THE

TOTAL SOLAR ECLIPSE,

JANUARY 22ND, 1898.

(1)

REPORT ON THE OBSERVATIONS AT DUMRAON

BY

T. A. POPE, Esq.,
ASSISTANT SURVEYOR GENERAL.

(2)

REPORT ON THE OBSERVATIONS AT PULGAON

BY

CAPTAIN G. P. LENOX CONYNGHAM, R.E.,
DEPUTY SUPERINTENDENT, SURVEY OF INDIA.

(3)

REPORT ON THE OBSERVATIONS AT SAHDOL

BY

MAJOR S. G. BURRARD, R.E.,
SUPERINTENDENT, SURVEY OF INDIA.

PUBLISHED UNDER THE DIRECTION OF

MAJOR-GENERAL C. STRAHAN, R.E.,
SURVEYOR GENERAL OF INDIA.

Dehra Dun:
PRINTED AT THE TRIGONOMETRICAL BRANCH OFFICE, SURVEY OF INDIA.

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THE TOTAL SOLAR ECLIPSE,

AS PHOTOGRAPHED BY THE SURVEY OF INDIA DETACHMENT, AT DUMRAON, ON JANUARY 22ND, 1898.

(Enlarged to three diameters).

REPORT

ON THE

TOTAL SOLAR ECLIPSE OF JANUARY 22ND, 1898.

ON the 17th February 1897, the Surveyor General of India addressed the Astronomer Royal enquiring in what way the Survey Department could assist in observing the total eclipse of the sun which was to take place in India on the 22nd January 1898, and offering, subject to the approval of the Government of India, the services of skilled observers and the use of certain instruments belonging to the Department which had been employed in observing previous total eclipses. Among the latter was mentioned an equatorially-mounted camera which had been used to obtain photographs of the corona at the total eclipses occuring in 1871 and 1875, and which only required a driving clock to be again made serviceable. In due course a reply was received from Captain E. H. Hills, R.E., Secretary to the Joint Permanent Eclipse Committee of the Royal Society and the Royal Astronomical Society, in the last paragraph of which he wrote as follows :—

"With reference to the instruments which you have mentioned as being available, we do not see our way to utilising any of them, as we have already as many instruments as the observers can employ to advantage. It would, however, be extremely desirable that an attempt to photograph the corona should be made at a point on the more northerly portion of the line, say near Patna, and if you could arrange so to utilize the equatorially-mounted camera that you mention, it would be of distinct advantage to science. Should you see your way to doing this, we should be happy to send you suggestions as to how the instrument might be employed to the best advantage." The Surveyor General thereupon directed me to examine the camera and ascertain what would be required to put it in thorough working order. Later on I received instructions to organize a small party from the Photographic and Lithographic Office to proceed to Bihar in January to obtain photographs of the corona with the instrument in question.

2. The equatorial camera had been used on the occasions of two previous total solar eclipses. It was purchased originally by the Government of India for the purpose of photographing the corona at the eclipse of 1871, at Dodabetta, on the Nilgiris, and was employed by Mr. Hennessey and Captain (now Colonel) Waterhouse with success on that occasion, when wet collodion plates were used. It was again employed for the same purpose by the party under Captain Waterhouse which proceeded to Camorta, in the Nicobars, to photograph the eclipse of April 6th, 1875, when, however, the operations were unfortunately unsuccessful owing to bad weather. On examination of the instrument it was found to be in fairly good order, only requiring to have a driving clock adjusted to it (the clocks previously used having been received on loan and returned), and certain additions made to facilitate its adjustment in the meridian. A suitable driving clock was procured from the Trigonometrical Branch Office, Dehra Dun, where a spare one, used for driving the large photo-heliograph, was fortunately available, and it was found to answer its purpose admirably. The work of fitting up the camera and adjusting and rating the clock was entrusted to Mr. T. R. Theakston, of the Mathematical Instrument Office, by whom also a telescope and striding level were attached to its polar axis, to enable it to be adjusted with accuracy in any latitude, and a small telescopic finder was added. The lens used on the two previous occasions was no longer available; but among the lenses in use in the Photographic Office was a precisely similar one, which was found to fit the camera exactly. It is a large doublet by Dallmeyer, with a working aperture of three inches and a focal length of about thirty inches, and it gives an image of the sun about five-sixteenths of an inch in diameter. The lens had a rack and pinion adjustment for focussing, but as a similar arrangement for focussing existed at the camera end of the instrument it was thought better to fix the focus of the lens by clamping a brass ring around it. The dark slides previously used were still available. They consisted of six single mahogany slides, made originally for wet plates, and as this number was insufficient I had six more exactly similar ones made up by our own carpenters. Each slide had a spring screwed into the inner edge on the right hand side, in order that all the plates might be pushed firmly against the left

edge of the slide and thus receive the image of the moon in exactly the same relative position upon each. At one time the idea was entertained of constructing two or three slides made to hold four plates each, so that after each exposure a fresh plate could at once be slid in front of the lens, and the loss of valuable time in changing plates thus obviated. But as I was advised that a comparatively small number of fairly long exposures would be most likely to give successful results, I abandoned this intention and adhered to the old single slides, which I found with constant practice could be easily removed, changed, and opened in the space of three seconds.

3. The instrument, when put in thorough working order, was removed from the Mathematical Instrument Office to the upper verandah of the Photographic and Lithographic Office in September 1897, and thereafter frequent rehearsals were held and many photographs taken of the moon and stars, in order to ascertain that the clock maintained its rate of working, to obtain the correct solar focus, and to familiarize the observers with their parts in the eclipse programme. As I had had no previous experience of eclipse photography, and required information as to the exposures to be given, speed of plates to be used, and various other minor details, I placed myself in communication with Captain Hills, sending him a photograph of the instrument and all necessary particulars regarding the lens, &c., together with my own somewhat crude ideas on the subject, and asked for his advice. To this Captain Hills most kindly sent me the following reply, dated October 8th, 1897 :—

"In reply to yours of September 14th, enquiring details as to the photography of the solar corona, I have much pleasure in giving you the following information :—

"(i).—The equatorially-mounted camera, of which you send me the photograph, appears to be a well designed instrument, and one with which you are likely to obtain valuable results.

"(ii).—As the instrument is apparently not provided with graduated circles for the purpose of adjustment, the following procedure should be adopted :—The camera should be removed and a small theodolite temporarily fixed in its place at the end of the polar axis, the horizontal plate of the theodolite being fixed central and perpendicular to the polar axis. The telescope of this theodolite can be regarded as an equatorial, the horizontal arc being the hour circle, and the vertical arc the declination circle. The whole instrument can then be adjusted in the usual way, *vide* Chauvenet, Vol. II, page 379, *et seq.* There is, however, a simpler method for the adjustment of an equatorial in the field described in Monthly Notices, R. A. S., Vol. LVII, page 102, 1897 January. The instrument should be adjusted with a limiting error of about three minutes of arc.

"(iii).—The number of plates that you propose to use is too great. Seven will be found ample. Make them in the following order :—

"2 5 15 10 20 5 2 seconds.

"The sum of these is 59 seconds. Changing slides should not take more than 6 seconds each, or 36 seconds in all, leaving 5 seconds spare. There is no particular object in using more than one sort of plate. The best that you can use are 'Ilford Empress' or, failing these, 'Ilford Special Rapid,' developed either with pyro soda or eikonogen.

"(iv).—It is necessary that the orientation of the plate should be determined with approximate accuracy. This may be done in a variety of ways. The camera should be clamped up in the same position as it will occupy at the eclipse, and a series of images of the sun taken with a pinhole aperture on the day before the eclipse. Or a set of star-trails may be taken across the plate. Perhaps on the whole the best method to adopt is to clamp up the camera immediately after the eclipse and leave it untouched till night, when a fresh plate can be put in and exposed to stars for an hour or so, thus getting a series of trails across the plate. A similar star plate had also better be taken on the night before in case of cloud on the following night. In order that the measurements on different plates may be comparable they should be in exactly the same position on the slide. Say for instance that the south and west edges of the plates are always placed tight against the side of the slide. The slides will not, of course, be absolutely identical, and the orientation plate should therefore be taken in one of the same slides as are used for the eclipse.

"(v).—All the plates should be backed. This is best done with a solution of asphalt in benzole, which can be partially scraped off before development.

"(vi).—It is very essential that the camera should be focussed with critical accuracy. Two methods are available.

"(*a*). By photographing star-trails. This is quite satisfactory, but of course dependent on weather.

"(*b*). By reflexion. Arrange a slide with half a plate in position and in the other half of the slide make a small aperture filled with a piece of wire gauze which is in the plane of the sensitive surface of the plate. Place the camera, lens downwards, over a mercury bath. The gauze being illuminated, the camera can be so arranged that its reflected image is thrown on the plate and can thus be photographed. When this image is in focus the camera is in focus for a distant object.

"(vii).—Be very careful to note down all details at the time. A time keeper should be employed who will book the exact time, referred to the commencement of totality of zero, of the opening and closing of the shutter for each plate. Each plate should have a label pasted on it giving all details. The E. and W. edge should be marked and the referring edge for orientation, and the number of the slide should be given."

With reference to para. (ii) of this letter, a somewhat simpler method of adjusting the camera in the field, suggested by Major General C. Strahan, R.E., Surveyor General of India, was eventually decided on, as will be described hereafter. As regards para. (iii), Captain Hills' programme of exposures was finally adopted, though at the actual time of the eclipse a trifling change was made by accident in the first exposure, which was probably for the better. The remaining instructions were carried out to the letter. As previous observers seemed to agree that only plates of the utmost sensitiveness should be used, I selected the "Ilford Special Rapid" brand, made by the Britannia Works Company, London, and on the 10th November I wrote to this firm asking them to specially prepare and send me, by the mail of the 10th December, twelve dozen plates, 5″ × 5″ in size, coated with the most sensitive emulsion they could make. This order was punctually complied with. The plates arrived on the 3rd January, each box packed in an air-tight tin case; and of the five dozen plates opened and used during rehearsals on the moon and stars and on the eclipse itself, each one was found to be in perfect condition, for which I am greatly indebted to the Britannia Company.

4. The selection of the station of observation was a matter of little difficulty. The nearest point to Calcutta crossed by the centre of the path of totality lay to the west of Bhojpur, a village about a mile from Dumraon railway station, on the East India Railway. On my writing to Mr. Charles Fox, the Manager of the estates of H. H. the Maharani of Dumraon, to enquire whether any accommodation would be available for the party at or near Dumraon, that gentleman at once replied that the Maharani would be glad to make all arrangements for the accommodation of the party. It was then arranged that I should pay Mr. Fox a short visit in the Christmas holidays to arrange preliminaries and select a suitable site for the instrument. Accordingly I proceeded to Dumraon on the 21st December and spent a couple of days there at Mr. Fox's residence, Bhojpur House, where it was decided that that the point of observation should be located. As the house stands within a mile from the centre of the line of totality no better position could possibly be selected. During my stay Mr. Fox kindly had a masonry pillar built for me as a support for the instrument. This was about two feet square, sunk to a depth of two feet underground. Its surface was dressed with Portland cement, carefully levelled, in which three wooden blocks were embedded, to enable the heavy iron casting supporting the camera to be firmly bolted to the pillar. Having made these arrangements I returned to Calcutta on the 24th December.

5. On the 12th January, the party under my orders, consisting of the marginally noted officers, left Calcutta for Dumraon, where we arrived at midday on the 13th. Mr. C. Little, M. A., Professor of Mathematics at the Presidency College, who had most kindly volunteered his services to obtain the exact times of the four contacts, and Mr. G. W. Kuchler, M. A., Professor of Astronomy, also accompanied us.

Personnel.

Mr. T. A. Pope, Asst. Surveyor General, in charge,
Mr. H. Haward, Head Asst., Photographic Office,
Mr. T. R. Theakston, Asst. Mathematical Instrument Maker,
One native carpenter,
One native mechanic,
Two chuprassis.

6. The work of setting up the instrument and dark-room was at once proceeded with, and by Saturday evening, January 15th, everything was satisfactorily completed. The dark-room was the one constructed by Captain Waterhouse for the Camorta expedition in 1875. It had been kept in the Office ever since, and only required a new outer covering of canvas and red twill cloth inside to be as good as ever. As it had to stand out in the open compound it was found necessary to cover it with a large tarpaulin, and when this was done it was perfectly light-tight and answered its purpose admirably. Mr. Haward had charge of the dark-room and made up the developing and other solutions under my orders, the actual development of plates being done by myself. Mr. Theakston's special charge was the equatorial camera. He set it up and adjusted it, and was always present when the clock was running or when experimental plates were being exposed on the moon and stars, of which a large number had to be taken before we could be satisfied that the lens was at correct solar focus. The method employed to adjust the instrument in the meridian, so that it should follow the sun's motion exactly, was as follows:—Before placing the instrument on the pillar, a theodolite was set up in its place and a meridian mark erected by its means at a distance of about one hundred yards to the true north. The polar axis of the equatorial was then adjusted as closely as possible in the meridian by means of the telescope attached to it. The final adjustment was made by bisecting the sun's limb with the wires in the small finder and allowing the clock to run for some hours. Any divergence of the sun from its initial position on the wires was remedied by slightly shifting the polar axis to right or left in the elongated screw-holes provided for the purpose. After repeated slight alterations it was found that the sun practically maintained the same position from early morning till sunset, when the instrument was judged to be adjusted with sufficient accuracy for all practical purposes.

7. The five days intervening between the completion of these arrangements and the day of the eclipse were devoted to constant rehearsals of the eclipse programme. These were held both during the day and after dark, in order to accustom us to working in the partial darkness which it was expected would prevail during totality, and nearly every rehearsal was carried out with the same strict attention to small details as was to be paid during the actual performance. According to the programme laid down for us by Captain Hills in the letter given in para. 3 above, seven plates were to be exposed during totality. At the suggestion of Mr. C. Michie Smith, Government Astronomer, Madras (from whom I received many useful hints), it was intended to expose an eighth plate exactly at the end of totality, and a ninth as soon thereafter as

possible, both these being rapid snap-shots by hand. The period of totality had been calculated for Dumraon to be exactly one hundred seconds. The programme of exposures was therefore as follows:—

No. of plate.	*Period of exposure.*	*Duration of exposure.*
1	1st to 3rd second.	2 seconds.
2	9th to 14th do.	5 do.
3	20th to 35th do.	15 do.
4	41st to 51st do.	10 do.
5	56th to 77th do.	20 do.
6	83rd to 88th do.	5 do.
7	94th to 96th do.	2 do.
8	100th do.	snap-shot.
9	106th do.	do.

Before each rehearsal, nine plates were placed in the slides, after being backed, and having the upper edge marked with the number of the slide on the film side. Tylar's backing solution was used at first, but afterwards a solution of asphalt in benzole, as recommended by Captain Hills, was adopted, as it was found easier to apply. The nine slides were then placed in order in a wooden box having nine compartments and a red cloth cover inside the outer lid, so that when the latter was opened the slides would still be protected from direct sun-light by the red cloth up to the last moment before totality, when the cloth could be thrown back. Two of these boxes were made up: one to hold the slides before exposure, and the other to receive them as they were taken from the camera. The boxes, one containing the slides and closed, and the other empty and open, were placed on small tables one on each side of the camera, and a chuprassi stood by each, one to hand me the slides in succession and the other to receive and place them in the second box after exposure. Mr. Haward then took up his position at the lens to make the exposures, and I reserved to myself the changing, opening, and shutting of the dark slides. The clock having been started by Mr. Theakston, and the lens pointed as nearly as possible in the direction of the position to be occupied by the eclipsed sun, the first slide was placed in the camera and the shutter opened, while the chuprassi stood by to hand me the second slide when required. The seconds were counted for us by Babu Ram Chander Chakravarti, of the Meteorological Office, Calcutta, who accompanied Mr. Little and volunteered his services in this capacity. He sat at a table near the camera with a chronometer, and on receiving the word from me began to count "noughts". After allowing him to count noughts for a few seconds, I gave the signal for the commencement of totality by covering one of his noughts with the word "one", distinctly uttered, but without any warning, on which the Babu, instead of counting another nought, counted "two", and continued counting until told to cease after the last exposure. This duty he performed exceedingly methodically and well, never making a mistake after the first few rehearsals. The word "one", uttered by me, was the signal for Mr. Haward to expose the first plate. No cap was used for this purpose, but a circular piece of zinc sheeting, about twelve inches in diameter, let into a wooden handle and resembling a fan, which was held lightly against the hood of the open lens from the moment the first slide was inserted in the camera. At the word "one", the fan was instantly removed, and again replaced the instant the Babu counted "three", thus giving two seconds exposure. The shutter of the first slide was then quickly pushed back and the slide withdrawn and handed to the chuprassi with the empty box, who laid it in its place and stood ready to receive the next. The second slide was in the same moment placed in my hands by the other chuprassi, inserted in the camera and the shutter withdrawn. All this only occupied three or four seconds, so that there were usually at least two seconds to spare before the word "nine" was reached and the second exposure had to be made, but the operations required a combination of smartness and lightness of touch that was only acquired after considerable practice. Any sticking of the shutter, or fumbling, would result in the correct moment of exposure going by and thus vitiate the whole rehearsal, which had to be commenced again *de novo*. To make them slip easily into the camera, therefore, the edges of the slides were kept well polished with powdered graphite. At the end of the seventh exposure, which closed at the ninety-sixth second, the manipulations had to be performed with still greater speed in order to secure the snap-shot simultaneously with the re-appearance of the sun at the hundredth second. However, with practice this could be managed without difficulty. After the rehearsal, the clock was stopped and the slide-box removed to the dark-room for development of the plates.

The above description of our rehearsals has been recorded in somewhat minute detail in the hope that it may possibly be of use to others engaged in similar operations at some future time.

8. In order to test the focus of the lens, star-trail plates were taken almost every night. This was done by placing a backed plate in a slide and exposing it for half an hour in the camera, the lens being pointed to the sky and the instrument clamped tight. The stars crossing the field of the lens during exposure left a faint trail across the plate, which, on examination with a strong magnifier, showed whether the focus was correct or not. The same means was adopted to discover whether the opening of the dark slide caused any tremor or vibration to the instrument during the ensuing exposure. In the course of the half hour's exposure to the stars the shutter was closed and opened several times, and it was found that unless this was done with the

Photo-etching. Survey of India Offices, Calcutta, February 1898.

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Dumraon, January. 1898.

utmost delicacy of touch there would always be a distinct "kink" in the trail immediately after the break caused by the momentary closing of the shutter. The vibration appeared to last only an instant, however, and there could be no doubt that it ceased entirely during the two or three seconds elapsing between the opening of the shutter and the uncovering of the lens at the given times laid down in the eclipse programme.

9. The morning of the 22nd broke bright and clear, and throughout the day there was not a cloud in the sky. There was a remarkable absence of dust in the air also, and all the conditions were most favourable. The interval between the first external and the first internal contact was occupied in making final preparations, and shortly before totality the clock was started by Mr. Theakston and the observers took their places. Watching the progress of the moon through a pair of dark binoculars, I waited till the crescent of the sun had almost disappeared, and then gave the word to Babu R. C. Chakravarti to begin counting noughts. It was expected that the shadow of the moon, which, according to the published accounts of previous total eclipses, should have been seen sweeping upon us from the south-west, would have given us an unmistakeable warning of the commencement of totality. The shadow, however, disappointed us on this occasion, as it was perfectly invisible; and in waiting for it I started late and gave the word "one" exactly three seconds after totality had commenced. This would have been of no consequence if totality had lasted the full one hundred seconds, as my programme gave me five seconds to spare at the end of totality. The whole programme was then gone through, as described in para. 7, without a hitch, except that I closed the shutter of the dark slide a second too soon in the first exposure, thus giving only one instead of two seconds as intended, a mistake which I have no reason to regret, as the red prominences in the chromosphere are more marked in this negative than in any of the others. Having lost three seconds at the beginning, the seventh and last exposure during totality (two seconds) commenced at the ninety-seventh and ended at the ninety-ninth second of totality, and according to the calculations which had been supplied me, which gave the period of totality at Dumraon as one hundred seconds, there should have been a full second to spare after the closing of the slide. To my surprise, however, a brilliant point of sunlight flashed out from behind the black disc of the moon at the ninety-eighth second, just before the slide was closed, and this negative was consequently spoilt and no trace of the corona appears upon it. The last two exposures were made as quickly as possible after the re-appearance of the sun, but no results of any value were obtained thereby.

The actual exposures given were as follows :—

No. of plate.	*Period of exposure.*	*Duration of exposure.*
1	... ... 4th to 5th second. ...	... 1 second.
2	... ... 12th to 17th do. ...	... 5 do.
3	... ... 23rd to 38th do. ...	... 15 do.
4	... ... 44th to 54th do. ...	... 10 do.
5	... ... 59th to 80th do. ...	... 20 do.
6	... ... 86th to 91st do. ...	... 5 do.
7	... ... 97th to 99th do. ...	... 2 do.
8	... ... 104th do. ...	... snap-shot.
9	... ... 110th do. ...	... do.

Immediately after the last exposure the clock was stopped and the camera clamped up in the same position as it occupied during the eclipse, to enable us to obtain a star-trail plate the same evening for the determination of the orientation of the plates. This was done at seven p.m., in brilliant star-light, slide No. 1 being used.

The eclipse negatives were developed immediately by myself, using the ordinary pyro and soda developer recommended by the Britannia Company, but slightly diluted. The plates developed clean and free from fog, and the image of the moon and corona came up slowly in the first two and sixth plates, but rather too fast in the three long exposures which were somewhat difficult to keep back, being considerably over-exposed. With the experience now gained I am inclined to think that a series of much shorter exposures would have given better results. My first plate (one second) just indicates the position of the prominences without showing them in great detail as it probably would have done had the exposure been much shorter or the plate a slower one. In the second plate (five seconds) the extension of the streamers is as great as in those which received ten, fifteen, and twenty seconds respectively, while their definition is better. Had I therefore to photograph the corona again under similar weather conditions I should be inclined to use slow plates for the first two and last two exposures and to make them as rapid as a hand exposure can be made. Those made in the middle of totality might be on faster plates (Ilford "Rapid" or "Empress"), and certainly not exceeding five seconds. In case of cloudy or hazy weather, however, these exposures would certainly require modification.

10. During totality my attention had necessarily to be concentrated upon the manipulation of the slides, and I was not therefore in a position to observe the attendant phenomena very closely. The longer exposures of course afforded brief opportunities to all of us of examining the corona and the sky conditions generally. Personally I may say that the impression made

upon me was somewhat disappointing. I had hoped to see marked colour effects, both in the corona itself and in the surrounding sky, together with a considerable degree of darkness, and above all the awe-inspiring advance of the moon's shadow. In all these respects the spectators at Dumraon were doomed to disappointment. The light certainly waned considerably just before totality, but it was never really dark, not, indeed, so dark as I have often seen it during a "nor-wester" in Calcutta. At the moment the sun entirely disappeared the air was filled with a soft, silvery radiance, much resembling the electric light, but the corona from which this radiance emanated was devoid of all colour, and the entire sky, except just around the black disc of the moon, was of an uniform, dull leaden hue. The shadow, which has been so graphically described by previous observers, and which ought to have swept down upon us like a sort of gigantic negative search-light, was conspicuous on this occasion by its absence. Nor was there observable on the faces of the on-lookers that peculiar livid ghastliness which, according to all the recognized authorities, should have been manifest during totality. No doubt, if the eclipse phenomena were on this occasion somewhat tame, the fact must be ascribed to the extreme clearness of the weather and the absence of cloud and haze—conditions which were strongly in favour of the observers, even though they may have detracted from the effect of the eclipse as a spectacle.

11. It may not be out of place to mention in this report that considerable assistance was rendered by the Photographic and Lithographic Office to the three eclipse parties which came out from England under the auspices of the Joint Permanent Eclipse Committee, *viz.*, those stationed at Viziadrug, Sahdol, and Pulgaon, under Sir J. Norman Lockyer, K.C.B., Dr. Christie, Astronomer Royal, and Mr. Stone respectively. European photographers were supplied from the Office to each of these parties. Mr. A. W. Turner, Photo-engraver, was detailed for Sir Norman Lockyer's camp, and Messrs. George and Harrold, Photographers, for those of Dr. Christie and Mr. Stone. Each of these assistants took with him a portable dark-room specially constructed in this Office, and a supply of photographic apparatus and chemicals. The Office was engaged on these preparations for some weeks before the eclipse, and they were not rendered easier by the fact that very little information was vouchsafed to us as to the special requirements of each party. It is hoped, however, that our efforts to satisfy them were successful. The absence of the Officer in charge and four of his principal photographic assistants for so long a period in the busiest season of the year necessarily caused some inconvenience, but I am glad to be able to report that the junior assistants who were placed in charge of the photographic sections during this period, under the supervision of Mr. A. E. Spring, Assistant Surveyor General, carried on the work very creditably.

12. I have to acknowledge the kind assistance rendered to my party by Her Highness the Maharani of Dumraon, whose guests we were, and who provided accommodation for us and ordered that everything we required should be forthcoming. To Mr. Charles Fox, Manager of the Maharani's estates, we are all of us indebted for his kind hospitality and assistance. He not only placed his own house at our disposal but lent us the services of the State employés and interested himself in our welfare in every possible way. My personal thanks are due to Mr. C. Little and Mr. G. W. Kuchler, who accompanied the party and gave me much useful advice and assistance.

Messrs. Haward and Theakston, my Assistants, rendered excellent service throughout the operations, and are entitled to much credit for the skilful manner in which they performed their respective duties.

13. The photograph of the eclipse at the beginning of this report is an enlargement to three diameters of the second negative taken, which received an exposure of five seconds, from the 12th to the 17th second from the commencement of totality. The group facing page 4 shows the party engaged in rehearsing the eclipse programme.

14. In conclusion, I would only observe that if, owing to the excellent results so fortunately obtained by the various scientific observing parties scattered along the line between Dumraon and Viziadrug, the work done by my small detachment and our single instrument is comparatively insignificant and of small value, there can be no doubt that the experience we have each of us gained while engaged upon it will be of permanent benefit to ourselves, and indirectly, I trust, to the Government also.

T. A. POPE,

Assistant Surveyor General.

THE TOTAL SOLAR ECLIPSE, JANUARY 22ND, 1898.

REPORT

ON THE OBSERVATIONS AT

PULGAON IN THE CENTRAL PROVINCES

BY

CAPTAIN G. P. LENOX CONYNGHAM, R.E.

REPORT

ON THE

TOTAL ECLIPSE OF THE SUN, JANUARY 22nd, 1898.

(PULGAON.)

