Daily Periodic Change of the Level in Artesian Wells.

By

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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

* 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

Fig 1.

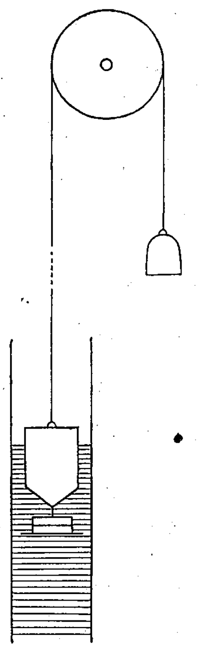
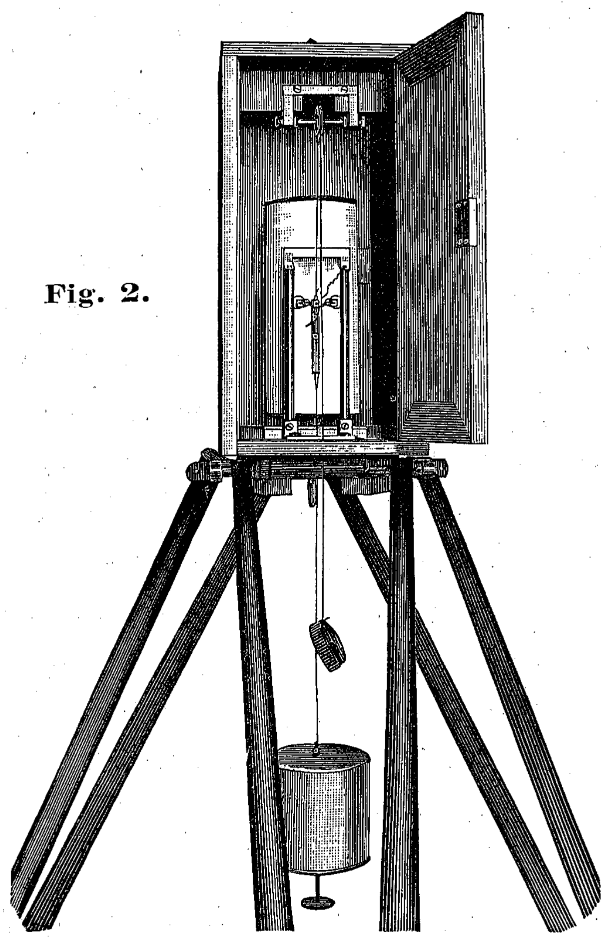


Fig. 2.



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 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, 2h 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.

