NOTES

ON THE

HORIZONTAL AND VERTICAL MOTION OF THE EARTHQUAKE

OF

MARCH 8, 1881.

BY

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[READ MARCH 23RD, 1881.]

My chief object in making a special note upon the earthquake of March 8th, is because I believe it is the first earthquake where, during a certain portion of the shock, which in this particular case was a period of over twenty-five seconds, there has been obtained a complete record of both the horizontal and vertical motion of an earth particle. The horizontal motion was obtained by using a pair of bracket ring machines similar to those suggested at a recent meeting of the Seismological Society by Mr. Thomas Gray, as an improvement on the instrument employed by Professor Ewing. The pointers of these which theoretically give a magnification of the earth's motion about twelve times, wrote their motions on a smoked glass plate which, at the time of the shock, was drawn along horizontally by clock work beneath them.

The vertical motion was written on a smoked glass plate attached at right angles to the plate on which the horizontal motion was being written.

The instrument which gave this vertical motion is constructed on a principle suggested to me by Mr. Gray, which instrument I described at a recent meeting of the Seismological Society.

One of the pointers of the bracket ring machine was intentionally placed so that it had a bearing of S. 23° W. that is towards Yokohama. This pointer therefore could not record

any motion coming directly from Yokohama, but would fully indicate any motion at right angles to such a direction. This machine I call No. 1. The other bracket ring machine was set at right angles to the pointers of No. 1. This machine I call No. 2. The machine for vertical motion I call No. 3.

The records obtained were as follows:—

Machine No. 1.—The motion indicated by this machine is almost wholly at right angles to a line joining Tokio and Yokohama. The motion is in places very irregular and here and there gives evidence of a series of independent shocks.

The largest possible motion which has been indicated is about 1.3^{mm}. There appear to have been on an average about seven vibrations in five seconds; that is to say, one back and forth motion of the ground occupied about $\frac{5}{7}$ of a second.

Machine No. 2.—Here the motion is very slight but sensible. This motion might indicate either a direct wave from Yokohama, or a component of a transverse wave not directly at right angles to the line joining Tokio and Yokohama.

If it is the former, it appears to be extremely slight.

Machine No. 3.—(Vertical motion.)—Here there are about six distinct waves or jolts in a space indicating about 25 seconds of time.

Observations with other Instruments.

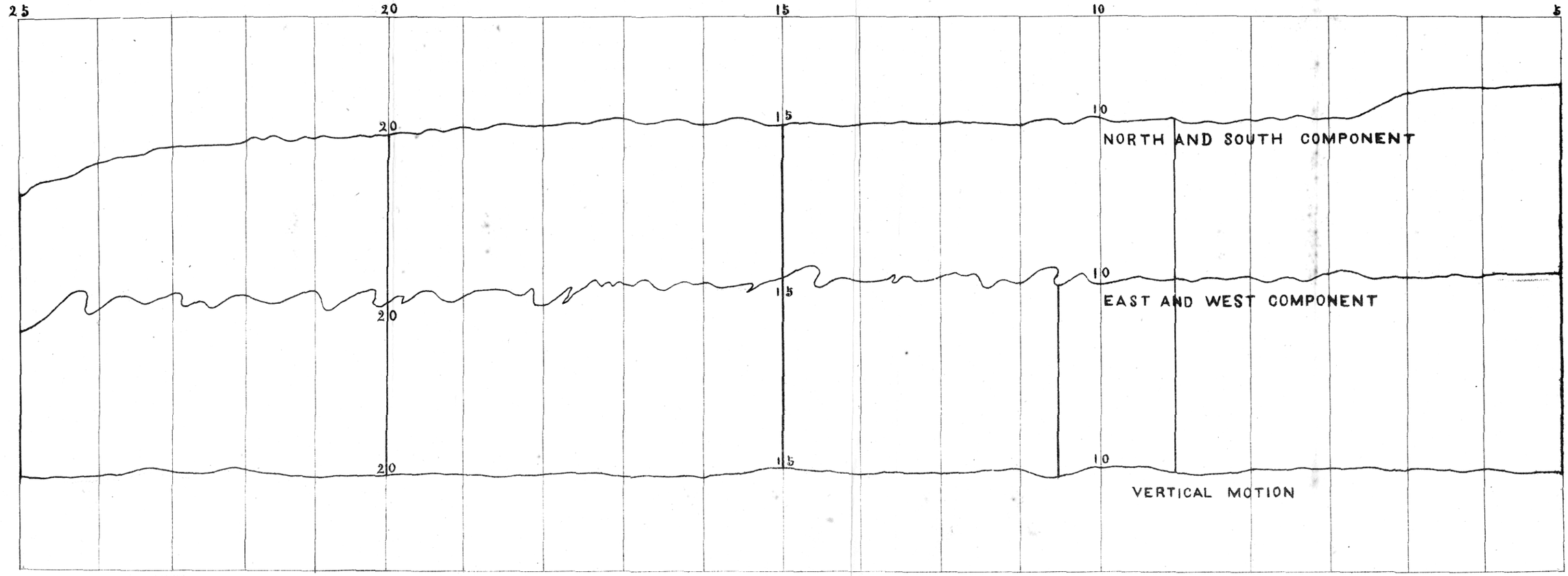
Tokio.—1. Mr. Gray's pendulum machine at the Kobu Dai Gakko gave a direction of N. 95° E., and a total motion of 3^{mm}. If there had been much N. and S. motion it must have been shewn.

