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A Duplex Horizontal Pendulum Apparatus.[1]

By

F. Omori, *Rigakushi, Rigakuhakushi,*
Member of the Imperial Earthquake Investigation Committee.

With Plates I and II.

The duplex horizontal pendulum apparatus, which is shown in fig. 2, Pl. I, is an improved form of the mechanically registering seismograph, which I have used for some years[2]; the modification consisting in the introduction of the principle of the duplex pendulum of Professors Gray, Ewing and Milne. The essential part of the instrument, which is shown in the accompanying figure, is made up of a heavy flat cylinder *c* (fig. 1) of brass filled with lead, about 16 kg in weight, suspended from the top, *a*, of a strong cast iron stand *af*, which is bolted at *f* to the foundation stone, *fe*; the strut *db* being pivoted at *b*. The pendulum *c*, which is first brought very nearly to a state of neutral equilibrium, is to be further adjusted by means of an inverted pendulum *ge*. The mechanical details of the latter as well as the recording arrangement are shown in Pl. II.

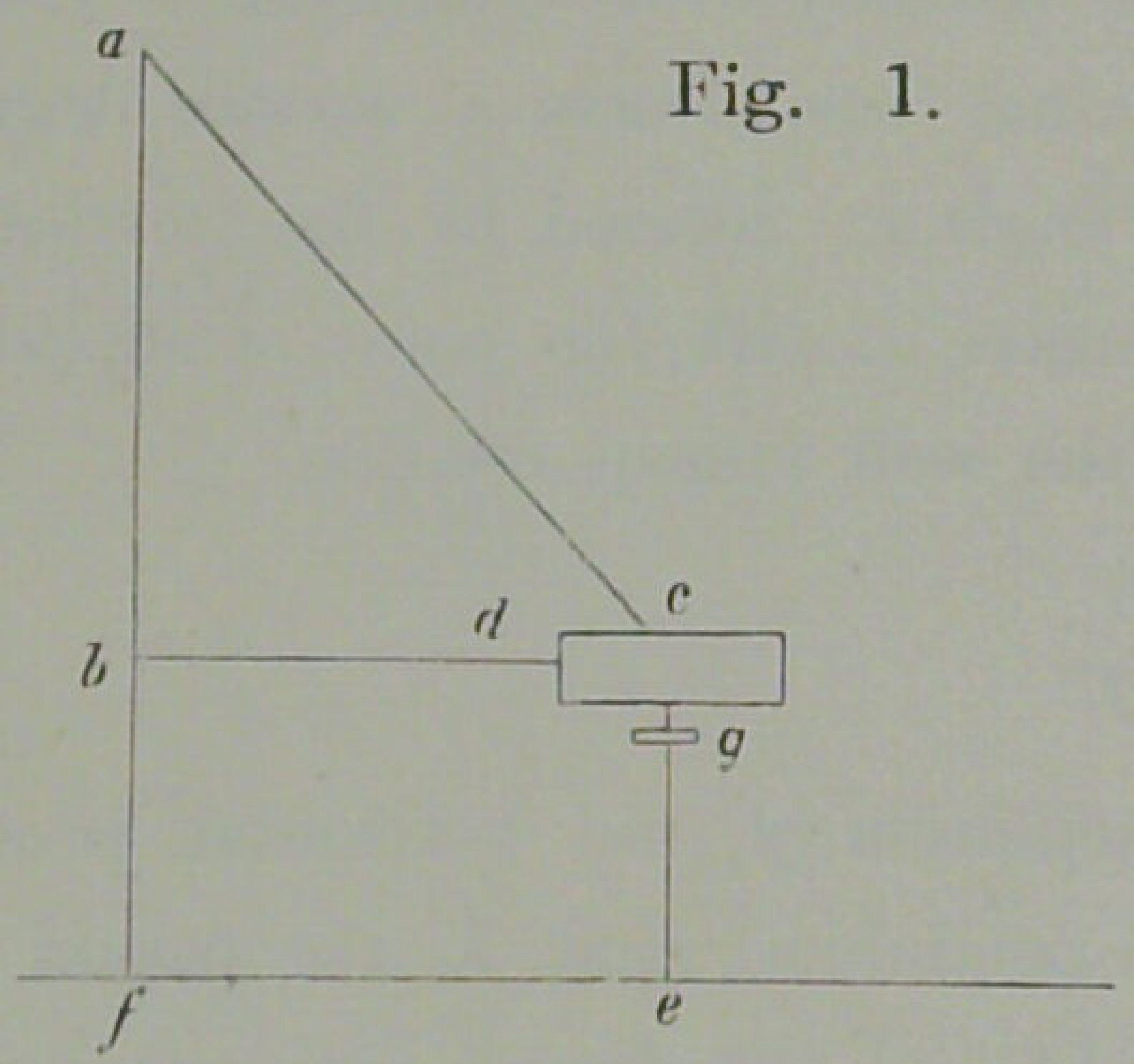

Fig. 1.

Pl. II. The auxiliary inverted pendulum consists of a light alu-

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[1] A short preliminary description of this instrument has been given in Tokyo Sugaku-Butsuri Gakkwai Kiji Gaiyō, Vol. II, No. 8, Jan., 1904.

[2] See the *Publications*, No. 5.

minium tube *eg*, about 30 cm in length, carrying a small metallic disc *g*, about 0·017 kg in weight, put very closely to the heavy bob *c*. The upper end of the tube *eg* is furnished with a brass fork, between whose two limbs fits exactly a highly polished steel axis *h*, about 2 mm in diameter and 3 cm in length, pivoted between two small supports, *ii*, attached to the lower face of the heavy cylinder *c*; the axis *h* being parallel to the strut. The lower end of the tube *eg* is furnished with two foot-screws, *jj*, which fit respectively in a conical socket and in a V-groove, mounted on a base plate *k*. The line formed by joining the apex of the socket and the vertex of the V-groove is to be brought exactly below and parallel to the axis *h*, by means of the screws *l*, *l*, *m*, which move the plate *k* in two rectangular horizontal directions.

It will thus be seen that the inverted pendulum *eg* can rotate only about a line parallel to the equilibrium position of the strut, its upper part being joined to the heavy weight in such a way that the friction at the point of contact is reduced to a minimum. Now, the equilibrium of a horizontal pendulum has always a certain degree of stability, which depends on the angle φ, formed by the vertical and the line joining the point of suspension, *a*, with the point of support, *b*; this angle being determined by the well known relation

$$\varphi = \frac{T_0^2}{T^2},$$

in which T is the period of oscillation of the horizontal pendulum (when not joined to the inverted pendulum), and T_0 the period when the system formed by the strut *bd* and the heavy bob *c* is made to swing as an ordinary vertical pendulum. If W and w denote respectively the weights of the heavy bob *c* and the small disc *g*, we have, for making neutral the equilibrium of the horizontal pendulum, the following relation :—

$$w = W \times \frac{H.\varphi}{L},$$

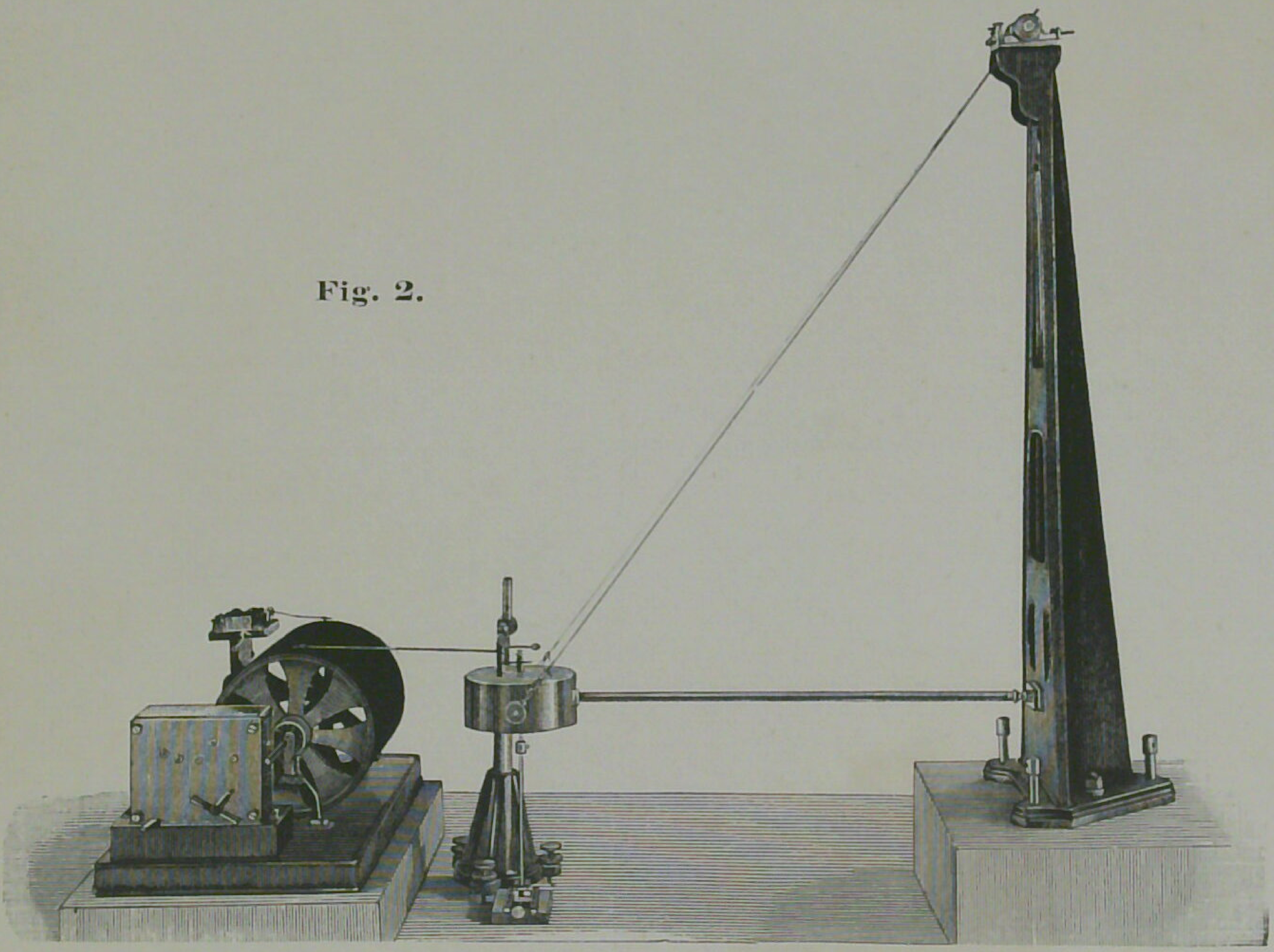
in which L is the length between the centre of the heavy bob *c* and the point of support *b*, and H is the height of the inverted pendulum *e.g.* To take an example, let $W=15$ kg, $L=100$ cm, $H=30$ cm, and $\varphi=\dfrac{2\times 2}{30\times 30}$; we then find $w=0{\cdot}02$ kg.

The mechanism at the top, *a*, of the cast iron stand, the multiplying pointer, and the record-receiver whose details will be seen from figs. 3 and 4, Pl. I, and from Pl. II, are exactly similar to those in the older instruments. With a portable instrument of this description, in which the length *bc* and the height *ab* is each equal to 1 metre, the complete period of free oscillation of the steady mass can be raised without much difficulty to 1 minute, the multiplication of the recording pointer being 20 to 30.

Tokyo. June, 1904.

Duplex Horizontal Pendulum Apparatus.

Fig. 2.



Pl. I.

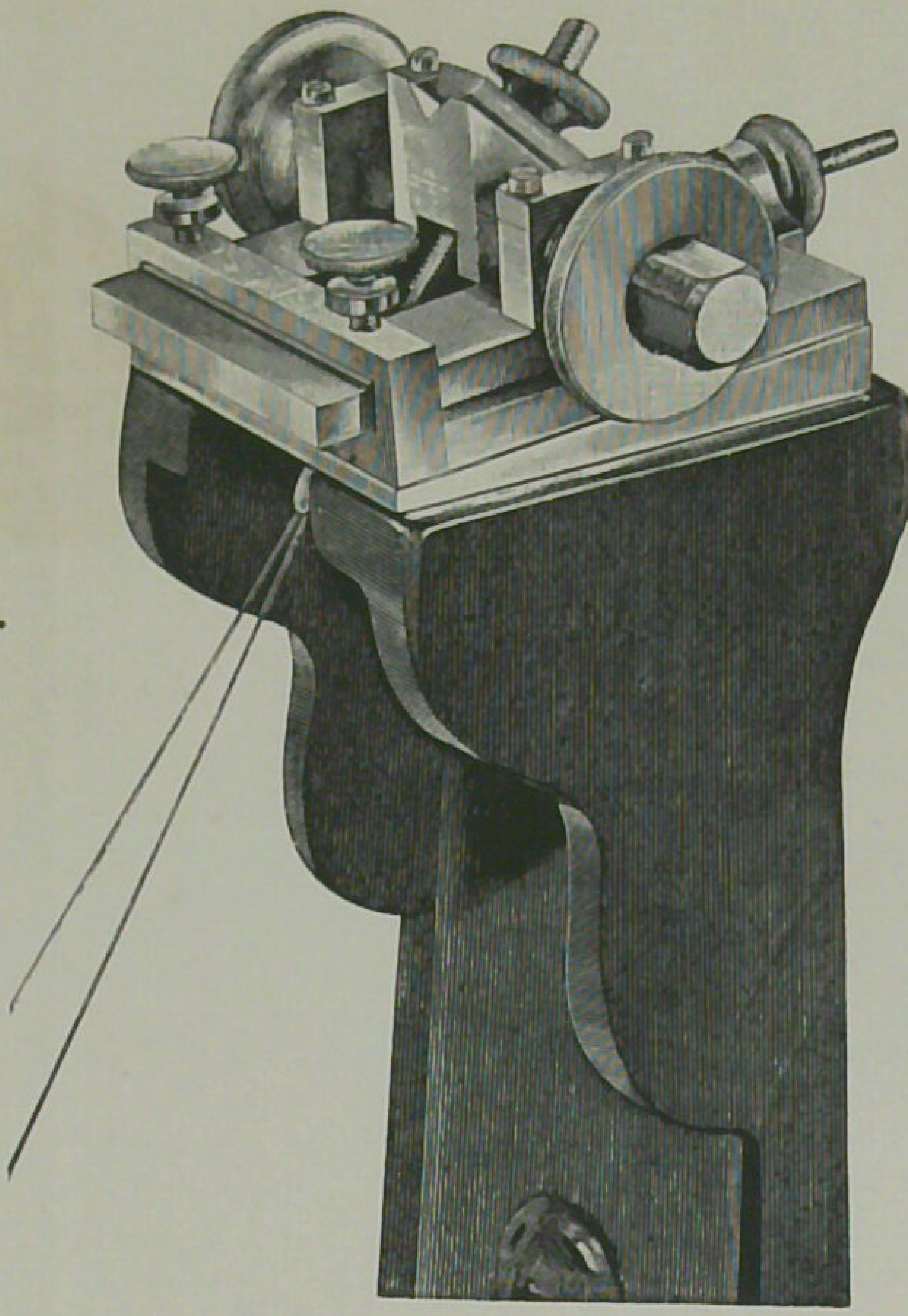
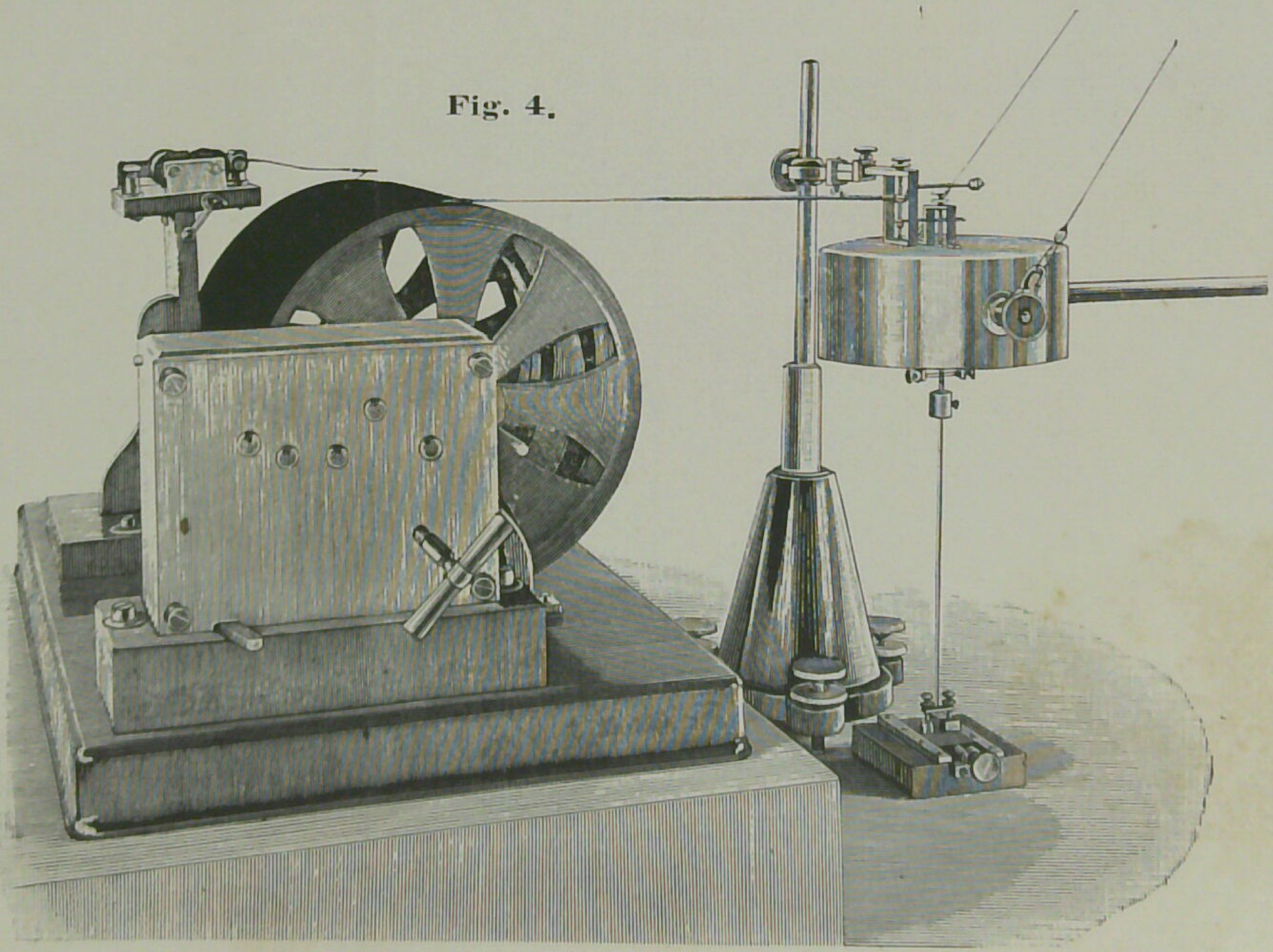


Fig. 3.

Fig. 4.



A Horizontal Tremor Recorder.

By

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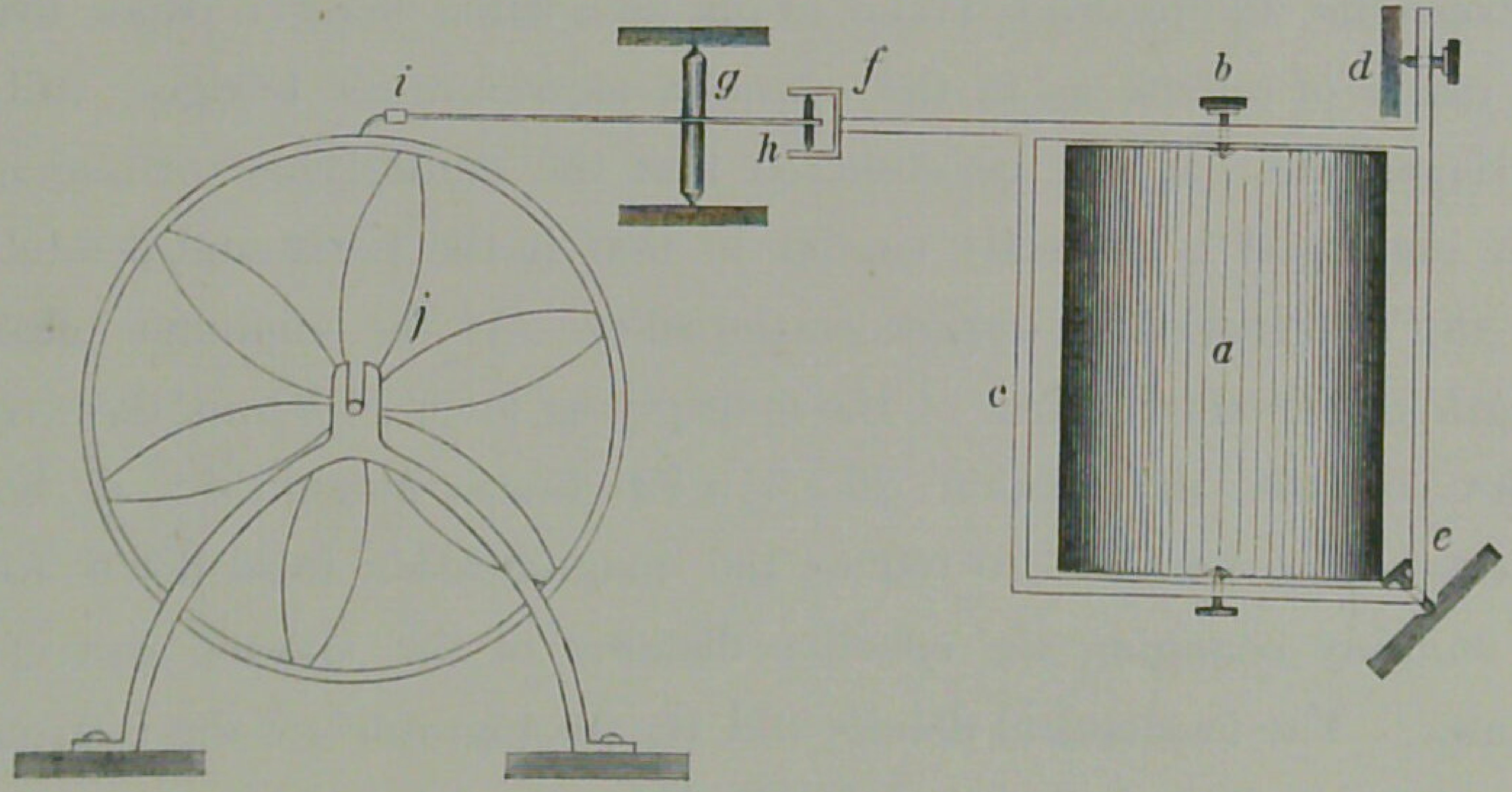
With Plates III and IV.

1. The Metropolitan Police had recently to consider several cases of complaints respecting the disturbances caused by steam engines, dynamos, etc. to neighbouring buildings; and the instrument which I am going to describe in the following pages has been constructed to measure the horizontal movement due to the above mentioned causes.

Fig. 1.



2. The essential part of the instrument, which is diagramatically shown in fig. 1, consists of a vertical brass cylinder, *a*, 16 cm in height and 10 cm in diameter, filled with lead, and about 15 kg in weight, pivoted in a strong iron frame *bc*, the latter being supported by means

of two screw points *d* and *e* from a strong brass stand, about 20 cm in height and furnished with three levelling screws exactly in the same way as in Prof. Ewing's horizontal pendulum. The distance between the pendulum axis and the centre of the heavy cylinder, or the steady point, is 6 cm; while there is attached to the iron frame in way of prolongation a stout aluminium rod *bf*, whose length is 15 cm. The horizontal motion, whose direction is normal to the pendulum plane, will thus be magnified 3½ times at the end of the aluminium prolongtion. There is, however, an independent multiplying pointer, consisting of a vertical axis, *g*, which is pivoted in an inverted bracket properly attached to an upright support, and which carries a horizontal light lever *hgi*. The shorter arm of the latter consist of a thin brass piece formed into a fork between whose two limbs fits exactly a highly polished axis of steel, *h*, pivoted in a small bracket attached to the end of the strong aluminium prologation before mentioned. The longer arm of the lever consists of a tapering tube of aluminium, 120 mm in length, at whose end, *i*, is hinged an index which writes on a smoked paper wrapped round a drum, *j*, driven by a clock work. In other instruments, the record is taken in ink on a white band of paper driven by means of rollers, as in the *vibration measurers* for bridges, railway carriages, etc. It will be observed that the multiplying arrangement here employed is perfectly similar to that in the horizontal pendulums for the observation of distant earthquakes. As the minimum effective length of the shorter arm of the multiplying lever is 6 mm, the writing index records the motion $20 \times 3\frac{1}{2} = 70$ times magnified; it being, however, also possible to reduce the magnification ratio down to 10, by suitably changing the effective distance of the shorter arm of the pointer. The mechanical details and the photograph* of the instrument are given in figs. 2, 3, 4 and 5, Pl. III.

For the complete observation of the horizontal motion, we require,

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* The photograph represents an instrument which is slightly different from that whose mechanical details are given in the Plate, the record being taken on a smoked paper.

of course, a pair of these instruments, with their pendulum planes at right angles to one another.

The horizontal tremor recorder has already been used in a few cases, of which the following are examples.

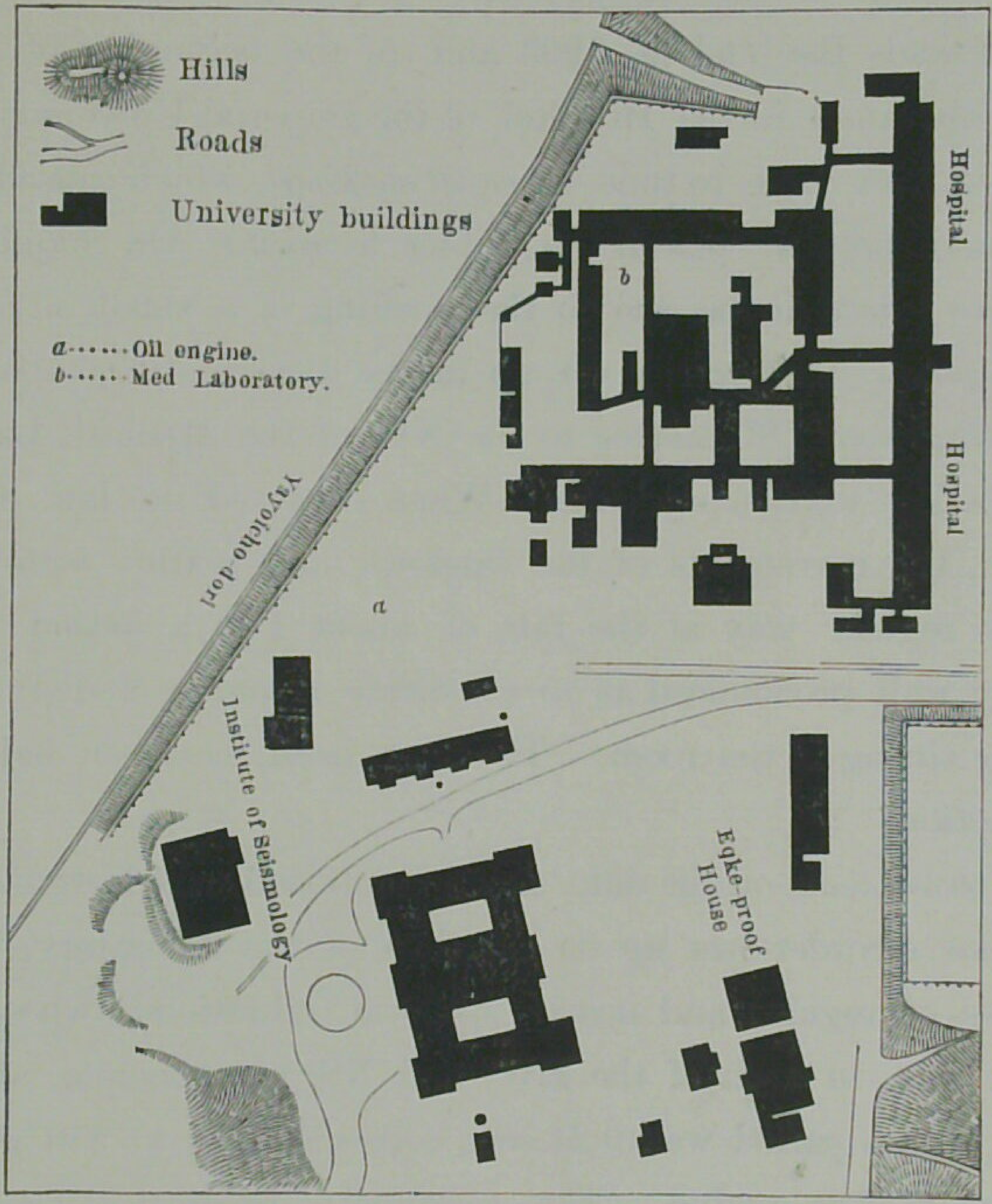
3. *Shakings in the Hospital of the Tōkyō Imperial University, Hongō.* Towads the end of 1903 and in the beginning of 1904, the Medical Laboratory in the Hospital of the Imperial University, Hongō, was subject from time to time to *unfelt shakings,* which caused windows to rattle and bottles placed on tables to rock. On inquiry, these effects were traced to be due to the working of a small oil engine of 10 horse power, temporarily set up in the University compound; the engine being about 87 metres to the NW of the Medical Laboratory, which is a low wooden structure. When observed on Jan. 8th, 1904, at 10 am., the movements of the windows and bottles were executed in a quite regular way at the rate of about 4 in a second and were sufficiently well pronounced as to constitute a source of disturbance to the people sitting in the room. The floor itself, however, indicated no *sensible* motion.

The movements on the date above mentioned, which were measured by a tremor recorder set up on the floor of the laboratory, consisted of a series of regular and nearly uniform vibrations, whose double amplitude was, in each of the EW and NS components, about 0·02 mm, and whose period was 0·24 sec., corresponding to 250 revolutions per minute of the engine. The absolutely greatest movements in the EW and NS components were respectively 0·028 and 0·034 mm.

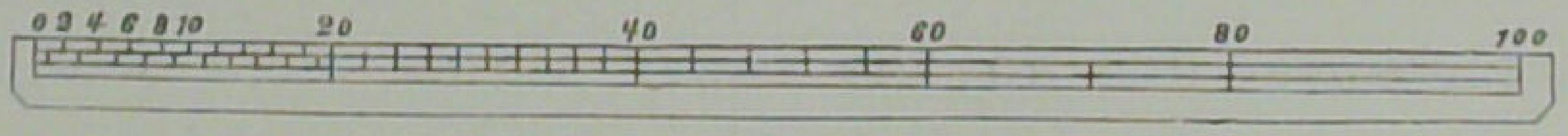
The disturbances due to the same source were simultaneously measured in the brick Earthquake-proof House, which is situated at a distance of about 110 metres to the south-west of the oil-engine. The movements there measured, on the solid concrete basement, were much smaller than in the Medical Laboratory, and consisted of a series of maximum groups, the absolutely greatest double-amplitude in the NS direction being 0·026 mm. The period was 0·24 sec.

The positions of the oil engine, the Medical Laboratory, and the Earthquake-proof House, are indicated in the accompanying plan of a part of the University compound.

Fig. 6. Plan of a part of the Tōkyō Imperial University compound.

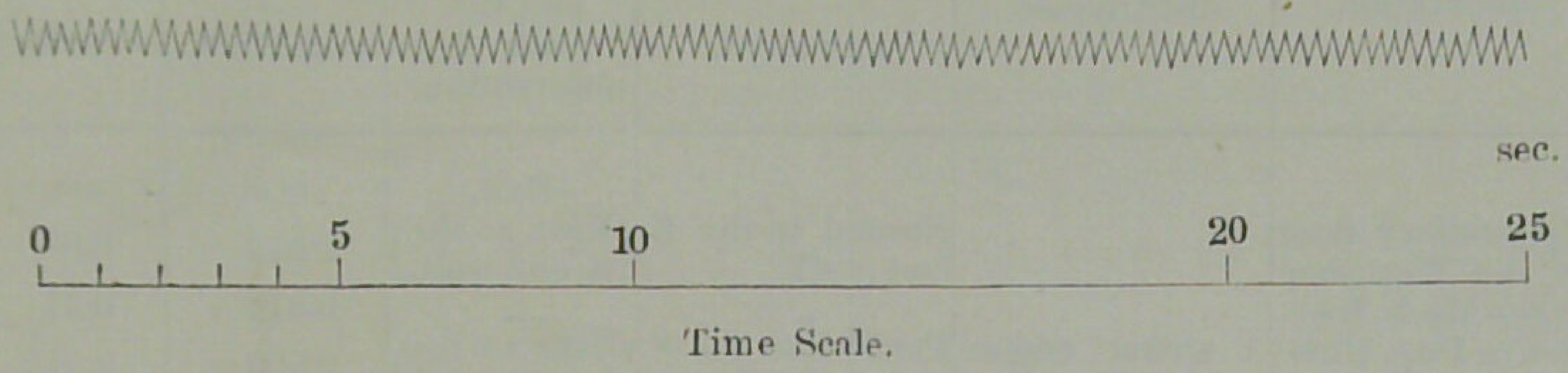


Scale of Ken (1 Ken = about six feet)



4. *Movement in the Seismological Institute.* On May 19th, 1904, the effects of the oil engine mentioned in the preceding § were very markedly indicated in the Seismological Institute, which is a one-storied wooden building. Fig. 7 is a part of the NS component diagram obtained on the above date by means of a horizontal tremor recorder set up on a solid brick column in one of the instruments rooms, whose

Fig. 7. Vibration caused by an Oil Engine.
NS component. Multiplication = 29.



distance from the engine was about 70 metres: the positions of the Institute being shown in the map (fig. 6). The max. double amplitude was 0·09 mm and the period was 0·227 sec., corresponding to 265 revolutions per minute ot the engine. The movements were perceptible and sufficiently intense to produce considerable amount of the rattling of the windows.

5. *Miscellaneous experiments.* (Pl. IV.) Fig. 8 and 9 are parts of the diagrams of the longitudinal motion of the ground at the distances respectively of about 17 and 60 feet from a small oil engine of the workshop of the Physical Institute. Again, figs. 10 and 11 represent the normal vibrations respectively of the eastern and southern up-stair walls of the workshop of the Mechanical Institute of the Engineering College due to the working of a small steam engine which is situated close to the southern wall.

The following table gives the results of the measurements made in 1903.

Place of observation.	Cause of disturbance.	Direction of the motion measured.	Distance between the origin of disturbance and the place of observation.	Max. double-amplitude.	Period of vibration.
			Feet.	mm	sec.
Upper-story floor of the Workshop of the Mech. Inst., Tokyo Imp. Univ.	A steam engine in the Workshop of the Mech. Inst., Tokyo Imp. Univ.	Normal to the E. end wall.	(Near to the E. end wall.)	0.018	0.09
		,,	,,	0.016	0.17
		Parallel to the S. nd wall.	(Near to the S. end wall.)	0.050	0.043
		,,	,,	0.016	0.097
Ground floor of the same Workshop.		Parallel to the piston of the engine.	18	0.015	0.071
Ground surface.	An oil-engine in the Workshop of the Physical Inst., Tokyo Imp. Univ.	45° to the direction of the piston.	90	0.02	0.10
		At right angles to the direction of the piston.	60	0.03	0.12
		45° to the direction of the piston.	9	0.17	0.25
Ground surface.	An engine in a crucible factory, at Shiba, Tokyo.	Parallel to the direction of the piston.	18	0.02 0.007	0.23 0.058
		At right angles to the direction of the piston.	,,	0.012	0.20
,,		——	48	0.007	0.087
,,		Parallel to the direction of the piston.	170	Very slight.	—
,,		Parallel to the direction.	78	0.018	0.12
,,		Normal to the direction of the piston.	,,	0.01	0.18
On the floor of a one-storied wooden house.		Normal to the direction of the piston.	60	0.018 0.022	0.24 0.086
		Parallel to the direction of the piston.	,,	0.02	0.23

From the above table, it will be seen that the movements measured were usually very small and amounted, at a distance of a few dozen metres from the origin of disturbance, to only a few hundredths of a mm; it being extremely rare that the double amplitude reaches some tenths of a mm. The period varied between 0·058 and 0·25 sec.

It is to be remarked that the motion of a wall (or house) is, for evident reasons, generally much greater than that of the ground on which it stands. Thus in the case of the Workshop of the Mechanical Institute of Tokyo Imperial University, the normal motion of one of the upper story walls amounted to 0·05 mm (period = 0·043 sec.), while that on the ground at a distance of 18 feet from the engine was 0·015 mm (period = 0·071 sec.). Similarly in cases of actual earthquakes, buildings generally act more or less as a kind of seismoscope, being sometimes thrown into vibrations many times larger than the motion of the ground.1)

6. *Sensible limit of small motion.* For practical purposes, it is desirable to fix the sensible limit of small motion in the disturbances of artificial origins. This is, however, a difficult problem, since the limit in question would be widely different for different persons. The following result is to be regarded only as a provisionary one.

From the study of the macro-seismographic diagrams obtained in Tokyo, the least value of the intensity, or maximum acceleration ($=\alpha$), of the sensible earthquake motion seems to be about 17 mm per sec. per sec. Denoting by T and 2a respectively the period and the double amplitude of a motion of sensible limit, we have

$$\alpha=\frac{2\pi^2\times 2\mathrm{a}}{T^2}\,, \quad \text{or} \quad 2\mathrm{a}=\left(\frac{\alpha}{2\pi^2}\right)\times T^2=0\cdot86\times T^2,$$

which latter equation gives the range of motion corresponding to a specified value of the period T. The figures contained in the following table have been calculated according to the above formula.

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1) See Prof. Milne: "Seismic Survey," Trans. Seism. Soc., Vol. X; and F. Omori: "Earthquake Measurement in a brick building," and "Motion of a Brick Wall produced by earthquakes," the Publ. of the Earthq. Inv. Com., Nos. 4 and 12.

T	2a	*T*	2a
sec.	mm.	sec.	mm.
0.10	0.009	0.043	0.0016
0.11		:	:
0.12	0.012	:	:
:	:	0.07	0.004
:	:	0.08	0.006
0.20	0.034	0.09	0.007
0.21	0.038		
0.22	0.042		
0.23	0.046		
0.24	0.050		
0.25	0.054		

Thus it will be observed that, with periods of 0·10 and 0·20 sec., the motion will become sensible respectively at ranges of about 0·01 and 0·03 mm. It is hereby to be noted that the quantities *a*, 2a and *T* relate all to the motion of the *ground*, which will be just strong enough to be felt by people sitting in wooden houses.

Tokyo. June, 1904.

Note on the Relation between Earthquakes and Changes in Latitude.

By

F. Omori, *Rigakushi, Rigakuhakushi,*
Member of the Imperial Earthquake Investigation Committee.

With Plates V and VI.

1. *Introduction.* The relation between earthquakes and changes in latitude is one of the subjects whose investigation was undertaken by the Imperial Earthquake Investigation Committee,[1] which instituted in 1895 the observation of latitude variation in Tokyo by means of a Wanschaff's zenith telescope of 81 mm aperture.[2]

I give next a short account of what has already been done by seismologists in this connection, and then proceed to compare the seismic frequency in Japan with changes of latitude in Tokyo.

2. In the British Association Report for the year 1900, Prof. Milne gives, for the years 1895 to 1898 inclusive, a comparison of the wanderings of the pole from its mean position with the registers of earthquakes which have disturbed the whole world, or, at least, continental areas; the conclusion arrived at being that when the pole displacements were comparatively great large earthquakes were frequent and *vice versa.* Prof. Milne's results are as follows.

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1) See Baron Kikuchi's Preface to No. 1 of the *Publications*; also No. 1 of the Reports (Japanese), published in 1893.

2) In 1898, the work of the latitude observation in Tōkyō has been transferred to the Imperial Geodetic Commission. The observations were made first by Dr. H. Kimura, and subsequently by Mr. K. Hirayama.

Year	Total latitude variation.	Number of large earthquakes.
1895	0″·53	9
1896	0·91	18
1897	1·07	44 or 47
1898	1·03[1]	30

Prof. Milne's investigation was continued by Dr. A. Cancani, who obtained, for the years 1899 to 1902 inclusive, the following results.[2]

Year.	Total latitude variation.	Number of large earthquakse.
1899	0″·72	27
1900	0·32	17
1901	0·53	22
1902	0·97	29

The inference to be drawn from the above table is similar to that already obtained by Prof. Milne, namely, that the total annual amount of the latitude variation was greater or smaller according as the number of large earthquakes was large or small.

In the British Association Report for the year 1903, Prof. Milne examines the numbers of large earthquakes in the ten parts, into which each of the years, 1892 to 1899, is divided; the results of the investigation being that this same type of earthquakes has been frequent when the change in direction of the movement of the pole has been marked.

§ 3. *Latitude variation at Tokyo.* The following table gives the mean monthly values of the latitude of Tokyo (the Astronomical Observatory) for nearly 8½ years between Aug. 1895 and Dec. 1903; the results being graphically illustrated in fig. 1.

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[1] Adopting the value corrected by Dr. A. Cancani.

[2] Dr. A. Cancani: Sopra un' ipotetica relazione fra le variazioni di latitudine e la frequenza dei terremoti mondiali. Boll. della Soc. Sism. Italiana, Vol. VIII.

RESULTS OF LATITUDE OBSERVATIONS AT TOKYO.

AUG. 1895—DEC. 1903.

Mean date.	Decimal of the year.	Latitude.	Mean date.	Decimal of the year	Latitude.
1895 Aug. 12	1895.61	35°39′16″.59	1900 Apr. 18	1900.30	35°39′16″.84
Sept. 14	70	16.71	May 13	37	16.81
Oct. 18	80	16.72	June 13	45	16.82
Nov. 16	88	16.81	July 26	57	16.81
Dec. 15	96	16.80	Aug. 15	62	16.76
1896 Jan. 32	1896.06	16.75	Sept. 18	72	16.79
Feb. 12	12	16.73	Oct. 15	79	16.88
Mar. 16	21	16.68	Nov. 15	87	16.82
Apr. 13	28	16.60	Dec. 12	95	16.79
May 16	37	16.57	1901 Jan. 16	1901.05	16.76
June 15	46	16.47	Mar. 23	23	16.70
Sept. 20	72	16.69	Apr. 13	28	16.70
Oct. 19	80	16.83	May 18	38	16.69
Nov. 12	87	16.84	June 16	46	16.67
Dec. 12	95	16.87	July 26	57	16.69
1897 Jan. 13	1897.07	16.85	Oct. 22	1901.81	16.98
Feb. 13	12	16.85	Nov. 22	89	17.04
Mar. 16	21	16.78	Dec. 14	95	17.01
Apr. 23	31	16.77	1902 Jan. 13	1902.04	16.98
May 19	38	16.59	Feb. 15	13	16.85
June 13	45	16.52	Mar. 13	20	16.83
July 18	55	16.41	Apr. 16	29	16.67
Aug. 17	63	16.39	May 16	37	16.64
Sept. 15	71	16.54	June 10	44	16.62
1898 Oct. 15	1898.79	16.58	July 13	53	16.67
Nov. 12	87	16.78	Aug. 28	66	16.86
Dec. 14	95	16.88	Sept. 18	72	16.92
1899 Jan. 19	1899.05	16.95	Oct. 16	79	16.95
Feb. 11	12	16.94	Nov. 15	88	17.02
Mar. 20	22	17.02	Dec. 19	97	17.03
Apr. 18	30	17.02	1903 Jan. 15	1903.04	17.04
May 15	37	16.95	Feb. 15	13	16.92
1899 June 12	1899.45	16.85	Mar. 13	20	16.85
July 21	55	16.66	Apr. 16	29	16.75
Aug. 17	63	16.60	May 16	37	16.61
Sept. 13	70	16.61	June 13	45	16.54
Oct. 18	80	16.68	July 22	56	16.53
Nov. 15	87	16.67	Aug. 20	64	16.56
Dec. 24	98	16.69	Sept. 15	71	16.61
1900 Jan. 21	1900.06	16.73	Oct. 16	79	16.69
Feb. 16	13	16.77	Nov. 13	87	16.77
Mar. 17	21	16.81	Dec. 17	96	16.89

To see the relation, if any, between the latitude variation in Tokyo and the frequency of large Japan earthquakes, the latter are marked along the abscissa or time axis of the diagram (fig. 1); each black dot (•) denoting a great and more or less destructive shock, while a small circle (○) denotes a large earthquake which was not destructive, but whose area was extensive and about 10,000 square *ri*[1] or more.

An examination of fig. 1 shows that all the destructive earthquakes occurred exactly or very nearly at those epochs when the latitude was at a maximum or a minimum. The non-destructive extensive earthquakes indicate also a similar tendency, though in a less marked degree.

Note. From fig. 1 it will be at once observed that the curves *b* and *c* and the curves *b′* and *c′* are nearly symmetrical with respect to the curve *a*; *b* and *c* correspond to the epoch June 1901 to June 1903, *c′* and *b′* to the epoch Aug. 1897 to Aug. 1899, while *a* corresponds to the epoch Aug. 1899 to June 1901. The latitude variation was smallest in the epoch denoted by the curve *a*.

The following table contains a list of the successive epochs of the different phases of the latitude variation, deduced directly from the diagram (fig. 1), each sign (×) denoting a destructive earthquake. It will be seen that all the destructive earthquakes occurred during the epochs of the maximum and minimum latitude, as above stated.

Minimum Latitude.	Maximum Latitude.	Decreasing Latitude.	Increasing Latitude.
Year. Month.	Year. Month.	Year. Month.	Year. Month.
1896, VI–VIII. × ×	1895, XI–XII.	1896, I–V.	1895, VIII–X.
1897, VII–VIII. ×	1896, X–1897, II. ×	1897, III–VI.	1896, IX.
1898, IX. ×	1899, I–V. × ×	1899, VI.	1898, X–XII.
1899, VII–XII.	1900, IV–XI. ×	1901, I.	1900, I–III.
1901, II–VIII. × × × × ×	1901, X–1902, I. ×	1902, II–III.	1901, I–X.
1902, IV–VII.		1903, II–V.	1902, VIII–X.
1902, XI–1903, I.			1903, IX–XII.
1903, VI–VIII.			
Aggregate duration =26 months.	Aggregate duration =16 months.	Aggregate duration =14 months.	Aggregate duration =14 months.

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[1] 1 *ri*=4 km nearly.

4. *Sensible earthquakes in Tokyo.* The total numbers of the *sensible* earthquakes in Tokyo, which occurred during the different phases of the latitude variation, between 1895 and 1903, were as follows:—

With minimum latitude	111	earthquakes.
„ maximum „	69	„
Sum	$=E_1=180$	„
With decreasing latitude	76	„
„ increasing „	47	„
Sum	$=E_2=123$	„

These figures apparently indicate that the earthquakes of the kind under consideration occurred most frequently with the minimum latitude and least frequently with the increasing latitude. In reality, however, such was not the case. Thus the total numbers of the months included under the different phases were as follows:—

Minimum latitude	26	months
Maximum „	16	„
Sum	$=S_1=42$	„
Decreasing latitude	14	„
Increasing „	14	„
Sum	$=S_2=28$	„

The ratios $\frac{E_1}{S_1}$ and $\frac{E_2}{S_2}$ are practically identical, being respectively 4·3 and 4·4; a result which seems to indicate that the frequency of the sensible esrthquakes in Tokyo has no relation to the latitude variation.

5. *Earthquakes of area greater than 1000 square ri.* The numbers of recent Japan earthquakes of land area of disturbance[1] greater than 1000 square *ri*, which happened during the different phases of

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[1] "Area of disturbance" of an earthquake means here the area within which the shaking was felt, or strong enough to be perceptible without instrumental aid.

the latitude variation, between 1895 and 1903, were as flollows:—

With minimum latitude	49	earthquakes.
,, maximum ,,	29	,,
Sum	$=E_1'=78$	,,
With decreasing latitude	36	,,
,, increasing ,,	18	,,
Sum	$=E_2'=54$	,,

The preponderance of the earthquakes in the epochs of the maximum and minimum latitude is here again only apparent; the total numbers of the months included under the different phases being as follows:—

Minimum latitude	12	months.
Maximum ,,	12	,,
Sum	$=S_1'=24$	,,
Decreasing latitude	10	,,
Increasing ,,	7	,,
Sum	$=S_2'=17$	,,

The ratios $\frac{E_1'}{S_1}$ and $\frac{E_2'}{S_2'}$ are equal to one another, being 3.3 and 3.2 respectively.

6. From what has been said in §§ 4 and 5, it seems that great destructive earthquakes in Japan have a marked tendency to occur in the epochs of the maximum and minimum latitude at Tokyo, a conclusion which is in harmony with the results already obtained by Prof. Milne (§ 2). On the other hand, the frequency of the small earthquakes or those whose areas of disturbance is, say, under 10,000 square *ri*, seems to have no particular relation to the latitude variation.

7. *Note on the long-period variations of seismic frequency.*

(*a*) Destructive earthquakes in Japan. Great seismic disturbances happen sometimes singly or isolated but generally tend to occur in groups. Thus the 154 destructive earthquakes in Japan since the beginning of the 14th century may be more or less definitely divided into 41 groups, whose mean epochs recurred, on average, every $13\frac{1}{3}$ years.

(*b*) *Earthquakes in Kyōto.* Kyōto was the capital of the Empire during the 1070 years between 797 and 1867. The record of earthquakes in this city is therefore most complete, and includes 1318 shocks, of which 34 were destructive, 194 *strong*, and the remaining 1090 *slight*. Confining our attention to the two most disturbed epochs, namely, the 9th century and the time interval between the years 1340 and 1609, the seismic *activity*[1] presents a series of fluctuations of periods, whose mean value is $6\frac{1}{2}$ years. Especially between the years 854 and 890 the variations were regular and had an average period of 6 years.[2] (See fig. 2.)

In connection with the periodicities of the seismic activity above considered it is interesting to note that, according to Dr. H. Kimura, who studied the latitude variation during the intervals between the years 1890 and 1902, the polar motion has a six years' period, the maximum deviations of the instantaneous pole having occurred in 1891 and 1897, and the minimum in 1894 and 1900.[3]

The mean period of seismic activity at Kyōto is thus equal to that of the pole motion, while the mean epochs of the destructive earthquakes recur at intervals of nearly double the length.

8. *Earthquakes in Japan between 1885 and 1903.* For the sake of reference I give in the following table the numbers of earthquakes in the whole of Japan during the 19 years between 1885 and 1903, classified according to the land area of disturbance, and also to the

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[1] *Seismic activity* for each year is here the sum of the numbers of small, strong, and destructive earthquakes multiplied respectively with the coefficients 1, 2, and 2.

[2] F. Omori: Notes on the Earthquake Investigation Committee Catalogue of Japanese earthquakes. Jour. Sc. Coll., Tōkyō Imp. Univ., Vol. XI.

[3] H. Kimura: On the Six years' cycle of the polar motion during the interval 1891-1902. Astr. Nachr., No. 3932, Feb. 1904.

*intensity*1) of motion at the epicentre or at the nearest sea-coast in cases the latter was submarine. Some of the *slight* earthquakes were unfelt ones, which were, however, intense enough to be registered by ordinary Gray-Milne type seismographs.

JAPAN EARTHQUAKES IN RECENT YEARS.

Year.	Land area of disturbance. (in square *ri*)					Intensity.			Sum.
	<100	>100	>1,000	>5,000	>10,000	Strong.	Weak.	Slight.	
1885	309	143	28	2	0	—	—	—	482
1886	349	104	18	1	0	—	—	—	472
1887	349	97	34	3	0	—	—	—	483
1888	482	104	41	3	0	58	266	306	630
1889	767	117	44	2	0	51	290	589	930
1890	707	96	39	3	0	49	264	532	845
1891	1875	628	157	9	1	84	332	2164	2670
1892			26	4	0	85	242	1591	1918
1893			27	2	0	49	220	1267	1536
1894			25	12	5	65	335	2329	2726
1895			10	4	1	28	189	1200	1417
1896			15	20	3	56	273	1578	1907
1897			9	21	6	29	209	1493	1731
1898	1280	235	45	15	3	37	226	1384	1647
1899	1389	243	30	12	7	40	153	1562	1755
1900	1496	237	130	20	5	45	200	1643	1888
1901	1278	251	132	20	6	34	215	1361	1610
1902	1177	220	113	20	3	37	184	1267	1488
1903	1051	184	99	11	3	43	175	1131	1349

---

1) The *intensity* of non-destructive earthquakes is indicated as *strong*, *weak*, or *slight*. A *slight* shock is one which is very feeble and just sensible; a *weak* shock is one whose motion is well pronounced but not so severe as to cause general alarm; and finally a *strong* shock is one which is sufficiently severe to knock down some furniture, to cause people to run out of doors, etc

With respect to the above table, two things are to be remarked, namely, (1), that an enormous increase of earthquakes since 1891 is due to the after-shocks of the great earthquakes which took place in that and the subsequent years; and, (2), that a marked increase in the number of the earthquakes of area greater than 1000 square *ri* since 1900 is mainly due to the recent increase of the Gray-Milne type seismographs in the different parts of the country and to the consequent enlargement of the *area* of disturbance.

