IV. *Comparison of Simultaneous Magnetic Disturbances at Several Observatories.*

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[Plates 8, 9.]

In my former papers on Magnetic Disturbances and Earth Currents, which were read at the meetings of the British Association at Swansea in 1880 and at York in 1881, a comparison was made of the declination and the horizontal force traces given by the self-recording instruments at five European stations, also at one station in India, one in China, and one in Australia. An attempt was made to determine the relative amounts of the simultaneous changes at the several observatories by comparing them with one another by means of the scale values of the instruments employed, which were all of the pattern of the self-recording instruments at the Kew Observatory. It was found on comparison that there were great differences in the scale values of the instruments of the same kind at the different observatories, and in some cases there was great uncertainty as to the scale values, because no determination of them had recently been made. Hence great difficulty was found in arriving at the true meaning of the records which were taken regularly at the different observatories.

The comparison was sufficient to show the great importance of adopting the same scale values for the like instruments at all observatories. In my paper a recommendation was made that for horizontal force records a scale value of ·0005 millimetre-milligramme for a difference of scale reading of 1 mm. should be adopted as being the most convenient. The same scale value was recommended by Dr. Wild, of the St. Petersburg Observatory, and for the vertical force magnetometer the same scale value might conveniently be adopted. With this scale value the instruments would be sufficiently sensitive to give for a considerable magnetic disturbance changes which are capable of being measured, but yet would not be so sensitive as to send the spot of light off the photographic paper, even in a violent magnetic storm.

A violent magnetic storm was experienced in August, 1880, and the records from these observatories, viz., Kew, Stonyhurst, Lisbon, Vienna, St. Petersburg, Bombay,

Zi-ka-wei, and Melbourne, as well as those from the Toronto Observatory in Canada, were compared and discussed in the paper read before the British Association at York in 1881, and printed among the Reports of that year.

During the last ten years the number of self-recording magnetic observatories where Kew instruments are used has increased to 8 in Europe, 3 in Asia, 1 at the Mauritius, 1 at Melbourne, and 2 in the United States of America, whilst there are self-recording instruments of a different type at Greenwich, Paris, Utrecht, and Toronto.

For the bifilar magnetometer or horizontal force instrument a scale value not greatly differing from ·0005 millimetre-milligrammes of horizontal force for 1 mm. of scale has been adopted at Kew, St. Petersburg, Vienna, Wilhelmshaven, Lisbon, San Fernando, Colaba, and Batavia, and the satisfactory nature of the results now obtained at these observatories clearly shows that it would greatly advance the study of terrestrial magnetism if the same scale value were adopted at other observatories. Nearly the same scale value is adopted for the balance or vertical force magnetometer at Kew, St. Petersburg, Lisbon, Batavia, and Mauritius, but at nearly all other observatories the instruments are considerably less sensitive, and their indications in ordinary magnetic disturbances are too small to be of much service for comparison or measurement of the amount of change of the magnetic forces or of the magnetic potential of the earth.

Thus in the disturbances on August 11th, 1880, at the beginning of the magnetic storm at 10.20 A.M., G.M.T., the disturbance of horizontal force is measured at Colaba (Bombay) by a rise of 3 mm., at Toronto by 7 mm., at Zi-ka-wei by 19 mm., and at Vienna by 13 mm.; but, as appears from Table I., the values of these deflections are very nearly the same, viz., a change of about ·005 millimetre-milligramme. With the scale value recommended, the measurements for this disturbance would have been from 10 to 12 mm.

TABLE I.

	Scale value for 1 mm.	Deflection at 10.20 A.M.	Value in mm.-mgr.	Deflection at 11.30 A.M.	Value in mm.-mgr.
		mm.		mm.	
Kew	·00127	..	..	− 7	·00889
Vienna	·00051	+13	·0066	−25	·01275
St. Petersburg	·00029	+24	·00696	−55	·01595
Colaba	·00167	+ 3	·00501	− 5	·00835
Melbourne	·00066	+ 6	·00396	−12	·00792
Zi-ka-wei	·00025	+19	·00475	−43	·0108
Toronto	·00072	+ 7	·00504	+13	·00936

Thus the sudden changes of force at stations widely separated over the Earth's

surface do not differ very greatly from one another. A direct comparison of the several photographic records reduced to Greenwich mean time shows in a very marked manner that the character of a disturbance is the same over a very wide area of the Earth's surface, and that the different phases of the disturbances take place at the different stations at the same instant of time.

In the present paper a comparison is made of more recent magnetic disturbances in June, 1885, at ten other observatories in addition to the seven observatories whose records were previously compared.

Quite recently two additional sets of Kew magnetic self-recording instruments have been set up in the United States of America, at Washington and at Los Angeles, and the first Report from Washington, which has just been published and gives a record of work done in 1889, is very satisfactory, and should stimulate older magnetic observatories to bring their results into a state in which they will be more useful than at present and to publish them. It is satisfactory to find that the scale values adopted at Washington are nearly the same as the scale values which have been adopted at St. Petersburg, Vienna, Wilhelmshaven, Kew, and some other magnetic observatories. The importance of adopting as nearly as possible the same scale values for the similar instruments at different observatories cannot be too strongly enforced in the interest of the study of terrestrial magnetism.