2. A small iron column fell N. E.

3. At Senji, a three component pendulum machine gave a direction of N. 20° E.; but from the imperfect manner in which the records gave this result, it is undoubtedly very inaccurate.

4. Seven pendulum machines with bifilar indicating pointers, which I have established at and in the neighbourhood of my house, chiefly indicated an east and west motion.

5. Palmieri's instrument at Yamato Yashiki gave as maximum intensities 5° 10′ on the W.N.W. and W.S.W. tubes.



EARTHQUAKE OF MARCH 8th 1881 AT 12. 18. 0 P. M.
MULTIPLICATION = 24

Bisecting the direction of these equal indications we obtain east and west motion.

6.—At Kisaradzu, two similar pendulum machines placed in different positions each gave directions approximately east and west.

From the above observations it will be seen that in Tokio a considerable amount of approximately east and west motion was experienced, and we have but very little evidence of a north and south movement. The only north and south motion is the slight movement of machine No. 2 in the first record which is given.

Time of the Shock.—In Tokio I observed the shock in telegraph time at exactly $12^h.\ 18^m.\ 0^{sec}$. By Palmieri's instrument situated at Yamato Yashiki the time of the shock reduced to Telegraph Time was $12^h.\ 17^m.\ 54^{sec}$. In Yokohama, Mr. Talbot observed the shock at $12^h.\ 17^m.\ 28^{sec}$. and this observation was confirmed by an observation made by Mr. Favre Brandt. As the shock occurred within 18 minutes of the transmission of the electric signal by which Mr. Talbot's clock and mine are daily compared our error is probably very small. The only important error which may enter into the calculation of the differences in time in the observation of the shock in Yokohama as compared with its observation in Tokio, is the fact, that the observation taken at one station may have been made at a point in the shock different to the point at which the observation at the other station was made. This I may say is also from a practical point of view probably small, and as it has been previously discussed before this society I will not again enter on it.

In conclusion then we may say that the shock was certainly felt in Yokohama about 40 seconds before it was felt in Tokio. This agrees with observations on *several* other of our recent earthquakes and was used as an argument to shew that they originated at a point much nearer to Yokohama than to Tokio.

As a confirmation of this result I may mention that the shock on the 8th was followed by one on the 12th, by two on the 16th and by one on the 17th. Of these shocks it was only

the latter one for which time observations were obtained.

These shewed that the motion was felt in Yokohama about 1 minute before being felt in Tokio. Their direction was similar to the one we are discussing and they probably belong to a group having a similar origin.