* 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

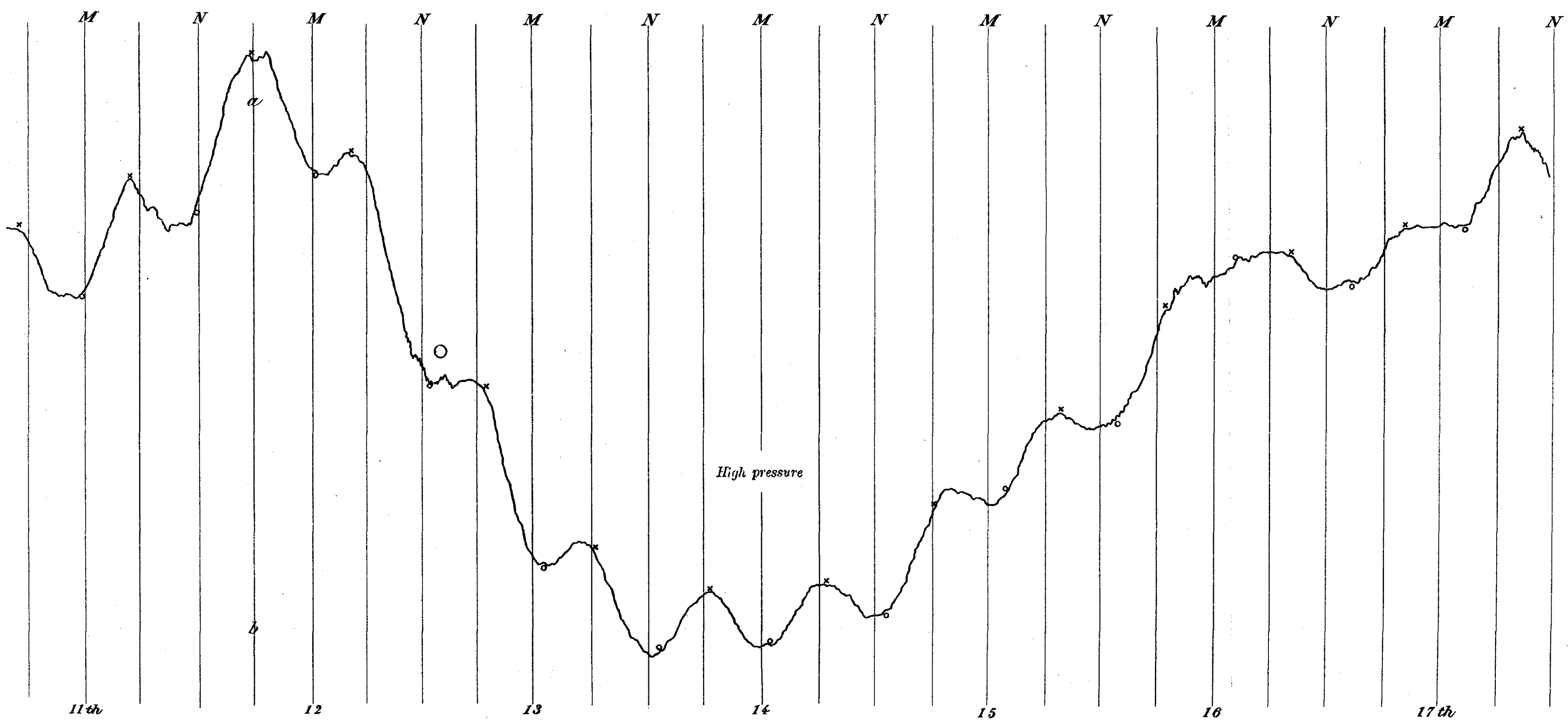
* F. Ōmori, Reports (Japanese) of the Earthquake Investigation Committee, Nos. 26, 30, and 32.

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.

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.

Tōkyō Artesian well. Fig. 2. August, 1903. Natural scale.

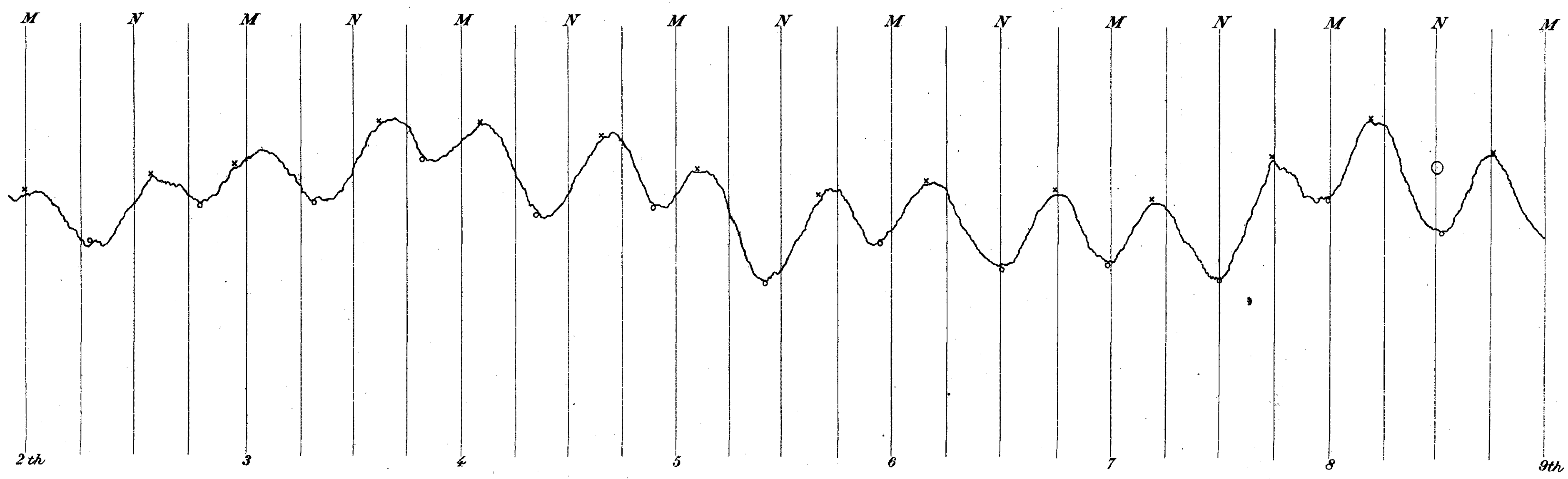


Fig. 3. July, 1903.

