REPORT ON THE GREAT INDIAN EARTHQUAKE OF 1905.

PART II: SEISMOGRAPHICAL OBSERVATIONS.

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Chapter I. Introductory.

1. ***Himalayan Range and Seismic Activity.*** The topography of British India is highly characteristic, the great Himalayan range forming a very beautiful circular are which extends in an east-west direction. (See Fig. 1.) As elsewhere stated, great earthquake regions often coincide with the steep convex, or outer, side of a curve formed by a mountain chain or a series of islands; the inner, or concave, side being only disturbed by occasional local shocks.* In the case of the Himalayan range, which rises abruptly from flat plains of India, the arcual form is probably due to a pressure from the Tibet side, which is still going on.

The large Indian seismic disturbance of April 4, 1905, usually known as the Kangra Earthquake, originated among the Sub-Himalayan chains in the Punjab (Fig. 1), and is to be regarded, together with the Assam and Bengal earthquake of June 12, 1897, as the result of the growth of the Himalayas. The latter form part of the great seismic zone extending from the Mediterranean on the west to Formosa on the east, along which no less than 11

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* See the *Bulletin of the Imperial Earthquake Investigation Committee*, Vol. I, No. 2.

large destructive earthquakes occurred within the 8 years between 1897 and 1905.*

2. *Area of Sensible Motion.* The approximate boundary of the area, within which the motion of the Kangra earthquake was sensible, is shown by the line B in Fig. 1, its western, southern, and eastern limits being Quetta (Afganistan), Surat and False Point, and Lakhimpur (Assam), respectively. The extreme distance, at which the motion was felt, was about 1670 km, the areas enclosed within the three isoseismals corresponding to Nos. 10, 9, and 8, of the Rossi-Forel scale of seismic intensity being, according to Mr. C. S. Middlemiss, of the Indian Geological Survey, respectively 200, 1600, and 2150 square miles.†

The meizoseismal district, where serious damage was caused, and whose intensity of motion corresponded to the Nos. VIII, IX, and X, of the Rossi-Forel scale, stretched in an NW-SE direction, from the vicinity of Kangra and Dharmsala to that of Mussooree and Dehra Dun, over a distance of about 350 km (A, Fig. 1); the earthquake motion being much stronger on the north-western half, than on the south-eastern half, of the zone under consideration. It seems probable that the latter extends towards the north-west of Kangra and Dharmsala for some more distance.

3. *Intensity of Motion.* The intensity, or destructive power, of the earthquake motion may be represented by the maximum acceleration of the earth's particle in its vibratory movement‡; the approximate values of this quantity at some places in the strongly or violently shaken areas, deduced from the observations

* The *Bulletin*, Vol. I, Nos. 1 and 2.

† C. S. Middlemiss: "Preliminary Account of the Kangra Earthquake of the 4th April 1905." Records of the Geological Survey of India, Vol. XXXII.

‡ See F. Omori: "Seismic Experiments on the Fracturing and Overturning of Columns." The *Publications*, No. 4.

Fig. 1. Map of India, showing the Position of the Epifocus and the Approximate Boundary of the Area of Sensible Motion of the Kangra Earthquake of April 4, 1905.

A......Epifocus.
B......Boundary of the Area of Sensible Motion.