As stated before, the maximum deviations of the polar motion took place in 1891 and 1897, and also probably in 1903; and it is interesting to remark in this connection that the great Mino-Owari earthquake occurred in 1891, and the greatest number of earthquakes of land area larger than 5,000 square *ri* occurred in 1897, although the seismic activity was small in 1903.

A glance at the above table also indicates that the number of strong earthquakes (which include also violent and destructive ones) is not necessarily proportional to that of large earthquakes or those of great area of disturbance.

Tokyo. Aprii, 1904.

Note on the Annual Variation of the Height of Sea-level at Ayukawa and Misaki.

By

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Member of the Imperial Earthquake Investigation Committee.

With Plate VII.

The present note, which is to be regarded as a supplement to my paper on the annual and diurnal variations of seismic frequency in Japan,[1] treats of the comparison of the amount of fluctuation of the height of sea-level with that of the barometric pressure, at Ayukawa and Misaki. These two places are both situated on the Pacific coast of the Main Island; Ayukawa, in the province of Rikuzen, having been selected on account of its proximity to the origins of the submarine earthquakes so often disturbing the north-eastern part of the Island, while Misaki, in the province of Sagami, has been taken for the sake of comparison.

The following table, which has been deduced from the tide-gauge observations during the year 1902 at Ayukawa and Misaki, gives the mean monthly values of the distance between the sea surface and the datum line in the mareogram at each of the two places.

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[1] See the *Publications*, No. 8.

Month.	Distance between sea surface and datum line in the mareogram.[1]	
	Ayukawa.	Misaki.
	metre.	metre.
January.	3.545	3.703
February.	3.666	3.832
March.	3.643	3.763
April.	3.621	3.729
May.	3.570	3.644
June.	3.495	3.661
July.	3.469	3.657
August.	3.482	3.606
September.	3.447	3.556
October.	3.494	3.584
November.	3.539	3.668
December.	3.509	3.575

The results contained in the above table are illustrated in fig. 1, which shows that the variation of the height of the sea level at Ayukawa was nearly similar to that at Misaki.

The following table gives the mean monthly relative heights of the sea-level at Ayukawa and Misaki, deduced from the preceding together with the mean monthly barometric pressures during the same year deduced from the mean of the observations at the meteorological observatories of Ishinomaki and Yokosuka; the two latter places being respectively near to Ayukawa and Misaki.

Month.	Mean height of sea-level.			Mean barometric pressure (reduced to sea-level and 0°C.)
	Misaki.	Ayukawa.	Mean	
	mm	mm	mm	mm mm
January.	129	121	125	700 + 61.3
February.	0	0	0	64.5
March.	69	23	46	62.2
April.	103	45	74	60.2

---

[1] The figures in the table were furnished by the Survey Department of the General Staff.

Month.	Mean height of sea-level.			Mean barometric pressure (reduced to sea-level and 0°C.)
	Misaki.	Ayukawa.	Mean.	
	mm	mm	mm	mm mm
May.	188	96	142	700+59.4
June.	171	171	171	56.4
July.	175	197	186	56.2
August.	226	184	205	58.8
September.	276	219	248	58.7
October.	248	172	210	64.1
November.	164	117	141	65.5
December.	257	157	207	61.0

From fig. 2, which graphically illustrates the results contained in the above table, it will be seen that the curve of the annual variation of the barometric pressure is nearly opposite to that of the height of sea-level. Further, the annual fluctuation of the mean monthly barometric pressure was 9.3 mm, which corresponds to $9.3 \times 13.6 = 126$ mm height of water. On the other hand, the annual fluctuations of the height of sea-level were 276 and 219 mm at Misaki and Ayukawa respectively. At these places, therefore, the fluctuation of the height of sea-level is opposite to, and nearly double, that of the atmospheric pressure. In other words, the sea bottom is subjected to a greater *total* pressure in the summer months than in Feb., March, and April, the difference between the maximum and minimum total pressure being nearly equal to that of the annual amount of fluctuation of the monthly mean barometric height. Such is probably true of the whole Pacific coasts of the Japanese islands.

The increase in the height of sea-level in summer months as above described is to be explained partly by the fall in summer of the atmospheric pressure over Japan and the neighbouring seas, and partly by the presence of a high pressure area on the northern Pacific in the vicinity of the Aleutian islands; the surface of the ocean being consequently thrown into a curve form, such that the surface of the water is depressed beneath the high pressure centre and elevated along the coasts of the Japanese islands. Similarly the decrease of the height of sea-level in winter months is to be explained by the rise of the atmospheric pressure over Japan and the presence of a low pressure area on the northern Pacific. This probably explains the occurrence in summer and in winter respectively of the maximum and minimum seismic frequencies at those places which are shaken principally by earthquakes of sub-oceanic origin.

Note on the Lunar-daily Distribution of Earthquakes.[1]

By

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With Plates VIII and IX.

1. INTRODUCTION. The relations between earthquake frequency and the moon's position were discussed by several seismologists since the middle of the 19th century. The following is a brief summary of the more important investigations in recent years.

M. de Montessus de Ballore[2] who treated a vast earthquake catalogue, has obtained a wholly negative result. Thus, dividing the lunar day of 24 h 50 m into eight parts, of which the middle of the first corresponds to the time of the upper culmination, he finds the following earthquake distributions[3] :—

I eighth	5579 earthquakes.
II	5558
III	5611
IV	5508
V	5802
VI	5564
VII	5571
VIII	5662

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1) Translation, with some additions, of an article by the Author published in the *Reports* (Japanese) of the Imp. Earthq. Inv. Com., No. 32, 1900.

2) Archives des Sciences Physiques et Naturelles, Tome XXII, 1889.

3) Trans. Seism. Soc., Vol. XV.

These figures are quoted from Dr. C. G. Knott's paper entitled: M. de Ballore's calculations on earthquake frequency[1]. He remarks that it is impossible to base any definite conclusion as to the lunar-daily periodicity in earthquakes on such numbers as these, the ratio of the maximum to the minimum being 105 : 100.

The most important of the recent investigations on the relation between earthquake frequency and the position of the moon is that by Dr. C. G. Knott, who examined the Japan earthquakes contained in Prof. Milne's great Catalogue (Seis. Jour. of Japan, Vol. IV), and arrived, amongst others, at the following results[2]: — (1) Earthquake frequecy is subject to a periodicity associated with the lunar day; (2) The lunar half-daily period is relatively prominent, and its phase falls regularly in relation to the time of the meridian passage of the moon.

2. In the discussion of the lunar influence on earthquakes, the after shocks of a great earthquake may be supposed as furnishing the best materials for investigation, on the following two accounts:—(1) after-shocks are probably no other than the removal of the residual unstable or weak points at the disturbed tract about the focus of a great seismic disturbance, which must be particularly sensitive to the action of external agencies; (2) these shocks are mostly small local shakings whose origins are near to one another. From these considerations, I have taken, by way of trial, the after-shocks at Nagoya of the Mino-Owari earthquake of 1891, and those at Nemuro of the Hokkaido earthquake of 1894; and for the sake of comparison, ordinary earthquakes at Tokyo. The earthquake observations at Nagoya, Nemuro, and Tokyo, whose distribution in the lunar-day considered in the following §§, have all been made instrumentally by means of the Gray-Milne type seismographs.

3. LUNAR DAY. The lunar day is divided into 24 hours, the 0 hour corresponding with the moon's upper culmination for Tokyo.

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1) Trans. Seism. Soc., Vol. XV.

2) Prof. C.G. Knott: On Luner Periodicities in Earthquake Frequency. Proc. Royal Soc. London, Vol. LX, 1897.

The times of occurrence of the earthquakes at Nagoya and Nemuro, as well as those at Tokyo, have all been referred to the lunar time for the last named place. This will, however, lead to no great inaccuracy, as the longitudes at these three places are not much different from each other, being respectively 136° 55′, 145° 35′, and 139° 45′ *E*.

4. **AFTER-SHOCKS AT NAGOYA.** The great Mino-Owari earthquake took place on Oct. 28, 1891, at about 6 h 37 m a.m. The number of the after-shocks observed at the meteorological observatory of Nagoya till the end of the year 1899 was 1854. In order to avoid the effect of the rapid decrease in the seismic frequency at the commencement, let us exclude the observations within the two weeks immediately after the initial earthquake. Thus we obtain 1270 shocks for the time interval between Nov. 11, 1891, and Dec. 31, 1899, whose lunar-daily distribution is as follows.

TABLE I. LUNAR-DAILY DISTRIBUTION OF 1270 EARTHQUAKES AT *NAGOYA.*

(Nov. 11th, 1891–Dec. 31st, 1899.)

Lunar hour \ Year.	1891	1892	1893	1894	1895	1896	1897	1898	1899	Sum.	
										Hourly.	3-hourly.
h h											
0– 1	9	7	4	8	4	8	2	3	1	46	174
1– 2	11	16	2	16	9	4	0	3	0	61	
2– 3	15	7	5	17	10	2	2	3	6	67	
3– 4	14	10	5	11	8	3	0	1	2	54	178
4– 5	10	10	4	22	3	10	4	0	0	63	
5– 6	18	11	1	12	7	1	8	0	3	61	
6– 7	14	12	4	11	2	4	3	1	1	52	156
7– 8	13	9	4	14	2	3	6	3	3	57	
8– 9	10	8	5	11	4	3	2	2	2	47	
9–10	4	8	6	11	4	6	3	3	4	49	148
10–11	5	14	6	14	11	0	1	0	1	52	
11–12	7	8	6	9	9	3	3	1	1	47	
12–13	8	9	11	14	5	6	5	3	2	63	162
13–14	14	9	2	13	5	3	1	1	0	48	
14–15	10	5	2	14	2	7	4	3	4	51	
15–16	8	7	5	6	11	12	5	1	2	57	168
16–17	15	7	10	6	9	6	5	1	1	60	
17–18	9	7	7	8	5	7	3	3	2	51	
18–19	11	5	4	15	3	3	1	4	0	46	143
19–20	10	6	2	9	3	4	1	0	3	38	
20–21	18	7	8	9	6	3	4	2	2	59	
21–22	13	9	2	9	7	1	0	2	1	44	141
22–23	14	5	3	16	7	4	0	1	1	51	
23–34	19	0	9	1	7	6	2	1	1	46	
Sum.	279	196	117	276	143	109	65	42	43	1270	
									Mean	53	159

The results in Table I are illustrated in figs. 1 and 4, x being the time and y the corresponding hourly number of earthquakes.[1]

Hourly distribution. The principal maximum and minimum hourly

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[1] The curve is drown free-hand through the mean positions of every two successive points representing the relation between x and y. This methcd of curve drawing has been used in the case of the other diagrams.

numbers of 67 and 38 occurred respectively between the 2nd and 3rd hours, and between the 19th and 20th hours:

Greatest hourly earthquake number $= a = 67$;
Smallest ,, ,, ,, $= b = 38$;
Mean ,, ,, ,, $= c = 53$;

$$a - b = d = 29;$$

$$\frac{d}{c} = e = 55\ \%.$$

The second maximum ($=63$) and minimum ($=47$) occurred respectively between the 12th and 13th hours, and between the 8th and 9th hours.

3-Hourly distribution. The curve, which is drawn by taking the earthquake numbers every 3 hours (fig. 4), indicates clearly two maxima and two minima. The principal maximum and minimum numbers of 178 and 141 occurred respectively between the 3rd and 6th hours and between the 21st and 24th hours:—

Greatest 3-hourly earthquake number $= A = 178$;
Smallest ,, ,, ,, $= B = 141$;
Mean ,, ,, ,, $= C = 159$;

$$A - B = D = 37;$$

$$\frac{D}{C} = E = 23\ \%.$$

The 2nd maximum ($=168$) and minimum ($=148$) occurred respectively between the 15th and 18th hours, and between the 9th and 12th hours.

The symbols a, b, c, d, e, A, B, C, D, E, have in the cases of Nemuro and Tokyo earthquakes considered next the same meaning as in the present §.

5. NEMURO AFTER-SHOCKS. The Hokkaido earthquake took place on March 22, 1894, at 7h 56m p.m. The after-shocks recorded at the Meteorological Observatory of Nemuro till the end of 1899 was 1057. Excluding the shocks which happened during the first three days, to avoid the effect of the rapid decrease at the commencement, there were

in the time interval between March 25th, 1894, and Dec. 31st, 1899, 799 earthquakes, whose lunar-daily distribution is as in Table II.

TABLE II. LUNAR-DAILY DISTRIBUTION OF 799 EARTHQUAKES AT *NEMURO.*

(March 25th, 1894—Dec. 31st, 1899.)

Year. / Lunar hour	1894	1895	1896	1897	1898	1899	Sum.	
							Hourly.	3-hourly.
h h								
0— 1	21	8	4	2	2	0	37	106
1— 2	20	8	7	2	1	2	40	
2— 3	18	1	1	2	2	5	29	
3— 4	20	7	4	2	1	5	39	117
4— 5	25	8	5	5	2	2	47	
5— 6	18	6	1	2	2	2	31	
6— 7	17	7	5	2	5	4	40	92
7— 8	11	2	4	1	1	1	20	
8— 9	17	7	3	3	1	1	32	
9—10	14	4	2	5	3	3	31	98
10—11	17	7	5	4	1	1	35	
11—12	21	3	4	2	1	1	32	
12—13	17	10	3	4	4	1	39	107
13—14	23	4	5	2	1	1	36	
14—15	14	7	2	2	2	5	32	
15—16	21	5	3	2	1	4	36	95
16—17	14	4	2	3	3	3	29	
17—18	17	2	4	4	1	2	30	
18—19	19	5	7	1	0	1	33	98
19—20	16	4	1	4	3	7	35	
20—21	25	1	2	1	0	1	30	
21—22	17	9	3	4	0	3	36	86
22—23	9	2	2	3	2	3	21	
23—24	12	6	4	0	3	4	29	
Sum.	423	127	83	62	42	62	799	

Mean........33....100

Hourly distribution. According to fig. 2, the principal maximum and minimum hourly numbers of 47 and 20 occurred respectively between the 4th and 5th hours, and between the 7th and 8th hours:

$$a=47 \text{ earthquakes.}$$

$$b=20 \quad ,,$$

$$c=33 \quad ,,$$

$$a-b=d=27 \quad ,,$$

$$\frac{d}{c}=e=82 \%$$

The 2nd maximum and minimum of 39 and 21 occurred respectively between the 12th and 13th hours, and between the 22nd and 23rd hours.

3-Hourly distribution. According to fig. 5, which shows the 3-hourly distribution of the earthquakes, there were two maxima and two minima. The principal maximum and minimum numbers of 117 and 86 occurred respectively between the 3rd and 6th hours, and between the 21st and 24th hours:—

$$A=117 \text{ earthquakes.}$$

$$B=86 \quad ,,$$

$$C=100 \quad ,,$$

$$A-B=D=31 \quad ,,$$

$$\frac{D}{C}=E=31 \%.$$

The 2nd maximum and minimum of 107 and 92 occurred respectively between the 12th and 15th hours, and between the 6th and 9th hours.

6. TOKYO EARTHQUAKES. The lunar-daily distribution of the 1462 earthquakes observed at the Central Meteorological Observatory during the 12 years between Jan. 1888 and Dec. 1899 is given nii Table III.

TABLE III. LUNAR-DAILY DISTRIBUTION OF 1462 EARTHQUAKES AT TOKYO.

(Jan. 1888—Dec. 1899.)

year / Lunar hour.	1888	1889	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	Sum.	
													Hourly.	3-hourly.
h h														
0— 1	4	3	6	7	4	2	9	9	13	7	5	2	71	190
1— 2	4	4	2	5	6	4	1	10	6	5	5	4	56	
2— 3	4	6	7	3	4	3	2	5	10	7	4	8	63	
3— 4	6	5	1	4	6	3	6	3	9	4	5	6	58	184
4— 5	6	5	4	4	2	0	7	4	9	14	9	4	68	
5— 6	3	3	5	3	3	3	3	4	12	5	4	10	58	
6— 7	2	9	8	6	5	3	6	4	9	8	6	2	68	185
7— 8	8	8	3	4	7	3	3	5	5	4	8	3	61	
8— 9	3	4	3	4	4	3	3	5	9	2	8	8	56	
9—10	3	2	5	4	5	1	4	5	8	8	10	4	59	167
10—11	2	2	4	6	4	1	4	5	13	7	6	1	55	
11—12	5	3	4	6	2	3	4	2	8	7	5	4	53	
12—13	4	7	3	7	7	6	6	5	9	5	9	4	72	189
13—14	3	8	3	3	3	0	3	5	10	5	8	3	54	
14—15	6	3	2	5	2	4	5	5	10	9	7	5	63	
15—16	5	4	7	7	4	0	4	6	12	11	7	4	71	186
16—17	4	5	2	3	3	1	1	4	4	10	3	6	46	
17—18	4	9	1	5	5	4	3	4	14	6	7	7	69	
18—19	2	3	3	1	3	5	4	10	9	7	4	8	59	188
19—20	7	8	6	6	3	0	5	4	11	5	5	5	65	
20—21	5	3	3	5	3	2	6	6	8	7	8	8	64	
21—22	3	2	2	4	2	4	5	10	12	6	4	8	62	173
22—23	4	5	6	7	4	2	1	4	5	4	3	8	53	
23—24	4	2	3	14	1	4	6	7	5	5	3	4	58	
	101	113	93	123	92	61	101	131	220	158	143	126	1462	

Mean. 61......183

Hourly distribution. According to fig. 3, the principal maximum and minimum hourly earthquake numbers of 72 and 46 occurred respectively between the 12th and 13th hours, and between the 16th and 17th hours:—

$a = 72$ earthquakes

$b = 46$ „

$$c=61 \text{ earthquakes}$$

$$a-b=d=26 \qquad ,,$$

$$\frac{d}{c}=e=43\ \%$$

The 2nd maximum of 71 occurred between the 0 and 1st hours, and the 2nd minimum of 53 between the 11th and 12th hours and also between the 22nd and 23rd hours.

3-Hourly distribution. The curve of the 3-hourly distribution (fig.6) indicates clearly a 12-hours period. The maximum and minimum numbers of 190 and 167 occurred respectively between the 0 and 3rd hours, and between the 9th and 12th hours:—

$$A=190 \text{ earthquakes}$$

$$B=167 \qquad ,,$$

$$C=183 \qquad ,,$$

$$A-B=D=\ 23 \qquad ,,$$

$$\frac{D}{C}=E=\ 13\ \%.$$

The 2nd maximum and minimum of 189 and 173 occurred respectively between the 12th and 15th hours, and between the 21st and 24th hours.

7. SUMMARF OF RESULTS. The results obtained in the preceding three §§ may be summarized as follows.

Hourly distribution. The curves of the hourly earthquake distribution for the three places are similar to one another, each indicating two maxima, of which the 1st occurred between the 0 and 5th hours, and of which the 2nd occurred in all the three cases between the 12th and 13th hours. In the case of the Tokyo earthquakes the two maxima were nearly equal to one another; while in the cases of Nagoya and Nemuro earthquakes, the 1st maximum was somewhat greater than the 2nd. The occurrence of the two seismic maxima, at a mean interval of 12 hours, and approximately at, or a little after, the meridian passages of the moon, may probably be due to the stress in the earth's crust caused by the direct attraction of the moon.

The dotted lines in figs. 1, 2 and 3, showing the mean variation of the earthquake frequency, indicate in each case, two maxima, of which the 1st occurred between the 7th and 12th hours, and the 2nd between the 19th and 23rd hours.

It is hereby to be remarked that almost the total number of the earthquakes at Nemuro and Nagoya were small local shocks, whose origins were, in the two cases, totally different. Further, the Nemuro earthquakes were entirely of submarine origin, and Nagoya earthquakes mostly of inland origin; while the Tokyo earthquakes, whose origins were different from those at the two above places, were partly submarine and partly inland. Notwithstanding these differences in the origins of earthquakes the lunar-daily distribution of earthquakes at the three places were alike to one another. The values of *c*, or the amount of fluctuation of the hourly number of earthquakes, for Nagoya, Nemuro, and Tokyo, were respectively 55, 82, and 43%, giving an average of 60%.

8. TIDES. The relation between earthquakes and the position of the moon must be a complicated one, as, besides the direct stress caused by the moon in the earth's crust, there we have also to deal with the effect of the tides, for which the times of high and low waters are considerably different in various portions of the coasts of the Japanese Islands. At Reigan-jima, Tokyo, the high water occurs from 5 h to 6 h 20 m after the meridian passage of the moon. The times of the high water at some places along the Pacific and Japan sea coasts, referred to that at Reigan-jima, are as in the following table; being positive (+) when additive, and negative (−) when subtractive.

Place.	Time of High water.	Place.	Time of High water.
Kuwana.	+0h 37m	Yokohama.	−0h 01m
Hyogo.	+1 34	Ishinomaki.	−1 16
Osaka.	+2 01	Hakodate.	−1 03
Shimonoseki.	+3 06	Niigata.	−3 01
Nagasaki.	+1 56	Fushiki.	−2 57

From the above table, it will be seen that the times of the high water at the different places on the Japanese coasts are 2 to 9½ hours after the meridian passage of the moon. The fluctuations in the seismic frequency shown in figs. 1, 2, and 3, may entirely, or partly, be due to the tidal motion of sea waters. (See also § 9.)

9. *3-Hourly variation.* The curves of the 3-hourly seismic variation at the three places (figs. 4, 5, and 6) are approximately identical with one another, each indicating two maxima and two minima. The two maxima occurred respectively between the 0 and 6th hours, and between the 12th and 18th hours; the 1st maximum being somewhat greater than the 2nd. The two minima occurred respectively between the 6th and 12th hours, and between the 21st and 24th hours. The values of the ratio E, or the amount of the fluctuation of the 3-hourly seismic frequency, were for Nagoya, Nemuro and Tokyo, respectively 23, 31, and 13%, giving an average of 22%.

10. The conclusions above obtained for the three places of Nagoya, Nemuro and Tokyo, may be different from those for other places. It is, for instance, quite possible that for some places the lunar-daily distribution of earthquakes indicates only a single maximum and a single minimum. The discussion of earthquakes observed at Gifu, Kumamoto, Kagoshima, Ishinomaki, Utsunomiya, etc., will form the subject of another note.

11. COMPARISON OF THE LUNAR AND BAROMETRIC EFFECTS ON THE SEISMIC FREQUENCY. Let us compare the lunar effect discussed above with the effect of the barometric pressure on the diurnal seismic frequency at the same three places. In the *Publications,* No. 8, there ar tables showing diurnal distributions of 1851, 991, and 2208 earthquakes observed at Nagoya, Nemuro and Tokyo respectively. From these tables, as well as from those given in §§ 4, 5 and 6, I have constructed the following, showing for each place the excess of the different hourly earthquake numbers over the least.

TABLE IV. LUNAR-DAILY AND DIURNAL VARIATIONS OF SEISMIC FREQUENCY.

Lunar hour.	MOON'S EFFECT. (Lunar-daily seismic variation.)					Hour.	BAROMETRIC EFFECT. (Diurnal seismic variation.)				
	Nagoya.	Nemuro.	Tokyo.	Sum.	Sum—Minimum.		Nagoya.	Nemuro	Tokyo.	Sum.	Sum—Minimum.
0— 1	46	37	71	154	29	a.m. 0— 1	99	39	92	233	64
1— 2	61	40	56	157	32	1— 2	117	40	81	238	72
2— 3	67	29	63	159	34	2— 3	96	40	90	226	60
3— 4	54	39	58	151	26	3— 4	101	50	85	236	70
4— 5	63	47	68	178	53	4— 5	103	50	71	224	58
5— 6	61	31	58	150	25	5— 6	82	48	87	217	51
6— 7	52	40	68	160	35	6— 7	61	44	95	200	31
7— 8	57	20	61	138	13	7— 8	60	50	92	202	36
8— 9	47	32	56	135	10	8— 9	82	44	96	222	56
9—10	49	31	59	139	14	9—10	67	37	113	217	51
10—11	52	35	55	142	17	10—11	57	43	93	193	27
11—12	47	32	53	132	7	11—12	82	53	84	219	53
12—13	63	39	72	174	49	p.m. 0— 1	55	41	79	175	9
13—14	48	36	54	138	13	1— 2	79	26	91	196	30
14—15	51	32	63	146	21	2— 3	56	25	85	166	0
15—16	57	36	71	164	39	3— 4	72	45	104	221	55
16—17	60	29	46	135	10	4— 5	65	44	97	206	40
17—18	51	30	69	150	25	5— 6	78	42	81	201	35
18—19	46	33	59	138	13	6— 7	55	38	89	182	16
19—20	38	35	65	138	13	7— 8	75	43	93	211	45
20—21	59	30	64	153	28	8— 9	67	41	104	212	46
21—22	44	36	62	142	17	9—10	79	41	100	220	54
22—23	51	21	53	125	0	10—11	85	30	107	222	56
23—24	46	29	58	133	8	11—12	81	37	99	217	51
Sum	1270	799	1462	3531	531	Sum	1854	991	2208	5053	1069

Let N, S, S_1, and S_2 denote, for the lunar-daily distribution, the following quantities:—

N = Hourly number of earthquakes;

S = Total earthquake number;

$$S_1 = 24 \times b\,;$$
$$S_2 = \Sigma(N-b) = S - S_1\,;$$

b denoting the minimum hourly earthquake number, as in §§ 4, 5 and 6. Further let the symbols b', N', S', S_1', and S_2' denote the corresponding quantities for the diurnal distribution of earthquakes. Then the results contained in the above table may be summarized as in the two following ones.

Lunar-daily Earthquake Distribution.

Place.	S	$S_1 = 24 \times b$.	$S_2 = S - S_1$	Ratio, $\frac{S_2}{S_1}$	Ratio, $\frac{S_2}{S}$
Nagoya.	1270	912	358	0.39	0.28
Nemuro.	799	480	319	0.66	0.40
Tokyo.	1462	1104	358	0.33	0.25
3 places taken together.	3531	3000	531	(mean) 0.46	(mean) 0.31

Diurnal Earthquake Distribution.

Place.	S'	$S_1' = 24 \times b'$.	$S_2' = S' - S_1'$	Ratio, $\frac{S_2'}{S_1'}$	Ratio, $\frac{S_2'}{S'}$
Nagoya.	1854	1320	534	0.40	0.29
Nemuro.	991	600	391	0.65	0.39
Tokyo.	2208	1704	504	0.30	0.23
3 places taken together.	5053	3984	1069	(mean) 0.45	(mean) 0.30

From the above two tables, we see that, for each of the three places, the ratios $\frac{S_2}{S_1}$ and $\frac{S_2}{S}$ are very nearly equal respectively to the ratios $\frac{S_2'}{S_1'}$ and $\frac{S_2'}{S'}$, which shows that in the diurnal and lunar-daily seismic variations the moon's effect is approximately equal to that of the barometric pressure. This fact admits of a simple explanation, provided the *lunar effect* be considered not as the effect of the moon's direct attraction, but as the effect due to the weight of the sea waters in the tidal motion. Thus, according to my note on the annual variation of the height of sea-level,1) the total change of pressure at the sea bottom off the Pacific coast of the Main Island seems to be opposite in sense, but equal in amount, to that of the barometric pressure on land.

The numbers S_2 and S_2', which may be assumed respectively as the aggregate amount of the lunar and barometric effects on the lunar-daily and diurnal seismic variations are as follows:

For Nagoya : $S_2+S_2'=28+29=57$ %
,, Nemuro: ,, $=40+39=79$,,
,, Tokyo ; ,, $=25+23=48$,,

It thus seems that a considerable proportion of earthquakes, from some 50 to 80 %, are caused, or accelerated to occur, by the agencies of the atmospheric pressure and the moon's influence or tidal stress.

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1) This volume, pp. 24–26.

Lunar-daily distribution of Earthquakes.

Fig. 1. Nagoya.

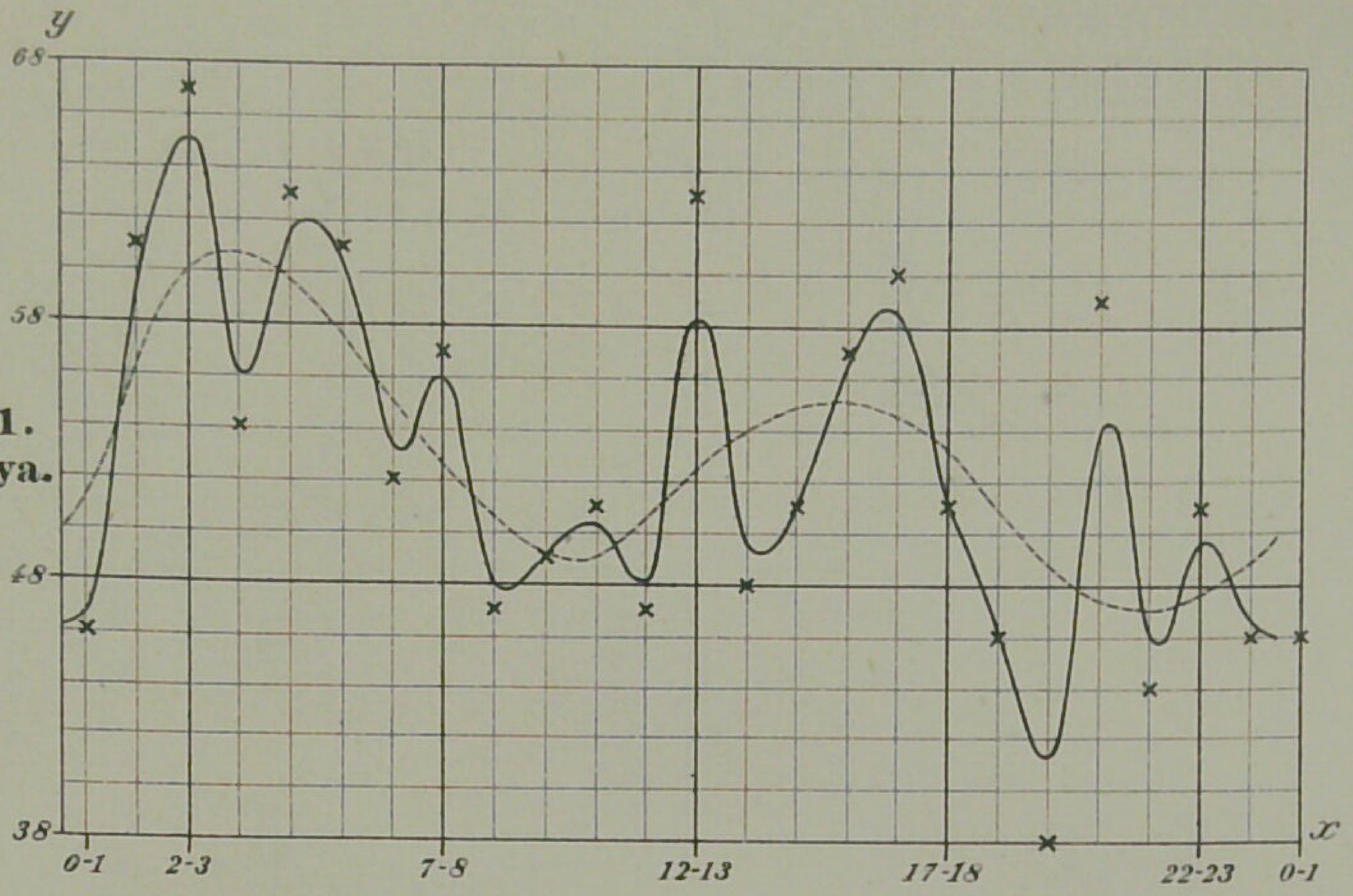


Fig. 2. Nemuro.

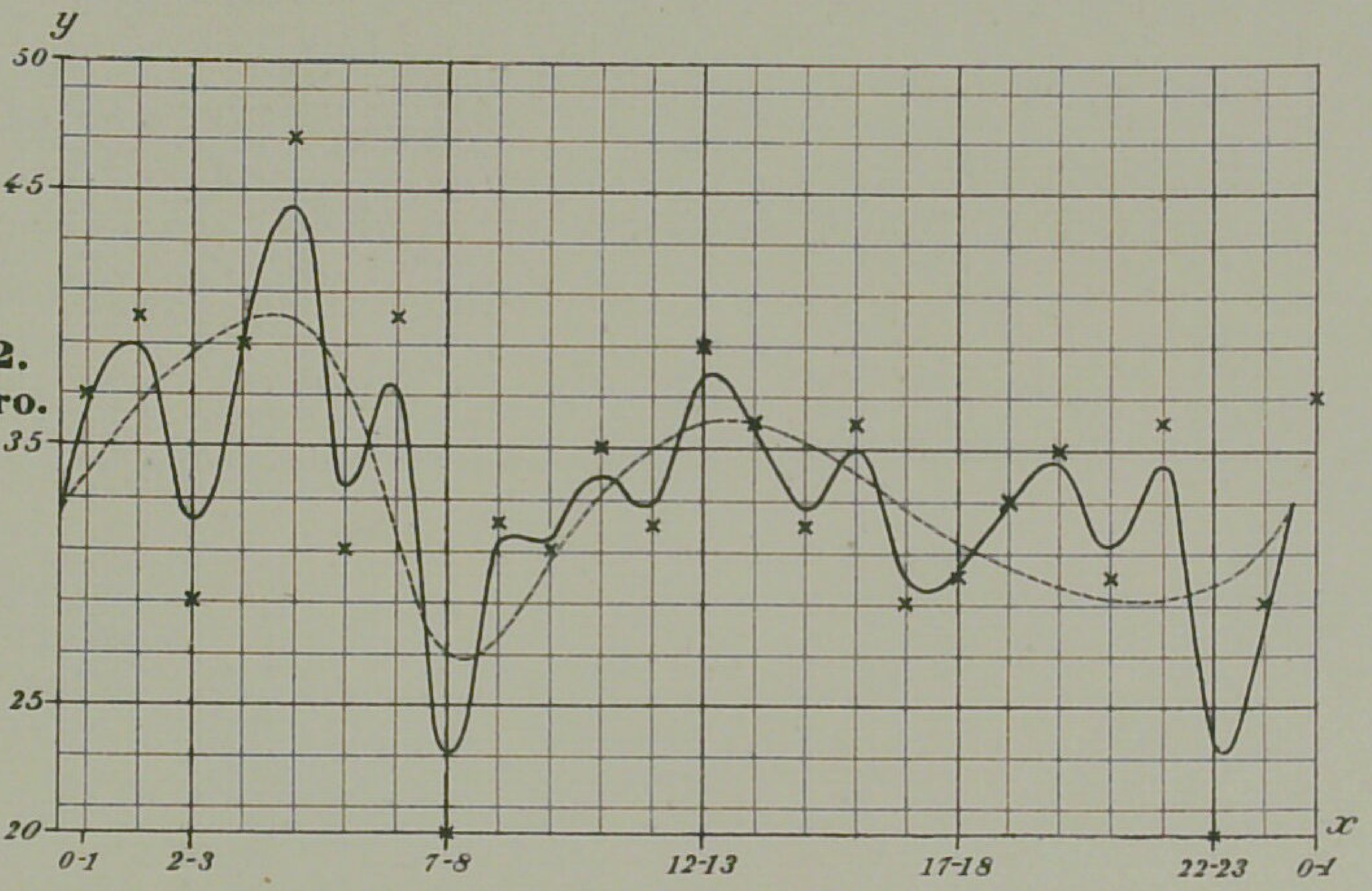
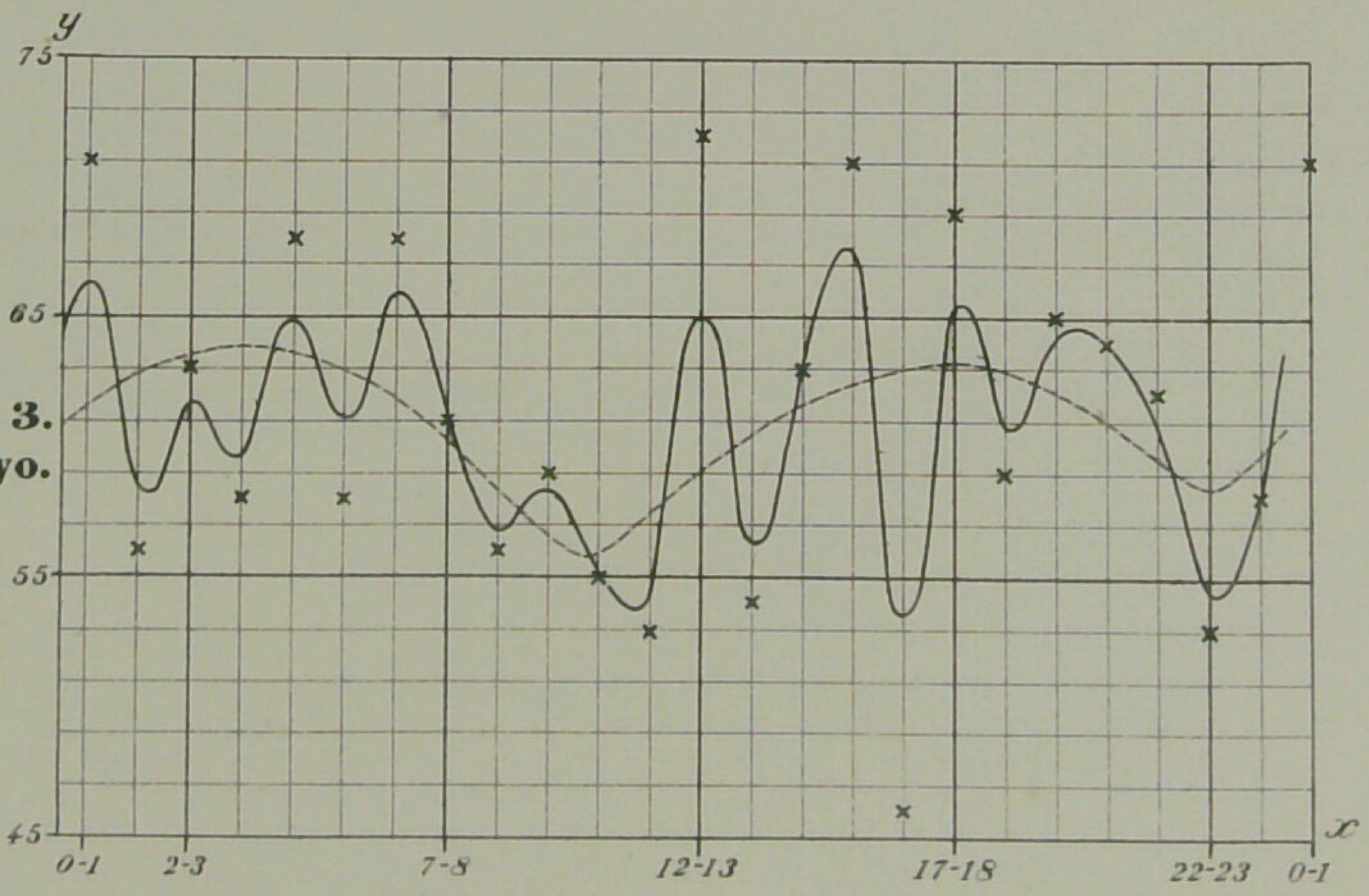


Fig. 3. Tokyo.



x = Time (lunar hour).

y = Hourly (lunar) number of earthquakes.

Lunar-daily distribution of Earthquakes.

Fig. 4.
Nagoya.

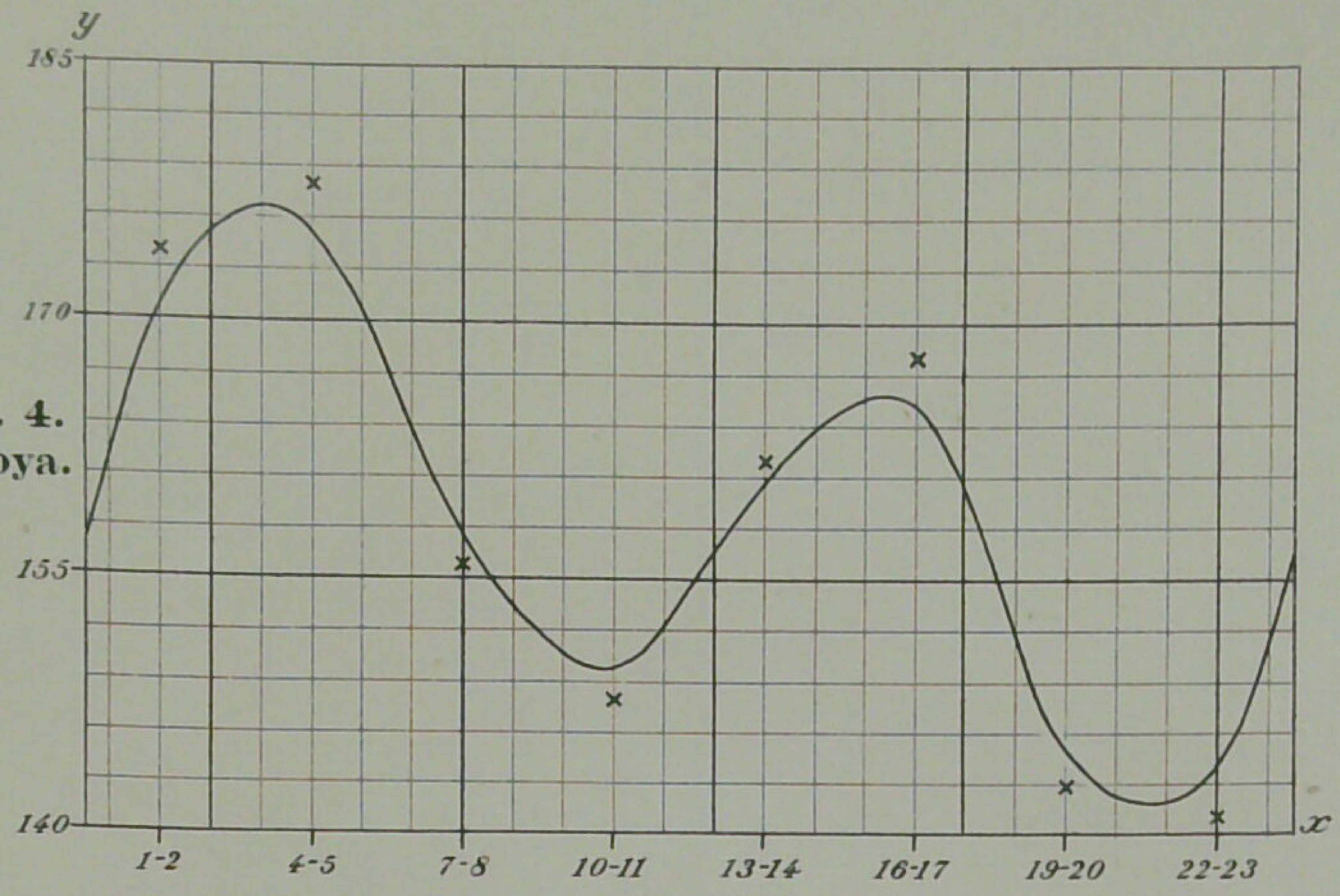


Fig. 5.
Nemuro.

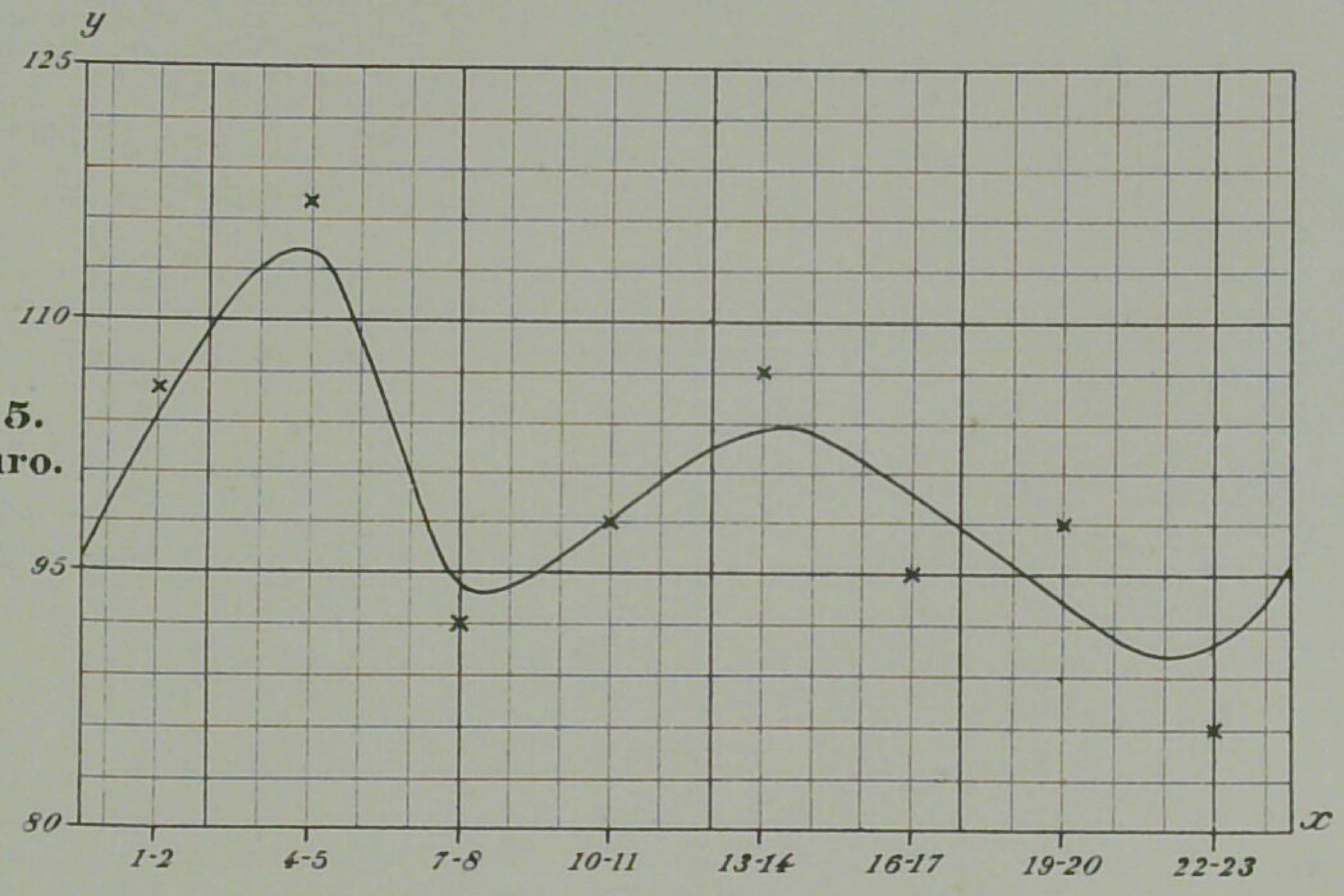
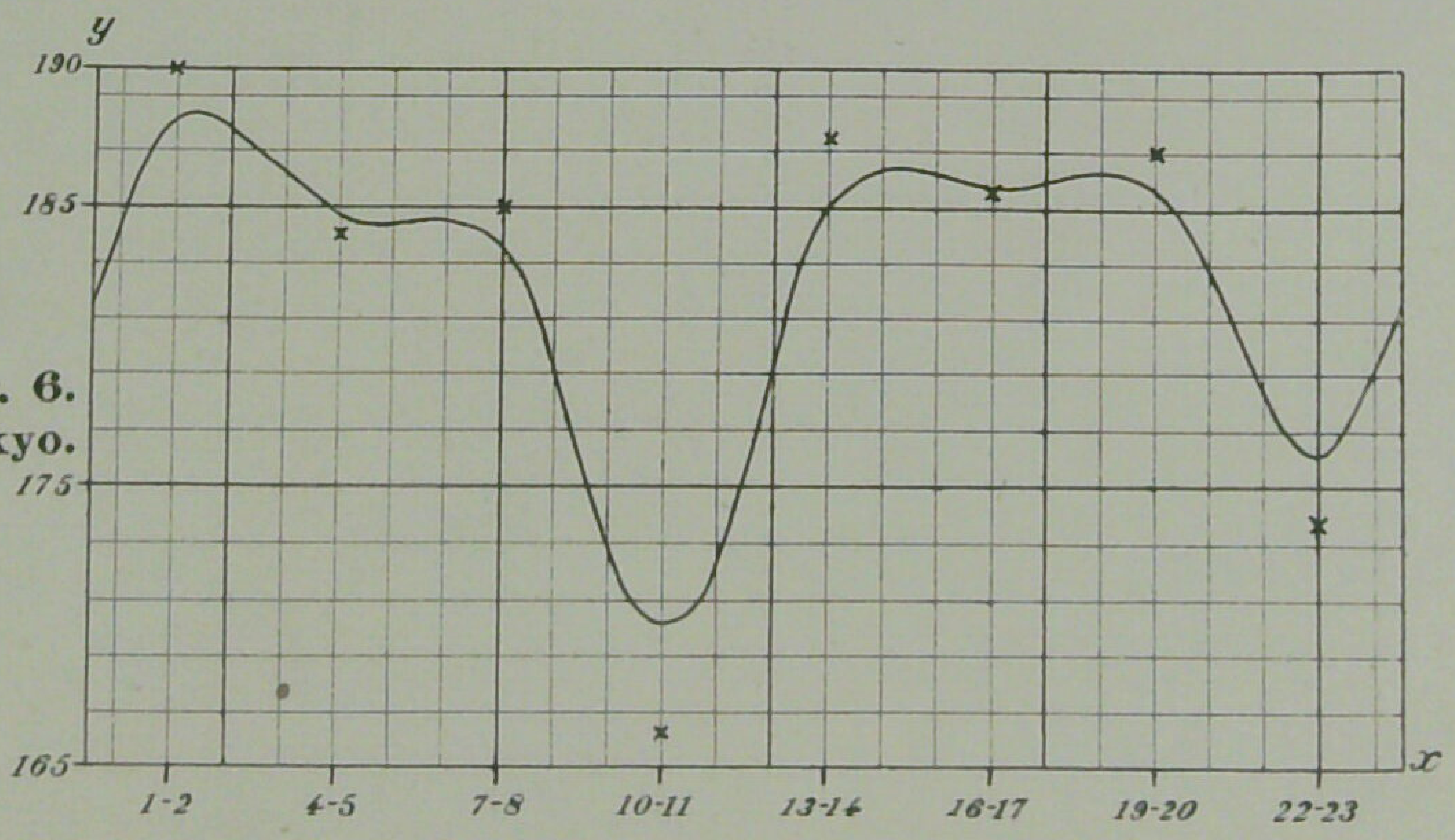


Fig. 6.
Tokyo.



x=Time (lunar hour).

y=3-hourly (lunar) number of earthquakes.

Synodic-monthly Variation of Seismic Frequency in Japan.

By

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Extraordinary Member of the Imperial Earthquake Investigation Committee.

With Plates X-XVII.

I. Introduction.

1. The relations between the periodic fluctuations of earthquake frequency and the external agencies, which have already been discussed by several seismologists, may be supposed to be most distinctly shown when the earthquakes treated are confined into certain localities, as a few recent investigators have done.

2. Dr. Omori was the first to discuss fully the after-shocks of great earthquakes, the advantage in considering these shocks with respect to the problem above mentioned being that they are numerous and ought to be readily affected by external agencies. Thus treating, besides the 1462 earthquakes observed in Tōkyō, 1270 after-shocks of the great Mino-Owari earthquake of 1891, and 799 after-shocks of the Nemuro earthquake of 1894, he arrived at the conclusion that earthquakes occurred most frequently within a few hours after the meridian passages of the moon and least frequently about 6 hours later[1], the result being similar to that obtained by Dr. Knott[2] who made an analytical study of 7000 Japanese earthquakes contained in Professor Milne's Catalogue. Dr. Oldham's result of the discussion of 1274

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[1] This volume, pp. 27–40.

[2] Proceedings of the Royal Society of London, vol. VX.

after-shocks of the great Assam earthquake of 1897 is that the shocks were most frequent between 10 and 11 p.m., and again between 6 and 7 a.m.[1] This is very similar to the conclusion arrived at by Dr. Omori, who, treating 18279 seismic observations at 26 Meteorological Stations in Japan obtained many important results, from which it appears that the seismic frequency is more affected by the barometric pressure than by the direct influence of the sun such that the curve of diurnal seismic frequency follows closely that of barometric pressure, large seismic numbers corresponding to high pressures.[2]

3. An interesting study on the distribution of seismic occurrences with respect to the relative position of the sun and moon has been undertaken also by Dr. Knott, who arrived at the conclusion that the seismic frequency reaches its maximum at the times of the conjunction and opposition of the sun and moon, and its minimum at the times of quadrature.[3]

4. The treatment, similar to that last mentioned, having been very easy with respect to the Japanese historical earthquakes contained in our Committee's Catalogue, in which the dates of occurrences are given both in Japanese synodic and European calendars, I have taken up the problem again and found that the maximum seismic frequency occurred not only at the times of the conjunction and opposition of the sun and moon, but also at the times of quadrature. This latter conclusion is found to be the same in the case of the recent Japanese earthquakes observed at the different Meteorological Stations. A detailed account is given in the following Chapters.