It will not be necessary for me to give an account of the negotiations and correspondence which led up to the decision that the Trigonometrical Branch of the Survey of India should undertake to prepare two camps for the reception of the two official parties of observers sent out from England, under the direction of the Joint Eclipse Committee of the Royal and Royal Astronomical Societies; suffice it to say that I finally received instructions to form a camp not more than 5 miles from the central line of the Eclipse, near the intersection of this line with the Nágpur Branch of the G. I. P. Railway, and as conveniently situated with regard to a railway station as possible.

The central line cuts the railway between the stations of Talni in Berar and Pulgaon in Wardha District. Although Talni was slightly the nearer to the central line, still Pulgaon was well within the assigned limit, and as it was evident that supplies, equipment, &c., would for the most part be obtained from Nágpur or Wardha, it seemed desirable to select it, so that interviews with the Civil Officers of the District could be combined with the business of procuring the necessary furniture and making all the domestic arrangements.

2. The original party destined for the camp consisted of Mr. and Mrs. H. F. Newall, Captain and Mrs. E. H. Hills, R.E., and Mr. E. J. Stone, but the last named gentleman died during the autumn of 1897 and his place was not refilled. Sanction was early obtained from the Directors General of Ordnance and Military Works to borrow tents and furniture, and indents for the former were submitted. Correspondence was also entered into with the Commissioner of Nágpur, and the Deputy Commissioner of Wardha, from which it appeared that there would be no difficulty in finding a suitable site near Pulgaon, and that all supplies would be obtainable. The Commissioner also very considerately issued orders that an Assistant Commissioner from the Wardha District should attend the camp, and medical attendance and a police guard were also arranged for.

In due course I received a letter from Captain Hills, giving detailed instructions as to the disposition of the observatory huts, and enclosing plans and elevations of the masonry pillars required for the reception of the instruments.

3. By the middle of December all arrangements that could be made by letter had been completed, and it then became necessary to commence action. I had at that time been for a month in Agra engaged on my regular work, which I was unwilling to break into more than was absolutely necessary. I therefore on December 15th despatched Sub-Assistant Superintendent Hanuman Prasad to Wardha, armed with copies of Captain Hills' instructions and plans, and with orders to report himself to the Deputy Commissioner; and having done so to move to Pulgaon and there to select a site, and, if no difficulties presented themselves, to commence building the pillars. He took with him a theodolite in order to be able to lay down the meridian. On December 23rd I had the pleasure of meeting Captain

and Mrs. Hills, who came out to India somewhat earlier than the rest of the observers, and who, at my suggestion, came straight up to Agra from Bombay. This was a great advantage as I was able to discuss with him more in detail the requirements of the instruments and also to come to some understanding as to the proportion of comfort to economy which would be to the taste of the party.

The intention had been that Lieutenant Beazeley and I should leave Agra for Nágpur together on December 27th, but I was unfortunately obliged to postpone my start for a day or two, so Lieutenant Beazeley went alone. He busied himself zealously in interviewing the Officers of the Military Works and Commissariat Departments and in examining the resources of Nágpur; the latter were found to be rather meagre, and there was a good deal of difficulty in collecting the furniture, china and glass required for the camp. My warm thanks are due to Captain Kemp, R.E., and Lieutenant Eustace, R.E., of the Military Works Department and to Captain Wanliss of the Commissariat Department for their very ready and efficient assistance in all matters wherein their respective departments were able to afford it. The Executive Engineer, Public Works Department, Mr. W. Starky, also lent us from his rest-houses a considerable quantity of useful furniture.

4. On the 3rd of January, Lieutenant Beazeley and I went down to Pulgaon for the day to see the site and inspect the pillars and huts which Sub-Assistant Superintendent Hanuman Prasad had erected.

At Pulgaon Station the railway runs nearly due east and west though it very soon curves up to the north-east on the Nágpur side, and from a point close to the station a metalled road (the only one in the Wardha District I believe) runs nearly due north towards the village of Arvi. It was on some open ground just to the west of this road, and about one mile north of the railway station, that the site of the camp lay. With the exception of the absence of shade for the living tents, a fault which it was impossible to remedy, as the district is very treeless, the position was suitable. The piece of ground was bounded on the east by the road, on the north and west by a winding *nála* containing some water, and on the south by fields under cultivation. The eastern side was a good deal higher than the rest, and on this part the observatories had been set up. The prevailing wind during the month of January is from the north-east, the whole of the encampment was therefore placed to the west and south-west of the observatories.

There was a little difficulty about drinking water, the nearest source being a well belonging to the Pulgaon Spinning and Weaving Company, about one mile distant; but the directors very kindly gave us permission to draw from it, and the *tahsildar* made efficient arrangements for having an ample supply brought to the camp.

The tents I had brought with me, not including those for my own use, were two large single-poled tents and one hill tent; besides these, I had received from the Bombay Arsenal two I. P. Privates' tents and six Staff Sergeant's tents. Mr. Nedham, Commissioner of Nágpur, very kindly lent me a *shámiána,* which made a most convenient dining room, and Mr. Chitnavis, Deputy Commissioner of Wardha, lent me, I fear at considerable personal inconvenience, a fine single-poled tent. It may be of interest to give the distribution in detail.

Dining Room	Mr. Nedham's *shámiána.*
Drawing Room	Single-poled tent, Astronomical Party.
Office	I. P. Privates' tent.
Workshop and Store	I. P. Privates' tent.
Mr. and Mrs. Newall... ...	Single-poled tent, Astronomical Party, and 1 Staff Sergeant's tent.
Captain and Mrs. Hills ...	Mr. Chitnavis' single-poled tent, and 1 Staff Sergeant's tent.
Office of Astronomical Parties...	1 Staff Sergeant's tent.
Mr. Harrold (Photographer) ...	1 Staff Sergeant's tent.

For accommodation of other visitors 2 Staff Sergeant's tents, and 1 hill tent.

For the accommodation of *khalásis,* Police guard, servants, &c., there were about 20 *shouldaries,* some belonging to the Astronomical Parties, and some from the Bombay Arsenal.

5. We finally moved into camp on January 6th, on the 10th Mr. and Mrs. Newall arrived, and on the 12th Captain and Mrs. Hills, then the real work of preparation began.

The equipment of the observers consisted of three separate sets of instruments:—

(1). A spectroscope with two slits so arranged as to throw upon the field of view the spectra of parts of the Corona situated at opposite ends of the Solar Equator. This instrument was specially designed by Mr. Newall, for the purpose of ascertaining whether the Corona revolves with the Sun; if this is the case the fact will be revealed by the opposite displacement of the lines in the spectrum, caused by the motion in the one case towards the observer, and in the other case away from him, of the parts of the Corona examined. The spectroscope contained five prisms constructed so as to deflect the ray through an angle of 180°, so that the instrument was of the form of the letter **U**; at one end were the slits and at the other the camera. The whole was grasped at the centre by a massive iron fork which was in one piece with a revolving axis. This axis was adjusted parallel to the axis of the earth and was caused to revolve by a driving clock. A small mirror of speculum metal was attached to the slit end of the spectroscope, pivoting on an axis perpendicular to the polar axis, so that the whole formed a very convenient polar siderostat. This instrument was mounted on a masonry pillar in the easternmost hut.

The observation attempted by Mr. Newall was of great difficulty, for the Sun's rotation is so slow that the velocity in the line of sight which it was hoped to detect could only amount to about 2½ miles per second.

Besides this, his chief instrument, Mr. Newall was also provided with a powerful grating spectroscope without collimator, with which to make visual observations during the longest of the exposures, his object being to observe the details of the Corona in the monochromatic light emitted by the unknown gas which gives rise to the celebrated green line 1474 **K**. There is a strong presumption that this line is peculiar to the Corona, so strong indeed that it has been proposed to call the substance which gives rise to it "Coronium", but further evidence on the subject is required before a definite statement can be made.

(2). The second main apparatus consisted of a pair of spectroscopes arranged side by side so that the slits of both received rays from the same heliostat through separate objectives.

One of the spectroscopes contained prisms of quartz which are exceedingly transparent to the ultra violet rays of the spectrum, and the other prisms of flint glass, which while opposing much resistance to the ultra violet rays, are highly transparent to blue, green and yellow light. With the latter special plates were used so prepared as to be sensitive to green and yellow.

These spectroscopes belonged to Captain Hills, and with them he proposed to obtain, *firstly*, a number of photographs of the spectrum at very short intervals beginning while still part of the photosphere was unobscured and continuing until a few seconds after totality, so as to secure a record of the spectrum of the parts which lie close to the Sun's limb and which are only visible at the moments just before and just after totality. Captain Hills was particularly anxious to obtain satisfactory photographs of this region, as its nature is a subject of discussion among scientists. All these short exposures were made in the flint spectroscope. *Secondly*, he desired to examine into the chemical constitution of the Corona; and to do this he arranged the slits of both spectroscopes so as to cut right across the image of the Corona and Moon and took photographs with longer exposures, thus obtaining records of the spectra of the Corona and prominences on both sides of the Moon in both spectroscopes, and the latter being, as has already been said, adapted to different parts of the spectrum, a very complete result was expected from the combination.

(3). The third instrument was a double camera about 6 feet long, with which to take photographs of the Corona. In one tube of the camera there was merely a single lens producing an image on the focusing glass of ½-inch diameter, but in the other there was a second lens which served to increase the magnitude to 1½-inch diameter. It was hoped that features which the one failed to show would be revealed by the other and *vice versâ*.

This camera was mounted on fixed supports and the image of the Sun was reflected into it by a very beautiful 18-inch cœlostat. The mirror of this cœlostat, as also that of the 12-inch heliostat used by Captain Hills, was made by Dr. Common; six plates were to be exposed in this camera, or rather twelve, for each slide held two plates, one for each tube.

The focusing of this instrument gave a great deal of trouble, there being no method of adjustment but that of removing the screws which held the frame of the lens in its place, and then pushing it up or down with the aid of a long stick. As it was considered necessary to test the focus by taking photographs, the process was long and tedious.

6. A complete set of meteorological instruments was set up in a shed built for the purpose. The daily readings of the maximum and minimum thermometers were very interesting, showing a very large range of temperature, namely from a minimum of about 42° F. to a maximum of 93° and even 96°. A rain-gauge was not omitted, but was useless,

except perhaps as a sign to the weather god that we were not to be caught napping. Captain Hills had asked me to keep a record, from the date of my arrival, of the amount of cloud at or about the hour at which the Eclipse would occur. I found it convenient to carry the record in my head; from first to last it may be summed up in one word "nil".

7. The locality of Pulgaon was not by any means a favorable one for introducing visitors from England to the pleasanter sides of Indian camp life. There was not the smallest vestige of sport to be had, and the surroundings were very uninteresting. The proximity of the Wardha river was the only relief, and even it was devoid of fish. Mr. Blennerhassett Assistant Commissioner of Wardha and his *tahsildar* arranged some pleasant little expeditions up and down the river for the entertainment of the party; and to be rowed along seated tailorwise on *charpoys* bridging the space between two dug-outs, was perhaps something of a novelty at any rate to the ladies. However, there was always plenty of business to be got through, and the absence of amusements was not very much felt.

8. The observers did not require to know their Latitude and Longitude with any great accuracy; but, as the plotted position of the railway on the Atlas Sheet was not a very reliable thing to deduce that of the camp from, I instructed Sub-Assistant Superintendent Hanuman Prasad to visit the neighbouring secondary stations of Náchangaon and Pipalkhuta which were mutually visible and from both of which the chimney of the Pulgaon Spinning Factory could be seen; this being fixed it was easy to cut in the position of the observatory, for both the chimney and Náchangaon h.s. were visible from it.

9. The preparations and adjustments were practically completed by the 17th of January, and the drill of the observers and their assistants had to commence.

I have not so far alluded to the arrival of Mr. J. Harrold from the Photo-zincographic Office in Calcutta. He gave me valuable assistance by undertaking the erection and arrangement of the dark room which had been made up in Calcutta; and helped Captain Hills in the preparation of developers and other dark room requisites.

This dark room consisted of a teak frame-work with walls of coarse canvas thickly covered with white paint and lined inside with red cloth. This did not prove sufficiently light-tight, and on a future occasion it would be better to line the walls with a double layer of black twill. In other respects the room was satisfactory, if somewhat heavy.

The following computers, deputed from the Trigonometrical Branch Office of the Survey, arrived at the same time as Mr. Harrold, and rendered valuable and intelligent aid:—Babus Shiv Nath Saha, Shoshee Bhushan Shome, Ishan Chandra Dev, B.A., and Sarat Chandra Goho, B.A. Babu Lal Singh recorder of No. 2 Astronomical Party was also present.

The number of observers and assistants available when drill began, with their several stations, was as follows:—

Double Slit Spectroscope.

Observer Mr. H. F. Newall.

Assisted by Mrs. Newall, Mr. Blennerhassett, C.S., and Babu S. B. Shome.

The two Spectroscopes with Heliostat.

Observer Captain E. H. Hills, R.E.

Assisted by Mrs. Hills, Lieutenant G. A. Beazeley, R.E., and Babu I. C. Dev.

The double tube camera.

In charge Captain G. P. Lenox Conyngham, R.E.

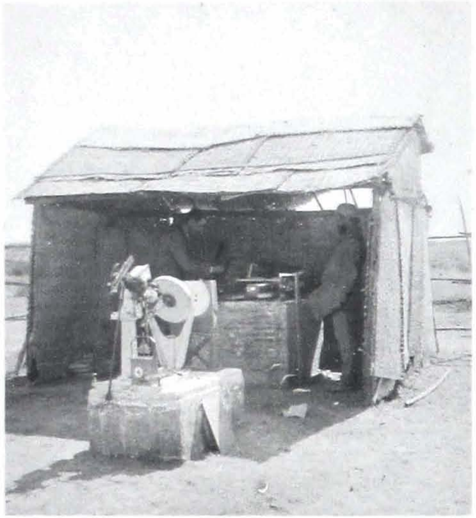
Assisted by Babu S. N. Saha, Babu S. C. Goho and three *khalásis*.

Time keepers Sub-Assistant Superintendent Hanuman Prasad and Babu Lal Singh.

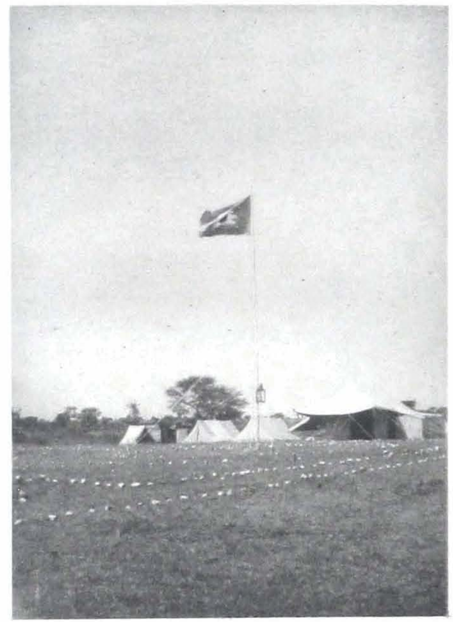
On the day of the Eclipse several other officers were present, in particular Colonel St. G. C. Gore, R.E., who noted times of contact, Captain G. C. Kemp, R.E., who recorded the temperatures every 10 minutes from half an hour before first contact to half an hour after last contact, and Lieutenant Eustace, R.E., who further assisted Captain Hills.

10. The system of drill was as follows:—

The officer in charge of the double tube camera kept his eye on the image of the Sun on the ground-glass, and when the shadow had advanced so far that totality would occur in one minute, he gave the warning word 'one minute', when there were but fifteen seconds left, he gave 'stand by', and at the instant of totality, the command 'go'. The distance on the ground-glass from horn to horn of the unobscured part of the Sun had been calculated and a scale made, and by applying this the proper time for the two warning words was known. On the word 'go' the time keepers, who were placed in the centre of the space between

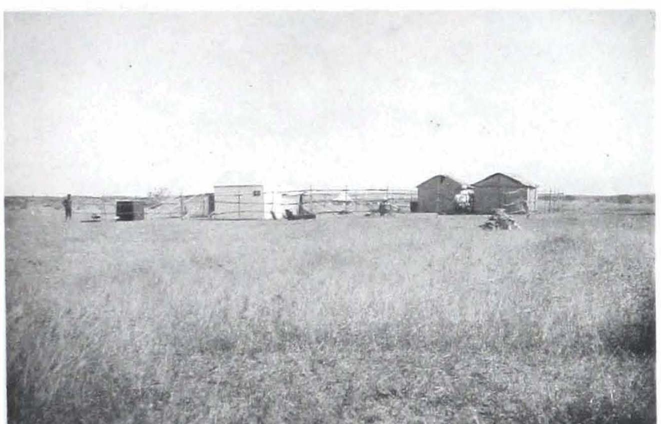


2. HELIOSTAT & DOUBLE SPECTROSCOPE.



1. CAMP COLOR.

3. CAPT. HILLS ADJUSTING COELOSTAT.



4. GENERAL VIEW OF OBSERVATORY.

5. VIEW OF CAMP.

Photo-etching.

Survey of India Offices, Calcutta, September 1898

6. GENERAL VIEW OF CAMP.

7. GROUP OF OPERATORS.

Photo-etching.

Survey of India Offices, Calcutta, September 1898.

the huts and were provided with a chronometer and a metronome regulated to beat seconds, began to count, being careful to give 0 for the first beat, so that the numbers after that represented the number of seconds of totality that had elapsed. There were two time keepers and at the close of the first minute the second took up the count with 'one' over again. The change of voice was very useful in notifying the fact that the second minute had been entered upon. The plan of having two counters is good also, because it allows to each an interval of leisure for looking at the eclipsed Sun.

The programme for the double tube camera of which I had charge, consisted of the exposure of six pairs of plates, each pair being contained in one slide. The exposures varied from 2 to 24 seconds and were, as far as I can remember, as follows:—2, 8, 12, 24, 12, 4, making a total of 62 seconds. This total allowed of ample time for changing the plates without undue haste. I found that I could make these exposures in 1^{m} 35^{s}, so that to change slides took about 5 seconds.

Having placed a slide in position and opened the shutter, I gave the word 'expose 8' or whatever the number should be. Babu S. C. Goho then raised the screen he held from its position between the cœlostat and the mouth of the tube, being careful to do so on a beat of the metronome, and held it up for the requisite time, at the same time Babu S. N. Saha recorded the time of exposure, by listening to the time keeper's count, and afterwards that of closing in the same manner. In the case of the longer exposures, he mentally added the number of seconds to the time of opening and informed me of the result, so that I was able by listening to the count to know how much time I had to spare and so to make the most of opportunities of looking at the Corona.

The last slide was not removed but the shutter was closed, a cap put over the mouth of the tube, and the driving clock of the cœlostat stopped. All was left *in statu quo* till night when the plate was exposed for about two hours and star trails permitted to impress themselves upon it, thus giving excellent means of orienting the negative without seriously damaging it. The pictures obtained were very successful, especially those with the shorter exposures.

11. With Captain Hills the procedure was as follows:—

He himself besides superintending in general, took charge of the flint spectroscope in particular. Lieutenant Beazeley was posted at the telescope of a theodolite mounted on the polar axis of the heliostat, and it was his business by means of the slow-motion screw to keep the wire of the theodolite on the centre of the diminishing or increasing crescent before and after totality, and during totality on the more important prominences in turn. This ensured the image of the part in question being placed exactly on the slit.

Lieutenant Eustace, R.E., was in charge of the slides of the quartz spectroscope; Babu I. C. Dev held a screen for cutting off the light from either or both of the spectroscopes, and Mrs. Hills recorded the times of each of the exposures.

The arrangement of the instruments before totality was as follows:—

The quartz spectroscope was closed and the shutter put in charge of Lieutenant Eustace, so that he could expose the plate at the proper moment. The slit of the flint spectroscope was only shielded from light by a hand screen held by Babu I. C. Dev, but there was also a small brass sliding shutter placed over part of the slit so as to cut off all except the part of the image near the second point of contact. The photographic plate holder was of special design, capable of being moved down any required distance by means of a rack and pinion, so that new parts could be exposed to the band of the spectrum in a very convenient manner, and a number of successive pictures obtained on the same plate. Very soon after the word 'stand by' had been given, Captain Hills began a series of short exposures on the moveable plate giving the words 'expose', 'close' alternately to Babu I. C. Dev, he himself racking his plate down a suitable distance after each exposure. The exposures lasted about 1 second each, and ten were made.

At the end of these Babu I. C. Dev, keeping his screen in front of the slit with one hand, with the other removed the sliding brass shutter above alluded to, and Captain Hills at the same time put in a new plate. As soon as this was ready he gave the word and a long exposure of about 1^{m} 15^{s} was made; this began about 25 seconds after the commencement of totality and lasted till some 15 seconds before third contact. After this the slide was again changed, the sliding brass shutter was put in in the reverse position and a second series of short exposures was made as before.

No short exposures were made with the flint-glass spectroscope, but one long one beginning about 7 seconds after totality and lasting about 1½ minutes.

12. I am not able to give so detailed an account of the procedure in Mr. Newall's hut, but it was somewhat as follows:—

Beginning a few seconds after the word 'stand by', a series of rapid exposures was made so as to obtain a record of the flash spectrum, then about 30 seconds after totality occurred, a plate was put in and exposed for one minute. During this period Mr. Newall occupied himself in examining the spectrum in the grating spectroscope; finally another series of rapid exposures was made.

13. It was a great disappointment to Mr. Newall, and indeed to all, to find that the exposure of one minute had not been sufficient for the faint light of the Corona at the points on which the slits were directed, to produce any effect on the plate. Points as far as were thought safe from the Moon's *limb* had been selected, so that the linear rate of approach and recession might be as great as possible; evidently the safe limits had been exceeded, for no record was obtained. Captain Hills' long-exposure photographs showed clearly that the intensity of the Coronal light fades very rapidly on receding from the limb, for he obtained only a very narrow band on his plate showing much less radial extension than he had expected, but this did not materially detract from the value of his own results, with which he was well satisfied.

The telegrams sent to the Astronomer Royal directly after the development of the plates give the opinions of the observers succinctly and well. These telegrams also found their way into the *Pioneer*, but as there were one or two errors in the published version, it may be of interest to give them correctly here:—

22nd January. "Eclipse observed here perfectly. Twelve photographs of Corona and twenty-four of spectrum secured. Shadow bands were well seen. Corona magnificent, extending in places to three solar diameters from the limb with brilliant prominences".

23rd January. "All photographs developed. Double tube very good, star trails were put for orientation on one plate with Abney lens. Hills' Corona spectra excellent, showing small radial extension of lines. Hills got splendid series of exposures for flash at beginning and end of totality, showing whole spectroscopic history of Sun's limb from solar spectrum through flash to prominence. Newall found Coronal spectrum too faint at quarter diameter from Sun's limb for determination of velocity in line of sight, but caught bright lines in spectrum on another photograph at end of totality. Newall observed very strong polarisation in Corona visually, also observed green Coronal ring with objective grating spectroscope. There was no fine Coronal structure of the Sun in the green light, but general form was similar to photographs of Corona".

14. A sheet had been hung up in a convenient position for the shadow bands to be seen on it, and Mr. Harrold endeavoured to obtain a photograph of them with an ordinary camera, using a lens of wide aperture and very sensitive plates, but, as was indeed to be expected, they proved too illusive and evanescent for the means at his disposal to catch. The shadow bands were, however, well seen by several spectators.

This closes the account of the operations undertaken, and it would of course be premature to attempt to say any thing with regard to the results likely to be deduced from them. With the exception of Mr. Newall's attempt to measure the rotation, all the photographs gave promise of answering the purposes for which they had been taken.

15. Most of us had expected a more striking rush of darkness as totality began. "The sweep of the shadow" of which so much had been written was not at all noticeable. No doubt we had not sufficiently considered the smallness of the extent of the shadow, on account both of the very small margin by which the Moon overlapped the Sun, and also because of the nearness to our midday of the time at which the Eclipse was visible; the dusty atmosphere of January too certainly helped to increase the light by reflection.

There were certain signs of confusion among the animal world, such as the crowing of cocks, but I was much surprised to learn on my return to Agra that there the effects had been much more marked, though the Eclipse was only partial: so great was the darkness, I was positively informed, that the very *chaukidárs* (watchmen) came out and began to cough!

16. Much time was spent during the two nights following the Eclipse in developing and reproducing all the photographs, which were then divided into two sets of which Captain Hills took one and Mr. Newall the other, so as to give a certain security against any accident on the journey to England.

17. Of the more permanent residents in the camp I have now only to mention Mr. Chitnavis, Deputy Commissioner of Wardha, who joined us for a week and twice entertained the whole party at dinner. I have no doubt but that the extreme ease and smoothness with which every thing worked, and the readiness with which supplies were forthcoming, were due to the interest he took in our welfare and the objects of the expedition ; and the fact that there was no appearance of fuss or difficulty made the situation still more agreeable. The actual arrangements before the arrival of the party and during the whole time of our stay were in the hands of Mr. Blennerhassett, C.S., and nothing could exceed the cheerfulness and efficiency with which he ministered to our wants, there seemed to be nothing which could not be produced—if not from Pulgaon, at any rate from Wardha.

18. The camp broke up on January 23rd, and all those who had been there permanently moved to Nágpur, in response to the very hospitable invitation of Mr. Nedham. A short stay there enabled me to see to the return of all the hired and borrowed things, of which business many of the most troublesome parts were taken off my hands by Lieutenant Beazeley and Sub-Assistant Superintendent Hanuman Prasad.

On January 26th we left Nágpur for Agra, feeling that we had taken part in a great historical event, that our interest in scientific matters had received an impetus which would last long, that we had seen a sight of unexampled wonder and awe, that we had spent a very pleasant month, and last but not least that we had made the acquaintance of some very delightful people.

G. P. LENOX CONYNGHAM.

THE

TOTAL SOLAR ECLIPSE,

JANUARY 22ND, 1898.

REPORT

ON THE OBSERVATIONS AT

SAHDOL IN CENTRAL INDIA

BY

MAJOR S. G. BURRARD, R.E.

REPORT

ON THE

TOTAL ECLIPSE OF THE SUN, JANUARY 22nd, 1898.

(SAHDOL.)

This report is divided into six parts as follows :—

PART I.—Preliminary correspondence and Instructions.
,, II.—Preparatory work at Sahdol.
,, III.—Results of the observations of the Eclipse.
,, IV.—The Hindu method of Eclipse prediction.
,, V.—Future Eclipses in India predicted.
Appendix.—Opinions of the Eye-observers.

LIST OF PLATES.

PLATE No. I.—Plan of Astronomer Royal's observatory.
,, No. II.—Plan of the camp at Sahdol.
,, No. III.—Photographs of the Astronomers and of Sahdol camp.
,, No. IV.—Photographs of the two Eclipse observatories.
,, No. V.—Diagram showing effect of the Eclipse on temperature.
31 Hand sketches of the Corona.
Table of observed Times.
12 Charts showing tracks of Eclipses past and future.