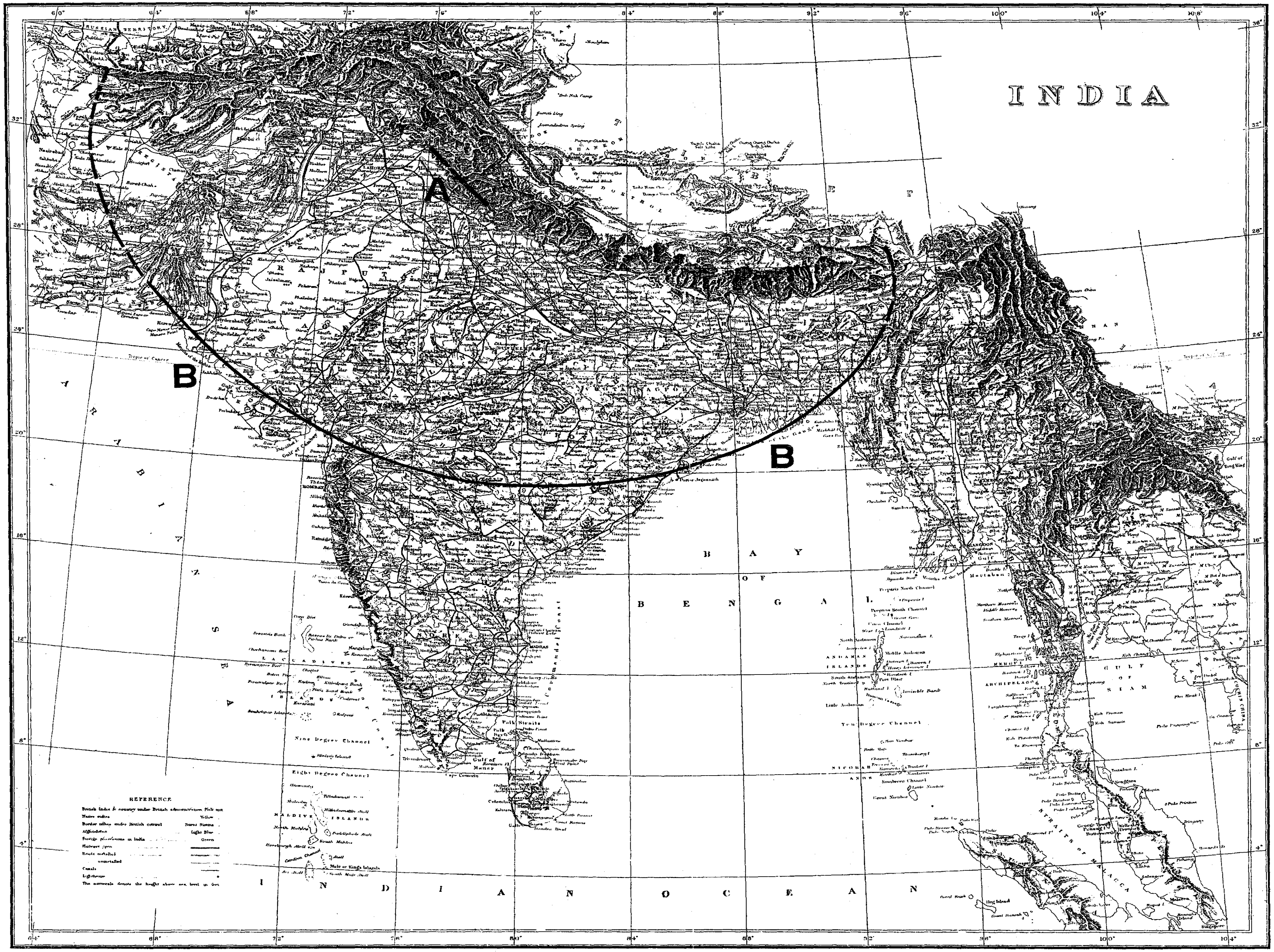
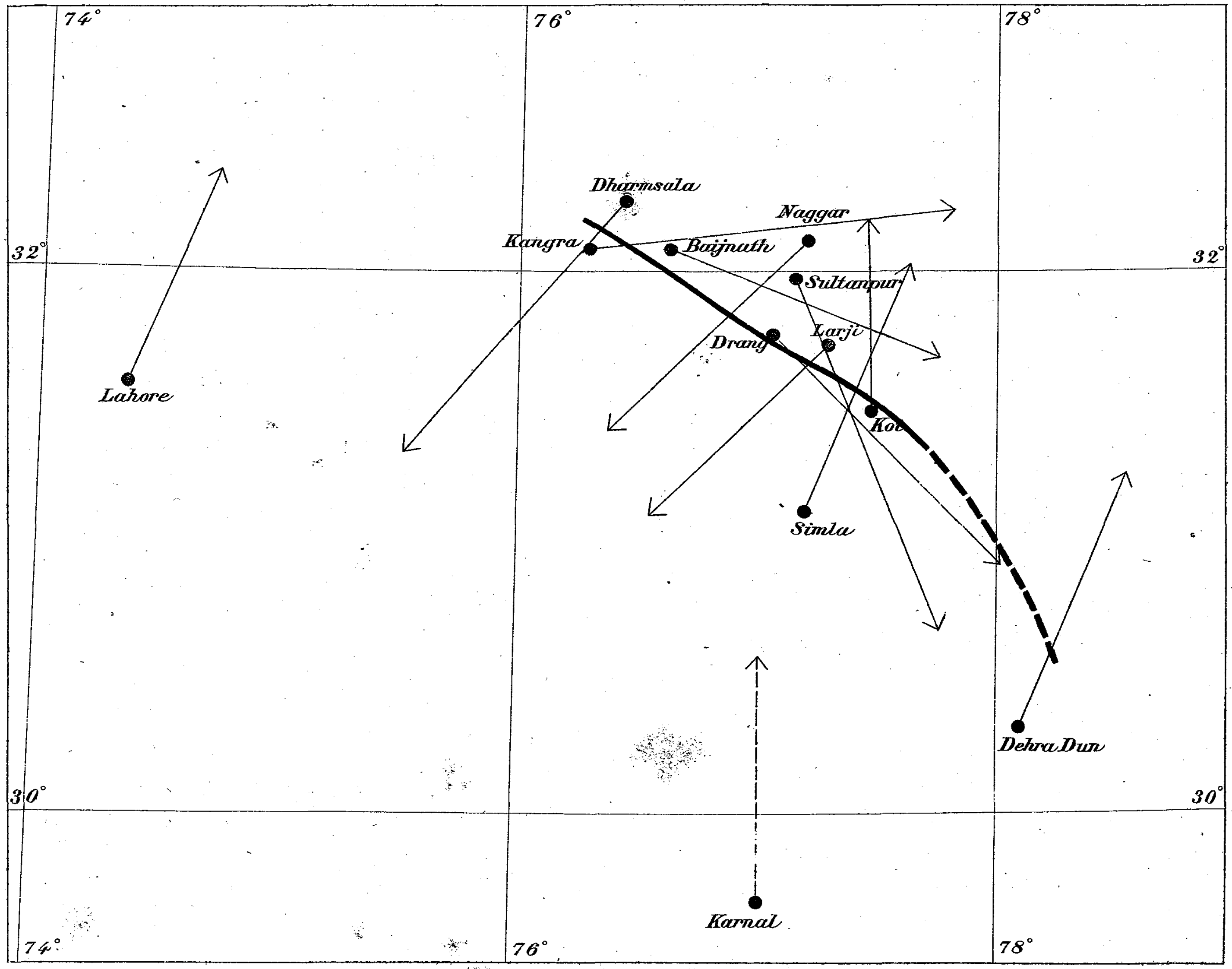


Fig. 2. Indian Earthquake of April 4, 1905.

The Direction of Motion and the Epifocal Zone.

Arrow indicates the direction of motion. The thick red line indicates the Epifocal Zone, the dotted part marking its probable south-eastern continuation.



of overturned bodies, or inferred from the comparison of the earthquake effects in the present case with those in the great Mino-Owari (Central Japan) earthquake of 1891, being as follows :—

Simla. Max. acceleration = about 400 mm/sec^2.

Pathankot. Motion was weaker than at Simla.

Shahpore. Motin was much stronger than at Pathankot, and weaker than at Simla.

Rihlu. Motion was much stronger than at Shapore.

Lahore. Max. acceleration = about 500 mm/sec^2.

Amritsar. Motion was slightly weaker than at Lahore.

Delhi Motion was rather weaker than at Amritsar.

Upper Dharmsala. Max. acceleration was not greater than 2300 mm/sec^2.

Kangra. Max. acceleration was not greater than 3500 mm/sec^2.

Palumpur. Max. acceleration was not greater than 2350 mm/sec^2.

Mandi. Max. acceleration was not greater than 2280 mm/sec^2.

Naggar. Motion was stronger than at Simla, but much weaker than at Sultanpur.

Thus it seems that the intensity of motion in the epicentral district of the Kangra earthquake was not so great as in that of the Mino-Owari earthquake of 1891. On the occasion of the latter catastrophe, the maximum acceleration of the earthquake movement in the Mino-Owari plain exceeded 4000 mm/sec^2., that in the epicentral zone of the famous Neo-Valley being much higher. Again, there was, in the Kangra earthquake, no surface manifestation of remarkable faults. These facts seem to indicate that the focus or centre of the earthquake under consideration was very deep below the surface.

4. *Earthquake Damage.* For the account of an absolute scale of strong seismic motion, or the destructive effects corresponding to different values of the maximum acceleration of the earthquake motion, the reader is referred to the *Publications*, No. 4. It is easy to understand that the amount of casualties and the number of houses destroyed by an earthquake depend largely on the method of buildings. Thus, badly built mud or stone houses are completely destroyed by an earthquake shock with an intensity of about 2000 mm/sec^2., while properly built wooden or iron frame structures can resist any shock whatever. One special feature of the seismic effects on structures built with very bad material, which has practically no tensile strength, is that thickness of the walls gives no capacity of resisting seismic force. In fact a massive thick-walled house of inferior masonry work, which has no frame bindings, forms virtually a heap of stone and is simply shattered down at once by an earthquake shock; typical specimens of this sort being the barracks at Dharmsala, where many Gurka soldiers were killed and wounded.

