

XX. *Spectroscopic Observations of the Sun.**By J. NORMAN LOCKYER, F.R.S., and G. M. SEABROKE, F.R.A.S.*

Received February 2,—Read March 19, 1874.

WE have the honour to communicate to the Royal Society the accompanying Spectroscopic Observations of the Chromosphere and of the Sun generally, made during the period between the 1st October, 1872, and the 31st December, 1873.

The London observations have been made in Alexandra Road, Finchley Road, N.W.; the Rugby observations in the Temple Observatory at that place.

The following details are given of the instruments and methods of observation employed.

LONDON OBSERVATIONS.

A $6\frac{1}{4}$ -inch refracting telescope by COOKE, of York, mounted equatorially, was employed, to which is attached the 7-prism spectroscope by BROWNING, of London, already described. A position-circle, made by COOKE, of York, was used for obtaining the position-angle of the prominences and of the various details of the chromosphere.

On the side towards the spectroscope the circle is provided with a pinion, which, acting on a circular rack, causes the graduated half of the circle to rotate, the vernier being on the fixed half attached to the telescope-body.

On the 16th of September, 1873, the prisms spectroscope was replaced by a diffraction-grating of speculum-metal containing 6121 lines to the inch, made by Mr. L. M. RUTHERFURD, of New York, by whom it was generously placed at Mr. LOCKYER's disposal; the whole apparatus is only 15 inches in length, and weighs 3 lbs., while the 7-prism spectroscope, with its mounting, is 24 inches long, and weighs $10\frac{3}{4}$ lbs., the principal weight, moreover, being 18 inches from the end of the telescope. In dispersive power the 2nd order spectrum of the grating is equal to 7 prisms, while with equal dispersive power the grating gives much more light.

The positions of the prominences have been determined as follows:—

Standing with the back to the sun, and looking at the sun's image on the slit plate, the bottom of the image, being the image of the real North of the sun, is called North, the left-hand side of the image East, the right hand West, and the top South. The degrees are reckoned from North as zero through East to North again in the same direction as the hands of a watch, N., E., S., W. of the image on the plate being of course in the contrary direction to N., E., S., W. as seen directly on the sun. If,

MDCCCLXXV.

4 H

then, the ring of chromosphere, as seen on the slit plate, be cut at North or 0° and straightened, we obtain a line with N. or 0° on the left hand, and extending to the right from N. 0° through E. 90° , S. 180° , West 270° , to N. 360° .

The adjustments for recording the positions of various parts of the chromosphere as observed with either the radial or tangential slit having been made, the telescope is clamped in R.A., the clock set going, and the spectroscope focused for the C line.

Should a prominence be observed, the telescope is moved in R.A. or Declination, until it appears in the middle of the field of the spectroscope, and the position-circle is then moved until the slit is either tangential or radial to the part of the limb where the prominence appears; this is determined, in the case of the tangential slit, by the narrow strip of continuous spectrum which flashes in the moment the limb of the sun overlaps the slit exactly.

In the drawings executed in London, which accompany this paper, the positions of the prominences have been determined as follows, viz. the smaller ones, those from 2° to 3° wide, have had the central point of their base taken for the position, those wider than this have, in every case where possible, had the position-angle of each side determined, and very complicated groups have had, as far as possible, their principal components determined.

The height has been obtained by causing the slit to travel up the prominence, and estimating how many slits high above the limb it was—a process which is easy, as there are nearly always in the prominence details of structure which can be used as points for measurement.

The height of each prominence is set down in slits, and the width of the slit is measured at the end of the operation, and the true height in seconds calculated from the measurement.

The London observations and drawings have almost entirely been made by Mr. R. J. FRISWELL, Mr. LOCKYER's assistant, to whom great credit is due for the zealous and intelligent manner in which he has taken up this branch of the research.

RUGBY OBSERVATIONS.

The $8\frac{1}{4}$ -inch equatorial by ALVAN CLARK, to which is attached the ring-slit arrangement, producing a virtual eclipse of the sun, described by us before this Society in January 1873, has been used for these observations. The spectroscope attached is constructed on the return principle, giving a dispersion of 8 prisms of 60° . The position of the prominences has been determined as follows:—Arranged radially round the disk, which cuts off the light from the body of the sun, are fine platinum wires at a distance of 10° from each other, and these being seen together with the ring of chromosphere serve to fix the position of the prominences, the shape and position-angle of which can be then easily drawn. There are four wires crossing the annulus 90° from each other that are rather thicker than the others, and these are made to coincide with the N., S., E., and W. points of the sun respectively by causing the upper or lower

