pagated along the great circle between Kashgar and Tōkyō on the opposite side of the earth.

Again, at 3. 50. 15 p.m., or 3 h 40 m 42 s after the commencement of the first earthquake, there appeared another group of very slight maximum movements; these were the seismic waves which first reached Tōkyō directly from Turkestan, proceeded further in the same direction, and again reached Tōkyō after passing its antipode, thus travelling once completely round the earth.

§ 36. (k) *Earthquake of Sept. 22, 1902; 10.52.16. a.m.* Total duration = 4 h.

The 1st and 2nd preliminary tremors lasted together 4 m 4 s.

At 1. 52. 39 p.m., or 3 h 0 m 23 s after the commencement of the earthquake, there appeared a group of slight slow movements of an average period of about 19,5 s, which were the same seismic waves propagated along the great circle between the centre of disturbance and Tōkyō through the antipode of the latter.

At 2. 12. 24 p.m., or 19 m 45 s after the commencement of the preceding set of waves, there appeared again a group of very small vibrations, which lasted some 15 m and had an average period of about 19,5 s. These were the seismic waves which were first propagated directly from the origin to Tōkyō and reached the latter a second time after proceeding further in the same direction and passing its antipode.

XIV. Character of Motion of Great Distant Earthquakes.

§ 37. The following discussion of the character of seismic motion is based on the EW component diagrams of the 11 great distant earthquakes, (a), (b), (c).....(j), (k), described in detail in the preceding section.

§ 38. *Amplitude.* The max. 2a in the successive portions of the earthquake motion are given in Table XXXIII, from which we

obtain the following mean relative magnitudes of the different maxima :—

Max. 2a in the	1st	preliminary	tremor	= 100,
„ „	2nd	„	„	= 560,
„ „	1st	phase of princ.	portion	= 550,
„ „	2nd	„	„	=1820,
„ „	3rd	„	„	=1220,
„ „	4th	„	„	= 840,
„ „	5th	„	„	= 560,
„ „	6th	„	„	= 430,
„ „	7th	„	„	=——.

Thus, the motion in the 1st preliminary tremor is much smaller than in other epochs of the earthquake; while the motion in the 2nd preliminary tremor is practically equal to that in the 1st phase of the principal portion. The amplitude is greatest in the 2nd and the 3rd phases of the latter portion, becoming gradually smaller in the three subsequent phases. (See also § 8.)

According to § 47, the movements in the 3rd phase of the principal portion would be the *longitudinal* motion, while those in the 6th phase would correspond to the transverse motion. The relative values of the maximum 2a in these two phases are respectively 1220 and 430, which are nearly in the ratio of 3 : 1.

TABLE XXXIII.

MAXIMUM RANGES (DOUBLE AMPLITUDES) IN THE SUCCESSIVE STAGES OF MOTION OF THE DISTANT GREAT EARTHQUAKES.

Eqke.	1st prel. tremor.	2nd prel. tremor.	Principal Portion.						
			1st phase.	2nd phase.	3rd phase.	4th phase.	5th phase.	6th phase.	7th phase.
	mm	mm	mm	mm	mm	mm	mm	mm	mm
a	0,25	4,1	5,6	15,2	11,1	5,0	3,0	1,7	—
b	0,35	3,4	2,3	10,5	3,2	2,1	0,9	0,8	—
c	0,06	0,1	0,1	0,10	0,9	0,2	—	—	—
e	0,06	0,08	0,08	0,13	0,13	—	—	—	—
f	0,13	0,28	0,50	1,00	2,20	1,00	0,63	0,35	—
g	0,54	1,78	1,43	4,30	1,50	1,43	0,78	—	—
h	0,11	0,38	0,25	2,10	1,04	—	—	—	—
i	0,65	1,20	0,70	2,80	0,63	0,44	0,31	—	—
j	0,22	2,10	0,87	3,00	5,70	4,00	2,50	1,25	0,62
Mean.	**0,24**	**1,35**	**1,32**	**4,36**	**2,93**	**2,02**	**1,35**	**1,03**	—

§ 39. *Period.* Table XXXIV gives the periods in the successive stages of the earthquake motion, while Table XXXV gives the mean results deduced from the different earthquakes contained in the former. The general average values, $P_1P_2 \ldots\ldots P_8$ of the various periods are indicated in the last column of Table XXXV, the figures within brackets indicating the numbers of the cases from which the respective values of the periods have been deduced.

From Table XXXV, it will be seen that the 1st phase of the principal portion is characterized by slow movements of P_6, P_7, and P_7' types, or those whose average periods are respectively 34,4; 42,9; and 54,0 sec. The 2nd phase is also characterized by slow undulations, the one most frequently occurring being those of P_6 type, whose period is 34,4 sec. In the 3rd phase, the P_5 period (=24,6 sec.) occurs very often; while in each of the three succeding phases

the P_3 period (=14,5 sec.) occurs more frequently than the other period. The P_2 period occurs very often in the 1st and the 2nd preliminary tremors and in the end portion.

