

# EARTH PULSATIONS IN RELATION TO CERTAIN NATURAL PHENOMENA AND PHYSICAL INVESTIGATIONS.

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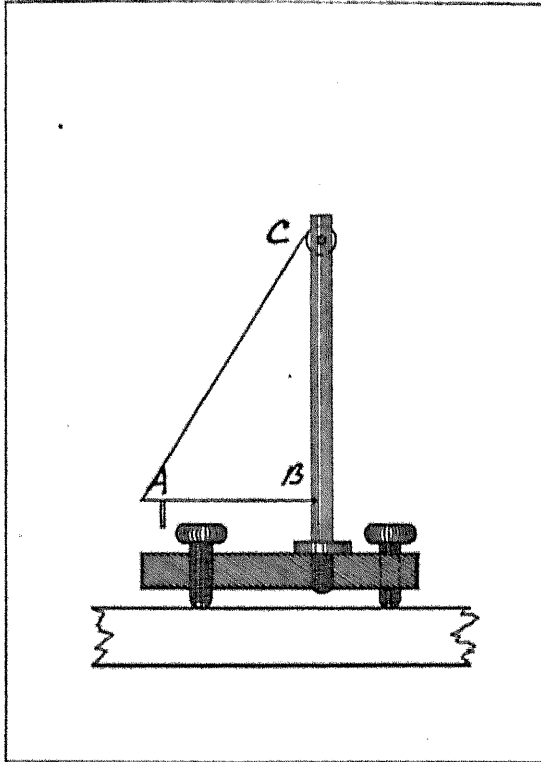
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I.—RECORDING EARTH PULSATIONS—From time to time during the last sixteen years the writer has given attention to the recording of movements of the ground called <sup>Earth Tremors.</sup> From all that we know of these movements be as common in other countries as they are instruments employed to record them have in all instruments which have been used in Europe special instruments have been designed in this

Amongst the former, several instruments were identical with the mirror-pendulum arrangement by Messrs. G. and H. Darwin in their research Laboratory on the Lunar disturbance of tromometers, like the "normal tromometer" of have been used. The pendulums which were usually about 3 feet in length, but also pendulums even  $\frac{1}{4}$  in. in length, suspended in a vacuum

employed. An instrument which gave continuous records for several years consisted of a pendulum, the movements of which were magnified about 100 times by a long multiplying lever. The latter moved freely in the air, but every five minutes by means of clockwork contacts and an induction coil, sparks were discharged from its extremity, which perforated moving bands of paper. With this instrument the writer obtained records of the duration of "tremor" storms and measures of their relative intensity. All the records have been compared with the frequency of earthquakes, the state of the wind, the state of the barometer, barometric gradients, and other natural phenomena. As many of the instruments indicated changes in the vertical, for a period of nearly two years, observations were made on the movement of the bubbles of two delicate levels placed at right angles. Although every ordinary precaution was taken to avoid disturbances due to change of temperature, for several reasons it was concluded that the records were untrustworthy. One reason which is sufficient to guarantee this conclusion is the fact that when the levels were side by side and parallel, the bubble of one might creep to the left whilst the other crept towards the right. This observation is by no means original, it having been previously pointed out by M. d'Abbadie. The instrument now employed by the author to give a continuous record of tremors or tilting will readily be understood from the accompanying figure:—AB is a needle carrying at A, a mirror and kept in a horizontal position by the silk fibre AC. At B a needle point slightly turned downwards rests in an agate cup. The arrangement is that of an extremely light conical pendulum to which any degree of stability may be given by means of the adjusting screws. A vertical beam of light impinges on A, and is reflected back upon a scale, or to a horizontal slit, leading into a box where a photographic film is moving either quickly or slowly by clock work. Two of these conical pendulums with their arms at right angles reflecting light into the same box constitute a complete instrument. When the mirrors have a period of 4 or 5

seconds a deflection of the light upon the scale of 2 mm. is equivalent to a tilting of about 1 in 200,000 or 1" of arc. Greater sensibility may be given if required.



The advantages which this type of instrument possesses over the Italian form of tromometer, and other instruments in which a more or less heavy pendulum is employed, are that in consequence of its small inertia it is not likely to show a maximum of motion when earth movements are actually small, it is more likely to give the direction of motion than can be obtained from a pendulum which has a tendency to change its plane of swing, and lastly its records are continuous and automatic.<sup>1</sup>

<sup>1</sup> At the end of this volume an epitome is given of the excellent work accomplished

2.—NATURE OF EARTH PULSATIONS.—One set of observations made in Japan which do not appear to have been made in other countries relate to the nature of the movements called earth tremors. Because the writer, at the time of a considerable barometrical depression when the place of observation was crossed by a steep barometric gradient, has observed the bubble of a delicate astronomical level every .5 to 3 seconds, pulsating through a range of from .25 to .5 mm., it was difficult to arrive at any conclusion other than that at these times the surface of the earth was being subjected to a series of minute tilts. Pronounced phenomena like these are, however, rare. What, however, is common to every so-called tremor storm, is that the spots of light from the last mentioned instruments do not swing equal distances to the right and left of a given line, nor do they commence their motion gradually.

By watching the light from two similar instruments, placed side by side and approximately *parallel*, we see that the motion of both commence *simultaneously, suddenly*, and in the *same direction*, giving the impression that the column had been tilted. The synchronism of motion, probably on account of the want of agreement in the natural period of the pendulums, is, however, quickly destroyed. The sudden impulses are repeated every one or two seconds, and during a tremor storm marked periods of maxima are reached every four or eight minutes.