II. Synodic-daily distribution of the Japan historical earthquakes.

5. The Earthquake Investigation Committee Catalogue contains

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[1] Journal of the Asiatic Society of Bengal, vol. LXXXI.

[2] Publications of the Imp. Earthquake Inv. Comm. in Foreign Lagunges, No. 8.

[3] Dr. Knott: On Lunar Periodicities in Earthquake Frequency. Proceedings of the Royal Society of London.

a list of 1898 earthquakes, a large disturbance and its after-shocks being reckoned as a single number.[1] These earthquakes are classed according to the intensity as *destructive*, *strong*, or *small*, each of which corresponds approximately to *violent*, *strong*, and *weak* or *slight* of the scale adopted by the Central Meteorological Observatory.

6. A few words must be said of Japanese synodic calendar. The first day of the lunar month is approximately the time of the conjunction of the sun and moon, while the 16th is the time of opposition. As a complete synodic month is almost equal to 29.53 mean solar days, months consisting of 29 and 30 days come alternately, or in other words the 30th day numbers 53 % of any other day during a sufficiently long period. Hence I multiplied, for the use of drawing the frequency curve, the factor 100/53 into the seismic number in the 30th, in order to raise the datum of this day into equal weight as in the other days.

7. Let us now turn our attention to Tables I and II. The first of these relates to the earthquakes all over Japan, while the second relates to the 1317 earthquakes recorded in Kyoto.[2] The column with the heading "sum with weight" is *filled up* with the sums of small, strong, and destructive earthquakes of successive days each multiplied with the factors 1, 2, and 3 respectively. The last column with the heading "reduced" consists of numbers of the corresponding days in the former column divided by the daily average of the numbers in that column.

1–2. In a few cases, date of occurrences is unknown.

TABLE I.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES RECORDED IN JAPAN, BETWEEN 416 AND 1860, A. D.

Synodic day.	Small.	Strong.	Destructive.	Sum without weight.	Sum with weight.	Reduced.
1	66	14	8	88	118	1.40
2	71	5	5	81	96	1.14
3	55	9	5	69	88	1.04
4	45	11	5	61	82	0.97
5	50	8	7	65	87	1.03
6	46	12	5	63	85	1.01
7	56	8	12	76	108	1.28
8	37	11	3	51	68	0.81
9	39	8	8	55	71	0.84
10	44	10	4	58	76	0.90
11	45	8	3	56	70	0.83
12	43	6	12	61	91	1.08
13	70	8	2	80	92	1.09
14	54	10	6	70	92	1.09
15	48	6	8	62	84	1.00
16	55	7	6	68	87	1.03
17	48	10	2	60	74	0.88
18	50	9	3	62	77	0.91
19	47	9	5	61	80	0.95
20	33	9	7	49	72	0.85
21	41	11	6	58	81	0.96
22	45	11	5	61	82	0.97
23	47	1	11	59	82	0.97
24	46	11	8	65	92	1.09
25	56	9	7	72	95	1.13
26	37	7	11	55	84	1.00
27	46	14	6	66	92	1.09
28	39	4	5	48	62	0.74
29	44	12	4	60	80	0.95
30	24	4	3	31	77	0.91
Sum.	1427	262	182	1871	2525	—

TABLE II.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES RECORDED AT KYOTO, BETWEEN 416 AND 1860, A. D.

Synodic day.	Slight.	Strong.	Large.	Sum without weight.	Sum with weight.	Reduced.
1	44	10	1	55	67	1.26
2	51	4	1	56	62	1.16
3	42	4	0	46	50	0.94
4	35	10	2	47	61	1.14
5	40	7	1	48	57	1.07
6	33	8	3	44	61	1.14
7	45	6	2	53	63	1.18
8	22	7	1	30	39	0.73
9	34	8	2	44	56	1.05
10	32	4	0	36	40	0.75
11	38	3	1	42	47	0.88
12	35	2	5	42	54	1.01
13	50	7	0	57	64	1.20
14	41	9	1	51	63	1.18
15	34	4	2	40	48	0.90
16	42	5	1	48	55	1.03
17	36	7	0	43	50	0.94
18	40	5	2	47	56	1.05
19	33	6	0	39	45	0.84
20	29	5	2	36	45	0.84
21	34	6	0	40	46	0.86
22	34	9	3	46	61	1.14
23	39	0	1	40	42	0.79
24	34	8	5	47	65	1.22
25	45	8	1	54	64	1.20
26	28	7	1	36	45	0.84
27	37	12	0	49	61	1.14
28	31	2	0	33	35	0.66
29	34	10	2	46	60	1.12
30	13	3	1	17	42	0.79
Sum	1085	186	41	1312	1604	—

8. The *weighted* numbers of earthquakes of successive days, when drawn in curves (figs. 1–2), indicate two distinct pairs of maxima on the 1st and 14th, and the 7th and 24th. The method of drawing curves here adopted is as follows:—Let x represent the synodic days, and y the actual seismic number of the corresponding day. Marking down on a section paper so many points (×) corresponding to the different sets of x and y, the curve is obtained by drawing a continuous free-hand line, which passes through the mean positions of every two consecutive points (×) tangentially to the broken line connecting directly the points themselves.[1]

9. As regards the causes of the two pairs of maxima, the first is probably due to the combined tidal effort of the sun and moon, and the second to the resultant of tidal and barometric pressures. For the explanation, the reader is referred to Chapter IV.

III. Synodic-daily distribution of the seismic observations at the different Meteorological Stations.

10. I shall now proceed to discuss the distribution of earthquakes observed at the different Japanese Meteorological Stations. As regards the full description of the observations at these stations, the reader is referred to Dr. Omori's paper on "annual and diurnal variations of seismic frequency in Japan."[2] As the monthly frequency is decidedly affected by the after-shocks of a certain large earthquake, I excluded them together with those earthquakes which occurred within a complete synodic month after that earthquake. For this reason, the observations at Nemuro, Gifu, Nagoya, etc., which have been taken into consideration were considerably reduced in number. The exclusions are given in Table III, which besides gives the observations at the 22 Meteorological Stations. My examination relates also to the obser-

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[1] See Dr. Omori: Publications of the Imp. Earthquake Inv. Comm. in Foreign Languages, No. 8.

[2] Loc. cit.

vations at 8 other stations, but, the materials in these cases having been very scanty, a definite result could not be obtained.

11. Tables IV–XXV are constructed in the same way as Tables I-II, the "sum" or the "seismic number" being used in the same meaning as the "sum without weight" in the first two tables.

TABLE III.

EARTHQUAKE OBSERVATION AT THE 22 METEOROLOGICAL STATIONS.

Meteorological Station.	Date of commencement of earthquake observations taken into account.	Time interval between Dec. 1902 and the date in the former column.		Date after which observations are excluded for a complete month.	No. of earthquake observations taken into account.
		years.	months.		
Tokyo.	Jan. 1876	27	0	Oct. 28, 1891; June 15, 1896.	2464
Nemuro.	March 1894	8	9	March 22, 1894.	755
Nagoya.	Jan. 1894	9	0	Jan. 10, 1894.	799
Gifu.	Jan. 1894	9	0	Jan. 10, 1894.	938
Ishinomaki.	Jan. 1886	17	0	———	1307
Fukushima.	May 1889	13	8	Aug. 9, 1901.	476
Osaka.	July 1882	20	6	Oct. 28, 1891.	293
Mito.	Jan. 1900	3	0	———	557
Fukuoka.	Aug. 1898	4	5	Aug. 12, 1898; Feb. 20, 1900; April 9, 1900.	410
Oita.	Jan. 1887	16	0	———	243
Miyako.	March 1883	19	10	———	923
Aomori.	Jan. 1882	21	0	March 22, 1894; Oct. 22, 1894; April 20, 1896; June 15, 1896; Aug. 31, 1896; Aug. 9, 1900.	631
Hakodate.	Jan. 1873	30	0	———	366
Akita.	Jan. 1883	20	0	Aug. 31, 1896.	400
Utsunomiya.	Feb. 1891	11	11	———	677
Maebashi.	Dec. 1896	6	1	———	270
Yamakata.	Dec. 1889	13	1	Aug. 31, 1896.	235
Niigata.	April 1886	16	9	———	228
Nagano.	Jan. 1889	14	0	———	418
Hikone.	Jan. 1894	9	0	Jan. 10, 1894.	289
Wakayama.	Sept. 1879	23	4	———	472
Kagoshima.	March 1885	17	10	———	527

Total number of earthquake observations = 13678.

TABLE IV.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT TŌKYŌ.

(Jan. 1876—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	78	3	0	81	0.97
2	68	10	0	78	0.94
3	89	6	0	95	1.13
4	70	7	0	77	0.92
5	69	4	1	74	0.88
6	89	7	0	96	1.14
7	80	6	1	87	1.04
8	76	1	0	77	0.92
9	83	7	2	92	1.10
10	75	2	0	77	0.92
11	82	7	0	89	1.06
12	65	5	1	71	0.85
13	70	5	0	75	0.89
14	63	5	0	68	0.81
15	63	6	0	69	0.82
16	70	11	0	81	0.97
17	84	6	2	92	1.10
18	76	11	3	90	1.07
19	84	7	2	93	1.11
20	75	3	1	79	0.94
21	74	7	2	83	0.99
22	86	8	1	95	1.13
23	88	7	0	95	1.13
24	81	9	0	90	1.07
25	67	1	1	69	0.82
26	73	6	1	80	0.95
27	67	3	1	71	0.85
28	74	11	0	85	1.01
29	93	5	0	98	1.17
30	54	3	0	57	1.30
Sum.	2266	179	19	2464	—

TABLE V.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NEMURO.

(March 1894—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	23	5	0	28	1.10
2	25	6	0	31	1.22
3	16	4	0	20	0.79
4	31	2	0	33	1.30
5	17	4	0	21	0.83
6	30	3	0	33	1.30
7	22	5	0	27	1.06
8	21	1	0	22	0.86
9	33	1	0	34	1.36
10	21	4	0	25	0.98
11	27	2	0	29	1.14
12	20	0	1	21	0.83
13	20	2	0	22	0.86
14	20	0	1	21	0.83
15	18	3	0	21	0.83
16	22	2	0	24	0.94
17	15	0	0	15	0.59
18	33	6	0	39	1.53
19	25	4	0	29	1.14
20	22	3	0	25	0.98
21	18	3	0	21	0.83
22	26	3	0	29	1.14
23	17	1	0	18	0.71
24	25	1	0	26	1.02
25	24	6	0	30	1.18
26	18	1	0	19	0.75
27	26	3	0	29	1.14
28	23	2	0	25	0.98
29	21	8	0	29	1.14
30	7	2	0	9	0.67
Sum.	666	87	2	755	—

TABLE VI.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NAGOYA.

(Jan. 1894—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	17	1	0	18	0.69
2	23	0	0	23	0.88
3	22	1	0	23	0.88
4	28	3	0	31	1.19
5	21	1	0	22	0.84
6	26	1	0	27	1.03
7	16	1	0	17	0.65
8	23	2	0	25	0.96
9	25	2	0	27	1.03
10	19	0	0	19	0.73
11	36	0	0	36	1.38
12	32	1	0	33	1.26
13	20	1	0	21	0.80
14	25	3	0	28	1.07
15	26	4	0	30	1.15
16	27	0	0	27	1.03
17	20	2	0	22	0.84
18	23	1	0	24	0.92
19	23	0	1	24	0.92
20	27	0	0	27	1.03
21	38	1	0	39	1.49
22	18	2	0	20	0.76
23	14	2	0	16	0.61
24	30	3	0	33	1.26
25	29	0	0	29	1.11
26	44	2	0	46	1.76
27	31	2	0	33	1.26
28	21	0	0	21	0.80
29	28	2	0	30	1.15
30	8	0	0	8	0.57
Sum.	740	38	1	779	—

TABLE VII.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT GIFU.

(Jan. 1894—Dec. 1902.)

Synodic day.	Eqke sound.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	1	22	3	0	26	0.82
2	1	23	2	0	26	0.82
3	4	34	2	1	41	1.29
4	0	30	2	1	33	1.04
5	0	36	5	1	42	1.33
6	1	31	2	0	34	1.07
7	1	36	0	0	37	1.17
8	0	24	4	0	28	0.88
9	0	34	2	0	36	1.14
10	1	25	1	0	27	0.85
11	4	28	3	0	35	1.10
12	1	30	3	0	34	1.07
13	4	16	6	0	26	0.82
14	3	36	3	1	43	1.36
15	0	23	2	0	25	0.79
16	1	27	3	0	31	0.98
17	0	23	4	0	27	0.85
18	1	31	1	0	33	1.04
19	3	27	1	0	31	0.98
20	1	31	0	0	32	1.01
21	4	20	3	0	27	0.85
22	0	22	0	0	22	0.69
23	2	25	1	0	28	0.88
24	1	32	4	0	37	1.17
25	3	26	1	0	30	0.95
26	3	30	3	0	36	1.14
27	2	31	1	0	34	1.07
28	1	23	0	0	24	0.76
29	0	35	2	0	37	1.17
30	1	14	1	0	30	0.95
Sum.	44	825	65	4	938	—

TABLE VIII.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT ISHINOMAKI.

(Jan. 1886—Dec. 1902.)

Synodic day.	Intensity not stated.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	13	30	2	0	45	1.02
2	7	24	2	2	35	0.79
3	9	22	4	1	36	0.82
4	11	31	1	1	44	1.00
5	7	34	4	0	45	1.02
6	11	18	5	0	34	0.77
7	12	35	3	1	51	1.16
8	9	26	6	0	41	0.93
9	10	26	1	0	37	0.84
10	13	41	1	1	56	1.27
11	7	22	8	1	38	0.86
12	10	35	1	0	46	1.04
13	11	31	1	0	43	0.98
14	14	19	3	1	37	0.84
15	23	30	7	0	60	1.36
16	19	34	1	1	55	1.25
17	18	28	5	0	51	1.16
18	8	39	2	2	51	1.16
19	13	27	2	1	43	0.98
20	12	22	1	0	35	0.79
21	12	23	4	1	40	0.91
22	12	24	1	3	40	0.91
23	16	29	2	0	47	1.07
24	15	29	3	0	47	1.07
25	13	42	2	0	57	1.29
26	15	35	5	0	55	1.25
27	12	24	0	2	38	0.86
28	14	25	3	0	42	0.95
29	13	24	4	0	41	0.93
30	5	11	1	0	17	0.73
Sum.	334	840	85	18	1307	—

TABLE IX.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT FUKUSHIMA.

(May. 1889—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	18	0	0	18	1.13
2	14	0	0	14	0.88
3	14	1	0	15	0.94
4	15	1	0	16	1.00
5	10	2	0	12	0.75
6	12	0	0	12	0.75
7	18	0	0	18	1.13
8	16	0	0	16	1.00
9	13	0	0	13	0.81
10	22	0	0	22	1.37
11	11	1	0	12	0.75
12	18	2	0	20	1.25
13	23	0	0	23	1.44
14	21	0	0	21	1.31
15	19	0	0	19	1.19
16	15	0	0	15	0.94
17	16	1	0	17	1.06
18	19	0	0	19	1.19
19	13	0	0	13	0.81
20	10	0	0	10	0.63
21	17	0	1	18	1.13
22	13	1	0	14	0.88
23	17	0	0	17	1.06
24	19	2	0	21	1.31
25	19	0	0	19	1.19
26	17	0	0	17	1.06
27	10	0	0	10	0.63
28	14	0	0	14	0.88
29	16	0	0	16	1.00
30	5	0	0	5	0.56
Sum.	464	11	1	476	—

TABLE X.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT OSAKA.

(July 1882 – Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	10	2	0	12	1.2
2	12	1	0	13	1.3
3	9	0	0	9	0.9
4	8	1	2	11	1.1
5	3	1	0	4	0.4
6	8	2	0	10	1.0
7	10	0	0	10	1.0
8	8	0	0	8	0.8
9	7	0	0	7	0.7
10	6	0	0	6	0.6
11	9	1	0	10	1.0
12	16	1	0	17	1.7
13	8	0	0	8	0.8
14	7	1	0	8	0.8
15	6	0	0	6	0.6
16	4	0	0	4	0.4
17	9	0	0	9	0.9
18	6	0	0	6	0.6
19	7	1	0	8	0.8
20	14	0	0	14	1.4
21	7	1	0	8	0.8
22	8	2	0	10	1.0
23	6	3	1	10	1.0
24	15	2	0	17	1.7
25	7	0	0	7	0.7
26	15	0	2	17	1.7
27	9	0	0	9	0.9
28	16	1	1	18	1.8
29	8	2	0	10	1.0
30	5	2	0	7	1.3
Sum.	263	24	6	293	—

TABLE XI.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT MITO.

(Jan. 1900—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	22	0	0	22	1.16
2	11	1	0	12	0.63
3	20	1	0	21	1.11
4	16	2	0	18	0.95
5	13	0	1	14	0.74
6	22	0	0	22	1.16
7	14	4	0	18	0.95
8	17	0	0	17	0.90
9	9	0	0	9	0.48
10	15	3	0	18	0.95
11	22	1	2	25	1.32
12	19	0	0	19	1.01
13	26	0	0	26	1.37
14	23	2	1	26	1.37
15	17	4	0	21	1.11
16	16	2	0	18	0.95
17	26	2	0	28	1.48
18	27	2	0	29	1.53
19	11	1	0	12	0.63
20	9	1	0	10	0.53
21	8	2	0	10	0.53
22	20	1	0	21	1.11
23	14	0	0	14	0.74
24	18	4	0	22	1.16
25	13	2	0	15	0.79
26	24	4	1	29	1.53
27	14	0	0	14	0.74
28	15	1	0	16	0.85
29	20	0	1	21	1.11
30	10	0	0	10	1.01
Sum.	511	40	3	557	—

TABLE XII.

SYNODIC-DAILY DISTRIBUTION OF EARTHQUAKES OBSERVED AT FUKUOKA.

(Aug. 1898—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	unfelt.	Sum (unfelt excluded).	Reduced.
1	13	0	0	0	13	0.93
2	12	0	0	0	12	1.86
3	14	0	0	0	14	1.00
4	20	0	0	0	20	1.43
5	17	0	0	0	17	1.21
6	10	0	0	0	10	0.71
7	11	0	0	0	11	0.79
8	8	0	0	4	8	0.57
9	11	0	0	0	11	0.79
10	12	0	0	4	12	0.86
11	16	0	0	14	16	1.07
12	13	0	0	2	13	0.93
13	10	1	0	2	11	0.79
14	12	0	0	9	12	0.86
15	15	0	0	4	15	1.07
16	16	0	0	1	16	1.14
17	13	0	0	4	13	0.93
18	22	0	0	11	22	1.57
19	17	0	0	11	17	1.21
20	16	0	0	0	16	1.14
21	12	1	0	0	13	0.93
22	17	0	0	0	17	1.21
23	16	2	2	0	20	1.43
24	16	0	0	0	16	1.14
25	7	0	1	0	8	0.57
26	11	0	0	0	11	0.79
27	16	0	0	0	16	1.14
28	11	0	0	2	11	0.79
29	9	0	0	0	9	0.64
30	10	0	0	0	10	1.36
Sum.	403	4	3	68	410	—

TABLE XIII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT OITA.

(Jan. 1887—Dec. 1902.)

Synodic day.	Slight.	Weak.	Strong.	Sum.	Reduced.
1	7	3	1	11	1.34
2	15	1	0	16	1.95
3	8	2	0	10	1.22
4	5	1	1	7	0.85
5	7	0	0	7	0.85
6	4	2	0	6	0.73
7	8	6	0	14	1.71
8	5	2	0	7	0.85
9	6	1	0	7	0.85
10	10	2	0	12	1.46
11	9	3	0	12	1.46
12	3	2	0	5	0.61
13	7	3	0	10	1.22
14	6	0	0	6	0.73
15	5	1	0	6	0.73
16	6	1	0	7	0.85
17	2	3	0	5	0.61
18	8	3	0	11	1.34
19	5	0	0	5	0.61
20	1	0	0	1	0.12
21	7	4	0	11	1.34
22	4	1	0	5	0.61
23	7	2	1	10	1.22
24	5	2	0	7	0.85
25	5	3	1	9	1.10
26	7	0	0	7	0.85
27	4	1	0	5	0.61
28	7	3	0	10	1.22
29	9	2	0	11	1.34
30	3	0	0	3	0.73
Sum.	185	54	4	243	—

TABLE XIV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT MIYAKO.

(March 1883—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	28	0.89	11	29	0.92	21	18	0.57
2	27	0.86	12	24	0.76	22	36	1.14
3	34	1.08	13	26	0.83	23	43	1.37
4	29	0.92	14	25	0.80	24	32	1.02
5	29	0.92	15	23	0.73	25	38	1.21
6	33	1.05	16	31	0.99	26	39	1.24
7	47	1.50	17	30	0.95	27	19	0.60
8	49	1.56	18	40	1.27	28	27	0.86
9	27	0.86	19	21	0.67	29	37	1.18
10	44	1.40	20	17	0.54	30	21	1.24

Total seismic number=923.

TABLE XV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT AOMORI.

(Jan. 1882—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	20	0.92	11	24	1.10	21	23	1.06
2	23	1.06	12	20	0.92	22	21	0.97
3	18	0.83	13	18	0.83	23	19	0.87
4	21	0.97	14	21	0.97	24	11	0.51
5	23	1.06	15	27	1.24	25	18	0.83
6	28	1.29	16	21	0.97	26	20	0.92
7	22	1.01	17	23	1.04	27	20	0.92
8	27	1.24	18	23	1.04	28	18	0.83
9	20	0.92	19	20	0.92	29	21	0.97
10	15	0.69	20	24	1.10	30	22	1.89

Total seismic number=631.

TABLE XVI.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT HAKODATE.

(Jan. 1873 – Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	12	0.97	11	16	1.29	21	16	1.29
2	7	0.56	12	9	0.73	22	12	0.97
3	12	0.97	13	16	1.29	23	8	0.65
4	12	0.97	14	13	1.05	24	6	0.48
5	15	1.21	15	7	0.56	25	19	1.53
6	20	1.61	16	16	1.29	26	10	0.81
7	8	0.65	17	12	0.97	27	10	0.81
8	14	1.13	18	10	0.81	28	18	1.45
9	13	1.05	19	10	0.81	29	16	1.29
10	9	0.73	20	13	1.05	30	7	1.05

Total seismic number=366.

TABLE XVII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT AKITA.

(Jan. 1883—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	6	0.43	11	9	0.66	21	12	0.88
2	15	1.10	12	10	0.73	22	16	1.17
3	18	1.32	13	10	0.73	23	21	1.54
4	15	1.10	14	10	0.73	24	18	1.32
5	15	1.10	15	15	1.10	25	13	0.96
6	20	1.47	16	16	1.17	26	16	1.17
7	19	1.40	17	14	1.03	27	13	0.96
8	16	1.17	18	18	1.32	28	6	0.43
9	3	0.22	19	10	0.73	29	18	1.32
10	12	0.88	20	8	0.59	30	8	1.10

Total seismic number=400.

TABLE XVIII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT UTSUNOMIYA.

(Feb. 1891—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	10	0.43	11	27	1.17	21	19	0.83
2	17	0.74	12	29	1.26	22	18	0.78
3	24	1.04	13	25	1.09	23	30	1.30
4	22	0.96	14	15	0.65	24	32	1.39
5	26	1.13	15	22	0.96	25	23	1.00
6	22	0.96	16	18	0.78	26	33	1.44
7	35	1.52	17	21	0.91	27	23	1.00
8	15	0.65	18	24	1.04	28	24	1.04
9	14	0.61	19	22	0.96	29	31	1.35
10	24	1.04	20	18	0.78	30	14	1.13

Total seismic number = 677.

TABLE XIX.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT MAEBASHI.

(Dec. 1896—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	7	0.76	11	13	1.41	21	5	0.54
2	8	0.87	12	8	0.87	22	8	0.87
3	8	0.87	13	13	1.41	23	12	1.30
4	9	0.98	14	10	1.09	24	13	1.41
5	6	0.65	15	11	1.20	25	11	1.20
6	10	1.09	16	5	0.54	26	11	1.20
7	12	1.30	17	13	1.41	27	10	1.09
8	4	0.43	18	13	1.41	28	6	0.65
9	5	0.54	19	11	1.20	29	8	0.87
10	4	0.43	20	9	0.98	30	7	1.41

Total seismic number = 270.

TABLE XX.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT YAMAGATA.

(Dec. 1889—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	11	1.39	11	7	0.89	21	10	1.27
2	9	1.14	12	7	0.89	22	6	0.76
3	8	1.01	13	8	1.01	23	13	1.65
4	5	0.63	14	7	0.89	24	7	0.89
5	13	1.65	15	10	1.27	25	8	1.01
6	7	0.89	16	7	0.89	26	11	1.39
7	17	2.15	17	7	0.89	27	6	0.76
8	5	0.63	18	11	1.39	28	5	0.63
9	4	0.51	19	9	1.14	29	8	1.01
10	3	0.38	20	2	0.25	30	4	0.89

Total seismic number=235.

TABLE XXI.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NIIGATA.

(April 1886—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	2	0.26	11	10	1.30	21	7	0.91
2	5	0.65	12	6	0.78	22	12	1.56
3	10	1.30	13	8	1.04	23	14	1.82
4	2	0.26	14	4	0.52	24	8	1.04
5	5	0.65	15	7	0.91	25	8	1.04
6	4	0.52	16	4	0.52	26	7	0.91
7	7	0.91	17	14	1.82	27	2	0.26
8	2	0.26	18	21	2.72	28	2	0.26
9	9	1.17	19	11	1.43	29	14	1.82
10	7	0.91	20	12	1.56	30	4	0.91

Total seismic number=228.

TABLE XXII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT NAGANO.

(Jan. 1889—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	16	1.10	11	7	0.48	21	13	0.90
2	22	1.52	12	11	0.76	22	15	1.03
3	12	0.83	13	11	0.76	23	9	0.62
4	13	0.90	14	5	0.35	24	16	1.10
5	21	1.45	15	14	0.97	25	17	1.17
6	17	1.17	16	17	1.17	26	16	1.10
7	18	1.24	17	15	1.03	27	16	1.10
8	9	0.62	18	25	1.73	28	11	0.76
9	12	0.83	19	20	1.38	29	14	0.97
10	6	0.41	20	11	0.76	30	9	1.17

Total seismic number=418.

TABLE XXIII.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT HIKONE.

(Jan. 1894—Dec. 1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	8	0.82	11	12	1.22	21	10	1.02
2	11	1.12	12	12	1.22	22	10	1.02
3	9	0.92	13	7	0.71	23	11	1.12
4	8	0.82	14	15	1.53	24	8	0.82
5	5	0.51	15	12	1.22	25	9	0.92
6	10	1.02	16	7	0.71	26	11	1.12
7	11	1.12	17	9	0.92	27	10	1.02
8	12	1.22	18	11	1.12	28	7	0.71
9	11	1.12	19	10	1.02	29	14	1.43
10	6	0.61	20	7	0.71	30	6	1.12

Total seismic number=289.

TABEE XXIV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT WAKAYAMA.

(Sept. 1879—1902.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	15	0.94	11	12	0.75	21	17	1.06
2	13	0.81	12	12	0.75	22	14	0.87
3	19	1.19	13	12	0.75	23	12	0.75
4	21	1.31	14	18	1.12	24	21	1.31
5	16	1.00	15	17	1.06	25	20	1.25
6	16	1.00	16	10	0.62	26	23	1.44
7	15	0.94	17	7	0.44	27	20	1.25
8	14	0.87	18	8	0.50	28	25	1.56
9	17	1.06	19	15	0.94	29	20	1.25
10	18	1.13	20	17	1.06	30	8	0.94

Total seismic number=472.

TABLE XXV.

SYNODIC-MONTHLY DISTRIBUTION OF EARTHQUAKES OBSERVED AT KAGOSHIMA.

(March 1885—Dec. 1903.)

Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.	Synodic day.	Seismic number.	Reduced.
1	17	0.96	11	30	1.69	21	15	0.84
2	16	0.90	12	12	0.67	22	9	0.51
3	19	1.07	13	27	1.52	23	11	0.62
4	19	1.07	14	24	1.35	24	16	0.90
5	29	1.63	15	26	1.46	25	16	0.90
6	10	0.56	16	20	1.13	26	11	0.62
7	8	0.45	17	21	1.18	27	23	1.29
8	23	1.29	18	21	1.18	28	10	0.56
9	15	0.84	19	22	1 24	29	22	1.24
10	16	0.90	20	12	0.67	30	7	0.73

Total seismic number=527.

12. Drawing the frequency curves (figs. 3–24) in the way already explained, we notice firstly, that in most cases there occur two distinct pairs of maxima, one about the times of the conjunction and opposition of the sun and moon, and the other at intermediate times; and secondly, that the first pairs of maxima is pronounced at certain stations, and the second pair at some other stations, while at the remaining stations the two pairs develop equally well. The relation expressed in the second statement may possibly be due to the fact that the observed earthquakes were mostly of inland origin, or of submarine, or of both origins. With this view, I have grouped the different stations into three sets (*A*), (*B*), and (*C*), according as their observations related mostly to inland earthquakes, both inland and submarine, and submarine respectively. Table XXVI shows this arrangement and grouping; the frequency curves at the different stations have also been arranged in the same order. The numbers in the right hand columns of the table are the days at which the frequency curve reaches their maximum height, days relating to more pronounced being printed with fat letters.

TABLE XXVI.

Group.	Meteorological stations.	Day of Maximum Seismic Number.			
A	Nagoya.	2	18	6	26
	Fukuoka.	30	18	4	23
	Niigata.	30	18	11	23
	Tokyo.	30	18	7	23
	Kagoshima.	29	14	4	—
B	Gifu.	29	14	—	25
	Osaka.	28	12	—	—
	Nagoya.	4	15	11	21,25
	Wakayama.	28	14	4	20
	Aomori.	30	15	7	20
	Oita.	2	18	9	24
	Hikone.	29	14	8	—
C	Maebashi.	30	15	7	24
	Mito.	30	14	6	26
	Hakodate.	28	—	6	21
	Nemuro.	—	18	9	26
	Yamagata.	1	15	7	23
	Fukushima.	2	13	7	24
	Ishinomaki.	1	16	10	25
	Utsunomiya.	29	12	6	24
	Akita.	30	17	6	23
	Miyako.	30	17	8	24
	Average.	30	15	7	23

13. Let us now compare the frequency curves in the two extreme cases, namely, those of Nagano and Miyako. The former station which is situated in the high land of Shinano, about 180 km. distant from the Pacific coast is disturbed mostly by local shocks, earthquakes which occurred in the Pacific basin having been registered there only when the disturbance was very strong at the origin. In the frequency curve, we notice one distinct pair of maxima on the 2nd and 18th. The seismic number in each of these days is about 3 times of the

minimum and 1.6 times of the daily average. Another pair of maxima occurred on the 6th and 26th.

14. Miyako is, on the other hand, situated on the Pacific coast bordering the earthquake region which runs parallel to the coast line at a distance of some 100 to 200 km. from it. Earthquakes which were felt at Miyako originated mostly in this zone, with a few exceptions of shocks which occurred in the eastern part ot Mutsu province. The frequency curve has a pair of the pronounced maxima on the 8th and 24th, the seismic number in each of these days amounting to 2 times or more of the minimum and 1.5 times of the daily average. A pair of minor maxima occurred on the 30th and 17th.

15. Thus we see that the days of maximum seismic number for the two stations coincide almost with each other, the only difference being that the days of pronounced pair in one station is replaced by those of minor pair in the other. The state of things is very similar between the frequency curves to the stations (*A*) and (*C*), though the difference is not so distinctly marked as in the two typical stations. It will also be seen that the stations in the group (*B*) stand between the two other groups so far as the above-mentioned characteristic is concerned.

16. For the sake of comparison, I give another example of the distribution of submarine earthquakes. Among the earthquakes contained in the Earthquake Inv. Comm. Catalogue there are 28 large ones which were accompanied by destructive sea-waves, and 62 others which were not apparently accompanied by sea-waves but which may be inferred, on account of the disturbed area, to have originated at sea coast places or under the sea. These two sorts of earthquakes are tabulated as follows:—

TABLE XXVII.

Synodic day.	Number of earthquakes.			Synodic day.	Number of earthquakes.		
	With sea-waves.	Without sea-waves.	Sum.		With sea-waves.	Without sea-waves.	Sum.
1	0	2	2	16	2	3	5
2	0	2	2	17	0	0	0
3	0	0	0	18	0	2	2
4	2	1	3	19	1	3	4
5	1	6	7	20	0	2	2
6	0	2	2	21	1	3	4
7	1	6	7	22	2	3	5
8	1	0	1	23	2	6	8
9	0	4	4	24	1	3	4
10	0	1	1	25	3	3	6
11	0	1	1	26	3	3	6
12	1	1	2	27	1	0	1
13	0	0	0	28	1	3	4
14	2	2	4	29	0	1	1
15	1	1	2	30	1	0	1
				Sum.	28	62	90

From this table, it will be seen that the greatest number of the submarine earthquakes occurred about the 23rd, and the next greatest about the 7th and the 16th, the state of things being very similar to the fact remarked in connection with the observations at the different Meteorological Stations.

IV. Causes of the four maxima in the frequency curves.

17. The existence of two maximum seismic numbers at the times of the conjunction and opposition of the sun and moon, being due to the joint effect of these two heavenly bodies, does not require further discussion. The following may be an explanation for the existence of the other pair at the 7th and 23rd.

18. According to Dr. Omori, the barometric pressure has marked influence upon the seismic frequency in Japan; the curves showing the time variations of the two quantities being similar to each other. Now the barometric pressure which reaches in its diurnal variation

its maximum at 9h and 22h, will interfere with the tidal force helping or cancelling the latter according as high-water or low-water occurs at these times. In Tokyo, the synodic days corresponding to the former case are the 7th and 22nd, the days corresponding to the latter are the 12th and 27th. Allowing an hour or two for time difference of occurrences of maximum tidal and barometric pressures at other localities, the days 6th–9th and 21st–24th are ones in which the resultant of the two influences becomes most effective. Thus we may look for the maximum seismic numbers about the 7th and 22nd which correspond roughly to the actual maxima in question.[1]

Although the diurnal variation of seismic frequency follows generally that of barometric pressure, yet we see in several cases that the former variation does not necessarily follow the latter. Thus in the curves of diurnal variation of seismic frequency for Nemuro and Nagoya we notice several maxima in the following hours, those in the first column relating to the more pronounced maxima.

Nemuro....	4.0–11.5 (a.m.).	5.0—7.0 (p.m.).
Nagoya....	1.5 (a.m.), 4.5 (a.m).	10.0 (p.m.).

If there are causes which influence the seismic occurrences of these regions at such hours, they will interfere with the tidal force and will give rise to a great number of seismic occurrences at the days when high-water and the assumed causes take place at the same time. These days are found in cases of Nemuro and Nagoya as follows :—

Nemuro....	1–10, 16–25.	3–6, 17–20.
Nagoya....	10,25 ; 13,28.	7,21.

On comparing these days with the days of actual maximum seismic number, we see at once that a tolerably fair correspondence exists between the two as it is indicated in figs. 18 and 10, in which the days found from deduction are given in larger letters along the axis of x.

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[1] This explanation was suggested to me by Dr. Honda of the Physical Institute of the Sc. Coll., Imp. Univ. Tokyo.

20. With the above-stated view, I have constructed the following table in which the days of actual and deduced maximum seismic numbers are so arranged as to be readily comparable. From the table, it will be seen how tolerably well the days found by the two different methods agree with each other.

Station.	Time of high-water, relative to that of Tokyo Bay.	Hour of occurrence of maximum in diurnal seismic variation.	Synodic days in which hours in the above column and of high-water coincide.	Synoidc days of actual maximum seismic number.	Hour of occurrence of maximum in diurnal seismic variation.	Synodic days in which hours in the above column and of high-water coincide.	Synodic days of actual maximum seismic number.	Hour of occurrence of maximum in diurnal seismic variation.	Synodic days in which hours in the above column and of high-water coincide.	Synodic days of actual maximum seismic number.
Tokyo.	0	9.5^{h} am.	7,22	6,22						
Kagoshima.	$+1.0^{h}$	1.5 am,pm.	10,26	11,27	6.5(slight) am,pm.	1,16	?	10.5(slight) am,pm.	7,23	8,24
Gifu.	+0.6	4.5 am.	13,28	14,29	0.5(slight) pm.	10,24	9,24	9.0 pm.	6,20	5,19
Nagoya.	+0.6	1.5(large) am.	10,25	11,26	4.0 am	14,28	15,29	10.0(slight) pm.	6,21	4,21
Wakayama.	0	4,5(slight) am.	14,29	14,28	7.0(slight) pm.	4,18	4,20	10.5 pm.	8,23	10,24
Aomori.	−1.0(?)	1.5 am.	11,27	11,26	9.5 am.	7,24	8,26	6.0 pm.	3,19	6,20
Nemuro.	−1.6	4.0 am.	1,16	2,18	11.5 am.	10,25	9,25	5–7 pm.	3−6,17−20.	4−6,17−19
Fukushima.	−1.0	9.5 am.	7,24	7,24	7.0 pm.	4,21	4,21			
Ishinomaki.	−1.3	2.5 p.m.	13,28	15,25						
Utsunomiya.	−0.5(?)	9.0 am.	6,23	7,26	7.5 pm.	4,21	5,23			
Miyako.	−1.0	1.5(slight) am.	12,26	(?),26	9.5 am.	8,23	8,23	6.0 am.	3,18	3,18

V. *Conclusion.*

21. Earthquake occurrences in Japan, when they are distributed

in synodic days, reach the greatest number at two pairs of times, namely:—

Firstly, at the times of the conjunction and opposition of the sun and moon, the combined effort of the two heavenly bodies being the cause;

Secondly, at the times of quadrature, the combined effort of the moon and barometric pressure being the cause.

22. I have confined myself to the study of the historical earthquakes in Japan, and the recent earthquakes registered by ordinary Gray-Milne type seismographs at the 22 Meteorological Stations in Japan. In the next occasion, I wish to study the synodic monthly distribution of the earthquakes which originated only in the immediate vicinity of Tokyo, and further the relation of the occurrence of each earthquake with the tidal and barometric pressures of successive days.

Nov. 9th, 1903.

Seismological Institute.

Explanation of Figures.

Figs. 1–2 show the synodic monthly distribution of historical earthquakes.

Figs. 3–24 show the synodic monthly distribution of the instrumental observations of recent earthquakes.

For figs. 1–24:

x = Japanese synodic day.

y = actual number of seismic observations at the corresponding day.

Number in larger letters along the axis of x in figs. 6, 7, 8, &c. indicates the day of *deduced* maximum seismic number (Chapter IV).

Fig. 1. Japan.

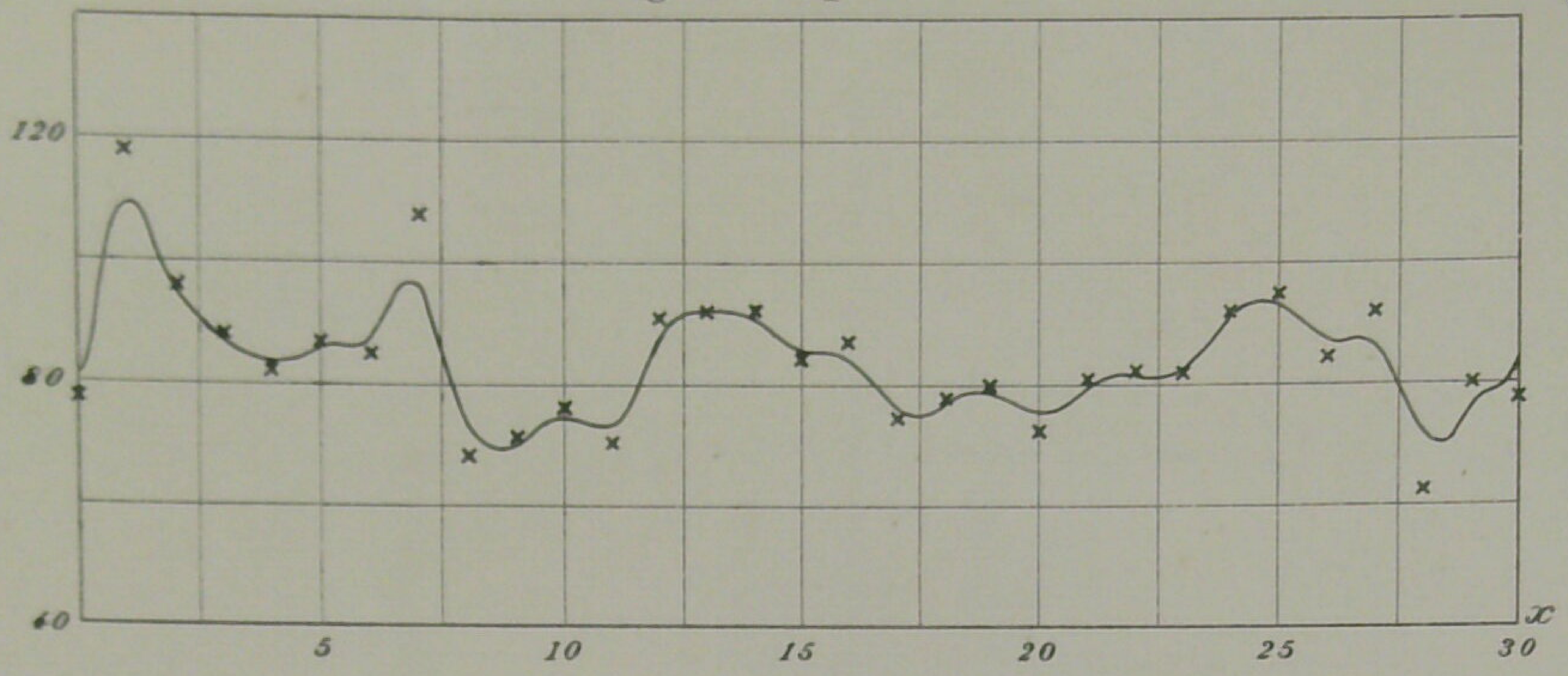


Fig. 2. Kyoto.

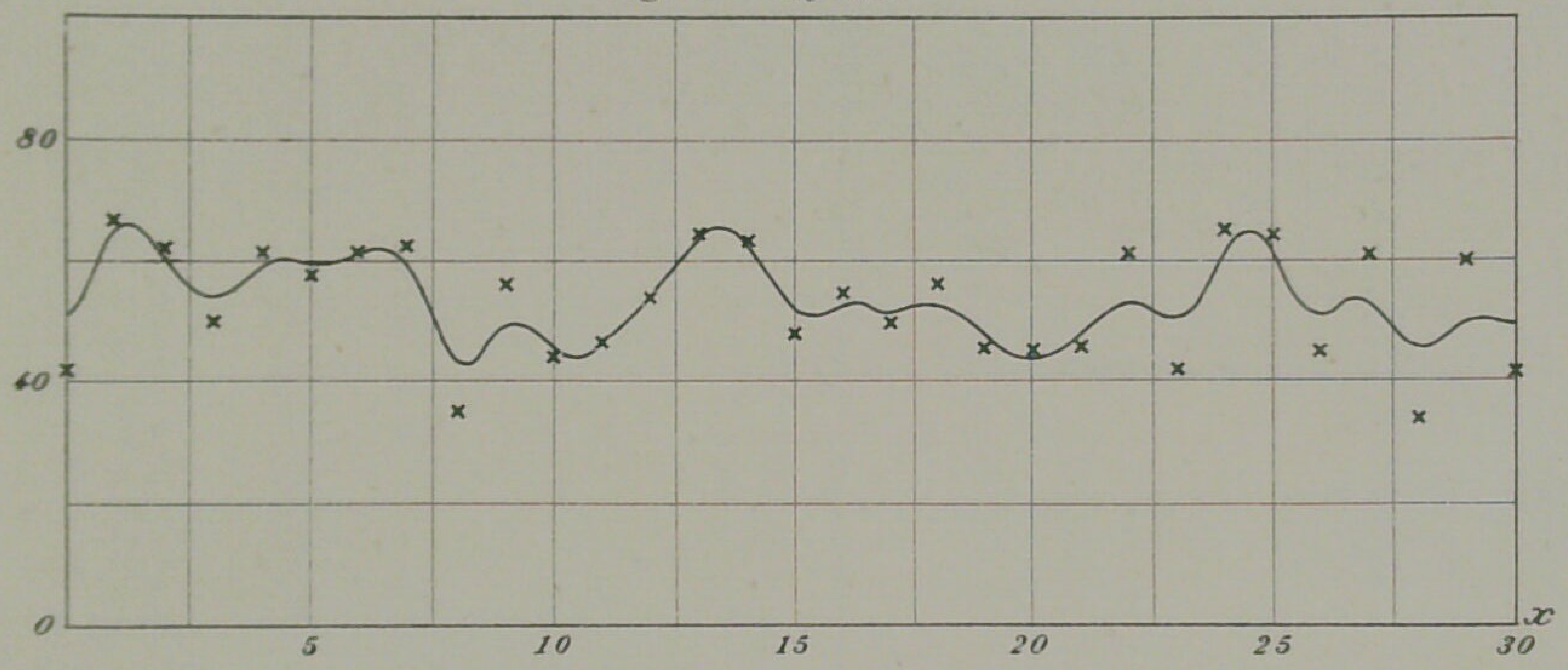
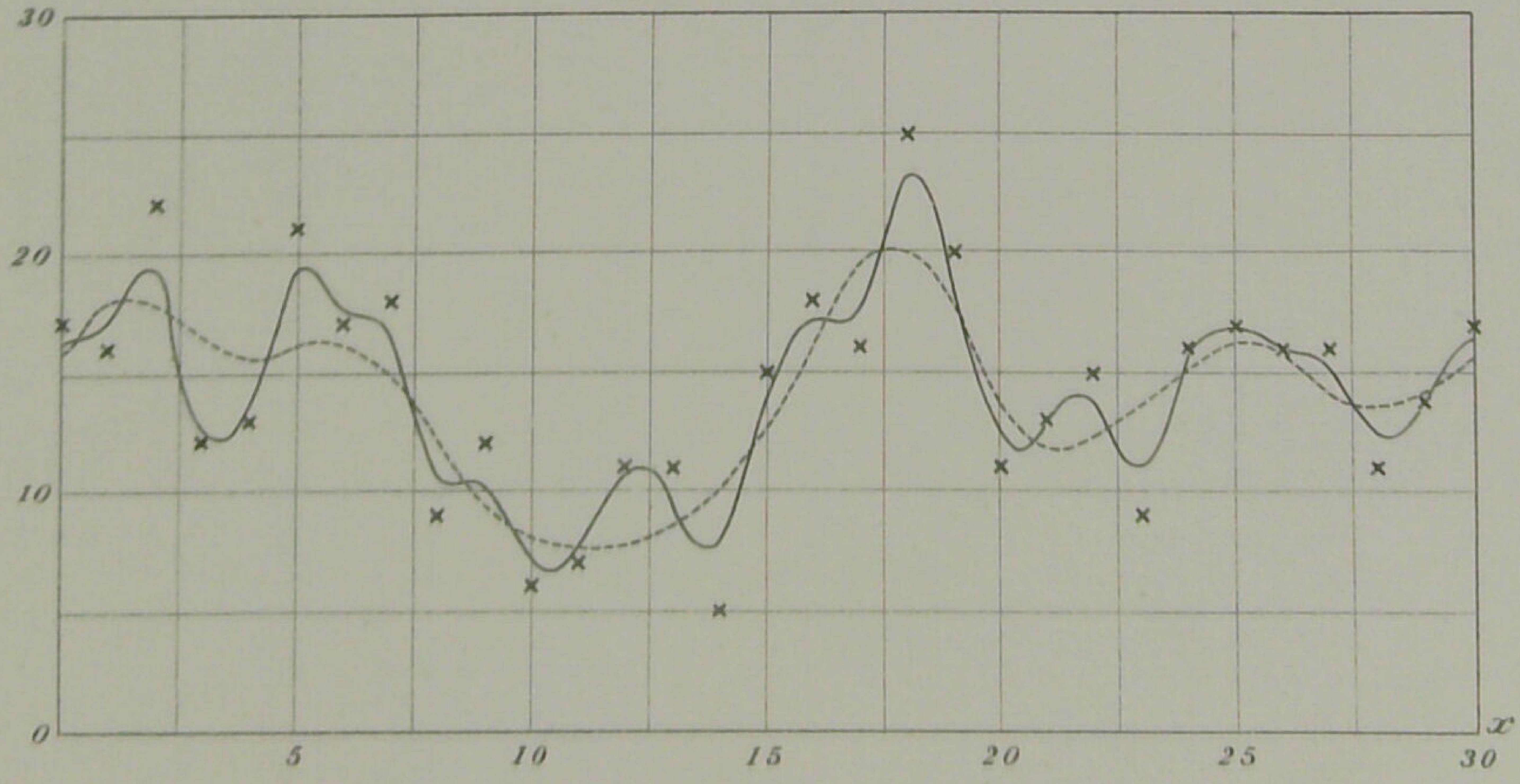


Fig. 3. Nagano.



Pl. XI.

Fig. 4. Fukuoka.

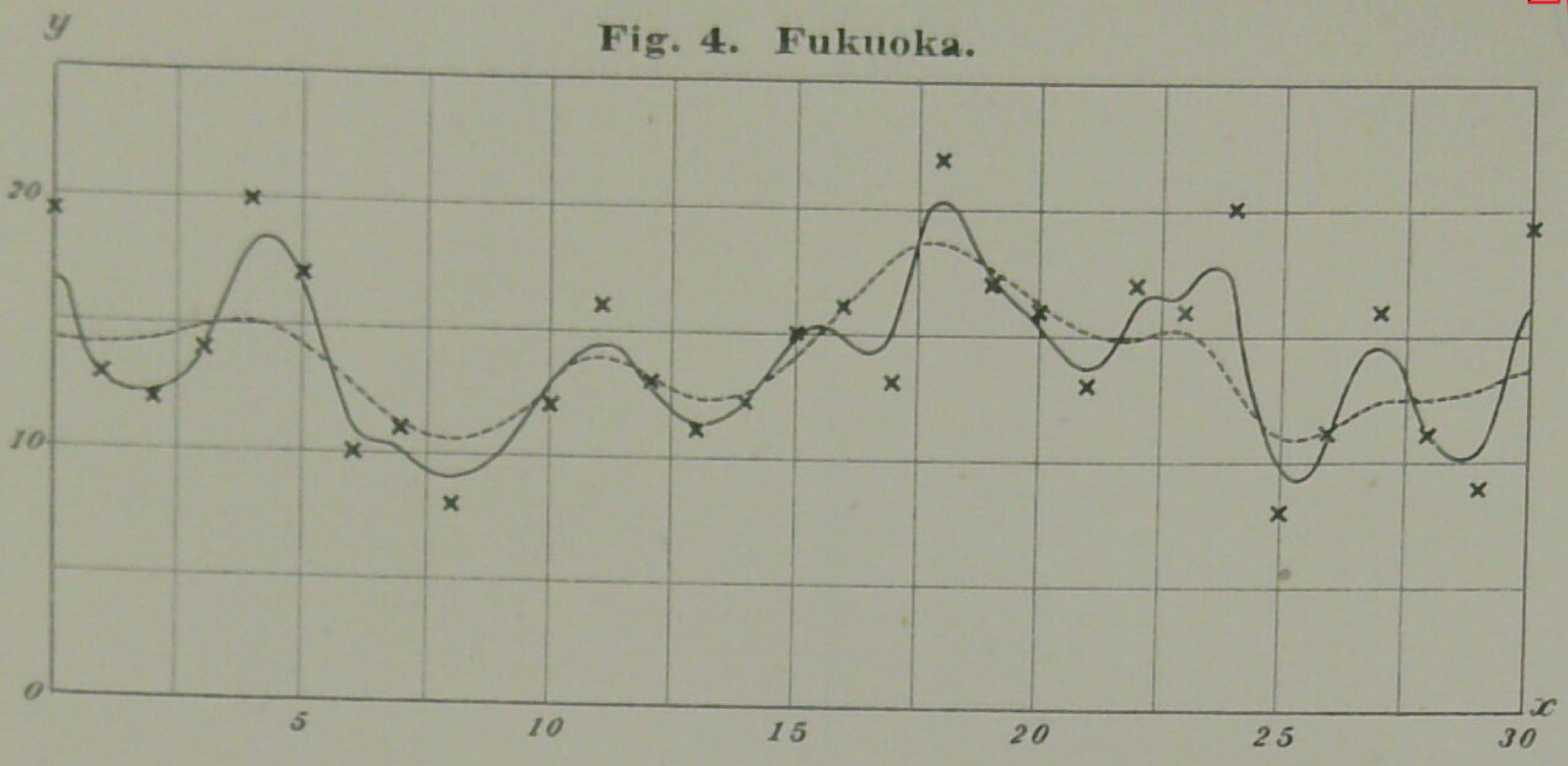


Fig. 5. Niigata.