It is hereby to be noted that slow periods of 30 to 40 seconds occurred sometimes in the 1st and the 2nd preliminary tremors, while quick periods of some 3 or 7 seconds occurred in the 1st phase of the principal portion.

TABLE XXXIV.

PERIODS OF VIBRATION IN THE DIFFERENT PORTIONS OF THE EARTHQUAKES.

Eqke.	1st prel. tremor.	2nd prel. tremor.	Principal portion.						End portion.
			1st. phase.	2nd phase.	3rd phase.	4th phase.	5th phase.	6th phase.	
	s	s	s	s	s	s	s	s	s
a	3,5 7,9 18,0	7,9 25,2	34,5 66,0	32,6	23,5	14,9	13,8	13,4 25,0	9,7 10,3 20,6
b	4,3 9,3	5,8 24,4	44,5	32,5 37,0	20,7	14,9	13,4	14,4	9,8
c	6,0 8,7	10,5	—	11,8 29,0 41,4	18,3 24,3	13,4	—	—	13,9
d	7,2	7,1 13,0	—	7,7 34,8	20,1 24,1	13,4 16,0	12,3	—	10,9
e	5,3 14,1	7,3 15,3	—	14,1 32,7	10,1 21,0	15,2	15,8	—	15,8
f	4,2 8,6	3,8 7,7 15,2	35,1	26,7	22,4	10,0	8,5 15,7	8,1 14,6	9,7
g	1,5 3,7 14,2	7,8 19,6 24,8	7,5 44,7	28,6 35,7	21,4	18,2	14,6 25,0	—	9,2 22,0
h	7,4 14,0	7,8 15,6 32,6	2,9 10,0 56,0	10,3 25,8 31,2 45,4	21,9	—	—	—	18,0
i	6,9 9,2 14,7 40,3	8,6 28,1	7,3 38,7	26,7 33,3	20,1 34,3	21,6	—	—	18,7
j	3,3 7,1 12,3	9,2 16,0	52,0	41,3	18,0	11,6	10,4	15,7	13,1

TABLE XXXV.

PERIODS OF VIBRATION IN THE DIFFERENT PORTIONS OF THE EARTHQUAKES. *(Continued.)*

(Mean values.)

1st. prel. tremor.	2nd prel. tremor.	Principal Portion. 1st phase.	2nd phase.	3rd phase.	4th phase.	5th phase.	6th phase.	End portion.	Mean.*
sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.	sec.
1,5 (1)	—	—	—	—	—	—	—	—	1,5 (1) = —
4,1 (6)	4,8 (2)	2,9(1)	—	—	—	—	—	—	4,1 (9) = P_1
7,8(10)	**8,2** (9)	8,7(2)	9,9(3)	10,1(1)	**11,7**(3)	9,5(2)	8,1(1)	**9,9**(6)	**8,9**(37) = P_2
13,9 (5)	**15,0** (5)	—	14,1(1)	—	**14,9**(5)	**14,3**(6)	**14,5**(4)	**14,3**(3)	**14,5**(29) = P_3
18,0 (1)	19,6 (1)	—	—	**20,4**(9)	19,9(2)	—	—	**19,8**(4)	**20,0**(17) = P_4
—	24,8 (3)	—	—	**24,0**(3)	—	25,0(1)	25,0(1)	—	24,6 (8) = P_5
—	30,4 (2)	—	**27,4**(5)	—	—	—	—	—	28,3 (7) = P_5'
—	—	**36,1**(3)	**33,7**(8)	34,3(1)	—	—	—	—	34,4 (12) = P_6
40,3 (1)	—	44,6(2)	42,7(3)	—	—	—	—	—	42,9 (6) = P_7
—	—	54,0(2)	—	—	—	—	—	—	54,0 (2) = P_7'
—	—	66,0(1)	—	—	—	—	—	—	66,0 (1) = P_8

§ 40. *Duration.* The durations of the different stages of the seismic motion are given in Table XXXVI, from which it will be seen that the successive intervals are *roughly* equal to one another;* the 1st and the 2nd phases of the principal portion being taken together. The durations of the two latter phases are in the ratio of 1 : 1,6.