Ordinary buildings in the Kangra Valley, where the shock was strongest, had walls of mud or rubble masonry with a heavy slate roof, being of the worst type of structure with respect to the earthquake shock. The total number of the houses destroyed in the Kangra District and the Mandi State amounted to 112,477, and the number of persons killed reached 18,815, exceeding anything recorded of great seismic catastrophes in the recent times.*

5. *Direction of Motion and the Earthquake Origin.* The direction of the maximum earthquake motion at a given place may be assumed to be identical with the mean direction towards which different bodies are mostly overturned.† The directions

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* Excepting the north Japan earthquake of June 15, 1896, which caused great tidal disturbances along the north-eastern coast of Japan, resulting in the death of 21,953 persons.

† See the *Publications*, Nos. 4 and 12.

thus estimated for a number of places in the strongly shaken area of the Kangra earthquake were as follows.

Dharmsala.	Towards	S40°W.
Kangra and *Daulatopur.*	,,	N83°E.
Nagrotha.	,,	W a little S.
Baijnath.	,,	E a little S.
Drang.	,,	SE.
Mandi.	,,	NE—SW (?)
Sultanpur and *Bajaura.*	,,	S a little E.
Between *Sultanpur* and *Naggar.*	,,	NE—SW (?)
Kot.	,,	N.
Larji.	,,	SW.
Dehra Dun and *Mussooree.*	,,	NEN.
Lahore.	,,	N a little E.
Simla.	Towards	N a little E—S a little W.
*Karnal.**	,,	N.

The direction of motion as above given are to be regarded as only gross approximations, the observations being in many instances unsatisfactory or few in number. One marked fact, however, is that the direction at Kangra was towards E a little N, and therefore nearly opposite to that at Dharmsala where the direction was towards SW. Further, comparing together the results for the different places, we see that the latter may be grouped into 2 sets as follows:—

Group *A*:—Lahore, Kangra, Simla, Kot, Dehra Dun, Karnal.

Group *B*:—Dharmsala, Naggar, Baijnath, Sultanpur, Drang, Larji.

At *A* Group places, the direction of motion was towards N, NEN, or ENE, while at *B* Group places it was towards SW, SES,

* The direction at Karnal has been inferred from the observation of Mr. Hanly, Assistant Engineer, Dharmsala.

or ESE, so that the maximum earthquake movements at these two different sets of places may be regarded, on the whole, to be opposite to one another, as shown in Fig. 2, probably denoting a certain symmetry of the direction of motion with respect to the earthqnake origin. The red line in the figure, drawn midway between *A* and *B* Group places, is to be regarded as marking the epifocal zone, and the dotted line indicates the possible extension towards the southeast; the entire length of the focus thus supposed being about 270 km or 170 miles. The most central point of the seismic disturbance may be assumed to be situated some distance to the SE of Dharmsala and Kangra, say, at

Latitude, **31° 49′** N.
Longitude, **77° 00′** E.

This position has been taken as the earthquake centre in the calculations of the propagation velocities of the different phases of the earthquake motion.

6. ***List of Stations.*** Table I gives for each of the 69 different stations, where the Kangra Earthquake was observed, the latitude, longitude, epicentral distance ($=x$), and the time ($=t_1$) of earthquake occurrence.* The last named element of motion was deduced from the seismograms, except in the 5 cases marked (*M*), whose epicentral distance was under $21°\frac{3}{4}$, and whose time of commencement, obtained from magnetogragh records, may be regarded as corresponding to the beginning of the "principal portion."

The times are always given in G.M.T.

The earthquake was insensible at all the places given in the table, except Dehra Dun, where the motion was severe; the nearest and furthest teleseismic stations being respectively Taschkent ($x=11°\ 20'$) and Tacubaya ($x=128°\ 39'$).

* The time of earthquake occurrence at the origin itself is given in the next Chapter.

The epicentral distance x has been calculated by the following formula:—

$$\cos x = \sin \phi . \sin \phi_0 + \cos \phi . \cos \phi_0 . \cos(\lambda - \lambda_0),$$

where ϕ and λ denote the latitude and longitude of a given station, and ϕ_0 and λ_0 those of the epicentre.

TABLE I. List of Stations; Observation of the Indian Earthquake of April 4, 1905.

Station.	Position.		Epicentral Distance $=x$	Time of Eqke Occurrence. $=t_1$ (G.M.T.)
	Latitude.	Longitude.		
Epicentre.	**31° 49′ — N**	**77° — — E**	———	**$0^h49^m48^s$** $(=t_0)$
India.				
Dehra Dun.	30°19′19″ N	78°03′19″ E	1° 45′	(M) $0^h50^m38^s$
Colaba (Bombay)	18°53′45″ N	72°48′56″ E	13 28....	0 53 08 (M) 0 57 04
Barrackpur	22°46′29″ N	88°21′39″ E	13° 32′	(M) 0 55 41
Alipore (Calcutta)	22°34′— N	88°24′— E	13 42	0 52 00
Kodaikanal	10°13′50″ N	77°27′46″ E	21 35 ...	0 55 48 (M) 1 01 00
Burma.				
Taungoo.	18°55′45″ N	96°27′03″ E	21° 44′	(M) $1^h00^m03^s$
Russian Turkestan				
Taschkent	41°19′31″ N	69°17′42″ E	11° 20′	$0^h52^m24^s$
Caucasus. (Russia)				
Tiflis	41°43′08″ N	44°47′51″ E	27° 26′	$0^h55^m48^s$
Achalkalaki	41 25 — N	43 29 09 E	28 21	0 55 59
Batum	41 40 — N	41 38 35 E	29 45	0 56 14
Borshom	41 51 — N	43 23 08 E	28 30	0 55 52
Derbent	42 04 — N	48 18 — E	24 58	0 55 03
Schemacha	40 38 — N	48 38 — E	24 23	0 55 09
Siberia.				
Irkutsk	52°16′— N	104°18′33″ E	28° 28′	$0^h55^m44^s$