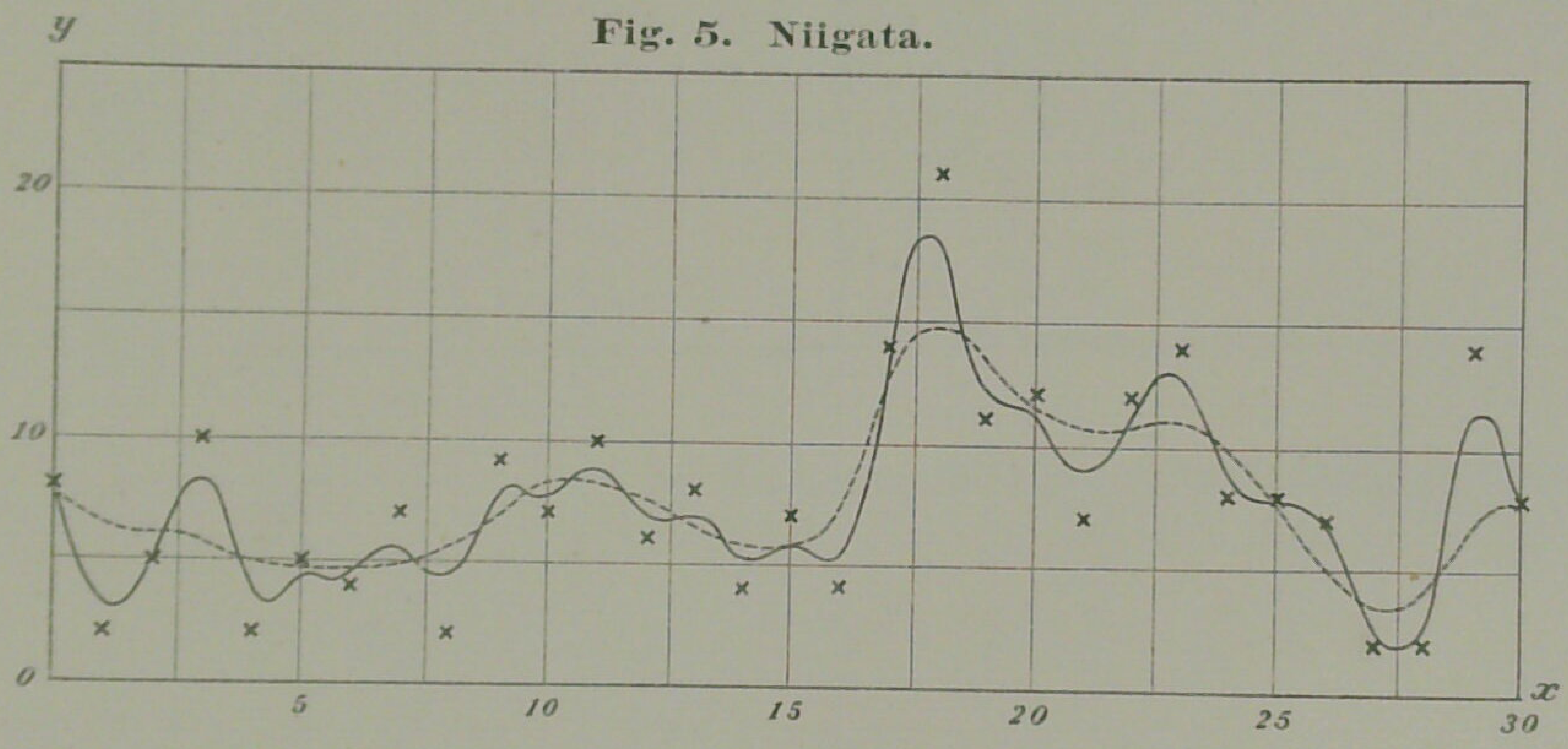


Fig. 6. Tokyo.

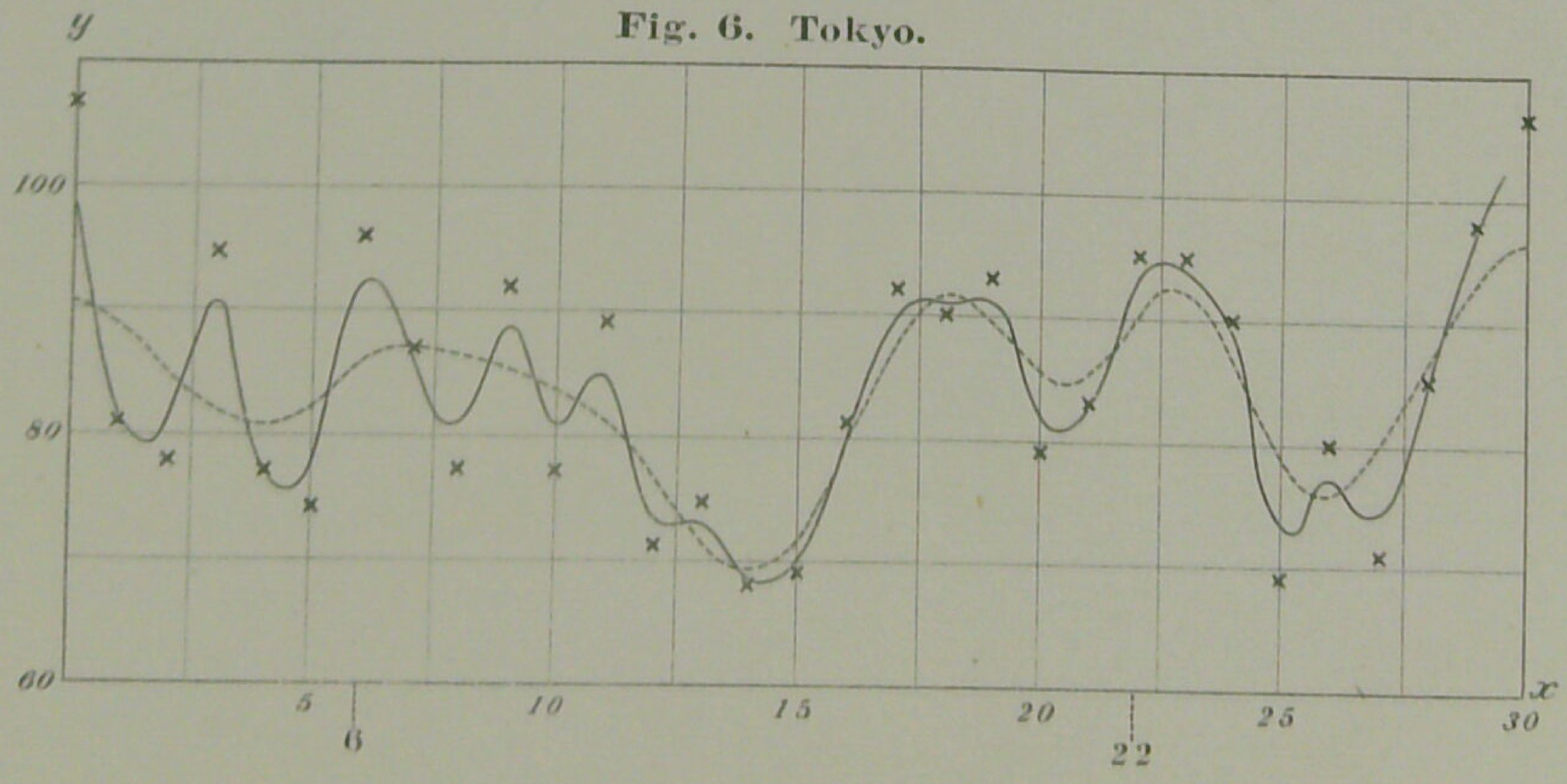


Fig. 7. Kagoshima.

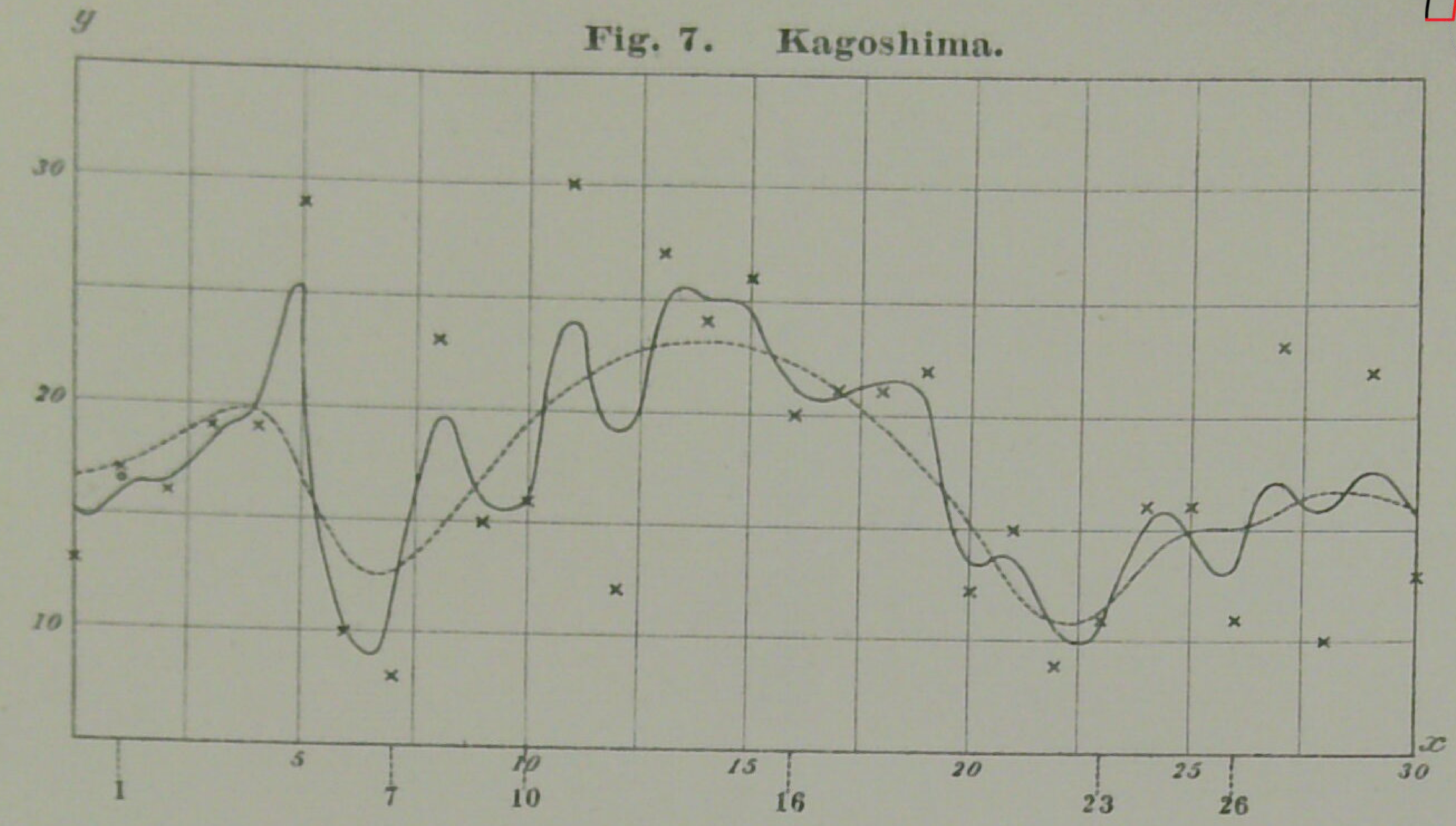


Fig. 8. Gifu.

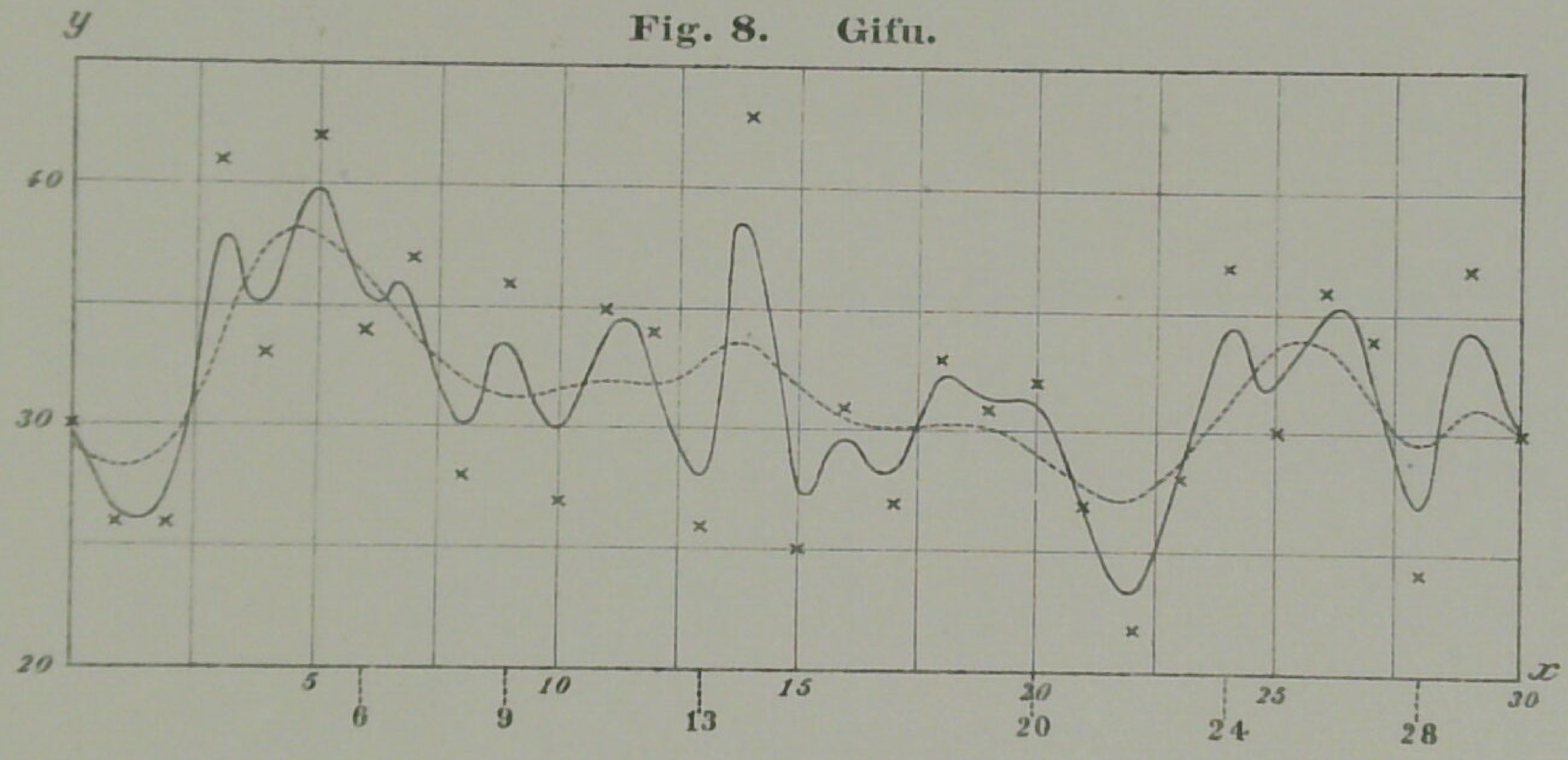


Fig. 9. Osaka.

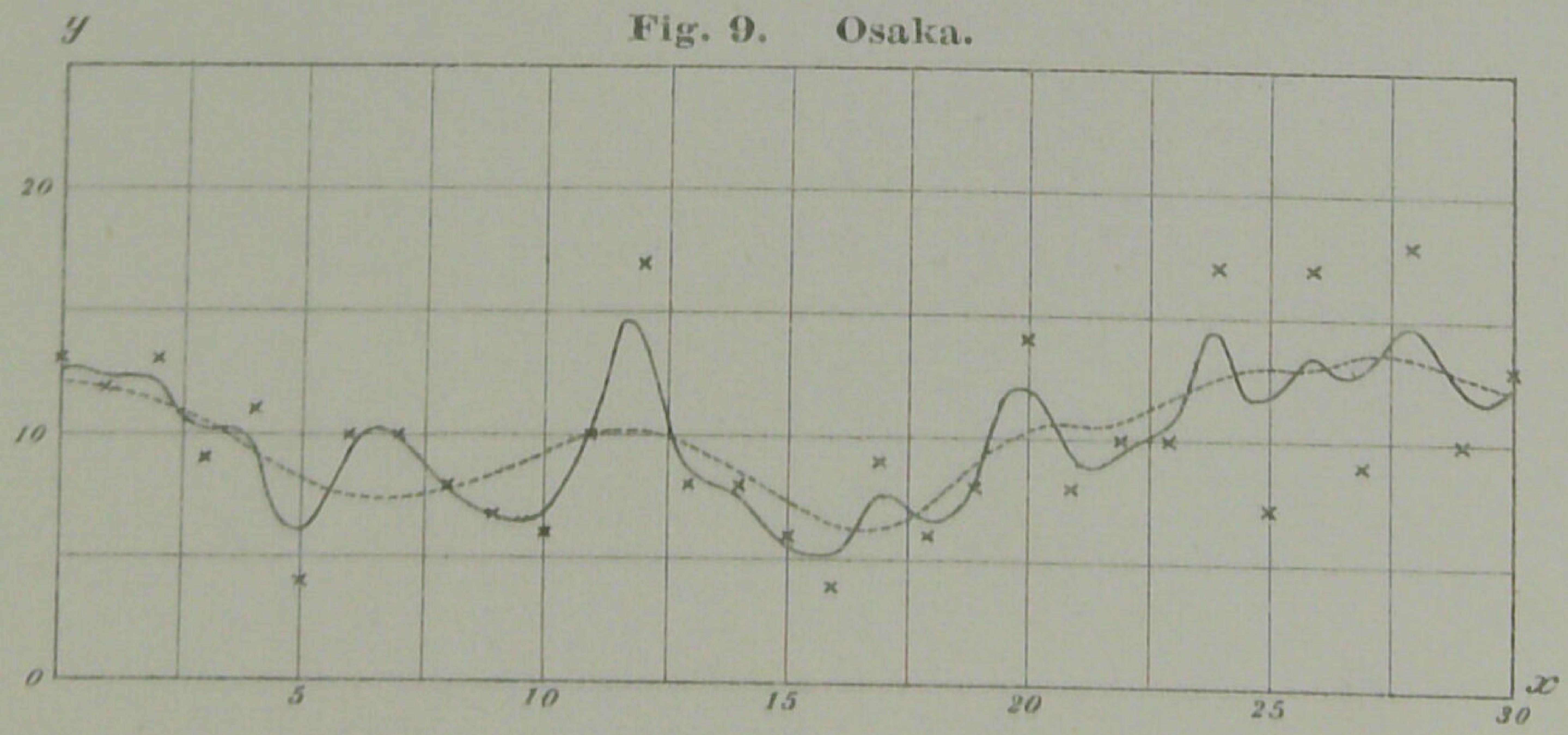


Fig. 10. **Nagoya.**

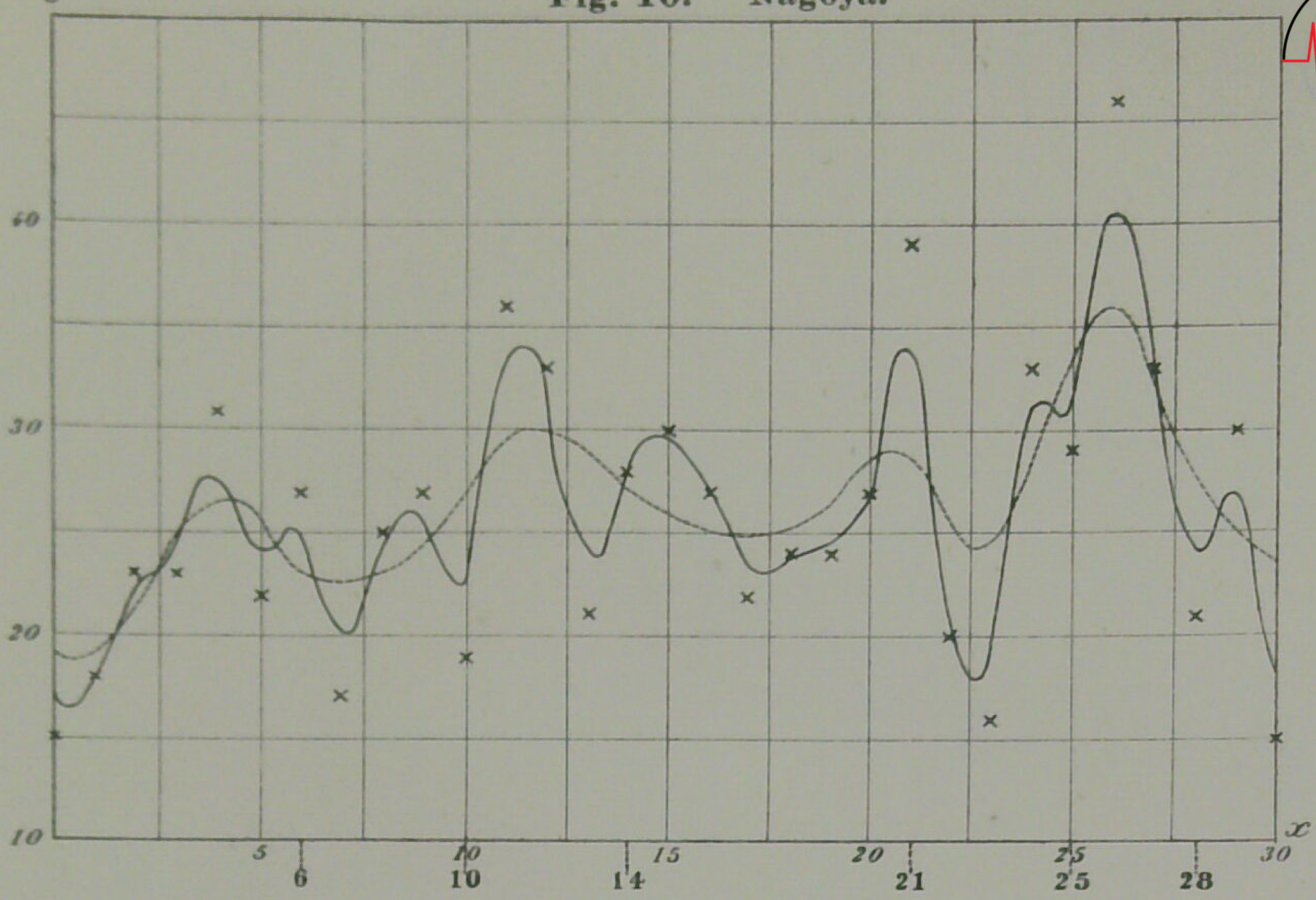


Fig. 11. **Wakayama.**

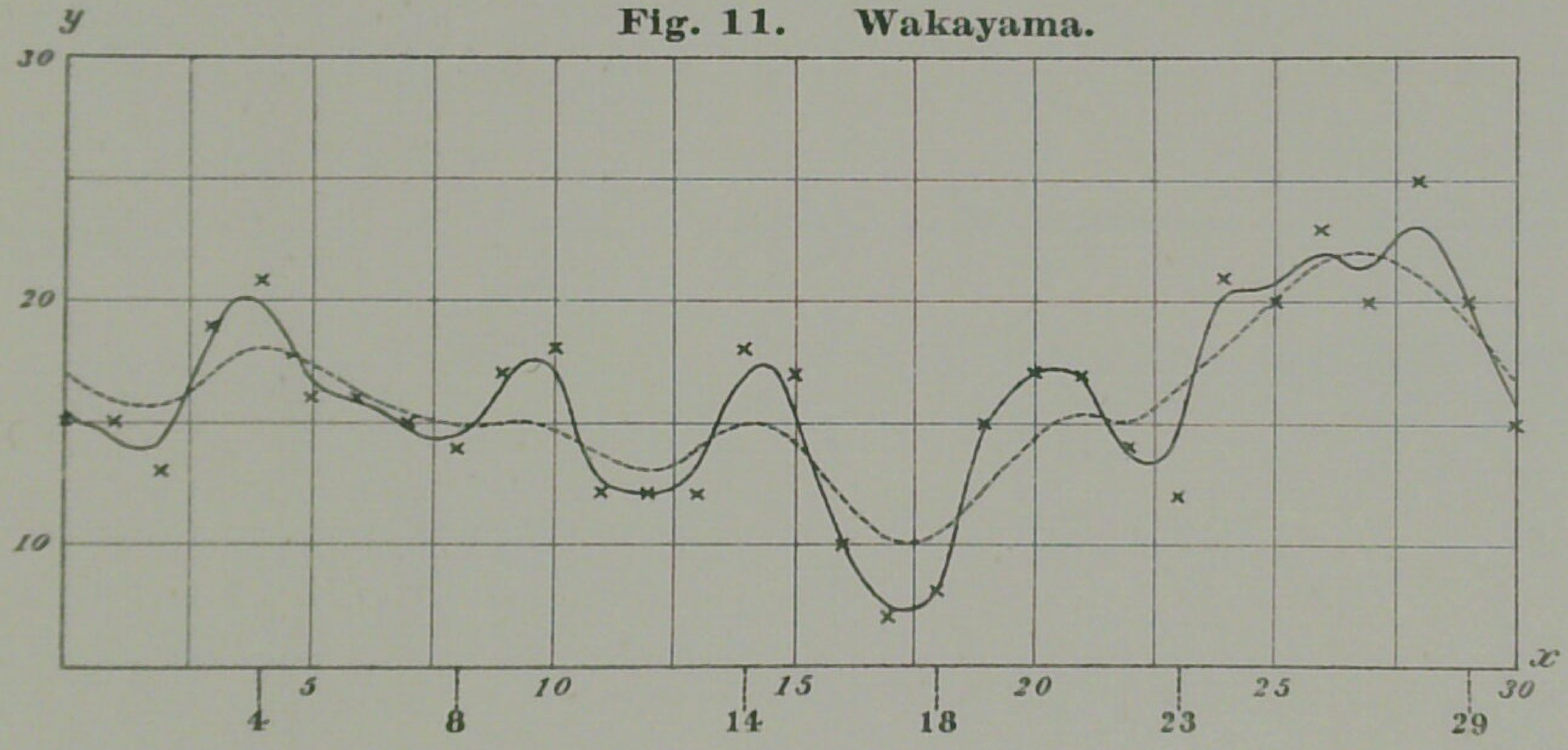


Fig. 12. **Aomori.**

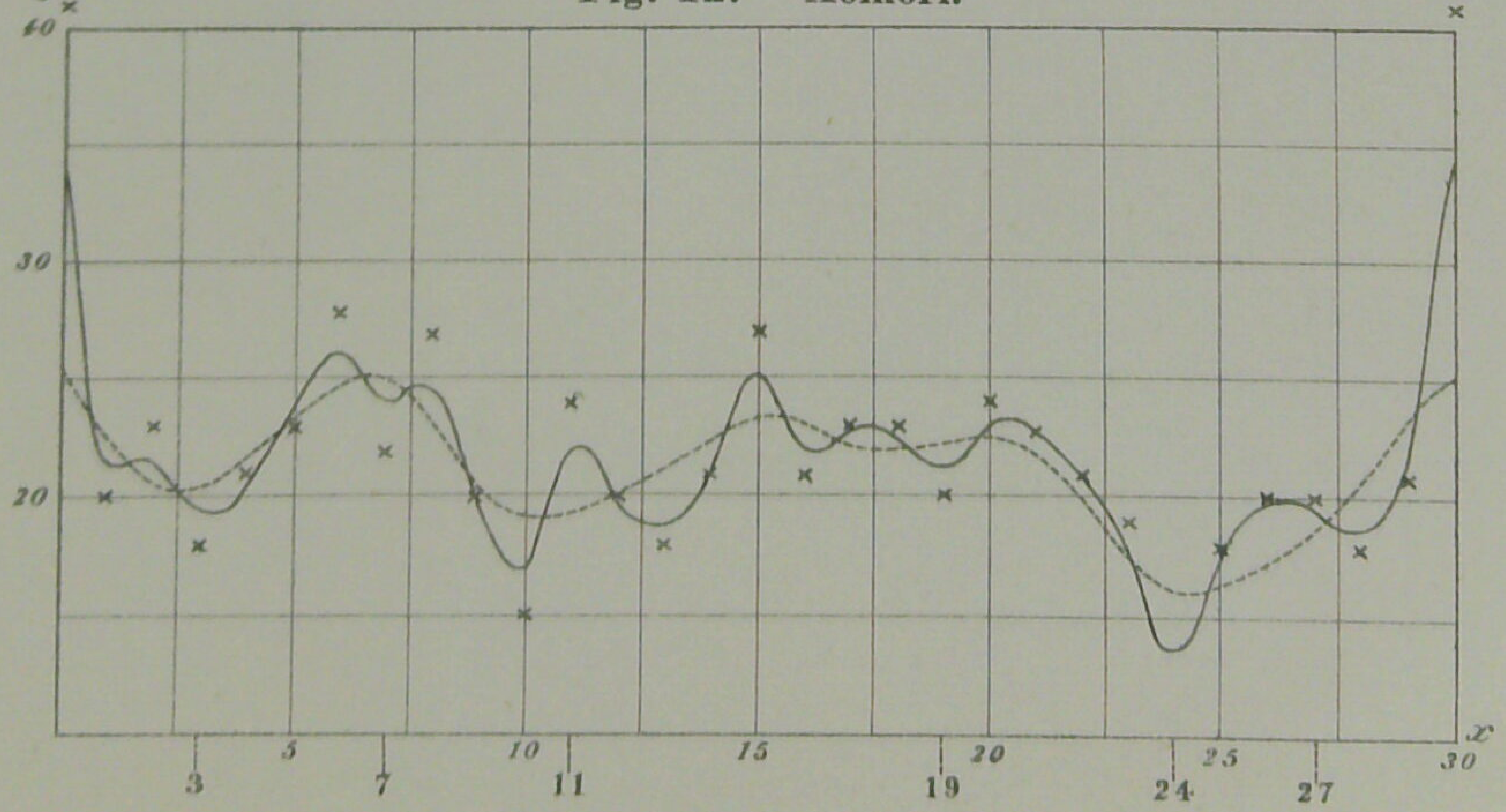


Fig. 13. Oita.

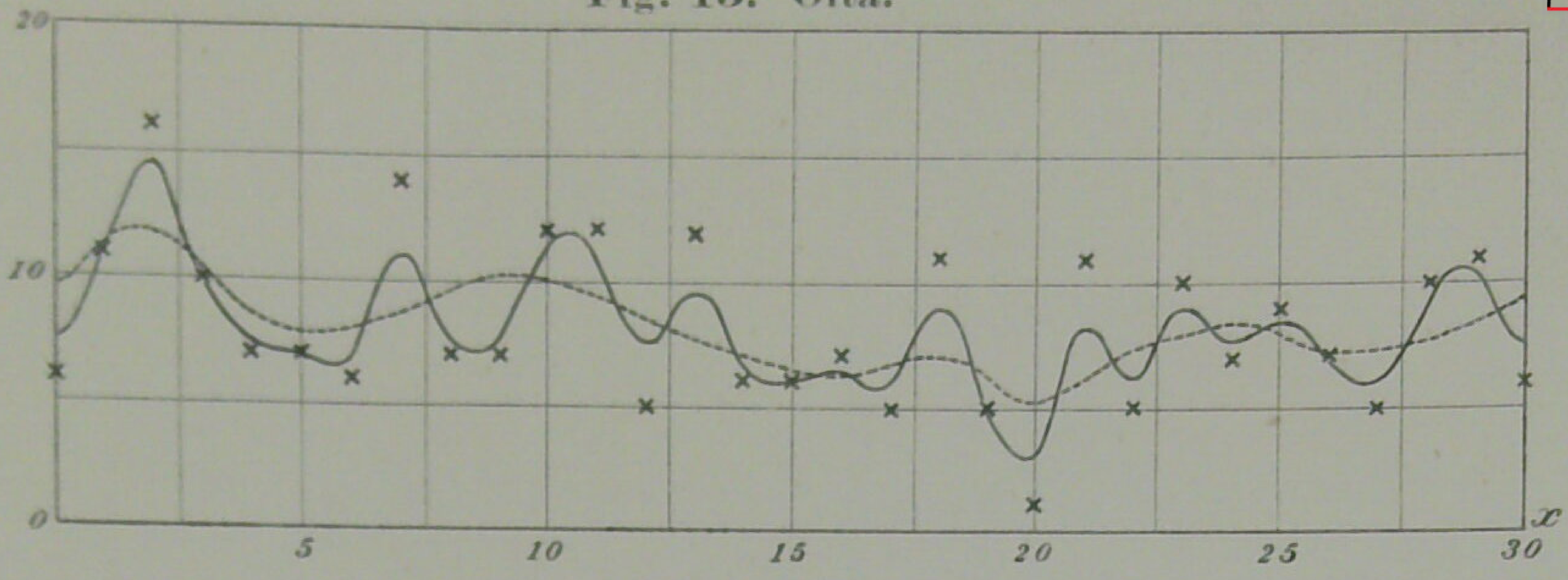


Fig. 14. Hikone.

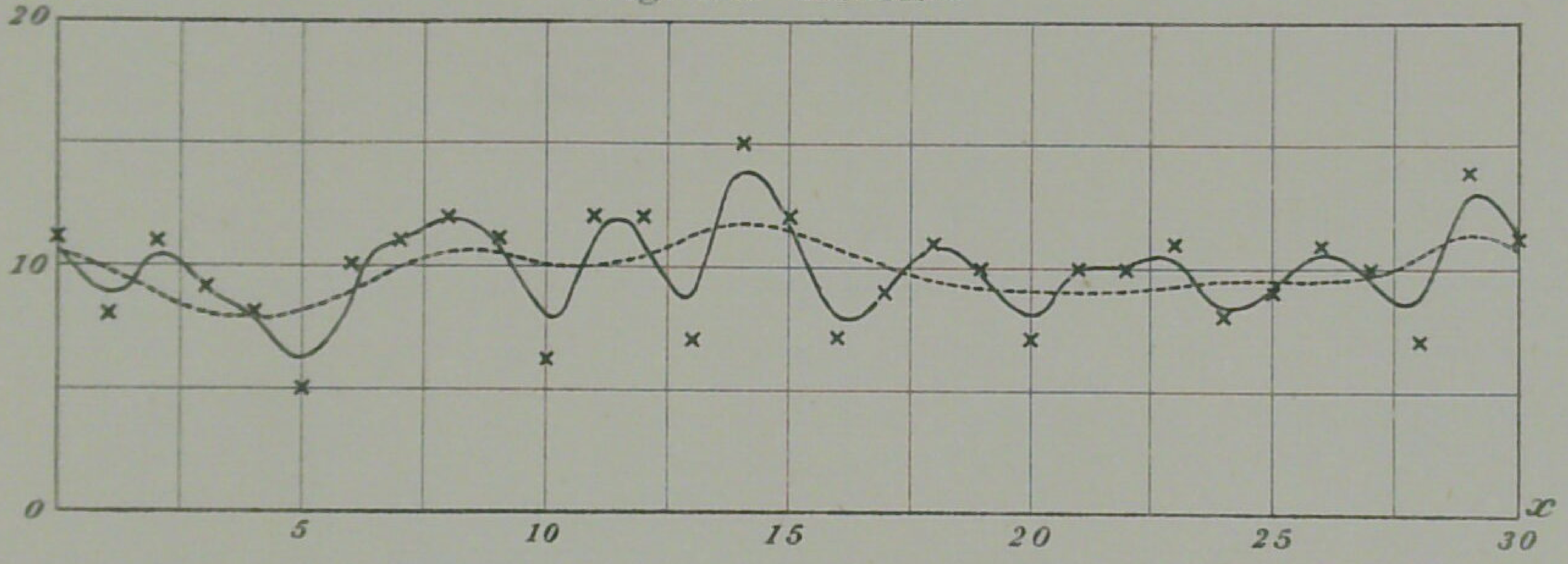


Fig. 15. Maebashi.

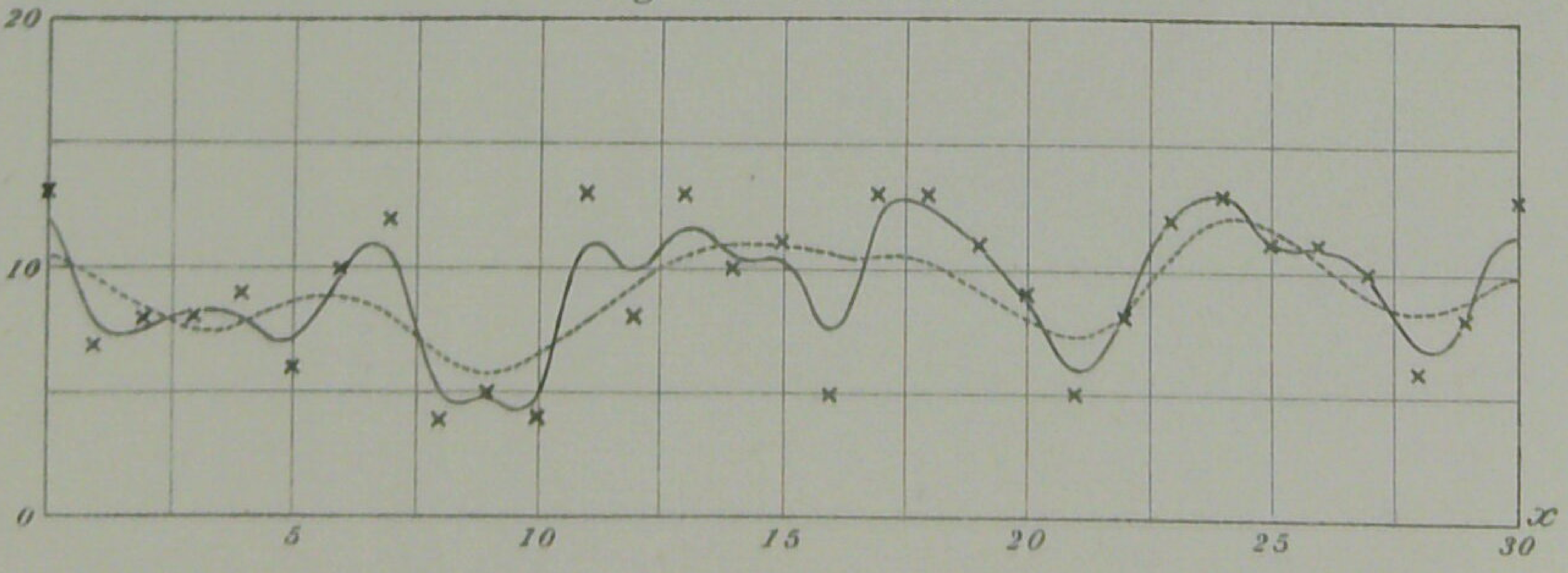


Fig. 16. Mito.

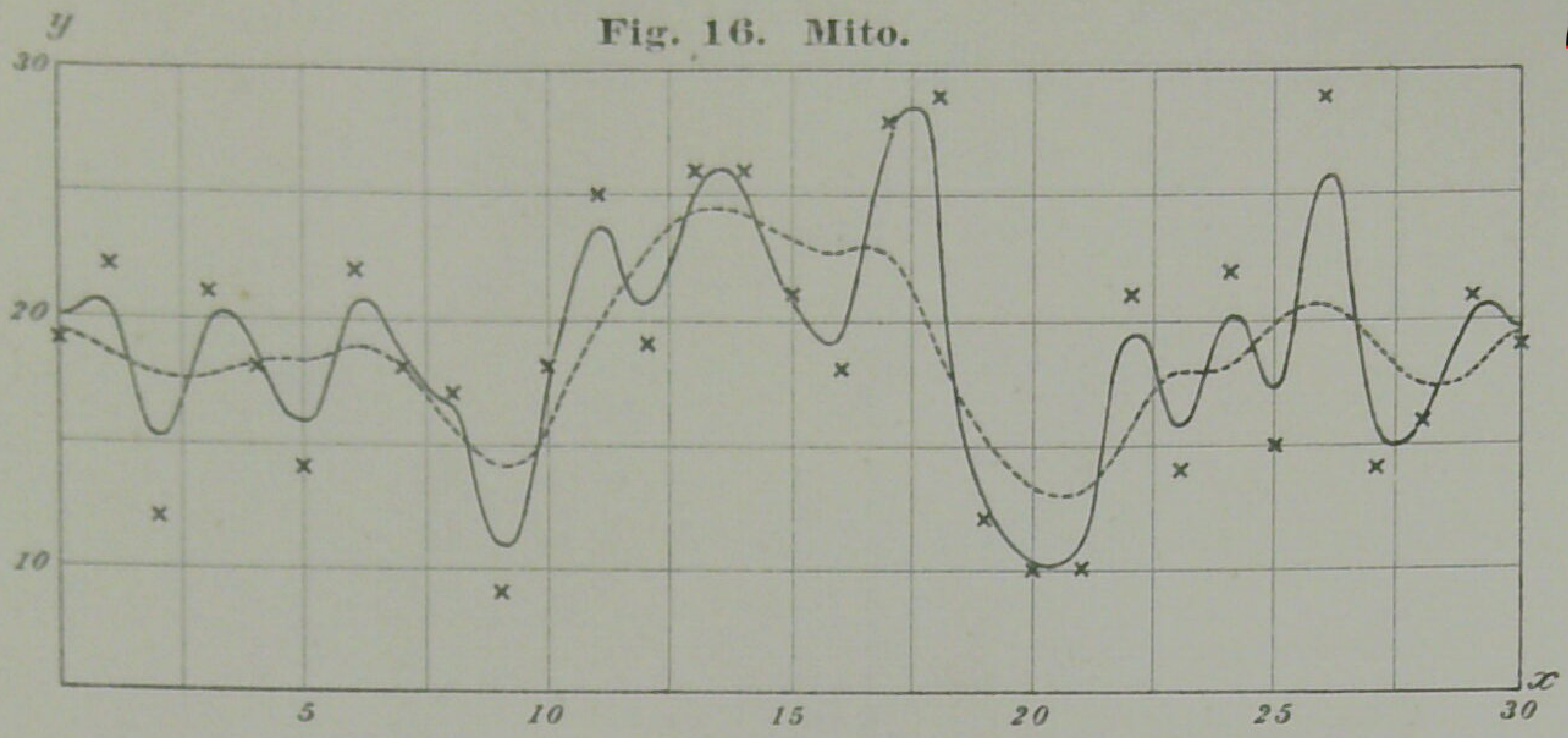


Fig. 17. Hakodate.

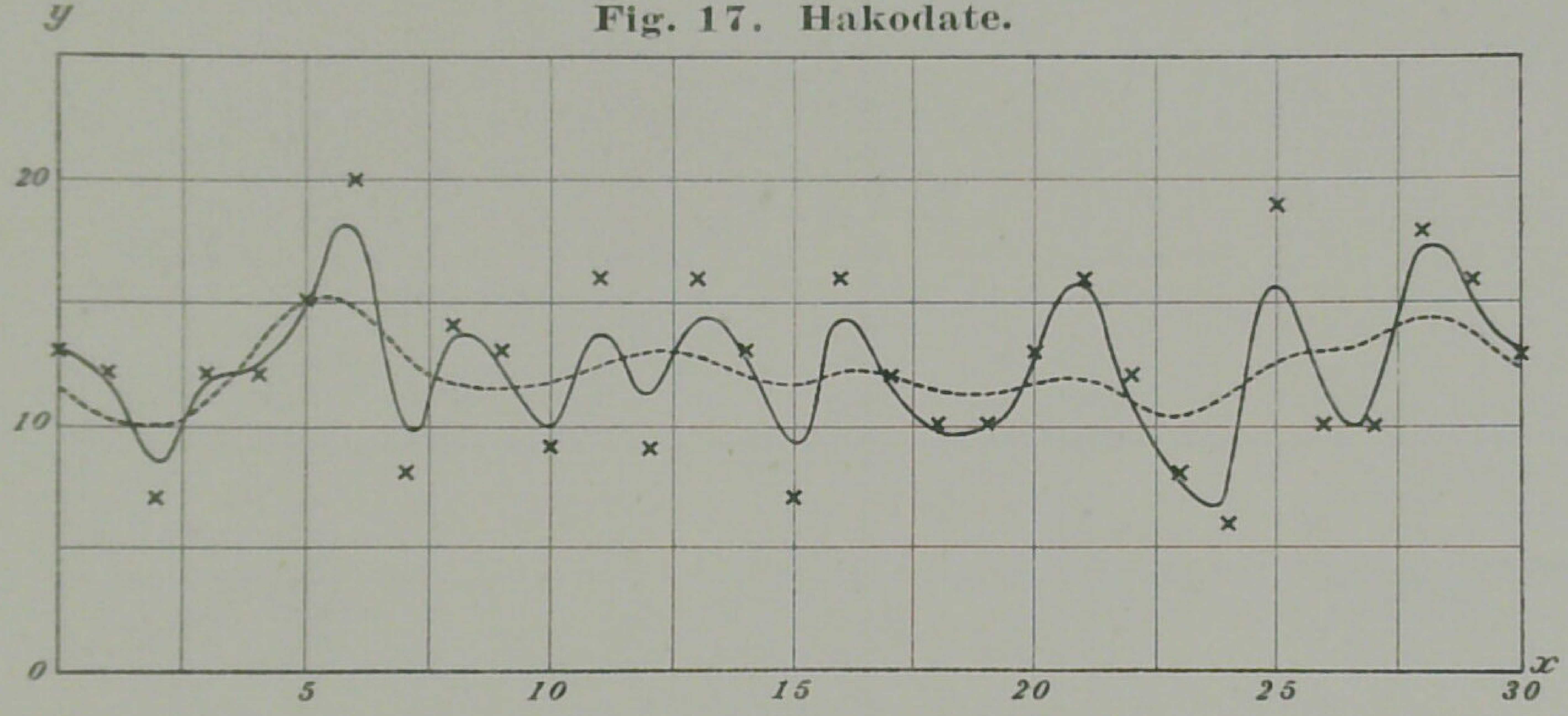


Fig. 18. Nemuro.

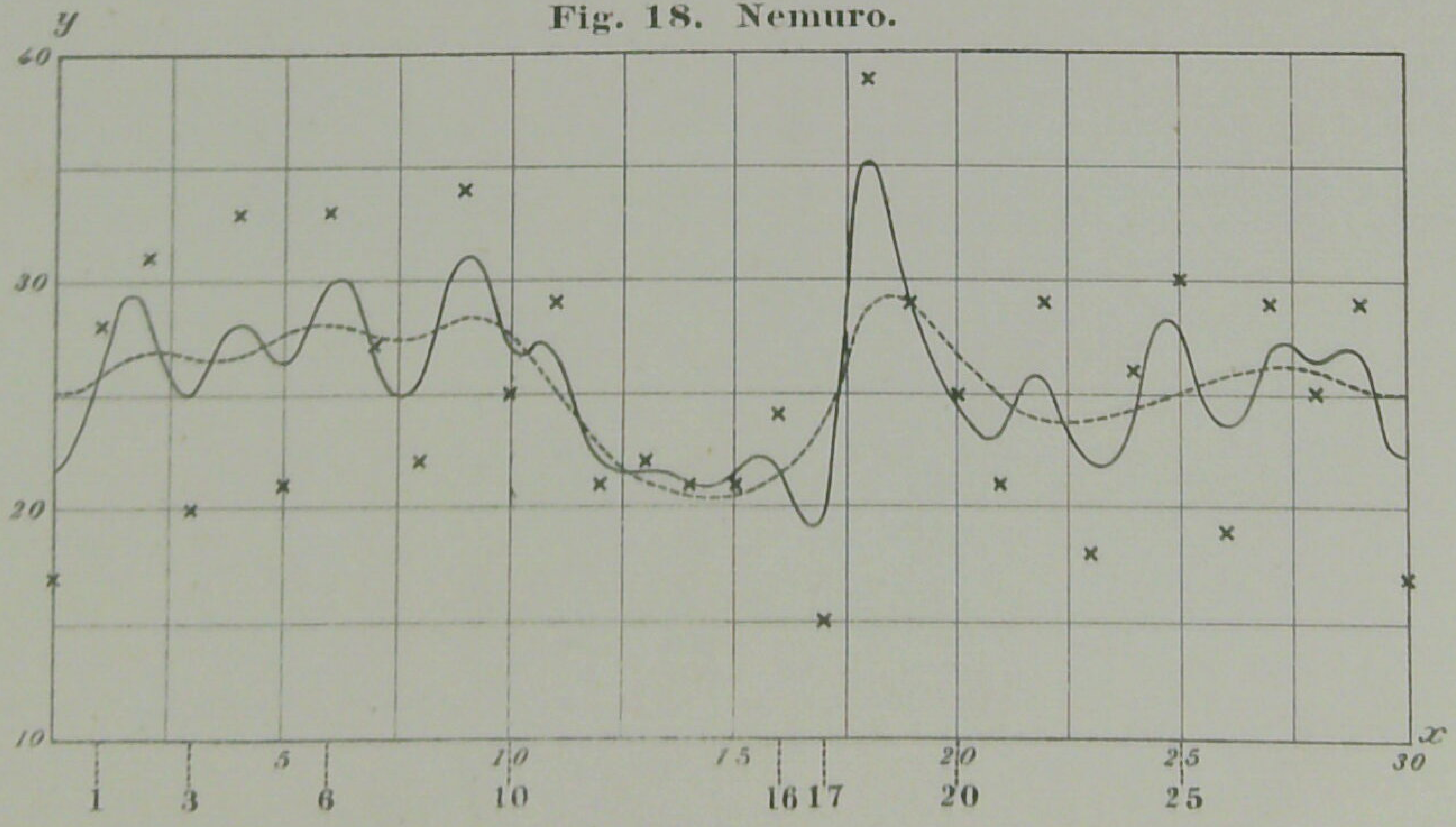


Fig. 19. Yamagata.

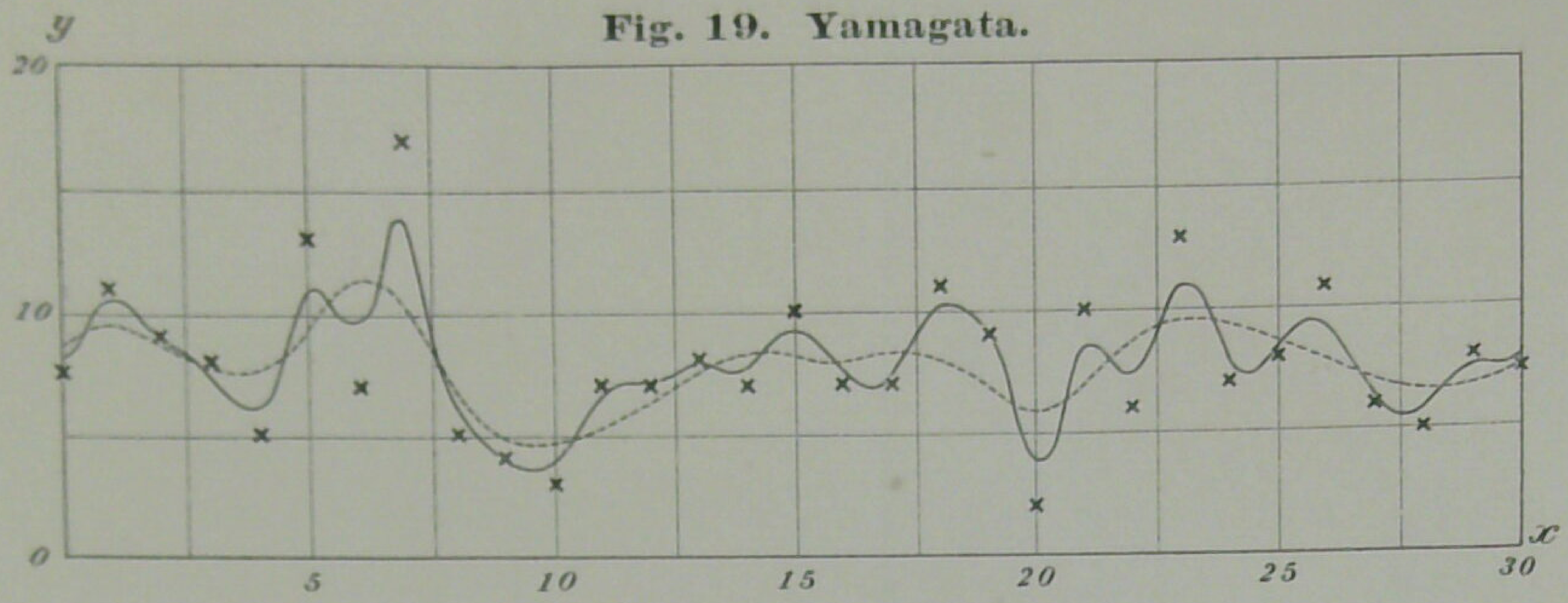


Fig. 20. Fukushima.