Part I.

Preliminary Correspondence and Instructions.

In April 1897, the Eclipse Committee of the Royal Society and Royal Astronomical Society informed the Surveyor General of India, that they were proposing to send out three parties of observers to India, one to be posted at Viziadurg, one near Sátára (or Jeúr) and one at Pulgaon. I was then stationed at Poona in charge of the Tidal and Levelling Party, and I received intimation, that I should probably be given charge of the Sátára Eclipse Camp. The Eclipse Committee's letter stated that the Sátára Party would consist of:—

Mr. Christie, Astronomer Royal of England;
Dr. Common, President of the Royal Astronomical Society;
Professor Turner, Savilian Professor of Oxford University.

The work to be undertaken by these observers was as follows:—

Mr. Christie,	(1) Large Scale photos of Corona, (2) Determination of the place of the Moon;
Dr. Common,	Spectroscopic observations;
Professor Turner,	Photos of the Corona with a double camera.

The Eclipse Committee asked that the Sátára and Pulgaon Camps might have one Royal Engineer Officer and two Photographers attached to them: the Royal Engineer Officer was required to "take general charge of the camp, arrange for all camping requisites, "commissariat, &c., and act as channel of communication between the observers and any "Native artificers and labourers that would be employed". "He ought", they said, "to be "on the spot at least three weeks before the Eclipse, get the observing Stations fenced in, "get brick foundations in position for the instruments, and he would of course be available "to render *skilled* assistance in the actual observations.

"The Photographers were to come provided with a dark room and all requisites for "developing dry-plates up to 12 × 10 size."

The Eclipse Committee also stated that, as it was the Astronomer Royal's intention to attempt a determination of the Moon's place, he would require to know his latitude, longitude and time with the *utmost possible precision*.

Site selected at Karád.

2. In May 1897, I was ordered by the Superintendent, Trigonometrical Surveys, to report on the relative merits of Sátára and Jeúr as sites for the Astronomer Royal's Camp. The choice lay between these two localities, because they were the only two points in the Deccan, where the centre line of totality intersected a railway line. With the concurrence of the Hon'ble Mr. Spence, C.S.I., Commissioner of the Central Division, I selected a site on the Southern Mahratta Railway between the stations of Karád and Masur; this site was superior in the matter of water and supplies to the station of Jeúr on the Great Indian Peninsula Railway; it was also less liable to cloud, and it would be favored at the Eclipse with a longer duration of totality. In every Eclipse the duration of totality varies with the latitude. As the Moon's shadow sweeps easterly over the Earth with a velocity of 2000 miles an hour, an observer on the equator is being carried eastward by the Earth's rotation at a rate of 1000 miles an hour: the nearer he is to the North or South pole, the slower he moves, and the sooner will the shadow pass him by, and the shorter be the period of solar obscuration. The path of the recent Eclipse was in a north-easterly direction, and consequently the duration of totality in India was greatest on the coast, and grew less inland; if the path had been south-easterly, the duration would have been least on the western coast and would have increased with the easterly progress. The duration of the total phase at Karád was to be $2^m\ 7^s{\cdot}9$, and at Jeúr $2^m\ 4^s{\cdot}9$.

It was arranged to indent on the Poona Ordnance Depôt for the tents for Karád, and on the Military Works Department for the Camp furniture.

Site changed to Jeúr and Ghunghuti.

3. During October 1897, the plague was raging throughout the Sátára district, and the town of Karád was suffering terribly. At the advice of the Hon'ble Mr. Spence, a new site was chosen in the Sholápur district between Jeúr and Kem, and that between Karád and

Masur was abandoned. On December 6th, when preliminary arrangements were in progress, I was informed by the Surveyor General of India, that a telegram had been received by Government from the Secretary of State on the subject of the Eclipse Camps, and that my Eclipse Camp had been transferred from the Deccan to Ghunghuti, a station in Central India on the Bengal-Nagpur Railway.

The centre line of totality plotted on a large scale map of this *new* region, showed Sahdol to be a more favorable station than Ghunghuti: the data given in the Nautical Almanac made the centre line of totality cut the railway between the two places at a point 7 miles from Ghunghuti, and 5 from Sahdol: the French data in the *Connaissance des temps* placed the centre line 4 miles nearer Sahdol than Ghunghuti, and the German data from the *Astronomische Jahrbuch* gave Sahdol an advantage of 6 miles over Ghunghuti.

I wrote to the Political Agent of Rewah and informed him, that it was proposed to form an Eclipse Camp near Ghunghuti, and that the most suitable astronomical locality would be some two miles west of Sahdol.

The following was the Political Agent's reply: "although the Rewah Durbar will "no doubt make every endeavour to arrange for the supply of food, yet it should be remem- "bered that the spot selected for your operations is in the middle of dense jungle and far "away from any town or centre of supplies. I recommend you to send your camp kit "at once to Sahdol and come yourself to Sutna, where I will meet you and talk over the "whole subject; ordinary supplies such as grain, wood, grass and earthenware pots will no "doubt be procurable, but owing to the nature of the country and the late famine there will "be great difficulty about getting poultry, eggs or sheep and I would recommend you to order "all such supplies from Allahabad or Jubbulpore, and have them sent down by rail. As "regards the site I should recommend you to choose this for yourself after seeing the "country between Sahdol and Ghunghuti."

The Astronomer Royal's Instructions.

4. On December 14, I received the following letter from the Astronomer Royal dated Greenwich, November 19th: "Enclosed are our instruc- "tions for our Eclipse Camp and plans of huts and piers, "which I hope you will find sufficiently explicit. Last Friday "Sir C. E. Bernard still thought we might go to Karád, but the news of the plague since "puts a different complexion on the case, and I think now we must give it up and go to a "station on the Katni-Bilászpur line."

The following were the written instructions which the Astronomer Royal enclosed in his letter:—

INSTRUCTIONS FOR THE ECLIPSE CAMP.

Station. A suitable site should be selected within 3 or 4 miles of the central line. Near Karád or Jeúr would be the best site astronomically, but if there is difficulty on account of the plague, a site on the central line near the railway joining Katni and Bilászpur would do well.

Party. The party will consist of :—

Mr. Christie and his son Harold of 13 years of age.

Professor Turner.

Date of Arrival. The party will arrive at Bombay by the S. S. "Ballarat", due January 3rd, and at the station about January 10th to 12th.

Date of Departure. Should no results be obtained the camp could be struck on January 23rd. If the Eclipse is successfully observed it could be struck on January 24th or 25th.

Eclipse Camp. A sketch plan is enclosed showing proposed arrangements of the Observing Camp and details of the piers and huts.

Outlook of Camp. The outlook of the Observing Camp must be clear to the South. The sun should be visible from all parts of it from 9 A.M. to 3 P.M.

Instrument Piers. The piers for the instruments may be made of concrete or brick-work.

Huts. The huts may be constructed in any way that is found locally convenient.

Office Tent. A marquee should be provided as an office and store tent.

Dark Room. A Photographic dark room suitable for work in the day time should be provided.

Fence. The observing Camp should be completely fenced in. Arrangements must be made for the police protection of the Camp. Special attention must be paid to the danger of fires being lighted in the vicinity on the day of the eclipse, as the smoke might interfere with the observations.

Assistants. The following assistants are required :—

2 Photographers
6 Trained Natives (accustomed to such work as recording observations, &c.)
4 Coolies.

Stores. In addition to the stores required for the construction of huts, piers, &c., the following should be provided.

1 Barrel Portland Cement
150 feet run of timber about $2^{in} \times 3^{in}$
2 cwt. of iron or stone for clock weights
2 gallons of methylated spirits

Photographic Stores. The two photographers should come provided with all materials for developing dry plates up to $12^{in} \times 10^{in}$ size.

Living Camp. The living camp should be between 100 and 300 yards from the Observing Camp.

Time and Longitude. Accurate local time (determined with a Transit Instrument) will be required on the day of the Eclipse and also the accurate Longitude of the station. This latter may be determined afterwards, as it will only be wanted if the photographs of the partial phase for determination of position of the moon relatively to the sun are successful.

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5. With these instructions were two sheets of drawings, giving plans and elevations of the huts and piers. The huts were to be 19 feet long by 9 feet wide and 9 feet high, and were to be so constructed, that the sun's rays would reach an inside mirror from 11 A.M. to 4 P.M. Each Astronomer required three pillars to be built in his hut: one of these pillars was to carry the mirror or cœlostat, and the other two were to support the telescope. The cœlostat pillar had to be placed with its longer sides parallel to the meridian, and its shorter parallel to the prime vertical. The meridian line was to be marked across its surface and the line of the prime vertical drawn one foot from its southern edge. From the point of intersection of these two lines a third line was to be laid down in a direction somewhat north of west; this third line was to be inclined to the line of the prime vertical at an angle equal to the declination of the Sun on the day of the Eclipse; and it was to cut the two telescope pillars at right angles through their centres. The three pillars were then to be raised to such relative heights that the Telescope, when depressed ten degrees, should point to the centre of the mirror.

Camping arrangements.

6. Having settled with Captain Lenox Conyngham at Agra the questions concerning khalásis and instruments, I proceeded to Sutna where I met Captain A. F. Pinhey, the Political Agent of Baghelkhand. He took great interest in the work, rendered me cordial assistance and attached an Assistant Commissioner and Police Officer to my Camp.

From Sutna I went to Jubbulpore to arrange for tents, furniture, liquor, food and servants. As Sahdol was outside the Bombay Command, my previous arrangements for camp equipage were cancelled, and I was ordered to draw tents from the Agra and Allahabad arsenals, and get barrack furniture from the Executive Engineers, Military Works Department, Allahabad and Jubbulpore. Captain Lenox Conyngham lent me durrees, which he had borrowed from the Military Secretary to the Viceroy for the Pulgaon Camp, and the Chief Commissariat Officer at Jubbulpore lent me cooking pots and crockery. Mr. Fox Strangways, the Chief Secretary to the Central Provinces Government, kindly gave me leave by telegram to borrow three fine single-poled tents* from the camp equipage of the Chief Commissioner, which was stored in the Jubbulpore Jail.

At Jubbulpore I was met by Lieutenant Crosthwait, R.E., who had recently been attached to the Tidal and Levelling Party, and who, I was thankful to find, was an expert at mess-management and catering. We engaged a staff of servants for five weeks, and laid in stores, wines, soda-water and vegetables.

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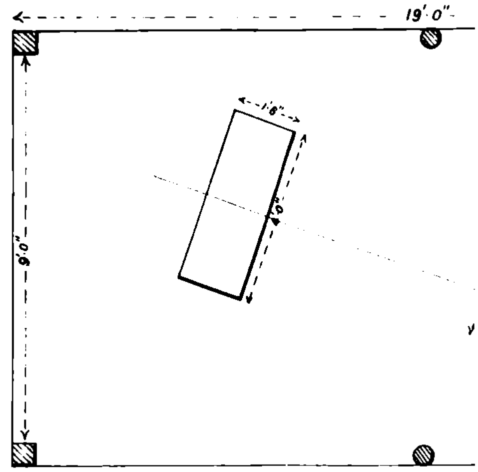
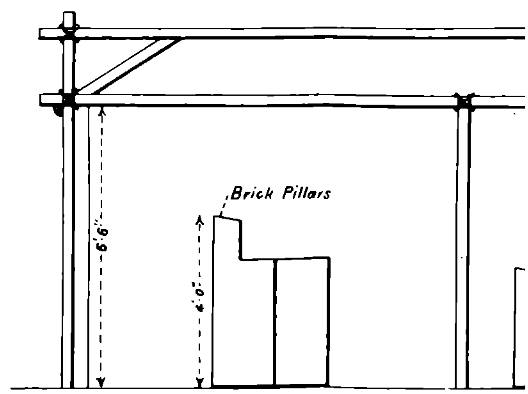
* At Sahdol one of these was allotted to Mr. Christie and his son, one to Professor Turner, and the third was used as the mess-tent.

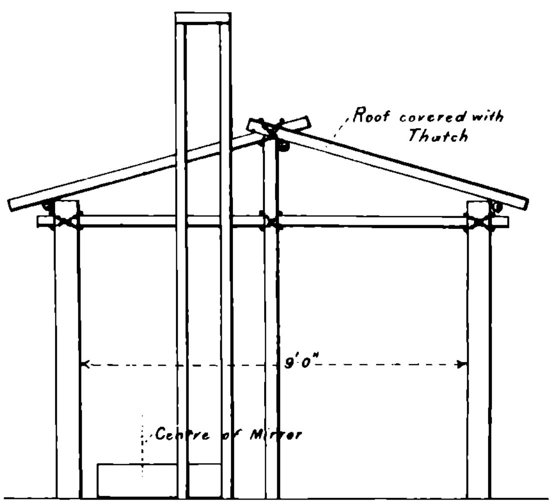
TOTAL ECLIPSE OF THE SUN
22nd January 1898
ASTRONOMER ROYAL'S OBSERVING HUT
Camp Sahdol, India.

PLA



LONGITUDINAL

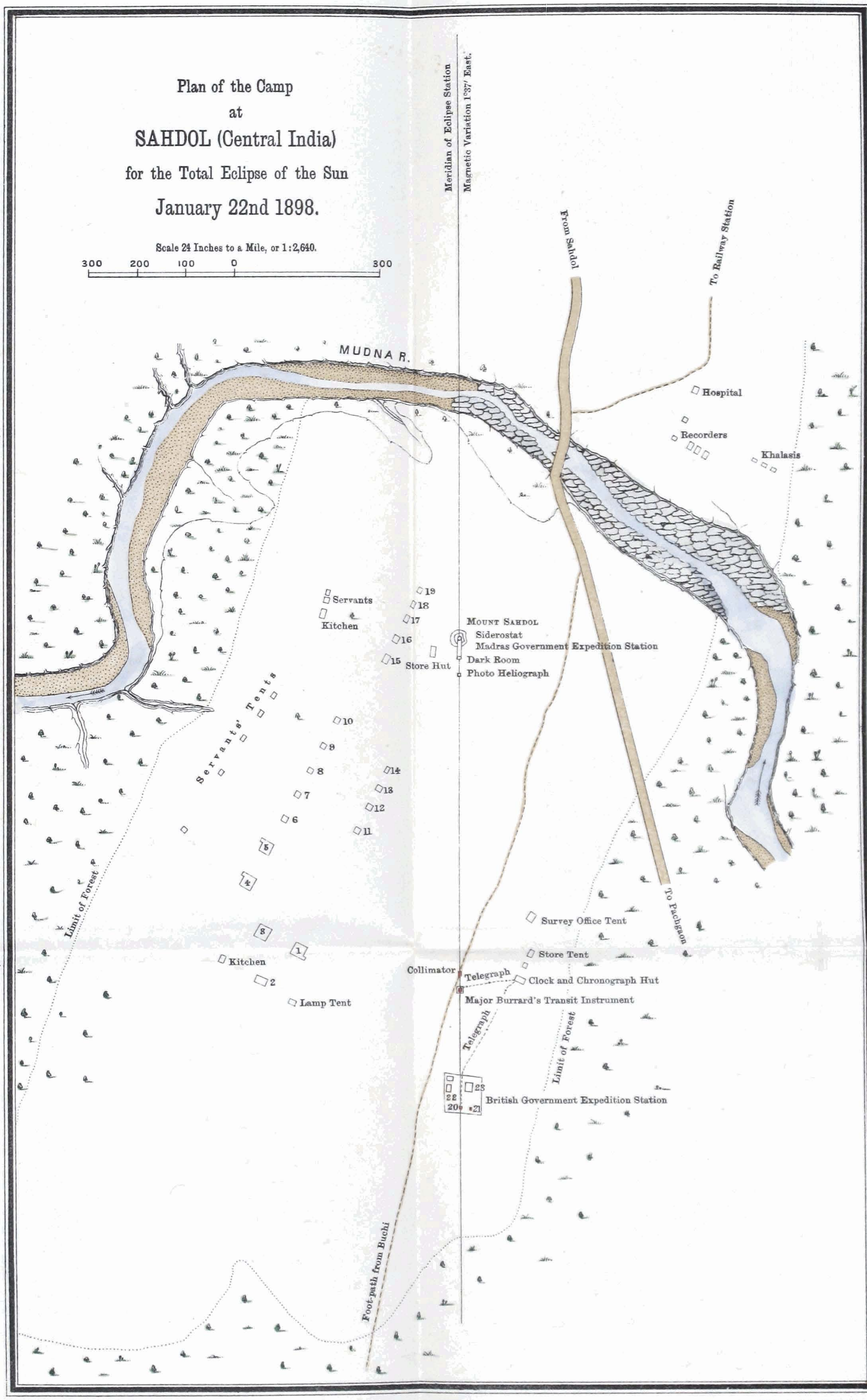




END VIEW

NOTE.— Foundations of all pillars $2\frac{1}{2}$ feet deep and packed with sand.

Scale $\frac{1}{40}$.



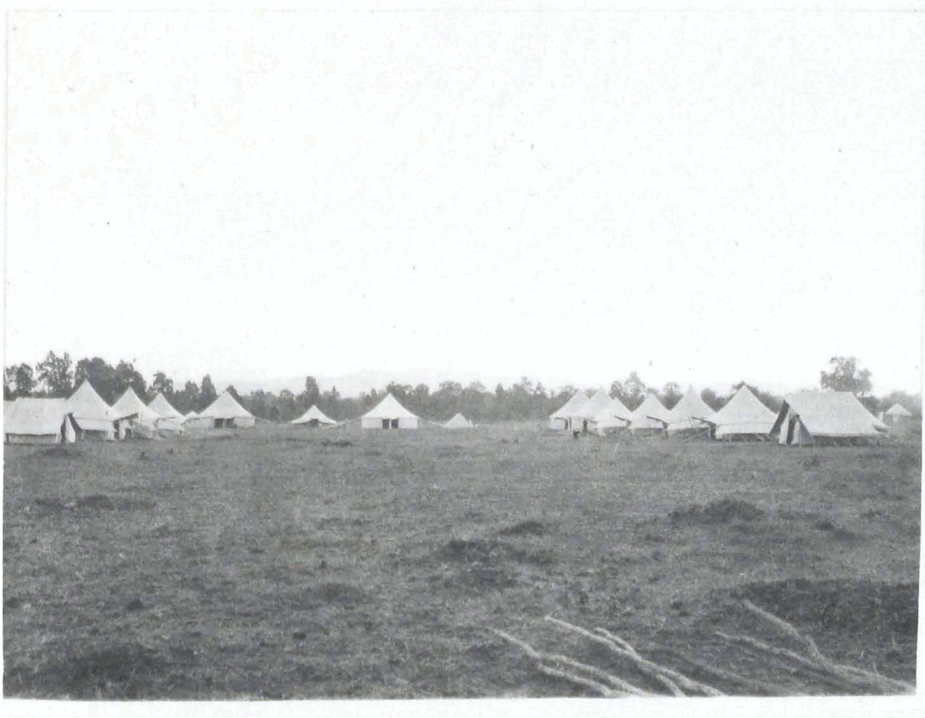
REFERENCE.

1. Mr. W. H. M. Christie, C.B., F.R.S.; Master Harold Christie
2. Lieut. H. L. Crosthwait, R.E.
3. Mess
4. Professor H. H. Turner, F.R.S.
5. Major S. G. Burrard, R.E.
6. Mr. C. H. McA'Fee
7. Mr. R. George
8. Captain E. D. Bullen, R.E.
9. Colonel Sir T. H. Holdich, K.C.I.E., C.B., R.E.
10. Captain J. A. Dealy, R.E.
11. General C. Strahan, R.E.; Colonel St. G. C. Gore, R.E.
12. General R. G Woodthorpe, C.B., R.E.
13. Mr. C. Michie Smith
14. Captain W. Ewbank, R.E.
15. Mr. A. H. Campbell, I.C.S.; Surgeon-Major J. L. Van Geyzel, I.M.S.
16. Madras Mess
17. Doctor J. W. Evans
18. Mr. F. W. Lawrence; Mr. A. F. N. Moos
19. Mr. R. Ll. Jones; Mr. H. Kelsall Slater
20. Mr. Christie's Cœlostat { Lat. 23° 16′ 45″·3 N.; Long. 81 21 33·0 E.; Height 1502·4 feet.
21. Professor Turner's Cœlostat
22. Dark Room
23. Instrument Tent

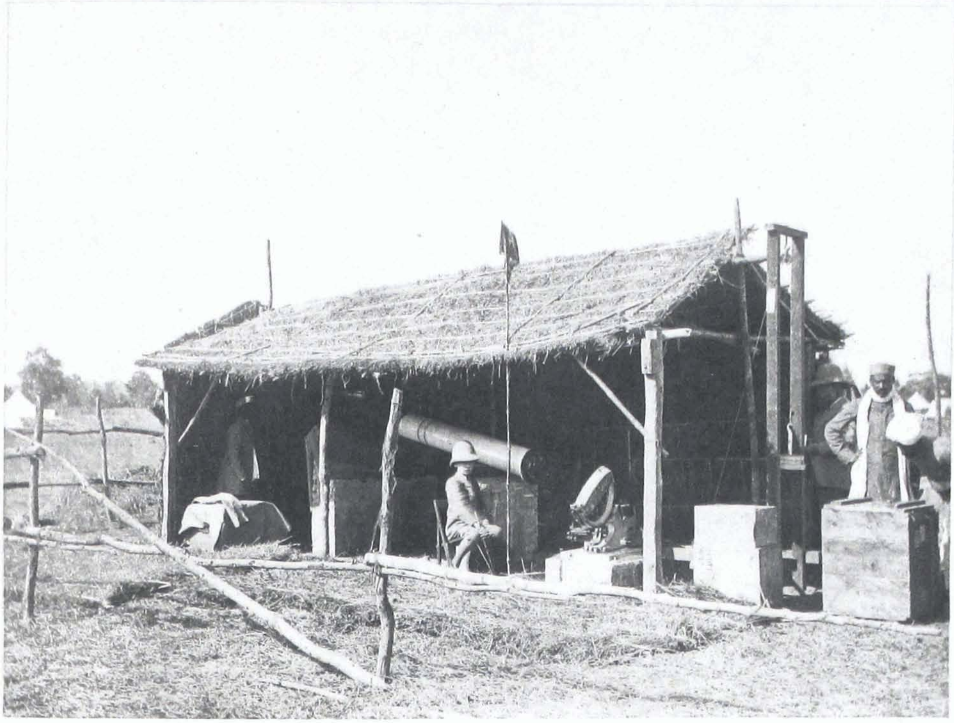
Reg. No 350, S. I. D.—Sept. 98.—200.

Litho., S. I. O., Calcutta.

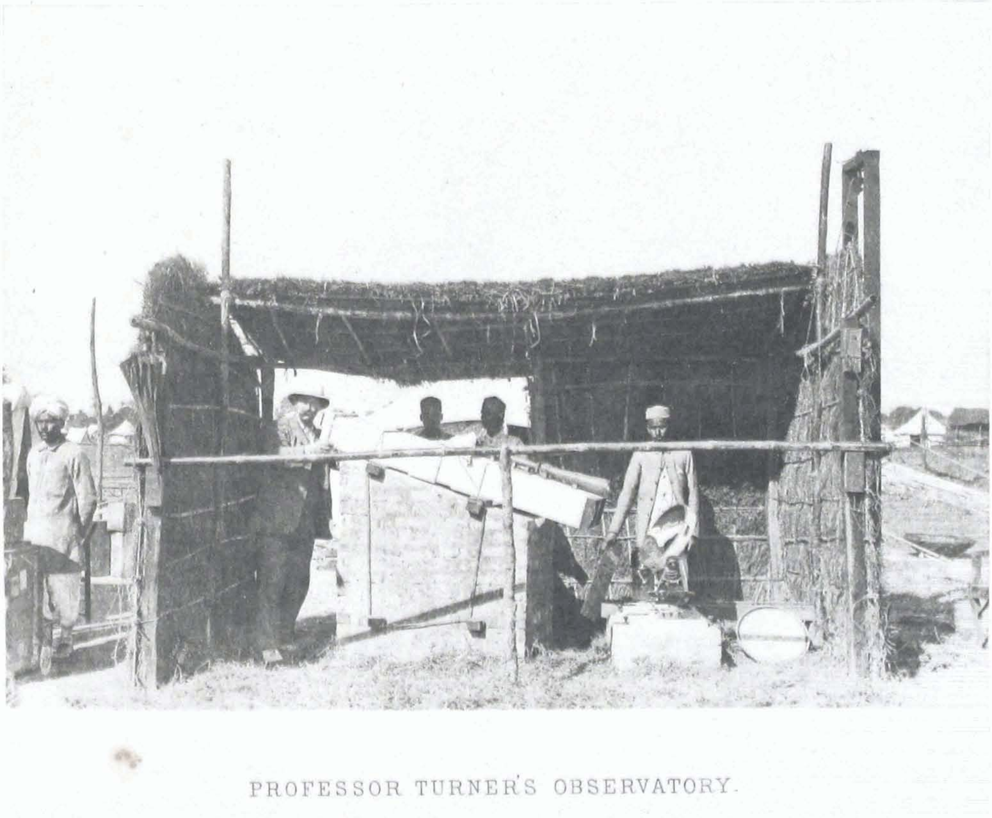
PROFESSOR H. H. TURNER, F.R.S. MR. W. H. M. CHRISTIE, C.B., F.R.S.
MASTER HAROLD CHRISTIE.



CAMP SAHDOL.



THE ASTRONOMER ROYAL'S OBSERVATORY.



PROFESSOR TURNER'S OBSERVATORY.

Photo-etching. Survey of India Offices, Calcutta, September 1898.

Part II.

Preparatory work at Sahdol.

7. By December 28th I was in camp at Sahdol, with Lieutenant Crosthwait, two computers, two carpenters and ten Khalásis. In the selection of the site for the Astronomer Royal's station, which was our first duty, it had to be borne in mind that the latitude and longitude were required with precision, and that therefore a connection by triangulation with principal trigonometrical stations would be necessary. We were fortunate in finding a point, from which two trigonometrical points were visible, and which was equilaterally situated with regard to them. It was near the Mudna River, and *sufficiently* near the centre line of totality, being within half a mile according to the Germans, one and a half according to the French, and three and a half according to the Nautical Almanac. The jungle was rather thick and an area of 400 yards square had to be cleared; the trees were cut down, the long grass burnt, all stumps dug up and the ground levelled.

The Thákur of Sohágpur called on us and placed an elephant at our disposal, and the Assistant Commissioner of Rewah proved of great assistance.