TABLE I. *Cont.*

Station.	Position. Latitude.	Position. Longitude.	Epicentral Distance $=x$.	Time of Eqke Occurrence $=t_1$ (G.M.T.)
Asia Minor.				
Bairut	33°54′— N	35°30′— E	34° 41′	$0^h58^m00^s$
Russia.				
Jurjew	58°22′48″ N	26°43′20″ E	42° 49′	0 57 52
Nikolajew	46 58 18 N	31 58 27 E	37 20	0 58 54
Java.				
Batavia	6°08′— S	106°50′— E	42° 35′	0 58 33
Philippines.				
Manila	14°34′41″ N	120°58′33″ E	43° 34′	0 58 25
China.				
Shanghai (Zikawei)	31°11′33″ N	121°10′45″ E	37° 24′	0 53 17
Japan.				
Tōkyō	35°42′33″ N	139°45′53″ E	51° 26′	$0^h59^m08^s$
Mizusawa	39 08 — N	141 07 — E	51 39	0 59 08
Kōbe	34 41 — N	135 11 — E	48 03	0 58 26
Ōsaka	34 42 — N	135 31 — E	48 19	0 58 51
Tadotsu.	34 17 — N	133 46 — E	47 02	0 58 49
Formosa (Japan).				
Taihoku	25°02′— N	121°30′— E	39° 27′	0 57 19
Taichu	24 09 — N	120 42 — E	39 05	—
Tainan	22 59 — N	120 12 — E	39 06	—
Mauritius.	20°11′— S	57°31′— E	55° 15′	0 58 54
Servia.				
Belgrade.	44°48′— N	20°09′— E	45° 29′	0 57 47
Germany.				
Potsdam.	52°22′56″ N	13°03′59″ E	49° 48′	$0^h58^m46^s$
Leipzig.	51 20 06 N	12 23 30 E	50 16	0 58 44
Jena.	50 56 — N	11 35 — E	50 48	0 58 54
Hamburg.	53 33 55 N	10 01 19 E	51 34	0 58 14
Göttingen.	51 33 — N	9 58 — E	51 45	0 58 55
Strassburg.	48 35 00 N	7 46 10 E	53 31	0 58 26

TABLE I. *Cont.*

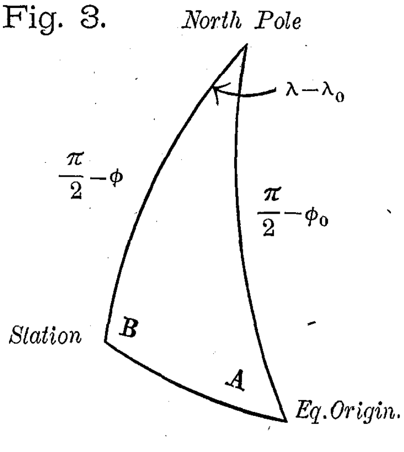
Station.	Position.		Epicentral	Time of Eqke Occurrence
	Latitude.	Longitude.	Distance $= x$.	$= t_1$ (G.M.T.)
Austria-Hungary.				
Krakau	50°03′50″ N	19°57′36″ E	45° 30′	0h58m12s
Laibach	46 03 — N	14 30 — E	49 19	0 58 46
Triest.	45 38 45 N	13 45 45 E	49 52	0 58 44
Pola.	44 51 49 N	13 50 44 E	49 55	0 58 50
Sweden.				
Upsala.	59°51′30″ N	17°37′30″ E	47° 41′	0 58 22
Italy.				
Messina.	38°11′45″ N	15°33′18″ E	49° 46′	0 59 00
Port d'Ischia.	40 44 27 N	13 56 34 E	50 30	0 58 56
Rocca di papa.	41 46 — N	12 42 — E	51 15	0 58 51
Querce (Florence).	43 47 18 N	11 16 42 E	51 54	0 59 08
Ximeniano. („)	43 46 40 N	11 15 24 E	51 55	0 58 33
Quarto-Castello („)	43 49 11 N	11 13 11 E	51 56	0 58 47
Padova.	45 24 3 N	11 52 18 E	51 20	0 58 58
Great Britain.				
Kew	51°28′06″ N	0°18′46″ W	58° 05′	1 00 12
Edinburgh.	55 57 23 N	3 10 46 W	58 48	1 00 00
Birmingham.	52 28 — N	1 53 — W	58 49	1 00 35
Shide (I. W.)	50 42 — N	11 9 — W	58 52	1 01 00
Liverpool (Bidston).	53 24 04 N	3 04 18 W	59 18	1 00 36
Paisley.	55 51 — N	4 25 — W	59 30	1 00 00
Spain.				
San Fernando.	36°27′40″ N	6°12′19″ W	66° 47′	1 02 30
Azores.				
Ponta Delgada.	37 46 — N	25 41 — W	79 54	1 01 00
Cape of Good Hope.	33 56 03 S	18 28 41 E	85 46	1 02 30
Canada.				
Victoria, B.C.	48 27 — N	123 22 — W	97 42	1 06 48
Toronto.	43 39 36 N	79 23 24 W	101 30	1 06 36
Hawaii.				
Honolulu.	21 19 — N	153 04 — W	108 27	1 04 36

TABLE. I. *Cont.*

Station.	Position.		Epicentral Distance $= x$.	Time of Eqke Occurrence $= t_1$ (G.M.T.)
	Latitude.	Longitude.		
United States.				
Baltimore.	39°17′48″ N	76°37′12″ W	104° 47′	1^{h}10^{m}30^s
Washington.	38 54 18 N	77 03 06 W	105 17	1 08 25
Cheltenham	38 44 00 N	76 50 30 W	105 22	1 08 39
Porto Rico.				
Vieques.	18 09 — N	65 26 — W	118 25	1 10 25
Samoa (Apia)	13 48 24 S	171 45 54 W	115 08	1 01 36
New Zealand.				
Christchurch.	43 31 50 S	172 37 18 E	115 03	1 10 00
Wellington.	41 17 — S	174 47 — E	115 45	1 09 48
Brazil.				
Rio de Janeiro.	22 54 24 S	43 10 21 W	126 53	1 59 41 (?)
Mexico.				
Tacubaya.	19 24 18 N	99 11 37 W	128 39	1 11 25

7. *Directions of Observing Stations relative to the Earthquake Origin.* Table II gives, for a number of the observing places, besides the epicentral arcual distance (x) expressed in km, the azimuth (A) of a given station with respect to the earthquake origin, and the azimuth (B) of the latter with respect to the former, both counted from the north.* (See Fig. 3, in which ϕ and ϕ_0 have

Fig. 3.



* This calculation has very kindly been undertaken by Mr. K. Ōi, Assistant Professor in the Science and Engineering College, Kyōto Imperial University.

the same meanings as in the preceding §). The azimuths A and B have been calculated by the following formulae :—

$$\sin A = \frac{\cos \phi.\ \sin(\lambda - \lambda_0)}{\sin x};$$

$$\sin B = \frac{\cos \phi_0.\ \sin(\lambda - \lambda_0)}{\sin x}.$$

TABLE II. Distance and Azimuth of Observing Stations.