An attempt has also been made to apply the Gaussian analysis to the simultaneous magnetic disturbances in order to discover the amount of change in the magnetic potential of the Earth, which would be sufficient to account for these sudden magnetic disturbances.

The large increase in the number of magnetic observatories with self-recording instruments seemed to warrant this attempt, but great difficulty has been experienced because we have scarcely yet arrived at the state foreshadowed by GAUSS fifty years ago, "when trustworthy and complete observations from all parts of the Earth shall be obtained."

For the complete solution of the problem, we should require records from Africa, from the continents of North and South America, and from Siberia, similar to those which are already obtained in Europe and Asia.

In order to obtain some fair approximation to the changes of magnetic potential, necessary to give rise to the magnetic disturbances, I have collected photographic records of the traces given by the self-recording instruments for June 24th and 25th, 1885, and for other more recent storms, from the observatories whose positions are given in Table II.

The following tables give (1) the positions of these observatories, (2) the absolute values of the magnetic elements, (3) the comparative scale-values of the self-recording instruments for June 24th, 1885, as far as it has been possible to arrive at them; (4) the values, in metric units, of certain magnetic disturbances. From these it will

be seen that the instruments of the same type at the different observatories still have very different degrees of sensitiveness.

In some cases the scale-values of the magnetic instruments have not been determined, especially in the case of vertical force instruments. Hence the number of stations to which GAUSS's method is applicable is very limited.

On June 24th, 1885, a magnetic storm began quite suddenly at 10.32 P.M., Greenwich mean time, in which there were several well-marked features.

At 3.48 A.M., on June 25th, there was a sudden and very great disturbance; at 10.20 A.M., there was another characteristic, but rather small disturbance, and a larger disturbance at 12.15 P.M. The storm continued until about 8 A.M., on June 26th.

The values of certain sudden changes in the magnetic elements and the comparative scale-values of the self-recording instruments are given in Table III., except in cases where they are too small, or where there are no means of determining them. From this table it will be seen that at several European stations the sudden change in the horizontal force, at the beginning of the storm, is nearly the same; also the change in the horizontal force at 3.48 A.M., on June 25th, is nearly the same in amount at European stations, and at Colaba and Batavia.

The disturbance at Toronto is very abnormal in all the magnetic elements, and far greater than at any other station.

In Plates 8, and 9, the curves have been carefully traced from the photographic records, and set to Greenwich mean time, and grouped so as to bring out prominently the common features from widely distant stations.

TABLE II.—Latitude, Longitude, and Values of the Magnetic Elements in Metric Units.

	Latitude.	Longitude.	Difference of time.	Declination.	Dip.	H.F.	V.F.	Total force.
	° ′	° ′ ″	h. m. s.	° ′	° ′			
St. Petersburg	59 52 N.	+ 30 29 0	2 1 57	0 35	70 45	1·64	4·65	4·97
Stonyhurst.	53 51 N.	− 2 28 15	−0 9 53	19 47 W.	69 13	1·70	4·48	4·79
Wilhelmshaven	53 32 N.	+ 8 8 48	0 32 35	12 46 W.	67 38	1·80	4·37	4·73
Utrecht.	52 5 N.	+ 5 7 48	0 20 31	18 48 W.	68 12	1·76	4·40	4·74
Kew	51 28 N.	− 0 18 45	−0 1 15	18 15 W.	67 36	1·81	4·39	4·75
Brussels	50 51 N.	+ 4 22 12	0 17 29	18 0 W.	67 0	1·82	4·29	4·66
Paris.	48 49 N.	+ 2 20 45	0 9 23	16 10 W.	65 17	1·94	4·21	4·64
Vienna	48 13 N.	+ 16 21 0	1 5 0	9 32 W.	63 23	2·06	4·13	4·60
Toronto.	43 40 N.	− 79 23 39	−5 17 35	3 41 W.	74 52	1·65	6·10	6·33
Coimbra	40 12 N.	− 8 23 15	−0 33 33	19 18 W.	60 27	2·22	3·92	4·50
Lisbon	38 43 N.	− 9 8 45	−0 36 35	18 46 W.	58 54	2·29	3·80	4·44
San Fernando	36 28 N.	− 6 12 24	−0 24 50	22 0 W.	59 0	2·287	3·806	4·44
Zi-ka-wei	31 12·5 N.	+121 26 15	8 5 45	2 9 W.	46 18	3·29	3·44	4·76
Colaba	18 54 N.	+ 72 48 56	4 51 16	− 0 56 E.	19 43	3·74	1·34	3·97
Batavia	− 6 11 S.	+106 49 55	7 7 20	− 1 51 E.	− 27 30 S.	3·67	1·91	4·14
Mauritius	− 20 6 S.	+ 57 33 9	3 50 13	10 33 W.	− 55 5 S.	1·584	2·802	4·24
Melbourne	− 37 50 S.	+144 58 42	9 39 55	8 0 E.	− 67 9 S.	2·36	5·45	6·03

TABLE III.—Scale Values and Changes in the Magnetic Elements in Metric Units, June 24 and 25, 1885.

