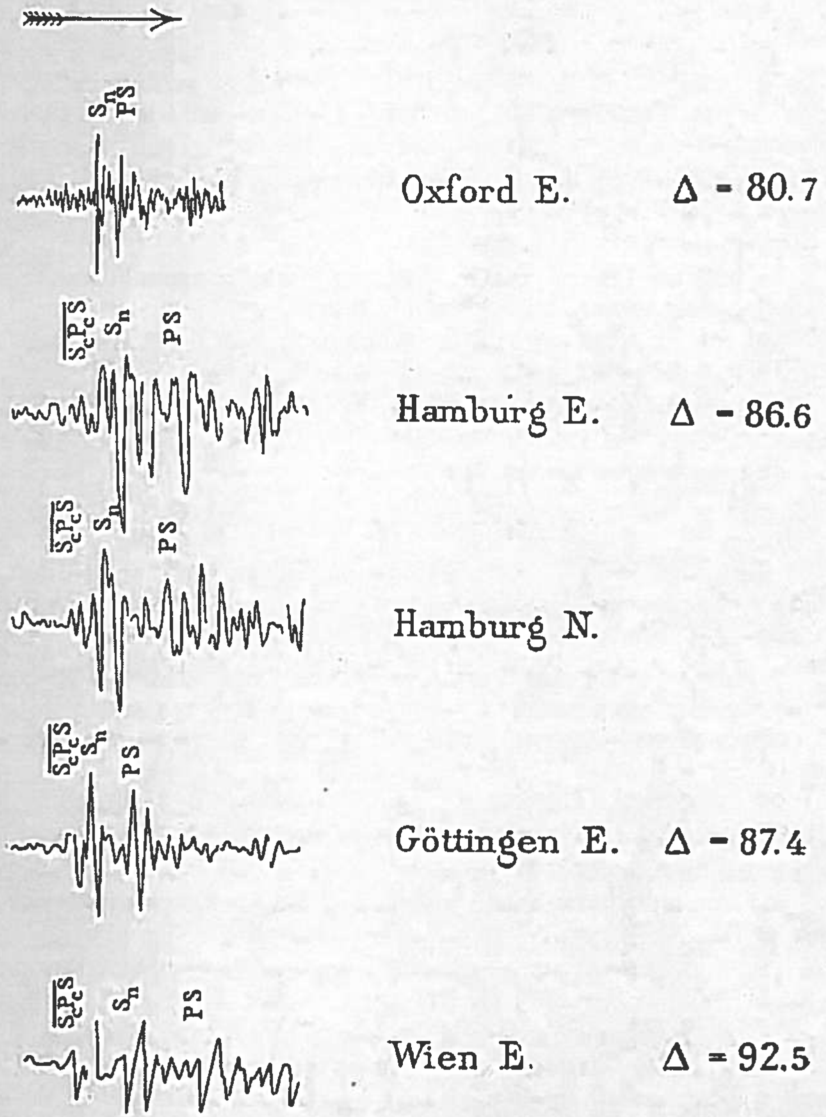

Fig. 1. *S* Records, 22 III 1928.

shorter distances does not seem to be present. For greater distances the stations are too far apart to make it possible to follow the development of the S phase from one station to another, and we shall not consider them here.

Table II col. 6 contains the readings of the beginning of the S phase for distances from 81.7° (Toledo). This phase has been identified as $\overline{S_c P_c S}$. The latter part of the S phase has been identified as S_n and is found in col. 4, where the readings of the S phase for shorter distances have also been given.

There is an indication of a phase between $\overline{S_c P_c S}$ and S_n, as is also seen in the Hamburg E record, but it is not very clearly marked and its readings have not been included here.

In fig. 2 the times of $\overline{S_c P_c S}$, S_n and PS have been plotted against the epicentral distance.

Up to $\varDelta = 89°$, the S_n points are seen to lie close to the right line drawn in between them. The equation of the right line is

$$S_n = 39 \text{ m } 26 \text{ s} + (\varDelta \div 80) \times 10.7 \text{ s}$$

or, with the adopted time of the earthquake

$$S_n \div O = 22 \text{ m } 28 \text{ s} + (\varDelta \div 80) \times 10.7 \text{ s}.$$

The differences between the observed and the smoothed values of S_n have been found and introduced in col. 5 of the table. For distances smaller than 70°, S_n has been calculated from Byerly's tables.