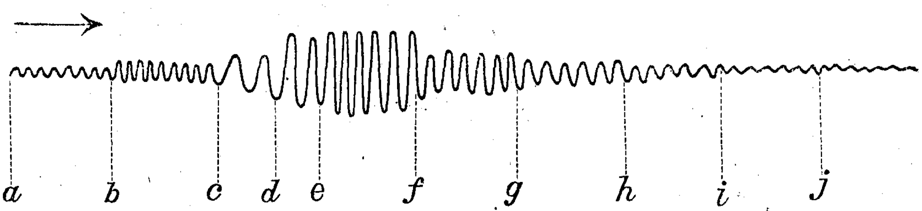
Station.	Epicentral Distance.		Azimuth A. (from North)	Azimuth B. (from North)
	in Angle.	in km.		
Tiflis.	27°26′06″	3050	W 59°41′37″	E 79°22′20″
Osaka.	48 19 11	5372	E 69 50 31	W 75 59 26
Potsdam.	49 47 46	5536	W 42 52 56	E 88 02 40
Tokyo.	51 25 47	5718	E 67 25 58	W 75 05 36
Göttingen.	51 45 10	5754	W 46 48 18	E 85 01 10
Quarto-Castello.	51 56 07	5774	W 56 41 45	E 79 49 50
Kew.	58 05 04	6458	W 45 43 22	E 77 35 10
San Fernando.	66 47 11	7425	W 60 20 17	E 66 39 00
Toronto.	101 29 49	11285	W 17 11 54	E 20 19 16
Washington.	105 16 39	11705	W 20 40 11	E 22 40 14
Cheltenham.	105 22 21	11716	W 20 53 42	E 22 51 43
Christchurch.	115 03 11	12792	E 127 12 26	W 68 59 01
Wellington.	115 44 30	12868	E 124 15 11	W 69 10 26
Rio de Janeiro.	126 53 19	14108	W 96 10 58	E 66 32 04
Tacubaya.	128 38 55	14303	W 4 35 54	E 4 08 31

As will be seen from the above table, Tacubaya lies very nearly on the meridian passing through the earthquake centre; while the azimuth (B) for Tiflis, Osaka, Tokyo, Potsdam, Göttingen, Quarto-Castello, and Kew, is not much different from 90°, varying between 75° and 88°. It may be concluded, therefore, that the NS and EW components of the seismogram at Tacubaya corresponded almost exactly to the *longitudinal* and *transverse waves* respectively. On the contrary, the same two components at the

7 other above named stations approximately corresponded to the *transverse* and *longitudinal waves,* respectively. Of the remaining places given in the table, Toronto, Washington, and Cheltenham, are situated not very much out of the meridian through the origin of disturbance, while the azimuth for San Fernando, Christchurch, Wellington, and Rio de Janeiro, was nearly 70°. The approximate relation to the position of the earthquake centre of the other stations not above mentioned may be inferred from that for those places given in the table.

8. ***Character of the Teleseismic Motion.*** The earthquake motion due to a distant origin consists generally of a series of different sections or stages, in each of which the period* remains essentially constant, while the amplitude is also on the whole constant, except for the occurrence of maximum and minimum groups.

Fig. 4.



The successive sections of the earthquake motion, illustrated in Fig. 4, are as follows.

The *preliminary tremor* (*a b c*), which consists principally of vibrations of small amplitude and of comparatively short period, is divided into the 1st *section* or the *first preliminary tremor* (*a b*), and the 2nd *section* or the *second preliminary trmor* (*b c*). Commencement of the latter is marked by an increase of the amplitude and, in many cases, also by the appearance of slow vibrations.

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* The term "Period" is used in the sense of the *complete period.*

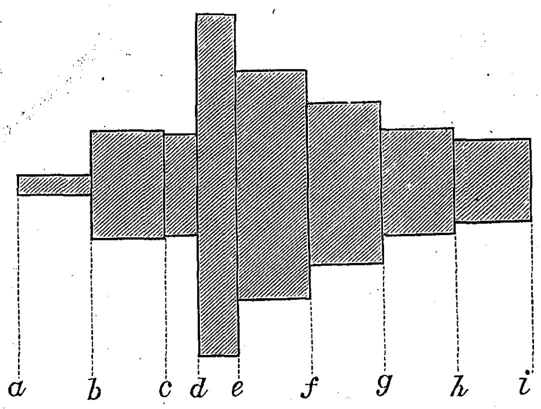
The *principal portion*, which comprises the 3rd to 7th *sections* (*cd*, *de*, *ef*, *fg*, *gh*), denotes the most active part of an earthquake, which follows the preliminary tremors and consists of movements of larger amplitude. The subdivisions of the *principal portion* are as follows :—The *1st phase* (3rd *section*), consisting of a few very slow vibrations; the *2nd phase* (4th *section*), consisting also of slow movements whose period is somewhat shorter than in the 1st phase; the *3rd phase* (5th *section*), consisting of vibrations of period much quicker than that in the preceding two phases; the *4th phase* (6th *section*) and the *5th phase* (7th *section*), the vibrations in these two stages being quicker and smaller than in the 3rd phase.

Lastly, the *end portion*, or *tail*, which comprises the 8th and subsequent *sections*, (*h i*, ...) denotes the feeble finishing part of the earthquake motion, following the principal portion.

In earthquakes of near origin, the motion is, on account of the predominance of quick vibrations of macro-seismic character, much more complex than in distant earthquakes, it being generally difficult to subdivide the principal portion into the different phases.

Range of Motion (Double Amplitude) and Duration. The relative magnitudes of vibrations in the successive sections, or stages, of the teleseismic disturbance are different from those of the near earthquake motion, the predominating periods in each epoch being different according to the epicentral distance. In the case of the 11 large distant earthquakes observed between 1899 and 1902 in Tokyo, the relative magnitudes of motion in the successive sections of motion were as shown in the 2nd column of Table III. From the latter it will be seen that the range of motion in the 1st preliminary tremor (1st section) was only about $\frac{1}{5}$th or $\frac{1}{6}$th of that in the 2nd and 3rd sections, namely, the 2nd preliminary tremor and the 1st phase of the principal portion; the 2nd phase (4th section) of the latter having the maximum motion, which is more than 3 times greater than those in the two preceding sections. The ranges in the 3rd and 4th phases of the principal portion were respectively about 12 and 8 times greater than that in the 1st preliminary tremor. The motion in the next phase, 7th section, was equal to that in the 2nd preliminary tremor and the succeeding phase, and may be regarded as forming the finishing part of the principal portion; the 8th section, whose motion was still smaller, properly belonging to the tail or end portion. As shown in the 3rd column of Table III, the durations of the successive sections of motion were roughly equal to one another, the 1st and 2nd phases of the principal portion being taken together. Fig. 5 gives a diagramatic representation of the teleseismic motion, so far as the durations and amplitudes are concerned.*

Fig. 5.



ab ......1st Section, or 1st Prel. Tremor.
bc ......2nd „ , „ 2nd „ „
cd ......3rd Section, 1st Phase, Princ. Portion.
de ......4th „ , 2nd „ , „ „
ef ......5th „ , 3rd „ , „ „
fg ......6th „ , 4th „ , „ „
gh ......7th „ , 5th „ , „ „
hi ..... 8th „ Tail, or End Portion.
....