	Scale values for 1 mm.			Changes on June 24 at 10.32 P.M.		Changes on June 25 at 3.48 A.M.		
	Declination.	H.F.	V.F.	H.F.	V.F.	Declination.	H.F.	V.F.
				mm.	mm.		mm.	mm.
St. Petersburg . .	0′·96	·000497	·000544	12 = ·00596		44′	30 = ·0149	3·5 = ·0019
Stonyhurst . . .	1·128	·0024 or ·0022	·0002	3·5 = ·0084 or ·0077	− 4 = ·0008	13·54	7·5 = ·0180 or ·0166	5 = ·0010
Wilhelmshaven . .	1·15	·0005	·0011	13·5 = ·00675	..	13·8	30 = ·0150	
Utrecht.	1·15	..	..	15·5 = ·0082	− 13·6 = ·0142	19·55	..	− 30 =*
Kew.	0·87	·0005	·0005	13·5 = ·00675	3 = ·0015	13·9	27 = ·0135	2 = ·0010
Brussels	1·1	..	..	3 =	2 =	..	6 =	7·5 =
Paris	1·39	·00093	·0008	7 = ·0065	2 = ·0016	..	13 = ·0121	3 = ·0024
Vienna	..	·00055 (?)	..	12 = ·0066	3 =	..	22 = ·0121	5 =
Toronto	1·279	·001083	·0011	11 = ·0119	3 = ·0033	53·72	43 = ·04657	43 = ·0473
Coimbra	1·13	·00079	·0007					
Lisbon	1·13	·00055	·000475	9·5 = ·00523	..	5·65	22 = ·0121	
San Fernando . .	1·146	·00041	..	7 = ·0029	3 =	3·43	17 = ·0070	5 =
Zi-ka-wei	0·63	..	..	6 =	..	..	18 =	
Colaba	2·9	·000514	·00127	7 = ·0036	..	..	22 = ·0113	
Batavia.	1·14	·000475	·000569	7 = ·0033	4·5 = ·00256	..	24 = ·0114	8 = ·00455
Mauritius	1·116	·0017	·000535	1·5 = ·0026				
Melbourne. . . .	1·14	·0015	·00138	2·5 = ·00375	..	13·68	15 = ·0225	12 = ·01656

* The change in V.F. depends on the change in H.F., which at 3.48 A.M. was not recorded.

With regard to the scale values in Table III., we may note that the values of H.F. and V.F. in metric units, for 1 mm. of height of scale, and the values of H.F. and V.F. in centimetre-gramme-second units for 1 cm. of height of scale, are expressed by the same number. Thus, in the Kew curves, the values of H.F. and V.F. in metric units for 1 mm. of height of scale is ·0005 unit, and the values of H.F. and V.F., for 1 cm. of height of scale is ·0005 in c.g.s units.

Hence, in comparing past measurements in metric units, with 1 mm. for unit of height, with measurements in c.g.s. units, taking 1 cm. as unit of height, there will be very little trouble, as the scale values in the two sets of units are expressed by the same number.

Hence, in future, it will be advisable for the sake of comparison, and, at the same time, more in accordance with the c.g.s. system of units, to state the scale values under the form, 1 cm. = ·0005 c.g.s. units.

On comparing the traces for H.F. from different observatories (see Plate 8) it will be seen that the trace from Stonyhurst shows what may at first be regarded as a very slight disturbance, and, at 3.48 A.M., the maximum disturbance appears to be comparatively small, but from Table III., it will be seen that the actual disturbance is as large, or even larger, than at any other station except Toronto.

There is every reason to suppose that the trace at Stonyhurst would have shown the individual features of the storm quite as well as the Colaba, or the Kew, or the Lisbon traces, if the scale value, ·0005, had then been in use instead of the scale value ·0022, and the measurements could then have been made with much greater accuracy. On the other hand, the vertical force magnetometer at Stonyhurst is very much more sensitive than that at any other station, and the trace is very similar in character to the St. Petersburg V.F. trace. At 3.48 A.M. there is very little disturbance at Kew, and a small disturbance in V.F. at Stonyhurst, viz., a fall of ·001 metric unit.

The V.F. trace for Batavia is placed near to the Stonyhurst trace in Plate 8, but, as is shown in Table III., the sudden fall in V.F. at Batavia, at 10.32 P.M., on the 24th, is nearly four times as great; and at 3.48 A.M., on the 25th, is more than four times the corresponding fall in V.F. at Stonyhurst.

As Batavia is south of the equator, a diminution of the vertical force means a change in the direction of the needle corresponding to an increase of dip of the pole pointing towards the north; hence, for comparison with stations in the northern hemisphere, the Batavia V.F. trace inverted is also given in Plate 8.

The disturbance in V.F. is very much smaller than the disturbance in H.F., at all stations except Toronto, Batavia, and Melbourne. At Utrecht, the disturbance in V.F. nearly resembles the disturbance in declination, and is much greater *apparently* than the V.F. disturbances at Wilhelmshaven, or at any other observatory in the north-west of Europe. Unfortunately, the photographic paper on which the traces are taken is too narrow, and so the H.F. trace passes off the paper during the

great magnetic disturbances, but there is a great resemblance between the traces given by the three Utrecht instruments. This resemblance is due to the fact that the horizontal and vertical force changes are given by means of deflecting magnets and iron induction bars according to LAMONT's plan; hence, the horizontal and vertical force needles are affected by changes in declination, and the vertical force trace is also affected by changes in horizontal force.