When there are no tremors and the mirrors are caused to swing artificially, from photographic records taken on quickly running plates, it is seen that the period of swing is constant. On the contrary, when the mirrors are swinging under the influence of tremors, a similar class of records show that the period of successive waves vary within wide limits. In one experiment the periods recorded varied from 3.4 to 4.6 seconds. (See Fig. 1 in paper by Prof. Burton p. 26.)

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by Dr. Reubeur-Paschwitz with an instrument of this type. Dr. Paschwitz's investigations chiefly relate to change in the vertical whilst the present writer has chiefly devoted his attention to earth pulsations. In a Report to the British Association, the writer describes his photographic method of obtaining records as new. This, however, is hardly correct, as about the same time it was being used by Dr. Paschwitz and also in Italy.

Experiment has shown that these instruments are not affected by elastic vibrations such as might be produced by a passing carriage or even by the beating of a small steam hammer situated about 60 yards distant.

The conclusion arrived at by the author is that these movements called *earth tremors are movements in the crust of the earth not altogether unlike the swell upon an ocean*. These long flat waves, which vary in amplitude and length as they pass along, produce a tilting. Their period is from 1 to 4 or 5 seconds, and from the distance through which the light is deflected their maximum slopes may be from 1 in 40,000 to 1 in 200,000. This latter observation is, however, for the present, only given as a rough approximation and is subject to correction when the writer is provided with instruments capable of more accurate calibration.

Other observations, for example, that at times there is an apparent slow change in the vertical, that "tremors" are more pronounced in one direction than in another, that they are more frequent with a low than with a high barometer, that they are more pronounced in winter than in summer, &c., are common to Japan and Italy, and are detailed in many publications. An account of such observations may be found in the following papers by the present writer:—

- 1.—Observation of Tremors, &c., in the Takashima Colliery, *Japan Gazette* Jan. 12th, 1884.
- 2.—Earth Tremors. *Trans. Seis. Soc.*, Vol. VII., Pt. 1. 1883.
- 3.—Earth Tremors in Central Japan. *Trans. Seis. Soc.*, Vol. XI. 1887.
- 4.—Earth Tremors in Central Japan. *Trans. Seis. Soc.*, Vol. XIII., Pt. 1. 1888.
- 5.—Earth Tremors and the Wind. *Journal Royal Meteorolog. Soc.*, Vol. XIV., 1888.
- 6.—Reports upon Volcanic Phenomena in Japan to the British Association, 1881, 1883, 1884, 1885, 1887, 1888, 1892.

3.—A POSSIBLE CAUSE OF EARTH PULSATIONS.—In the interpretation of the meaning of the records, the conclusions

arrived at by the writer are in many respects widely different from the conclusions arrived at by many of the Italian observers. The chief differences relate to the causes which may possibly produce the movements. In Italy, tromometric disturbances which occur at the time of a low barometer are usually referred to as *baro-seismic* motions, whilst those occurring at the time of a high barometer are called *volcano-seismic*, both of which terms apparently imply a subterranean origin. M. de Rossi even suggests that the origin of the motion may be directly connected with variations in the escape of steam from a molten magna beneath the crust—the variations in activity being immediately connected with variations in external pressure. Further, he points out the connection between micro-seismic storms and earthquakes. The writer, who has carefully examined continuous records extending over several years, fails to find any connection between the time of occurrence of earthquakes and these earth movements,\* whilst on the other hand there is a very close connection between these phenomena and local or distant winds; but what the writer now recognizes of greater importance, is a still closer connection with the state of the barometric gradient. For example, the writer finds that in the Italian Peninsula tremors appear *whenever there is a steep gradient, whether the barometer is high or whether it is low.*

The same law, as shown by the following table, appears to be also true for Japan. The gradients are measured in millimeters per 120 geographical miles, this being a convenient quantity to measure on the weather charts:—

With a gradient 0, tremors were observed in 20 per cent. of the observations.

With a gradient 1, tremors were observed in 57 per cent. of the observations.

With a gradient 2, tremors were observed in 44 per cent. of the observations.

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\* Earthquakes and tromometric disturbances are, however, each most marked during the winter months.

With a gradient 3, tremors were observed in 50 per cent. of the observations.

With a gradient 4, tremors were observed in 88 per cent. of the observations.

With a gradient 5, tremors were observed in 71 per cent. of the observations.

With a gradient 6, tremors were observed in 100 per cent. of the observations.

With a gradient 7, tremors were observed in 100 per cent. of the observations.

With a gradient 9, tremors were observed in 100 per cent. of the observations.

With very high gradients it is seen that tremors have *always* occurred. With moderate gradients they have *generally* occurred. When they did not occur it may be that the gradients extended across the country in a direction or in a form unfavourable for the production or propagation of pulsatory movements. This has yet to be investigated; but it may be here stated that with gradients causing a wind from the S. or S.W. the tromometric disturbances are unusually well marked, and precede or outrace the wind by 5 or 10 hours. In the few cases where tremors were observed with a low gradient the tremors were exceedingly small, and, *in fact little more than movements that are almost at all times observable.*

Not only is there an immediate connection between a tromometric disturbance and the gradients existing at the time of its occurrence, but there is a general connection, inasmuch that earth pulsations are most frequent at the seasons when barometric gradients are the steepest—which for the northern hemisphere at least, is particularly marked during the winter months. It must also be remarked that it is during these months that we have the greatest barometrical fluctuations.

If these disturbances are connected with the state of the barometric gradient, inasmuch as the effect of a gradient influences a large area, we should expect tremors to be practically

simultaneously observed over a large area, and, generally, that curves showing monthly maxima should closely follow each other over an area, for example, like Central and Western Europe. Observations show that both of these phenomena are clearly marked throughout the Italian peninsula.