The differences are small and show that, although the phase forms the immediate continuation of another phase, it is very well defined. Its large amplitude makes it possible to separate it from the preceding phase.

There are some comparatively large positive deviations. They are due to the cases where a separation is difficult because the first movement increases towards the beginning of the second. Therefore there has not been given much weight to them in the smoothing of the values.

For distances greater than 89° the S_n curve seems to bend a little; the points are not on the continuation of the straight line, but a little lower.

If we compare the S_n values found with those of other tables we see that they are greater; the values of S_n—P are also greater. Table III contains the smoothed S_n—P values of this earthquake and those of Wiechert-Zoeppritz, Macelwane and Byerly-Jeffreys.

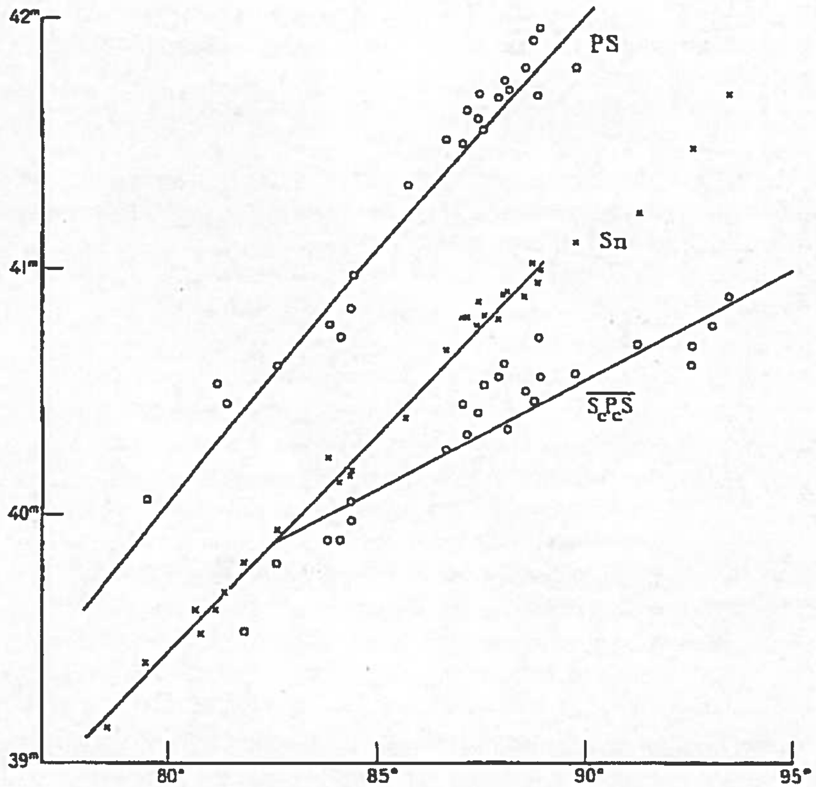

Fig. 2. 22 III 1928.

Table III. $S_n - P$.

$\varDelta$	Obs.	W.-Z.	Mac.	B.-J.
Degrees	m s	m s	m s	m s
80	10 17	10 4	10 12	10 6
85	43	31	35	28
90	11 6	58	57	54

For these distances our S_n values are not in good agreement with Byerly-Jeffreys' tables.

When in this case greater values have been found for S_n than those of the existing tables this is presumably due to the fact that these tables have been based on a material containing values of $\overline{S_c P_c S}$ as well as of S_n.

Considering next the observations of $\overline{S_c P_c S}$, we see that this phase is not so well defined as the phase S_n; the points are scattered and we cannot attempt a smoothing of the values. The line drawn in the figure has been determined as:

$$\overline{S_cP_cS} - O = (P - 1\,s) + 10\,m\ 30\,s$$

where P is drawn from the B.-J. tables. 10 m 30 s is the mean-value found for $\overline{S_cP_cS} - P$ in the investigation previously referred to.

We must examine the records to see why the uncertainty in the determination of $\overline{S_cP_cS}$ is so great.

We have said already — and it is seen in the diagrams of Hamburg — that the beginning of $\overline{S_cP_cS}$ is weak; the movement increases, sometimes in steps, sometimes gradually, towards S_n. This gives rise to much uncertainty in the reading of the beginning of the phase. The more sensitive instruments will record the beginning clearly, whereas this will not be visible on the records of the less sensitive instruments which will render the later part of the phase only. An examination of the records shows that some of the stations at distances of about 88 and 89° have undoubtedly failed to record the beginning of the phase.