Periods. There are a number of periods occurring in different parts of the earthquake motion. Amongst others, the two periods denoted by P_1 and P_2 occur very often,* being respectively identical

* See the *Publications*, No. 13.

with the two periods Q_1 and Q_2 of the "pulsatory oscillations." Other periods of microseismic or insensible nature, which are of a more or less frequent occurrence may be denoted by P_3, P_4, P_5, ...P_{13},....... The average values of the different periods are as follows :—

P_1= 4.2	sec.	P_8 =32.3	sec.
P_2= 8.7	„	P_9 =35.4	„
P_3=14.1	„	P_{10}=41.8	„
P_4=17.5	„	P_{11}=45.0	„
P_5=20.4	„	....	
P_6=24.9	„	P_{13}=54.0	„
P_7=28.3	„	....	

In the 4th column of Table III, which gives the periods of the predominating vibrations in the different sections of motion of the same 11 great teleseismic disturbances, those of a specially frequent occurrence are printed in fat characters.

TABLE III. Amplitude, Duration, and Periods of Great Teleseismic Motion. (Tokyo Observation, 1899–1902.)

Phase of Motion.	Relative Amplitude.	Relative Duration.	Predominating Periods.
1st Preliminary Tremor.	100	100	P_1; $\boldsymbol{P}_2$; P_3
2nd „ „	560	95	P_1; $\boldsymbol{P}_2$; P_3; —; —; P_6; P_7
1st Phase, Princ. Portion.	550	30 } 79	—; P_2; ... P_9; P_{10}; ... P_{13}
2nd „ „ „ „	1820	49 }	—; P_2; ... P_7; $\boldsymbol{P}_9$; P_{10}
3rd „ „ „ „	1220	91	...........$\boldsymbol{P}_5$; P_6
4th „ „ „ „	840	95	—; P_2; $\boldsymbol{P}_3$; P_5
5th „ „ „ „	560	95	—; P_2; $\boldsymbol{P}_3$
8th Section (Tail)	430	88	—; —; $\boldsymbol{P}_3$
End Portion (Tail).	—	—	—; $\boldsymbol{P}_2$; P_3; P_5

As will be seen from the above table, the period P_2 (=8.7

sec.), which occurred very frequently in the 1st and 2nd preliminary tremors, happened more or less almost through the entire series of the different sections of motion. In the 2nd preliminary tremor, slow periods of P_6 (=24.9 sec.) and P_7 (=28.3 sec.) began to appear; while in the 1st phase of the principal portion, very slow periods of P_{10} (=41.8 sec.) and P_{13} (=54.0 sec.), were of a frequent occurrence. In the 2nd phase of the same portion, the predominating period became a little shorter and P_9 (=35.4 sec.) occurred very often. In the 3rd phase of the principal portion, the vibrations still further quickened, the period of P_5 (=20.4 sec.) occurring most frequently. In the two subsequent phases of the principal portion and the 1st phase of the tail, the predominating period was P_3 (=14.1 sec.). Towards the end of motion the period of common occurrence became again P_2 (=8.7 sec.), being the same as that prominent in the 1st and 2nd preliminary tremor.

The foregoing short account of the teleseismic motion, based on the previous observations made in Tokyo, has been given for the sake of reference, the complete discussion on the character of the vibrations being reserved for a later chapter.

9. *Time of Occurrence of the Kangra Earthquake.*

(i) *Time of Earthquake Occurrence inferred from Teleseismic Records.*

The time ($=t_0$) of earthquake occurrence at the origin itself may be estimated by the following formula*:—

$$t_0=t_1-1.165\ y_1 \quad \ldots\ldots\ldots\ldots\ldots (1)$$

in which t_1 and y_1 denote respectively the time of commencement, and the duration of the 1st preliminary tremor, of the earthquake motion at a given observing station. This equation is to be regarded as being roughly approximate, but seems to give fairly

* The *Bulletin of the Imperial Earthquake Investigation Committee*, Vol, 1, No. 1.

satisfactory results; the time of occurrence at the origin, estimated by (1), agreeing in the cases of the Calabrian earthquake of Sept. 8, 1905, and of the San Francisco earthquake of April 18, 1906, almost to within 1 minute.

For the time of commencement (t_0) of the Kangra earthquake, we have, applying, for example, the Tokyo observation to the equation (1):—

$$t_1 = 0^h\ 59^m\ 08^s \text{ (G.M.T.)};\ y_1 = 7^m\ 16^s.$$
$$t_0 = 0^h\ 59^m\ 08^s - (1.165 \times 436s) = 0^h\ 50^m\ 40^s \text{ (G.M.T.)}$$

Again, taking the averages from the observations at the 18 stations of Tokyo, Osaka, Mizusawa, Tadotsu, Kobe, Upsala, Laibach, Triest, Pola, Potsdam, Leipzig, Göttingen, Messina, Ischia, Rocca di papa, Querce, Ximeniano, and Quarto-Castello, whose epicentral distance varied between 47° 02′ and 51° 56′, we obtain:—

$$mean\ t_1 = 0^h\ 58^m\ 58^s \text{ (G.M.T.)};\ y_1 = 7^m\ 12^s$$
$$t_0 = 0^h\ 58^m\ 58^s - (1.165 \times 432^s) = 0^h\ 50^m\ 35^s \text{ (G.M.T.)}$$

These values of t_0 agree very well with the time of occurrence at the origin inferred from the magnetograph observations made at Dehra Dun, namely, 0h 49m 48s, G.M.T. (See the next §.)

(ii) *Earthquake Recorded by Magnetographs.*

The only instrumental record of the shock within the meizoseismal area is that given by the magnetograph at Dehra Dun, which is thus extremely valuable in connection with the determination of the time of earthquake occurrence at the origin of disturbance. The following detailed account respecting the magnetograms obtained at Dehra Dun and three other stations of Barrackpore (near Calcutta), Kodaikanal (Madras), and Taungoo (Burma), has very kindly been furnished by Captain Thomas, the officer in charge of the Magnetic Department at Dehra Dun, and his assistant, Mr. Mazumdar; a very useful check on the time found for each place consisting in comparing the interval between the earthquake shock and a well marked apex in magnetic disturbances either preceding or following the latter.

"On the Time of the Principal Earthquake Shock on the 4th April 1905 as registered on Magnetograph Curves.

"*Accuracy of Measurement*......The process of measuring the exact moment of time of a particular point on the trace is burdened with several sources of error, in the measurement of small quantities.

"......The accordance, however, of many of the results in the following §§ when independent measures were taken by two or more observers, is such that there should be no hesitation in accepting some groups as correct at least to 1 minute of time.

"There is moreover a check on the times found for each observatory, by comparing the intervals derived from the time of shock at each observatory with the intervals obtained by measuring the interval between the shocks and the well marked apices of disturbances on the same date.

"......Two apices of disturbance have been utilized and the measurement has been made in two ways. An additional advantage applies to these methods in that error of cut off, parallax, and error of clock are not involved.