As might be anticipated from the close relationship between the occurrence of these earth waves or "ground swell," and the steepness of the barometric gradient, there must also be a close relationship between earth waves and local or distant winds, and, in the author's previous work, although it was often shown that fluctuations in atmospheric pressure might be a possible cause of tremors, it was suggested that the immediate cause was the mechanical action of the wind upon the sides of mountains and other surface irregularities. Now that recent investigations have shown that earth motions are more pulsatory than tremulous, vibratory or micro-seismic, the author returns to the view first expressed in 1883 (Sec. Trans. Seis. Soc., Vol. VII. Pt. 1, p. 14), namely that these movements may be due to fluctuations in atmospheric pressure acting over considerable areas of the earth's crust, which it must be observed is of varying elasticity. That there may be deflections in the earth's crust due to barometric pressure, was shown by Prof. George Darwin in a report to the British Association in 1882 on the Lunar Disturbance of Gravity.

Assuming the superficial layers of the earth's crust to have a rigidity greater than that of glass, Prof. Darwin shows that a gradient of 50 millimeters in 1,500 miles would produce a deflection of 90 millimeters, which represents a slope of about 1 in 26 million.

With the rigidity reduced to, say one-third, which would bring this factor nearer to the rigidity of rocks as they exist on the surface of the earth, and with a steeper gradient, which is of common occurrence, the deflection would be increased.

If we imagine an elliptical area of isobars in the centre of



which the pressure is low and round its periphery high, the gradient being, say, 4 mm. per 120 miles, existing over an elastic surface, the one side of the area would be depressed and the centre raised. Let the area of isobars move at the rate of 35 miles per second, which may be taken as an average rate for a barometric depression to travel, then the rate at which the load would be changed per second at any point may be represented by about  $\frac{1}{8000}$  millimetres of the mercury column. As it is probable that the earth would adjust itself to the form due to the load changing so gradually, it is not likely that at any given station whilst the depression approached and passed, anything more than a change in the vertical, first in one direction and then in another, would be observable.

Conditions of possibly greater importance are the facts that a given set of isobars do not move at a uniform rate, sometimes increasing and sometimes decreasing their relative distances, and also as is evidenced in the gusts of a storm and in the movements of a barometer, that they progress in impulses. In exceptional cases the writer has observed barometric fluctuations of .03 to .05 inches with a periodicity of from 1 to 3 seconds. Taking these latter facts in conjunction with the fact that isobars often advance in lines curving inwards or outwards, that the area over which they travel is of varying elasticity, that the rigidity of material on the surface of the earth is less than that hitherto assumed in calculations, and that the effect of suddenly applied stresses in producing deflection may be double that which would be produced by gradually applied loads, we may ask ourselves whether such conditions are likely or not likely to throw the surface of the ground into a series of flat undulations, the existence of which has apparently been experimentally demonstrated.

As to whether earth waves would outrace a depression travelling at a rate of 35 feet per second in the same manner that waves on the ocean outrace a storm, the following facts may be considered.

The Earthquake shock of October 28th, 1892, was transmitted to Tokio, a distance of about 200 miles, at a rate of about 6,000 feet per second. The resulting waves in the soft earth of Tokio were slow undulations, the length of which it was endeavoured to determine by the angle through which bracket seismographs had been tilted taken in conjunction with the records of vertical motion. For various reasons the method was unsatisfactory, and special instruments have been designed to measure such movements more accurately.

The results showed that they may have been 50 feet in length whilst their period was 1 second.

The writer has measured the speed of surface undulations produced by explosions of dynamite at less than 200 feet per second. The elastic vibrations of earthquakes have attained a velocity of about 17,000 feet per second, but usually they are very much lower, the velocity depending largely on the intensity of the initial disturbance and the medium through which it is propagated.

From the above we see that even under the worst conditions, as for example, across an alluvial plain, the waves, if produced would in every probability outrace the cause producing them.

With a steep gradient as measured at Tokio there is generally a high wind somewhere in Japan, but after an examination of the weather maps it is clear that the velocity of the wind, as measured in Tokio, or as blowing in Central Japan generally, is not proportional to the gradient. Possibly, it depends upon the direction of the gradient. The extent to which wind velocity may vary will be realized from the following five examples:

| 1886.            | Time.      | Wind in<br>Tokio. | Wind in Cen-<br>tral Japan. | Gradient. | Direction of<br>Gradient. |
|------------------|------------|-------------------|-----------------------------|-----------|---------------------------|
| January 20th ... | 9 p.m. ... | 0 ...             | 1 or 2 ...                  | 5.45 ...  | S.E. to N.W.              |
| January 21st ... | 2 p.m. ... | 3 ...             | 3 or 4 ...                  | 5.21 ...  | W. to E.                  |
| January 21st ... | 9 p.m. ... | 1 ...             | 2 or 3 ...                  | 4.80 ...  | W. to E.                  |
| January 22nd ... | 6 a.m. ... | 1 ...             | 2 or 3 ...                  | 5.53 ...  | W. to E.                  |
| January 22nd ... | 2 p.m. ... | 3 ...             | 3 ...                       | 3 ...     | N.W. to S.E.              |

Wind 0=0—1.5 m. per sec. Wind 1=1.5—3.5 m. per sec. Wind 3=3—10 m. per sec. The gradients are in mm. per 120 geographd miles, and their direction is measured from high to low.

Mr. T. Wada, of the Meteorological Bureau in Tokio, tells me that the variation of the wind with a given gradient is especially marked during the winter. He also remarks that as a centre of depression travels towards the N.E. the velocity increases at Tokio, especially when the centre is near Tokio, at which time the gradient is at a maximum.

Because tremors follow steep gradients more closely than they follow the winds, this fact may indicate that earth pulsations are more closely connected with the state of the barometric gradient, and possibly also its direction, and the form of the isobars, than they are with winds.