Thus the change in horizontal force in metric units

$$\delta X = \cdot 000376\,(p_1 - p),$$

where p_1 and p are the changes in ordinates of horizontal force and declination expressed in millimetres.

If δZ be the increase of vertical force, and p_2 the change in the ordinate of the vertical force in millimetres, then

$$\delta Z = \cdot 00326\,(p_2 - p) + \cdot 00172\,(p_1 - p).$$

Thus, at 10·32 P.M. on June 24, $p = -\ 6\cdot 4$ mm.,

$$p_1 = +\ 15\cdot 5 \text{ mm. and } p_2 = -\ 13\cdot 6 \text{ mm.}$$

Hence

$$\delta X = \cdot 000376\,(15\cdot 5 + 6\cdot 4) = \cdot 0082 \text{ metric unit},$$

and

$$\delta Z = \cdot 00326\,(-\ 13\cdot 6 + 6\cdot 4) + \cdot 00172\,(15\cdot 5 + 6\cdot 4) = \cdot 0142 \text{ metric unit.}$$

Plate 9 contains only traces of horizontal force for June 25, 1885, from mid-day until 8 P.M. From 2.10 P.M. there is a large and continuous well-marked period of disturbance, beginning with an increase of force varying from ·006 to ·01 metric unit, followed by a decrease of very nearly the same amount at 3 P.M.

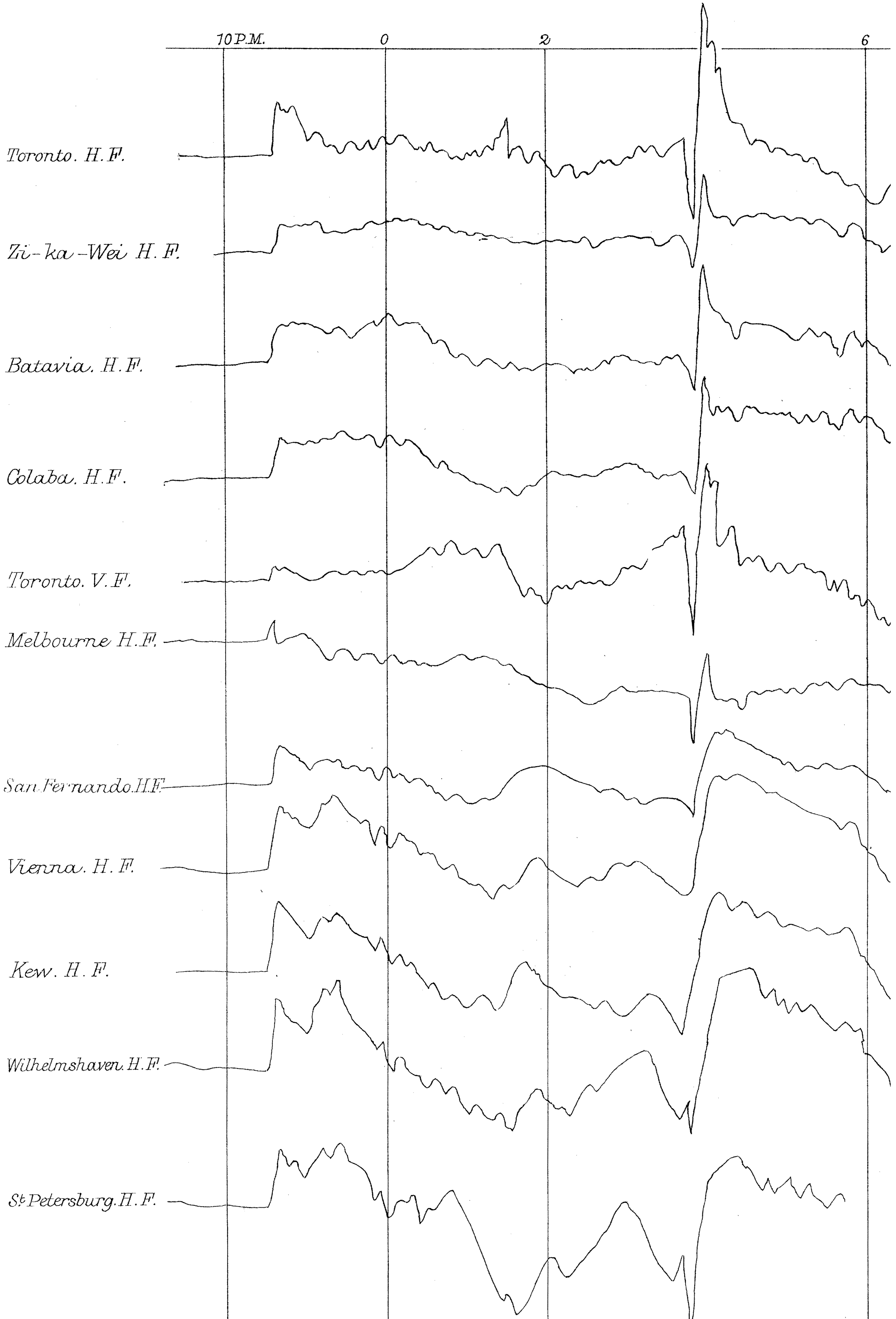
Another similar period of disturbance, well-marked at Melbourne, Batavia, and Bombay, as well as throughout Europe, occurs between 5.30 P.M. and 6.30 P.M. on the same day.