The relative lengths of the durations of the successive epochs are as follows:—

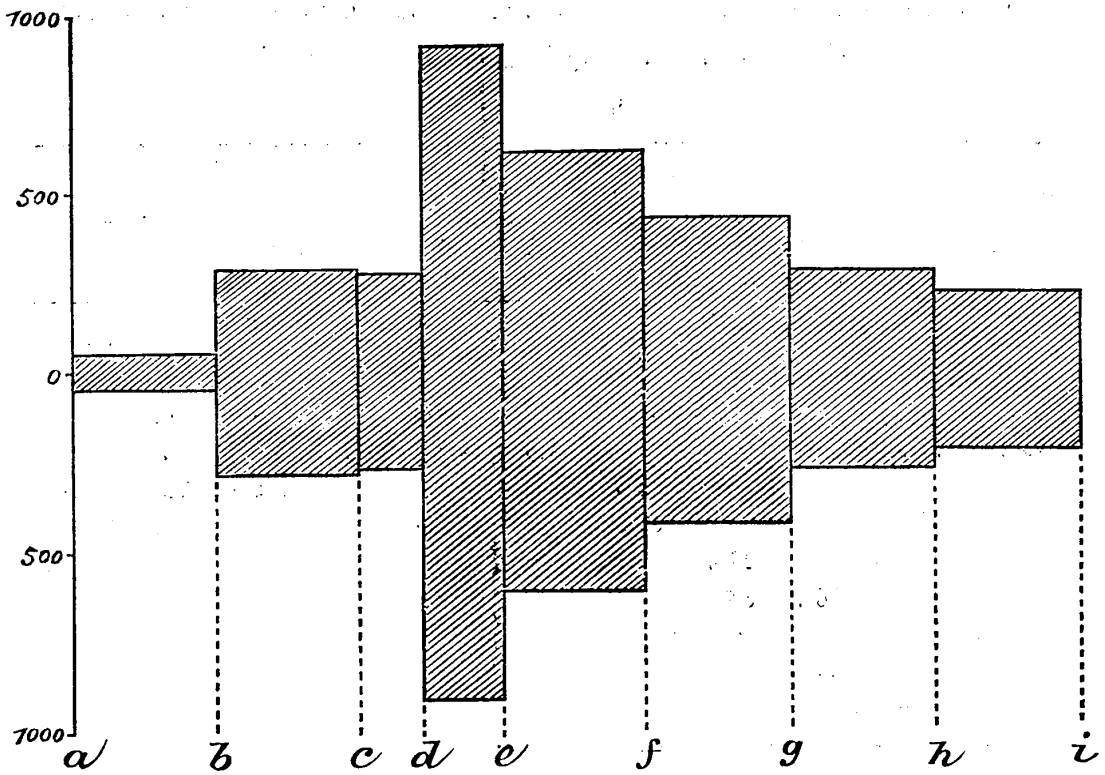
100 : 95 : (30+49) : 91 : 95 : 95 : 88
1st p.t. 2nd p.t. 1st ph. 2nd ph. 3rd ph. 4th ph. 5th ph. 6th ph.
Principal portion

The character of motion of great distant earthquakes is diagrammatically illustrated in Fig. 7.

* The notations P_1P_2.....are the same are those employed in § 5, with the exception of P_5' and P_7', which have here been introduced.

Fig. 7.

Diagram showing the relative magnitudes of vibration in the successive stages of motion of distant great earthquakes.



ab....1st Prel. Tremor.		*ef*....3rd phase of Princ. Portion.	
bc....2nd „	„	*fy*....4th „	„
cd....1st phase of Princ. Portion.		*gh*....5th „	„
de....2nd „	„ „	*hi*....6th „	„

(The range of motion in the 1st prel. tremor is taken as 100.)

TABLE XXXVI.

DURATIONS OF THE SUCCESSIVE STAGES OF MOTION OF THE GREAT DISTANT EARTHQUAKES.

Eqke.	1st prel. tremor.	2nd prel. tremor.	Principal Portion. 1st phase.	2nd phase.	3rd phase.	4th phase.	5th phase.	6th phase.	7th phase.
	m s	m s	m s	m s	m s	m s	m s	m s	m s
a	7. 36	6. 47	2. 35	3. 48	4. 42	5. 28	7. 20	—	—
b	7. 43	6. 30	1. 29	3. 21	8. 48	8. 42	7. 48	8. 09	—
c	10. 19	12. 00	(12 m	0 s)	11. 45	8. 23	—	—	—
e	10. 40	11. 00	(15	54)	14. 13	—	—	—	—
	m s	m s	m s	m s					
f	4. 32	4. 32	1. 46	2. 00	2. 14	8. 34	8. 50	9. 40	—
g	7. 22	5. 05	(4 m	05 s)	6. 14	6. 40	13. 15	—	—
	m s	m s	m s	m s					
h	16. 55	15. 36	2. 49	12. 13	13. 21	—	—	—	—
i	15. 40	14. 40	7. 04	4. 13	13. 34	17. 58	—	—	—
j	6. 44	6. 46	1. 41	3. 14	4. 48	6. 00	9. 10	7. 50	9. 15
Mean	**9. 43**	**9. 13**	**2. 55**	**4. 48** (8 42)	**8. 50**	**9. 11**	**9. 11**	**8. 33**	—