Another point of significance is the fact that earth waves are usually pronounced when the rate at which barometric pressure changes is rapid. For example, when the rate of change per 8 hours at Tokio is 6 or more millimeters, which usually occurs with a falling barometer, tremors are usually large—but the amplitude of the tremors does not appear to be proportional to the amount of the change.

ON THE POSSIBLE CONNECTION BETWEEN EARTH PULSATIONS,  
THE ESCAPE OF FIRE DAMP, THE ESCAPE OF STEAM FROM  
VOLCANOES, AND THE FLOW OF SPRINGS.

**FIRE DAMP.**—From the writer's own experience at mines, but especially from the reports of Austrian, German, French, and English Commissions, appointed to enquire into the cause leading to the escape of fire damp, and the observations of many engineers, the relationship of fire-damp to barometrical pressure and earth pulsations appears to be as follows:—

1.—The appearance of fire damp at mines *containing old workings* in which gas may accumulate is certainly very closely related to barometrical depressions.

2.—The relationship between the escape of fire-damp *from the coal* to barometrical depression, is not so clearly established. At certain mines experiments have shown that occasionally an outflow of gas is very closely related to a decrease in atmos-

pheric pressure, but usually, although there may be a fall in pressure, the escape of gas is by no means proportional to the fall, whilst it may often happen that a fall may take place and the quantity of gas issuing from the coal remains unchanged. In short, it does not appear that there is any well marked connection between the height of the barometer and quantity of gas issuing from coal; and farther, as has been remarked by other observers at mines, when gas is confined under high pressure, it is hardly reasonable to suppose that a slight variation in atmospheric pressure should produce any appreciable change in the gas which is escaping.

The writer is not aware that any observations have been made upon the escape of gas and the state of the barometric gradient. It, however, may be remarked, that when isobars are crowded together and the gradient is steep, which is during the winter months, in Germany and roughly speaking also in England, colliery explosions have been most numerous. Farther the author observes on examining the diagrams given by M. Chesneau of his experiments at Douai, that the quantity of gas was greater during the winter months than during the summer. This evidence, small as it is, suggests the idea that not only will there be found to be a seasonal connection between the escape of mine gas and the general state of the barometric gradient, but that possibly there may be a very much closer connection between the escape of gas and the state of the barometric gradient than there is with the height of the barometer. The relationship between the escape of gas and barometric disturbances has been but little studied.

In 1883, the writer established instruments in the Takashima Colliery near Nagasaki for making such investigations, but these had barely commenced, and he had returned to Tokio, than the news arrived that everything had been destroyed by a fall of the roof.

In 1886, similar observations were made at Douai, and from the analyses of these, given by M. Chesneau, the relationship

\* existing between the escaping gas and earth movements is certainly more clear than it is with barometrical fluctuations. A point of some importance which the writer observes in the only detailed curves showing the relationship of tremors, the escape of gas, and barometric movements, is that on December 8th, 1886, when the former reached a maximum about 6 hours before the gas reached its maximum, and at least 20 hours before the barometer had fallen to its lowest point. As indicating a general relationship between the frequency of earth pulsations and the escape of gas, it may be mentioned that the yearly barometric curves for Italy show a close relationship with the curves showing the monthly frequency of colliery explosions in Germany.

The observations, so far as they have gone, are certainly encouraging, but to complete them the writer makes the two following suggestions.

- 1.—That comparisons be made between the escape of gas and the barometric *gradient* existing at the time of observation.

- 2.—That observations be made with a tromometer which approximately measures the steepness of the earth waves, their period, and the direction in which they advance. The objections to instruments of the pendulum type have already been stated.

Should any decided results be arrived at, then the necessity of certain mining districts obtaining information respecting barometric gradient will be as great as similar information is for our sea ports, and tromometers at many mines may be found more necessary than the barometer.

As it is likely that the relationship between earth waves and isobars may be as complicated as the relationship between isobars and the weather, we have to make our comparisons, not only with the gradient, but with the direction of gradient, the rapidity with which isobars may be travelling, their form, and generally to all those changes which meteorologists recognize as causing alterations in our weather.

### ESCAPE OF STEAM FROM VOLCANIC ORIFICES AND THE FLOW OF SPRINGS.

It is often stated that there is a relationship between the escape of steam at volcanic vents and the movements of the barometrical column, and as an illustration, reference is repeatedly made to the volcano of Stromboli. From the writer's own experience at volcanic vents, although admitting that there are variations in the amount of escaping steam, he fails to recognize how a slight change in pressure, as indicated by any fall of the barometer, could cause any appreciable difference in the quantity of vapour escaping where it is under such pressure as its roaring often indicates. In cases where vapours issue gently or water escapes slowly, a barometrical fall may result in an increased volume or flow of liquid, but in other cases it may be asked whether these fluctuations have not a closer relationship with barometric gradients and earth pulsations.

Earth pulsations, we know from experiment, to exist far below the surface, but whether by repeated compression and extension due to bending, they are capable of mechanically causing an increase in the gas of coal mines, the escape of steam from volcanoes and the flow of water from springs yet remains a subject for investigation.

### EARTH PULSATIONS AND THE MOVEMENTS OF BALANCES.

As an illustration of the effect of earth pulsations upon a certain class of physical instruments, the following notes are given of the writer's experiments with two delicate balances.

One balance is an assay balance by Oertling, with light arms each 100 mm. in length. The pointer is 120 mm. long and moves over an ivory scale, with divisions each 1.6mm. Facing this pointer, a microscope has been placed. The field takes in a little over one division of the ivory scale which corresponds to 6 divisions of a micrometer scale. These 6 divisions can be easily divided by the eye into quarters and approximately into tenths. The least angular displacement that could be read

would therefore correspond to a tilting of 1 in 4800. I cannot imagine the ground to be tilted to so great an angle, but I can imagine the balance receiving a succession of impulses until it was caused to swing even through greater angles.