The values of these changes in metric units are given in Table IV.

TABLE IV.—Changes in Horizontal Force on June 25, 1885.

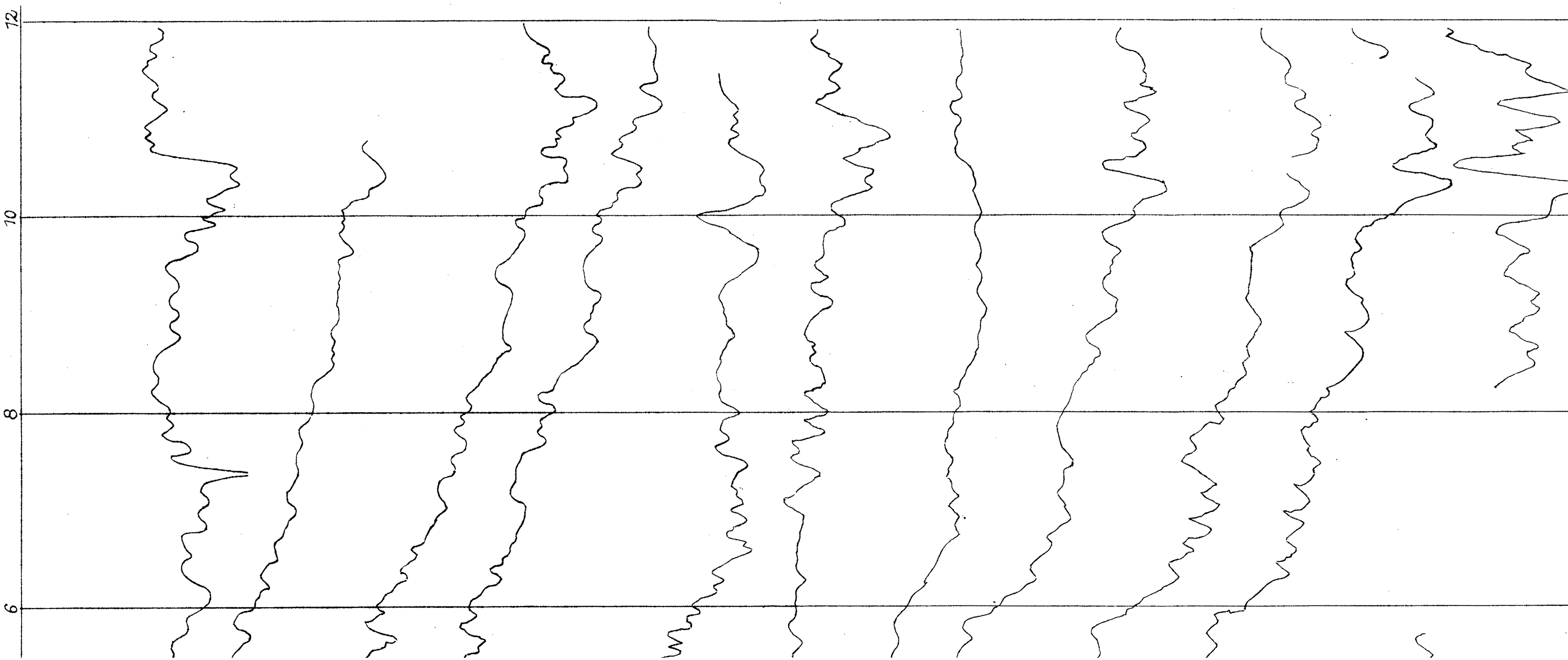
	At 2.10 P.M. (G.M.T.).	At 3 P.M.	At 5.10 P.M.	At 5.30 P.M.	At 6.20 P.M.
St. Petersburg	·0075	− ·0070	·0005	− ·008	− ·010
Stonyhurst	·0088	− ·0066	·011	− ·011	− ·009
Wilhelmshaven. . . .	·0090	− ·0075	·0062	− ·009	+ ·011
Utrecht	·0056	− ·0056	·0056	− ·003	− ·006
Kew	·0060	− ·0050	·0080	− ·008	− ·010
Vienna	·0055	− ·0050	·0033	− ·003	− ·005
Lisbon.	·0027	− ·0022	·0033	− ·002	− ·003
San Fernando	·0012	− ·0012	·0025	− ·001	− ·002
Colaba	·0015	− ·0015	·0010	. .	− ·001
Batavia	·0014	− ·0014	·0010	− ·001	− ·001
Melbourne	·0037	− ·0022	·0030	− ·003	− ·004