limb of the sun's image to traverse the disk, and then turning the instrument round until the limb exactly passes from one wire to the opposite one; then, on bringing the sun's image concentric with the disk, the left-hand wire, as seen by looking on the disk with the back to the sun, corresponds to the East side of the sun as looked at directly, and is therefore at the position of 90° , and the right-hand one corresponds to the W. of the sun 270° ; the lowest wire will then correspond to the North or 0° , and the upper to the South or 180° . The direction of reckoning the degrees is as usual N., E., S., W., or as looking directly at the sun in the contrary direction to the hands of a clock; but as looking on the disk with the back to the sun N., E., S., W. will be in the same way as the hands of a clock; and if the ring of chromosphere, as it would appear to an observer looking at it in the annulus with the back to the sun, be cut at N. or 0° and straightened, the appearance would be that shown in the drawings; although the annulus of chromosphere is looked at with the spectroscope from the opposite side to that of the sun, the image is half inverted by a diagonal reflecting prism in the telescope of the spectroscope, so that its appearance is the same as if looked at in the annulus from the same side as the sun. The width of the annulus through which the light from the chromosphere passes is such that a prominence $100''$ in height reaches across the annulus, so that the height of the prominences can be judged of with fair accuracy.

We have purposely refrained from any reduction of these observations, as we are of opinion that such reduction will be most usefully made when the observations of the Italian and other observers have been published, as it is hoped that the English and foreign observations may be in some cases so complementary of each other that long gaps may be avoided.

NOTES TO ACCOMPANY THE MAPS. (PLATES 59 TO 64.)

(LONDON OBSERVATIONS*.)

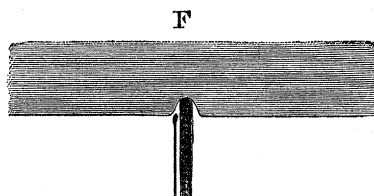
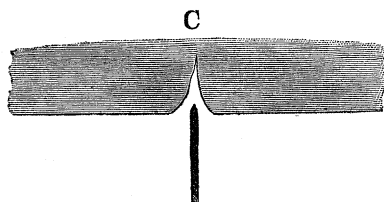
December 6th, 1872.—Chromosphere generally $10''$ high.

January 1st, 1873.—Chromosphere about the usual height, except 150° – 170° , where it was low.

March 8th, 1873.—Chromosphere very hair-like in its outline, about $12''$ high. Between 3.30 and 4.0 P.M. a large spot was observed between 240° and 250° , and close to the limb. Violent action was going on. C was intensely black over the spot, and, I think, slightly thickened; D was very thick, and bent towards the red. The magnesium lines did not seem to be affected; but the two lines of δ , $5166\cdot5$ $\left\{ \begin{array}{l} \text{Mg} \\ \text{Fe} \end{array} \right.$ and

* With these are included, in order of date, nine woodcuts of the more remarkable prominences, of the size of the original drawings, which were made, some at London by Mr. FRISWELL, some at Rugby by Mr. SEABROKE. The locality, date, and position-angle, which are given in each case, will enable the reader to find the places of these prominences in the Maps.

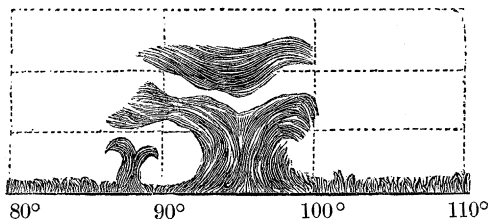
5168·5 $\left\{ \begin{array}{l} \text{Ni} \\ \text{Fe} \end{array} \right.$, violently bent towards the red. 4859·1 Fe intensely black and thick. F very black, and bent in all directions over the region between the spots on the limb; it was perhaps rather thickened, but I could not be certain of this.



C and F presented the above appearance on the limb near the spot. Once the bright part of F filled up the space between 4859·1 Fe and the dark F line. This was probably only half the bright part, but I did not see it on the other side.

Another spot was close to the one in question, a little to the N. and E. of it.

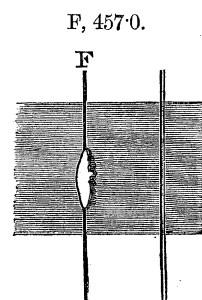
London.



March 8, 1873.

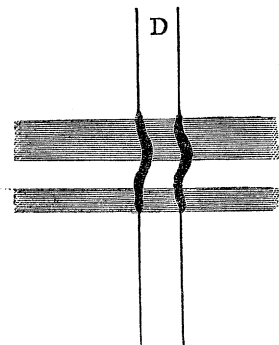
March 12th.—The bright line on the most refrangible side of b in the ordinary solar spectrum scarcely affected by the spot; b not thickened. C gone on the edge of the spot; F like this:—

March 17th.—A group of spots, probably those seen on the limb on the 8th and on the sun on the 12th; the magnesium lines were not thickened. D is very thick, and C very black; but it is doubtful if it is thickened. The continuous absorption of the spot on either side of C is very small.



March 24th.—The prominence at 230° changed a good deal in form and brilliancy. Two spots were seen, but no satisfactory observations were obtained. One of them seemed to give a continuous absorption only.

March 25th.—Chromosphere like the edge of a grass plot, about $15''$ high; a spot near N.E. limb. The following observations were made:—



Magnesium lines not much affected.

Calcium „ near D not much affected.