In the Oertling balance I assume that I am able to read to a quarter of the scale divisions, which correspond to a load of  $\frac{1}{100}$  of a milligramme, or the movement of a milligramme rider through half a division on the beam scale.

The second balance is a chemical balance by Bunge. The beam is 155 mm. long, and the pointer 270 mm. long.

In this balance the divisions on the ivory scale are .9 millimetres apart. With the aid of a magnifying glass I can read to half these divisions, but to obtain that movement requires the addition or subtraction of  $\frac{1}{10}$  milligramme. That is to say, the rider must be moved through 5 division of the beam scale to show an appreciable alteration in the position of the pointer. Both balances stand on an exceedingly massive stone column, which for many years carried an Equatorial. Both stand east and west, the Oertling facing the only window in the room, which is usually covered with a curtain.

The following are examples of a few of the observations which have been made :—

#### THE OERTLING BALANCE.

A spirit lamp burning for 15 minutes in front of the glass case covering the balance produces no appreciable change. By lighting a fire and raising the temperature of the room from 62° F. to 85° F. produced the following effects :—

| Time,<br>p.m. | Temp.    | Reading of Balance by Micrometer scale<br>and remarks. |
|---------------|----------|--|
| 7.30.....     | 62°..... | 5.0  |
| 7.35.....     | 62°..... | 5.2  |
| — .....       | 82°..... | 6.5  |
| 8.20.....     | 85°..... | 5.0  |
| 8.45.....     | 80°..... | 4.8  |
| 9.15.....     | 74°..... | 4.2  |

Lighted the fire.

These positions were  
taken up gradually.

At the time of these observations, two mirror tromometers standing on the same column showed that tremors or tilts were very small. The balance movements may have been due to change of temperature, but they are not greater than movements which are always taking place when there is no fire. The usual range of temperature in the room is about 5°, the effect of which, even if the above experiments produced the changes indicated, may be taken as inappreciable.

One point to be noticed in the above table is that the balance took 50 minutes to complete a back and forth motion. The following are a few examples of the records which were made. They usually commenced in the morning and were continued during the day until the evening. *Bar* means the Barometer, *Bal* means balance, the records of which are the readings of the Micrometer. If two numbers are given, thus 4.2—5, this means that the pointer was moving back and forth between these numbers. Sometimes it moved out of the field and then it had to be read directly on the ivory scale. When the numbers increase it means that the zero of the pointer is being displaced to the left, and as the same effect *might* be produced by tilting the balance on its right or Eastern side, this is *for convenience* sometimes expressed by "*E. lift*." A movement in the other direction would be "*E. sink*." The time taken for a complete swing or period is stated in seconds. On the same column parallel to each other and side by side, are two light tromometers, also recording east and west motion. The range of pulsatory movements called *Trens*, are indicated in millimeters. As these were not automatic records, in many cases they may not represent maxima in the disturbances, as maximum motions only occur at intervals of several minutes. Displacements of the spots of light which continue for several minutes or hours, are for *convenience* called *tilts*. They are measured in millimeters and we have *E. lifted*, *E. sunk*, *E. rising*, *E. falling*. The words *balance reset*, means that the pointer having wandered out of the field, the microscope had to be readjusted.



The barometric gradients are in millimeters per 120 miles, and are taken from the tri-daily weather maps, for 6 a.m. 2 p.m. and 10 p.m. For example, a record "S.W.-N.E. 3," means that the gradient was *from* South West *to* North East of 3 millimeters,—the barometric depression being towards the North East.

## OCTOBER 7TH.

6.25 p.m. Bar. 30.1. Trems. 1. Bal. 5.5-5.75. Period 34.42 and 39—6.30. Bal. 5.8—9.00 Bar. 30.35 Bal. 5.7—5.8 Bal. reset at 4.9. Set bal. swinging—9.48. Trems. 1 bal. 6—6.1. then 5.5—5.6—10.00 Bal. 5.8. Gradients N.E.-S.W. 3, —N.E.-S.W. 2—N.E.-S.W. 2.

## OCTOBER 8TH.

8.00 a.m. Bar. 30.0 Trems. 1. East lift 1. Bal. 7—7.5., therefore east may have lifted. Reset at 4.8—8.30 Trems. 1. East sinks. Bal. 4.5 and then E. may have sunk 8.35 Bal. 5.0 E. risen. Bal. moves intermittently—11.0 Bal. 4.3 and still. 1.30 Bar. 30. Trems. 1. Bal. 4.25 and steady—9.25 Bar. 30. Trems. 1. Bal. 3.9—4.1. Set bal. swinging—10.15 Bal. 3.5—4.0. Rain and bar. falling—10.20 Bal. 3.0. E. may be sinking. Movements very slow, now and then it stops—10.25. Bal. 2.9—3 weather calm—10.30 Bal. 3.5 and it remains so for 3 minutes. Gradients N.E.-S.W. 1, E.-W. 1, and from Tokio to N. and S. 2.

## OCTOBER 9TH.

7.40 a.m. Bar. 30. Trems. 5. Bal. 2.5 and steady—7.45 Bal. 2.5—3—9.28 Bal. 5—9.30 Bal. 4.5 and it keep steadily at this until 12.17 when the Bar. has fallen to 29.8. Although steady, there were apparently pulsatory tilts, say from 4.5 to 4.6 or say  $\frac{1}{100}$  part of a division on the ivory scale. Weather calm but rain—12.20 Bal. 4.8—3.9—12.25 Bal. again 4.5 and steady—2.46 Bal. 4.2 and steady for 5 minutes,—9.00 Bal. 4.3 Trems. .5—9.14 Bal. 4.6—9.21 Bal. 4.8—9 30 Bal. 4.6. It seems to take about 15 minutes for a half swing.