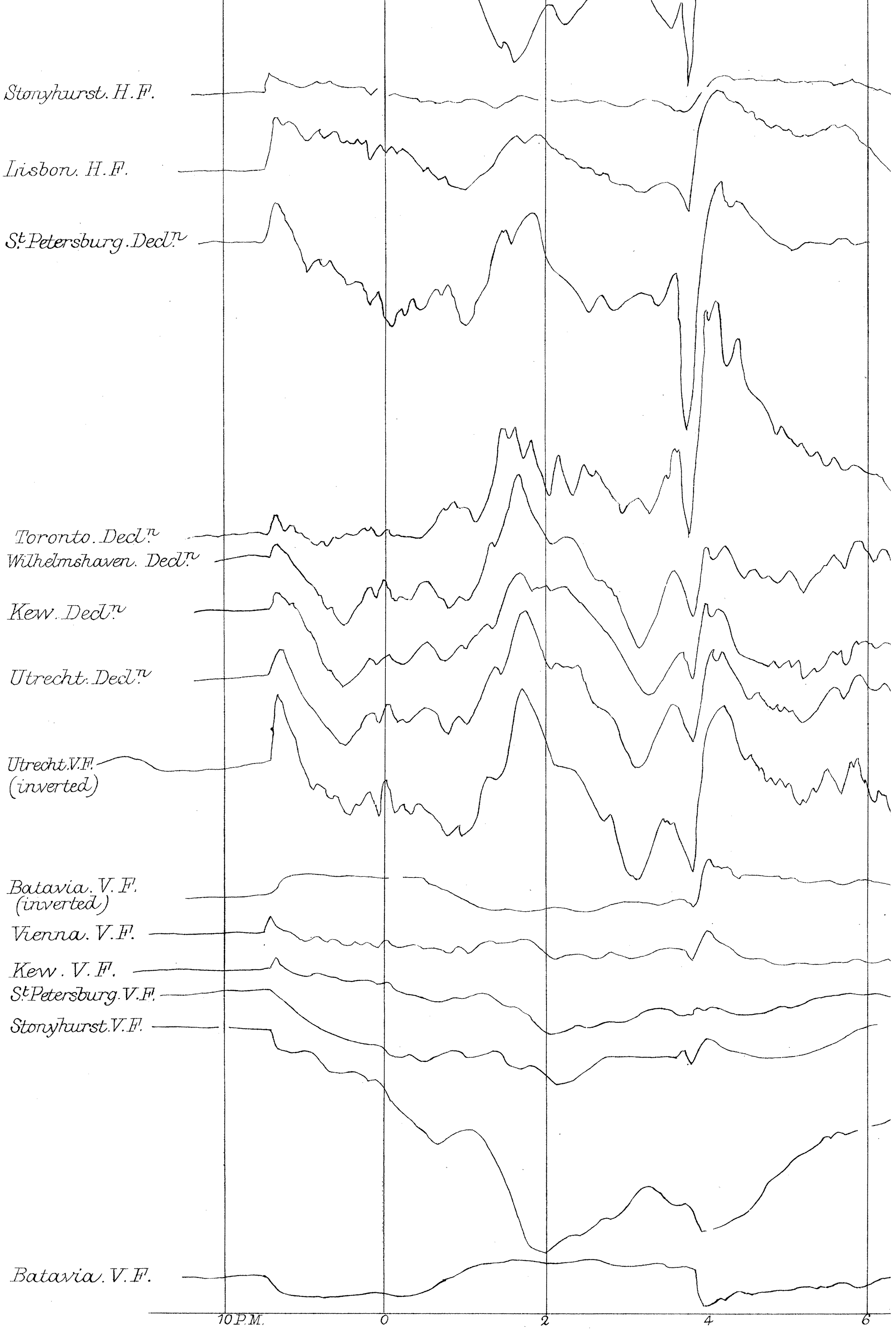
There is some little uncertainty as to the values at the four last stations in this table, because the measurements to be made are very small. This reduces the number of observatories at which the Gaussian analysis can be applied with advantage to too small a number to determine the Gaussian coefficients for this storm.



10 P.M.
0
2
6
Toronto. H.F.
Zi-ka-Wei H.F.
Batavia. H.F.
Colaba. H.F.
Toronto. V.F.
Melbourne H.F.
San Fernando H.F.
Vienna. H.F.
Kew. H.F.
Wilhelmshaven. H.F.
St Petersburg. H.F.