„ „ in red moderately thick, but certainly not in the same state of motion as the sodium; scarcely any, in fact.
Hydrogen thin and scarcely disturbed.

March 26th.—Chromosphere very hair-like, from 290° by 0° to 85° , except at 45° – 55° . At 20° the hairs inclined in all directions; at 290° inclined towards each other in two masses, one on each side of 290° ; at 65° sharp inclination to the prominence at 60° . The chromosphere was also hair-like at 110° – 130° , 135° – 150° , 215° – 245° .

March 27th.—The chromosphere about usual height, generally hairy.

March 28th.—From 90° to 180° no chromosphere seen, on account of mist and fog; from 180° by W. to 320° also misty, but observations made. Chromosphere hair-like in N.E. quadrant, and about $8''$ to $12''$ high.

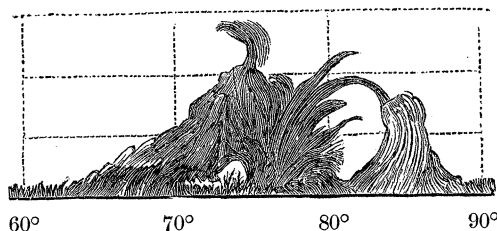
March 29th.—On a group of spots now in the centre of the disk the whole spectrum appeared full of narrow strips of absorption, as though the sun were mottled. The Ca lines enormously thickened on the left-hand spot, as seen in the spectroscope; D formed nearly one line, and b also appeared joined into one. Near F the absorption was so great and general that nothing could be seen.

April 1st.—Hairy chromosphere near 10° , 30° , 70° , 90° , and 210° , at which latter place the hairs were sharply inclined towards the prominence at 205° .

April 2nd.—The group of prominences between 210° and 225° changing considerably. Chromosphere generally low ($5''$?).

April 19th.—Chromosphere hairy, and inclined to S. at 180° – 190° and 270° – 280° , to N. at 240° – 250° , and straight up near 120° .

London.

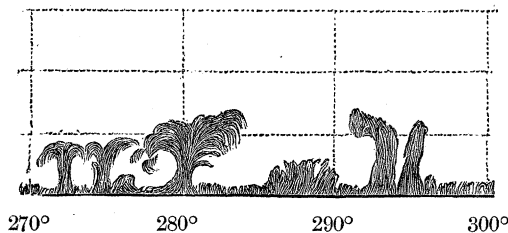


April 19, 1873.

April 21st.—Chromosphere very hairy, high, and hairs straight up at 35° to 85° .

May 1st.—Chromosphere generally hairy and rather low.

London.



May 2, 1873.

May 2nd and 9th.—Chromosphere rather low; on the 9th it was generally hairy, and the hairs straight up.

May 20th.—Chromosphere very low and regular, about $6''$ high; at $212\frac{1}{2}^\circ$ a prominence of honeycomb structure (the note says, "looks like a coarse sponge"); the two northern quadrants not observed on account of mist.

May 22nd.—Chromosphere low.

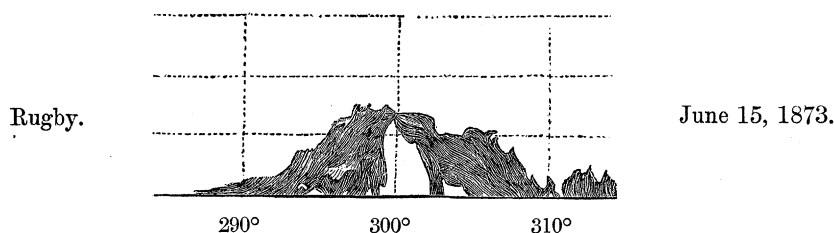
May 23rd.—Chromosphere about 10", inclined E. generally from 0° to 90°, and to E. at 105°–115°, 135°–145°, 155°–165°; straight up near 120°, 150°, 170°; a gap in it at 217°, and very low at 270°–275°.

May 24th.—Chromosphere very low at 330°–10°, and sharply inclined to the W. at from 225°–240°.

May 31st.—Chromosphere 10"–12" high at 220°; sharply inclined to prominence at 231°, and very hairy at 236°, so low as scarcely to be seen.

June 7th.—A spot observed. Calcium lines between C and D very thick; D and *b* very slightly or not at all affected.

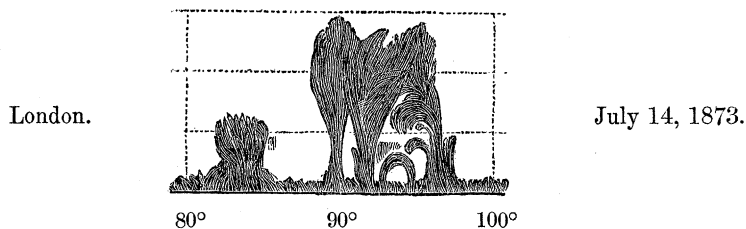
Chromosphere undecided in character.



June 27th.—Chromosphere about 8".