Gradients N.W. to S.E. 2.5. N.W. to S.E. 2.5. N.W. to S.E. 1.5.

OCTOBER 10TH.

7.32 a.m. Bar. 30. Trems. 2-4. East lifted. Bal. 4.5 but in 2 minutes 2.4, one minute later 4.5, but is now moving 4-3.8. Trems. show active tilting of East. Looking in the microscope every 2 or 3 minutes the readings run 3.5, 4.5, 4.5, 5.5, 5.3, 5, 5, and here it seems to stand as if the E. had been lifted by impulses. The weather is practically calm, there being a slight N. wind—9.40. Bar. 30. Trems. 4 Bal. 4.2-5 then 4-5. The period of these small swings is from 17 to 27 seconds—9.50. Bal. 4.6—12.18 Bar. 30. Trems. 3. Bal. 4.6. Weather calm—12.20 Bal. 4.8—12.26 Bal. 4.8—12.30 Bal. 4.6. Then these changes were made by small impulses—4.0 Trems. 2. Bal. 5.0 It has been a dull day—7.30 Bar. 30. Trems. 2—3. East lift. Bal. 5.2 but moving quickly, say from 4.2 to 5. Now and then it reaches 5.6 and 6—7.40. Bal. 5.5—6—7.42. Bal. 5.4—11.5 Bar. 30. Trems. 2-3. East lift. Bal. 2.8—6.2—11.10. Trems. 2-4. East lift 2 mm. Bal. 4.2—4.7. Now and then the Bal. stops. The tremors are large and erratic. Gradients N.W.S.E. 2.5—N.W. to S.E. 2.5. N.W. to S.E. 1.5. It must be here remarked that these gradients are about the same as on the 9th when tremors were small and the balance quiet. On both days it was generally calm in Japan, but on the 9th although there was a low barometer to the north and also to the south of Tokio; whilst on the 10th these areas of depression, and there was only one direction of gradient across the country, namely, from N.W. to S.E. Also on the 9th the isobars were nearly stationary, whilst on the 10th they were moving in the direction of their slope. That is to say although the gradients were fairly constant the atmospheric load on Central Japan was rapidly increasing. To this further reference will be made.

OCTOBER 11TH.

7.41 a.m. Bar. 30. Bal. 3-6.5 moving quickly back and forth. Trems. 2-3 and lift on east.

7.44 Bal. moves as follows 3.5-4.5. 3.5-5.5. 5.5-4.2 4.2-5.8. 5.8-4.8 &c.

7.47. Bal. inclines to settle at 4.6.

During the morning three series of readings were taken, each at intervals of 5 seconds. Keeping my eye to the microscope I gave the readings which were noted by a second observer who gave the time intervals. The results were plotted on squared paper and they are shown in the accompanying diagrams.

The gradients were W.N.W. to E.S.E. 2.5. The other two gradients were from Tokio to the N.E. and to the S.W. each about 5.

That the method of observing is fairly accurate, is testified by the manner in which in the dots indicating the observed position of the mirror, practically follow each other in a straight line whilst the balance is moving. The vertical lines represent divisions of the micrometer whilst the horizontal lines represent intervals of 25 seconds. On the original paper each of these were divided into fifths. From the diagram commencing at 8.30 we see that each half swing has differed in time and amplitude, the swings to the right having been greater and taken longer time than those to the left. The full period has varied from 50 to 35 seconds. During this time the pointer has moved from a mean position of 5.5 to a mean position of 5.7.

In the diagram taken at 9.50, the full period has varied from 45 seconds to at least 60 seconds. The increased period is apparently due to the long pauses at the end of each swing, especially when the swings are small. The amplitude has decreased, increased, and decreased. On the whole there has been a movement of the mean position from about 5 to 5.5. Both of these shifts in mean position might be explained by assuming that the eastern side of the column had been raised.

During this time the two tromometers showed move-

ments of 2 mm., and by the displacement of the light spot indicated a lift of the East of about 2 mm. At 3.25 p.m. a similar experiment<sup>33</sup> was made, but as there was with but little interruption a gradual movement from 4.7 to 5.3 in an interval of 4.25 minutes, this was not plotted. At the time the tremors were about 2 mm. whilst the tilt on the East side had decreased to 1 mm. As compared with the mean position of the balance at 9.50, the balance also might indicate a change in level following the same direction.

Next the balance was *caused* to swing, the last oscillation being from 4.3 to 5.2. Eight complete swings gave a period of from 39 to 41 seconds.

It came to rest at 4.7, which is where it was when we entered the room.

These diagrams from readings of movements, the range of which are about the same as those taken when the balance has been found to be swinging, when plotted, give a regular series of curves balanced about a central line showing a practically constant period.

A number of experiments were made to see the effect of quickly opening and shutting the door of the room, walking about heavily on the floor, which is only connected with the column through the outside foundations of the building and the earth, but no effect was observable.

As the time of the above observations it was calm and the Barometer stood at 30.35.

#### OCTOBER 12TH.

At 8.40 a.m. a five seconds record was made of the movements of the balance, the results of which are also shown in the accompanying plate.

A large movement, it will be observed, has a period of at least 70 seconds. This motion, which might represent a sinking and then a rising of the East side of the column, is performed altogether on one side of the neutral line. Between the smaller

movements there were pauses of from 35 to 95 seconds. The neutral line appears to be about 6, that is to say, since the 11th the movement has been as if the East had been raised.