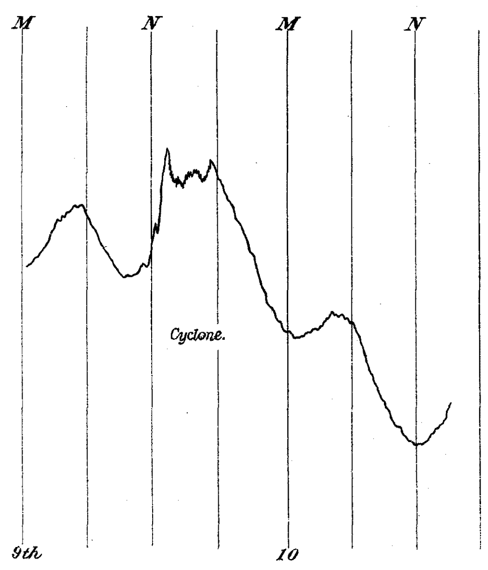
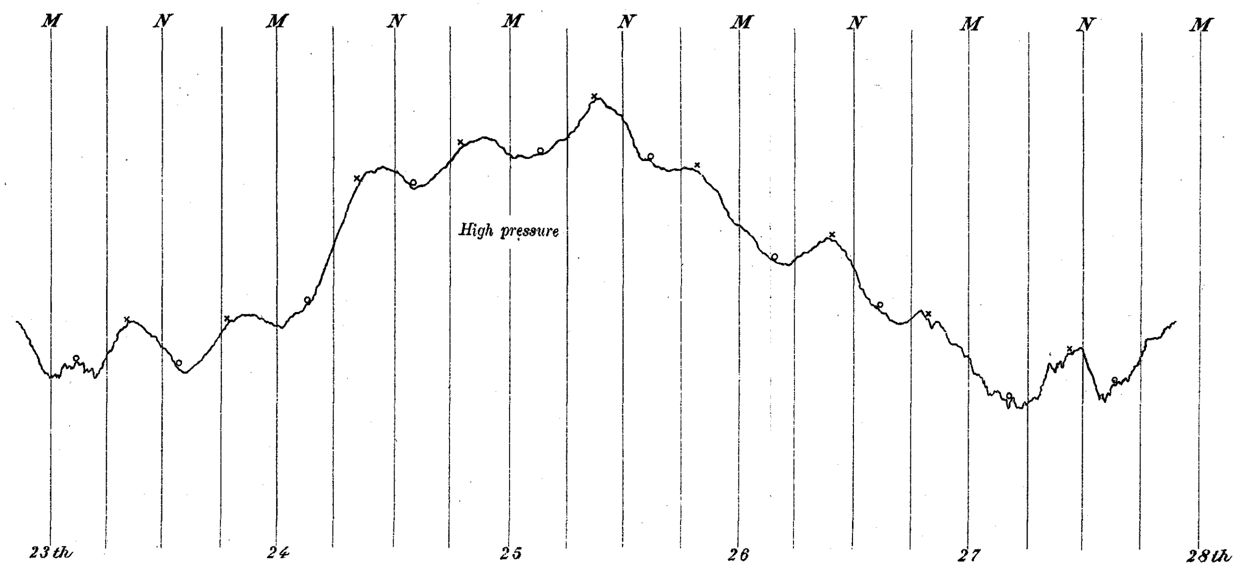


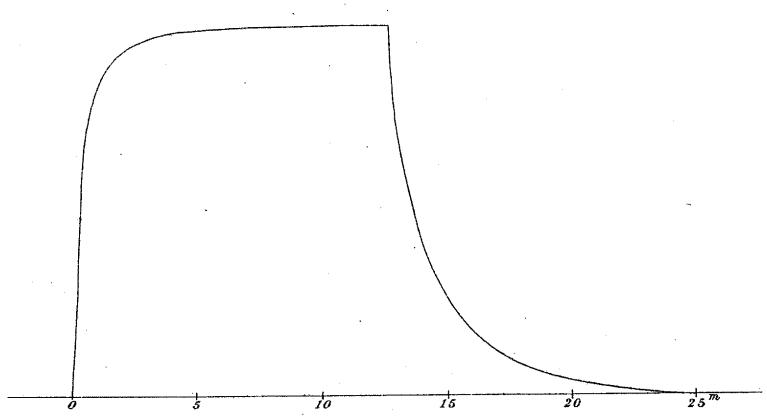
Fig. 5. October, 1903.