"In the first the absolute time of the apex of disturbance is found and the time interval derived by applying the absolute time of the shock already determined.

"In the second the interval is measured direct ....

"*Method of obtaining Time at the various observatories.* Before tabulating the results of the measurements of the magnetograms, and comparing them as above suggested, it would be well to briefly indicate the methods of obtaining correct time at the various observatories.

"At Dehra Dun time is obtained by comparision of the observer's chronometer with the sidereal clock at least twice a week, errors on other days being interpolated by the rates thus obtained.

"At Barrackpore and Taungoo time is obtained by observations to E and W stars.

"At Kodaikanal time is obtained by telegraphic signal from Madras daily and the observer's chronometer is compared daily with the Solar Physics Observatory clock.

"At all observatories the driving clock of the magnetographs is compared daily with the standard chronometer by means of a pocket chronometer but as before stated in the absence of a second hand on the driving clock, this determination is likely to be in error some seconds.

Time of principal shock measured from magnetographs.

"I. Direct measurement of time of shock. (All in Madras time, corrected for errors of clock, parallax and cut off).

Observer*		Capt. Thomas	Mazumdar	Omori
Delhra Dun ...	(*H*)	6^h—11^m—43^s	6^h—11^m—29^s	6^h—11^m—27^s
	(*δ*)	6—11—48	6—11—46	6—11—33
		(*Mean*=6—11—38.)		
Barrackpore ..	(*H*)	6—16—12	6—16—26	6—16—29
	(*δ*)	6—17—5	6—16—50	6—16—55
		(*Mean*=6—16—41)		
Kodaikanal...	(*H*)	6—21—40	6—21—37	6—21—30
	(*δ*)	6—22—4	6—22—36	6—22—30
		(*Mean*=6—22—0)		
Taungoo	(*H*)	6—20—3	6—19—45	6—19—58
	(*δ*)	very faint—not measured		
		(*Mean*=6—19—55)		

These give intervals:—

Dehra Dun—Barrackpore = 5^m—03^s

" —Kodaikanal = 10—22

" —Taungoo = 8—17

* H from HF curve; δ from Decl. curve.

"II. Measurement of time interval between an apex (a) of magnetic disturbance and time of the earthquake shock.*

(i) Absolute time of apex of disturbance (a).

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
9^h—12^m—22^s	9^h—12^m—09^s	9^h—12^m—21^s	9^h—11^m—11^s

Subtracting these values from the time of principal shock we get:—

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—0—41	2—55—35	2—50—21	2—51—17

This gives times for interval:—

Dehra Dun—Barrackpore = 5^m—06^s
" —Kodaikanal = 10—20
" —Taungoo = 9—24

(ii) Direct measurement of time interval.

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—0—30	2—55—22	2—50—17	2—51—3

This gives times for interval:—

Dehra Dun—Barrackpore = 5^m—09^s
" —Kodaikanal = 10—08
" —Taungoo = 9—28

"III. Absolute time of an apex of magnetic disturbance (b).

(i)

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
2—31—46	2—31—40	2—31—45	2—30—35

Subtracting time of principal shock we get:—

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—40—00	3—44—59	3—50—15	3—49—38

The differences are:—

Dehra Dun—Barrackpore = 4^m—59^s
" —Kodaikanal = 10—15
" —Taungoo = 9—38

(ii) Direct measurement of interval from apex (b) to principal shock.

Dehra Dun	Barrackpore	Kodaikanal	Taungoo
3—39—51	3—44—54	3—49—55	3—49—16

* The measurements here given are the means of those made by Capt. Thomas and Mr. Mazumdar separately.

These give the time differences:—

Dehra Dun—Barrackpore = 5^m—03^s
„ — Kodaikanal = 10—04
„ —Taungoo = 9—25.

"IV. Absolute times of disturbances. As found these are

	Disturbance (*b*)		Disturbance (*a*)		Difference (*a*)-(*b*)
Dehra Dun	2—31—46	*mean*	9—12—22	*mean*	6—40—36
Barrackpore	2—31—40	2—31—44	9—12—09	9—12—17	6—40—29
Kodaikanal	2—31—45		9—12—20		6—40—35
Taungoo	2—30—35		9—11—11		6—40—36

Difference, *Mean*—Taungoo = 1^m 08^s

This proves that the disturbances are simultaneous at all observatories within the limits of measurement and that Taungoo time is slow 1^m 08^s while the time at the other three observatories is very good. This conclusion is further borne out by consideration of the interval Dehra Dun-Taungoo by the two methods of measurement.

	Dehra Dun-Taungoo
By direct measurement of time of shock	8^m—17^s
By measurement from magnetic disturbances (which eliminates error of clock)	9^m—27^s

or Taungoo time slow 1^m 10^s

and mean correction to Taungoo + 1^m 09^s

"V. Comparisons of the intervals of time found from Dehra Dun to the other observatories.

Dehra Dun—Barrackpore:—

		mean
(*i*) Direct measurement	5^m—3^s	5^m—04^s
(*ii*) By measurement from disturbances..	5 —5	

Dehra Dun—Kodaikanal:—

(*i*) By direct measurement	10—22	10—18
(*ii*) By measurement from disturbances	10—13	

This shows that the clock times at Dehra Dun, Barrackpore and Kodaikanal are practically correct.

"VI. Final values of time of principal shock. For the reasons shown in V there is no good reason for not accepting the times given for Dehra Dun, Kodaikanal, and Barrackpore; the only correction is then to add 1^m 08^s to the Taungoo time.

The times then become:—

	(Madras Time) (G.M.T.)
Dehra Dun	6—11—38=0—50—38
Barrackpore	6—16—41=0—55—41
Kodaikanal	6—22—00=1—01—00
Taungoo	6—21—03=1—00—03

(iii) *The Probable Time of Earthquake Occurrence at the Origin.* Thus the time of earthquake disturbance as registered by the magnetograph at Dehra Dun was 0^h 50^m 38^s, G.M.T., the approximate distance of that place from the most central part of the epifocal zone being 1° 45′, or 195 km. Within such an epicentral distance, the velocity of propagation of the 1st preliminary tremor is probably 5 or 6 km per sec. If we assume the velocity to be 6 km per sec., the time taken by the seismic waves in travelling the distance of 195 km would be about 32 sec. Now, as the magnetograph is not so sensitive as a seismograph, the time moment recorded at Dehra Dun might correspond to the commencement of the principal portion, the duration of the total preliminary tremor being probably some 20 sec. Thus the time of earthquake occurrence at the epicentre may approximately be taken as 0^h 50^m 38^s minus about 50 sec., or

$$t_0 = \mathbf{0^h 49^m 48^s} \quad \text{(G. M. T.)}$$

10. *Comparison of Magnetic and Seismographic Records.*

(i) According to the Milne horizontal pendulum seismogram at Calcutta, the times of commencement of the 1st preliminary tremor and the principal portion were respectievly 0 52 00^s

and 0^h 55^m 24^s G.M.T. But according to the magnetograph record obtained at Barrackpore, which is not far from the above-mentioned place, the earthquake disturbance began first at $0^h55^m41^s$.