July 7th.—Chromosphere about 10".

July 14th.—Chromosphere about 9", undecided in character.



July 16th.—Chromosphere 8"–12" high, hairy in S.E. quadrant, and inclined to the W.; high from 130°–140°; measured 12" here at 110°; a jet overlapped the limb, but the prominence changed its form and it soon went off.

Much mist during observations of the two south quadrants.

July 21st.—180°, thin, very active, vertical hairs; 186°, the same; 190°, hairs increasing; 195°, chromosphere quieter; 200°, the same; 205°, vertical hairs; 210°, fuzzy; 215°, one hair longer than the rest; 220°, masses here and there; 225°, the same; 230°, fuzzy; 235°, more massive; 240°, nothing particular; 245°, chromosphere low; 250°, very low, not hairy; 255°, very faint.

July 22nd.—180°–185°, hairy, but massive; 195°–205°, tongues; 215°–225°, hairy, massive; 225°–235°, lumpy and low; a long cloud here connected with chromosphere by a very faint filament; 25°–35°, very spiky; 275°–295°, lumpy and very bright.

July 23rd.—175°–205°, spiky, and spikes inclined to S.; 205°–215°, very hairy, hairs straight up; 215°–225°, hairs inclined to S.; 225°–235°, same inclination, more

decided. In the N.W. quadrant the chromosphere lumpy, except near 0, where it is spiky.

July 24th.—S.W. quadrant, the chromosphere covered with fluffy hairs; in the N.E. quadrant it is very spiky.

July 25th.—Only the N.E. quadrant was observed, on account of the bad light; 0° – 10° , spiky; 25° – 35° , spiky; 40° – 50° , lumpy, with hairs all turned to N.; 50° – 60° , lumpy and low; 80° – 90° , low and bright.

July 26th.—From 40° – 90° , hairs inclined to S.; from 30° – 40° , very sharply inclined S., the chromosphere very hairy; N.W. quadrant, all the hairs inclined W., and high near 350° ; S.E. quadrant, hairs to E., jets or splashes cover 3° at 110° ; S.W. quadrant, spikes inclined to S., very decidedly at 190° .

July 28th.—Only the N.W. and N.E. quadrants were observed. In the former the chromosphere was hairy, and the hairs inclined to N. slightly, except at 330° , where they were divergent. In the N.E. quadrant the hairs were generally straight up from 90° to 20° , where they were slightly inclined to W. From 10° to 0° they were straight again.

There was a large spot nearly in the centre of the disk; the C, D, *b* lines and the chromium lines near *b* were not affected; the iron lines 5190.5, 5191.7, 5226.0, and 5232.0 scarcely, if at all, affected. The Ca lines near D were slightly thicker. The spot is rather faint; and as the general darkening of the spectrum is considerable and the selective absorption almost *nil*, a cooling only would seem to be indicated.

July 30th.—In the S.W. quadrant from 262° to 270° the chromosphere or a long low prominence was $25''$ high; at 310° to 316° there was another prominence, a portion of which (about 310° to 313° or 314°) was like a coarse sponge in texture.

July 31st.—The chromosphere as a rule is low, bright, and lumpy at from 120° to 140° ; there were indications of an inclination towards a prominence at 140° ; at from 308° to 320° there was a smoky appearance and a slight inclination to the W.

August 7th.—The chromosphere lumpy and low from 150° to 190° ; from 105° to 115° there was a very sharp inclination to E. In the S.W. quadrant it was generally lumpy and any hairs straight up; in the N.E. it inclined slightly to N., and was also lumpy. There was a spot close to the base of the prominence at 309° .

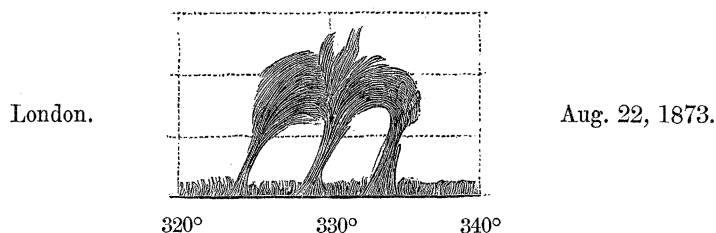
August 8th.—From 90° to 70° lumpy with straight hairs; at 48° a very low gap with a spike in the middle of it; there was scarcely a trace of chromosphere in the gap for 1° or 2° . From 70° to 30° the chromosphere was fummy or smoky, with hairs in the fume; at 23° it was very low again. From 20° to 10° it was fummy, but contained well-developed hairs. In the N.W. quadrant it was spiky, and high at 350° to 340° ; 340° to 330° fummy; at 320° it was denser, and exhibited a slight inclination of its details to N. In the S.W. quadrant the chromosphere was fummy with spikes, which latter were well developed at 182° .

August 9th.—The chromosphere had generally a peculiar look, as though it was

viscous and had been drawn out into spikes. From 110° to 180° it was fummy; from 90° to 105° there was an inclination towards E. In the N.E. quadrant it was of both characters (spiky and fummy), and the spikes were straight up. In the N.W. it was fummy; in the N.W. hairy from 270° to 340° , and from 340° to 0° rather fummy.