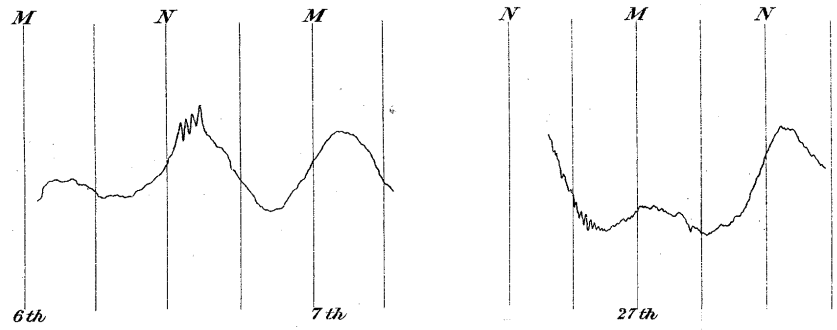
Tōkyō Artesian well.

Natural scale.

Fig. 4.



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



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

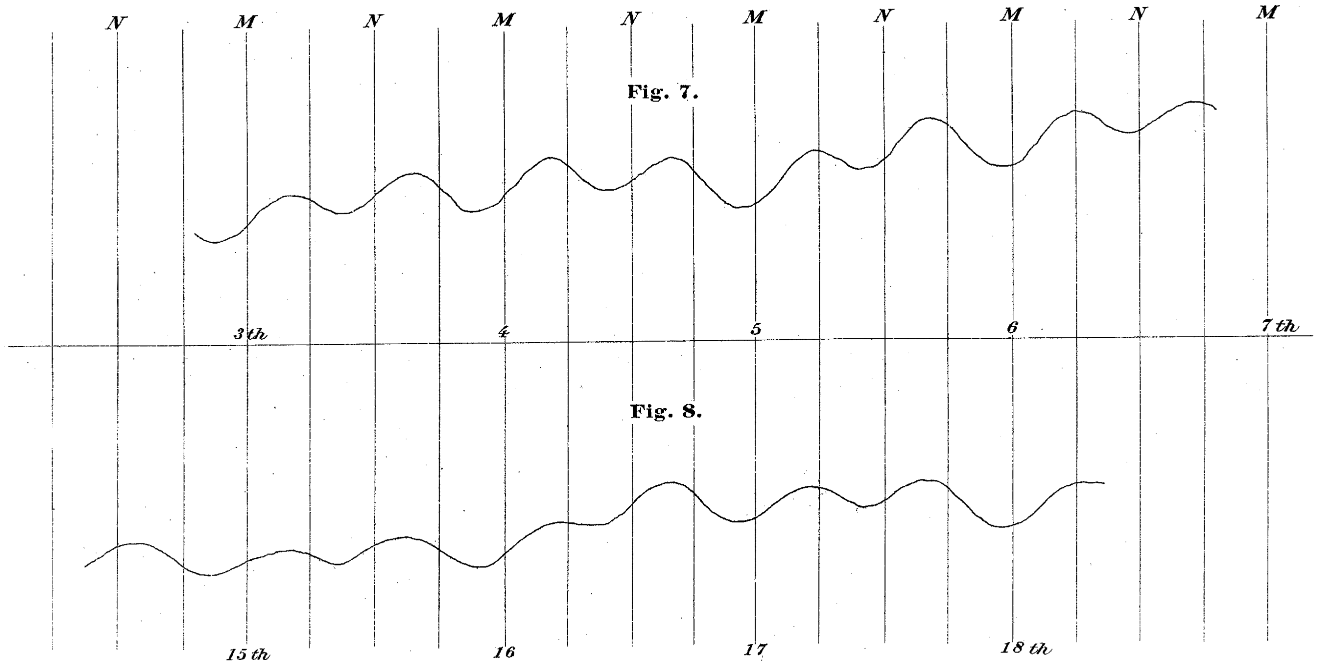


Fig. 7.