So far the uncertainty is instrumental; but there are deviations which cannot be explained in this way.

In København $\overline{S_cP_cS}$ has been read as late as 4 h 40.4 m although it is taken from Galitzin records; but in the bulletin of København (no. 5) S has been read already at 39 m 55 s on the N component. Here the movement actually begins, perhaps even earlier on the E record (e 39.8). On the N component the movement consists of regular oscillations of gradually increasing amplitude until S_n (in the bulletin read as PS) sets in with a very large amplitude. On the E component the movement also increases but not so regularly and a new phase seems to begin where $\overline{S_cP_cS}$ has been read. This may be the later part of the $\overline{S_cP_cS}$ phase mentioned before. The first beginning of $\overline{S_cP_cS}$ is then either very early at 39 m 55 s or else it is masked by a preceding movement. The early beginning of the movement is seen also on the Wiechert and Milne-Shaw records and is therefore not due to the high magnification of the Galitzin instruments. In the Mexican earthquake of June 17th 1928 a similar construction of the S phase is observed in the diagrams of København[1]).

There is also a great uncertainty in the reading of $\overline{S_cP_cS}$ from the Zürich record. Here, as in København, there is an early movement seen both on the Quervain-Picard and on the Mainka records and

[1]) See Bulletin of the Seismological Station København, no. 6, page 19.

Zürich reads it as S. $\overline{S_cP_cS}$ has here been read later, where the movement increases. It should perhaps be said, that the present reading has not been influenced by the desire to find the phase in any particular place, as it was done before the readings of the other stations were collected, but its certainty is not great.

In the Uccle E record there is a clearly marked phase beginning at 39 m 12 s; $\overline{S_cP_cS}$ sets in sharply at 40 m 3 s and there is no difficulty in the separation of the phases. The first phase is absent on the N record.

Most remarkable is the Toledo (81.7°) record. Here the S phase is very early; it is divided into two phases and the beginnings of both are clearly marked, the later being much stronger than the earlier phase. It seems natural to read the first phase as $\overline{S_cP_cS}$, though the phase is very early and of a longer duration than could be expected at this distance where it should hardly be found at all.

It will be seen from these examples that there is an uncertainty in the beginning of the phase $\overline{S_cP_cS}$ which is neither of instrumental nor of subjective origin. The cause must presumably be looked for in irregularities in its path, whether near the surface or in the interior of the earth (at the boundary of the core?). We therefore cannot expect to be able to determine the times of propagation of $\overline{S_cP_cS}$ with any great certainty.

It should, on the contrary, be possible to determine the time-curve of S_n at these distances. There is not much material available for this purpose at present, since, as a rule, it is the first beginning only of the S phase which is read. The S phase thus read is sometimes S_n, but more often it is $\overline{S_cP_cS}$ and then the marked beginning of S_n later in the phase is left unnoticed. It is to be hoped that further investigations will produce more material for the determination of the S_n curve for distances greater than 80°.

In fig. 2 the observations of PS have also been plotted. The curve drawn for PS has been so determined that PS—P are the values of Gutenberg[1]). PS is often recorded on the E record only.

As in the case of the earthquake of 16 VI 1929 where the phase P_2'[2]) was determined, we see in this case also that the study of the records of a well determined earthquake from stations which are situated close together gives us much information about the phases recorded. It is possible to

[1]) B. Gutenberg, Grundlagen der Erdbebenkunde 1927, page 120.

[2]) I. Lehmann, P' as read from the records of the earthquake of June 16th 1929. (Gerlands Beitr. z. Geophys. XXVI, 1930).

identify the phases with great certainty and to follow their development when records from stations at about the same distances from the epicentre can be compared directly with each other so that their characteristics become apparent.

We have here been able to determine a smoothed curve from the values observed for S_n for an interval of about 10°, just as in the former case for P_3'. In this way we get a good determination of the slope of the time-curve in the interval considered. This is very important because, if we attempt a determination of the path of the ray through the interior of the earth, it is the slope of the time-curve which forms the basis of our calculation.

When particular earthquakes are studied an attempt is often made to determine time-curves for all distances, even if for some distances but few observations are available. I think that perhaps it is more useful to attempt the best possible determination of the curves for short intervals where a great many observations crowd. Thus "differential coefficients" are determined with great certainty and a time-curve may, in the end, be obtainable by "integration".