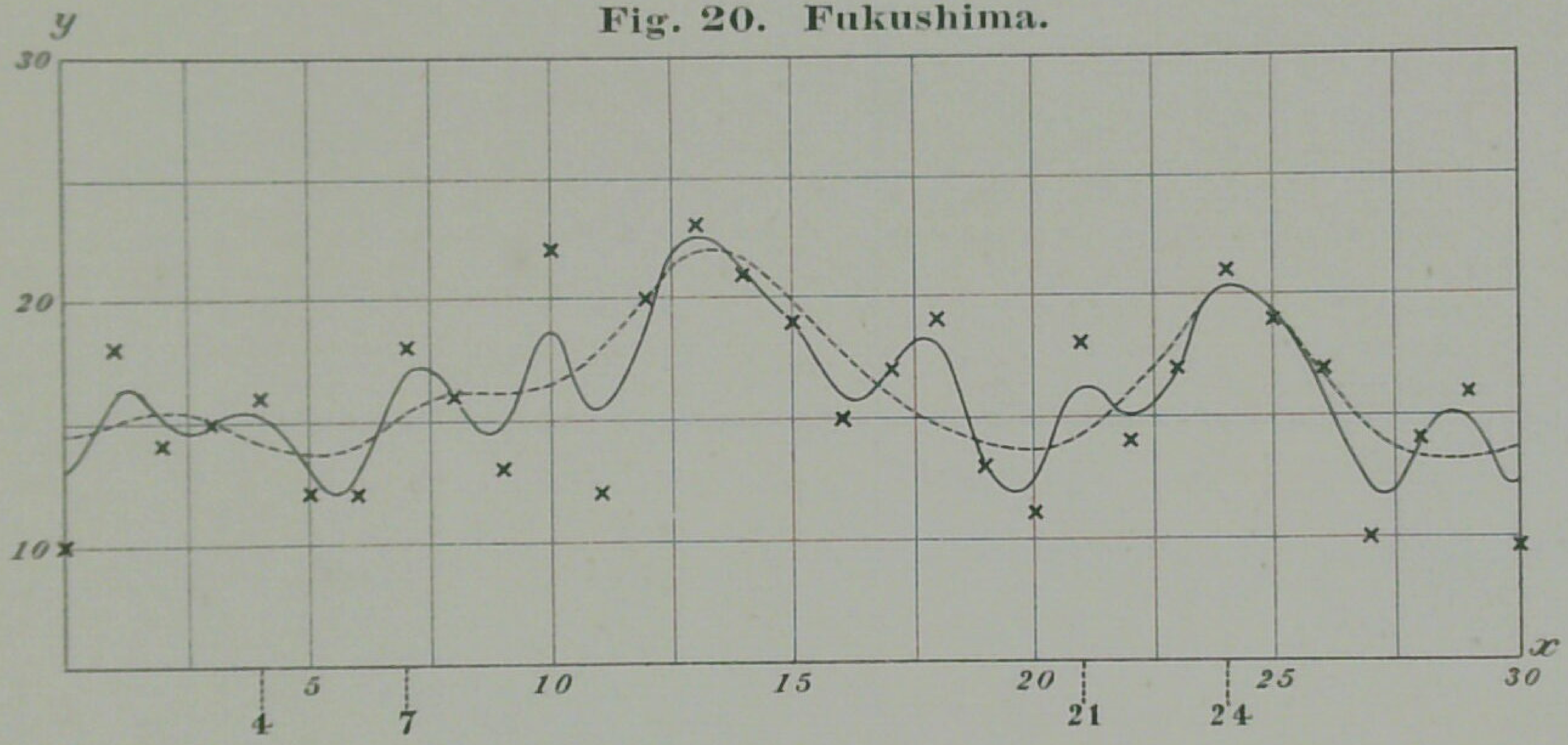


Fig. 21. Ishinomaki.

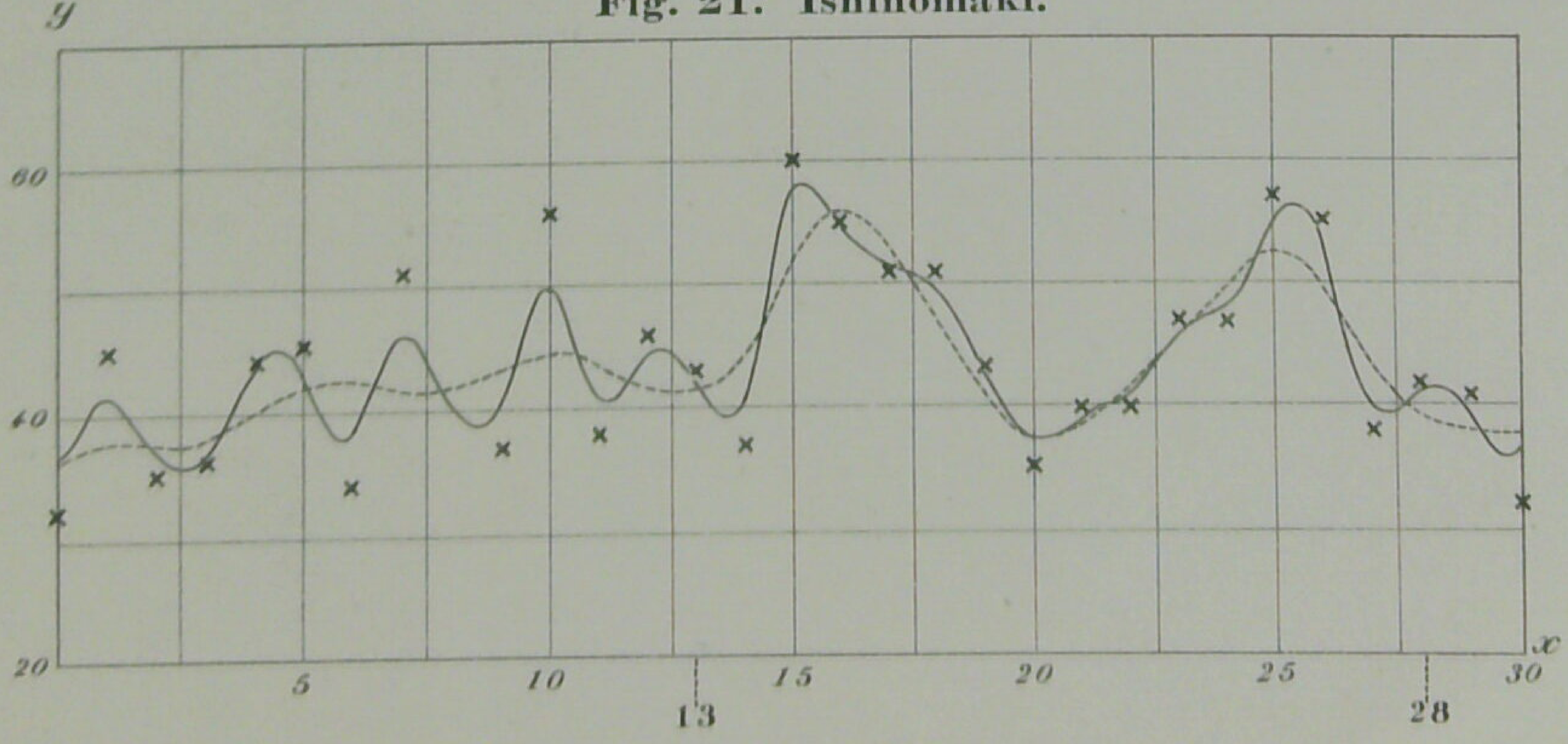


Fig. 22. Utsunomiya.

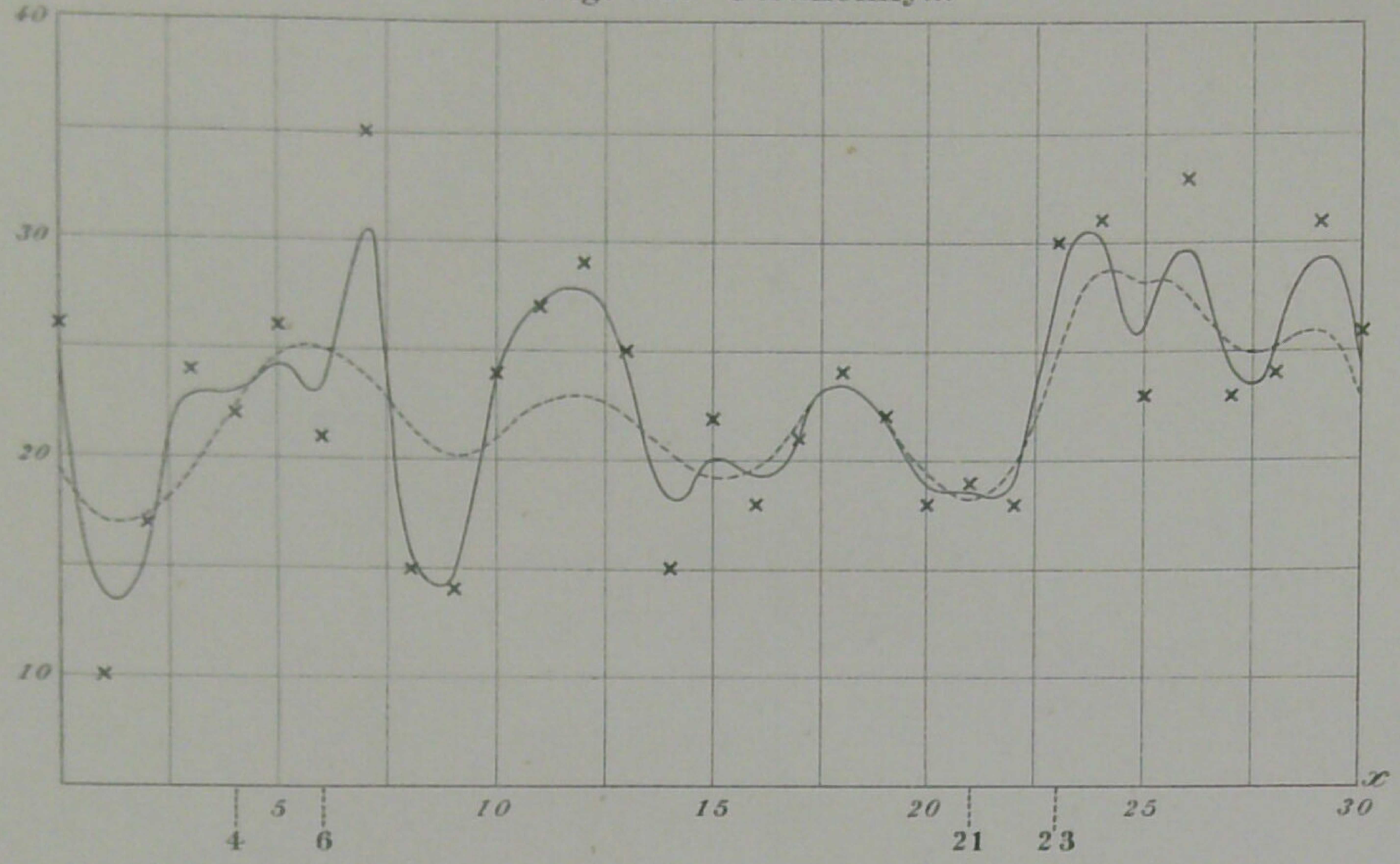


Fig. 23. Akita.

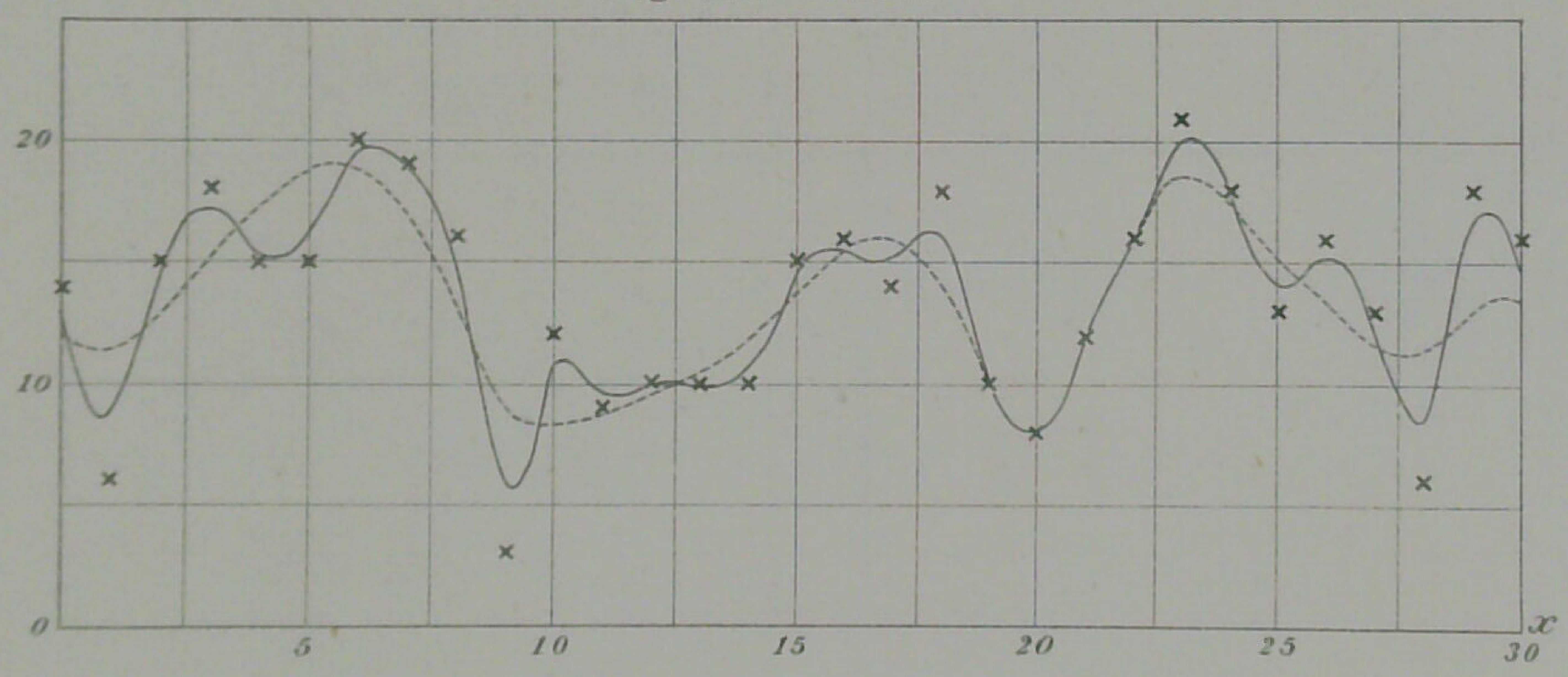
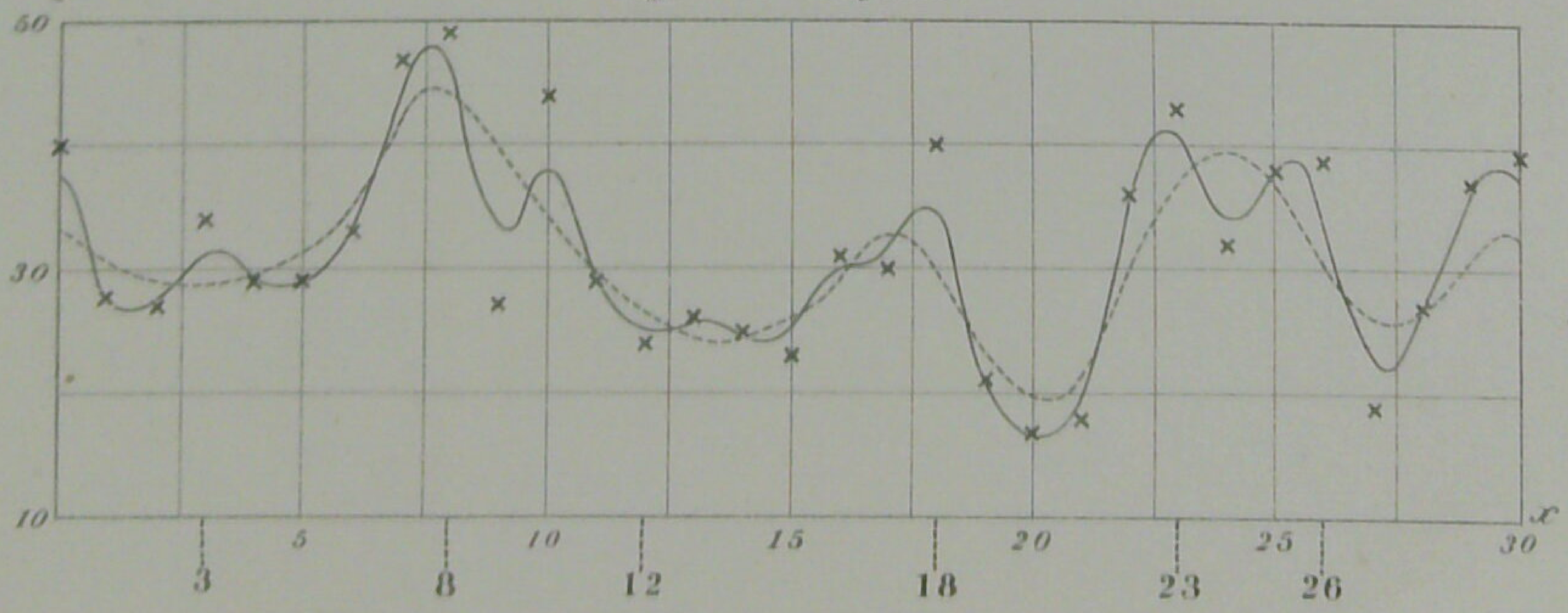


Fig. 24. Miyako.



Daily Periodic Change of the Level in Artesian Wells.

By

K. Honda, *Rigakuhakushi.*

With Plates XVIII—XXIII.

It is well known that in some natural springs, the rate of flow of water is quite parallel with the change of barometric pressure. The parallel change between the pressure and the level of the water was also observed in common wells,* which were not in use. Assistant Professor S. Nakamura observed the periodic change of the level in an artesian well in the compound of the Tōkyō Imperial University, and pointed out that its change is parallel to that of the barometric pressure, with its phase reversed. Being unable to continue this investigation, he left to me the further study of the phenomena. I also carried out similar investigations in artesian wells in Yokohama, Yoshiwara and Ōkubo. In three of these wells, the effect of the tidal motion on the level of water was observed in a remarkable manner. The following pages contain the results of observation in these wells.

Artesian Well in Tōkyō.

The well is at a place 15 m higher than the level of the sea, and 5.7 km distant from the nearest sea coast. It is 380 m deep, and its water-head is 3.2 m below the surface of the ground. The wall of the

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* Wilhelm Krebs, Meteorol. Zeitschrift VIII, p. 235, 1891. Franz Weyde, ditto, XX, p. 364, 1903.

well consists of stout iron tubes 14 cm in diameter jointed together one after another; the bottom of the well is closed by a long wooden plug, but the water may flow in or out through the interspace between the plug and the iron tube.

My arrangement which was a modification of Mr. S. Nakamura's, consisted of a buoy made of sheet zinc and a wire which was attached to the buoy and stretched vertically upwards by means of a pulley and a counter weight (Fig. 1.) The buoy carried a lead weight in its lower end, and the pulley rested in two agate caps by its horizontal axis. The motion of a point on the wire was recorded on a cylinder, rotating about a vertical axis, by a pen attached to the wire. To get the steadiness of the pen, and at the same time to diminish the friction as much as possible, the pen-holder carried two arms perpendicular

Fig 1.

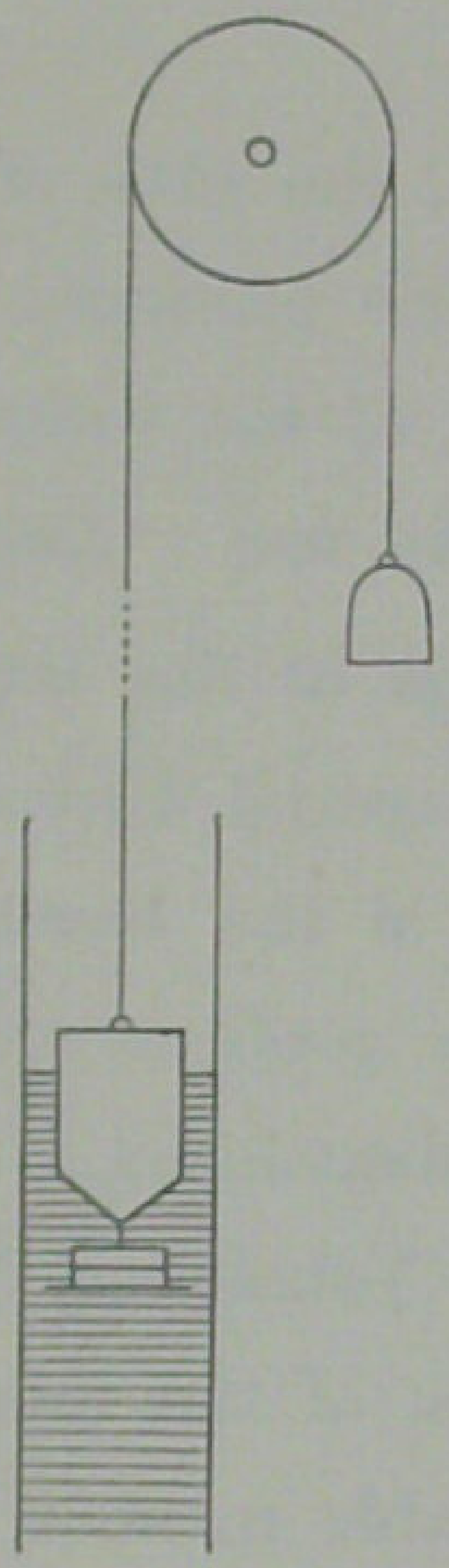
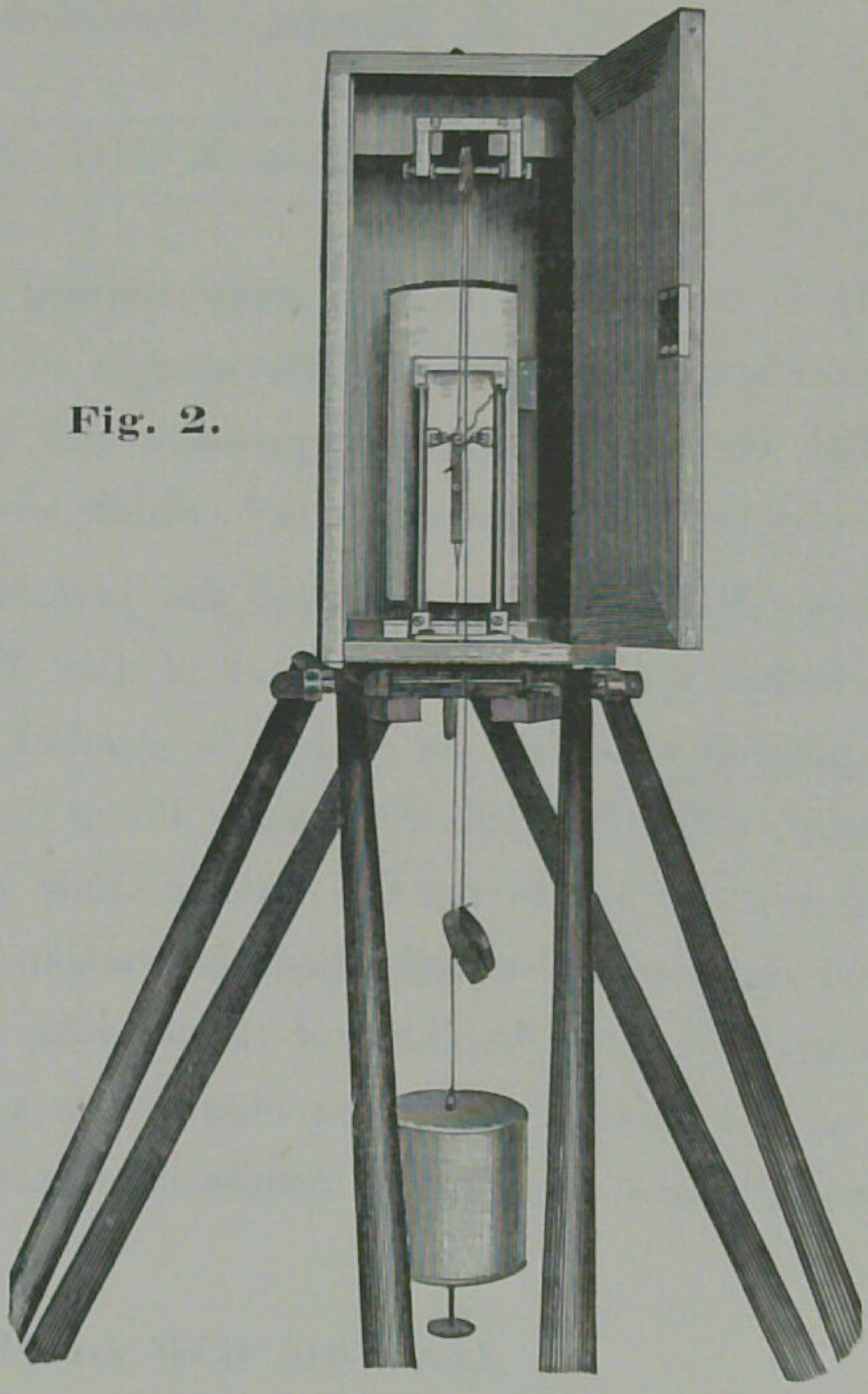


Fig. 2.



to the pen. At each end of these arms, a friction-wheel was fixed; the wheels rolled in the V-shaped grooves in two vertical guides.

The recording cylinder had the diameter of about 9 cm and revolved once per week. In some cases, the barometric pressure was also recorded on the same cylinder with the aneroid of six plates.

The present apparatus, when it is arranged as shown in Fig. 2, is very simple and portable, and may with advantages be used in the observation of the seiches.

The record was continuously taken from 4th of March to 17th of September in the last year, and also from 15th of October up to the present. Some of the records are given in Figs. 1, 2, 3. An examination of these records leads us to the following conclusions:—

1. In general the level of the water changes very regularly in passing through two maxima and minima in every 24 hours. The double amplitude varies from 3 cm to 1.

2. In days near the conjunction and the opposition, the succession of the daily maxima and minima is very regular, resembling the form of the ocean-tide. In these days, the amplitude is markedly greater than that in the quadratures.

3. The phases of the maxima and minima coincide with those of the tide in Tōkyō Bay, the high water corresponding to the high level.

4. In days near the conjunction and the opposition, the maxima and minima of the daily barometric change nearly occur at the opposite phases with that of the level; but as we recede from these days, the relative displacement of the phases proceeds in one direction. In days near the quadrature, the maxima and minima of the level change frequently occur just in the same phase as those of the barometric change.

5. The high barometer causes the lowering of the level, and the low one the rising of the level.

6. The rain or dry weather does not sensibly affect the level of the well.

As the probable causes of the change of level, we may mention

(*a*) the change of atmospheric pressure,
(*b*) the ocean-tide,
(*c*) the combined effect of these two.

The lower end of the well may probably be connected to a porous layer, filled with water and extended to a large area. The gas dissolved in water may accumulate in the upper parts of the layer and remain there compressed. Though the gas is scanty in each part, its whole volume may amount to a very large one, when integrated over the whole area; they act therefore as a large air cavity. When the atmospheric pressure increases, the water flows into this space and compresses the enclosed gases; when the pressure decreases, the water flows back into the well by the pressure of the compressed gases. The tide also causes the change of the underground pressure; this change of pressure, if it acted on the porous layer, causes the level of the well to be raised or lowered. The high water then corresponds to the rising, and the low to the falling of the level. Since the water-head of the well is about 12 m higher than that of the sea, it is not probable that the free communication exists between the well and the sea.

Comparing the curves in the barograph with those of the level change, it may safely be concluded that the high or low barometer extending for one or several days results in the change of level with amplitude magnified about 4.35 times.

As regards the causes of the daily change of the level, the daily barometric change and the ocean-tide may acts simultaneously, but judging from the forms of the curves, these two causes can not enter with equal importance, because their forms are too simple to be the effect of such a combination. If the first cause predominates, the positions of the maxima and minima can not regularly be displaced in one direction, as actually observed. The tidal effect must therefore be considered as the principal term in the daily change of level.

To assure the above inference, an arrangement artificially changing the pressure in the well was provided. A square brass plate with a hole in its middle part was horizontally soldered to the iron tube. A large bell jar was tightly fixed on the plate with the recording apparatus within it. The air inside the jar could be exhausted or compressed, the pressure of which was measured by the water or mercury manometer. With this arrangement, I studied the relation between the change of pressure and that of the level. The result is given in the following table:—

Pressure difference (p) in mercury.	Level change (h) in the well.	Ratio h/p (abs. value.)
-0.66 mm	$+7.5$ mm	11.4 mm
-1.61	$+20.5$	12.7
-4.53	$+58.7$	13.0
$+1.49$	-19.3	13.0
$+4.02$	-52.7	13.1
-9.56	$+129.2$	13.5
-241.8	$+3267.$	13.5

The above table shows that the level change for the pressure difference of 1 mm of mercury becomes greater as the change of pressure increases, soon approaching to an asymptotic value 13.5. The last pressure in the table is the pressure which was necessary to raise the level of the water to the mouth of the iron tube. The increase of the ratio h/p with the pressure may be explained to be the effect of the plug at the bottom of the well, because it prevents free motion of the water. The above result indicates the existence of the space filled with evolved gases, as I have already remarked.

When the pressure was applied or reduced, the level descended or ascended according to the logarithmic law with respect to time, as shown in Fig. 4. The form of the curve for the application of pressure or of exhaustion is always steeper than that for the release. It is to be remarked that though a given pressure was first applied, the level change caused the change of the volume in the enclosed air, and therefore the pressure was continuously changing as the time proceeds, till its final value was reached.

It appears from the above experiment that the daily change of the level is of such an amplitude as to be wholly explained by the daily barometric change. But it must be noticed that if the atmospheric pressure changes, it is partly transmitted through the earth crust and therefore the underground pressure must be affected. This change of the underground pressure produces the opposite effect on the level as the pressure acting on the head of the water. Thus the natural pressure produces the differential effect, so that the change of level for the pressure difference of 1 mm of mercury is only 4.35 mm, as actually observed. Hence the level change by the atmospheric pressure amounts only to 32 % of the change by the artificial pressure; the earth crust transmits therefore about 68 % of the pressure on its surface to a depth of 380 m. By the above consideration, it is now clear that the daily change of pressure generally causes the change of level ranging from 7 mm to 2. Since the amplitude of the daily level change is from 3 cm to 1, the barometric change must be considered as of second importance in the daily change of the level. The principal cause is then the tidal motion; as we have noticed, the phase of the level change is the same as that of the tide in Tōkyō Bay, and therefore the phenomenon must be considered as due to the tidal pressure. All the particulars above enumerated are well explained by this consideration.

As we have already remarked, the high pressure causes the falling of the level and the low the rising of it. If, however, the jar be sealed air-tight and also thermally, the effect of high and low pressures would reverse the phase of the level-change, because in this case, the pressure above the level does not change, while it acts on the neighbouring earth crust. To test this point, the jar was completely sealed and thickly covered with blankets and saw dust; the effect of the change of temperature was thus avoided. In this case, we also observed two maxima and minima in every 24 hours with the phases coinciding with those of the tide. The high and low barometers caused the rising and the falling of the level respectively, as it was expected. Fig. 5 is an example. In all cases, the amount of the level change was considerably reduced.

The reduction of the level change can be calculated in the following way. Let S be the area of the cross section of the iron tube, l its whole length, and h the height of the water level from the bottom of the well. Let p and P be the pressure of the sealed air and the underground pressure at the bottom of the well respectively, both expressed by water column. Then we get two equations

$$p+h=P \text{ and } pS\,(l-h)=\text{const.}$$

$$\therefore \qquad \frac{dh}{dP}=\frac{l-h}{p+l-h}=\frac{1}{1+\dfrac{p}{l-h}}\,.$$

In the present experiment,

$p=76\times 13.6=1030$, and $l-h$ is equivalent to 539 cm;

therefore $$\frac{dh}{dP}=0.343,$$

which gives the rate of the level change due to unit change of underground pressure. As an example, we take a high barometer on 23rd—24th of September, 1903; the pressure difference in the noons of these days was 9.98 mm. The corresponding change of underground pressure at the bottom of the well is therefore 6.78 mm and its equivalent water column is 9.25 cm, so that

$$dP=9.25 \text{ and } dh=0.343\times 9.25=3.17 \text{ cm.}$$

The actually observed value is 3.1 cm, which fairly agrees with the above calculation.

Near the artesian well, there is a common well 10 m deep; its level change was observed with a similar arrangement. Neither the pressure nor the tide affected, in a least degree, the level of the well; but the level was greatly influenced by the rain.

In passing it may be observed that in our records we sometimes observed a very regular harmonic curve (Fig. 6), in several successions, which if not so distinct, appeared also in the barograph; the period of oscillations was about 29 minutes. Thus, it is evident that in the atmosphere, such an oscillation is sometimes produced.

Artesian well in Yokohama.

The well at Negishi in Yokohama is about 2 m higher than the sea level and 2 km distant from the sea coast. It is 300 m deep; its upper 30 m is protected with iron tubes 15.3 cm in diameter. The well belongs to Mr. Numashima, to whom my best thanks are due. The water in the well was constantly flowing out over the tube; it was therefore necessary, for my experiment, to raise the head of the water to a suitable height so as to stop the flow of water. An iron tube 5 cm in diameter and 8 m long was vertically erected and tightly jointed to the thick tube by means of a joint-piece. The water soon rose to a height of about 3 m from the earth surface; it was therefore difficult to arrange my apparatus at such a high place. But the preliminary experiment showed that the daily level change was more than 12 cm; the following arrangement was therefore adopted.

Near the earth surface, a small side tube was branched; through a cork plug, it entered into a large bottle containing a quantity of mercury. From the bottom of the bottle, a glass tube 5 mm thick was erected through the cork; the upper part of the tube was about 4 times thicker. The mercury in the bottle then arose in this tube by the pressure of the water column. The level change in the main tube appeared then as the motion of the mercury-meniscus in the glass tube, its amplitude being reduced to $^1/_{14.1}$. To record the motion of the meniscus on a cylinder, a hollow ebonite disk with a vertical wooden rod was floated on the mercury. The upper end of the rod carried a pen of a similar construction as that used in the Tōkyō artesian well, and the motion of the pen was also guided by two vertical rods.

The record was taken from 18th of last November to 7th of February in this year. Figs. 7 and 8 are two examples. The following is the result of observations:—

(1) The mean level of the water during the day constantly increased from the first day when the tube was erected, up to the the 97th. The mean levels in several days are given in the following table:—

Nov. 14, 2^h P. M., 1903	3.10 M
15, noon	3.90
16, ,,	4.25
18, ,,	4.65
22, ,,	5.28
30, ,,	5.64
Dec. 10, ,,	6.11
20, ,,	6.42
30, ,,	6.70
Jan. 10, ,, 1904	6.87
20, ,,	7.00

Thus the rate of increase of the level becomes gradually less; but it does not vanish up to February 20th. The mean level increased more than double its initial value during about 60 days.

(2) The daily level change has an amplitude of about 10–14 cm, the phase of the change coinciding with that of the tidal motion in Tōkyō Bay.

(3) The atmospheric pressure has the similar effect on the level change as in the Tōkyō well. The level change for the pressure difference of 1 mm of mercury is 3.6 mm, a value little less than that in Tōkyō.

The constant increase of the mean level shows that the porous layer which feeds the well extends to some distant high places. The stopping of the flow may probably raise the level of the underground water in these places, and consequently causes the steady increase of the level.

It is obvious that the daily change of the level is due to the pressure of the tidal motion in the Bay. In Negishi, a canal 20 m wide passes by the well, and its level is affected by the tide by about 1 m. But the comparison of the phase of the level change with that in the well showed that the level in the well was not connected with the canal water.

Since the level change in the well was reduced to about $\frac{1}{14}$ of its actual size, the effect of a small barometric change did not appear in the curves recorded on the cylinder. The curves are therefore very simple, showing distinctly the form of the ocean-tide. It is interesting to observe that the positions of the maxima and minima of the curves in Tōkyō and Yokohama fairly coincide with each other.

An experiment of the artificial pressure was also performed with the results given in the following table:

Pressure difference in mercury.	Ratio h/p (abs. value).
+ 0.78 mm	11.2 mm
− 0.51	11.5
− 1.02	13.2
− 3.91	13.4
− 5.30	13.6
+11.40	13.6

Thus the asymptotic value of the level change per 1 mm of mercury is again 13,6 mm. In the well, the level changed almost instantaneously by applying the pressure or the exhaustion.

Now the artificial pressure causes the level change of 13.6 mm for the pressure difference of 1 mm of mercury, while the atmospheric pressure only causes the level change of 3.6 mm for the same change of pressure. The earth crust in the neighbourhood of the well transmits therefore 74 % of the pressure acting on the surface to a layer which feeds the well.

When the upper part of the main tube was replaced by a glass tube and the motion of the meniscus followed by the eye, a minute fluctuation of the level was observed, indicating that the atmospheric pressure was varying.* The amplitude of the minute level change increased in windy weather; in a breezing day, level oscillations with the amplitude of 0.1–0.7 mm and with the period of 3–4 sec. were observed. In the experiment, the effect of aspiration was excluded by leading the mouth of the tube to a calm place by a lead tube.

Since the barometric oscillations of such a short period are extremely local, this change of the atmospheric pressure must have the same effect as the artificial pressure applied directly on the head of the water; that is, it will cause the level change of 13.6 mm by the pressure difference of 1 mm of mercury. The motion of the meniscus can also be magnified 10 times or more, by inclining the glass tube, so that the pressure change of 1 mm of mercury produces the motion of the meniscus by 136 mm or the more.

Artesian well in Yoshiwara.

The well in Yoshiwara in the province of Suruga is about 10 m higher than the sea level, and 3.3 km distant from the sea-coast; it is only 24 m deep and its wall consists of bamboo tubes. The well belongs to Mr. Kawashima, to whom my best thanks are due. The water was flowing out over the tube, and therefore the flow was stopped by making the head of water with a thick tube 20 cm in diameter, but the water only rose to a mean height of about 1 m above the earth surface and did not increase with time.

The arrangement used in the well was the same as in Tōkyō; the record was taken from 3rd to 21th of January in this year. The following is the result of observation.

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* M. Toepler, Ann. der Phy. 12, 787, 1903.

(1) The daily level change (Fig. 9) is the exact copy of the tidal motion. Its amplitude is about 8–11 cm, and the phase of the level change coincides with that of the tide.

(2) The slow change of the barometric pressure does not seem to affect the level of the water.

(3) The effect of artificial pressure is the same as in the former two cases. The level changed almost instantaneously by the application of pressure or of exhaustion. The following table contains the result of observation:—

Pressure difference in mercury.	Ratio h/p (abs. value).
+0.97 mm	11.0 mm
+2.46	12.7
−0.89	11.6
−3.30	12.8
−5.03	13.5
−5.27	13.6

Thus in this well, we also observe a remarkable effect of the tidal pressure. Since the artificial pressure produces the level change of 13.6 mm by the pressure difference of 1 mm of mercury, whilst the slow barometric change does not cause any change of the level, it follows that the earth crust in the district transmits nearly all the pressure acting on the surface to a depth of about 30 m. To this inference, we may add that the district of Yoshiwara is formed of the deposition of the river Fuji.

It is interesting to observe that though the level of the well was not affected by the slow barometric change, we observed, in a windy weather, a minute level change of short periods in a vertical glass tube, jointed to the bamboo tube in the well. Thus we also see that the rapid fluctuation of the atmospheric pressure has the same effect as the pressure applied on the water-column. Hence such a well may conveniently be used for studying the barometric oscillations of short periods.

Artesian well in Ōkubo.

Ōkubo is a village on the slope of the Mount Fuji, 6 km distant from the sea-coast; the boring of the well is now going on. The well is at a place 230 m higher than the sea level; its depth is 110 m and its water level 38 m below the ground. It is fed with two water layers, one at 43 m and the other at 58 m; since the surface crust in the district consists of hard rocks, only the upper few meters of the well are protected with an iron tube.

The observations were taken with the same arrangement as in Tōkyō and continued only for 5 days, beginning from the first of January in this year. The results of observation were as follows:—

(1) The level constantly fell 11 cm during 5 days.

(2) In every 24 hours, we observe two maxima and minima of the amplitude of about 3 mm, their phases being opposite to those of the tide. The amplitude of the change becomes gradually less, as we recede from the time of conjunction.

(3) The barometric change does not seem to affect the level of the water.

(4) The effect of artificial pressure is the same as in the former cases, as shown in the following table.

Pressure difference in mercury.	Ratio h/p (abs. value).
−1.36 mm	13.4 mm
−4.28	13.5
+2.27	13.3
−6.32	13.6

When the pressure was applied or released, the level changed logarithmically with respect to time.

It is evident that the gradual falling of the level was due to the dry weather which prevailed on those days. On account of the small depth, the effect of the barometric change was absent in the well; hence the daily change of the level can not be explained by the daily barometric change; moreover the phase of the level change is opposite to what is to be caused by the pressure change. It is not unconceivable that the tidal pressure would diminish the underground pressure in such high place by the strain of the hard surface crust, and so cause the reversal of the phase in the level change; but the question of the tidal pressure in the well must be postponed to a future date, when we shall have a long series of observations.

Concluding remarks.

The fact that in each of the four wells, the pressure of 1 mm of mercury applied on the level of the water produces the level change of 13.6 mm shows the constancy of the pressure at an internal point in the well by compressing or exhausting the air above the level of the well; that is, it indicates the existence of the air space, which we have already discussed. Hence we may infer that in every artesian well, the level of the water is held in a position by the equilibrium of two pressures — the atmospheric pressure and the underground pressure. If one of these pressures undergoes a change, a corresponding change of level is produced.

It was thought probable that this remark would apply even to common wells. That the level of a well does not change by gradually pumping out or in the water, furnishes us a verification of the above view. To test it directly, a well 4 m deep was dug and its well was protected with an iron tube 15 cm in diameter; the water then rose to a height of 1.86 m below the ground. By changing the pressure above the water, the level slowly changed as in artesian wells. Reducing the pressure by 15.9 cm in mercury, the water just rose to the surface of the ground; the ratio h/p then becomes 11.7 mm, which falls a little short of the desired value. But this difference may be explained by the poor supply of water owing to the small depth of the well.

In connection with the above experiment, it was necessary to see, if the air may pass into a depth of a few meters through the soil (red clay) by the pressure above used. For this purpose, another well 2.5 m deep was dug, and its wall was likewise protected with an iron tube; the water did not spring. The experiment showed no trace of leakage when the said exhaustion was reached. It follows then that in common wells also, the atmospheric and the underground pressure are in equilibrium. But in most common wells, on account of their small depth, the change of the barometric pressure is almost transmitted through the soil, so that the level of the water is not sensibly affected by it.

The pressure at an internal point of the earth crust due to the pressure applied on the surface depends upon its depth as well as the nature of the crust. By the above consideration, the percentage reduction of the pressure at the point is found by simply observing the level change of a well due to the change of atmospheric pressure, if the well be so deep as to reach the point in question. It is very desirable to observe this reduction-factor in the different parts of the world.

From the daily change of the level observed in the three artesian wells, it is now clear that in the sea and also in the districts which are not far from the sea coast, the pressure of an internal point is considerably affected by the tidal motion. It seems also very probable that in our island, the underground pressure at any point is always changing by the tidal motion, if the depth of the point under consideration is comparable with the width of the island. But independently of such an assumption, it is highly interesting to investigate experimentally how far the tidal pressure extends into the inland.

In conclusion, the following remarks may not be out of place. Let it be supposed to be the case that the internal pressure undergoes the daily fluctuations by the tidal motion as well as the barometric change; such fluctuations of the underground pressure may give an opportunity for the earthquakes to take place. Professor F. Ōmori * investigated the relation of the activity of earthquakes to the phase of the moon in the lunar day, to the season of the year, and to the change of barometric pressure. He found, in each case, a remarkable connection between them. If the curve of the activity of earthquakes be plotted against the lunar time, the earthquakes due to the daily barometric change of pressure will be equally distributed over the whole day. Thus the earthquakes due to the tidal effect is separated. In this way, Professor F. Ōmori found several maxima in the activity-curves for three stations in Japan, namely Nagoya, Nemuro, and Tōkyō. By smoothing these curves, he obtained two distinct maxima in each curve, which occur at about 5th and 17th hours of the lunar day, the time beginning with the upper culmination of the moon. In Nemuro, the second maximum is slightly displaced towards the earlier time. These positions of the maxima nearly coincide with those of the high water.

If the curve of activity be drawn with the solar time, the earthquakes due to the tidal effect will be equally distributed over the day. The effect of the daily barometric change of pressure on the activity will thus be separated. Professor Ōmori found a remarkable coincidence between the pressure and the activity of earthquakes, the high pressure generally corresponding to the maximum activity.

As regards the annual distribution of the earthquakes, he also found a good coincidence between the activity-curve and the pressure-curve, the maximum activity generally corresponding to the high pressure. But in some stations, the phenomenon is just reversed, the maximum activity occurring at the low pressure. It seems probable that this reversal arises from the difference of the structure of the crust in these districts; in one place, the increase of the atmospheric pressure may augument the instability of a strained portion, while in the other, its decrease may have the same effect. The activity of the

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* F. Ōmori, Reports (Japanese) of the Earthquake Investigation Committee, Nos. 26, 30, and 32.

earthquakes must also be affected by the high tide in Spring, so that its activity is considerably large in Spring, as shown by Professor Ōmori.

Assistant Professor A. Imamura has investigated the synodic monthly distribution of the earthquakes, and found, in every case, two pairs of maxima, the one pair occurring at the days near conjunction and opposition, and the other at the days near 7th and 24th in each synodic month. The first pair occurs, when the tidal motion is maximum, that is, when the fluctuation of the internal stress due to the tide is maximum. The second pair of maxima occurs in the days, when the phase of the tidal pressure coincides with that of the barometric change; in this case, the fluctuations of the internal stress are also considerable. Thus the lunar effect on the activity of the earthquakes may be attributed to the tidal pressure.

The above consideration is also supported by the following remarks. The actual tidal motion at a station is more complex than to be judged from the phase of the moon; hence for studying the relation between the activity of earthquakes and the tidal motion, it is not convenient to draw the activity-curve against the lunar time. It is better to see, from the record of a tide-gauge in the station, in what phase earthquakes actually occurred, and to mark, in a figure of the tidal motion, the points having the same phases. In this way, Figs. 10, 11, 12 and 13, were obtained. These curves show that the activity of the earthquakes is maximum in high and low waters; there is another minor maxima in phases, where the variation of the tide is greatest. That the maximum activity occurs in high water as much as in low water is evident; for the earth crust is in equilibrium under the action of external pressures, and therefore an increase or decrease of the pressure acting on the surface may, in some cases, equally increase the unstability of a highly strained portion. Thus these positions of the maxima are consistent with the above view.

Fig. 11.

Earthquakes observed at Tōkyō, 1899.

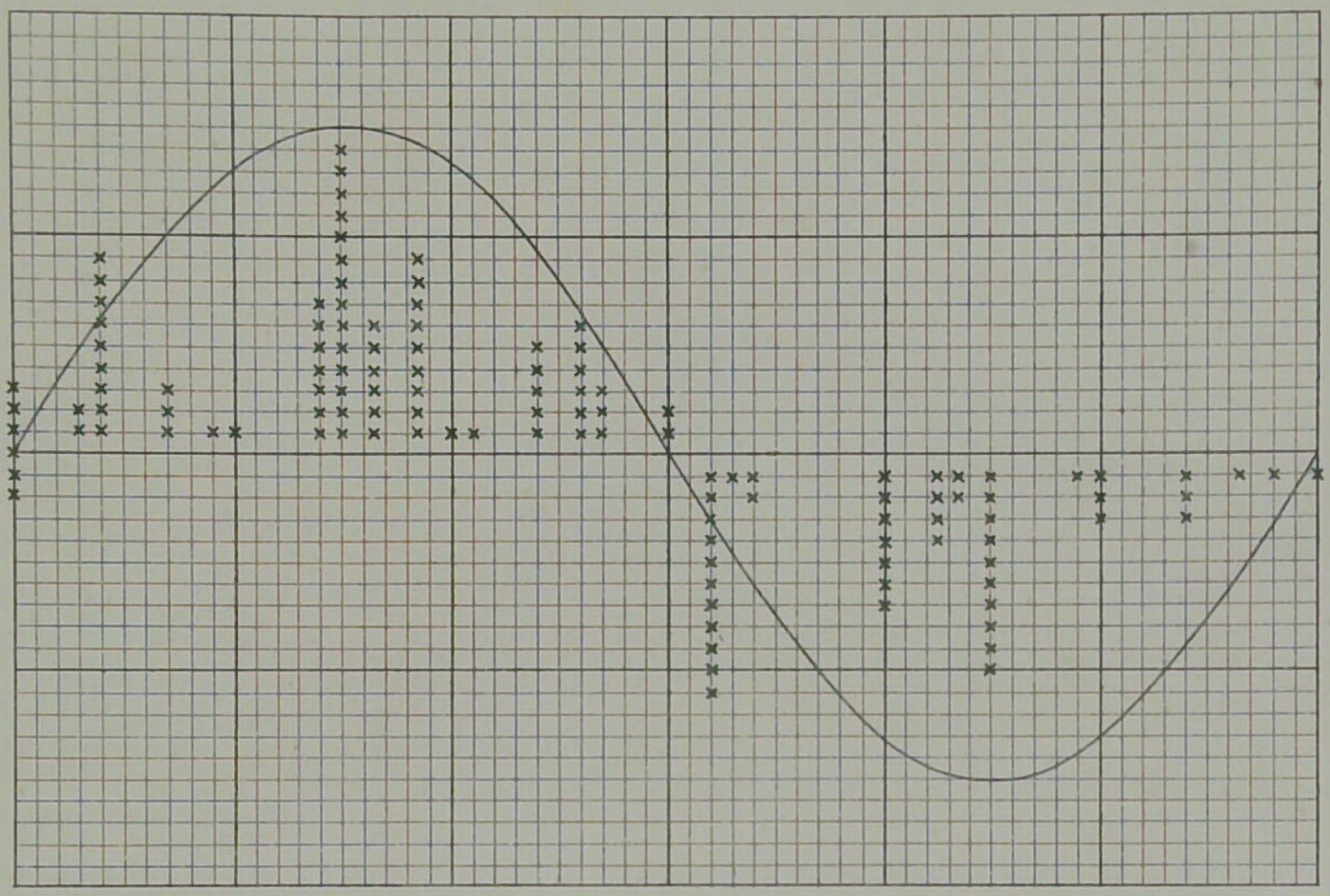


Fig. 10.

Earthquakes observed at Tōkyō, 1898.