Fig. 8.

Yoshiwara Artesian Well.

Natural scale.

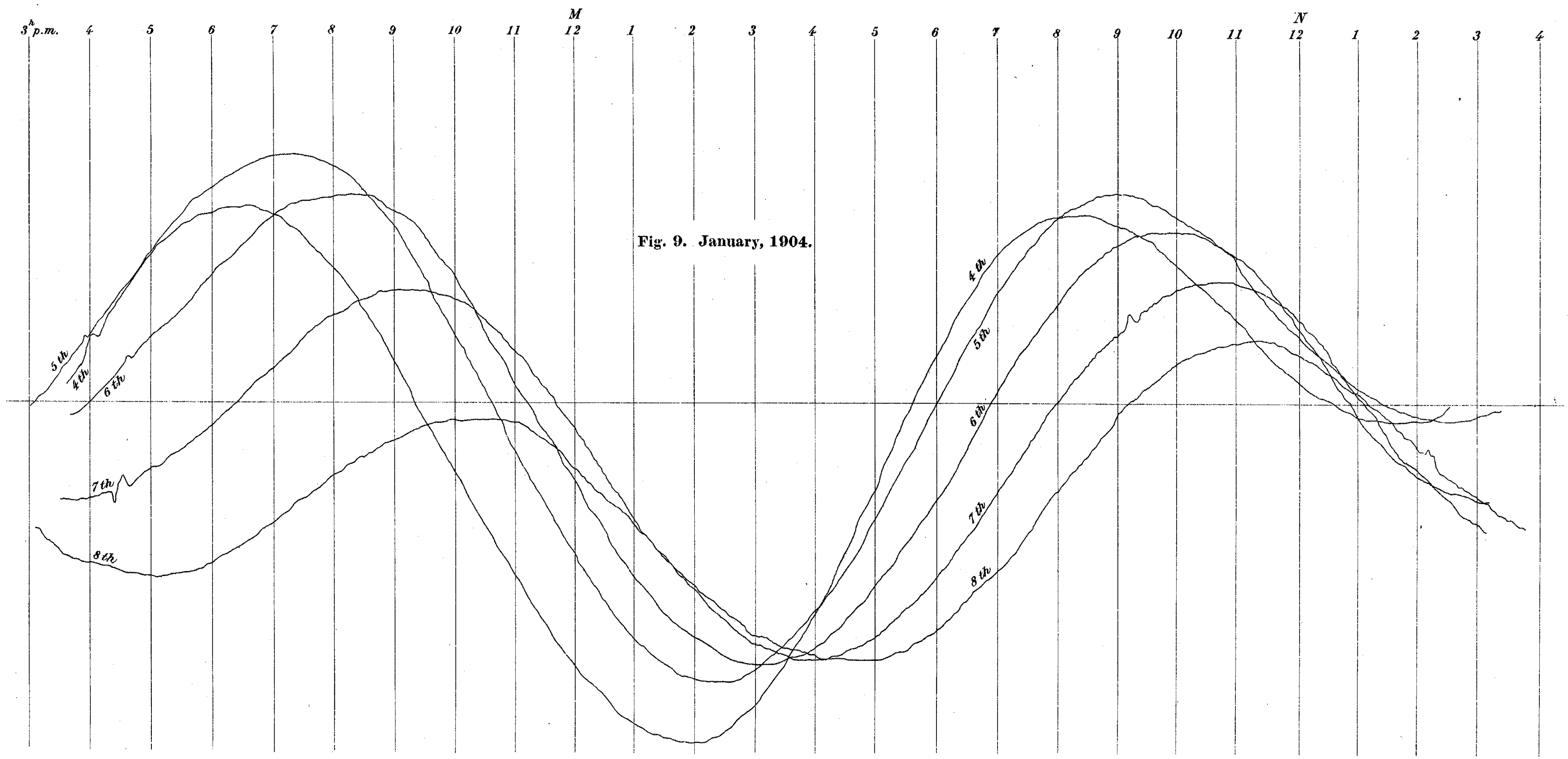


Fig. 9. January, 1904.