August 13th.—Observations at 5.20 to 6 P.M., when lowness of sun stopped them; S.W. and N.W. with part of S.E. observed the chromosphere moderately spiky, but its inclination indeterminate except at from 230° to 250° .

August 16th.— 90° to 115° spikes inclined E. 45° ; 115° to 180° lumpy; spikes straight at 120° to 130° to E. at 135° . In the N.E. the chromosphere was fummy and high, with hairs in the fume; the same in the S.E. from 300° to 0° ; from 285° to 295° the chromosphere and a prominence had a spotted or mottled appearance; about 275° spiky.



September 16th.—S.E. chromosphere hairy, with a slight inclination to the E., S.W.; and N.E., N.W. smoky with indistinct hairs.

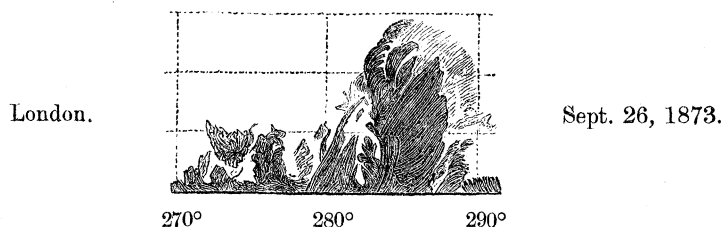
September 22nd.—The chromosphere was generally smoky in appearance; at 154° there was an exceedingly faint high prominence scarcely visible; its height appeared to be $1' 33''$.

September 23rd.—No particular details observable in chromosphere except at 115° , where it was lumpy; 253° , about, where it seemed composed of small flames; 307° , high and smoky. On the W. side of the large prominence at 327° to 330° the chromosphere for 4° or 5° (222° to 227°) was hairy, and turned towards the prominence.

September 24th.—Chromosphere in S.E. and S.W. smoky and covered with irregular tongues, not hairs. A spot was observed in which the C line was distorted and not thickened; D distorted and thickened; Ca lines much thickened, but not much distorted. When the C line was distorted D was still, and *vice versa*. *b* was distorted but not thickened. A prominence at 304° was undergoing considerable change.

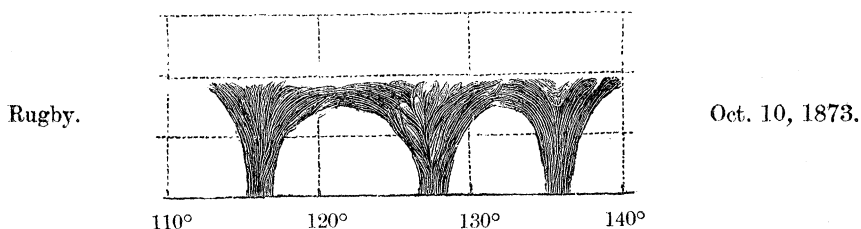
September 25th.—No particular features in the chromosphere in the S.E. and N.E. It was high round 270° . From 315° to 325° the chromosphere was high and covered with tongues, some $24''$ high.

September 26th.—A brilliant point at 109° at 2.15 P.M.; at 3.15 P.M. not a trace of it. In the N.W. the chromosphere was fummy with a spiky edge; from 290° to 300° it was $15''$ to $20''$ high in the whole quadrant, and up to about 20° in the N.E. quadrant it was inclined in the same direction, *i. e.* to E. down to 0° , and to S. from 0° to 20° . The C line was seen broken over a spot.



September 27th.—S.E. chromosphere smoky and covered with tongues; S.W. 180° to 200° fummy; 230° to 240° fummy, spikes inclined to E.; 250° to 260° chromosphere 20" high, spikes 30". For 1° or 2° it was very low at 262°, and from 262° to 275° higher, and inclined to prominences at 280° &c.

October 2nd.—S.E. and S.W. light very bad and chromoscope indistinct, but it appeared to be smoky; the same in N.E. In the N.W. the chromosphere hairy and about 16" high.



October 15th.—Chromosphere generally 12", near 100° low (8"), and at 115° sharply inclined to N.; at 145° it appeared to be squirting in all directions, as though from a hole; from 170° to 190° solid and spiky, very high and covered with tongues all through the S.W. quadrant; in the N.W. generally fummy, but more hairy in the eastern part; in the N.E. lumpy from 80° to 90°, a tuft of hairs 16" high and inclined to N. at 59°. A spot in this quadrant in which D, b, and the Ca lines are thick, but C unaltered.

October 17th.—Chromosphere very level and low (8"), but light very bad.