Origin of the shock.—From the time observations we are able to say that after the shock reached Yokohama it continued to travel for 40 seconds before it reached Tokio. This means that if it travelled at the rate of 5 seconds per mile, which, from what we know of earthquake velocities is a fair average for a velocity in the kind of materials around Tokio and Yokohama through which our earthquakes have to travel, it travelled 8 miles farther to reach Tokio after it had commenced to shake Yokohama.

Joining Tokio and Yokohama by a straight line and with Tokio as a centre describing a circle with a radius of eight miles, we see that the origin of the shock must lie in the centre of some second circle which touches this first circle and passes through Yokohama.

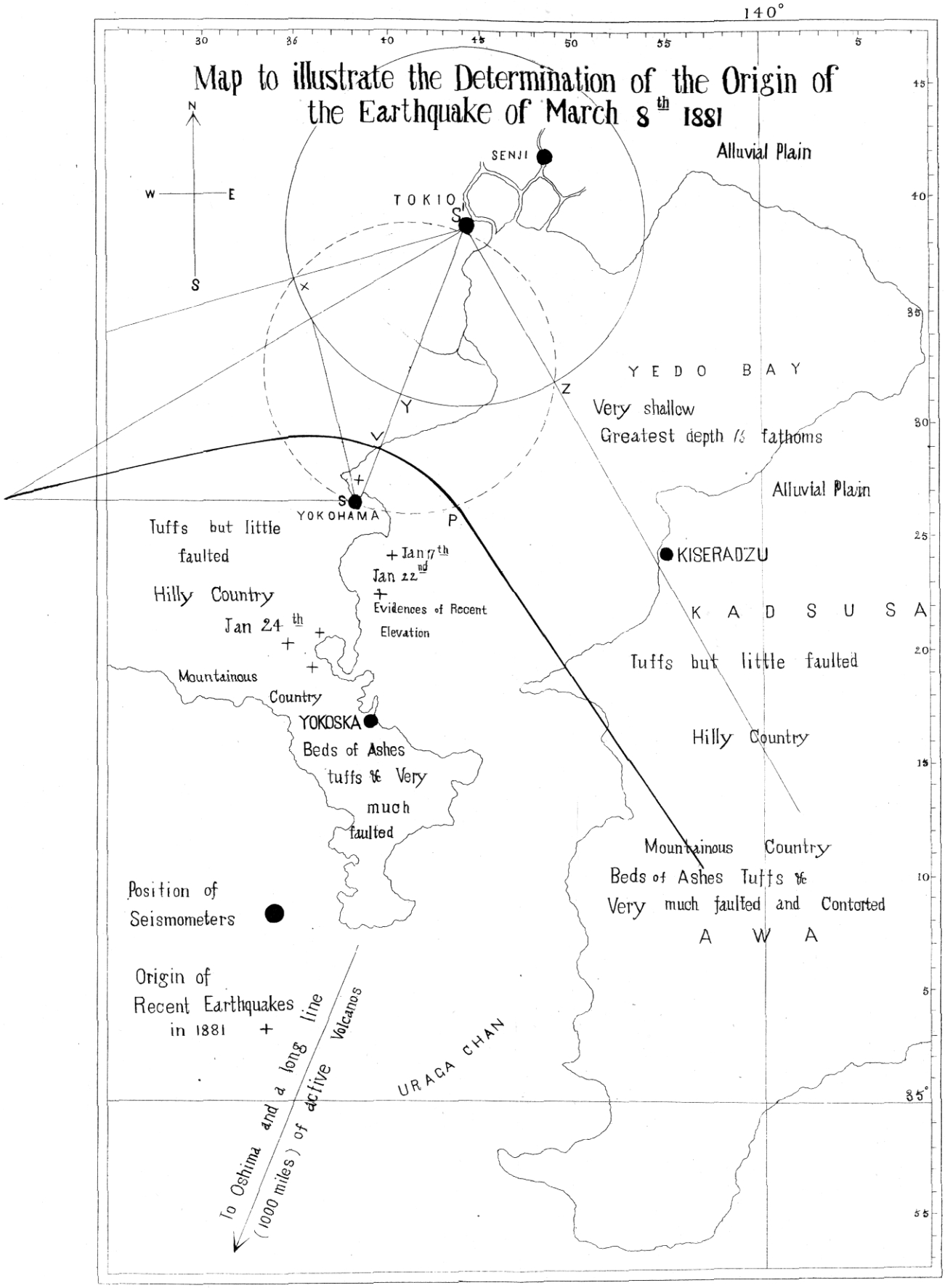
In the accompanying figure let S′ represent Tokio, S represent Yokohama, X Y Z the 8 mile circle. Bisect S′ S. in C and with C as centre describe the circle S P Z S′ X.