Fig. 11.
Earthquakes observed at Tōkyō, 1899.

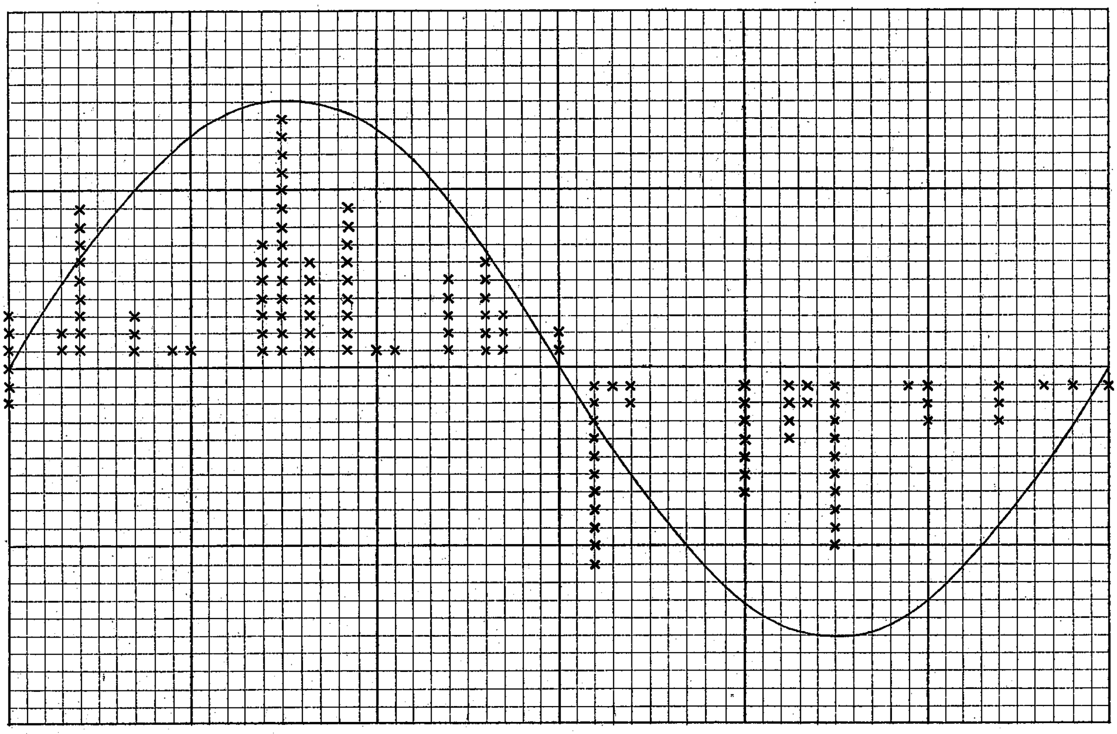


Fig. 10.
Earthquakes observed at Tōkyō, 1898.