(ii) At Colaba, Bombay, the times of commencement of the 1st preliminary tremor and the principal portion were, according to the "Colaba" seismograph, 0^h 53^m 08^s and 0^h 56^m 39^s, respectively. The times of the earthquake disturbance indicated by the magnetographs were as follows:—

H. F. Magnetograph,	$0^h56^m44^s$
D. „ ,	0 57 14
V. F. „ ,	0 57 14
Mean............	0 57 04

The commencement of the disturbance registered by the barograph was $0^h56^m44^s$, being practically identical with that indicated by the magnetographs.

(iii) The times of commencement of the earthquake motion at Kodaikanal were as follows:—

Milne Hor. Pend.....	Commencement of 1st Prel. Trem.,	$0^h55^m48^s$
	„ Prnic. Port.,	0 59 43
Magnetograph	....	1 01 00

From the preceding comparisons, it will be seen that the disturbances recorded by the different magnetographs were nearly simultaneous with the principal portion in the seismograms.

(iv) The commencement of the disturbance in the Taungoo magnetograph, which happened at 1^h 00^m 03^s, must also evidently be that of the principal portion.

The above magnetograph observations may be divided into two groups, according to the epicentral distances, as follows:—

Group.	Place.	Epicentral Distance.	Time of Commencement.	Time interval required by radial propagation.
A	Barrackpore.	13° 32′	$0^h\ 55^m\ 41^s$	$5^m\ 53^s$
	Bombay.	13 28	0 57 04	7 16
	Mean......	**13 30**	**0 56 23**	**6 35**
B	Kodaikanal.	21° 35′	$1^h\ 01^m\ 00^s$	$11^m\ 12^s$
	Taungoo	21 44	1 00 03	10 15
	Mean......	**21 40**	**1 00 32**	**10 44**

The "direct method" calculation† gives the following values of the transit velocity :—

Group (*A*) ....3.80 km per sec.
Group (*B*) ....3.73 „
Mean.................3.77 „

This approximately corresponds to the transit velocity of the 1st phase of the principal portion. The "difference mothod" calculation† gives :—

velocity=3.65 km per sec.

11. ***Analysis of Seismograms.*** The seismograms which I have analysed were nearly 70 in number, and related to the following 51 stations :—*Tōkyō* (*Hongō*, *Hitotsubashi*, and *Central Meteorological Observatory*) ; *Mizusawa* ; *Ōsaka* ; *Kōbe* ; *Tadotsu* ; *Taihoku* ; *Taichu* ; *Tainan* ; *Dehra Dun**; *Barrackpore**; *Bombay* (*Colaba*) ; *Taungoo**; *Calcutta* (*Alipore*) ; *Kodaikanal* ; *Shanghai* (*Zikawei*) ; *Batavia* ; *Manila* ; *Laibach* ; *Pola* ; *Triest* ; *O'-Gyalla* ; *Florence* (*Ximeniano* ; *Querce* ; and *Quarto Castello*) ; *Ischia* ; *Rocca di Papa* ;

† See the *Bull. Imp. Earthquake Inv. Comm.*, Vol. I, No. 1.

* For those stations marked with *asterisks*, we have only magnetograph records of the earthquake.

Potsdam; *Strassbury*;* *Göttingen*; *Leipzig*; *Upsala*; *Birmingham*; *Shide*; *Kew*; *Liverpool* (*Bidston*); *Edinburgh*; *Paisley*; *San Fernando*; *Mauritius*; *Cape of Good Hope*; *Toronto*; *Victoria, B.C.*; *Baltimore*; *Washington*; *Cheltenham*; *Tacubaya*; *Wellington*; *Christchurch*; *Rio de Janeiro.*

All the analyses have been made on the supposition that the vibrations recorded represent the movements of a particle of the ground, which are either rectilinear or curvilinear, but which can be resolved into horizontal and vertical components, and not the effects due to the tilting or inclination of the ground; that is to say, the range of motion has been obtained in each case by dividing the actual trace on the seismogram by the multiplication ratio of the pointer of the instrument. (See the *Publications*, No. 5.)

The elements of the earthquake motion relating to the following 21 stations, from which I did not get copies of the seismograms, have been taken from various monthly, weekly, and other seismological reports:—*Taschkent*; *Tiflis*; *Achalkalaki*; *Batum*; *Borshom*; *Derbent*; *Schemacha*; *Jurjew*; *Nikolajew*; *Irkutsk*; *Apia* (Samoa); *Vieques* (Porto Rico); *Honolulu*; *Bairut* (Syria); *Ponta Delgada* (Azores); *Belgrade*; *Krakau*; *Jena*; *Hamburg*; *Padova* †; *Messina.*

In the descriptions of the seismograms given in the succeeding chapters, the times are, unless otherwise stated, always given in the Greenwich Mean Civil Time. The symbols $2a$ and T denote respectively the range of motion (double amplitude) and the complete period of seismic vibration; a displacement, which is to be regarded as a single amplitude, being denoted by a.

* The photographic reproduction of the Strassburg registers were too faint, and I was not able to analyse them.

† The copy of the Padova seismogram had unfortunately neither time marking nor scale of magnitude, so that I have taken the elements of motion from the seismological bulletin issued by Prof. Vicentini.

The seismograms obtained at the different stations have been given in Pls. I to XXII of the *Publications*, No. 23.

Chapter II. Open or large time-scale Diagrams of the Kangra Earthquake, furnished by mechanically or photographically registering instruments.

12. ***List of the Seismograms.*** The diagrams described in this chapter are those registered either mechanically or photographically by the different seismographs, whose record-receiver moved at a sufficiently high rate, enabling us to measure the amplitude and period of the individual vibrations. The following is the list of the seismograms which I have examined

(1)	Hongō, Tōkyō	:	EW Component.	
(2)	,, ,,	:	NS ,,	
(3)	,, ,,	:	Vertical ,,	
(4)	Hitotsubashi, ,,	:	EW ,,	
(5)	Hongō, ,,	:	EW ,,	(Tromometer Record).
(6)	Central Met. Observatory, Tokyo	:	EW Component.	(,,).
(7)	Ōsaka	:	EW Component.	
(8)	Kōbe	:	NS ,,	
(9)	Tadotsu	:	EW ,,	
(10)	Taihoku	:	,, ,,	
(11)	Taichu	:	,, ,,	
(12)	Tainan	:	,, ,,	
(13)	O'Gyalla	:	EW and NS Components.	
(14)	Birmingham	:	EW Component.	