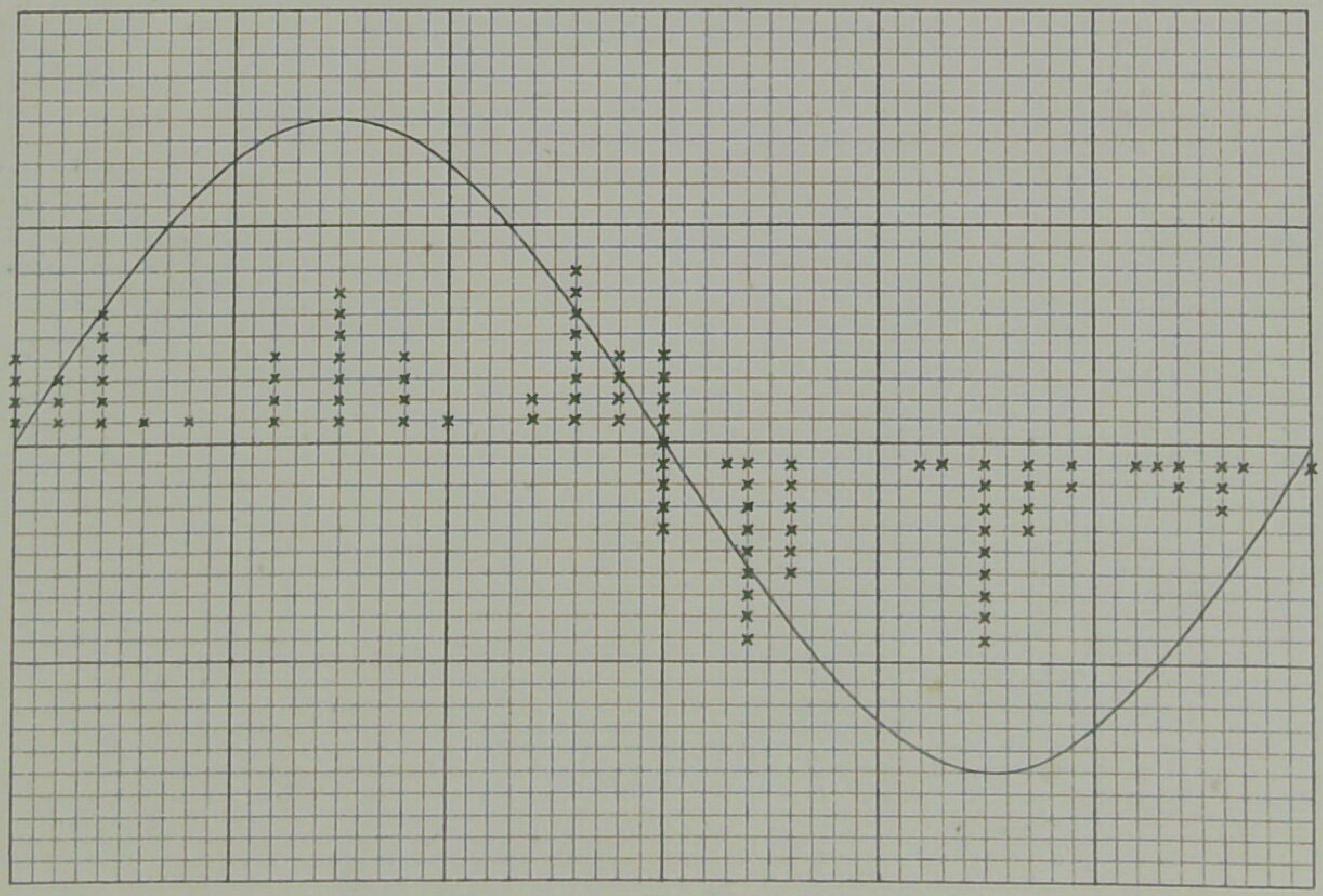


Fig. 12.
Distant earthquakes observed
at Tōkyō, 1900.

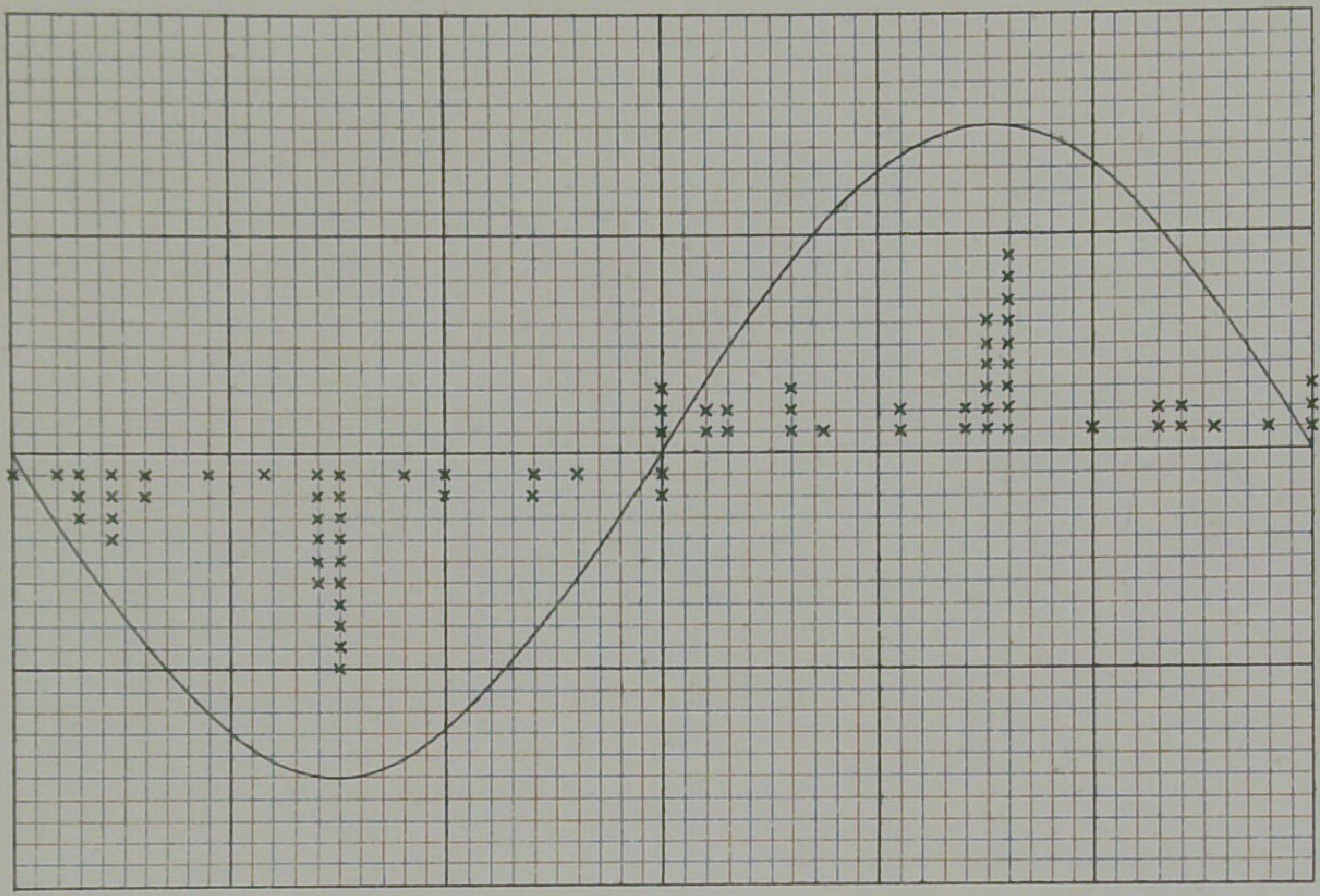
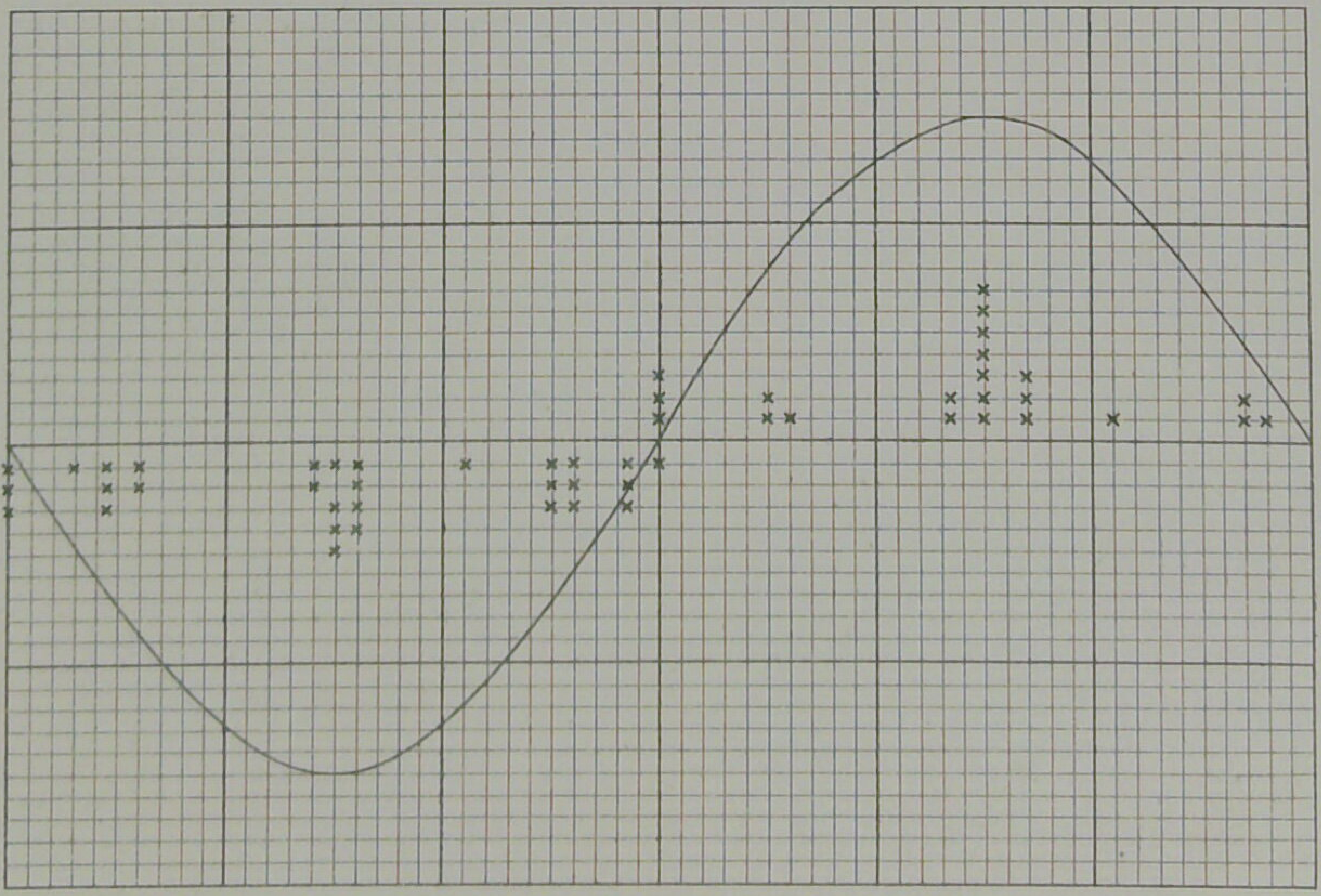


Fig. 13.
Earthquakes of submarine origin observed
at Tōkyō, 1900.



Note on the Seismic Triangulation in Tokyo.

By

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With Plate XXIV.

In a former report on the seismic triangulation in Tokyo,[1] the present writer has given the transit velocity of the wave at the commencement of the principal portion of the earthquake motion, this wave being usually well defined so that it can easily be identified in the diagrams obtained at the different seismic stations. In the present note, I add the transit velocities of the other waves which have not formerly been discussed; namely, those of the preliminary tremor and the waves following the initial wave of the principal portion.

I. *The preliminary tremor.*

As it was difficult to identify the waves in this phase in the diagrams of the 8 earthquakes registered at the different stations,[2] the transit velocity has been determined according to the formula

$$\frac{1}{v}=\frac{1}{V}-\frac{t}{d},$$

where v and V represent the respective transit velocities of the initial waves of the preliminary tremor and principal portion, t the duration of the preliminary tremor, and d the epicentral distance. The result

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[1] The *Publications*, No. 7.

[2] l. c.

is given in the following table, in which the duration of the preliminary tremor is taken from the diagrams given by one of the three Ewing type instruments.

Eqke. no.	Date.	t	d	v
		s	km	$\frac{\text{km}}{\text{s}}$
1	April 3, 1895.	2	110	3.5
2	Feb. 23, 1896.	18	160	5.3
3	March 6, 1896.	9	120	4.4
4	April 24, 1896.	8	70	5.4
5	Aug. 5, 1897.	14	450	3.7
6	Aug. 16, 1897.	12	300	3.8
7	Feb. 13, 1898.	7	60	6.0
8	July 12, 1898.	3	80	3.8

The initial wave in the registers of the eqkes. Nos. 1, 5, 6, and 8 is too large and does not probably represent the 'real' commencement of the earthquake motion. The rocks of Archean formation, which have a transit velocity of seismic waves as high as 6–7 km. per sec., may form a part of the path for the wave in the present discussion.

II. The principal portion.

The eqke. no. 7 was one which gave the most appropriate diagrams for the deduction of the transit velocities of the successive waves of the principal portion. The waves F–G and P–S in E–W component, and h–i and o–s in N–S one being very distinct, I have divided the principal portion into three successive phases, each of which began with one of the above-mentioned waves. (See the accompanying figure.) The result is given in the following tables.

E-W COMPONENT.

Phase.	Wave.	Time of arrival.			
		Hongo.	Hitotsubashi.	Astro. Obs.	Komatsugawa.
		s	s	s	s
I	A	7.57	8.22	8.83	8.87
	B	8.19	8.82	—	9.73
	C	8.50	9.12	—	—
	D	8.91	9.60	—	—
	E	9.49	10.27	—	11.09
II	F	10.17	11.00	—	11.70
	G	10.79	11.57	—	12.29
	H	11.63	12.18	—	12.88
	I	11.87	12.50	—	13.78
	J	12.19	12.90	—	14.09
	K	12.63	13.52	—	14.88
	L	13.45	14.12	—	15.45
	M	13.79	14.48	—	16.00
	N	14.15	14.87	—	16.37
	O	14.37	15.23	—	16.70
III	P	14.85	15.77	—	17.41
	Q	15.22	16.08	—	17.91
	R	15.66	16.51	—	18.46
	S	16.24	17.28	—	19.23
	T	17.15	18.24	—	20.00
	U	17.59	18.74	—	—
	V	18.28	19.26	—	—
	W	19.26	20.30	—	21.90

N-S COMPONENT.

Phase.	Wave.	Time of arrival.			
		Hongo.	Hitotsubashi.	Astro. Obs.	Komatsugawa.
		s	s	s	s
I	a	7.53	8 17	8.62	8.90
	b	7.87	8.52	9 00	9.26
	c	8.59	9.23	10.00	10.02
	d	9.19	9.79	10.77	10.98
	e	9.55	10.11	11.41	11 51
	f	9.86	10.50	11.79	12.05
	g	10.65	11.03	12.61	—
II	h	11.07	11.49	13.05	—
	i	11.36	11.93	13.67	13.62
	j	11.81	12.49	14.19	14.10
	k	12.13	12.86	14.41	—
	l	12.82	13.45	15.02	15 14
	m	13.53	14 30	—	15.86
	n	14.00	14.62	—	16.50
III	o	14.50	15.50	16.80	17.10
	p	14.88	15.90	17.62	17.52
	q	15 28	16.32	18.00	17.97
	r	15.91	16.77	18.21	18.55
	s	16.24	17.22	18.65	—
	t	16.79	18.15	19 28	19.30
	u	17.24	18 56	19.75	19.88
	v	17.64	18.97	20.10	—
	w	18.37	19 83	—	20.91

The following table gives for each phase the mean times of arrival of the successive waves at the 3 local stations, referred to the time of arrival of the same waves at Hongo.

Station.	E-W component.			N-S component.			Mean.		
	I	II	III	I	II	III	I	II	III
	s	s	s	s	s	s	s	s	s
Hitotsubashi.	0.67	0.73	0.99	0.59	0 63	1.15	0.62	0.69	1.08
Astronomical Obs.	1.26	—	—	1.69	2.23	2.49	1.52	2.23	2.49
Komatsugawa.	1.38	1.91	2.76	1.69	2.34	2.61	1.62	2 05	2.68

From these data, it will be seen that the directions of propagation of the different phases of the earthquake motion coincided roughly with one another, the approximate value being N25°W. The transit velocities of the various phases thus come out to be 3.0, 2.3, and 1.8 km. per sec. Each of these different values may probably relate to one of the strata which are supposed to lie near the earth's surface parallel to the latter, the terms corresponding to the superficial layer, into which the waves propagated through the assumed stratum refract to reach our observing stations, being eliminated in the process of taking the difference of the times of arrival.

The different phases discussed in the present note may possibly have certain relation with the three phases following the most active part of the principal portion of large distant earthquakes.

May 24, 1904.

Seismological Institute.

On the transit velocity of the earthquake motion originating at a near distance.

By

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With Plates XXV–XXVI.

1. *Introduction.*

The assumption of the existence of a stratum of the quickest earthquake propagation near the earth's surface parallel to the latter is very important in the study of the mode of propagation of the seismic motion. In fact, the linear relation which exists between the arcual epicentral distance of a distant station and the time taken in transit by the 1st preliminary tremor is well explained by considering the depth of the stratum to be a few hundred kilometres.[1]

It is a well-known fact that the mean velocity between the *origin* and a *near station* is comparatively small, becoming larger with the increase of the distance. For instance, the Kyushu, Formosa, and Manila earthquakes, which occurred in 1899–1902, had the velocities of 8·2, 10·6, and 10·9 km per sec. for the epicentral distances of 900, 2200, and 3050 km. respectively.[2] To see how the first phase is propagated from a *near station* to *another* in similar case, I have first examined the observations at Tokyo and Osaka of the earthquakes, which originated in NE Japan or in Kyushu, and obtained a transit

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[1] The *Publications*, No. 16, p. 116.

[2] See Dr. Omori: The *Publications*, No. 13, p. 141.

velocity as high as 12 km. per sec., the result of similar examination made afterwards of the observations at the Mizusawa Astronomical Observatory being nearly the same. It must be remarked that, the origin of each earthquake having been comparatively near the observing stations and approximately in the direction of the straight line connecting the latter, the difference of the epicentral distances is but little affected by an inaccurate determination of the epicentre, whether the path be acual or chordal.

The earthquakes taken into consideration are given in the following table:—

Earthquake No.	Date.	Time of occurrence. at epicentre.			Epicentre.	
					Latitude.	Longitude.
		1902.				
		h	m	s		
1	Jan. 29.	23	24	50	34°.5 N	139°.8 E
2	Jan. 30.	23	0	0	41.0	142.5
3	Jan. 31.	10	41	30	41.5	142.5
4	Feb. 21.	0	37	40	40.8	142.8
5	May 2.	20	31	0	40.5	144.0
6	May 8.	11	19	0	30.7	131.6
7	May 28.	18	1	40	42.8	144.8
8	June 13.	9	21	20	42.7	144.3
9	June 23.	7	42	20	35 5	139.8
10	July 1.	17	16	20	40.0	144.0
11	July 8.	23	5	—	41.5	142.5
12	July 10.	19	56	20	41.7	142.0
13	Aug. 3.	10	40	—	42.5	146.5
14	Aug. 7.	18	19	—	39.8	143.7
		1903.				
15	March 21.	19	35	50	33.7	132.0
16	April 1.	23	8	30	38.0	142.0
17	Aug. 10.	13	38	—	36.0	137.1
18	Aug. 10.	13	45	—	36.0	137.1
19	Aug. 14.	0	46	—	42.8	144.8
20	Oct. 11.	1	41	0	32.3	132.0
21	Dec. 3.	17	52	40	32.0	132.0
		1904.				
22	March 18	22	—	—	42.7	144.3
23	April 13	14	37	40	38.7	142.0
24	May 27	5	40	0	35.0	139.6

The positions of the epicentres and times of commencement at the latter were determined from the result of instrumental observations at the Meteorological Stations and observations of the seismic intensity by the meteorological reporters in the different parts of the country. The observations depending on the 1st category are given in the *Publications*, No. 16, or in the appendix to the present note. The numbers of observations of the 2nd category were 205 and 156 in Eqkes. Nos. 2 and 3 respectively. These two earthquakes are specially discussed later on.

II. Observations at Tokyo and Osaka.

The diagrams examined were given by Omori's H. P. Seismographs at the Seismological Institute and Osaka Meteorological Observatory. The following is the list of the instruments which gave the Tokyo register.

Instrument.	Orientation.	Magnification.	Free vibration period. s.
No. 1.	E-W component.	10	26
A	Do.	15	62
B	N-S component.	10	30

The instrument at Osaka was less sensitive and had a magnification of 6 times and a period of 25 sec.

The time which is marked every minute on the smoked paper, is kept at Tokyo by a chronometer, but at Osaka by a clock whose daily change of clock rate amounted seldom to 20 sec., being commonly one-half of the latter. The clock and chronometer are daily compared with the standard time at noon, the former by means of an electric signal sent directly from the Tokyo Astronomical Observatory, but the latter indirectly by the report of a cannon at a distance of 2.3 km.

Of the 41 earthquakes which were first taken into examination, the Osaka instrument did not record the time ticks in 20 cases, and gave 6 seismograms, 4 of which were too minute and the others were masked by pulsatory oscillations; besides, the correction of the clock was so uncertain in 2 cases that a reliable clock rate could not be obtained. In all, there were 13 earthquakes which were recorded tolerably well at the two stations.

Let P_1, P_2, and P_3 represent the initial waves of the 1st and 2nd preliminary tremors and principal portion, and V_1, V_2, and V_3 their respective transit velocities. The latter were calculated according to the formula

$$\text{Velocity} = \frac{d' - d}{t' - t},$$

where d and d' indicate the arcual epicentral distances of the two observing stations, and t and t' the times of arrival of each phase at the respective stations. The result is given in the following table.

Eqke. no.	Time of commencement at Tokyo.	Epicentral distance.			Diff. of times of arrival of P_1.	V_1	Duration.				Diff. of times of arrival of P_2	V_2	Diff. of times of arrival of P_3.	V_3.
		Nearer station.	Further station.	Diff.			Tokyo.		Osaka.					
							P_1–P_2	P_2–P_3	P_1–P_2	P_2–P_3				
	h m s	km	km	km	s	km/s	s	s	s	s	s	km/s	s	km/s
2	23 1 43	622	927	312	26	12.0	21	35	48	65	53	5.9	82	3.8
3	10 42 58	685	969	284	23	12.4	19	52	37	80	41	6.9	69	4.1
4	0 39 13	625	930	305	31	9.8	23	45	43	76	51	6.0	82	3.7
5	20 32 3	648	1005	357	33	10.8	29	56	48	80	52	6.9	85	4.2
7	18 3 43	898	1205	307	27	11.4	36	72	66	99	54	5.7	81	3.8
10	17 17 27	604	992	388	33	11.8	32	41	51	71	49	7.9	79	4.9
11	23 7 36	685	969	284	19	15.0	28	36	40	63	40	7.1	67	4.2
13	10 43 17	951	1285	334	26	12.9	78	72	103	99	53	6.3	80	4.2
14	18 20 50	571	917	346	28	12.4	27	35	48	66	49	7.1	80	4.3
15	19 37 36	341	743	402	35	11.5	41	56	18	18	58	6.9	96	4.2
16	23 9 24	324	688	364	24	15.2	20	23	48	56	52	7.0	85	4.3
20	1 42 38	420	810	390	36	10.8	56	69	27	30	56	7.0	95	4.1
21	17 54 38	442	826	384	28	13.7	52	79	28	36	52	7.4	95	4.0
Mean.	—	601	944	343	28.4	12.1	36	52	47	65	51	6.7	83	4.1

The values thus deduced do not much differ from those which are generally obtained in cases of large distant earthquakes, the formula adopted being the same.

Let us next compare these velocities with those which are obtained according to the formula

$$\text{Velocity} = \frac{d}{t - t_0},$$

where t_0 indicates time of commencement at epicentre, which was estimated with tolerable accuracy for the preceding earthquakes except Nos. 11, 13, and 14. In the following table only the mean values are given.

Place.	Epicentral distance.	Time taken in transit.			Transit velocity.		
		P_1	P_2	P_3	V_1	V_2	V_3
Tokyo.	679^{km}	91^{s}	124^{s}	177^{s}	$7.5\ \frac{\mathrm{km}}{\mathrm{s}}$	$5.5\ \frac{\mathrm{km}}{\mathrm{s}}$	$3.8\ \frac{\mathrm{km}}{\mathrm{s}}$
Osaka.	792	101	142	204	7.9	5.6	3.9

The difference of the values of V_1 due to the two different methods may be explained, as has been noted previously, by assuming the stratum of the quickest propagation to have a depth of a few hundred kilometres. For the seismic motion radiating from the origin, which may be situated comparatively near the earth's surface, is propagated directly to observing station in the epicentral district, while the initial wave observed at a more distant station may be the wave propagated from the origin first downward to the stratum of the quickest propagation, next through that stratum to a position near the observing station, and then refracting to the latter. In so supposing, the transit velocity estimated according to the 1st formula relates particularly to the assumed stratum, the term depending on the depth being eliminated in the process of taking the difference. If the velocity determined according to the 2nd formula represent the mean value between the origin and a distant observing station, it seems more proper to introduce in the term of epicentral distance a correction, which, roughly speaking, is equal to double of the distance between the seismic focus and the stratum of the quickest propagation.

Assuming the state of propagation of the 1st preliminary tremor as discussed above, the time which would have been taken by the wave-front in its transit from the seismic focus to the assumed stratum is calculated in the preceding 10 earthquakes to have been 20 sec. on the average. In the Kyushu, Formosa, and Manila earthquakes, previously cited, the times amount to 23, 25, and 31 sec. rerpectively. For the Aomori earthquake of Aug. 9, 1901, in which the focal depth was probably very shallow,[1] the value amounts to 60 sec. The time calculated in such a way may probably be used for the determination of the depth of the seismic focus and the stratum of the quickest propagation.

The path of P_3 seems, as usually accepted, to be superficial, for the velocities deduced by the two different methods do not much differ from each other. As regards P_2, the path may be inferred to lie between the two others.

III. Observations at Tokyo and Mizusawa.

The instruments at Mizusawa consist of a pair of Omori's H. P. Seismographs, that which registers E-W component motion being of the same type as that at Osaka but so adjusted as to have a free vibration period of 13 sec, while the other which records N-S component motion being of the same type and about equal period as the Tokyo instrument No. 1.[2]

The clock keeping the time tick was at first compared with the standard chronometer at the start and end of each smoked paper which lasts about 24 hours; but since the end of 1902, it was more frequently compared so that an accurate clock correction could be obtained whenever earthquake occurred. Hence, in the calculation of

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[1] The *Publications*, No. 16, p. 75.

[2] See also Annual Report of the Meteorological Observations at Mizusawa for the year 1903.

the mean values of transit velocity, the weight of the data relating to the former epoch is assumed to be one-half of that relating to the latter.

Many earthquakes, which originated near one of our stations, have been grouped against those which originated at distances greater than 400 km. The result for the different groups will be understood from the following tables.

OBSERVATIONS OF NEARER EARTHQUAKES.

Eqke. no.	Epicentral distance.			Time of commencement at Tokyo.			Diff. of times of arrival of P_1	V_1
	Nearer station.	Further station.	Difference.					
	km	km	km	h	m	s	s	$\frac{km}{s}$
1	139	529	390	23	25	10	39	10.0
2	237	622	385	23	1	43	45	8.6
3	287	685	398	10	42	58	43	9.3
4	233	625	392	0	39	13	41	9.6
5	287	648	361	20	32	3	41	8.8
9	22	420	398	7	42	39	45	8.8
10	264	604	340	17	17	27	45	7.6
11	287	685	398	23	7	36	27	14.7
12	294	694	400	19	57	53	35	11.4
14	235	571	336	18	20	50	44	7.6
16	148	324	176	23	9	24	13	13.5
17	243	496	253	13	40	9	27	9.4
18	243	496	253	13	46	12	27	9.4
23	88	388	300	14	38	30	34	8.8
24	92	479	387	5	40	34	39	9.9
Mean.	196	522	327	—			34	9.6

OBSERVATIONS OF REMOTER EARTHQUAKES.

Eqke. no.	Epicentral distance.			Time of commencement at Tokyo.			Diff. of times of arrival of P_1	V_1
	Nearer station.	Further station.	Difference.					
	km	km	km	h	m	s	s	$\frac{km}{s}$
6	944	1275	331	11	1	19	28	11.8
7	510	898	388	18	3	43	39	9.9
8	475	871	396	9	3	39	34	11.6
13	586	951	365	10	43	17	32	11.4
15	743	1015	272	19	37	36	21	13.0
19	510	898	388	0	48	8	25	15.5
20	810	1120	310	1	42	38	22	14.1
22	475	871	396	22	48	33	36	11.0
Mean.	633	984	351	—			28.4	12.4

Thus we arrive at nearly the same result as that deduced from the observations at Tokyo and Osaka, the value relating to the earthquakes which originated in near distances approximating to that calculated according to the 2nd formula in the previous case.

IV. Earthquakes of Jan. 30 and 31, 1902.

The 1st preliminary tremor of Eqkes. Nos. 2–3 were also recorded at several seismic stations in Europe and other parts of the world. The following is the result of those observations.

Eqke. No. 2.

Place of observation.	Epicentral distance.	Time taken in transit by P_1.	Place of observation.	Epicentral distance.	Time taken in transit by P_1
		m			m
Mizusawa.	2°.1	1.0	Nikolajew.	72°.7	11.5
Tokyo.	5.6	1.7	Hamburg.	76.9	11.9
Osaka.	8.4	2.2	Strassburg.	82.0	12.2
Irkutsk.	28.1	5.6	Trieste.	82.0	11.8
Calcutta.	49.0	8.0	Pola.	82.6	12.6
Taschkent.	53.3	9.8	Padova.	83.0	12.7
Batavia.	57.3	10.0	Shide.	83.4	12.3
Madras.	60.9	10.6	Firenze.	84.5	11.4 (?)
Bombay.	62.8	10.1	Roma.	85.6	13.0
Victoria.	62.8	10.2	Rocca di Papa.	85.6	13.2
Jurjew.	67.3	11.8	Ischia.	86.3	12.9
Tiflis.	68.8	11.4	Catania.	88.0	13.0

Eqke. No. 3.

Place of observation.	Epicentral distance.	Time taken in transit by P_1	Place of observation.	Epicentral distance.	Time taken in transit by P_1.
		m			m
Mizusawa.	2°.6	0.8	Nikolajew.	72°.3	11.5
Tokyo.	6.2	1.5	Hamburg.	76.6	11.7
Osaka.	8.7	1.9	Strassburg.	81.5	12.3
Irkutsk.	27.8	5.3	Trieste.	81.6	12.1
Taschkent.	53.1	8.4	Shide.	82.7	11.6
Bombay.	62.5	10.1	Firenze.	84.1	11.1 (?)
Jurjew.	66.8	10.6	Roma.	85.2	12.8
Tiflis.	68.5	11.2			

The mode of propagation of the earthquake motion may be understood from the graphical representation given in Fig. 1. The curves in the figure have been drawn according to the following method:—Marking down as usual on a section paper so many points corresponding to the different sets of the epicentral distance (x) and the time taken in transit (y), a continuous free-hand line was drawn connecting the 4 left-hand points and thence a straight line determined by the method of Least Squares from the 5 points for Irkutsk, Calcutta, and the 3 mean places for the stations whose epicentral distances are 53°–63°, 67°–77°, and 82°–88°[1] in Eqke. No. 2, and from the 4 points for Irkutsk, Taschkent, and the 2 mean places for the stations whose epicentral distances are 62°-77° and 81°–86°[2] in Eqke. No. 3 The linear relation seems to hold approximately for a distances as near as 10°, but the observations at comparatively near distances having been scanty, this part of investigation must be reserved for a future occasion.

The transit velocity comes out from the above mentioned straight line to be 14·3 and 14·1 km. per sec. in Eqkes. Nos. 2 and 3 respectively. These values are nearly equal to those obtained by Prof. Omori as a result of his more recent investigation.[3]

July 26, 1904.

Seismological Institute, Tokyo Imp. Univ.

[1-2] Firenze is omitted.

[3] Prof. Omori: The *Publications*, No. 13.

APPENDIX. EARTHQUAKE OBSERVATIONS AT THE METEOROLOGICAL OBSERVATIONS.* (THE TIMES ARE GIVEN IN THE FIRST NORMAL JAPAN TIME).

Eqke. No. 1. Jan. 29th 1902; 23h.

Mera.	25^{m} 0^{s}.	Weak.	Gentle.
Yokosuka.	25 30.	Do.	Duration long.
Tokyo.	25 9.	Slight.	
Kanayama.	25 10.	Do.	Duration short.
Maebashi	25 15.	Do.	
Mito	25 42.	Do.	Gentle.
Choshi.	25 45.	Do.	Duration short.
Nagano.	26 0.	Do.	
Kumagae	26 28.	Do.	
Miyako.	27 15.	Do.	Gentle.
Matsumoto	27 55.	Do.	
Akita.	27 58.	Do.	
Fukushima.	30 54.	Do.	
Utsunomiya.	34 48.	Do.	Gentle.

Eqke. No. 7. May 28th 1902; 18h.

Kushiro.	$1^{m}53^{s}$.	Strong (rather violent).	Sharp, houses shaken.
Tokachi.	2 15.	Weak.	Sharp.
Nemuro.	1 18.	Weak (rather slight).	Duration long.
Abashiri.	1 5.	Slight.	
Sapporo.	2 50.	Do.	Gentle.
Aomori.	3 6.	Do.	Sharp.
Miyako.	3 12.	Do.	Sharp, accompanied by vertical movement.
Wajima.	4 8.	Do.	
Mito.	4 30.	Do.	Sharp.
Ishinomaki.	3 10.	Slight (unfelt).	
Fukushima.	4 12.	Do.	

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* Observations of Eqkes. Nos. 2, 3, 4, 5, 6, 8, and 10 are given in the *Publications*, No. 16.

Akita.	4 47.	Do.
Kumagae.	$5^{m}11^{s}$.	Do.
Tokyo.	5 20.	Do.

Eqke. No. 9. June 23rd 1902 ; 7h.

Yokohama	$42^{m}58^{s}$.	Strong (rather weak).	Sharp, accompanied by vertical movement, houses shaken.
Tokyo.	42 20.	Weak.	Sharp.
Yokosuka.	42 35.	Do.	Sharp, accompanied by vertical movement.
Kumagae.	42 40.	Do.	Gentle.
Mito.	42 40.	Do.	Do.
Numazu.	43 40.	Do.	Do.
Mera.	45 40.	Do.	Houses shaken.
Choshi.	40 0.	Weak (rather slight).	Accompanied by earthquake sound.
Kofu.	43 11.	Do.	Houses shaken.
Nagano.	42 58.	Slight.	Duration long.
Utsunomiya.	44 20.	Do.	Gentle.
Wajima.	45 20.	Do.	
Matsumoto.	42 17.	Slight (unfelt).	Duration long.
Maebashi.	43 10.	Do.	
Fukushima.	43 11.	Do.	
Nagoya.	43 17.	Do.	Gentle.
Iida.	43 24.	Do.	
Hikone.	43 40.	Do.	
Ishinomaki.	43 49.	Do.	
Fukui.	44 0.	Do.	
Yagi.	44 45.	Do.	
Gifu.	47 23.	Do.	

Eqke. No. 11. July 8th 1902 ; 23h.

Tokachi.	6^{m} 0^{s}.	Weak.	Gentle.
Hakodate.	5 13.	Weak (rather slight).	Sharp.
Aomori.	8 42.	Do.	Windows rattled.
Miyako.	3 39.	Slight.	

Sapporo.	5 39.	Do.	
Ishinomaki.	$7^{m}29^{s}$.	Do.	
Akita.	7 41.	Do.	
Nemuro.	7 56.	Do.	Gentle.
Wajima.	8 23.	Slight.	
Kumagae.	4 12.	Slight (unfelt).	
Mito.	8 0.	Do.	
Tokyo.	8 36.	Do.	
Yokohama.	9 29.	Do.	Gentle.

Eqke. No. 12. July 10th 1902; 19h.

Hakodate.	$56^{m}35^{s}$.	Weak (rather slight).	Sharp.
Miyako.	55(?)38.	Slight.	
Aomori.	57 6.	Do.	Sharp.
Nemuro.	57 27.	Do.	Gentle.
Wajima.	58 12.	Do.	
Sapporo.	58 30.	Do.	Gentle.
Akita.	57 30.	Slight (unfelt).	
Fukushima.	57 55.	Do.	
Tokyo.	59 30.	Do.	
Mito.	60 27.	Do.	

Eqke. No. 13. Aug. 3rd 1902; 10h.

Nemuro.	38^{m} 0^{s}.	Slight.	Gentle.
Fukushima.	42 40(?).	Slight (unfelt).	
Kanayama.	44 55.	Do.	
Akita.	47 36(?).	Do.	

Eqke. No. 14. Aug. 7th 1902; 18h.

Aomori.	$19^{m}17^{s}$.	Weak (rather slight).	Gentle.
Wajima.	21 6.	Slight.	
Akita.	18 52.	Slight (unfelt).	
Kanayama.	20 13.	Do.	
Ishinomaki.	21 37.	Do.	

Mito.	22^{m} 3^{s}.	Do.	
Tokyo.	22 18.	Do.	
Iida.	23 5.	Do.	Gentle.

Eqke. No. 15. March 21st 1903; 19 h.

Kure.	$36^{m}10^{s}$.	Strong.	
Ashizurizaki.	35 0.	Strong (rather weak).	Sharp, houses shaken.
Oita.	35 38.	Do.	Accompanied by vertical movement, clocks stopped.
Murotozaki	35 40.	Do.	Houses shaken.
Niihama	36 6.	Do.	Duration long.
Hiroshima	36 25.	Do.	Windows rattled.
Miyazaki	37 0.	Do.	Sharp, houses shaken.
Tadotsu	41 58.	Do.	Accompanied by vertical movement, houses shaken.
Hamada	32 0.	Weak.	Houses shaken.
Ajino	32 3.	Do.	Clocks stopped.
Kochi	35 7.	Do.	Duration long.
Matsuyama	35 50.	Do.	Accompanied by vertical movement, houses shaken.
Sakai	36 0.	Do.	Houses shaken.
Besshi	36 0.	Do.	Accompanied by earthquake sound, houses shaken.
Okayama	36 25.	Do.	Houses shaken.
Kyoto	37 10.	Weak (rather slight).	Gentle.
Kumamoto	37 6.	Do.	Duration long.
Miyazu	37 10.	Do.	Do.
Fukuoka	37 20.	Do.	Do.
Saga	37 25.	Do.	Windows rattled.
Shimonoseki	37 32.	Do.	Accompanied by vertical movement, houses shaken.

Tokushima	37^{m} 0^{s}.	Slight.	
Kagoshima	37 4.	Do.	Gentle.
Fukui	37 15.	Do.	Duration long.
Hikone	36 35.	Slight (unfelt).	Sharp.
Osaka	37 17.	Do.	Gentle.
Iida	52 35.	Slight.	

Eqke. No. 16. April 1st 1903; 23 h.

Ishinomaki	8^{m}57^{s}.	Weak.	Houses shaken.
Kanayama	8 37.	Weak (rather slight).	Duration short.
Miyako	6 1.	Slight.	Duration long.
Fukushima	8 38.	Do.	
Yokohama	9 52.	Do.	Gentle.
Kumagae	8 51.	Slight (unfelt).	
Matsumoto	8 53.	Do.	
Mayebashi	9 24.	Do.	
Yamakata	9 25.	Do.	
Choshi	9 57.	Do.	
Tokyo	10 0.	Do.	
Iida	10 8.	Do.	Sharp.
Utsunomiya	10 53.	Do.	
Aomori	11 15.	Do.	
Kinkwasan	12 30.	Do.	Duration short.

Eqke. No. 17. Aug. 10th 1903; 13 h.

Takayama	37^{m}35^{s}.	Weak (rather slight).	Sharp, accompanied by earthquake sound, houses shaken.
Kyoto	34 19.	Slight.	Gentle.
Fushiki	39 40.	Slight (unfelt).	
Katsumoto	40 4.(?)	Slight.	
Hikone	40 12.	Do.	Gentle.
Tsu	40 15.	Do.	

Tokyo	41^{m} 0^{s}.	Slight.	
Iida	41 48.	Do.	
Nagoya	39 42	Slight (unfelt).	
Fukui	41 0.	Do.	
Kobe	41 7.	Do.	

Eqke. No. 18. Agu. 10th 1903; 13 h.

Takayama	48^{m}52^{s}.	Weak (rather slight).	Sharp.
Wajima	46 20.	Slight.	Duration short.
Tokyo	46 35.	Slight (unfelt).	
Fushiki	47 28.	Slight.	
Nagoya	45 47.	Slight (unfelt).	
Iida	46 10.	Do.	
Matsumoto	46 25.	Do.	

Eqke. No. 19. Aug. 14th 1903; 0 h.

Kushiro	46^{m} 5^{s}.	Strong (rather weak).	Duration short.
Tokachi	48 30.	Weak (rather slight).	Sharp.
Wajima	47 10.	Slight.	Gentle.
Nemuro	47 29.	Do.	Do.
Hakodate.	48 5.	Do.	Do.
Ishinomaki.	49 0.	Slight (unfelt).	
Mito.	50 2.	Do.	Gentle.
Aomori.	50 13.	Do.	

Eqke. No. 20. Oct. 11th 1903; 1h.

Toizaki.	37^{m}25^{s}.	Strong.	Sharp, houses shaken.
Miyazaki.	41 19.	Do.	Sharp, accompanied by vertical movement.
Kagoshima.	41 30.	Weak.	Houses shaken.
Oita.	39 0.	Do.	Clocks stopped.
Matsuyama.	52 22.	Slight.	Accompanied by vertical movement.

Kumamoto.	...$41^{m}42^{s}$.	Slight (unfelt).	Duration long.
Yagi. ...	...42 52.	Do.	
Fukuoka....	...44 50.	Do:	

Eqke. No. 21. Dec. 3rd 1903; 17h.

Miyazaki.	...53^{m} 4^{s}.	Weak.	Houses shaken.
Kagoshima.	...52 45.	Weak (slight).	Do.
Oshima. ...	.. 52 40.	Slight (unfelt).	Gentle.
Kumamoto.	...53 40.	Do.	
Oita. ...	...52 45.	Slight.	

Eqke. No. 22. March 18th 1904; 22h.

Nemuro. ...	...$24^{m}32^{s}$.	Weak.	Liquid in vessels overflowed.
Akita. ...	...44 52.	Do.	Duration long.
Aomori. ...	.. 45 1.	Do.	Windows rattled.
Kushiro. ...	.. 49 40.	Do.	Clocks stopped.
Tokachi. ...	.. 54 12.	Do.	Houses shaken.
Abashiri....	.. 44 40.	Weak (rather slight).	Accompanied by earthquake sound.
Ishinomaki.	...57 31(?).	Do.	
Shana. ...	.. 44 50.	Slight.	Gentle.
Kumagae.	.. 45 12.	Do.	Duration long.
Tokyo. ...	.. 46 15.	Do.	Gentle.
Nagano. ...	.. 46 40.	Slight (unfelt).	Duration long.
Iida.... ...	...46 53.	Do.	Gentle.
Maebashi.	...47 31.	Do.	
Matsumoto.	...47 48.	Do.	Gentle.
Miyako. ...	...43 56.	Slight.	Accompanied by earthquake sound.
Hakodate.	...45 6.	Do.	
Mito. ...	..45 0.	Do.	

Eqke. No. 23. April 13th 1904; 14h.

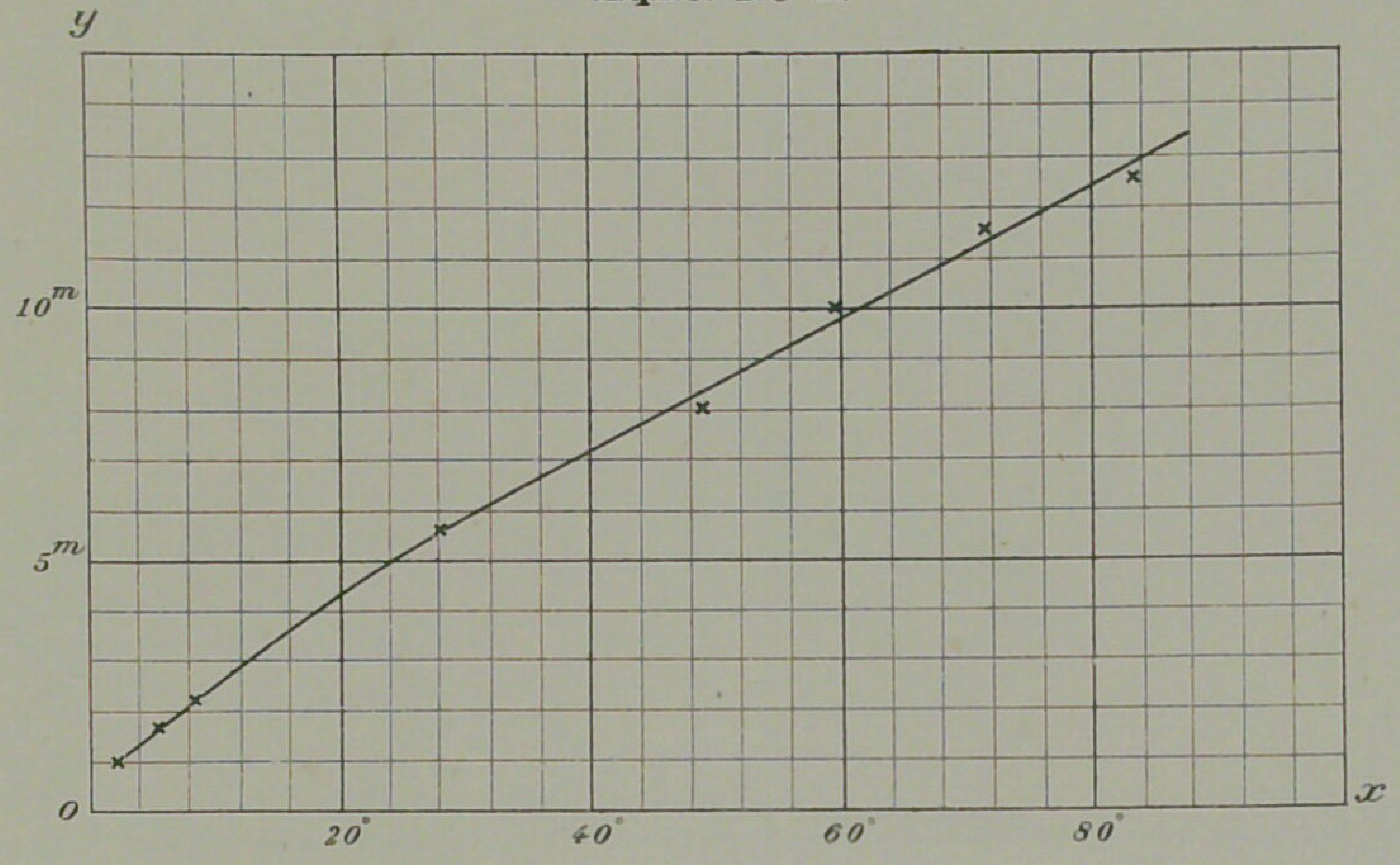
Miyako. ···	···37^m52^s.	Slight.	Accompanied by vertical movement.
Ishinomaki.	·· 38 8.	Do.	Gentle.
Akita. ···	·· 38 16.	Do.	Do.
Kumagae.	·· 38 54.	Slight (unfelt).	
Aomori. ···	·· 38 54.	Do.	
Utsunomiya.	··· 39 6.	Do.	
Tokyo. ···	·· 39 42.	Do.	Gentle.
Fukushima.	·· 38 23.	Do.	

Eqke. No. 24. May 27th 1904; 5h.

Mera. ···	·· 40^m 0^s.	Weak (rather slight).	Houses shaken.
Yokosuka.	·· 40 20.	Slight.	Windows rattled.
Tokyo. ···	···41 49.	Do.	Gentle.
Yokohama.	···32 26.	Slight (unfelt).	Do.
Kofu. ···	·· 41 3.	Do.	Do.
Kumagae.	···41 7.	Do.	
Ishinomaki.	···41 50.	Do.	
Mito. ··	···42 50.	Do.	

Fig. 1. Relation between arcual epicentral distance and time taken in transit by the 1st. preliminary tremor.

Eqke. No 2.



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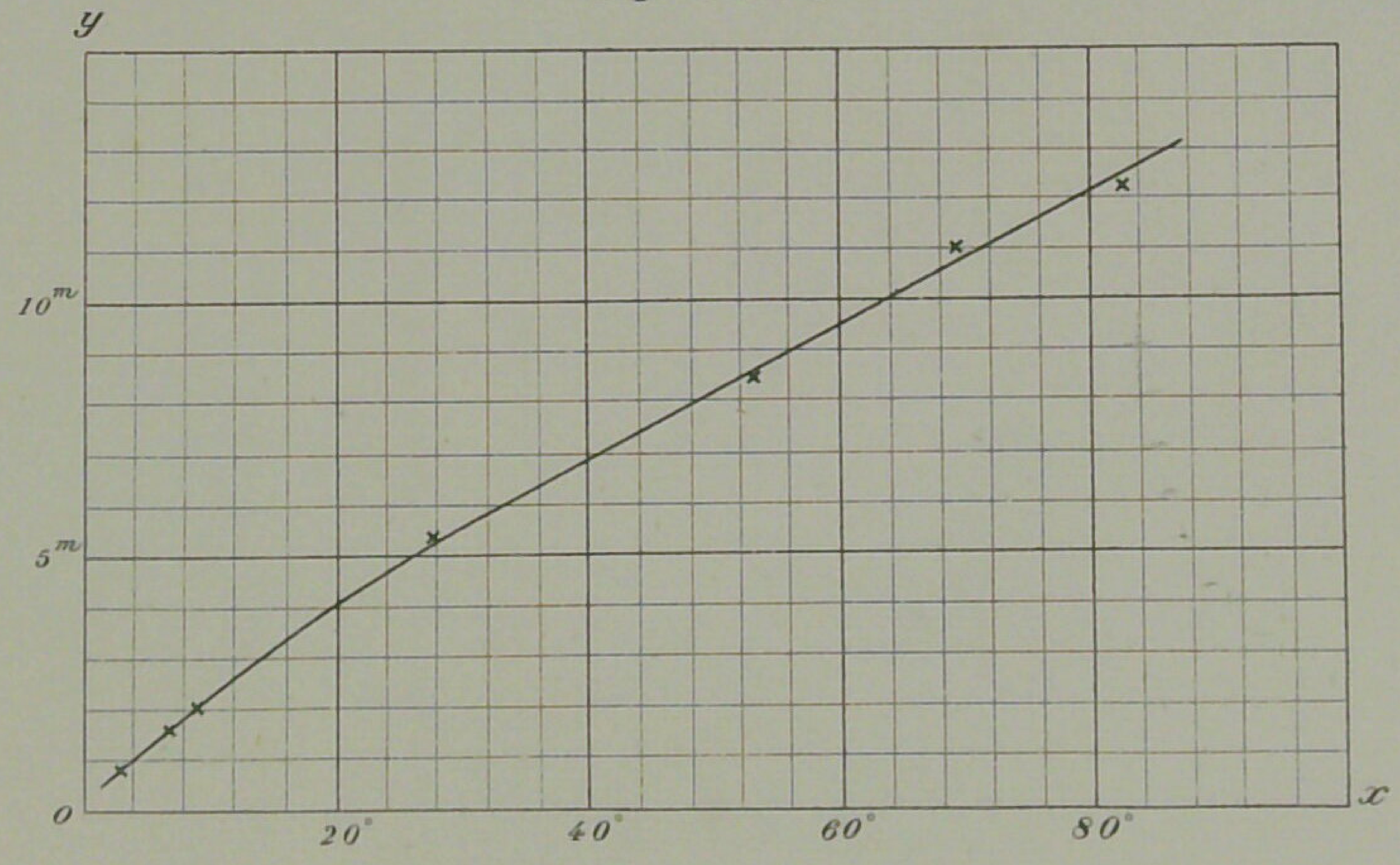


x = arcual epicentral distance.

y = time taken in transit.

A Tide Rectifier, or An Instrument for eliminating the tidal components from Tide-gauge Diagrams.

By

T. Terada, *Rigakushi.*

With Plates XXVII–XXVIII.

The *rectifier*, whose object is to eliminate the principal tidal components of oscillations from tide gauge diagrams, may be of some interest in connection with the study of the oscillations of sea water, which is, under the direction of Prof. H. Nagaoka, being carried on by the Imperial Earthquake Investigation Committee. The details of the instrument are given in Pl. XXVII.

Each of the diagrams to be rectified, which were obtained by a portable mercury tide-gauge constructed after Mr. Nakamura's design[1], consists of minor waves of periods $\frac{1}{2}-2$ cm. in length, superposed on the tide waves of period over 20 cm. To effect the elimination of the larger waves from such a curve, the conditions to be fulfilled by the instrument are as follows:—

1) While a point, say B (fig. 1), traces a simple harmonic curve, another point, say A, describes a straight line.

2) The deviation of the tracer B from simple harmonic curve is faithfully reproduced on the straight line described by A.

---

[1] S. Nakamura. On a portable mercurial tide-gauge. Tokyo Sugaku-Butsu. G. K. Gaiyo (Reports of the meetings of the Tokyo Physico-Mathematical Society) Vol. I, No. 15, 1902.

3) The instrument must be adjustable to curves of different periods and amplitudes.

Simplicity of the construction as well as the operation is also desirable.