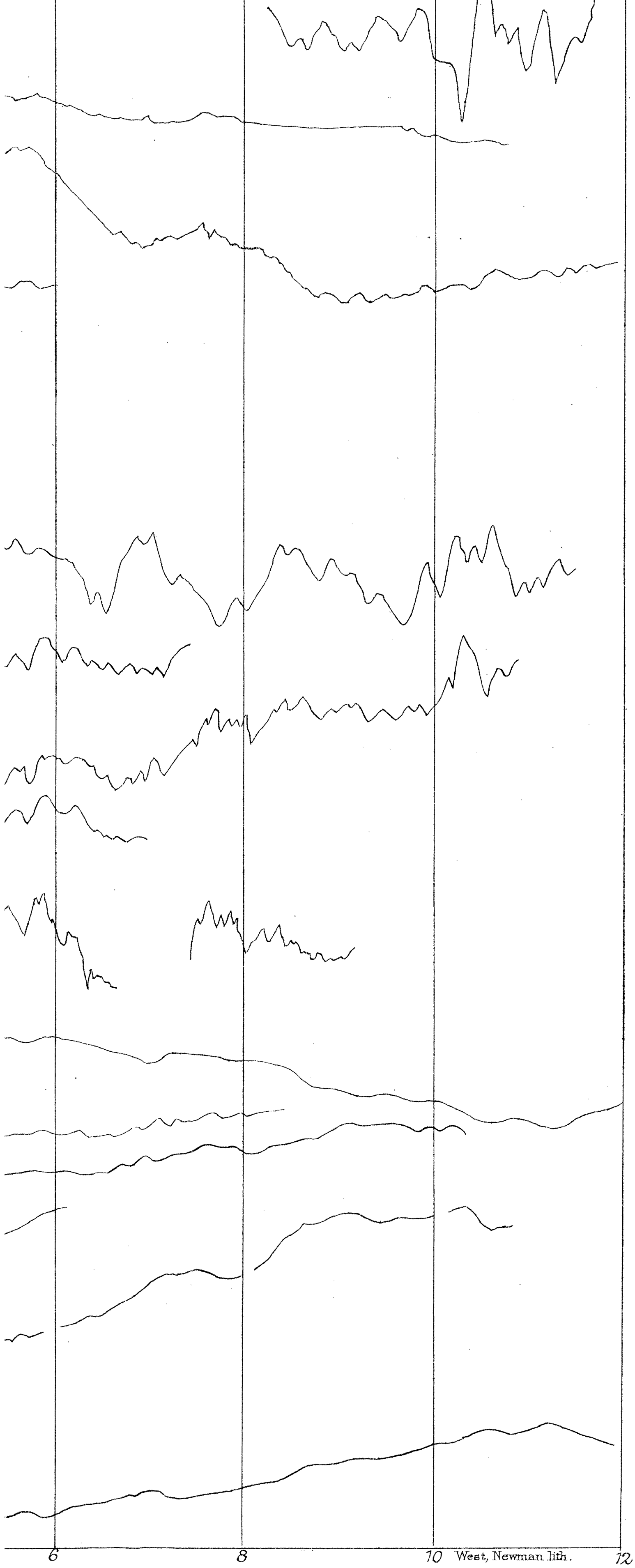
Adams.