On December 31st Mr. C. H. McA'Fee, Extra Assistant Superintendent, arrived from Dehra Dún, bringing 2 Khalásis and all the necessary astronomical instruments. The Dark-Room arrived safely from Calcutta, where it had been made under Mr. T. A. Pope, Assistant Surveyor General, and was easy to erect.

8. Lieutenant Crosthwait undertook the construction of the observing huts and pillars; he built the pillars according to the instructions given in para. 4, and then constructed the huts round them. The attached drawing, Plate No. I, shows the Astronomer Royal's hut and its pillars: Professor Turner's were almost identical. The pillars for the Survey Transit Instrument were built on the meridian of the Astronomer Royal's cœlostat-pillar, and a small hut erected near for our large astronomical clock, our chronographs and chronometers; a brick pillar was built to which the clock was affixed.

On January 1st 1898, Mr. Michie Smith, the Government Astronomer, arrived from Madras: I had cleared the jungle for his camp before his arrival, and he at once set to work to raise a mound of earth 20 feet high to carry his polar siderostat: this mound was christened "Mount Sahdol", and its centre was placed on the meridian of the Astronomer Royal's station and of my Transit Instrument.

By January 8th all the tents were pitched, the huts and pillars built, the transit instrument and astronomical clock erected, and the chronographs in working order.

Arrival of the Astronomers.

9. At 6 a.m. on January 9th, the Astronomer Royal, and his son and Professor Turner arrived at Sahdol. We met them at the Railway Station and arranged for the carriage of their telescopes and mirrors to the camp. Immediately after breakfast they commenced unpacking their boxes, and erecting their instruments, and for the next few days they used to work from 7 a.m. to 4 p.m.; the two mechanics of the Tidal Party proved of great assistance to them, and all the Khalásis were in constant use and request. Mr. George, the photographer, arrived on January 14th. From January 10th to January 17th the camp was a busy scene. The English Astronomers had a great deal of work in adjusting their instruments, in getting ready their dry plates and in arranging their chemicals. From January 12th Lieutenant Crosthwait commenced taking half-hourly readings of temperature and the barometer throughout the day, that we might know the ordinary daily variations, and thus see the effect of the Eclipse. At the request of the English Astronomers Mr. McA'Fee made a survey of the Sahdol camp, a print of which is attached to this report as Plate II. My own work during this period was the adjustment of the Transit Instrument and the determination by star observations of the clock and chronometer errors and rates.

Description of the Observations intended to be taken at the Eclipse.

10. Both the English Astronomers were provided with a combined camera and telescope and with a reflecting mirror called a cœlostat. Professor Turner had also a polariscope. There was no spectroscope, as Dr. Common, the spectroscopic observer, had been prevented by illness from coming.

The observations with the exception of the timings of the contacts were to be made by photography and not by eye: the timings of the contacts were the only part of the Eclipse programme entrusted to an eye-observer.

The cœlostat — and this is the first Eclipse at which one has been employed — is a mirror placed opposite the object-glass of the telescope and rotated by clock-work. It reflects the Sun's rays into the telescope, and its constant rotation keeps the Sun's image stationary on a sensitive plate. The advantages of the cœlostat are great: it does away with the necessities of mounting the telescope equatorially and of revolving it by clock-work, and the telescope can be kept *inside* a hut in the shade, instead of being pointed at the Sun and exposed to great heat and consequent disturbance of focus.

11. Eclipse work generally may be divided into two distinct classes, (a) Mathematical, and (b) Physical. The mathematical astronomer utilises an Eclipse for correcting solar and lunar motions, distances and positions, whilst the physicist employs the spectroscope, camera and polariscope to examine the Sun's constitution and radiations.

The use of the Mathematical Observations.

A Solar Eclipse is of value to the mathematician, because except at Eclipses the Moon cannot be observed, when she is on the same side of the Earth as the Sun. The path of the Moon, more complex than that of any other heavenly body, rests therefore on determinations made only, when she is in opposition to the Sun. At no recent Eclipses, however, have mathematical observations been taken, the physicist apparently having ousted the mathematician, just as the photographer is ousting the eye-observer. At the Eclipse of last January the Astronomer Royal made a new departure and decided to re-determine the position of the Moon, employing all the means placed at his disposal by modern photographic improvements.

12. Mathematical observations of an Eclipse require a knowledge not only of the exact position of the observatory on the Globe, but also a very accurate determination of time. Errors in terrestrial position and time become largely multiplied in celestial results. It is perhaps possible, that at recent Eclipses there were no means of determining latitude, longitude or time, and that the Astronomer Royal was influenced on this occasion by the fact, that the Eclipse was occurring in India. Eclipse parties generally travel lightly equipped, and only take such instruments as are actually necessary for Eclipse work: the determination of latitude, longitude and time, if to be made with real precision, requires astronomical telescopes, electric chronographs, pendulum clocks and telegraphic connection with Greenwich, and entails perhaps weeks of observation. In India the latitude and longitude of any place can now be found from a connection with the nearest Principal Trigonometrical points, and all the appliances necessary for accurate time determination are ready to hand.

13. The determination of the distance or place of the Moon is similar to fixing an inaccessible snow-peak, and in each case a base-line is necessary. In the case of a snow-peak the surveyor has merely to *measure* his base, but in the case of the Moon no measured base would be long enough, and we have to *calculate* one. At the total Eclipse of the Sun the base-line employed extended from Greenwich to Sahdol.

The calculation of the length of such a base-line is in two steps: the first step is to determine the latitude and longitude of its two ends, *i.e.*, their exact positions on the Globe; and the second is to calculate their distance apart. This second step is dependent on the size and shape of the Earth, and these elements are deduced from the trigonometrical surveys of Europe and India. The recent determination of the longitude of India (made in 1895-96) has been accepted in its entirety by the Astronomer Royal, and adopted as an element of his great terrestrial base in this measurement of the Moon's position. The place of the Moon, as corrected by the Sahdol work, will probably be incorporated in the Nautical Almanacs of the future, until opportunity arrives for again improving it.

The weak point at present in the calculation of a terrestrial base is the uncertainty that exists of the Earth's exact figure: compared to the whole surface of the Globe, the portions that have been trigonometrically surveyed are very small, and owing to the deflection of the plumb line, caused by the attraction of mountains, it is unsafe to generalise for the whole Earth from such areas as Europe and India.

14. It is popularly supposed—but the supposition is wrong—that the motion of the Moon is known with sufficient accuracy for practical purposes: some idea of the errors, that do exist in her accepted position, may be gathered from the discrepancies amounting to three or four miles between the German, French and English determinations of the central line at the recent Eclipse: the place of the Moon is in fact not well enough known for a

sailor or geographer to be able to determine his longitude within 5 miles. If the time ever comes, when we are able to photograph the stars by day-light and all celestial bodies through clouds, and to determine our latitude and longitude by simple photography, the mariner will still be working with his log and his compass, unless the Moon's position is improved upon.

The sun and stars tell us our Latitude: the Moon is the only mark in the heavens of Longitude.* For Longitude the heavens are the face of a watch, the stars representing the Roman numerals and minute-divisions, and the Moon is the only hand: the difficulty of exact observation will be appreciated, if one considers how inaccurately the time of day would be told from a watch, which carried no minute hand. Even the hour hands of our watches move round their faces in twelve hours, but the hand of the longitude watch takes 27 days to pass round its dial. To what accuracy could we tell the time of day, if our watches and clocks had only one hand, and that revolving in 27 days? But the longitude observer is at another disadvantage, in that the Moon's pace is not regular, and he has to allow for her quickening and her slackening; and even when this allowance is made with precision, there is still an error accumulating at the rate of 1 second of time in 8 years, which the theory of gravitation is unable to explain.

Determination of the Moon's place.

15. The method of observation, to be employed by the Astronomer Royal, was to observe the times of the four Eclipse contacts and to take a long series of instantaneous photographs (noting the time of each) during the partial phases from the 1st to the 2nd contact and from the 3rd to the 4th. Each of these photographs would give the relative positions of the Sun and Moon. The interval of 105 seconds between the 2nd and 3rd contacts was to be reserved for his physical observations.

Physical Observations.

16. The main object of physical research at Eclipses is to throw light on the vexed question of what the corona is. Does it belong to the Sun, or the Moon, or is its seat in the Earth's atmosphere? What is it made of, and is it connected with Sun-spots? Is it rotating or still? Is it an electric phenomenon, or due to the Sun's magnetism? Is it gaseous or meteoric or auroral? Is its light its own or reflected? These are the great problems now awaiting solution.

The corona is believed to be *mainly* a solar phenomenon, although it is not considered possible for a solar atmosphere to extend to a height of two or three diameters above the sun's surface. The attraction of the Sun is so great as to render it improbable, that its atmosphere reaches a height of half a diameter, and the extreme portions of the corona are therefore attributed to motes and ice-crystals floating in the Earth's atmosphere. The inner ring of radiance, shining as it does by reflected light, is believed to belong to the Moon, but its width is a matter of doubt.

The popular belief in the utility of Eclipse investigation would be strengthened, if astronomers could say what they are expecting to find; but this they cannot do. They are groping in the dark, not seeking for any particular thing, but trying to pick up *something*, that may indirectly benefit mankind. Most great discoveries—witness those of Faraday and Röntgen,—were made by men groping blindly, and alighting accidentally on an unexpected valuable. Eclipse observers are, however, at a disadvantage compared with all other investigators: workers at mechanics, chemistry or geology can give up their whole time to research, and can follow up each idea with experiments: but the Eclipse observer, even supposing that he devoted himself wholly to Eclipses for 50 years of his life, visiting and *observing* every possible Eclipse, would yet in the aggregate have only seen the corona for one hour and a half.

The physical observations of the Astronomer Royal were to consist of 7 photographs to be taken during the 105 seconds of totality, with different exposures, varying from 1 second to 20 seconds, giving images of the Sun 3½ inches in diameter.

Professor Turner's combined camera and telescope was double, and took two pictures of the Sun at each exposure, one being 1½ inches in diameter, the other half an inch. His contributions to physical research were to consist of a series of these double pictures taken with different exposures during totality. He intended to reserve the last 15 seconds of totality for taking photographs with his polariscope, to determine, whether the light of the corona is its own or reflected. The polariscope was mounted and fixed on the telescope.

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* The fancy methods of observation by Jupiter's Satellites are not possible at sea and not successful on land.

17. At Sahdol the work of the Survey Department was wholly auxiliary to that of the English Astronomers, and I placed every one's services for the day of the Eclipse at the disposal of the Astronomer Royal and Professor Turner.

Duties allotted for the day of the Eclipse.

The following is a complete list of members of the Survey Department, employed at Sahdol, with the parties from which they were drawn, and with the Eclipse duties allotted them by the Astronomers:—

Name.	Designation.	Office or Party.	Eclipse duty.
Major S. G. Burrard, R.E.	Superintendent	No. 25 Party	Responsible for time observations with the Transit Instrument, for determination of clock-errors, and for the timings of the Eclipse contacts and of the Astronomer Royal's photographs.
Lieut. H. L. Crosthwait, R.E.	Assistant Superintendent	,,	Responsible for Meteorological observations and for the electric arrangements for signalling the Astronomer Royal's times of exposure.
Mr. C. H. McA'Fee	Extra Assistant Superintendent	Trigonometrical Branch Office	In charge of the recorders and drill. To be responsible that the counter and each recorder fulfilled his allotted part. To be ready to assume any part in the event of a break-down.
Mr. George ...	Photographer	Photo Office, Calcutta	In charge of dark-room and chemicals.
Dhondu Vinayek	Surveyor ...	No. 25 Party	Professor Turner's chief recorder.
G. B. Joshi ...	,, ...	No. 22 Party	Counter for the first minute of totality.
Vinayek Narayen	,, ...	No. 25 Party	Handed the plate for each exposure to the Astronomer Royal.
N. V. Apte ...	Sub-Surveyor	,,	Counter for the second minute of totality.
G. R. Bhabhe ...	Computer ...	,,	Received the plate after each exposure from the Astronomer Royal.
V. B. Garud ...	,, ...	,,	Meteorological Recorder under Lieut. Crosthwait.
Tukaram Hanmantrao	Mechanic ...	,,	Handed the plate for each exposure to Professor Turner.
Shankar Devidas	,, ...	,,	Received the plate after each exposure from Professor Turner.
1 Tindal ...	...	No. 22 Party	Transit Observatory.
1 Daftary ...	...	,,	Office.
1 Chaprási ...	...	,,	With the Astronomer Royal.
1 do. ...	...	,,	With Professor Turner.
2 do. ...	...	No. 25 Party	With Officer in charge of camp.
1 Khalási ...	...	No. 23 Party	Dark-room.
2 Khalásis ...	...	Trigl. Branch Office	Astronomer Royal's Observatory.
3 do. ...	...	No. 22 Party	Transit Observatory.
2 do. ...	...	,,	Professor Turner's Observatory.
2 do. ...	...	,,	Clock House.

18. Every day the Eclipse programme was rehearsed: the counters counted from a chronometer placed between the two observatories; a recorder stood on each side of each astronomer, one to hand the plates for exposure, one to receive them after. A recorder in each observatory noted the durations of the exposures. The exposures during totality were to be made by hand, an opaque fan being interposed at the word "close" between the cœlostat and the telescope, and withdrawn at the word "expose". Master Harold Christie worked the fan for his father, and

System of drill.

Dhondu Vinayek for Professor Turner. Mr. C. H. McA'Fee stood between the two observatories, superintending the counters and recorders, ready to assume any part in the event of a break-down.

January 17th was a general holiday and a beat for big game was organised. The Thákur of Sohágpur was called into conference, and two rows of *macháns* constructed. We left camp on elephants before sunrise and were out in the jungle till after sunset. There were two beats, and several deer and *nílgái,* a tiger and a boar passed through the line of Astronomers.

The jungles around our camp in January were the resort of numbers of *banjára* gipsies, and the smoke from their fires used to lie heavily over our tents. As the Eclipse day drew near, the Assistant Commissioner was asked to prevent fires being lighted in our vicinity, lest the smoke should interfere with the photographs. The steps taken by the State Officials of Rewah, to caution the *banjáras* against fires and smoke, afforded much amusement to the English Astronomers: the method of warning adopted was to nail pages, torn from a *Whiteaway-and-Laidlaw's* advertising catalogue, to the trees surrounding the camp. In all directions in the jungle were pictures of ladies' corsets and bodices, frequently upside down, nailed to the trees. The measure was successful, and no *banjáras* approached our camp.

I had expected Colonel Gore, R.E., to arrive from Dehra Dún on January 13th, but he telegraphed that he was delayed. I had been looking forward to his coming, as we had been wishing to consult him on several electric and photographic points. He arrived on January 16th and stayed three days, leaving us then for the camp at Pulgaon.

All final arrangements had now been made: the Agent to the Bengal-Nágpur Railway had placed a saloon carriage at our disposal for visitors, and assisted us in many other ways. Mr. Eliot had promised to send us the weather telegrams daily; the Director General of Telegraphs had arranged for the transmission of foreign and press messages from Sahdol.

19. As January 22nd drew near, the population of Sahdol began to increase: the camps of the Agent to the Governor General for Central India, of the Mahárája of Rewah, and of the Political Agent of Rewah were laid out about a mile distant from us, and the tents of the district officials of Biláspur and Jubbulpore were pitched in the open spaces near the Railway Station: special trains for the Eclipse were announced to run into Sahdol from Nágpur, Jubbulpore and Biláspur.

The natives of the surrounding hills and forests began to converge on Sahdol, the news of the great coming Eclipse and of the preparations being made for it having penetrated to their villages; their desire to witness the phenomenon from Sahdol instead of from their homes was not so much due to their appreciation of the advantage of being on the centre line of totality, as to their belief that the Eclipse would be only visible from the English Astronomers' Camp.

Both the villagers and the *Khalásis* from Northern India prophesied that the Eclipse would be accompanied by an Earth-quake: I had never heard the idea before, but I now see that Dr. Ginzel, in *Himmel-und-Erde,* regards an Earth-quake as a probable terrestrial effect of an Eclipse, although the mechanism of connection is unknown.

On January 20th, General Strahan, General Woodthorpe and Sir Thomas Holdich arrived, and on January 21st Captain Bullen, Captain Dealy and Captain Ewbank, all of the Royal Engineers.

Part III.

Results of the Eclipse Observations.

20. The day of the Eclipse was cloudless, all observations were successful, no hitches or break-downs occurred, and the native recorders and counters acquitted themselves with honor. One or two seconds were perhaps lost by the Astronomers at the beginning of totality: the sweep of the shadow was to have been the signal for commencing their programme, but the sudden darkening, that had been expected, did not occur, and totality came on unawares.

For his determination of the place of the Moon, the Astronomer Royal took ten photographs during the partial phase preceding totality and ten more during the second partial phase: these were supplemented by the timings of the four contacts.

The results of the observations made during totality were:—

(*a*) Seven photographs of the Corona, taken by the Astronomer Royal with different exposures, giving images of the Sun, 3½ inches in diameter.

(*b*) Twelve photographs of the Corona, taken by Professor Turner with different exposures, six giving images of the Sun, 1½ inches in diameter, and six giving images ½ inch in diameter.

(*c*) Two photographs of the Corona taken by Professor Turner with the polariscope through prisms of Iceland Spar for testing the polarisation of coronal light.

21. The effects of the Eclipse on the temperature are exhibited in the accompanying diagram, Plate No. V. The black curve in this diagram shows the changes of temperature on January 23rd, which may be considered a normal day. The red curve shows the changes on the day of the Eclipse. The temperature was recorded every half hour for several days before and after the Eclipse, and it was our original intention to deduce the curve of normal temperature from the mean of a fortnight's observations. This method, however, was abandoned, because, during the third week of January, a wave of heat passed over India, and the temperature rose considerably, rendering a *mean* temperature very misleading and meaningless. It was considered fairer to compare January 22nd with the 23rd rather than with the 21st, because the early morning temperatures of the 22nd, the day of the Eclipse, agreed closely with those of the 23rd, but were four degrees higher than those of the 21st.

The Barometer was read every half hour on days preceding and succeeding the day of the Eclipse, and every 5 minutes on January 22nd. The Eclipse had apparently no effect on its readings.

The shadow bands were seen by Sir Thomas Holdich on the white-paper of his plane-table, which he had erected for his drawing of the Eclipse.

Captain Bullen, R.E., photographed the Corona with a camera of his own.

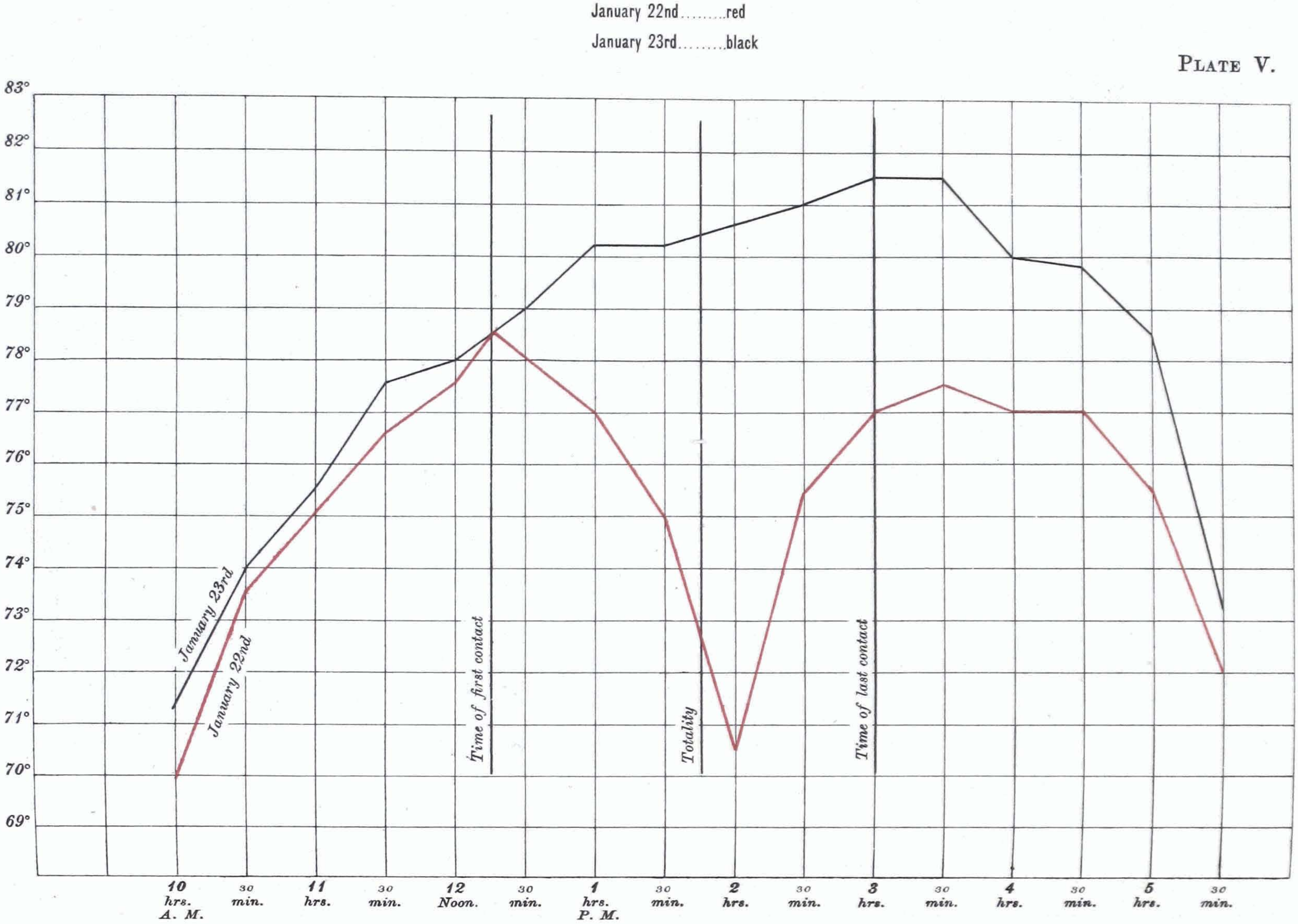
Coronal Drawings.

22. It had been decided beforehand to ask as many observers as possible to make hand-drawings of the Corona, and cards printed for the purpose at Dehra Dún were distributed at Jeúr, Pulgaon, Sahdol, Buxar and Dumraon. Unfortunately the objection was raised that at former Eclipses no two eye-sketches had ever been alike, and that their differences had been too great for reconciliation. The idea, that eye-drawings were worthless, gained ground and many people were influenced, and out of 100 cards issued only 31 were received back. The fact, that no two observers make the same drawing may well go to prove,* that the outer part of the Corona is a phenomenon due to the state of the terrestrial atmosphere in the observer's line of sight, and thus differing in appearance at very short intervals of distance. The Corona moreover may be in a state of pulsation and not constant in form, and different drawings would necessarily be different. A free-hand sketch may possibly exaggerate the coronal dimensions, just as our eye gives us an exaggerated idea of the size of a full Moon, but the retina for short exposures is more sensitive than any plate, and the photographs of the Corona fail to convey in any way the general impression, which I received, of totality.

After the Eclipse was over, I collected 23 coronal drawings from Sahdol, 3 from Dumraon, 2 from Buxar and 3 from Jeúr, making 31 in all.

* Tait's Recent Advances in Physical Science.

Curves of Temperature on January 22nd and 23rd 1898, Sahdol.



The following is a list of the eye-observers :—

At Sahdol.

1. Lieut.-Colonel D. W. K. Barr, C.S.I., Agent to the Governor General, Central India.
2. Mrs. Barr.
3. Miss E. C. Barr.
4. Captain A. F. Pinhey, Political Agent, Baghelkhand.
5. Mrs. A. F. Pinhey.
6. Lieutenant E. Barnes, 1st Assistant to the Agent to the Governor General.
7. Surgeon-Lieut.-Colonel P. A. Weir, Residency Surgeon.
8. Mrs. Weir.
9. Major-General C. Strahan, R.E., Surveyor General of India.
10. Colonel Sir T. H. Holdich, K.C.I.E., C.B., R.E.
11. Major-General R. G. Woodthorpe, C.B., R.E.
12. Major S. G. Burrard, R.E.
13. Captain W. Ewbank, R.E.
14. Captain J. A. Dealy, R.E.
15. Mrs. A. Cooke.
16. Mr. J. B. Leventhorpe, C.E., Superintending Engineer, Jubbulpore.
17. Mr. F. Marsh, Traffic-Superintendent, Bengal-Nágpur Railway.
18. Surgeon-Lieut.-Colonel A. M. Crofts.
19. Mr. Bijaynath Sirkar, B.A., C.E., Public Works Department.
20. Dr. E. H. Bingley, M.D., Medical Officer, Bengal-Nágpur Railway.
21. Mr. A. T. Goodfellow, Auditor, Bengal-Nágpur Railway.
22. Mr. G. D. Oswell, M.A., Principal Rajkumar College, Raipur.
23. Manohar Krishna, Under-graduate, Calcutta University.

At Jeúr.

24. Mr. Hari Gopal Kadne, College of Science, Poona.
25. Mr. H. F. Beale, C.E., Principal, College of Science, Poona.
26. Mr. Jurao Raghoba, College of Science, Poona.

At Dumraon.

27. Mr. M. F. Gauntlett, I.C.S., Assistant Accountant-General, Bengal.
28. Lieutenant F. A. Buzzard, R.A.
29. Mr. J. Eccles, M.A., Survey of India Department.

At Buxar.

30. Lieut.-Colonel Hanbury White, R.E.
31. Mrs. E. Scott.

Of the thirty-one hand-drawings I now attach fac-similes. These drawings, it should be remembered by critics, were made under great difficulties, the light was bad, the time was very limited and the splendour of the Eclipse was distracting to the attention. The draftsmen were asked to carefully estimate the lengths,* the positions, the directions and the forms of the streamers, but neatness and beauty, it was explained to them, were not required.