To fulfil the above conditions, pantographic joints (Pl. XXVII. JJJ) are made use of. The central pivot (C) is fixed to a slide (S) which is put in an oscillating motion of simple harmonic type in the direction of ACB with half the amplitude of that of the curve to be rectified, while the system moves in a direction perpendicular to ACB. Referring to Fig. 1, if A, C, B are the joints, we have always

$$AC=BC.$$

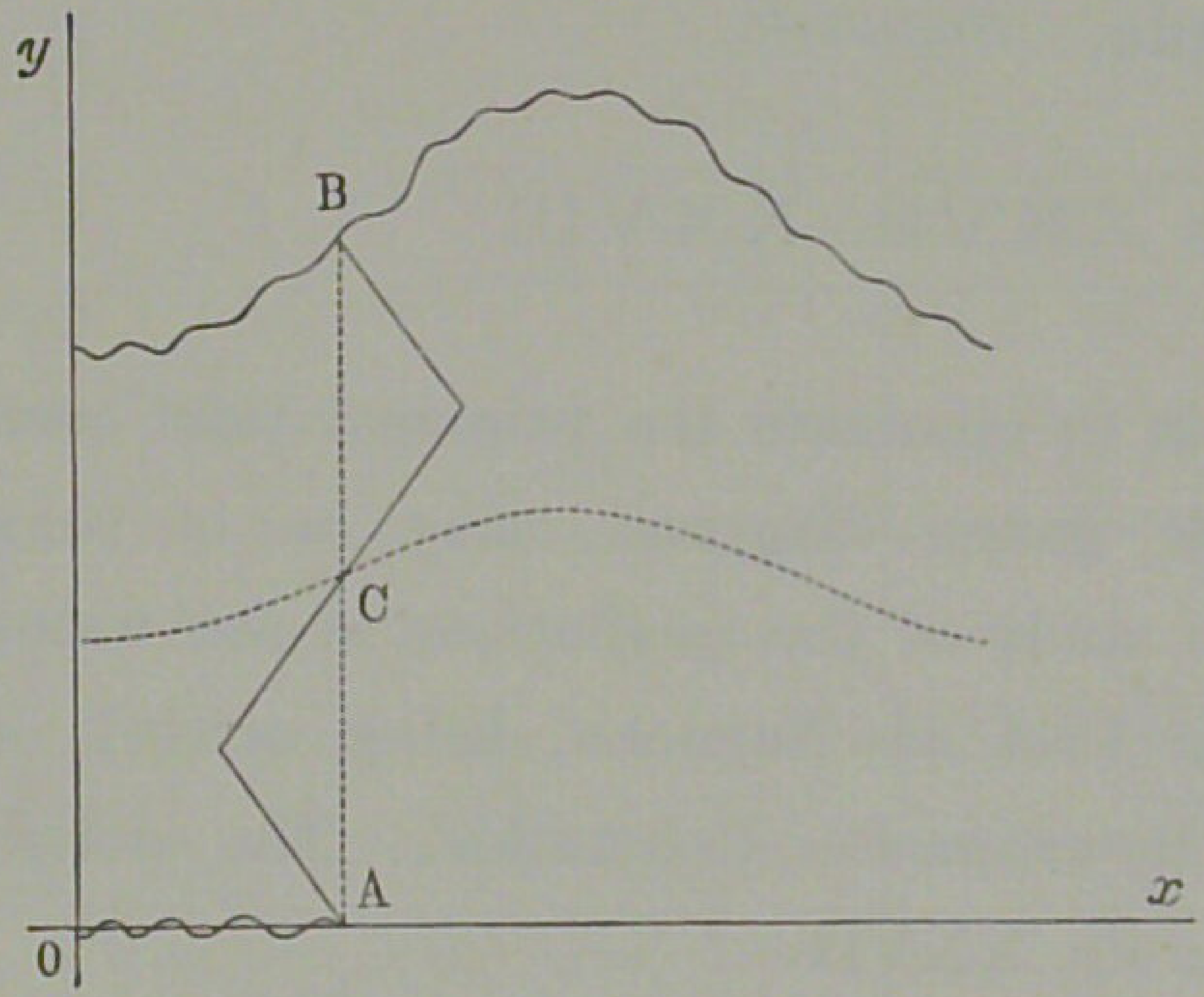
If the ordinate of the tidal curve be represented by y, we may put

$$y=a+b\sin nx+\sum_1^{\infty} b_m \sin n_m x.$$

Now, let C describe a curve

$$y'=\frac{a}{2}+\frac{b}{2}\sin nx$$

Fig. 1.



If the path of A be represented by y'',

$$y-y'=y'-y''$$
$$\therefore\ y''=2y'-y$$
$$=-\sum_1^{\infty} b_m \sin n_m x$$

The negative sign shows that the minor waves are reproduced. If the minor oscillations were to be reproduced in a magnified or reduced amplitude, the ratio of the arms of the joints is to be changed accordingly. In this case

$$k(y-y')=y'-y''$$
$$\therefore\quad (k+1)\,y'=ky+y''$$
$$y=a+b\sin nx+\sum_1^{\infty} b_m \sin n_m x$$

$$y'' = -k\sum_{1}^{\infty} b_m \sin n_m x$$

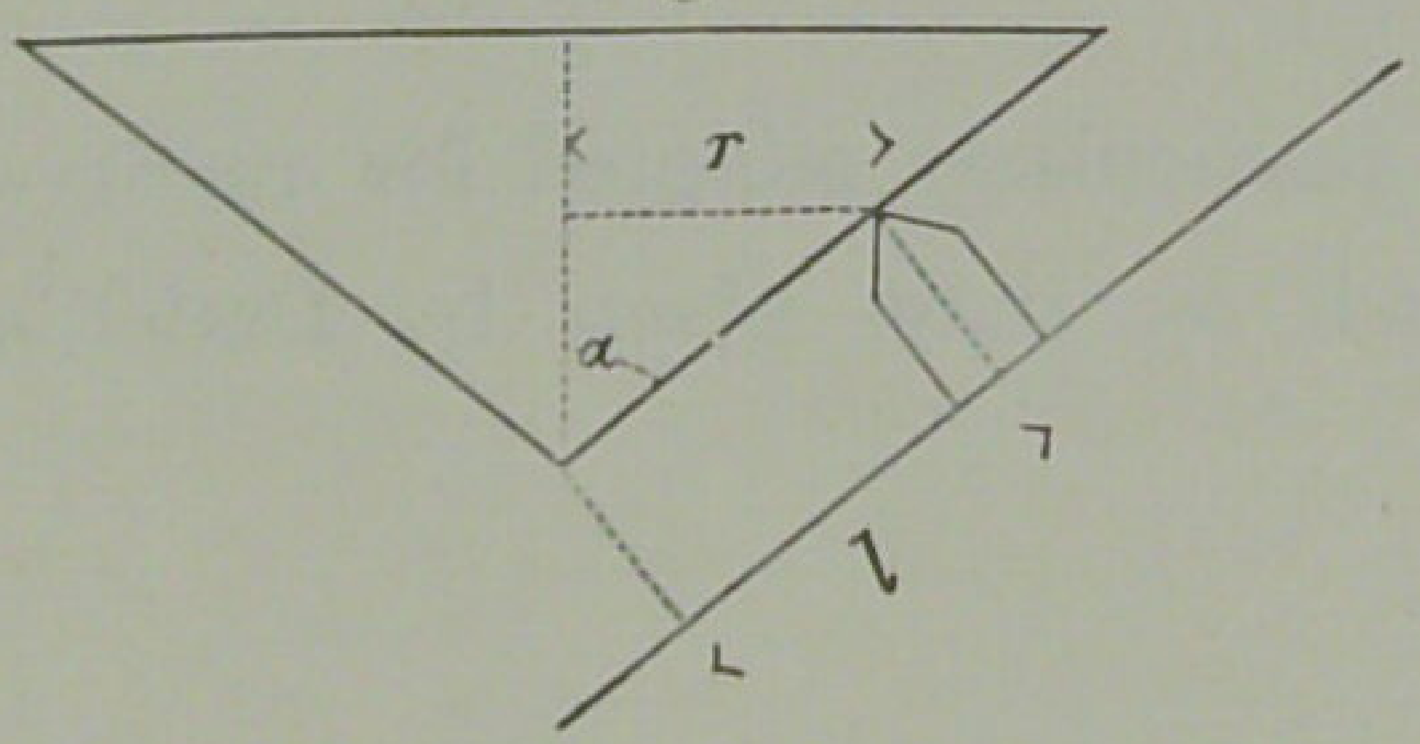
$$\therefore \qquad y' = \frac{ka}{k+1} + \frac{kb}{k+1}\sin nx$$

i. e. to magnify by k times, the amplitude of C must be adjusted to $\frac{k}{k+1}$ times that of the curve to be rectified.

The simple harmonic motion of the slide (S) is actuated by a peg (P), which slides smoothly in a groove (G), cut in the slide perpendicular to ACB, and fixed to a proper point of the crank (K) rotating with the conical wheel, (W) when the wheel rolls on the rail (R_1). The motion of the tracer (B) and the pen (A) is guided by the rails (LL). The whole frame-work rests and rolls on two rails (R_1) and (R_2). The latter is run over by a rectangular groove upon which fit two rollers attached to the frame. The former (R_1) has a sharp edge on which the conical wheel rolls. The rail rests on an inclined plane, parallel to the generating line of the cone passing through the point of contact with the edge, so that if the rail is shifted parallel to itself, the plane of rotation of the wheel remains unaltered. The edge is stretched over with a thin sheet of cautchouc to prevent the dead slip.

The period, *i. e.* the distance swept over by the instrument in one revolution of the wheel, is determined by the point of contact of the one with the rail (R_1). Referring to Fig. 2,

Fig. 2.



$$l = r \operatorname{cosec} \alpha$$

The period $T = 2\pi r$

$$\therefore \qquad l = \frac{T}{2\pi}\operatorname{cosec} \alpha$$

A table for the values of l for different values of T, may facilitate the adjustment.

The adjustment for the amplitude, may be performed by shifting the peg (P) to a proper distance from the axis of the crank, by means of a nut fixed to the peg, and a screw. The position of (P) may be read on a scale on the side of the crank. When these adjustment have been made, the instrument is ready for the operation.

Since the tidal curve is by no means simple harmonic, the elimination of a single component is not generally sufficient for the perfect rectification of a sheet of mareogram which contains maxima or minima of different amplitudes. Though this may be achieved by successive eliminations, it seems more plausible for the practical purpose to proceed as follows. The curve is rectified, as it were, piece by piece, *i.e.* we divide the curve into a number of portions each of which may approximately be regarded as simple harmonic, rectify them successively and arrange the rectified pieces into a continuous line. Fig. 1, Pl. II rectified in this way gives Fig. 2.1)

The following are some of the other applications of the instrument:--

1) If the tracer and the pen are interchanged and the former is drawn along a straight ruler, the latter describes a simple harmonic curve of desired size, provided suitable adjustments be made.

2) If the simple harmonic curve thus obtained be brought under the tracer and the phase of the crank as well as the position of the peg and the rail be properly adjusted, we may obtain a curve which is composed of two simple harmonic curves of desired size and phase difference. By successive operations, any desired numbers of simple harmonic curve may be composed, as long as the amplitude of the resultant curve does not exceed the limit as is naturally determined by the length of the rails (LL).

3) The instrument seems to be particularly adapted for rectifying diagrams of alternate currents such as those given by Dudell's oscillograph.

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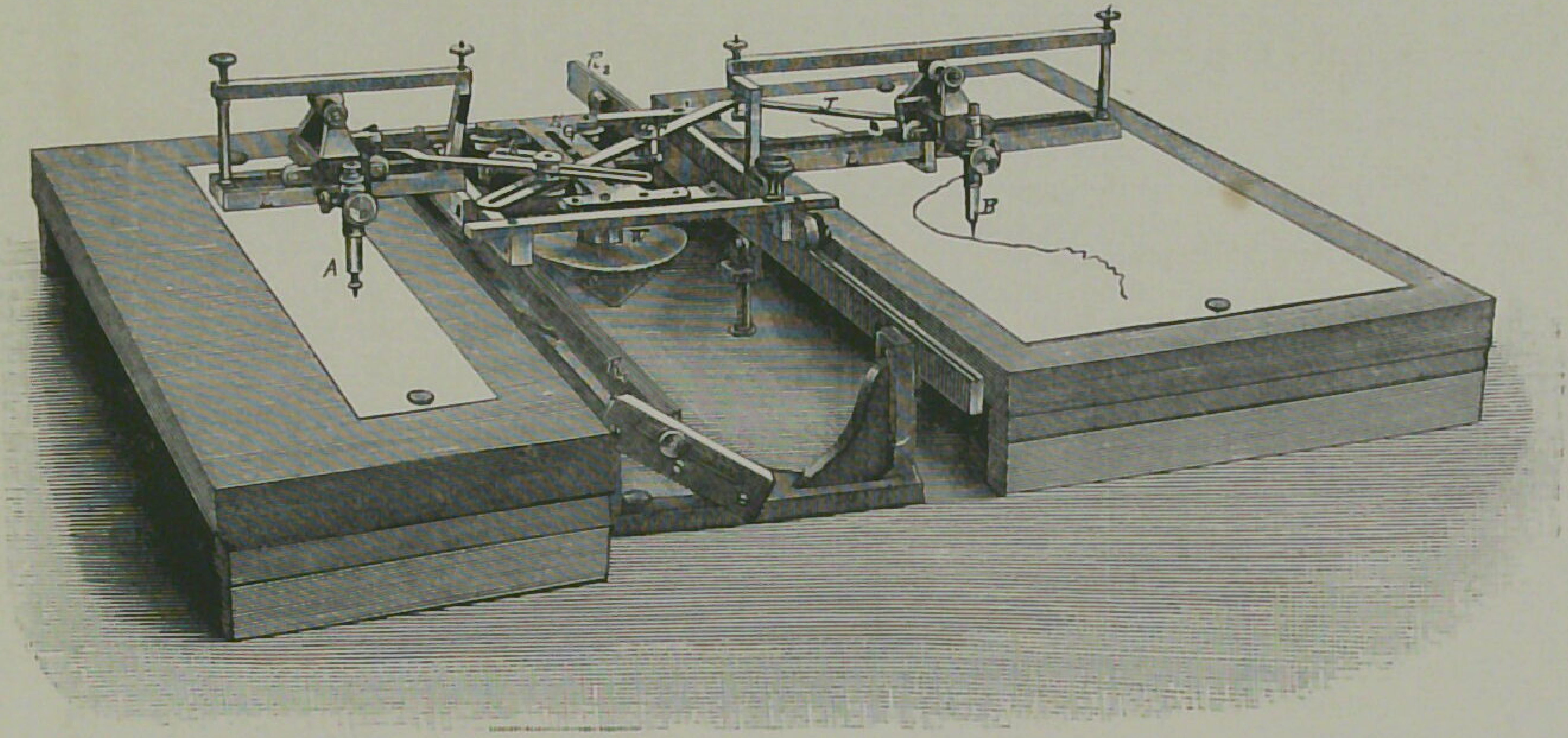
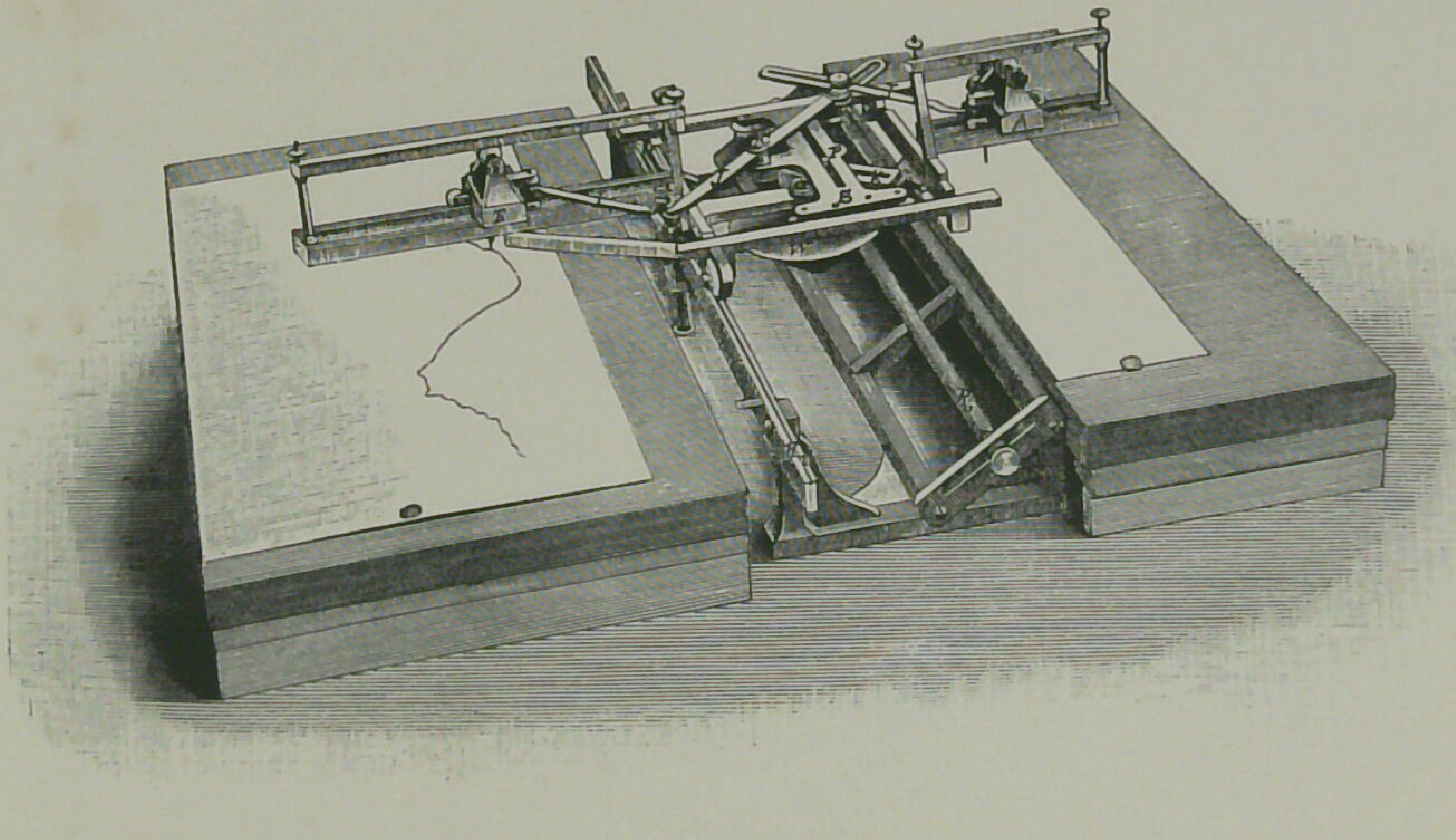
1) Here, the inverted curve is inverted once more by means of a tracing paper.

Pl. XXVII.





Note on the Horizontal Pendulum Observations at Osaka.

By

F. Omori, *Rigakushi, Rigakuhakushi,*
Member of the Imperial Earthquake Investigation Committee.

With Plate XXIX.

1. *Introduction.*

The continuous earthquake observation at the Osaka Meteorological Observatory was commenced in 1901 with an Omori Horizontal Pendulum[1] of multiplication 6 and of free period of vibration of 25 sec., set up so as to record the EW component motion, and 254 earthquakes have been there recorded in the course of 2 years 7 months between June 1901 and Dec. 1903. The following notes are based on the results of analysis of the diagrams of these earthquakes and of pulsatory oscillations given by Mr. N. Shimono, Director of the Observatory, in Nos. 1 and 2 of the "Osaka Chidō Kansoku Hōkoku" (Reports on the Horizontal Pendulum Observations of Earthquakes at Osaka).

2. *Pulsatory Oscillations.*

(*a*) *Frequency.* The following table gives the number of days, on which pulsatory oscillations occurred, in each of the months between June 1901 and December 1903, as well as the total monthly duration of storms of these movements in 1903.

---

[1] The instrument was of simple construction, which is similar to that shown in Pl. III, the *Publications*, No. 5.

Year. / Month.	1901.	1902.	1903.	Mean.	Total monthly duration (1903).
	Days.	Days.	Days.	Days.	Hours.
Jan.	—	9	17	13.0	288
Feb.	—	11	13	12.0	228
March.	—	8	12	10.0	192
April.	—	8	5	6.5	72
May.	—	8	8	8.0	108
June.	—	5	5	5.0	60
July.	—	3	6	4.5	108
Aug.	—	6	1	3.5	12
Sept.	2	4	2	2.7	24
Oct.	5	9	16	10.0	324
Nov.	5	8	9	7.3	108
Dec.	12	19	16	15.7	312
Sum.	—	98	110	104.	1836

From figs. 1 and 2, Pl. XXIX, which illustrate graphically the results contained in the above table, it will be seen that the frequency of pulsatory oscillations in the months April to September is much smaller than in October, December, January, February and March. The mean maximum and minimum monthly numbers of the days with pulsatory oscillations were respectively 15.7 and 2.7 which are in the ratio of about 6 : 1.

(*b*) *Period.* In the 123 cases of pulsatory oscillation storms, observed during the 1 year 7 months between June 1901 and Dec. 1902, the average period of vibration varied between 3.1 and 6.9 sec, and had a general mean of 5.1 sec.; the number of cases, in which the average period was between 4.0 and 5.9 sec., being 114. Again, in the 113 cases of pulsatory oscillation storms in the year 1903, the average period, with a single exception of 2.4 sec., varied between 3.0 and 6.4 sec, and had the geveral mean of 4.9 sec.; the number of cases, in which the average period was between 4.0 and 5.9 sec., being 100.

Thus the mean period of vibration of pulsatory oscillations at

Osaka may be taken at about 5.0 sec., which is not much different from one of the fundamental vibration periods at Tokyo, namely, 4.4 sec.[1]; the other fundamental period of pulsatory oscillations at Tokyo being 8.0 sec. It is probable that a careful examination of the Ōsaka diagrams will also indicate the existence of pulsatory oscillations of about 8 sec. period, as is to be inferred from the presence of vibrations of such peiod in the preliminary tremors and the end portion of earthquakes observed at the same place. (See next §.) I may here note that pulsatory oscillations of about 8 sec. period have also been observed at Leipsic with Prof. Wiechert's astatic pendulum.[2] It may be that the predominating period or periods of pulsatory oscillations, which are characteristic to the different places of observation, are approximately constant all over the world.

3. *Periods of earthquake vibrations.*

The 254 earthquakes before mentioned are divided, according to origin, into the following nine groups:—

Group I.	Distant earthquakes. (46 earthquakes.)
Group II.	Earthquakes which originated off the eastern coast of Hokkaido. (6 earthquakes.)
Group III.	Earthquakes which originated off the north-eastern coast of the Main Island. (33 earthquakes.)
Group IV.	Earthquakes in the vicinity of Tokyo. (55 earthquakes.)
Group V.	Earthquakes in Central Japan. (11 earthquakes.)
Group VI.	Earthquakes in the Kinai Provinces (27 earthquakes.)
Group VII.	Earthquakes in Kyushu. (15 earthquakes.)

---

1). F. Omori; Horizontal pendulum obsevations, etc. The *Publications*, No. 13.

2). Franz Etzold: Bericht uber die von Wiecherts astatischem Pendelseismometer in Leipzig vom 1. Januar bis 30. Juni 1903 registrierten Fernbeben und Pulsationen. Berichte der mathem. physichem Klasse der K. Sächs. Gesellschaft der Wissenschaften zu Leipzig, 1903.

Group VIII. Earthquakes in Formosa and off the Lyū-Kyū Islands. (15 earthquakes.)

Group IX. Local earthquakes, or those which originated in the immediate vicinity of Osaka. (36 earthquakes.)

As the Osaka instrument had a too great stability, there appeared very often proper pendulum oscillations in the principal part of earthquakes, consequently I take here only the preliminary tremors and the end portion, for which the average values of the different kinds of period are as follows, the figures within brackets indicating the number of cases from which the respective values of the periods have been deduced.

PERIODS OF VIBRATIONS AT OSAKA.
(EARTHQUAKES OF GROUPS I–IX.)

Group. / Phase of eqke. motion.	I, II, VIII.	III, IV, VII.	V, VI.	IX.
1st Preliminary Tremor.	sec. 1.7 (4) 2.2 (3) **3.0** (20) **4.9** (25) **7.5** (6)	sec.	sec.	sec.
2nd Preliminary Tremor.	1.2 (1) 2.4 (2) **3.6** (15) **5.2** (20) **8.6** (8)			
1st and 2nd Preliminary Tremors taken together.		— — — — **4.7** (13) 7.1 (3) 15.6 (4)	**0.8** (8) **1.4** (14) 2.7 (1) — 5.6 (3)	— 1.7 (3) **3.2** (7) — **4.9** (9)
End portion.	— — — **6.2** (20) **8.8** (7) **14.3** (7)	— **2.4** (14) — **6.0** (6) 8.7 (3) 15.8 (3)	**1.4** (7) **2.0** (8) **4.2** (10) — — —	— 2.8 (4) **5.1** (7) — 8.1 (3) —

In the above table, the periods most frequently occurring in each phase of the motion are printed in thick letters. The averages of the different periods taken from the preliminary tremors and end portion are as follows, the figures within the brackets having the same signification as before :—

0.84 sec.	(9)
1.5 ,,	(28)
2.7 ,,	(59)
3.8 ,,	(25)
5.3 ,,	(103)
8.2 ,,	(30)
15.0 ,,	(14)

Of these 7 classes of periods, the first two characterize the macroseismic movements at Osaka, the rest being of the nature of microseismic or insensible movements. It is to be noted that the period most frequently occurring, namely, that of 5·3 sec., is practically identical with the average period of pulsatory oscillations at Osaka. Periods of vibrations approximately equal to the 3rd, 5th, 6th, and 7th are found also in the earthquakes observed at Tokyo.

Tokyo. Aug., 1904.

Annual Variation of the Frequency of Pulsatory Oscillations at Osaka.

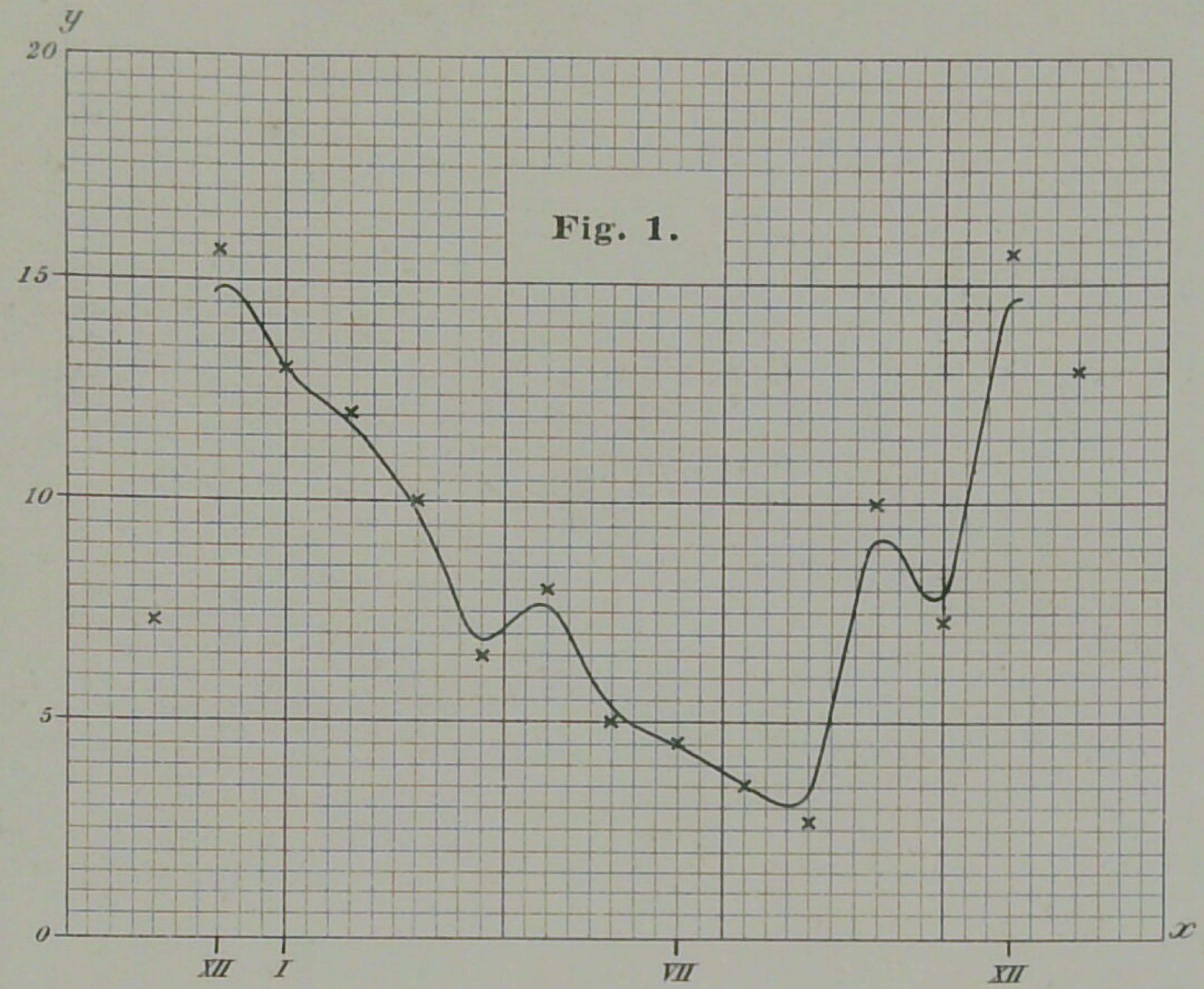


Fig. 1.

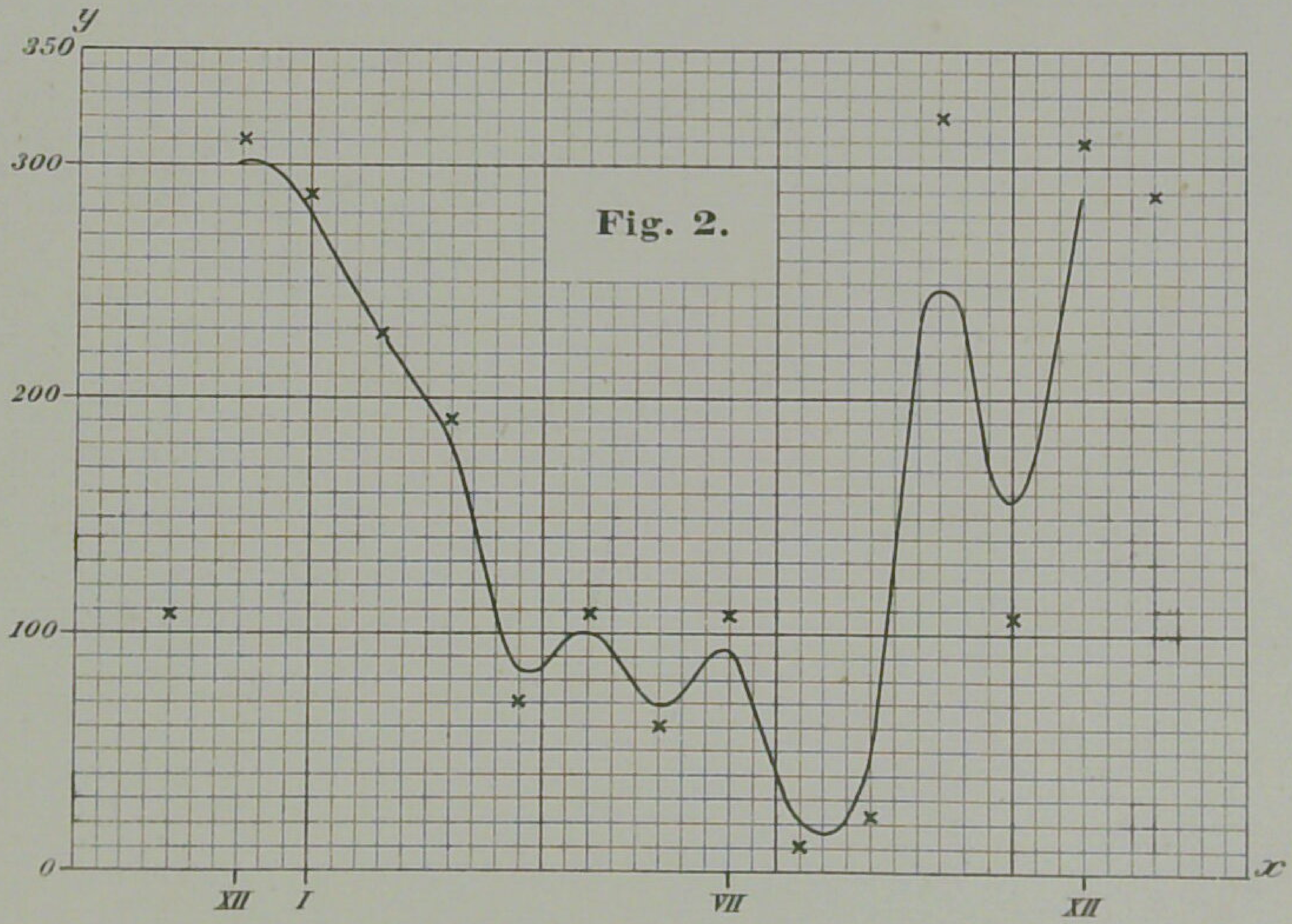


Fig. 2.

Fig. 1.
x = Month.
y = Monthly number of days, on which Pulsatory oscillations took place.

Fig. 2.
x = Month.
y = Monthly number of hours during which Pulsatory oscillations took place.

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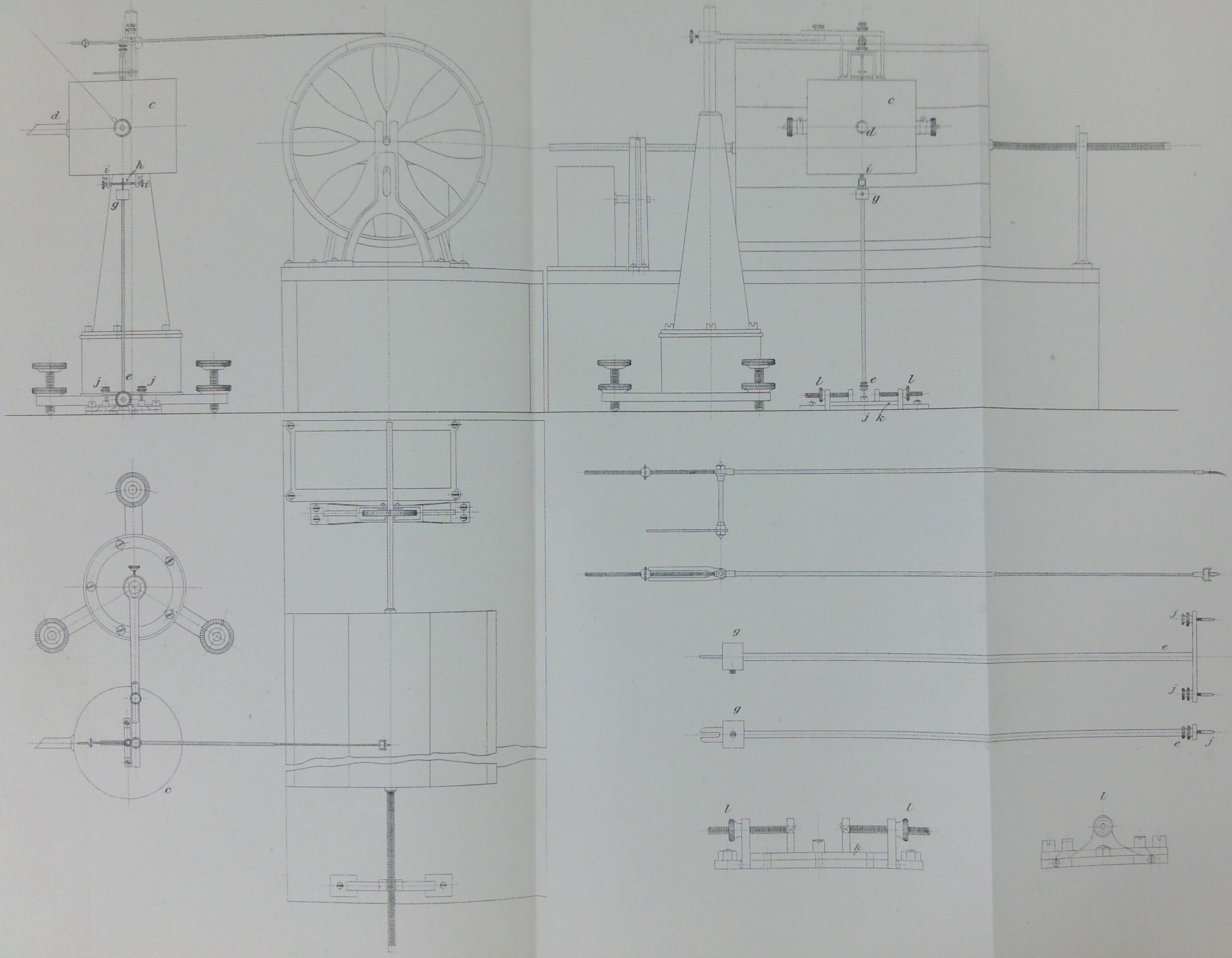
明治三十七年十月十三日印刷

Pl. II.



Pl. III.

A Horizontal Tremor Recorder.

Fig. 4.

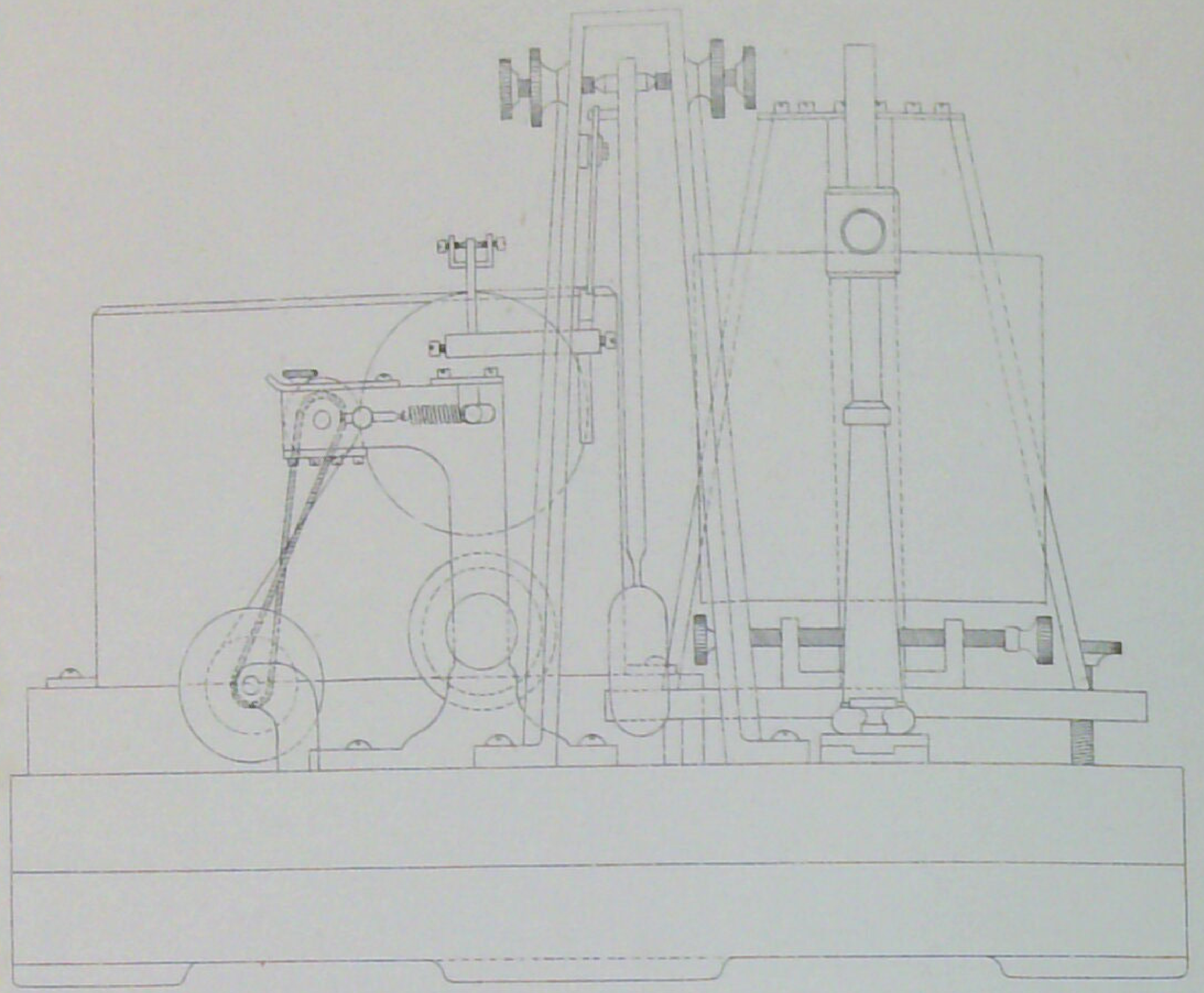
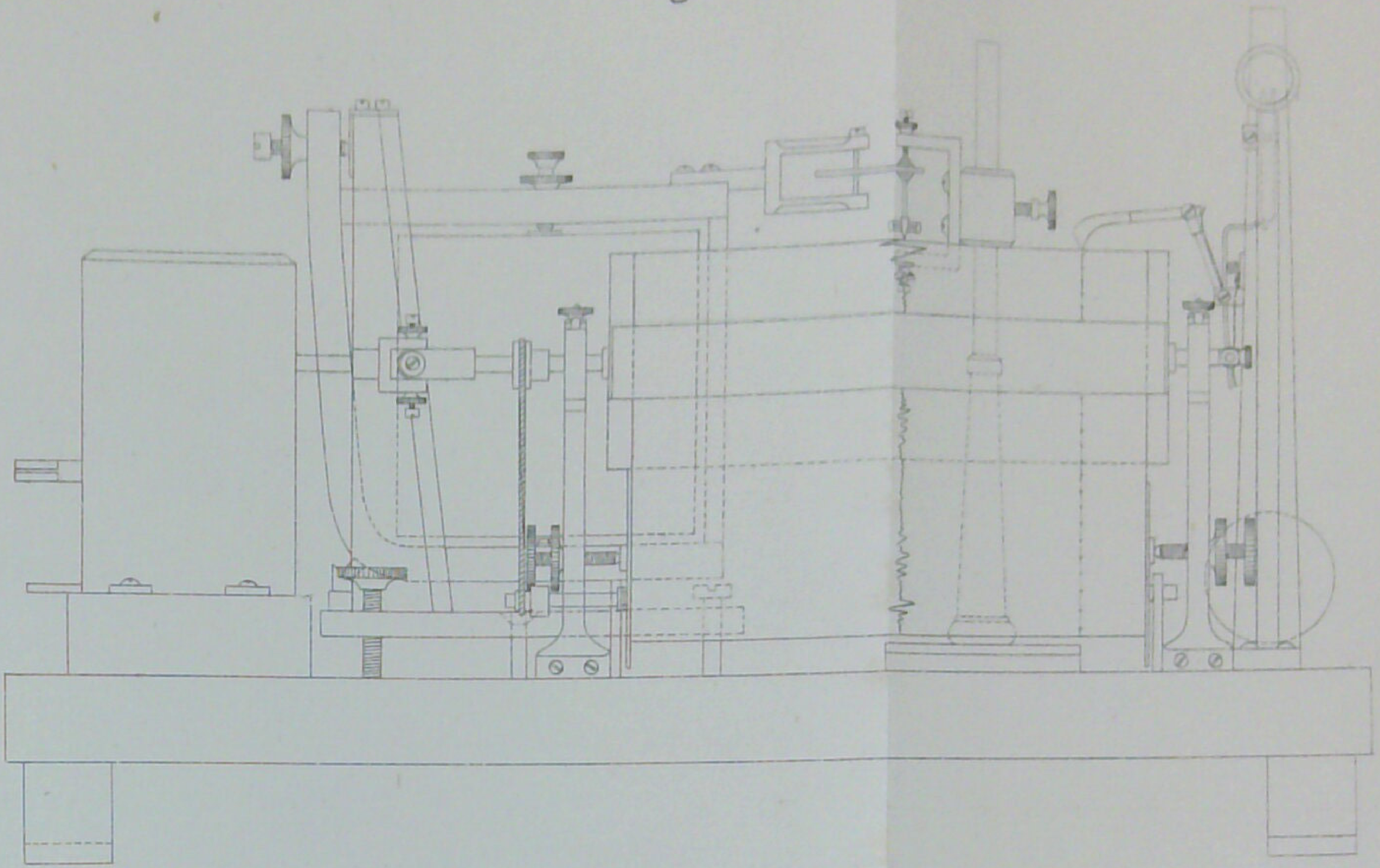


Fig. 2.



Scale for Figs. 2, 3 and 4.

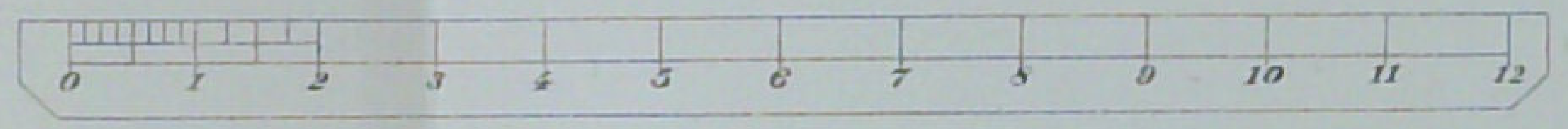


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Fig. 5.

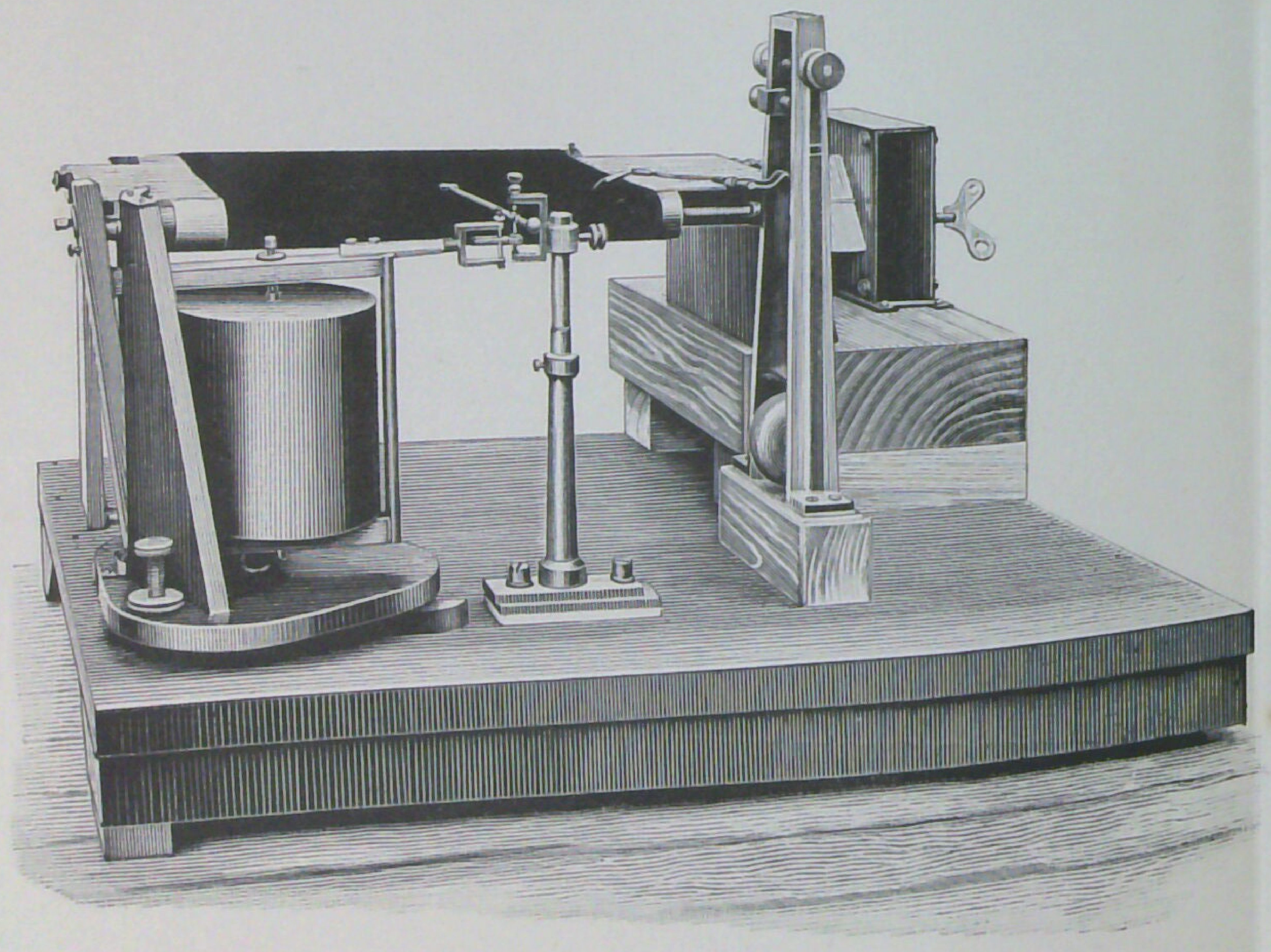
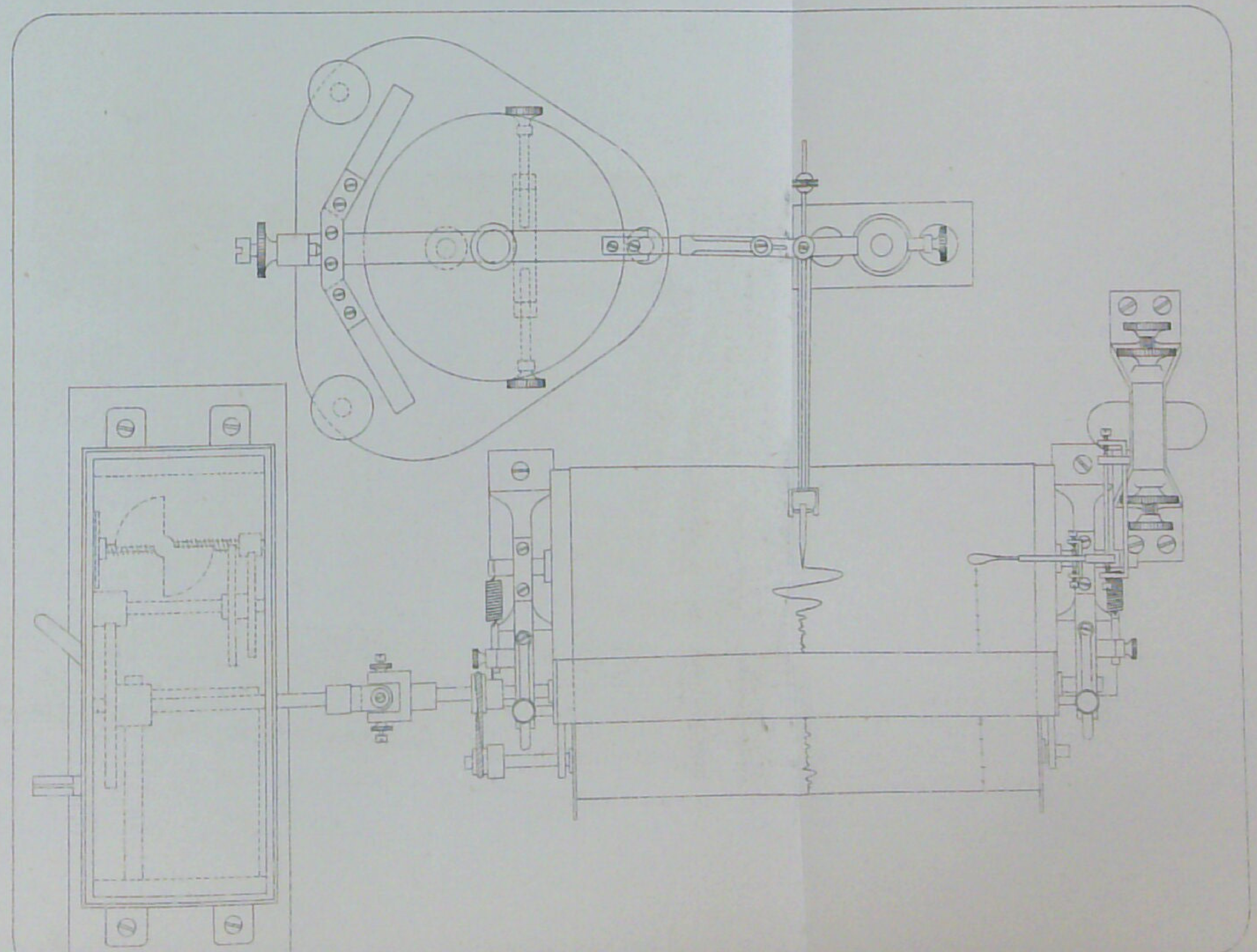


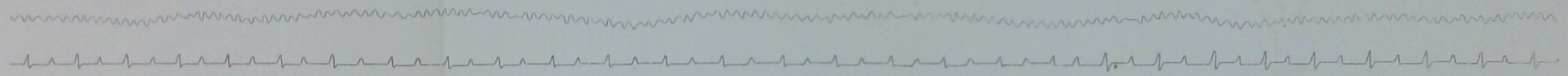
Fig. 3.