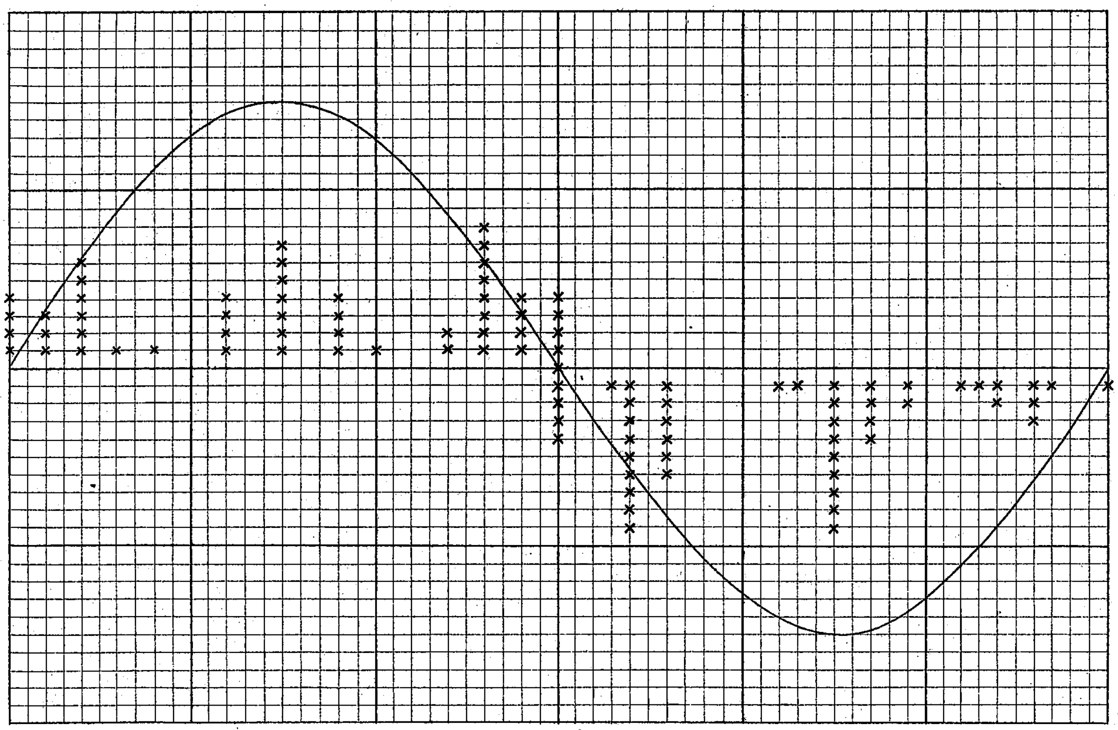


Fig. 12.
Distant earthquakes observed at Tōkyō, 1900.

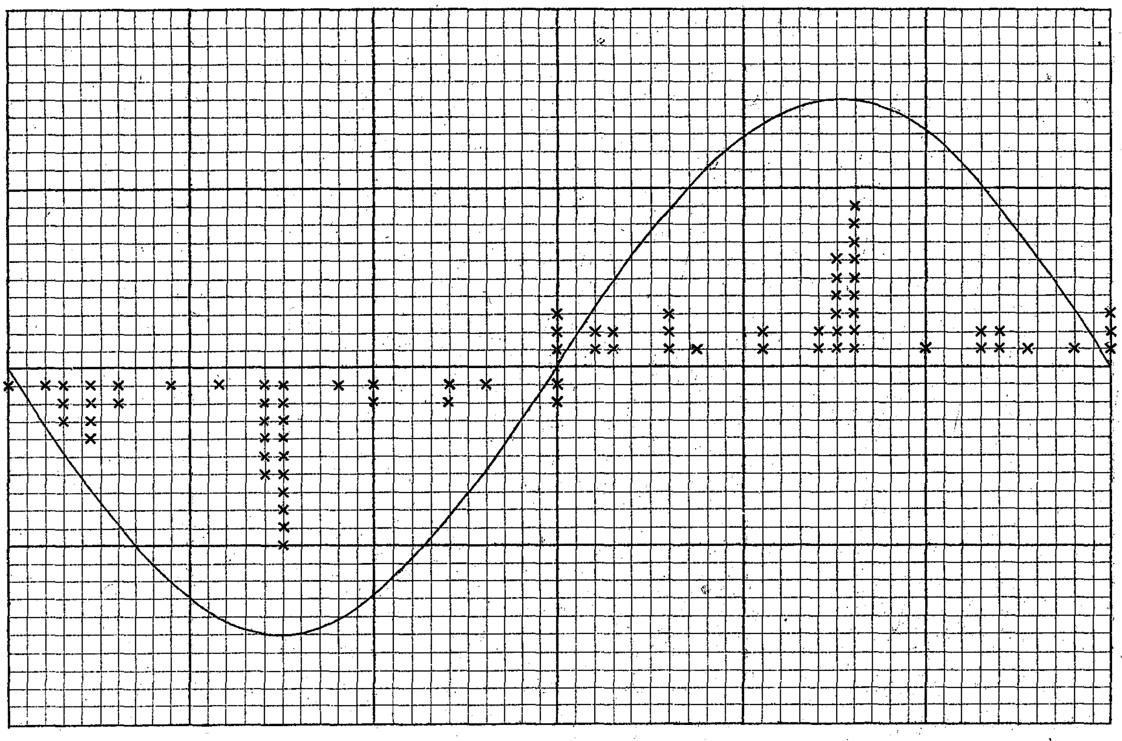


Fig. 13.
Earthquakes of submarine origin observed at Tōkyō, 1900.