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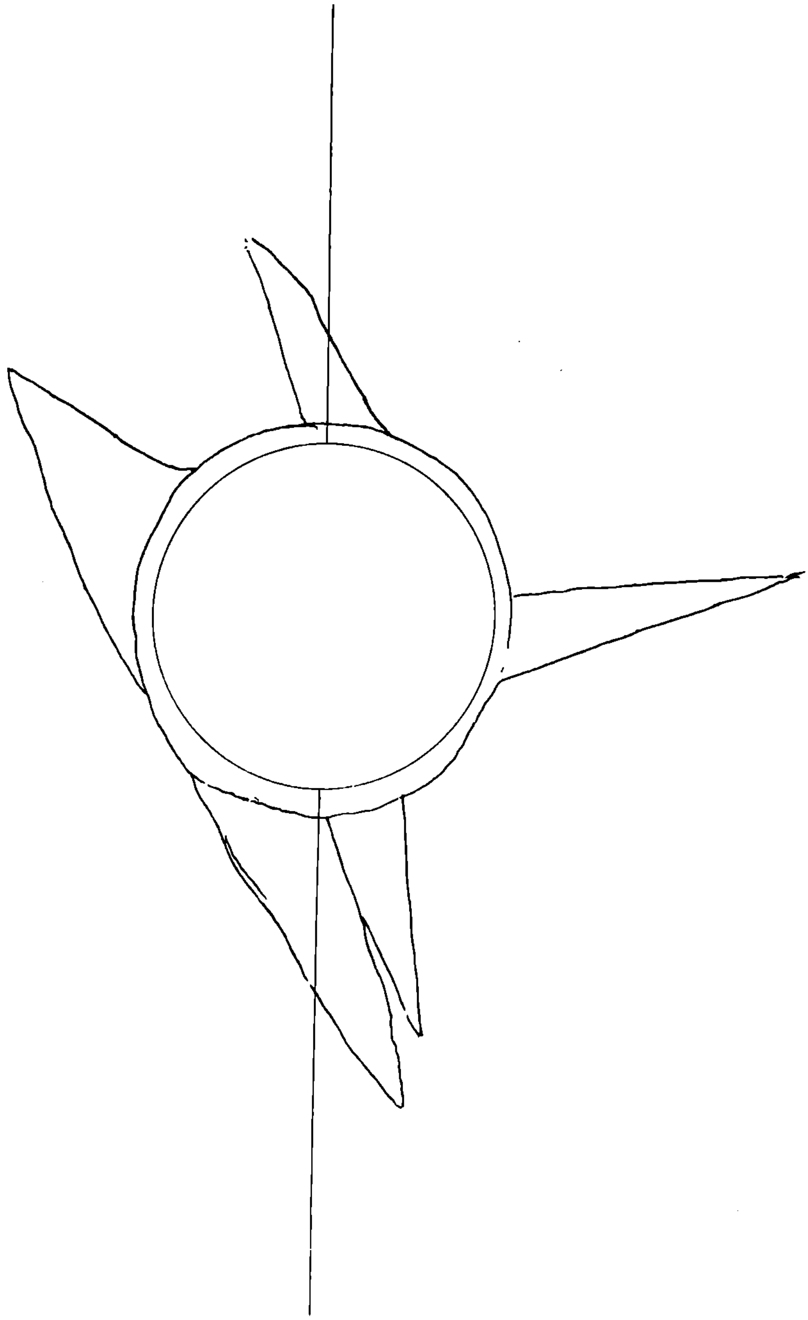
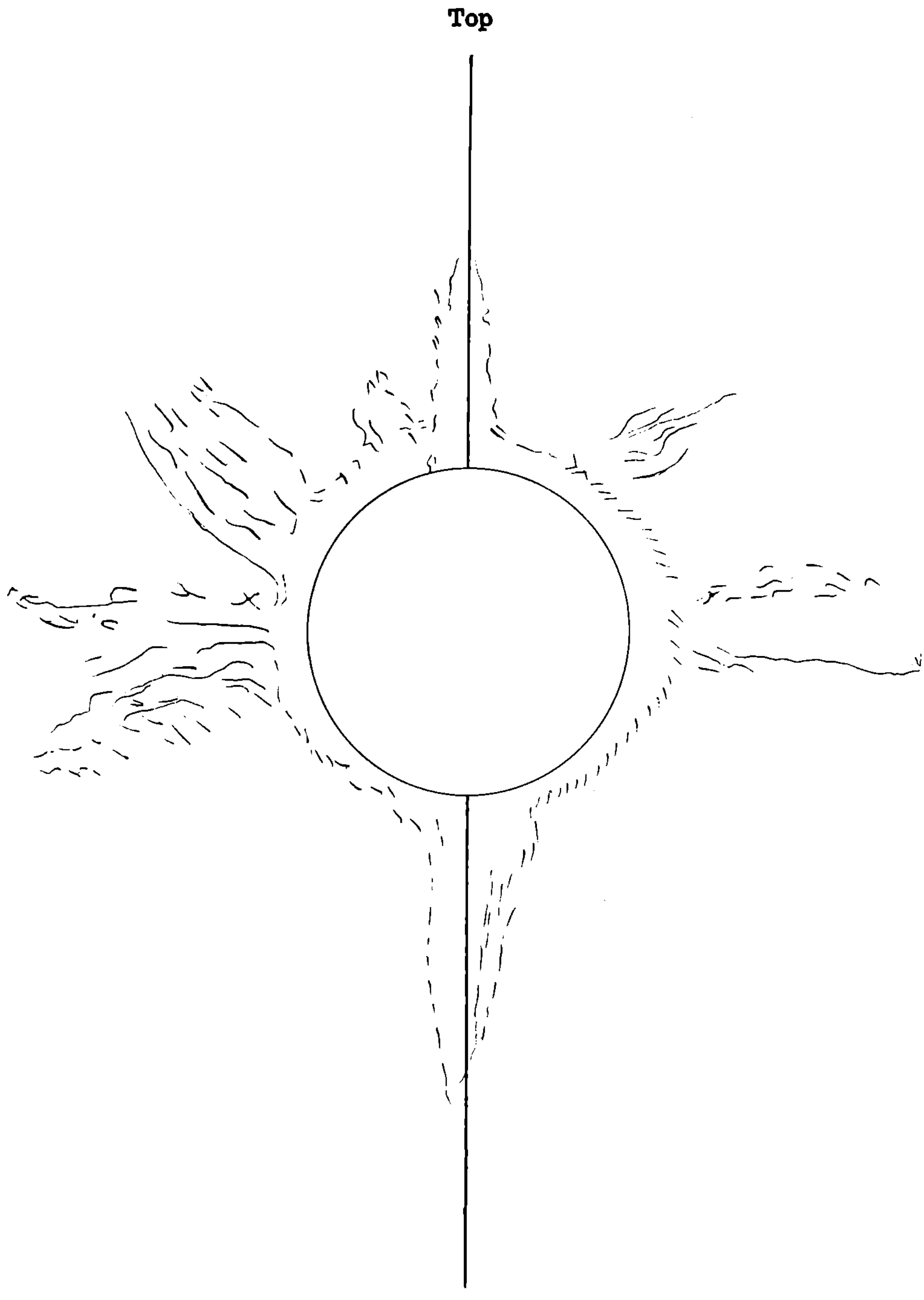
* The lengths of the streamers are shown differently in different drawings: it must not be assumed that such discrepancies are due to errors of estimation. It is more probable that the eyes of some observers were more sensitive than those of others, and really saw more.

Top



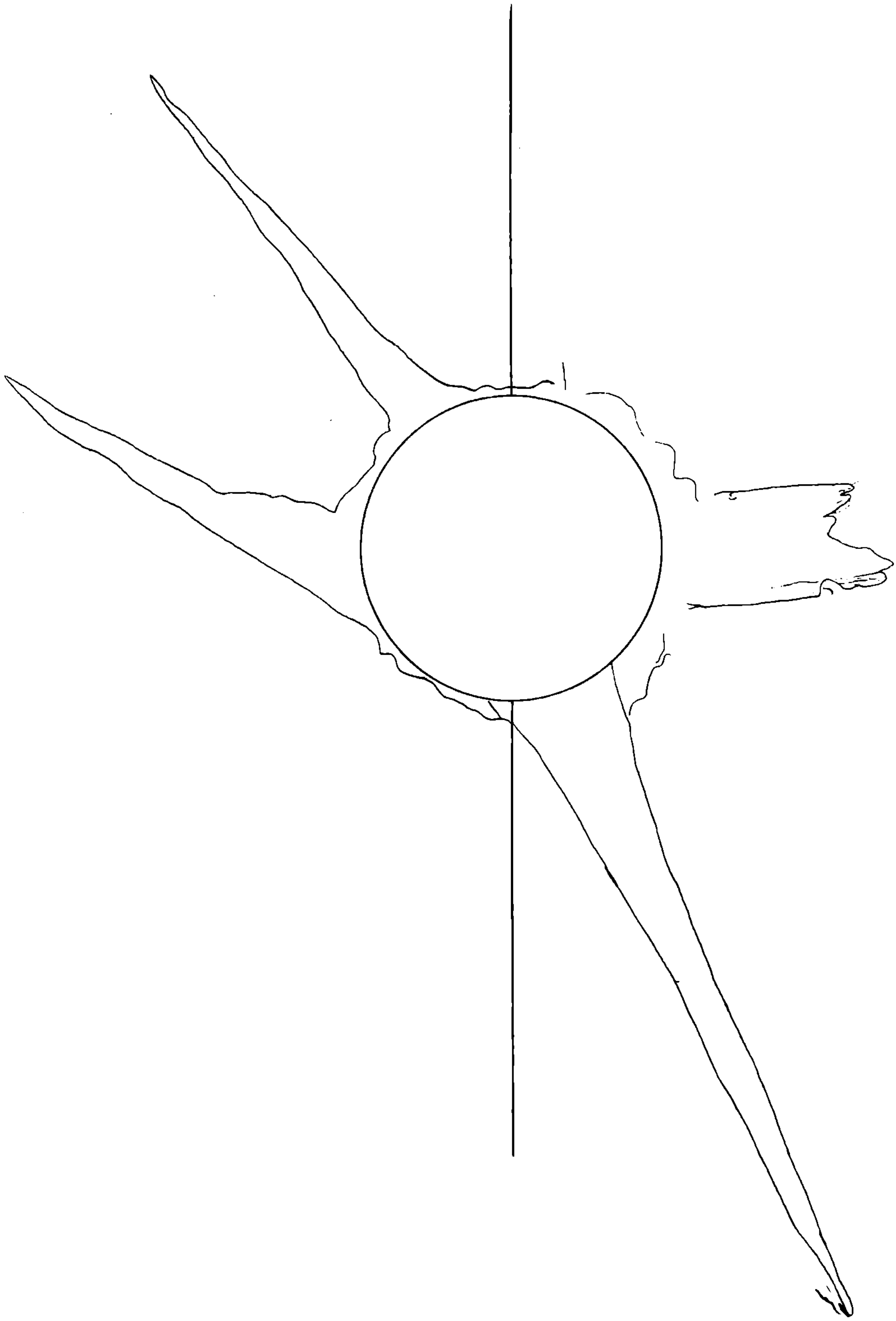
By Lieut. Col. D. W. K. BARR,
Agent Governor-General,
Central India.

(SAHDOL, No. 1.)



By Mrs. BARR,
(SAHDOL No. 2.)

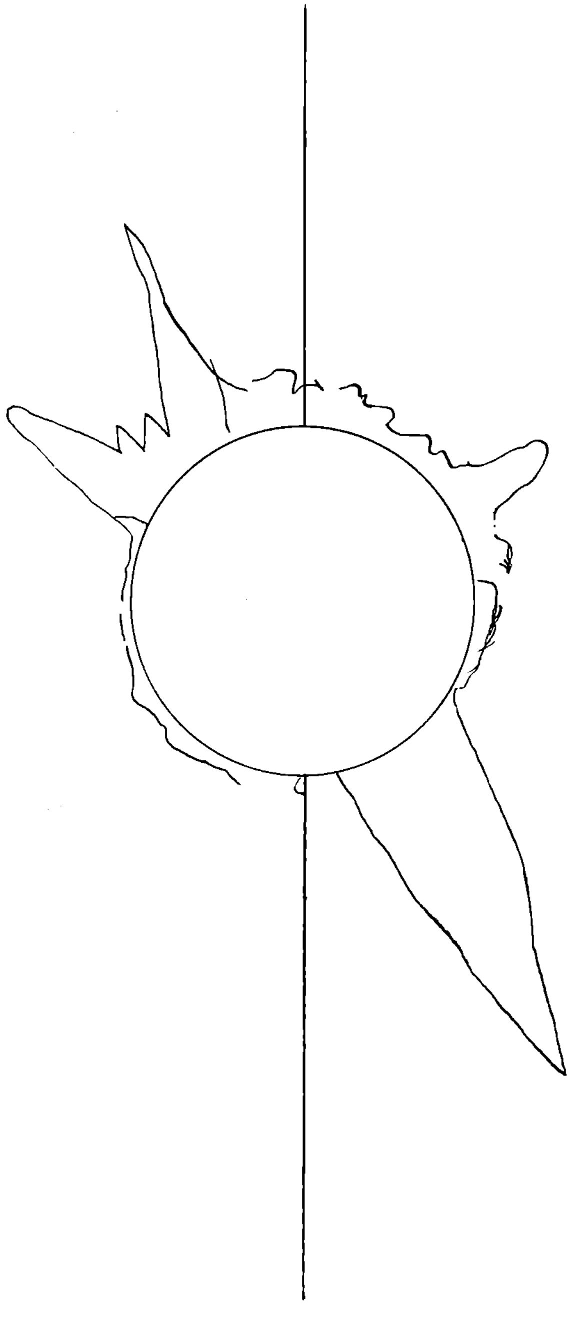
Top



BY MISS E. C. BARR,

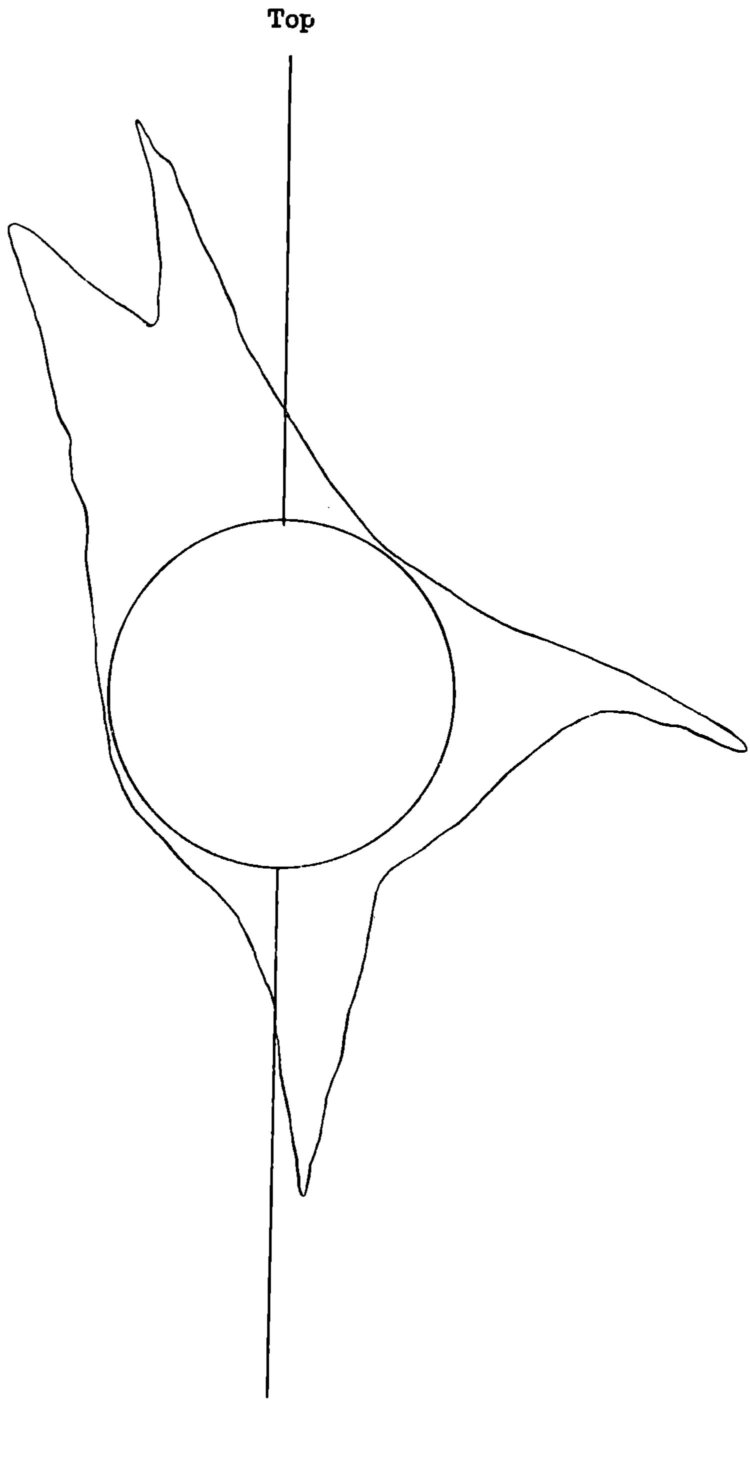
(SAHDOL No. 3.)

Photo. S. I. O., Calcutta.



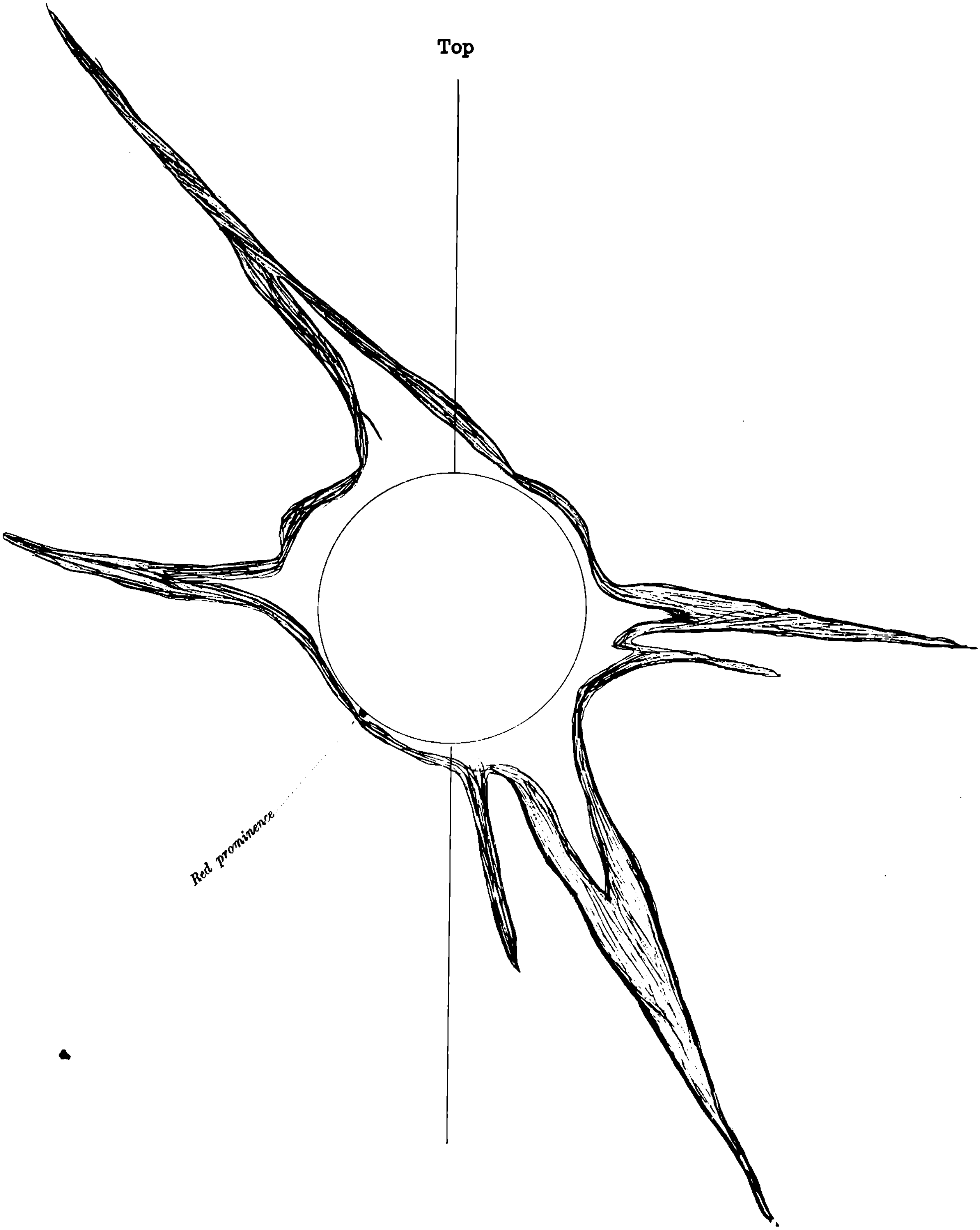
By Captain A. PINHEY,
(SAHDOL No. 4.)

Photo. S. I. O., Calcutta.



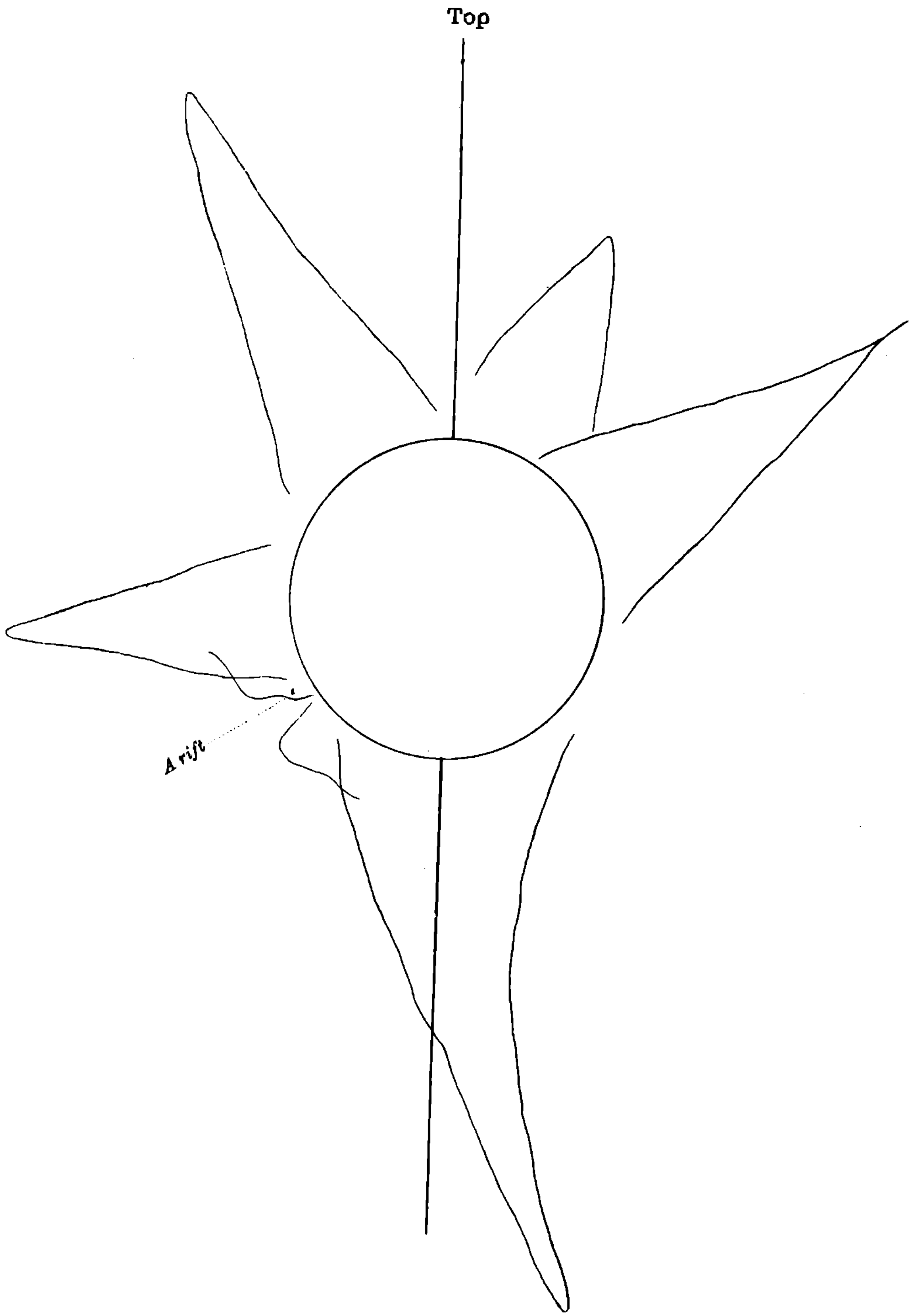
By Mrs. A. F. PINHEY,

(SAHDOL No 5.)



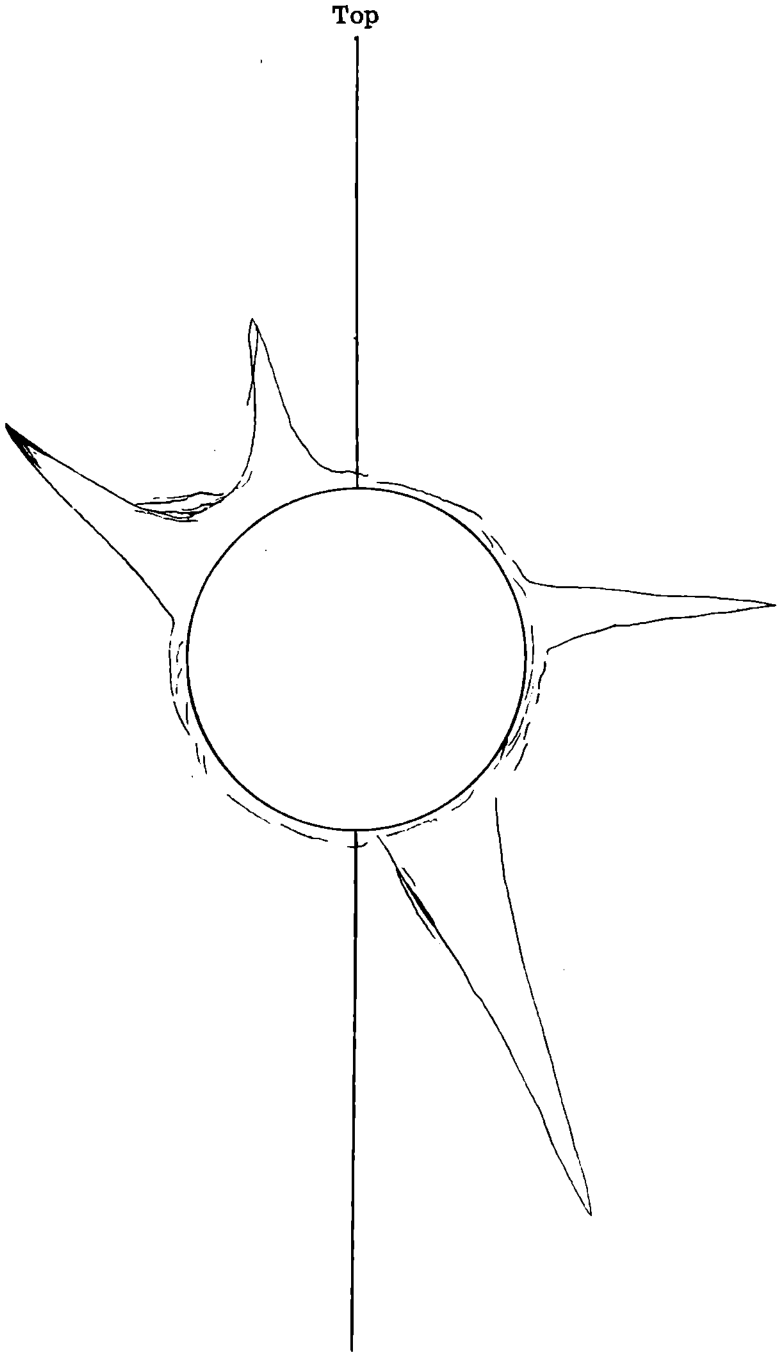
BY LIEUT. E. BARNES,
Assistant Agent Governor General,
Central India.