Vibration of the ground caused by an Oil Engine.

Fig. 8. NS Component. Multiplication = 70. Distance between the Engine and the place of observation = 17 feet.

Fig. 9. NS Component. Multiplication = 70. Distance between the Engine and the place of observation = 50feet.



Vibration of the walls of the Workshop of the Engineering College, caused by a Steam Engine.

Fig. 10. Normal motion of the eastern up-stair wall. Multiplication = 50.

Fig. 11. Normal motion of the southern up-stair wall. Multiplication = 50.

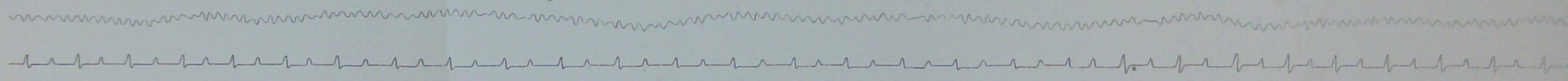
Time scale : 2 successive tick intervals = 0.71 sec.

Plate IV Left Hand Side

Vibration of the ground caused by an Oil Engine.

Fig. 8. NS Component. Multiplication = 70. Distance between the Engine and the place of observation = 17 feet.

Fig. 9. NS Component. Multiplication = 70. Distance between the Engine and the place of observation = 50feet.



Vibration of the walls of the Workshop of the Engineering College, caused by a Steam Engine.

Fig. 10. Normal motion of the eastern up-stair wall. Multiplication = 50.

Fig. 11. Normal motion of the southern up-stair wall. Multiplication = 50.

Time scale : 2 successive tick intervals=0.71 sec.

Fig. 1. Latitude Variation in Tokyo, between Aug. 1896 and Dec. 1903.

A black dot (●) along the abscissa axis denotes a destructive earthquake.

A small circle (○) along the abscissa axis denotes an earthquake, which was not destructive, but whose land area of disturbance was over 10,000 sq. *ri*.

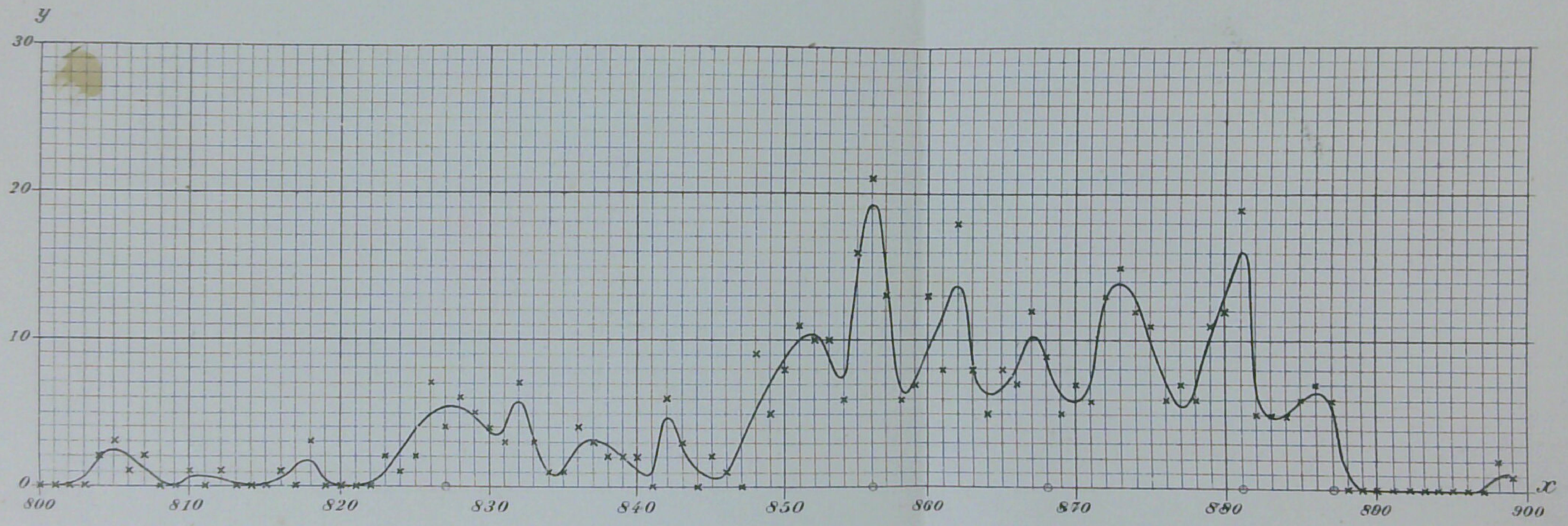
Plate V left Hand Side

Fig. 1. Latitude Variation in Tokyo, between Aug. 1896 and Dec. 1903.

A black dot (•) along the abscissa axis denotes a destructive earthquake.

A small circle (o) along the abscissa axis denotes an earthquake, which was not destructive, but whose land area of disturbance was over 10,000 sq. *ri*.

Fig. 2. Seismic activity in Kyoto during the 9th century.

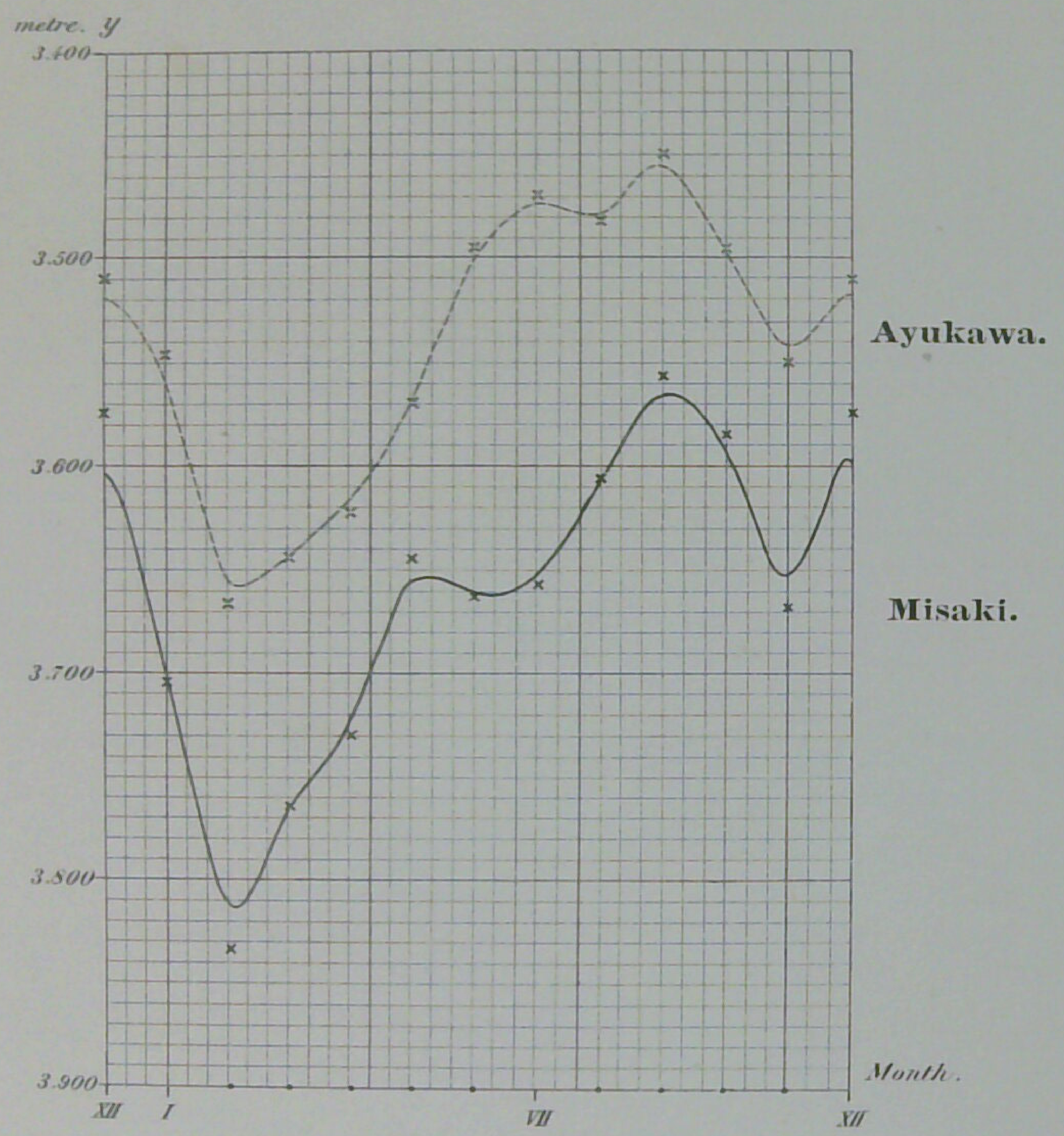


x=Time in years.

y=Yearly seismic activity.

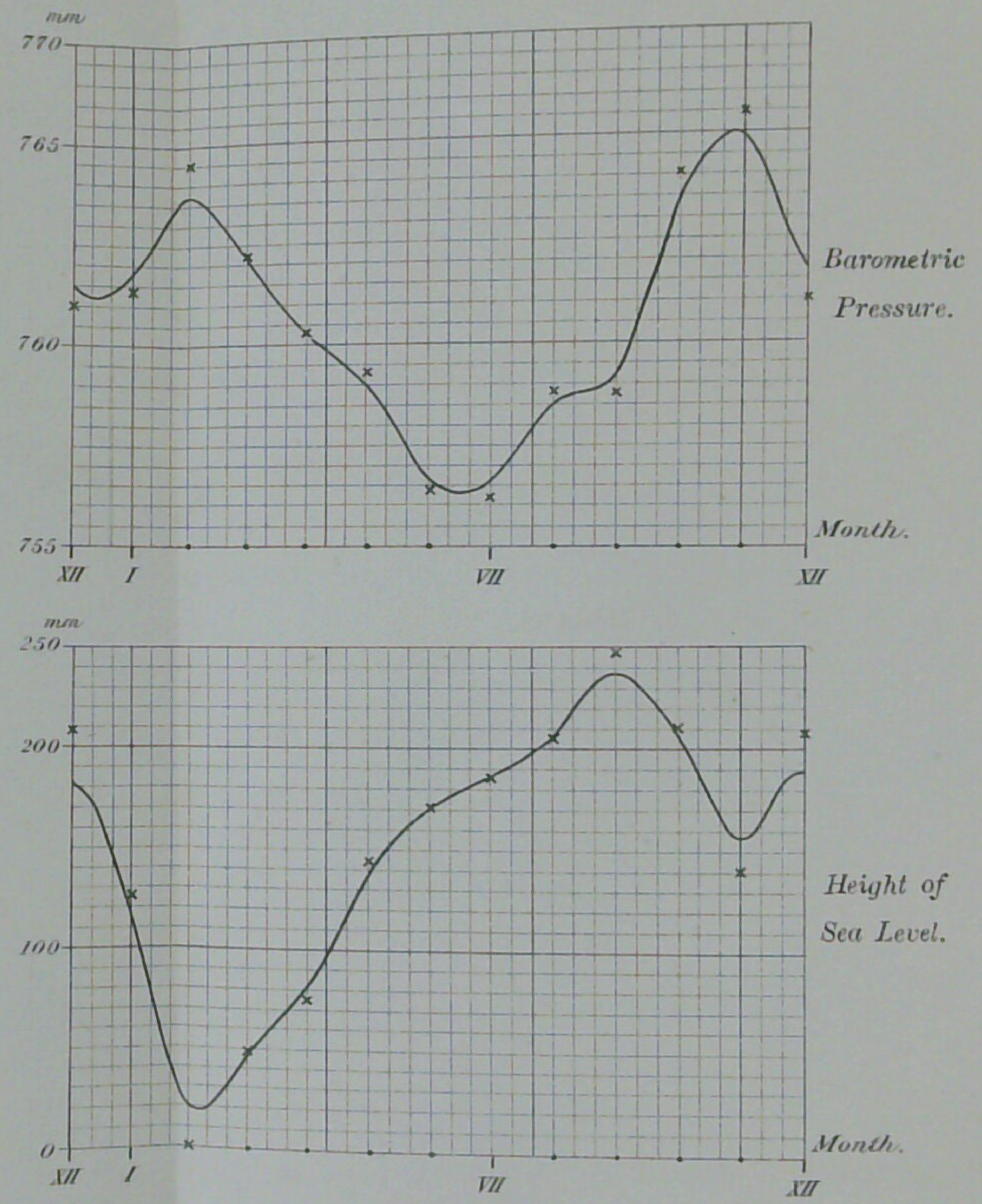
Each small circle (o) in the abscissa axis indicates a destructive earthquake in the year specified.

Fig. 1.



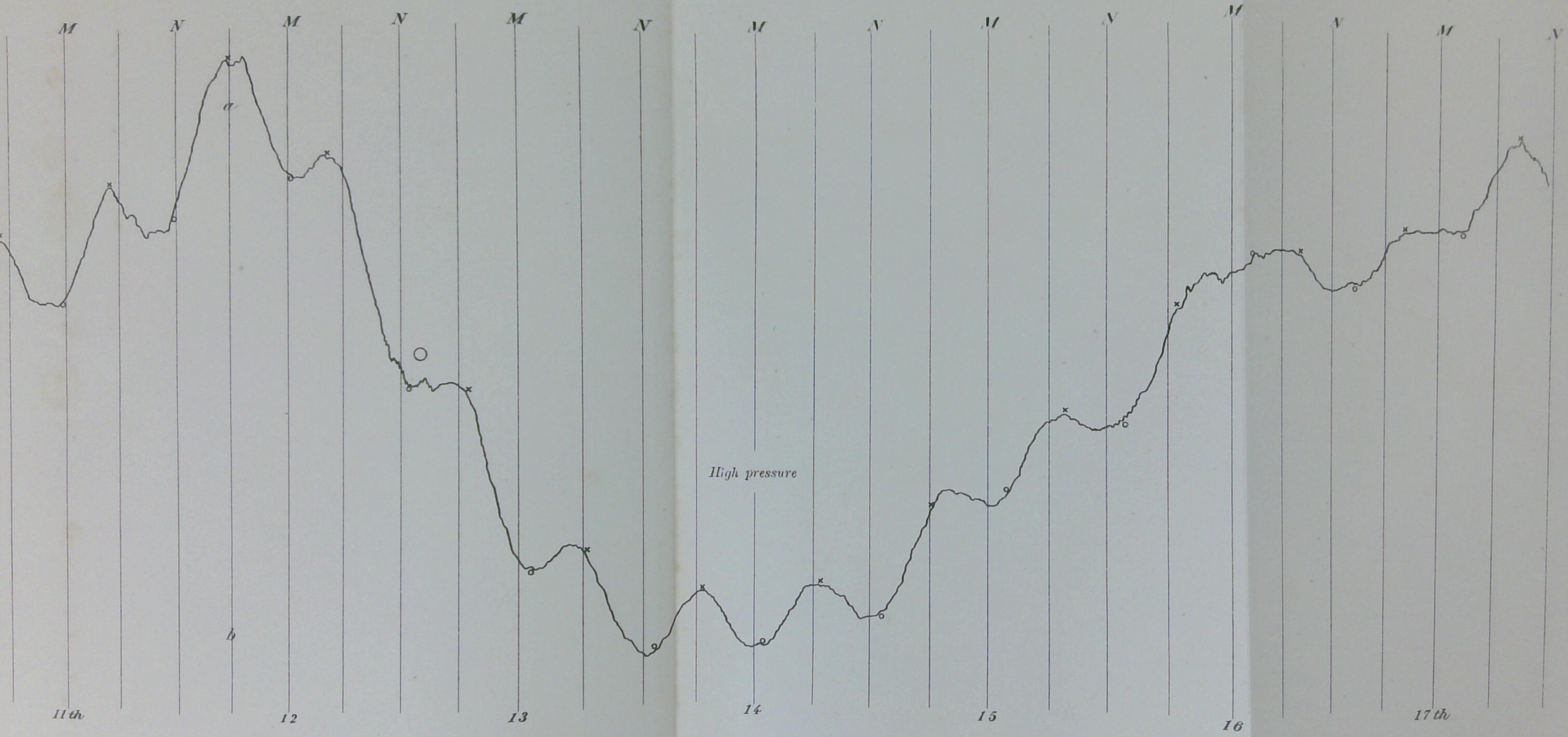
y = Mean monthly height above the sea water of the datum line in the Mareogram.

Fig. 2.



Pl. XVIII.

Tōkyō Artesian well. Fig. 1. April, 1903. Natural scale.

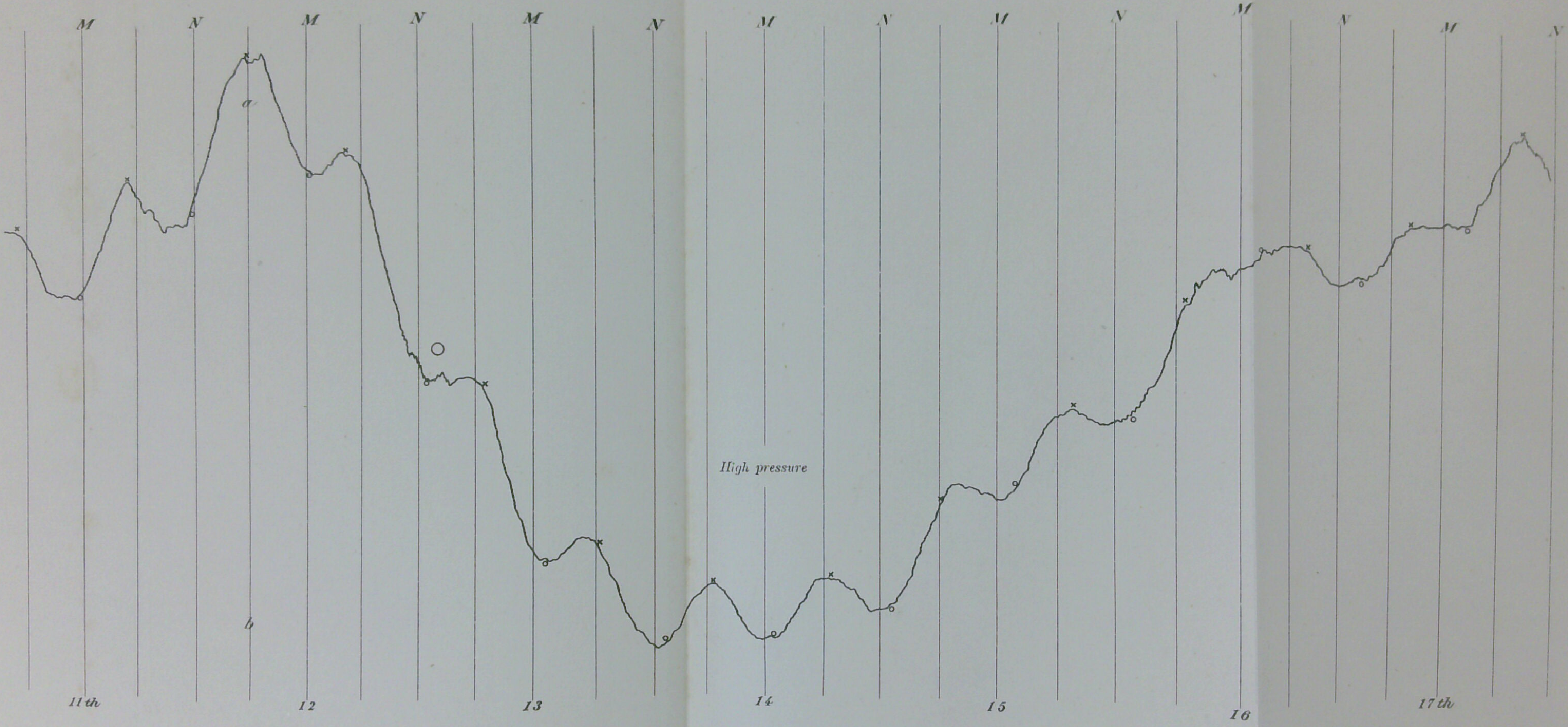


The height *ab* is the level change corresponding to a barometric change of 23 mm of mercury.

× ...Phase of high water in Tōkyō Bay,
o ... " " low " " " ",
O....Phase of the moon.

Plate XVIII Left Hand Side

Tōkyō Artesian well. **Fig. 1. April, 1903.** **Natural scale.**



The height *ab* is the level change corresponding to a barometric change of 23 mm of mercury.

× ...Phase of high water in Tōkyō Bay,
o ... „ „ low „ „ „ „
O....Phase of the moon.

Pl. XIX

Pl. X

Tōkyō Artesian well.

Fig. 2. August, 1903.

Natural scale.

Fig. 3. July, 1903.

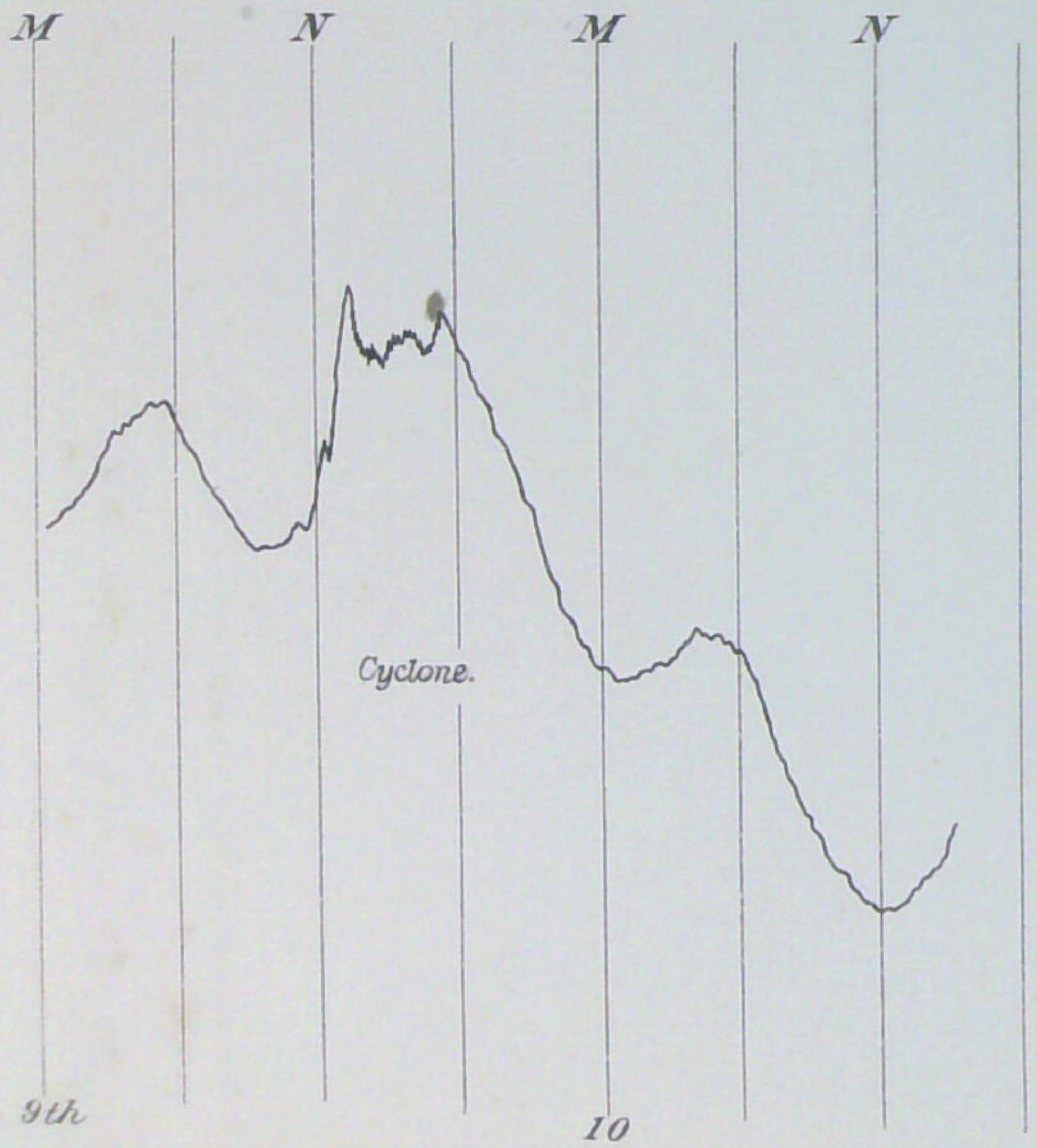
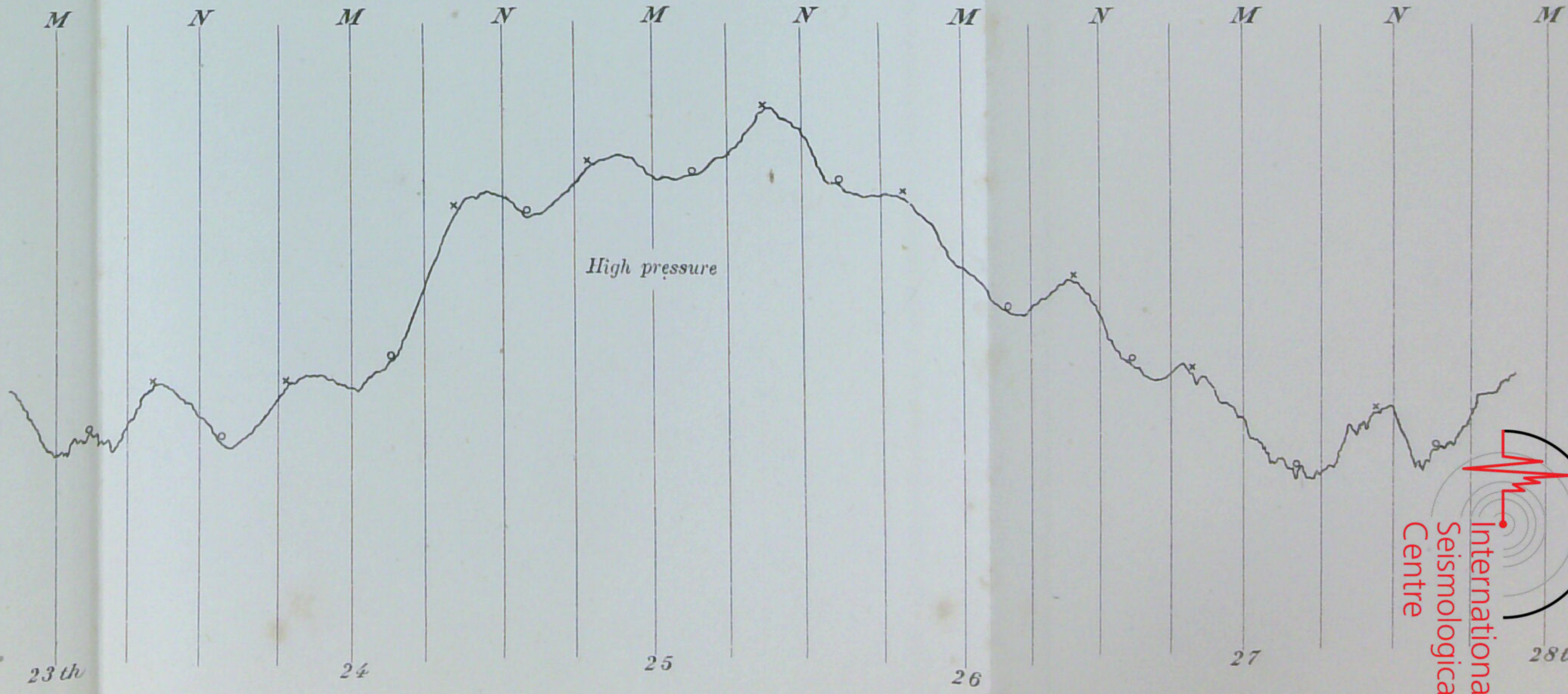


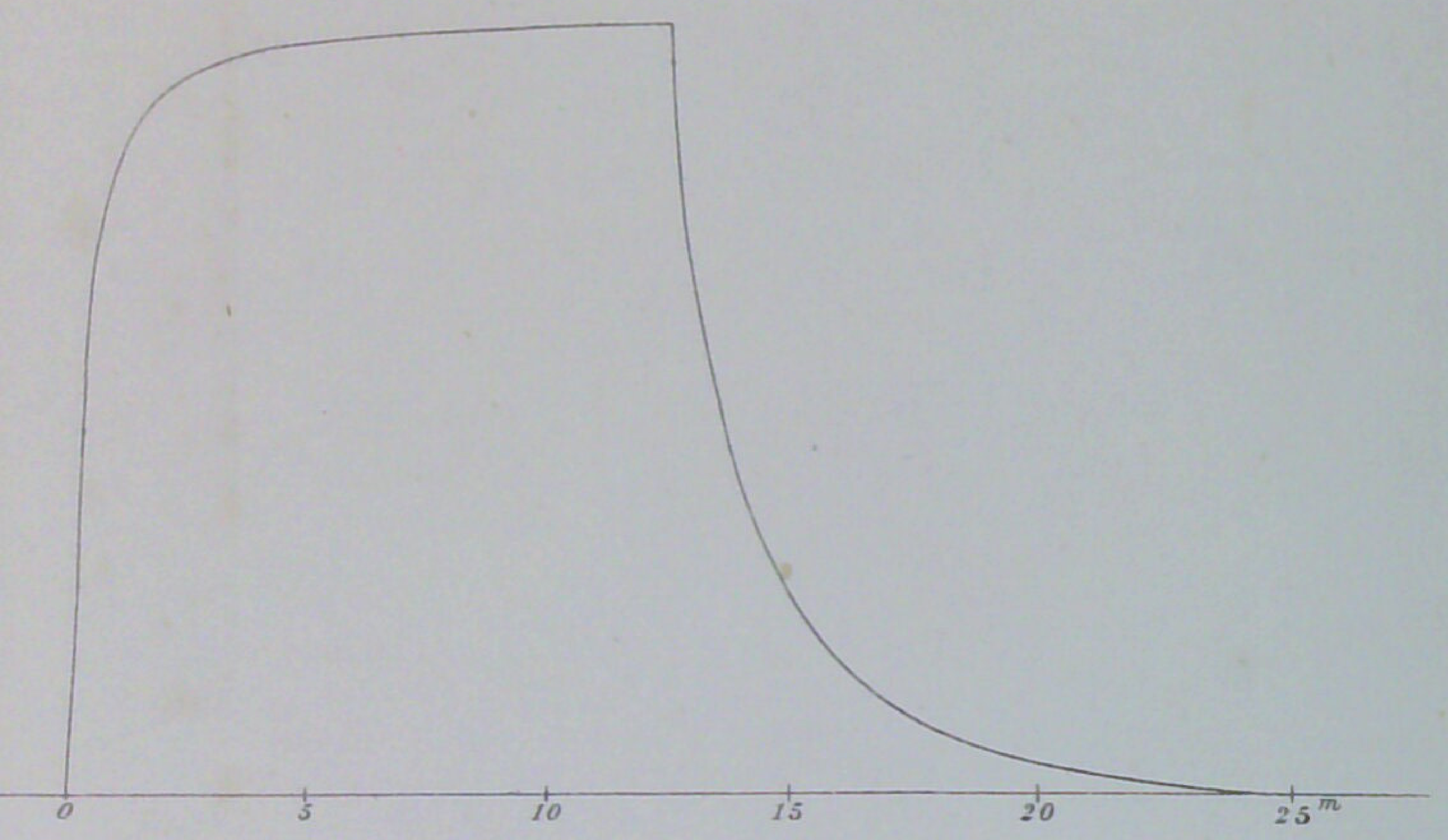
Fig. 5. October, 1903.



Pl. XX.

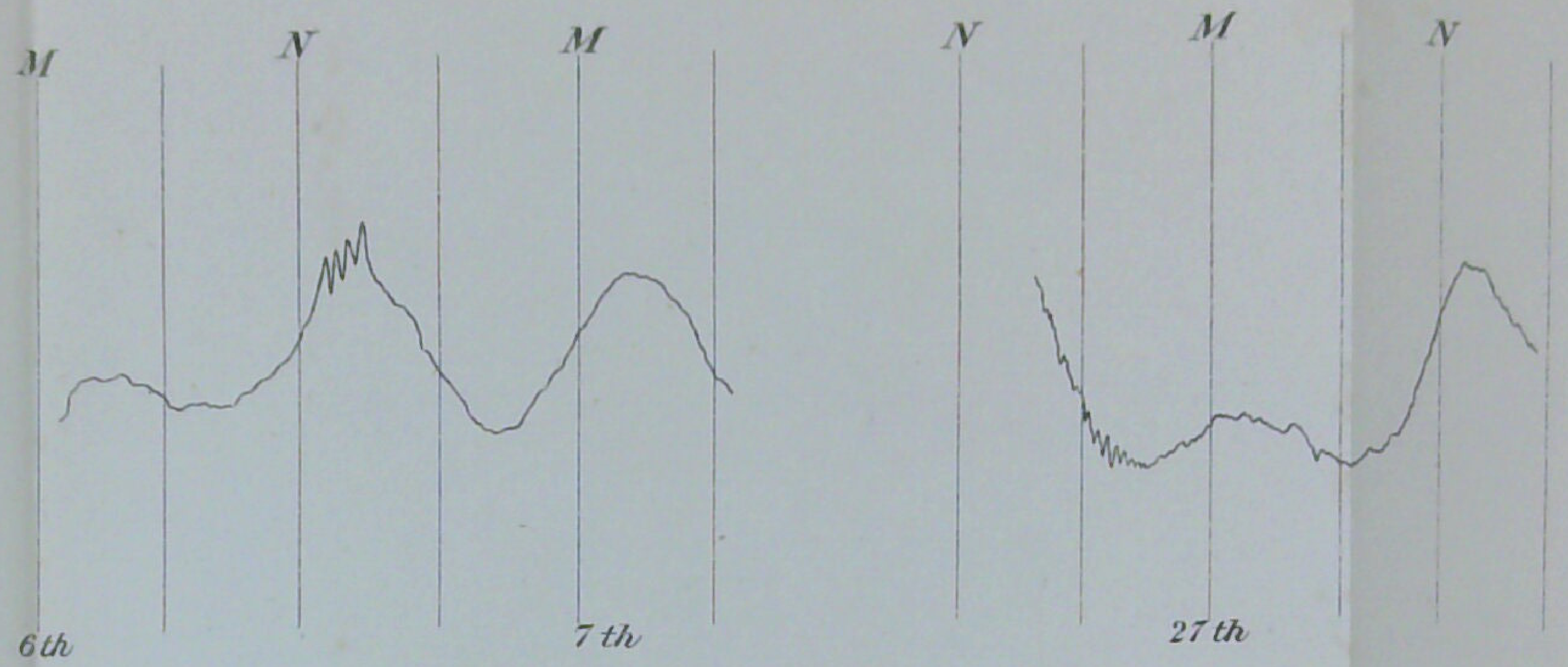
Tōkyō Artesian well.

Fig. 4.



Natural scale.

April, 1903. Fig. 6. January, 1904.



Yokohama Artesian Well. December, 1903. Scale $=\frac{1}{14.1}$.

Fig. 7.

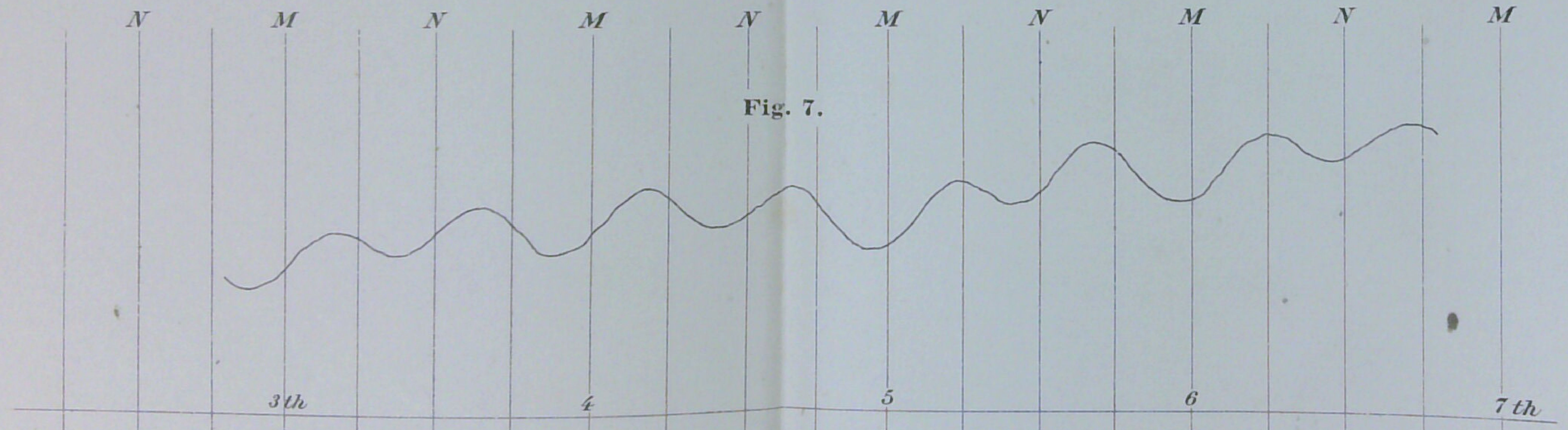
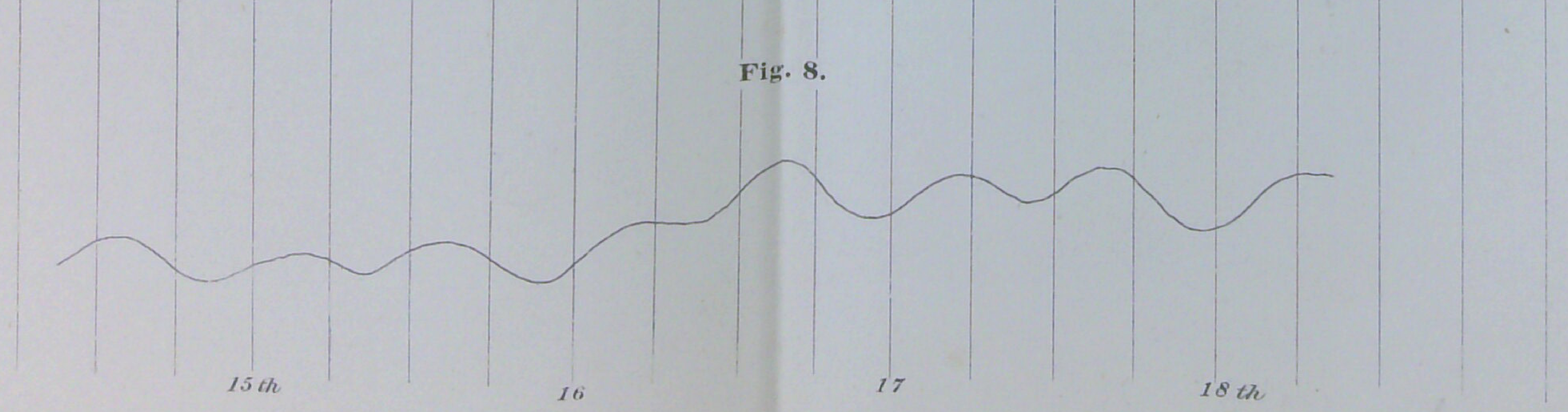


Fig. 8.



Pl. XXI.

ra Artesian Well.

Natural scale.

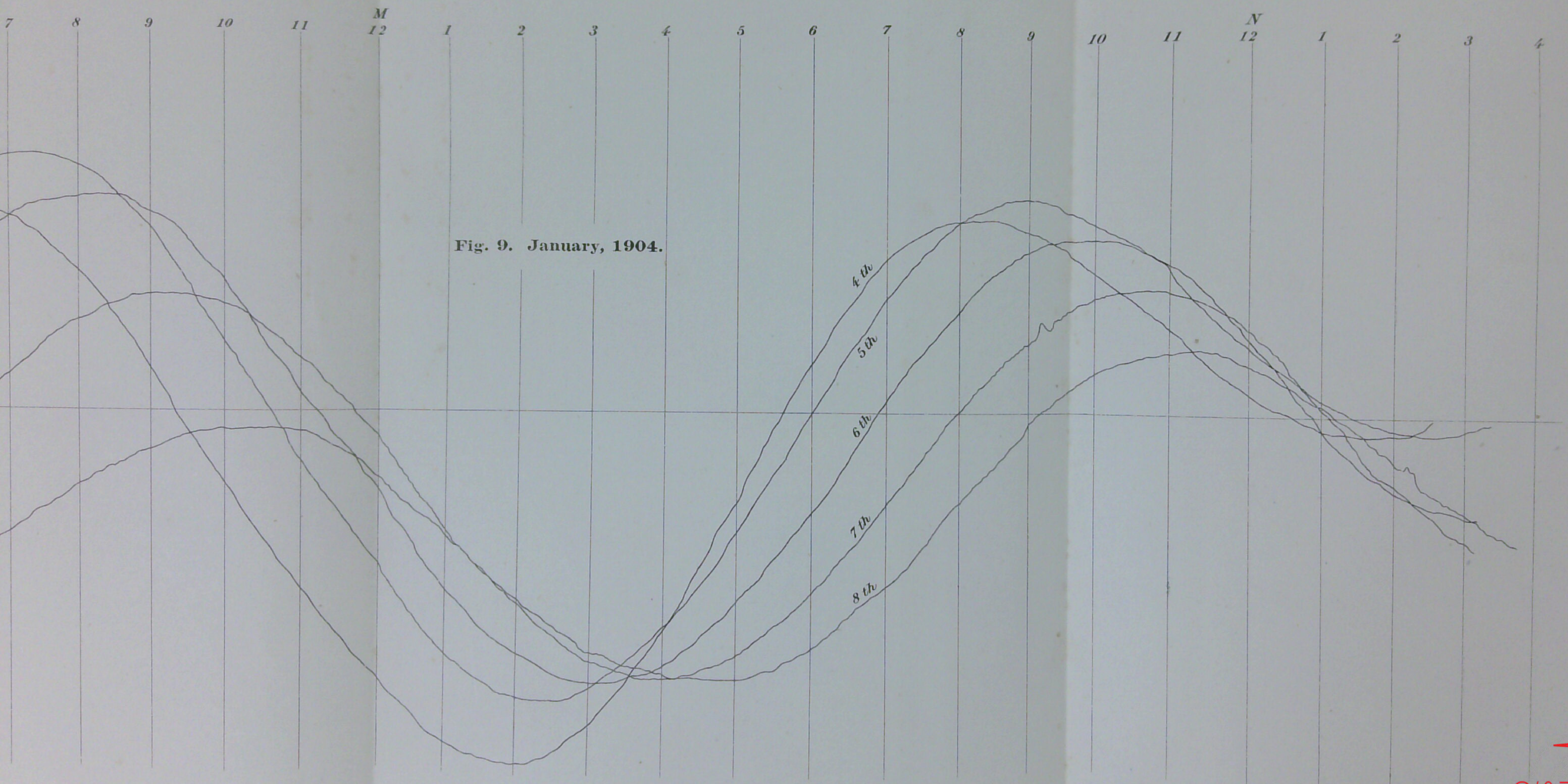


Fig. 9. January, 1904.

Plate XXI - Left Hand Side

Yoshiwara Artesian Well.

Natural scale.

Fig. 9. January, 1904.

Diagrams of Eqke. No. 7, reduced to a common time scale.

(Multiplication=5.)

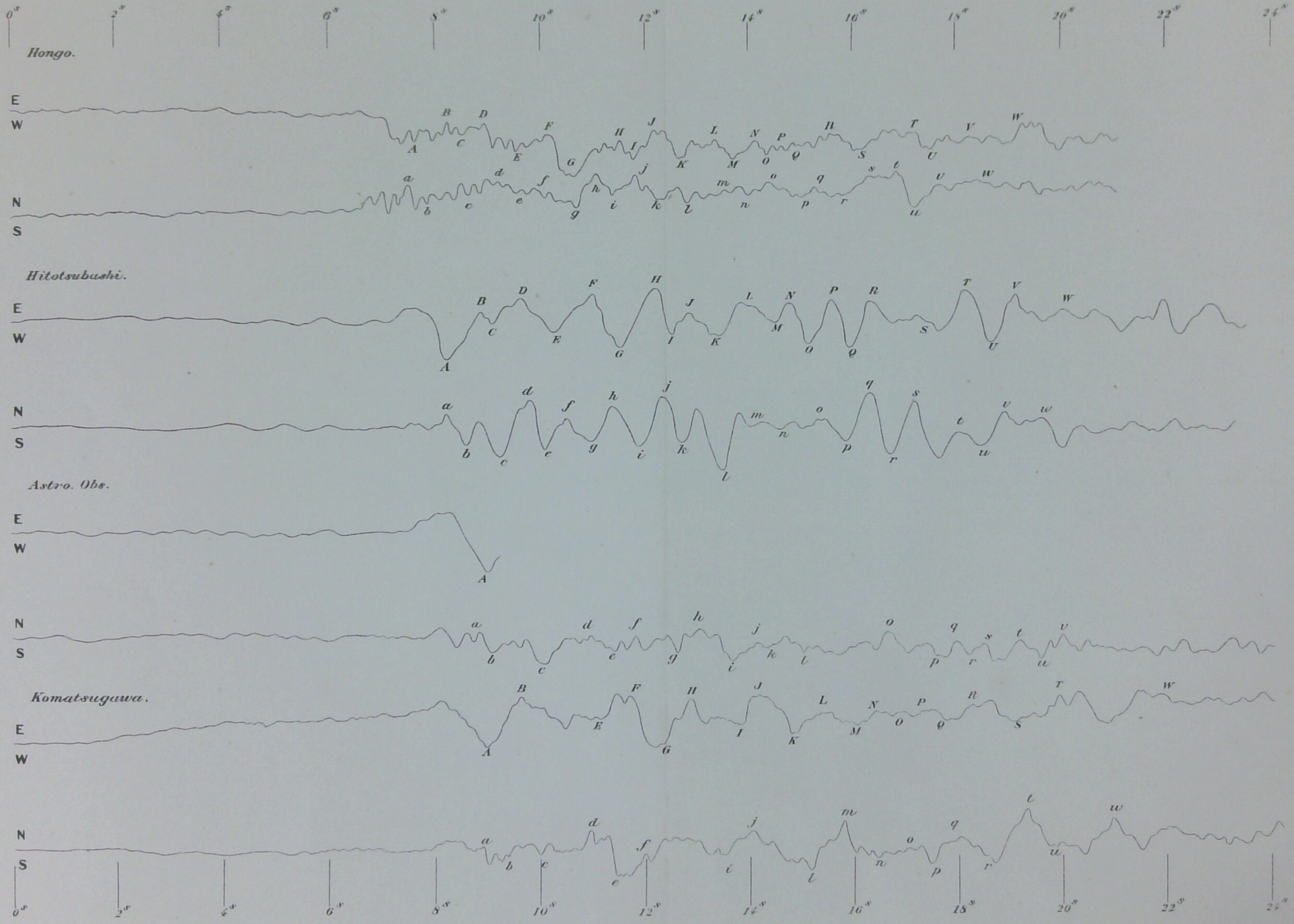
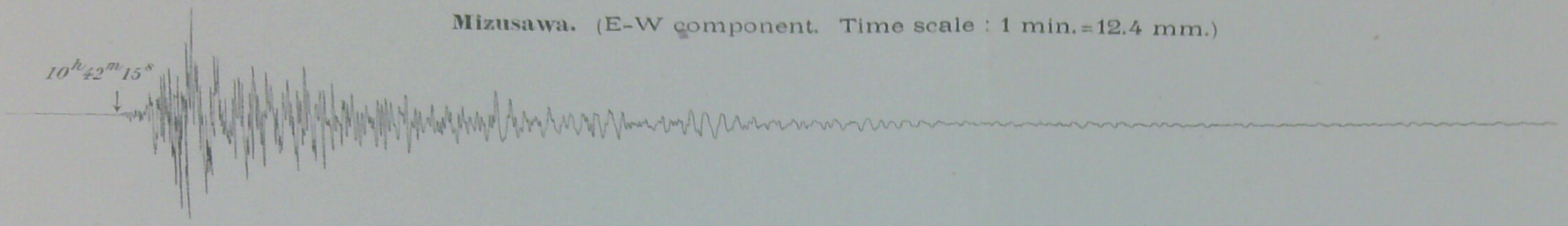


Fig. 2. Eqke. No. 3.

Mizusawa. (E-W component. Time scale : 1 min.=12.4 mm.)



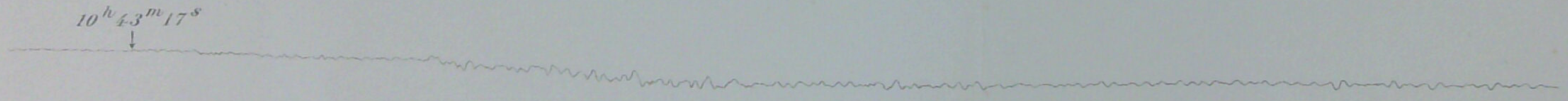
Tokyo. (Instrument No. 1. Time scale : 1 min.=16.1 mm.)

Osaka. (Time scale : 1 min.=13.9 mm.)

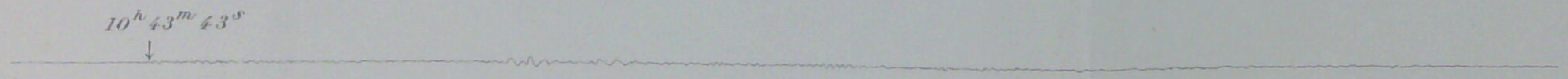
Fig. 3. Eqke. No. 13.

Mizusawa. (E-W component. Time scale : 1 min.=13.1 mm.)

Tokyo. (Instrument A. Time scale : 1 min.=14.2 mm.)



Osaka. (Time scale : 1 min.=12.6 mm.)



Susaki Mareogram, No. 8.
Aug. 14-15, 1903.

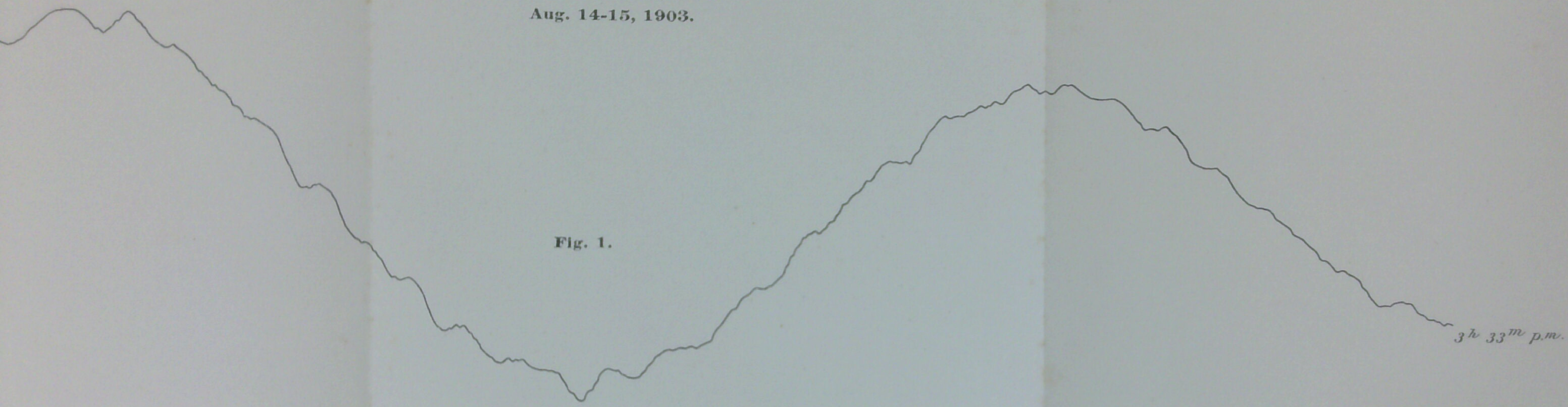


Fig. 1.

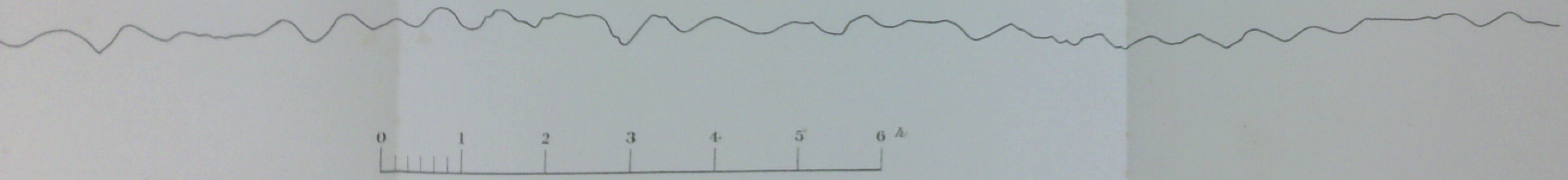


Fig. 2.

Plate XXVIII Left Hand Side

Susaki Mareogram, No. 8.
Aug. 14-15, 1903.

Fig. 1.

Fig. 2.