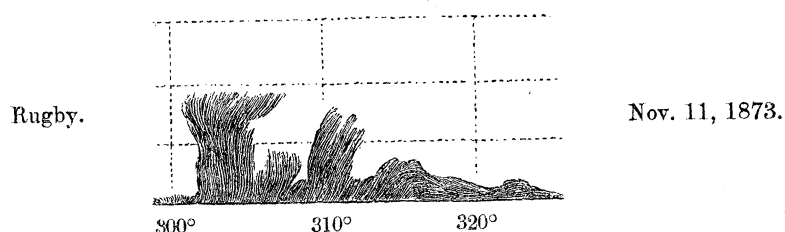
October 28th.—S.E. and S.W. lumpy and billowy with tongues; N.E. and N.W. rather more hairy.

October 30th.—Chromosphere about 8"; high, billowy, and smoky in N.E., S.E., and S.W.; in N.W. the same, with a direction to W.?

November 1st.—No details observed; observation unsatisfactory.

November 3rd.—Only the S.E. quadrant observed; chromosphere about 16".

November 11th.—S.W., N.W., and N.E. the chromosphere smoky with hairs; at 136° a prominence nearly separated from the chromosphere, which was fummy.



November 12th.—S.E. chromosphere billowy; S.W. 200° to 220° fumy, direction W.; 250° to 254° very high, fumy chromosphere; 260° to 270° direction S.; N.W. about 280° low and bright, direction N.; at 290° to 300° straight up; about 340° fumy and flamy, with a W. direction; about 0° fumy tongues with a W. direction.

November 15th.—S.E. fumy, a few spikes straight; at 95° very billowy; about 140° S.W. fumy and billowy; N.W. sharp inclination to N. at 280° to 290° , and hairy at that part; elsewhere fumy.

December 9th.—Chromosphere rather spiky near 160° ; from 185° to 210° fluffy; round 213° hairy hairs straight, remainder of the quadrant billowy; round 270° very brilliant; D_3 is very brilliant here between 265° and 272° in the lower parts of the chromosphere.

December 12th.—From 220° round by 0° to 90° light too bad for observation; rest of chromosphere regular.

December 17th.—From 58° to 90° hairs have a slight tendency towards 90° . Rest of chromosphere fumy, with a few tongues or billows.

December 29th.—Chromosphere near 20° hairy, then rather level; at 160° spiky, and inclined both to E. and S.; at 200° tongues, 215° hairy, which continues to 240° . Prominences at 241° and 244° are like wreaths of smoke; 315° to 360° tongues inclined towards W.

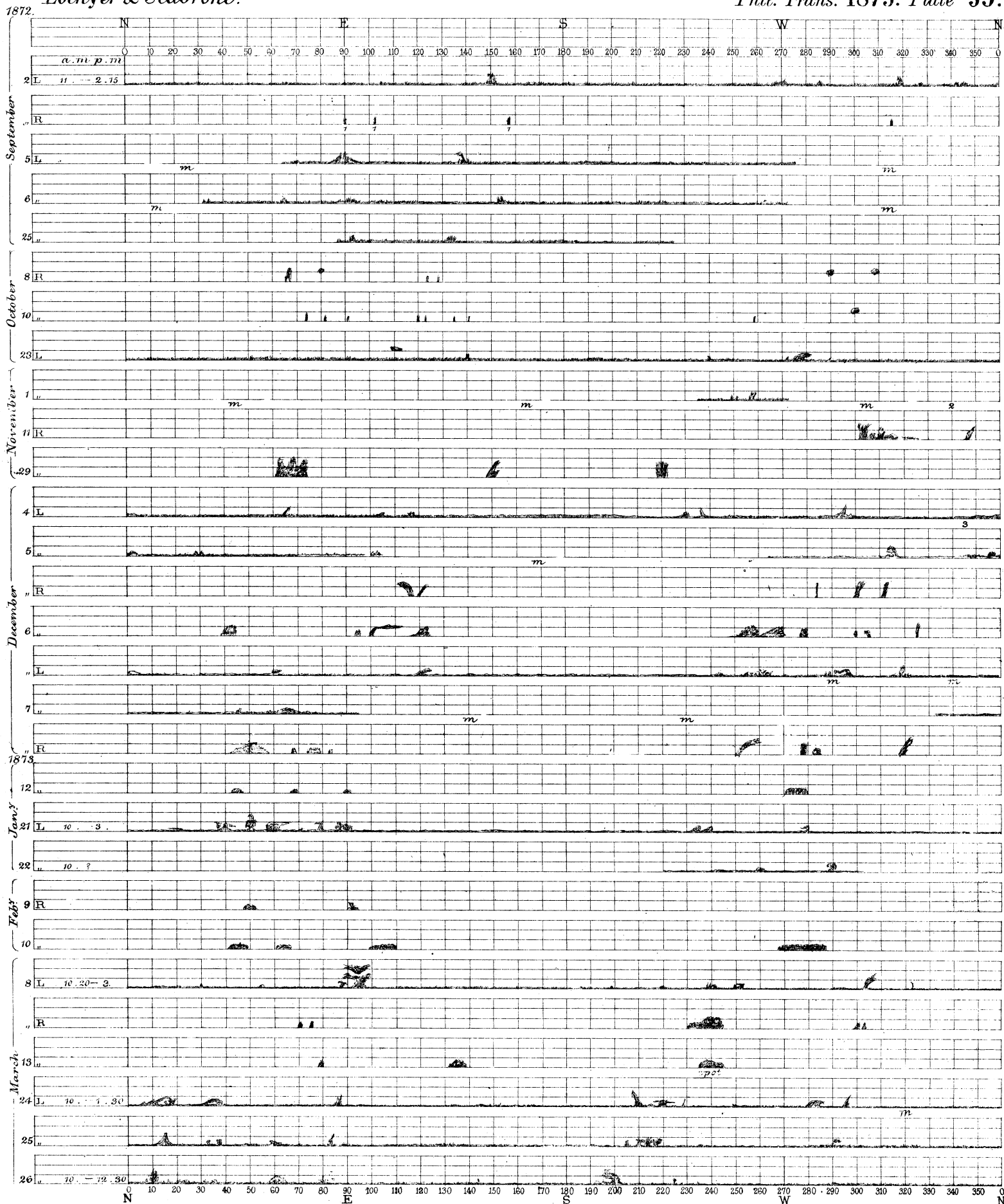
December 30th.—From 90° round by 0° to 160° light too bad for observation; 90° to 160° chromosphere level; higher at 120° to 130° .