Draw the lines S′ Z. and S′ Y. Bisect Y S in V.

It is now easy to shew that the locus of the centres of the second circles, or the points from which the shock may have originated, must lie on the hyperbola passing through V as its vertex, and with S′ Z. and S′ Y. produced as lines parallel to asymptotes through C as the center of the hyperbola. That the curve V P &c. is a hyperbola with S′ and S as foci is seen from the fact that S′ P—P S is a constant. We may remark that by varying our assumption with regard to the velocity of an earthquake we do not materially alter the general result.

It may here be pointed out that if we had time observations at three points like Tokio, Yokohama and Kisaradzu, and an average velocity for the transmission of motion, it would be possible to construct three hyperboloids, the common intersection of which would give us the origin of our shock.

I will now compare this determination of the origin with


140°
Map to illustrate the Determination of the Origin of the Earthquake of March 8th 1881
N
W
E
S
SENJI
TOKIO
S'
Alluvial Plain
X
Y
Z
V
YEDO BAY
Very shallow
Greatest depth 18 fathoms
Alluvial Plain
S
YOKOHAMA
P
Tuffs but little faulted
Hilly Country
+ Jan 17th
Jan 22nd
+ Evidences of Recent Elevation
Jan 24th
Mountainous Country
YOKOSKA
Beds of Ashes tuffs &c Very much faulted
KISERADZU
KADSUSA
Tuffs but little faulted
Hilly Country
Mountainous Country
Beds of Ashes Tuffs &c
Very much faulted and Contorted
AWA
Position of Seismometers
Origin of Recent Earthquakes in 1881 +
To Oshima and a long line (1000 miles) of active Volcanos
URAGA CHAN
35°

the already given observations on directions. Assuming it possible that the east and west vibrations observed in Tokio and Kisaradzu, were those of the direct normal vibrations, as has been suggested by Professor Ewing, the origin of the shock must have been at a very long distance from Tokio and Yokohama at some point on or near the left hand limb of the hyperbola,—for instance between Kofu and Fujiyama. Farther, after having assumed such an origin, we have to account for the fact that either the motion of vibration during its transit must have been turned through a considerable angle before reaching Tokio, or our instruments have all of them considerable errors.

A more easily understood solution of the question, is the assumption that the east and west vibrations are not normal vibrations but transverse vibrations. Speaking of the vibrations in the materials of the earth's crust Mr. Mallet, in his report on the facts and theory of earthquake phenomena to the British Association in 1858, says:—"My own experimental observations with the seismoscope have proved to me that the separation of the two waves can be noticed, and the interval of time measured upon even very moderate ranges of wave transit, &c." From other portions of Mr. Mallet's writings we see that he regards the normal vibrations as being those which are the more important, and transverse vibrations, if they do exist, it is highly probable that they play but a very subordinate part in observable phenomena of actual earthquakes. In *certain instances* therefore Mr. Mallet has been enabled to neglect transversal vibrations.

From theoretical considerations it would seem to be a difficult matter to transmit transversal vibrations through certain formations, as, for instance, through those which are much fractured. Also there appears to be but little doubt but that much of the destruction which earthquakes have occasioned has been a result of normal vibration. In a long series of experiments upon artificial earthquakes make by myself and Mr. Thomas Gray, we, however, found that although the normal vibrations were exceedingly well defined when near to the origin of our shock, (which was produced by allowing a

heavy iron ball about 1 ton in weight to fall from a height of 35 feet) nevertheless it was the transverse waves which were the most persistent.