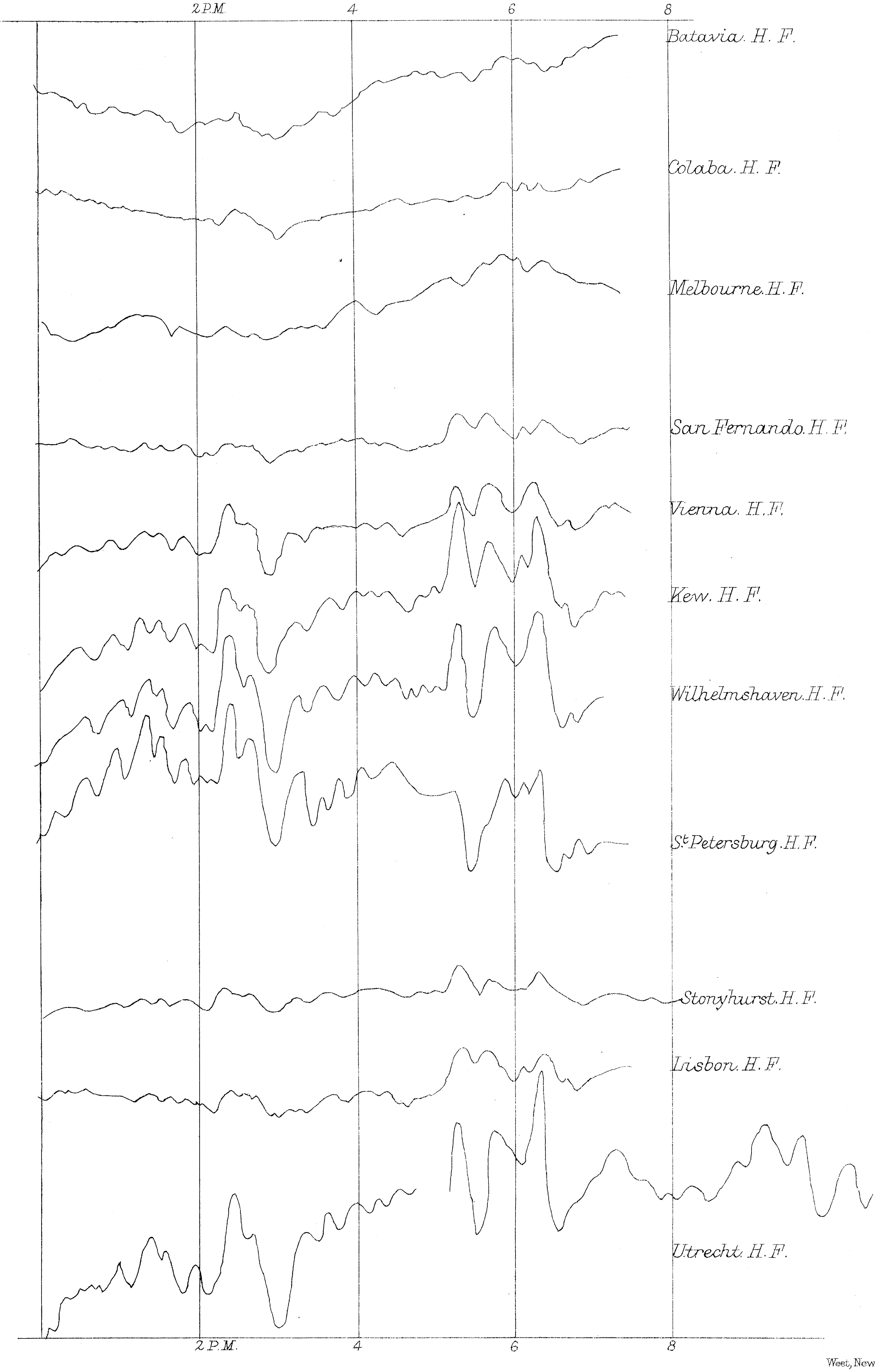




Stonyhurst. H.F.
Lisbon. H.F.
St Petersburg. Decl.n
Toronto. Decl.n
Wilhelmshaven. Decl.n
Kew. Decl.n
Utrecht. Decl.n
Utrecht. V.F. (inverted)
Batavia. V.F. (inverted)
Vienna. V.F.
Kew. V.F.
St Petersburg. V.F.
Stonyhurst. V.F.
Batavia. V.F.
10 P.M.
0
2
4
6

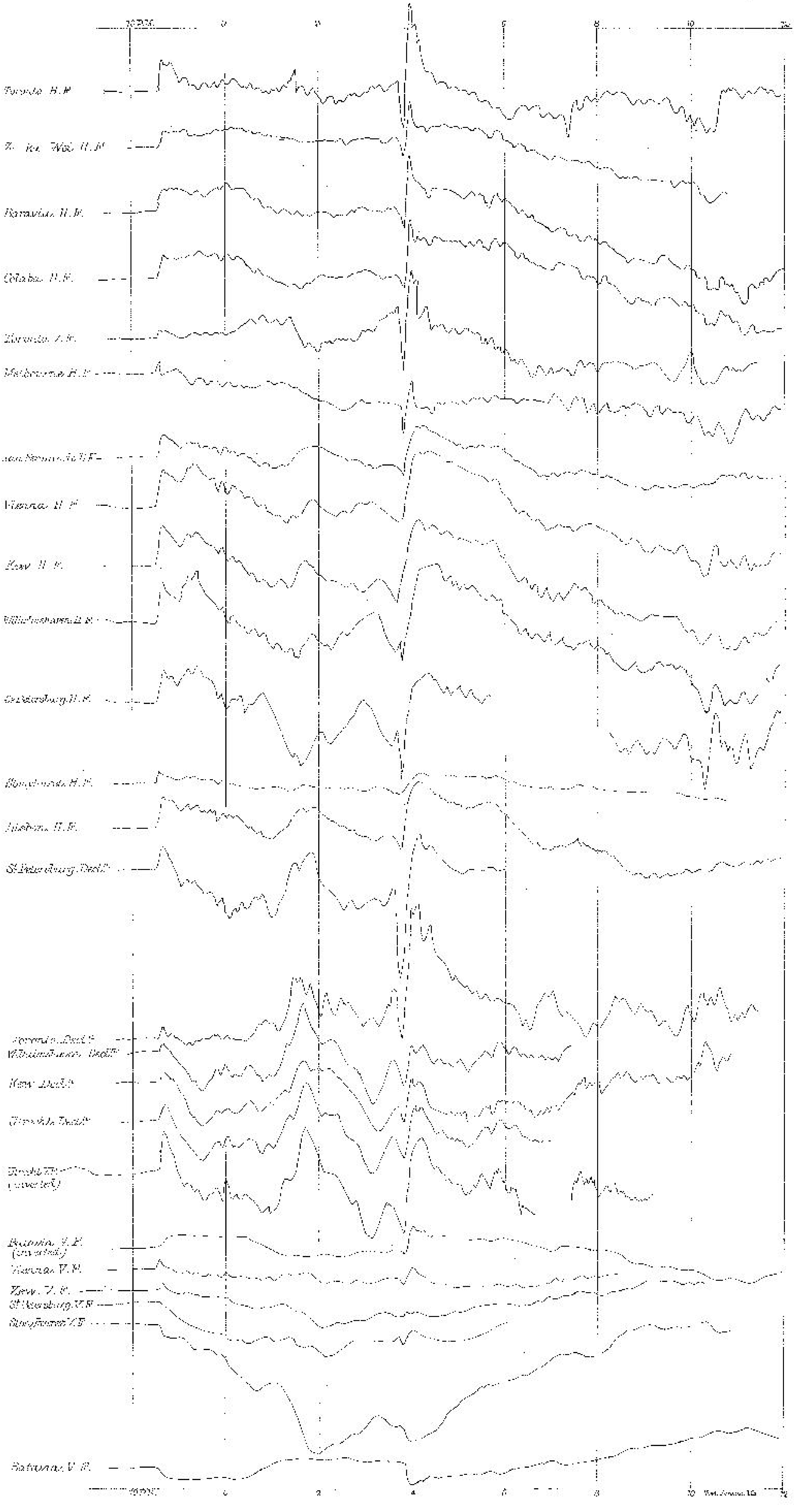
Phil. Trans. 1892. A. Plate 8.





West, Newman lith.

Adams.



Phil. Trans. 1892. A. Plate 8.