December 31st.— 0° to 90° light not good; high at 85° ; very faint cloud at 132° ; at 1.55 P.M. great changes going on in the group of prominences between 252° and 265° ; chromosphere generally level.

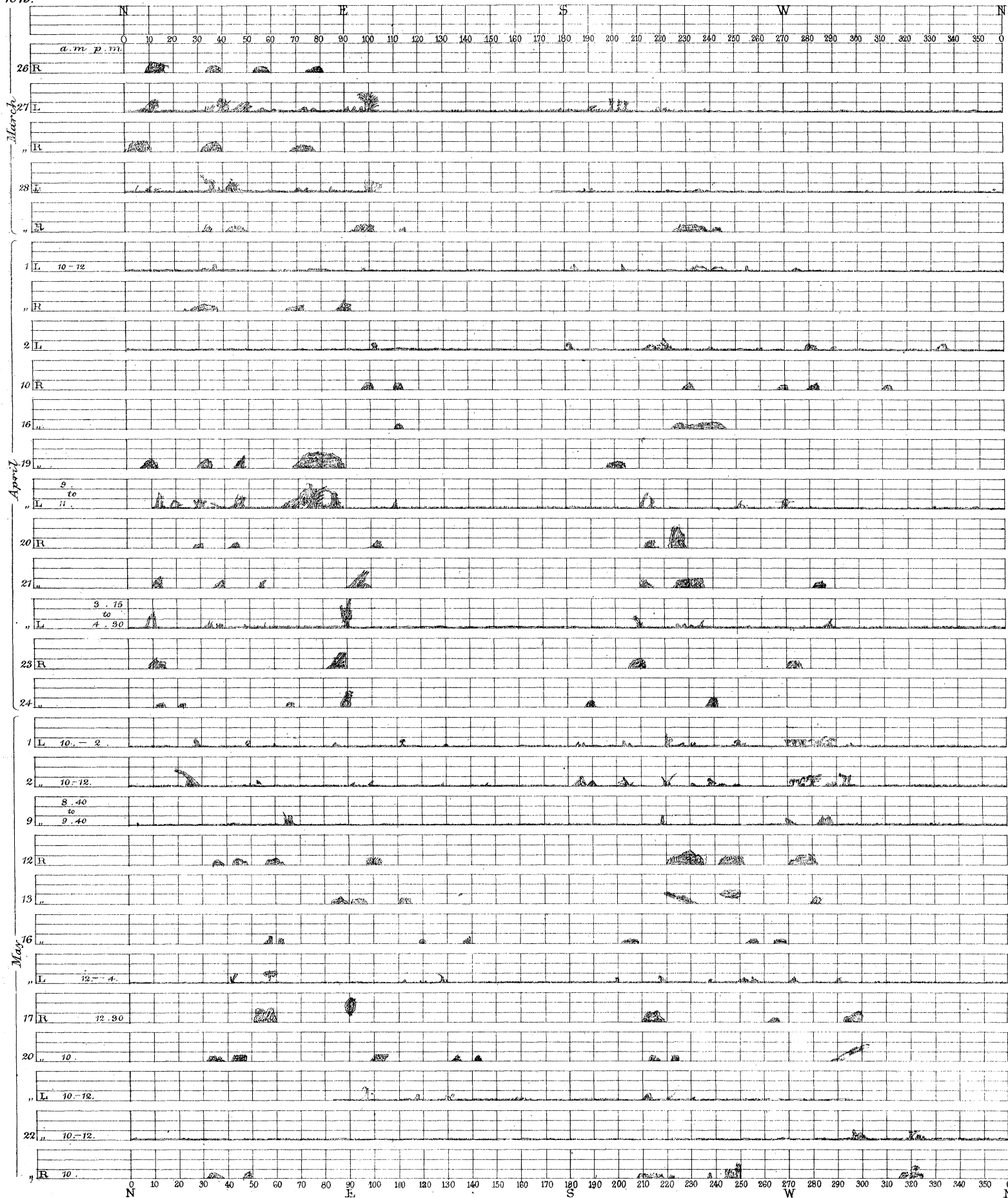
Spots were observed on the 23rd and 29th. On the 23rd D and the Ca lines near it slightly thickened, and D a little distorted, C and b not affected. Absorption general rather than selective. On the 29th general absorption again characteristic, C, D, b not affected.