The gradients at Tokio were from N.E. 5 and to the S.W. 2.5—E. to W. 4—E. to W. 7.

It will be observed that with this change in direction of a gradient, the East has been raised.

| a.m.                                   | E. up.                    |
|--|---------------------------|
| 10. ....                               | 6.8                       |
| 10.5.....                              | 6.4                       |
| 12.5.....30.1.....5.....0.....5.2..... | Shortly after 5-6.5 calm. |
| 3.7.....30.05 .....                    | 6.2—6.6.                  |

#### OCTOBER 13TH.

Caused balance to swing and its period is from 40 to 45 secs.

*Reset the balance at 4.*

3.40 p.m. The barometer at 29.6 and a heavy wind. The balance is remarkably steady at 4. Now and then the tremors are steady, but now and then there are large movements of 2 to 4 mm. During the day balance slightly wanders.

5.10 p.m. Balance at 4.5. Tremors of 4 mm. and the E. sinks.

7.35. Bar. 29.6, but wind has ceased. Balance is moving from 4.8. Tremors large 5 mm. as if the E. was sinking, and the light is displaced 2 to 3 mm. Bal. goes to 4.2.

9.4. Bal. 4.2. Yet calm. Tremors generally zero, but every 3 to 7 minutes a movement of 4 mm.

9.20 Tremors show a lift on the East and balance agrees in direction. 9.30 Bal. 5.1. 10.5 Bal. 4.5. Tremors decreasing. Whilst looking in the microscope the balance moves quickly up to 3.7 and back to 4.5; with a period of 58 seconds. It was as if there had been a sink and then a rise on the E side. 10.20 Balance 3.5 to 4.5. 10.30 Balance 4—5. Neither the heat from a spirit lamp, banging the door, or stamping on the floor altered this swing.

The gradients for the day were E. to W. 7—S. to N. 5 S.W. to N.E. 2.5. That is to say, between morning and night the E.

side of Japan was relieved of pressure and therefore might rise. This generally agrees with the movement of the balance, but not with the records from the tromometers.

## OCTOBER 14TH.

7.30. Bal. at 6. therefore E. has risen. Trems. 2 mm. and working back to their starting point as if the E. was rising. Fine. 11.00 Bal. 5.8. Trems. 1 mm. 2.00 Bal. 5.2 (E. sinking.) Trems. 2-4 and E. sinking. 5.00 Bal. 4.8. It is quite calm but there are Trems. of 4 mm. The gradients were S.W. to N.E. 1.5. S.W. to N.E. 1.5 W. to E. 2.

## OCTOBER 15TH.

8.30. Bar. 30.05. Fine weather. Balance much disturbed, moving quickly, 5.5 to 4.5 then 4 to 4.8. 8.40 Bal. reaches 6. 12.00 Bal. at 5. Trems. 1 mm. (Since last night a sinking of 2 mm.) 5.30 Bal. 4.5 and very steady. Trems. 2 mm. and increasing, and E. sinking, which agrees with balance since the morning. 7.30 Bal. 4. Trems. 0, but E. sunk. Therefore all day there has been a sinking on E. The gradients were W. to E. 1.5 W. to E. 2.5 N.W. to S.E. 2.

## OCTOBER 16TH.

9.5. Bar. 30.2. Bal. 6.2 (E. rising). Trems. 1m. (E. rising 2mm.) 1.20. Bal. 6.2. Trems. 2mm. 3.30. Bar. 30.2. Bal. 5.8. Trems. 0. 8.30. Bal. 6.8 (E. rising). Trems. now and then 1.5-2. 8.35. Bal. 4.5 and returning quickly. Trems. 2mm. (E. lifted.) 8.38. Bal. 6.2. 9.20. Rain but calm. Bal. 8.0 (E. rising). Trems. 4m. E. lifting. From this time the movements of the balance are very erratic, the ends of swings being, 5, 6, 5.8, 6.3, 6, 6.8, 5.3, 6.4, 5.9, 6.8, 6.2, 6.8, 5.7, 6.2, 5.9, 6.5, 5.7, 6.5, here it stands for 1 minute then, 6.8, 6.2, 6.5. Trems. 2mm. and E. lifted 4mm. 9.49. Bal. stands at 7 now, and then returning to 6.2. 10.00. Bal. stands at 6.5. Trems. now and then 4mm. The gradients were N. to S. 2. N. to S. 5 N.E. to S.W. 1.

## OCTOBER 17TH.

7.50 a. Bar. 30.15. Fine, but rain during night. Bal. 7.

Trems. 1mm. 7.52. Bal. quickly moving 3.5 to 8 and out of field. Trems. (E. sinking). 11.40. Bal. 6.7. Trems. 1mm. 4.00. Bal. 6.2. Trems. 0. 5.52. Bal. 5.8-5.9. Trems. slight. (East lift 5mm.) The gradients were N. to S. 5, N.W. to S.E. 2, N.W. to S.E. 2.