(SAHDOL No. 6.)



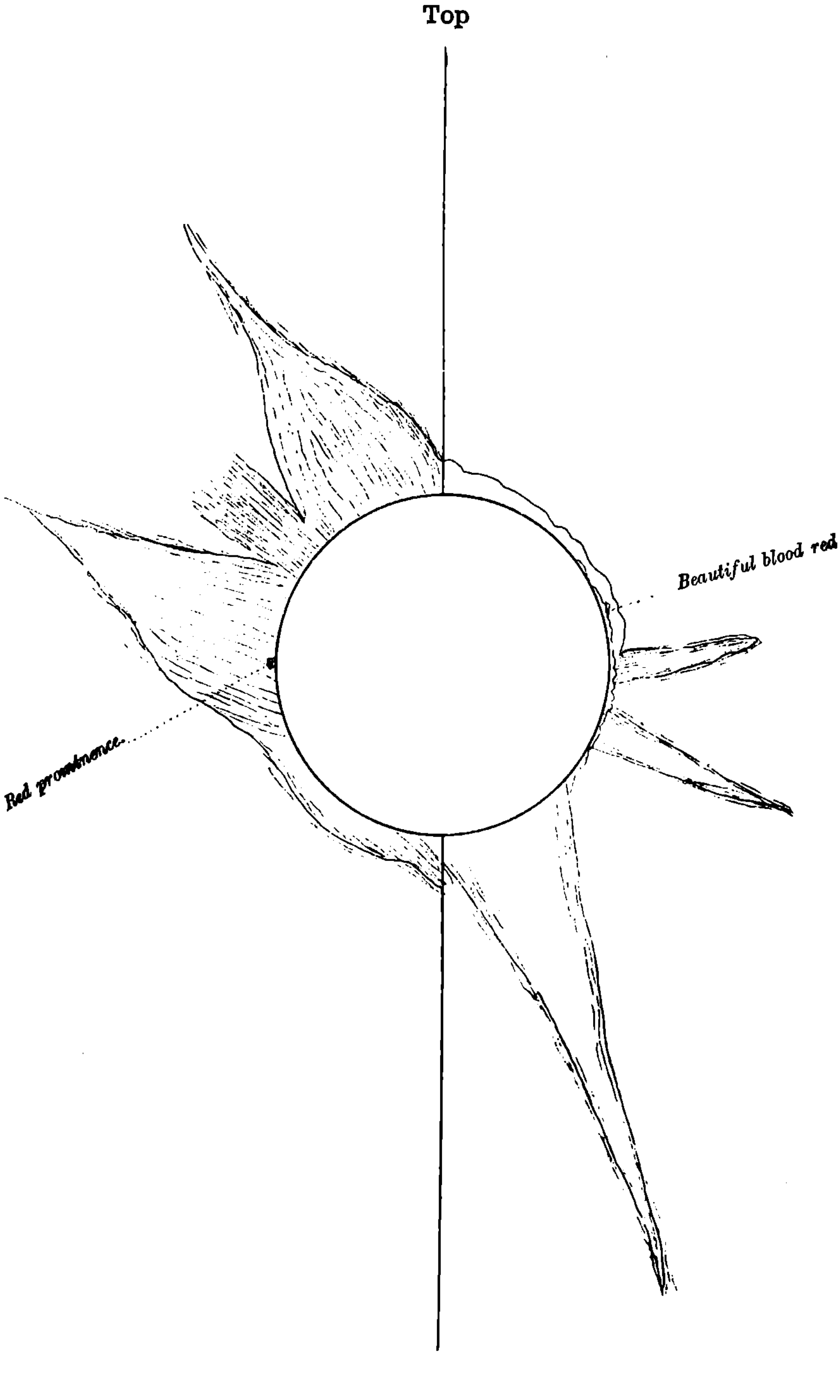
By Surgn. Lieut. Col. P. A. WEIR, I. M. S.

(SAHDOL, No. 7.)



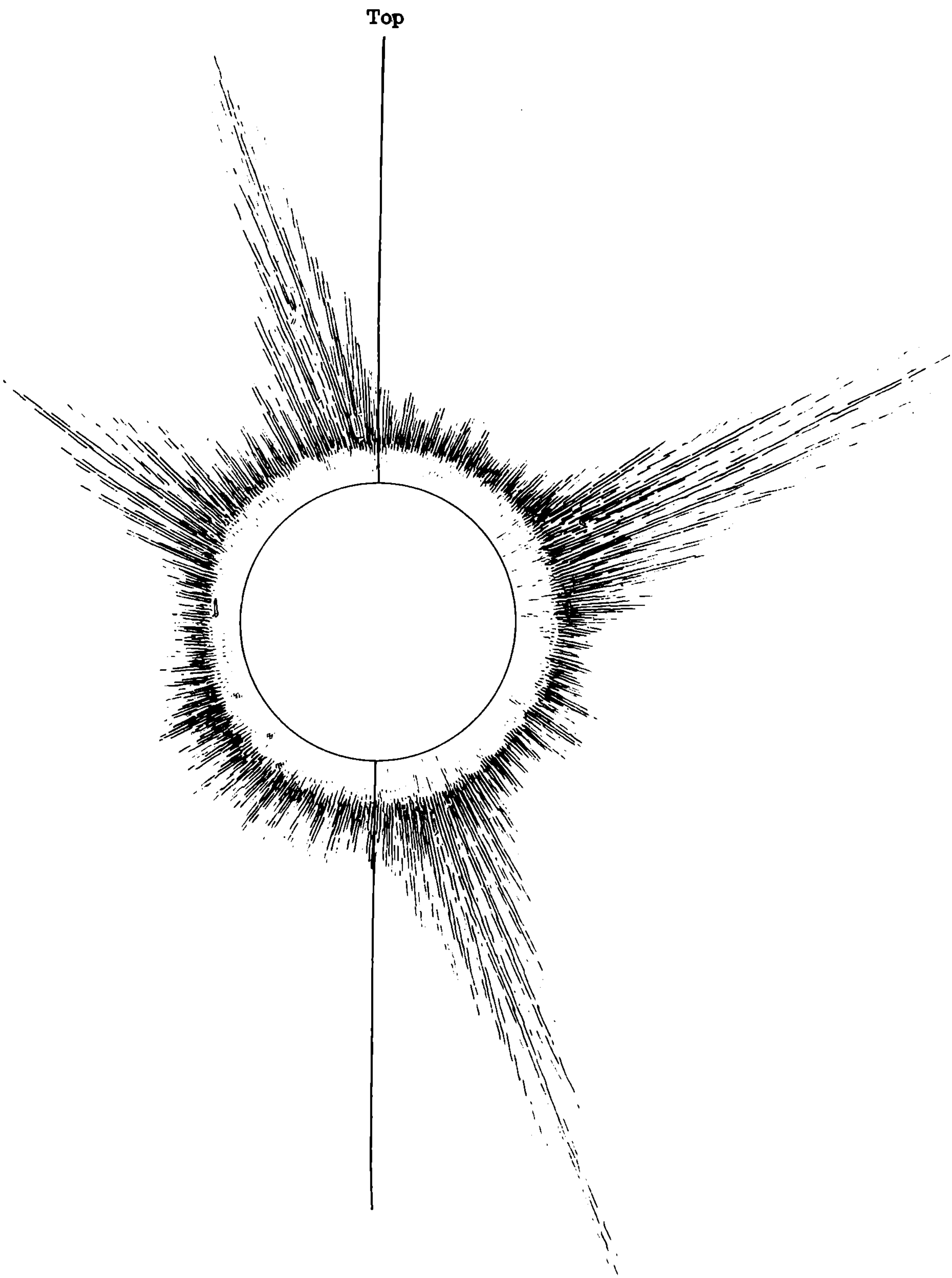
BY MRS. WEIR.

(SAHDOL No. 8.)



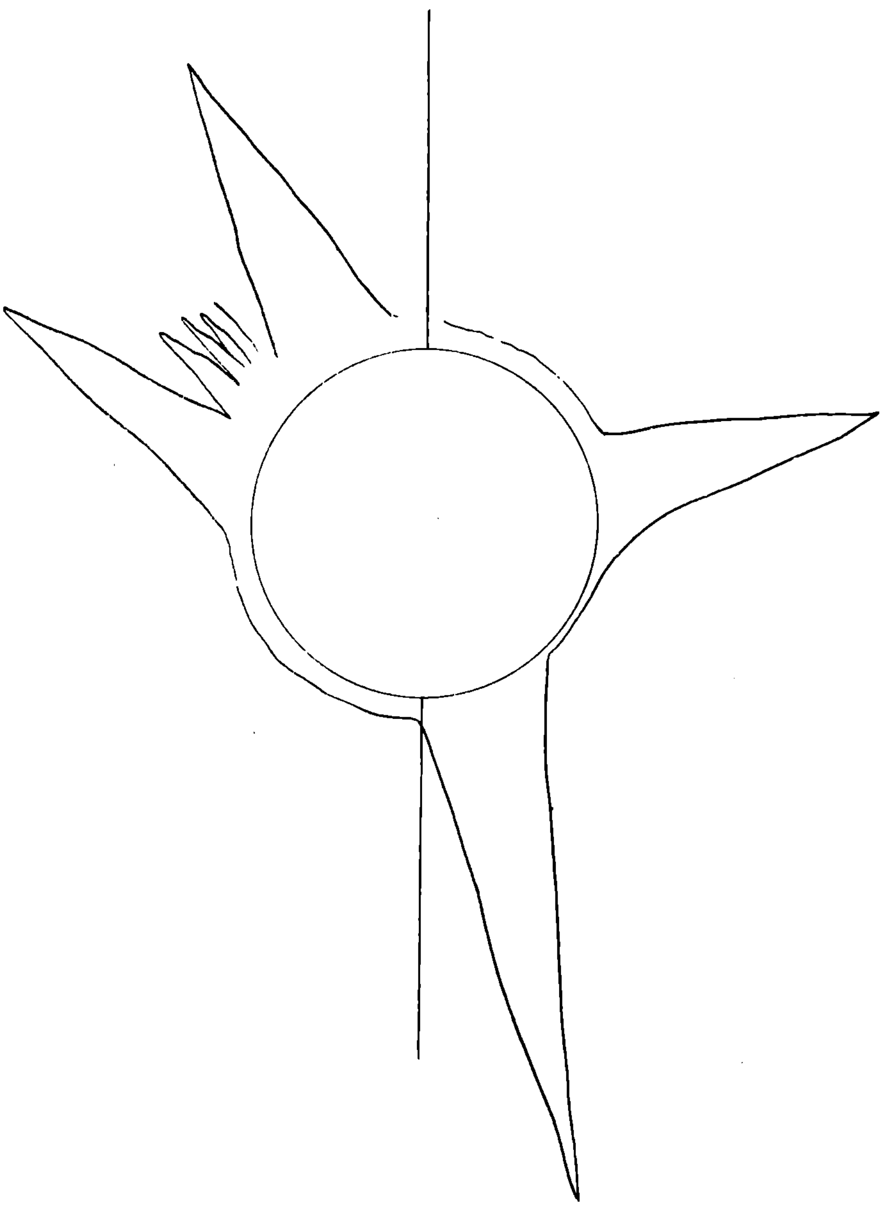
By General C. STRAHAN, R.E.

(SAHDOL No. 9.)



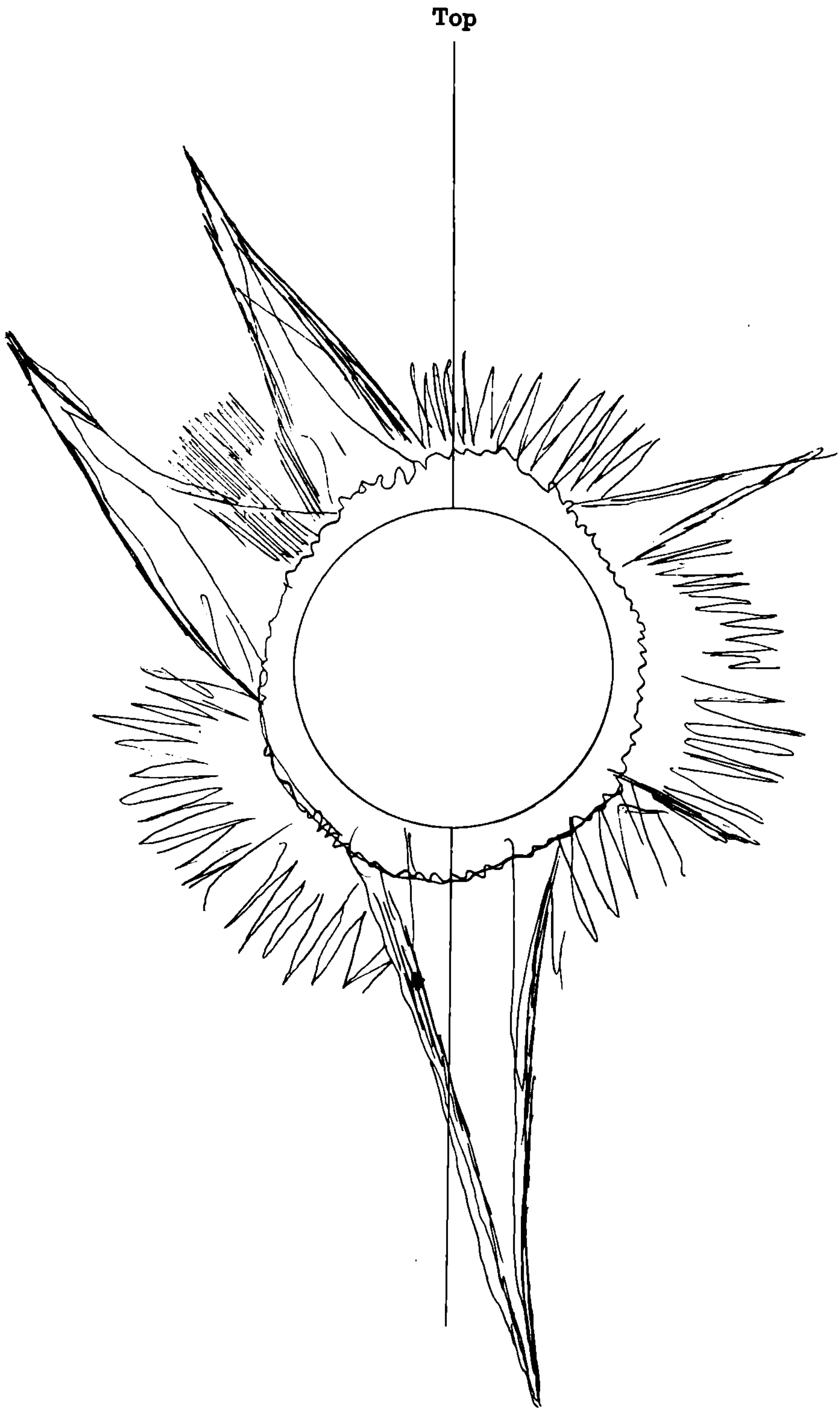
BY COL. SIR T. H. HOLDICH, K.C.I.E., C.B., R.E.

(SAHDOL No. 10.)



BY MAJOR-GENL. R. G. WOODTHORPE, C.B., R.E.

(SAHDOL No. 11.)



By Major S. G. BURRARD, R.E.

(SAHDOL No. 12.)

Photo. S. I. D., Calcutta.

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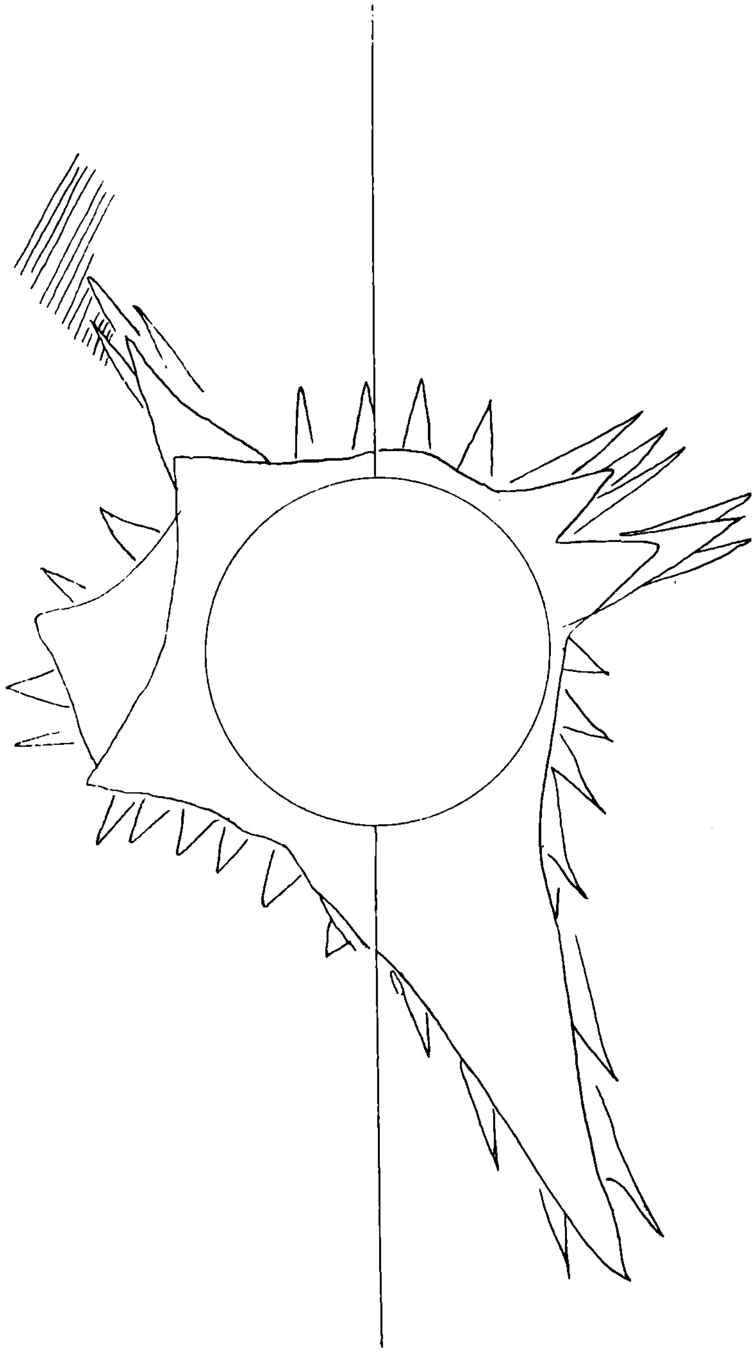
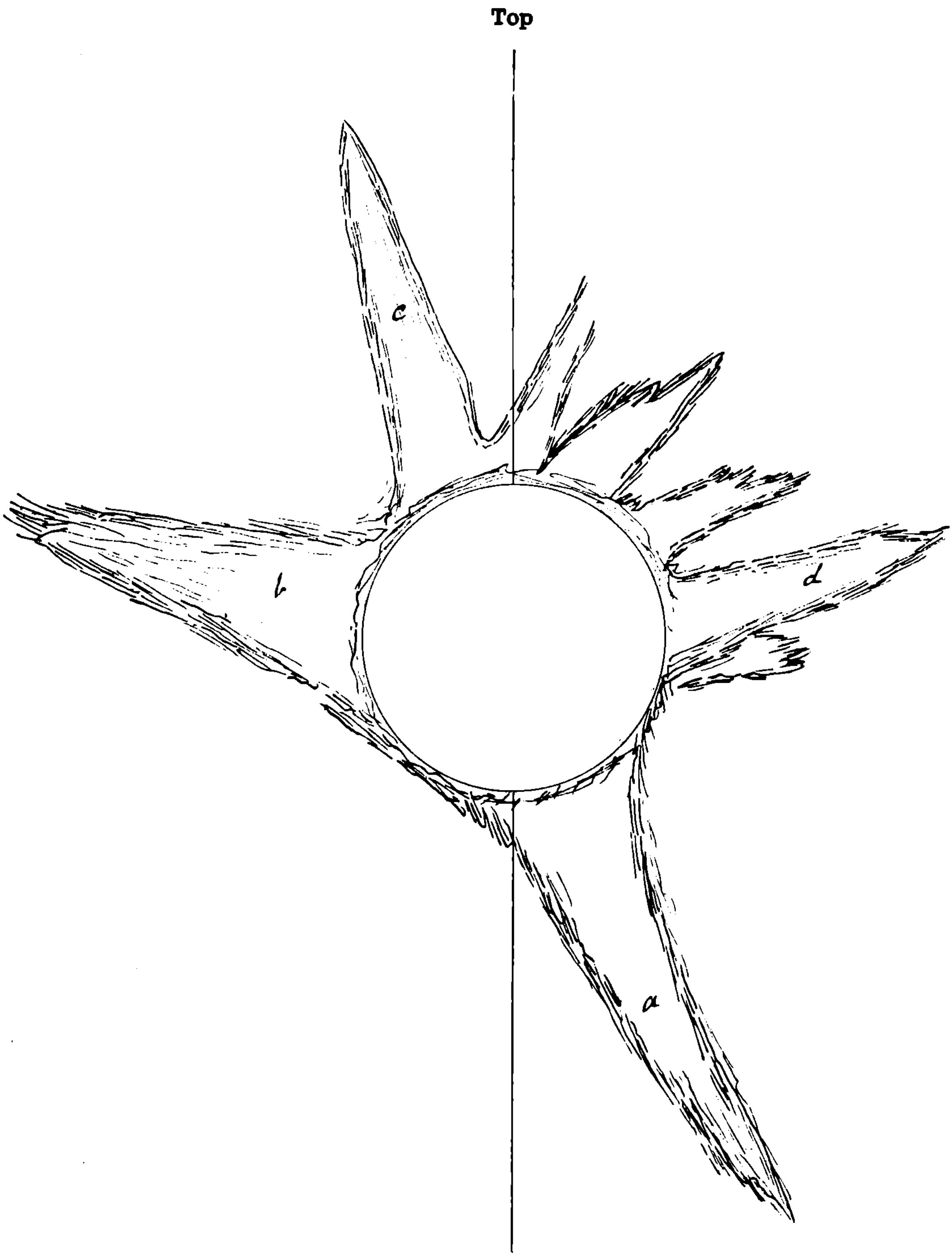


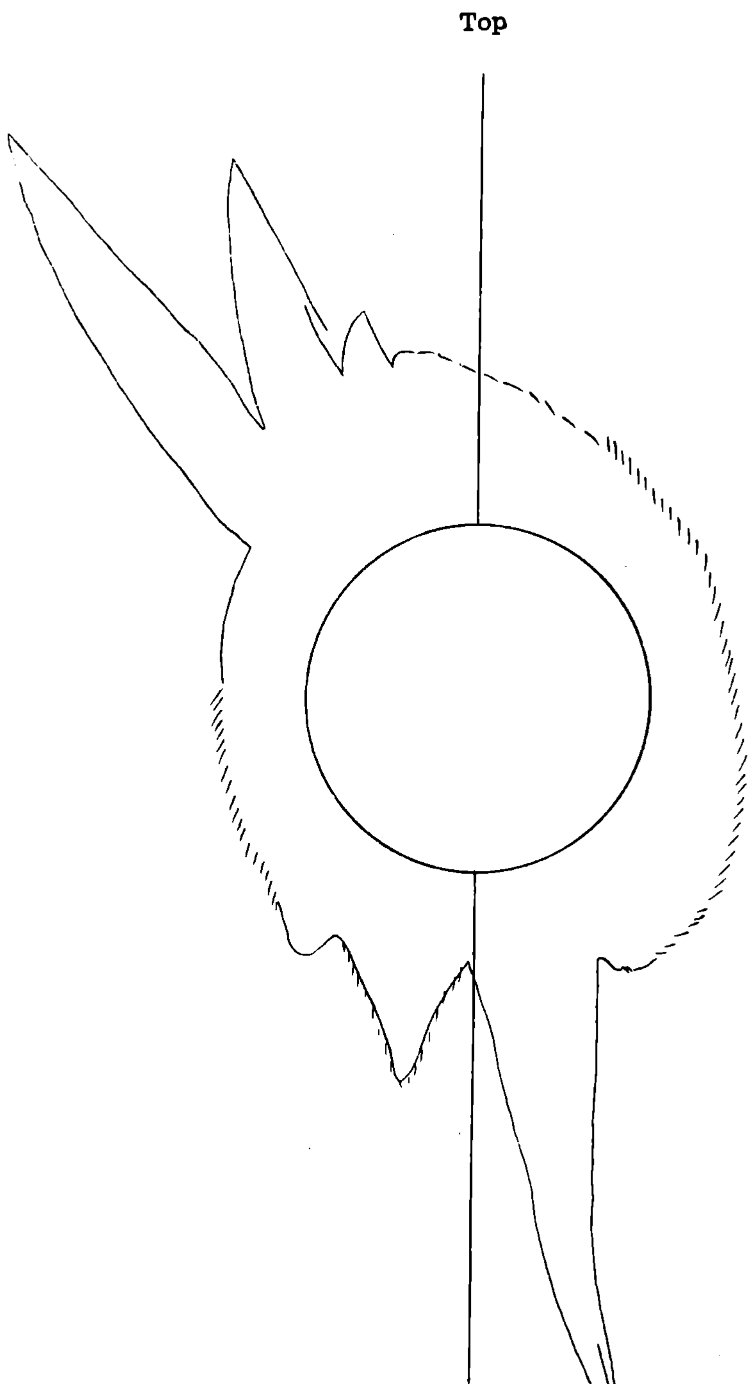
By Captain W. EWBANK, R.E.

(SAHDOL, No. 13.)



BY CAPTAIN J. A. DEALY, R.E.

(SAHDOL No. 14.)



BY MRS. ANGELA COOKE,
(SAHDOL No. 15.)