It has been noted at Rugby that all the cyclones observed from the beginning of 1872 have, with one exception, had a motion of rotation, direct when in the northern hemisphere, and indirect when in the southern, corresponding, therefore, to our terrestrial cyclones.

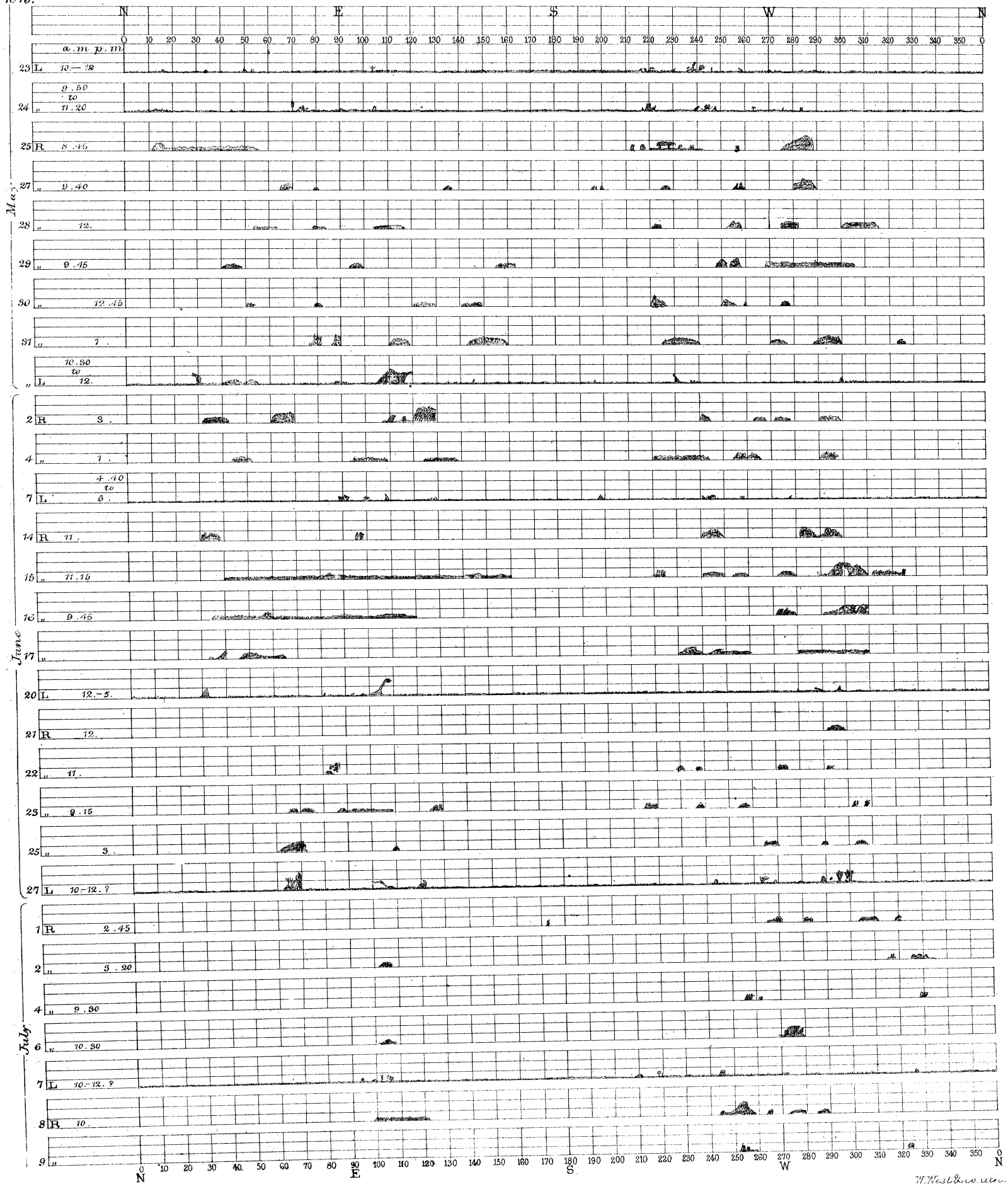
In the Plates accompanying this paper the horizontal lines represent each one minute.



1873.



1873.



1873.

Lockyer & Seabroke.

Phil. Trans. 1875. Plate 62.