## OCTOBER 18TH.

8.8 a. Bar. 30. Dull, but calm. Bal. 6.5-6.2. Trems. steady (sink in E). 12.00. Rain, calm. Bal. 4.3 to 8. Trems. 1 to 2mm. 1.13. Bal. 3 to past 8. Period 38 to 42 seconds. Trems. 2mm. after 5 large swings for 10 minutes. Bal. remains 6 to 7. 1.35. Bal. 7. Calm and dull. 3.35. Bal. 7 to past 8 out of field. Trems. 2 to 5mm. 9.34. Bal. 5.8 to past 8. Trems. 4mm. E. lifting Bal. 3.5 to past 8. Period 39 seconds. We have here large trems. and large oscillations, calm weather and a Bar. of 30.1. The gradients were N.W. to S.E. 2, N.W. to S.E. 5 N.W. to S.E. 2.5. Without giving more observations the conclusions arrived at appear to be as follows:—

1.—The balance is nearly always moving, sometimes quickly and sometimes very slowly. When the balance is apparently quiet and it is raised on the stops and then gently lowered so that it swings through two or three divisions of the ivory scale, its period is *about* 41 seconds. Its period when found swinging has been from 17 to 60 seconds; slower movements take anything between 1 and 50 minutes. As will be seen by reference to the diagrams and their description, the mean position of the pointer may in a short time change half a division on the micrometer scale or  $1/12$  division of the ivory scale. During a day it may creep through half a division of the ivory scale. The largest natural oscillations, which have been far out of the field of the microscope, have been 4 divisions of the ivory scale. These have been performed rapidly. Natural swings which vary in amplitude and period are usually performed almost entirely on one side of what for the time may be considered the mean position of the pointer. In the Oertling balance these movements are towards the left,

a result that might be obtained by raising the eastern side of the column,

The direction in motion, whether gradual or impulsive shown by the light spots from two independent tromometers agree in direction. On October 9th the balance remained steady for three hours, but this is rare. When tromometric movements are large the movements of the balance are rapid and large. Sometimes, however, the balance moves when there are no tremors, but at such a time it appears that the spots of light are being gradually displaced. This displacement may reach 3 mm. which may correspond to a tilt of 1 in 66,000.

It must be remembered that these movements have been observed in a darkened room where there is but little change in temperature, that the balance may be quiet when a wind is blowing, whilst when it is moving rapidly there may be an absolute calm, and that the movements closely follow those of the tromometers. The quick impulsive movements of tromometers I attribute to a pulsatory wave-like motion in the earth's crust, whilst the slower motions may be due to a gradual but intermittent tilting. The existence of the earth movements may be dependent on the state of the barometrical gradient, and also upon the rapidity with which atmospheric pressure is altered.

Assuming that other balances behave as mine have behaved, then the importance of paying attention to the existence or non-existence of tromometric movements when delicate weighing operations are being carried out, as for example when making determinations respecting standard weights, is evident. Even in delicate assay work if the zero of a balance may alter within five minutes there may be times when weighing by the method of "vibrations" may be affected—the displacements referred to, being very often large enough to be measured by the eye.

## 2.—THE OERTLING AND BUNGE BALANCES.

In the second experiments, which continued over a period of



20 days, the Oertling was observed directly by the eye, while for the Bunge an ordinary hand magnifying glass standing inside the glass case was found necessary. Both balances stood on the same column in parallel positions, one facing south and the other facing north. When both balances are apparently at rest and they are caused to swing, the period of the Oertling was about 42 seconds whilst that of the Bunge was about 23 seconds. When the Oertling is swinging 3 divisions right and left, it practically comes to rest in 11 or 12 minutes. From a slightly larger swing the Bunge comes to rest in 7 minutes. In the following statement of what I observed, I shall denote the Oertling Balance as O. and the Bunge as B. :—

- 1.—O. showed very much more movement than B.
- 2.—When O. was greatly disturbed, say swinging through 1 division, B. was greatly disturbed, moving through  $\frac{1}{2}$  a division.
- 3.—Twice I found O. moving over 4 divisions.
- 4.—With the assistance of my colleague, Prof. C. D. West, I have noted both balances disturbed simultaneously and in the same direction.
- 5.—Periods of disturbance usually occur with tromometric disturbances, but both balances sometimes move when no tremors are observable.
- 6.—Both balances have shown very slight but simultaneous displacements in the same direction between night and morning, —the tromometers showing displacements in the same direction.
- 7.—On November 4th at 8 a.m., the movements of O. were from 2 to 3.4, while B. moved from 1 to 1.5. From 11 a.m. on the same day both remained at rest until the evening of November 6th. This is the only long period when both balances practically gave constant readings.
- 8.—Both balances have shown considerable motion when it has been calm, the barometer high, and when the change in temperature has only been a few degrees.
- 9.—Both balances have remained practically at rest during a heavy gale and when the Barometer is at 29.2, as for ex-

ample, at the moment of writing, November 24th at 2 p.m.

Subsequently these balances were placed in the Balance Room of the Mining Department in the Engineering College where they stood on a massive oak shelf built in the brick wall. They were set free every morning and observed at intervals during the day. Slight changes in zero, say of .2 to 1 division of the ivory scale were continually observed, while now and then the movements were larger. On one day when as it was a holiday the buildings were empty (December 12th from 3 p.m.—4 p.m.) the swings were large, erratic and about different zeros.

#### EARTH PULSATIONS, GRAVITATION, AND ASTRONOMICAL OBSERVATIONS.

From what has been said respecting the behaviour of balances and horizontal conical pendulums, it would appear that whenever a pendulum is swung the results obtained may, amongst other things, depend upon the existence or non-existence of earth tilting and earth pulsations, which may accelerate or retard its motion, thereby altering its period and amplitude and even change its zero. In certain branches of astronomical work earth pulsations may be at least partially the cause of difficulties which hitherto have not yet been fully understood. In 1887 when Prof. Todd came to Japan in charge of an expedition to observe the eclipse of the sun, a portion of the work consisted in the endeavour to obtain photographs of the corona. To do this, the image, by means of a heliostat, was sent through a 40-foot lens before impinging on the photographic surface. From what I learn from Prof. W. K. Burton, although all parts of the apparatus were installed on solid stone columns, it appeared at times to be impossible to obtain a steady image. One cause to which this might be attributed would be to the fact that the time of observations may have coincided with a period of earth pulsations. In astronomical spectroscopic work such movements might cause considerable difficulties.