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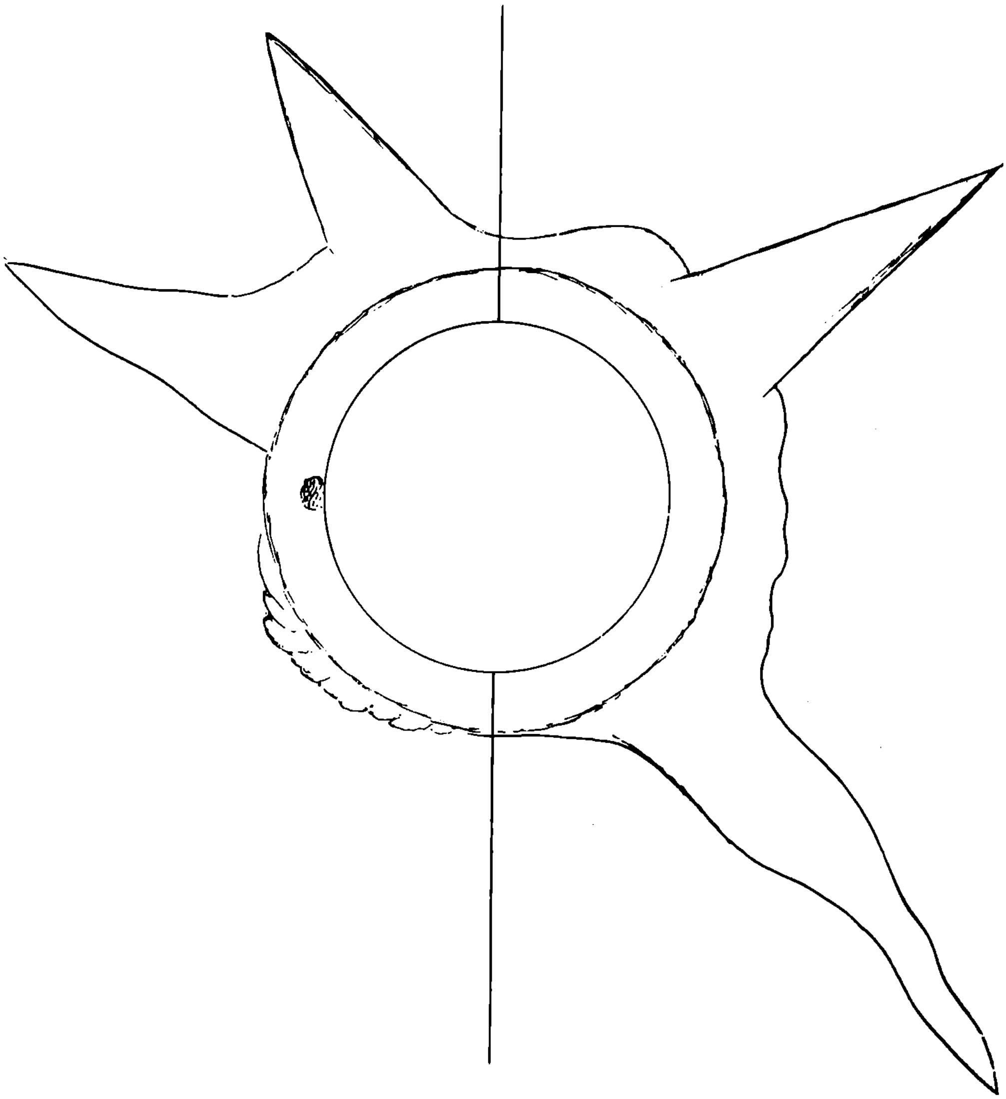

BY MR. J. B. LEVENTHORPE.

(SAHDOL No. 16.)

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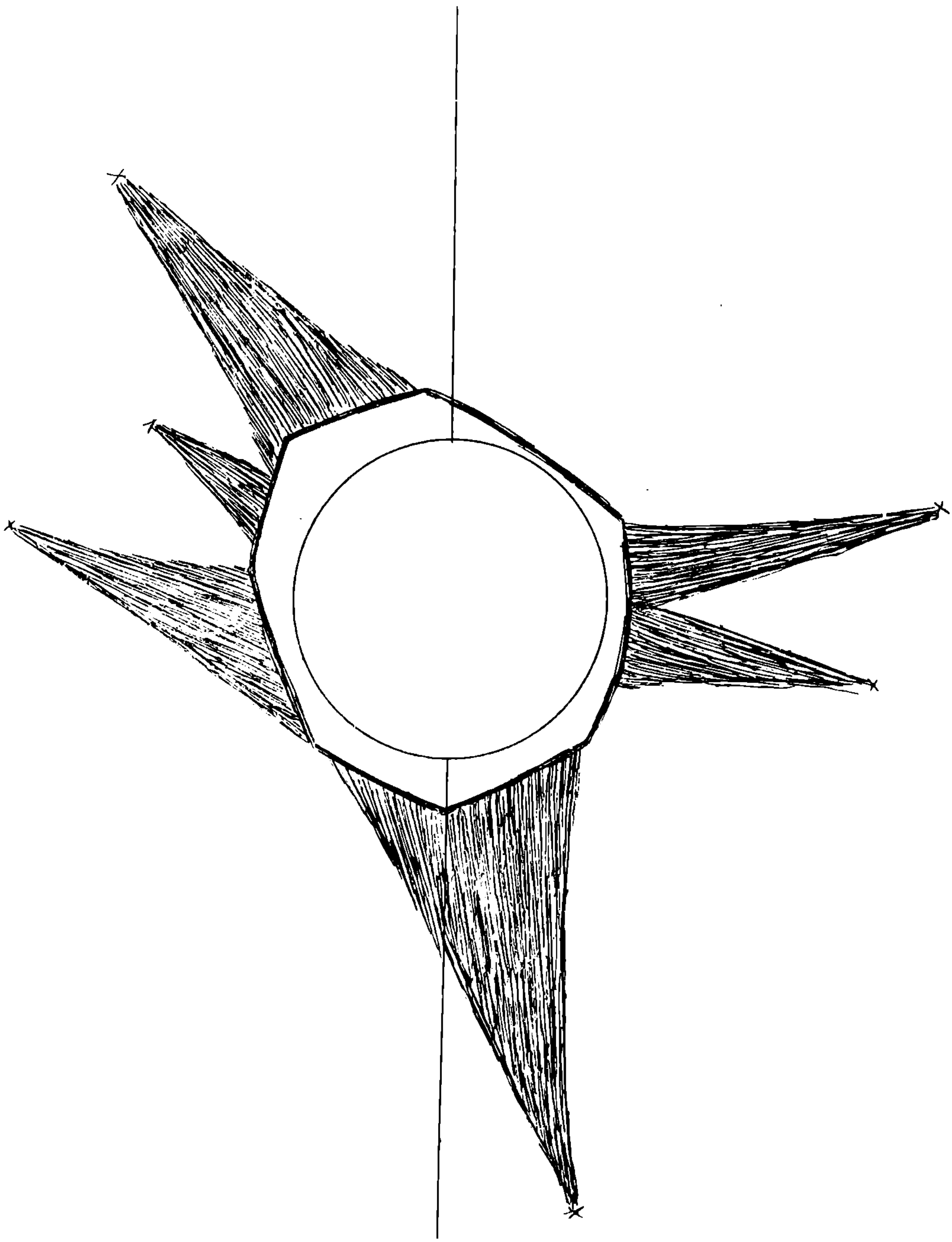
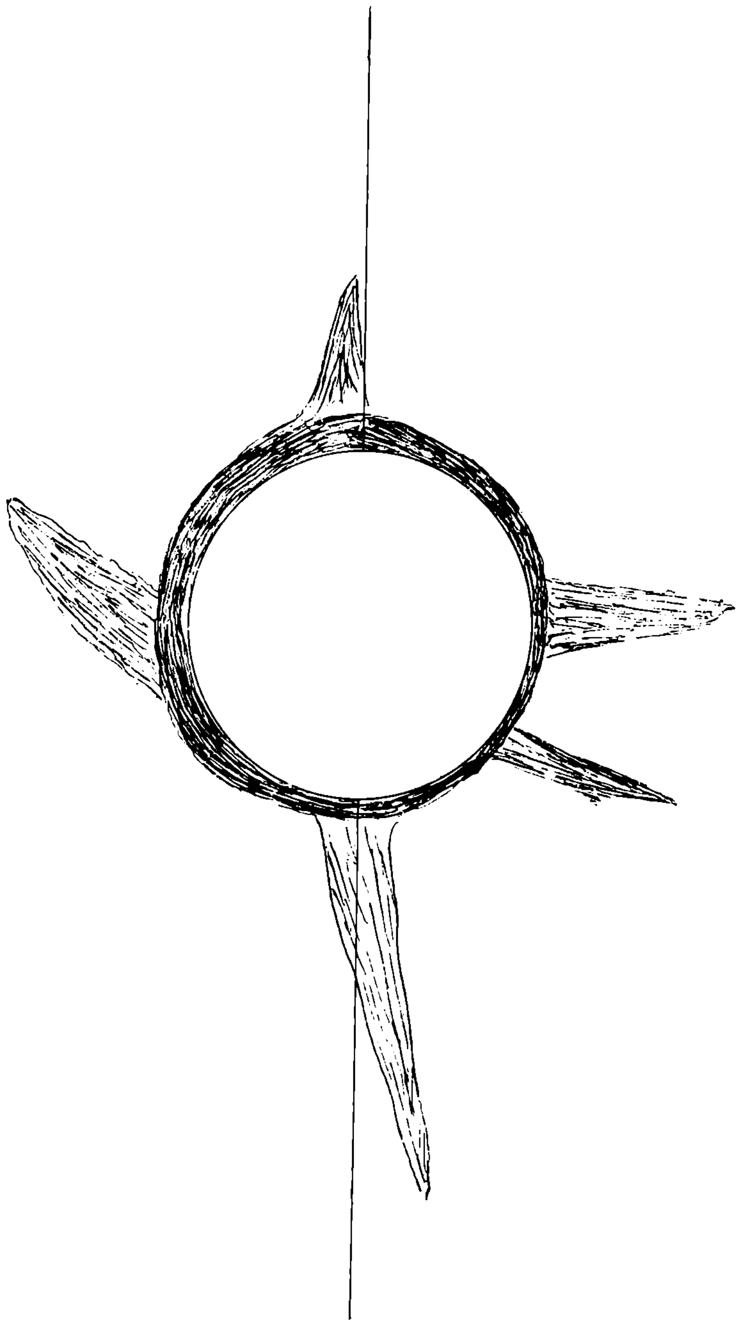


BY MR. F. MARSH,

B. N. Railway.

(SAHDOL No. 17.)

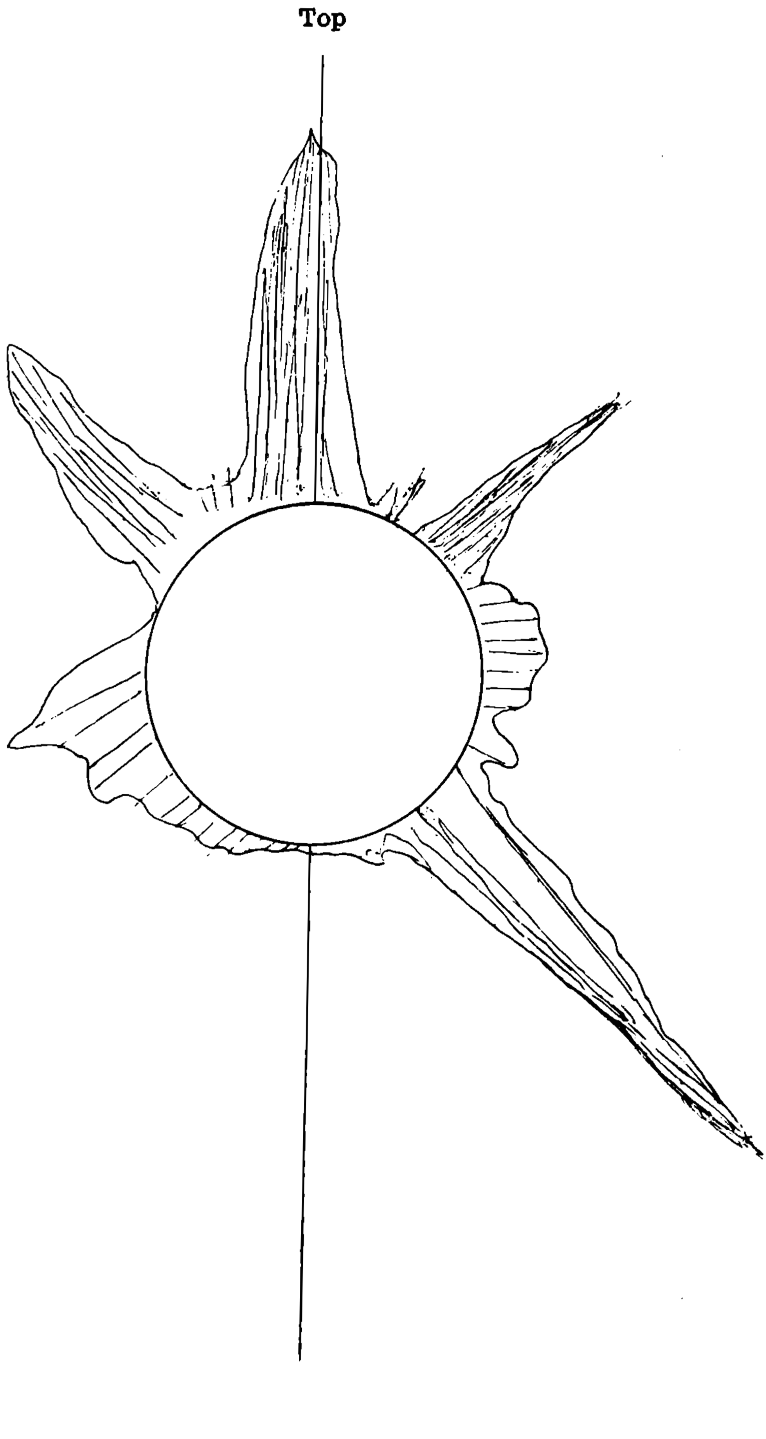
Top



BY SURGEON LIEUT. COLONEL A. M. CROFTS,

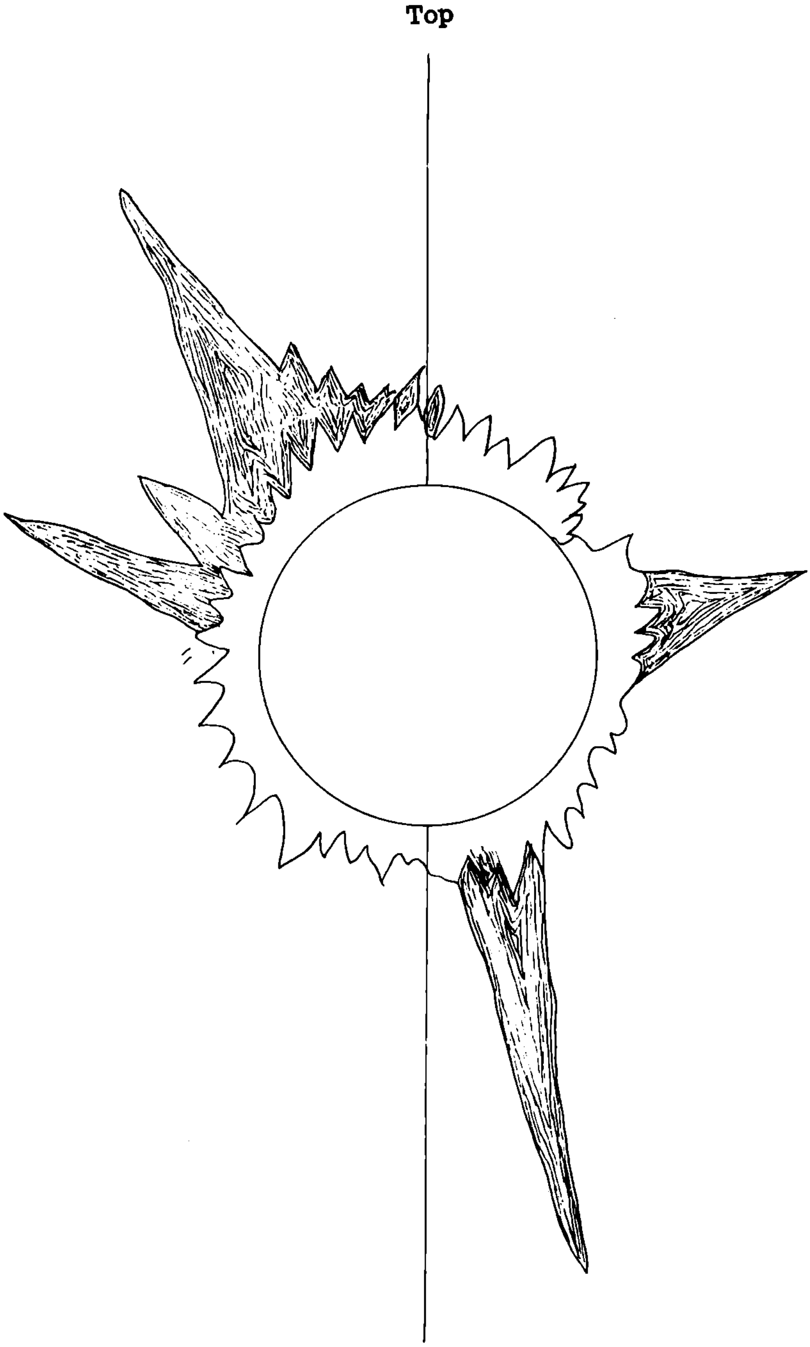
(SAHDOL No. 18.)

Pho'o. S. I. O., Calcutta.



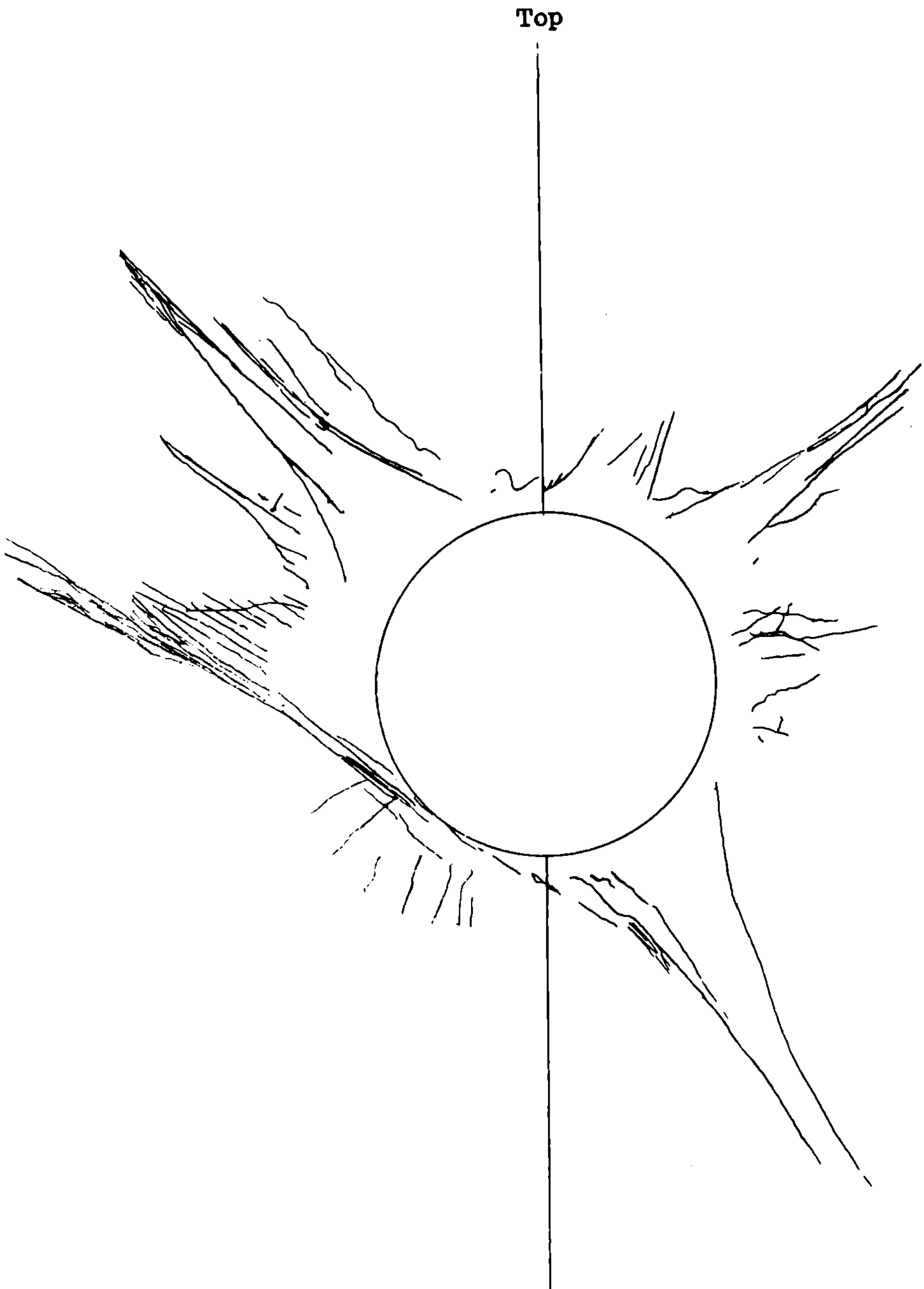
By Mr. BIJAYNATH SIRKAR, B.A., C.E.
Assistant Engineer.
(SAHDOL, No. 19.)

Photo. S. I. D , Calcutta.



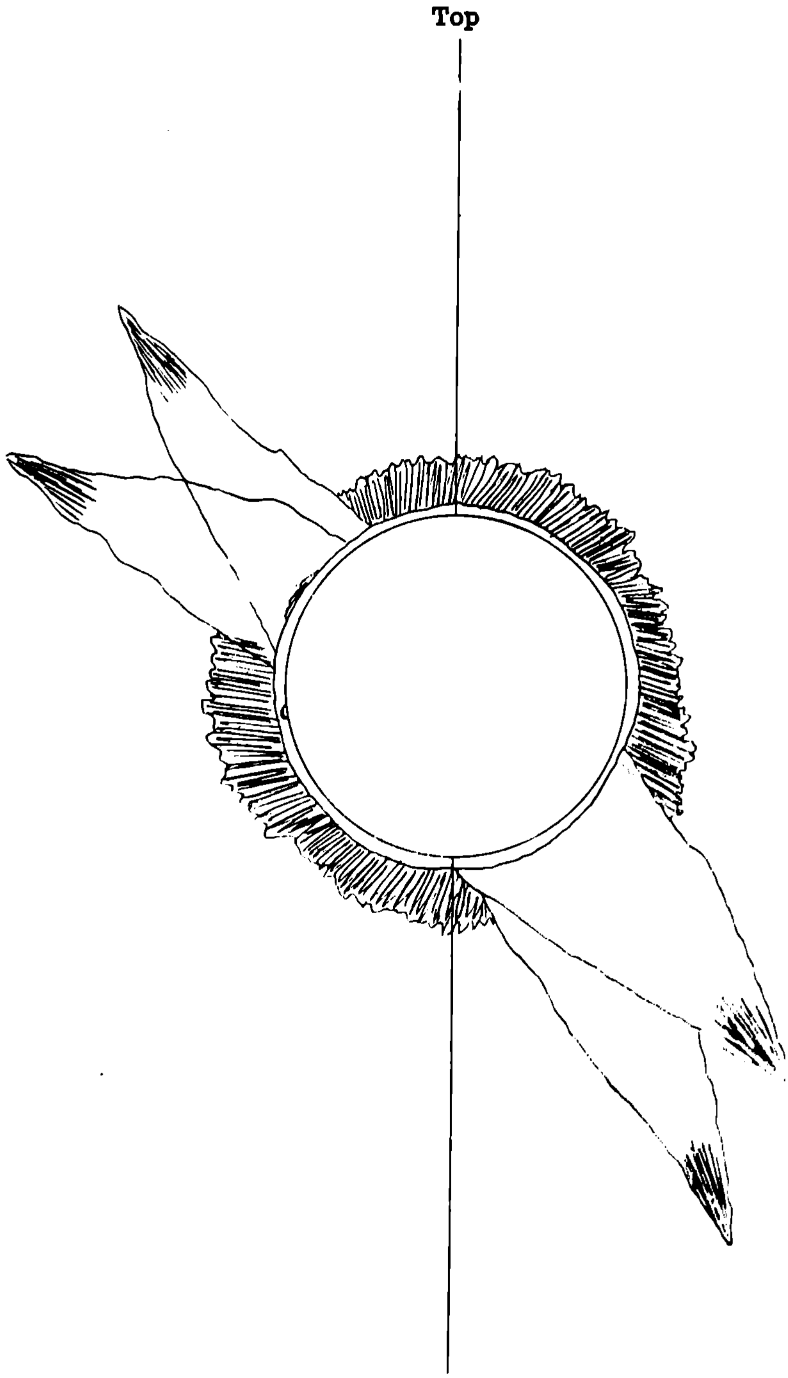
By Dr. E. H. BINGLEY.

(SAHDOL, No. 20.)