§ 41. *The transit velocities.* Let us denote by v_1, v_2, v_3, ... v_8 the transit velocities of the waves of the successive stages of the earthquake motion, namely, the two preliminary tremors and the six different phases of the principal portion. Further, let x denote the distance along the great circle between the earthquake origin and the place of observation; t the time interval required by the waves of the 1st preliminary tremor in traversing the distance x; and y_1 y_2 y_3 . . y_8 the durations of the successive stages of the motion. We then obtain, by supposing $y_1=y_2=y_3+y_4=y_5=y_6=y_7$, the following relations:—

$$\frac{1}{v_1}=\frac{t}{x};$$

$$\frac{1}{v_2}=\frac{t}{x}+\frac{y_1}{x}=\frac{1}{v_1}+\frac{y_1}{x};$$

$$\frac{1}{v_3}=\frac{t}{x}+\frac{y_1+y_2}{x}\doteqdot\frac{1}{v_1}+\frac{2y_1}{x}\text{ ; etc. ;}$$

where, according to § 54, $v_1=14{,}1\frac{\text{km}}{\text{sec.}}$

Now according to Table XXXVI, the mean value of the total duration of the 1st and the 2nd preliminary tremors is 18 m 56 s, which corresponds, in virtue of equation (1), to $x=8150$ km. Hence, we obtain the following *approximate* results:*—

$$\begin{aligned} v_1 &= 14{,}1\frac{\text{km}}{\text{sec.}},\\ v_2 &= 7{,}1 \;\;,,\;\;,\\ v_3 &= 4{,}7 \;\;,,\;\;,\\ v_4 &= (?) \;\;,,\;\;,\\ v_5 &= 3{,}5 \;\;,,\;\;,\\ v_6 &= 2{,}8 \;\;,,\;\;,\\ v_7 &= 2{,}3 \;\;,,\;\;,\\ v_8 &= 2{,}0 \;\;,,\;\;. \end{aligned}$$

§ 42. *Lengths of the seismic waves.* The length (λ) of the waves constituting the motion of great distant earthquakes must be generally large. Thus, taking as examples the predominating vibrations in the 1st and 3rd phases of the principal portion, we find, according to §§ 39 and 41,

1st phase of princ. portion, ... $\lambda=4{,}7^{\text{km}}\times 36{,}1^{\text{sec.}}=170^{\text{km}}$;

3rd „ „ „ , ... $\lambda=3{,}3^{\text{km}}\times 20{,}4^{\text{sec.}}=67^{\text{km}}$.

From these calculations it is evident that the slow period earthquake movements are not modified by the nature of the ground.

§ 43. *Paths of the different seismic waves.* In the *Publications*, No. 5, I have stated the view that the disturbances with the transit velocity v_1 probably travels parallel to the earth's surface at some constant depth. The consideration on the prevailing periods in the 1st preliminary tremor (§ 23) seems also to favour this supposition. The layer, along which these high velocity waves are propagated

* These calculations are an extension of similar ones given in the *Publications*, No. 5.

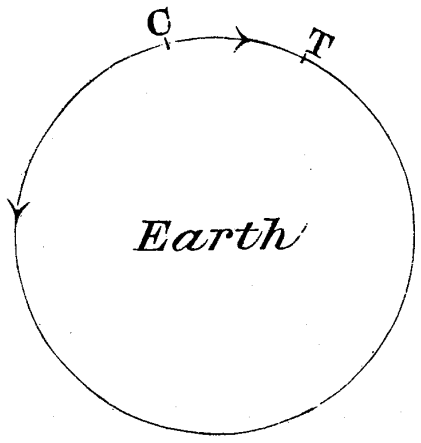
may be, as Professor H. Nagaoka suggests, one of the maximum transit velocity; or may mark the limit beyond which the seismic waves are, on account of certain physical properties of the underlying medium, unable to penetrate. Further, the consideration on the transit velocity of the Caracas earthquake of 1900 (§ 55) seems to indicate that, the waves with the transit velocity v_2 also travel along a layer parallel to the surface of the earth.

That the waves with the transit velocity v_5, or those in the 3rd phase of the principal portion, travel along the surface of the earth is perfectly evident. (See also § 46.)

XV. Propagation of Seismic Waves completely round the Earth.

§ 44. Let T (Fig. 9) be the observing station (Tōkyō), and C the earthquake origin. Then there are three sets of motion, which

Fig. 8.



we may call respectively W_1, W_2, and W_3 waves, as follows:—*firstly*, the W_1 waves are those propagated from C to T along the shortest *surface* path; *secondly*, the W_2 waves are those propagated from C in the opposite direction and reach T after passing through the antipode of C; and *thirdly*, the W_3 waves are the W_1 waves propagated further in the same direction, beyond T, and again reach