Although I fully appreciate the reasons why the transverse vibrations should become extinguished, in consequence of these experiments I am at present compelled to regard the maximum portion if not often the total of the east and west vibrations we experience in Tokio as transverse motions. It was partly on account of this that the pointers of one of my instruments were set in the direction towards Yokohama and the other at right angles, it being from some district in that direction from which many of our late shocks have emanated.

As it seems to be almost an impossibility to explain the phenomena of the earthquake on the assumption that the vibrations which I registered were normal vibrations, *I must conclude that they were transversal vibrations, and that the shock originated at no great distance from the vertex of the hyperbola near to Yokohama.*

In previous communications to this society I have suggested that it was very probable that many of the earthquakes we feel have originated from the formation or extension of faults. On the east and west sides of Yedo Bay at its southern end, that is, near to the entrance of the bay, the stratified rocks (beds of tuff and ashes) are tilted at high angles and are excessively faulted. As we go northwards near to Yokohama on one side, and Kisaradzu on the other; the beds gradually become almost horizontal, and the faults less numerous.

In this district I may also remark that we have distinct evidences of very recent elevation. I say *very* recent because the shell borings in the cliffs which indicate this elevation, are in rocks of such extreme softness that, in consequence of the ordinary processes of degradation, it is impossible they could have existed for many years without obliteration.

May it not here be asked whether it is unlikely for the faulting and contortion which we observe so strongly marked 20 miles to the south of us to be gradually extending northwards and whether the earthquakes we so often feel are evidences of the production of new faults?

As a farther support of the view that the earthquakes we feel are the result of faulting, we may refer to the irregularity of the motion which we feel and record upon our instruments. The earthquake motion is certainly suggestive of the sliding and jolting of one mass of rock as it passes across the surface of another mass.

By the tearing open of a fissure, and the movement of one body of rock across another: it would seem that a sheering action must take place. In consequence of any action of this description *a wave of distortion might be produced without a wave of compression.* If an earthquake originates from a blow we obtain *a wave of compression together with that of distortion;* the existence of the latter being dependent on the existence of the former.

If these views are correct we shall require to make considerable modifications in our definitions of earthquake motion. I may also add that they suggest to us the means of making a definite classification of our earthquakes.

Another indication that the earthquake of which we write was, as felt in Tokio, almost entirely composed of transverse vibrations, I call attention to the slowness of the motion—this slowness or sluggishness of motion being due to the fact that the modulus for distortion is less than Young's modulus. This remark may perhaps help to explain the various records which have been given to the Asiatic Society by Professor Ewing.

It therefore appears to me that the earthquake of March 8th, was produced by the formation or continuation of a fault at, or near Yokohama. This fault may possibly have had a direction which was about east and west. A fault with such a direction would have produced vibrations, which would have been recorded both in Yokohama or Kisaradzu as having an approximately east and west direction. This earthquake has already been discussed by Professor Ewing before the Asiatic Society of Japan.—(See *Japan Weekly Mail,* March 19th, 1881.)

The two sets of vibrations which Prof. Ewing there refers to, I regard as being *chiefly* due to his machine having been obliquely placed to the direction of the transverse wave, each

machine consequently registering a certain component. If normal vibrations existed, judging from my own records they must have been small. The largeness of the motion indicated by Prof. Ewing's instrument as compared with the extent which has been indicated by mine, although our two instruments are constructed upon similar principles, I am inclined to regard as being principally due to differences in the adjustment of the instruments.

In conclusion I must remark that although I regard this earthquake as having originated in the neighbourhood of Yokohama, near to which place I have already located the origin of several previous shocks, I by no means wish it to be inferred that all the shocks we feel originate in this locality. To many of them, probably owing to the confusion in my records of direct and transversal vibrations, I have been unable to assign any origin.