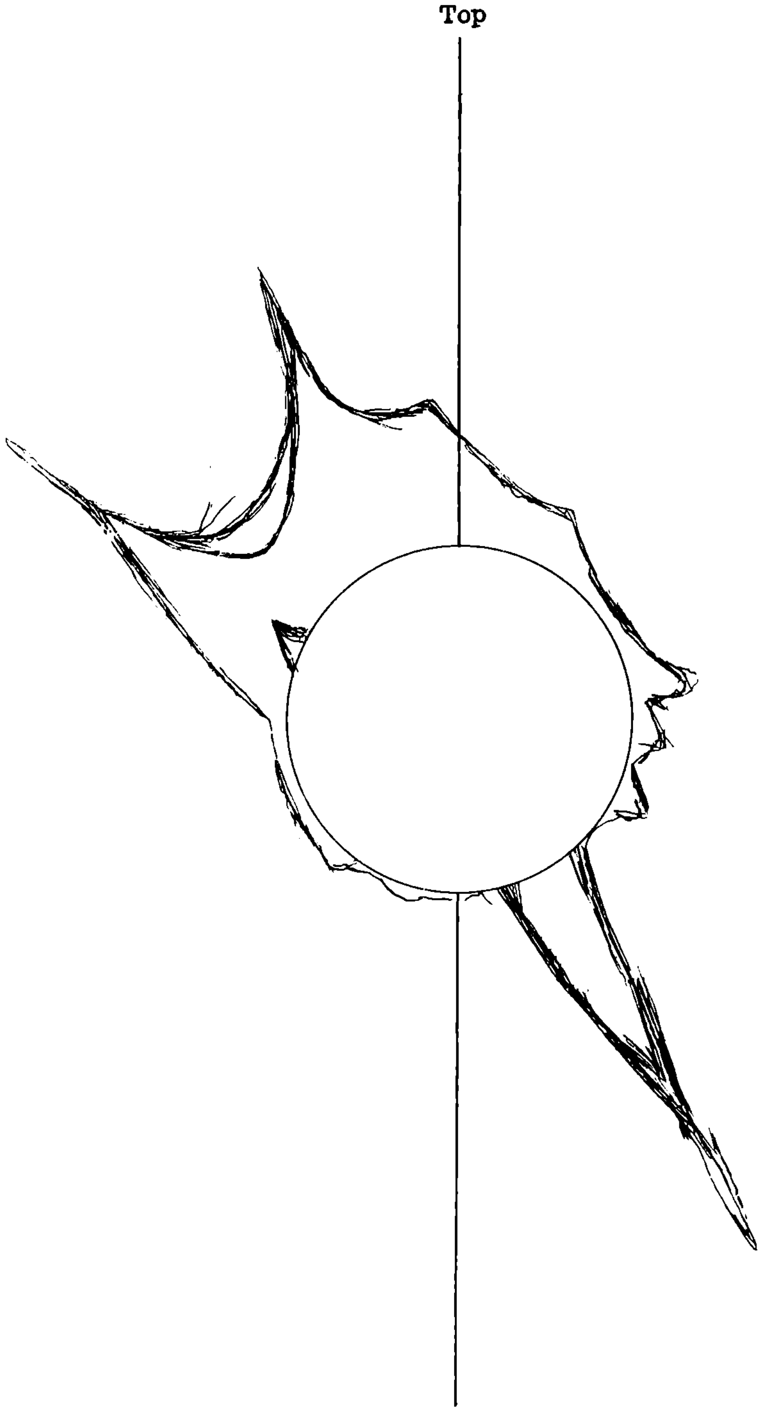


By Mr. A. T. GOODFELLOW.

(SAHDOL, No. 21.)



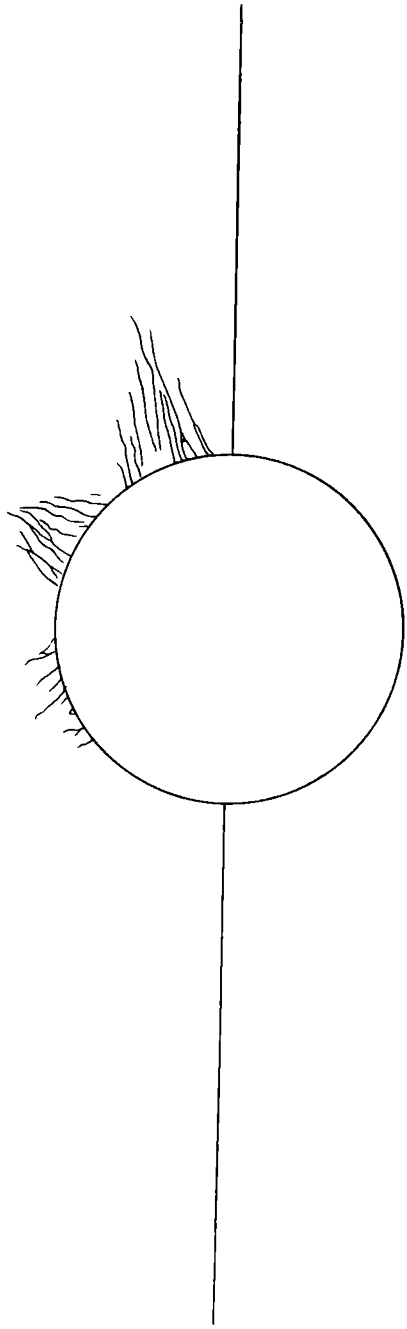
BY MR. G. D. OSWELL.
(SAHDOL, No. 22.)



BY MANOHAR KRISHNA,
Student.

(SAHDOL, No. 23.)

Top

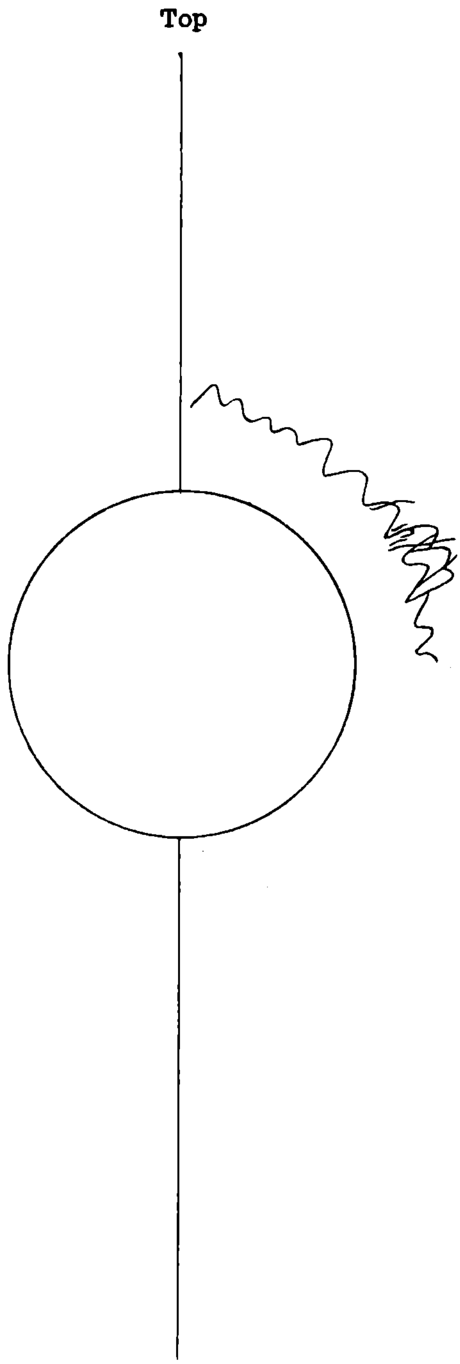


BY MR. HARI GOPAL KADNE.

(JEUR, No. 24.)

To be viewed in combination with drawings Nos. 25 and 26 on the two following pages.

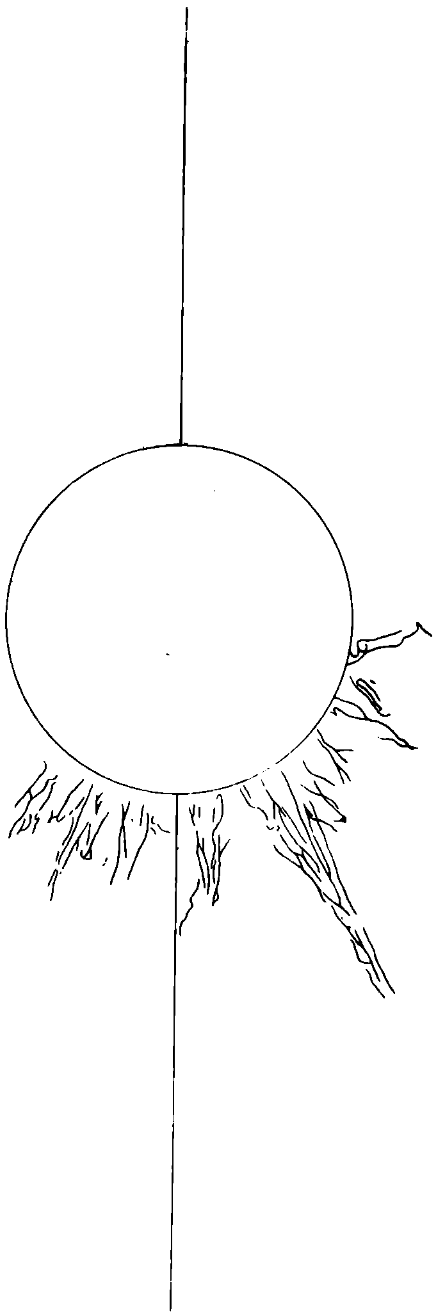
Photo. S. I. O.,



BY MR. H. F. BEALE.

(JEUR, No. 25.)

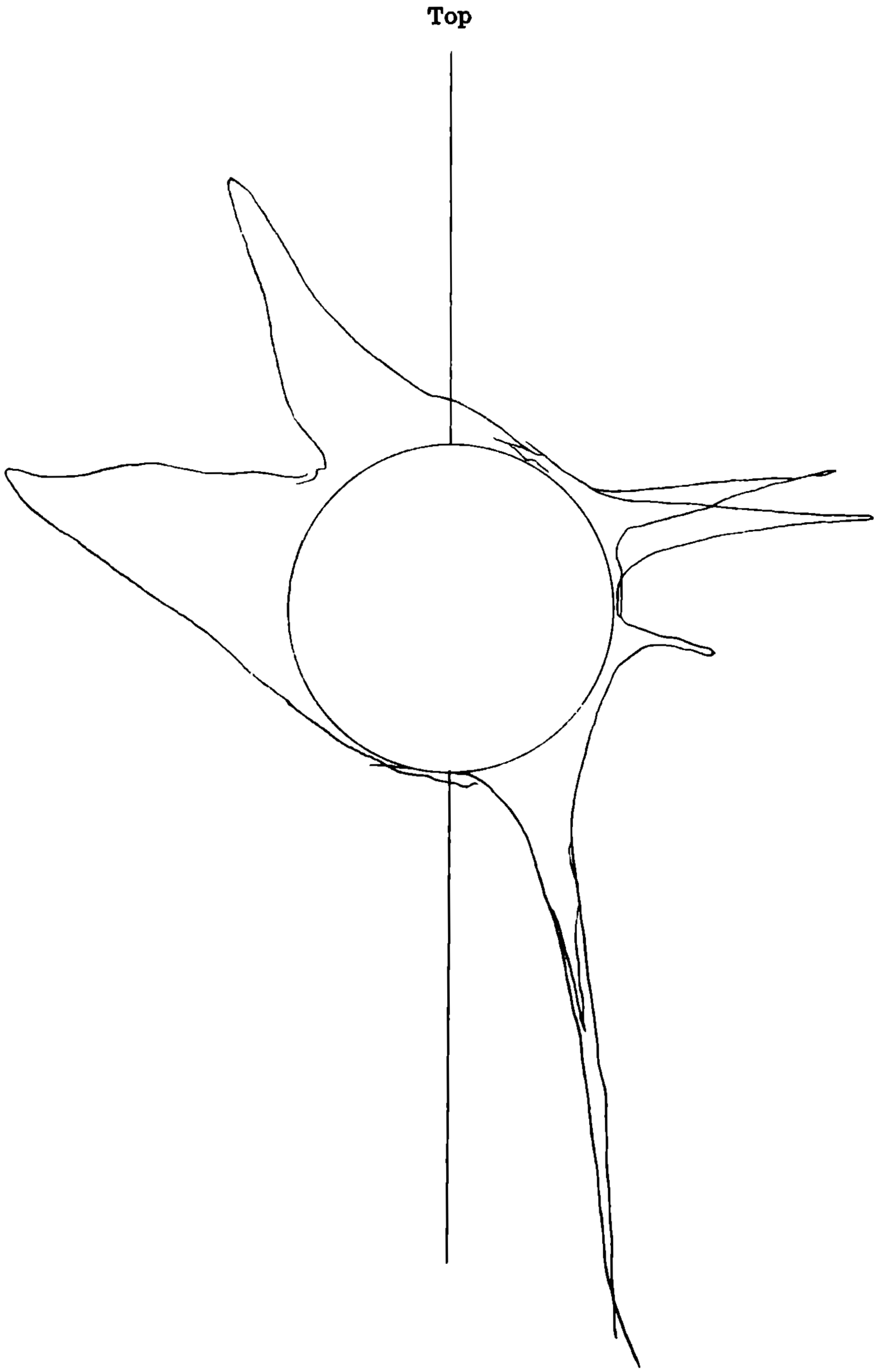
To be viewed in combination with drawings Nos. 24 and 26 on pages 69 and 71.



By Mr. JURAO RUGHOBA.

(JEUR, No. 26.)

To be viewed in combination with drawings Nos. 24 and 25 on the two preceding pages.

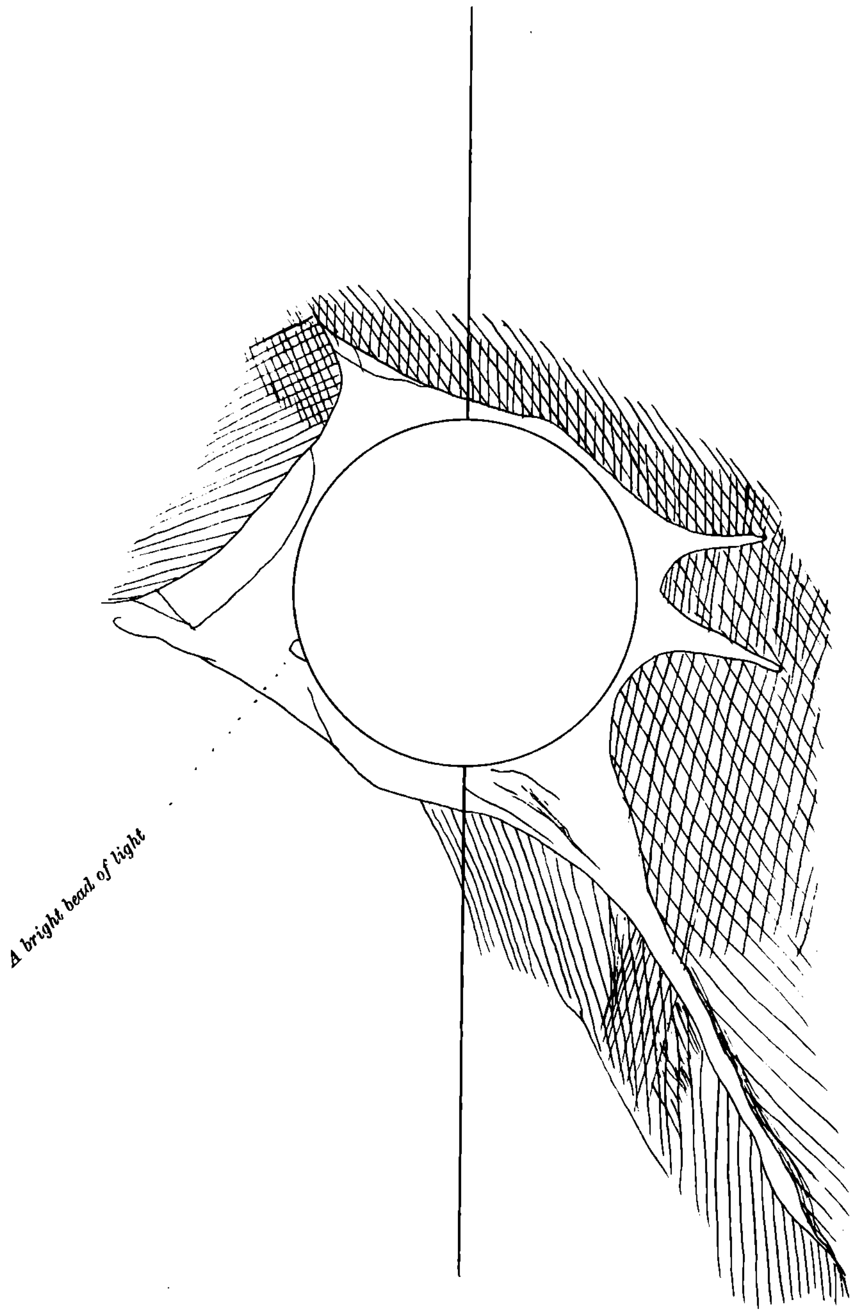


BY MR. M. F. GAUNTLETT.

(DUMRAON, No. 27.)

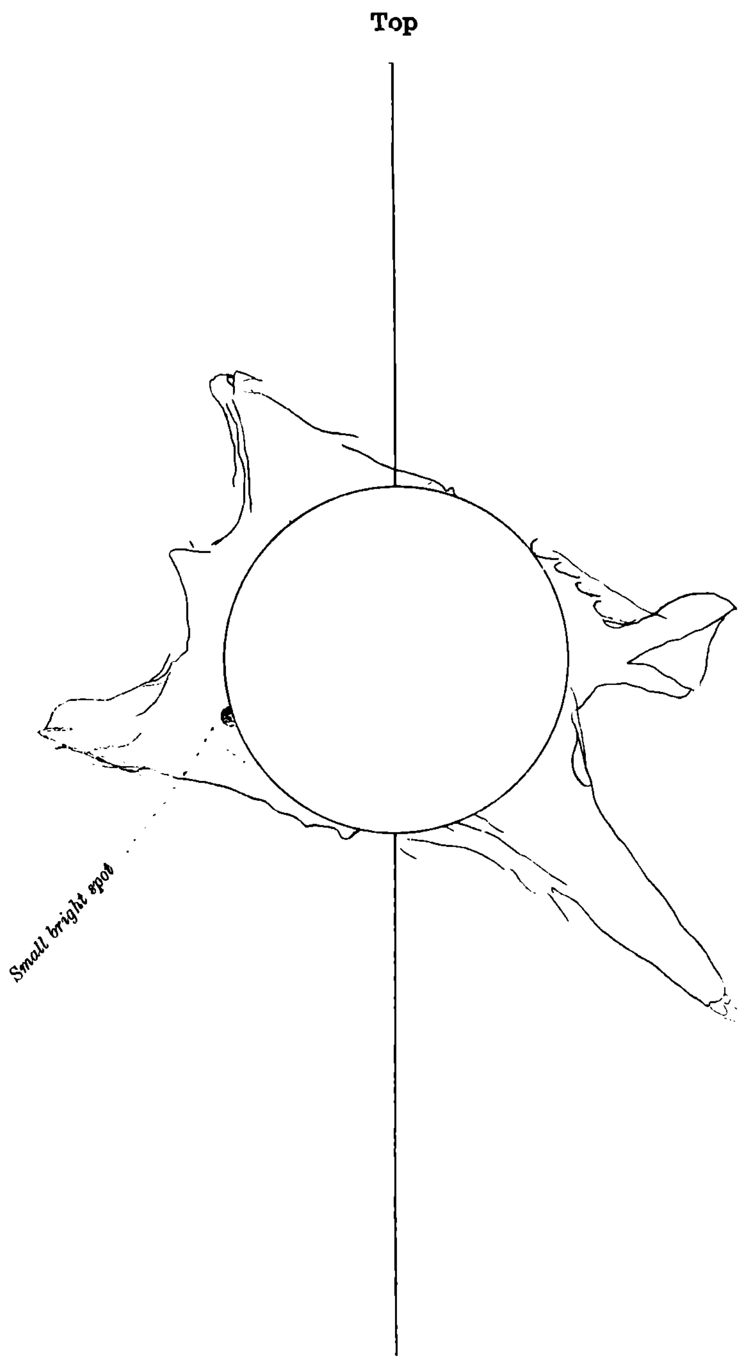
Photo. S. I. D., Calcutta.

Top



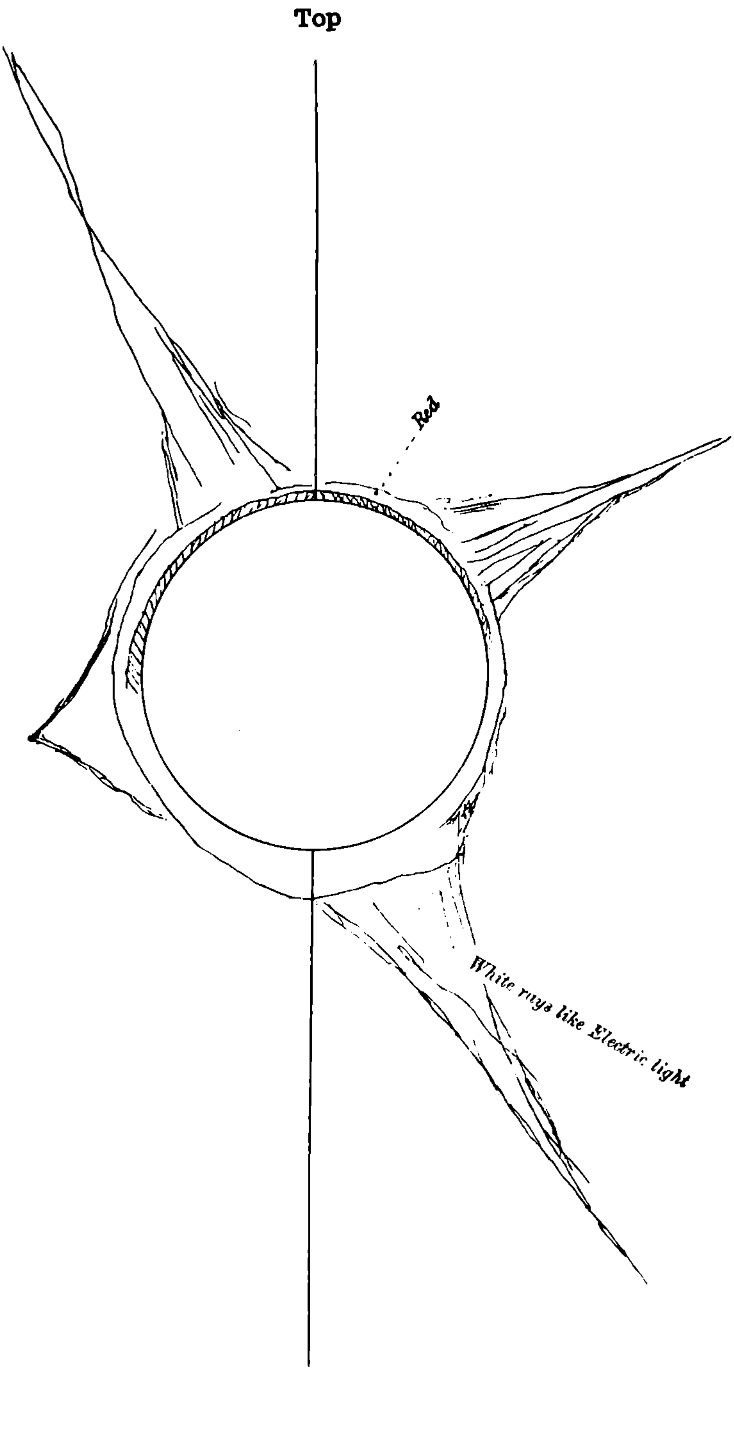
By Lieut. F. A. BUZZARD. R.A.

(DUMRAON, No. 28.)



By Mr. J. ECCLES, M. A.,

(DUMRAON, No. 29.)

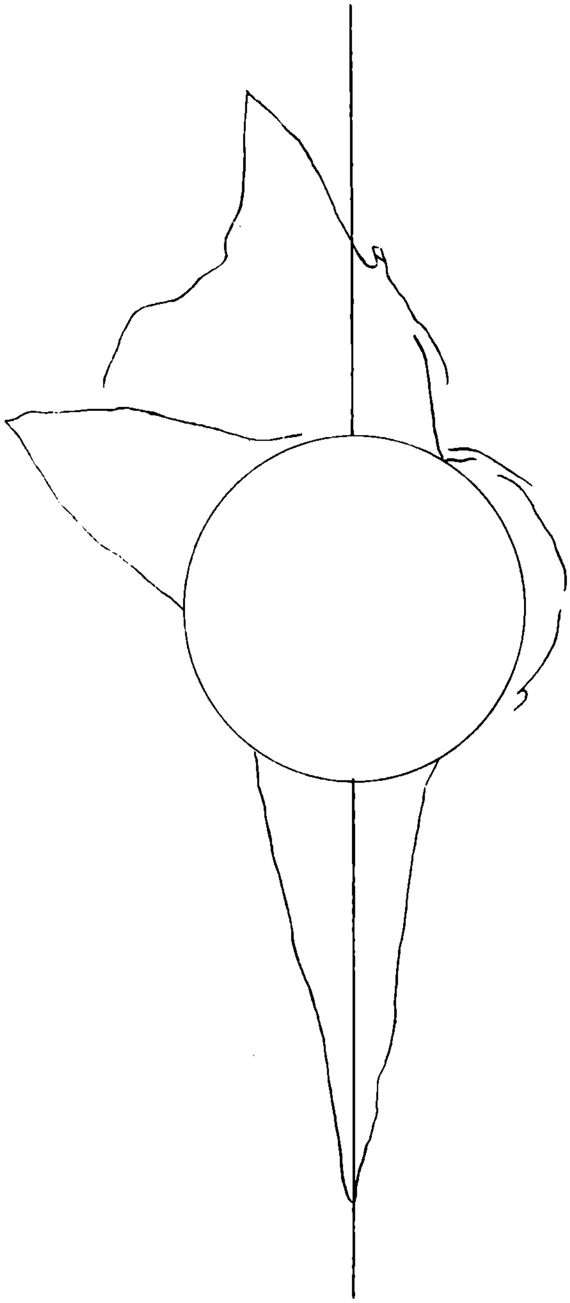


By Lieut. Col. HANBURY WHITE, R.E.

(BUXAR, No. 30.)

Photo. S. I. C., Calcutta.

Top



By Mrs. E. SCOTT.

(BUXAR, No. 31.)

Reg. No. [illegible] T. Sur.—Sep. 98—200

Photo. S. I. D., Calcutta.

23. The accordance between these drawings is more remarkable than their discrepancies. The only eye-observer, who detected the curved forms of the two left-hand upper streamers of the corona, was General Strahan, and the sketches of experienced draftsmen like Sir T. Holdich and General Woodthorpe show the boundaries of the streamers straight: the existence of the curves was generally disputed after the Eclipse, but they appear marked in the photographs.

Many of the eye-observers, as will be seen in the appendix to this report, remark on the sudden appearance of banks of clouds during totality, where none were visible in daylight, attributing the phenomenon to the change of light. It is possible, however, that these clouds were actually called into existence by the Eclipse, and that the fall in temperature consequent on the Eclipse condensed them out of the atmosphere.

24. The days following the Eclipse were occupied in developing plates and dismantling instruments; the plates were all developed successfully, and lest the originals should get damaged in transit to England, a transparency, or glass positive, was taken of each and left in India in my custody.

The English Astronomers left Sahdol on January 27th, and except for the triangulation and the computation of the transit observations, our Eclipse work was now complete. Our official duty of rendering all assistance to Mr. Christie and Mr. Turner had proved a service of the greatest interest and the greatest pleasure.

25. After the Astronomers had left, I remained at Sahdol a week with Mr. McA'Fee. The triangulation for connecting Sahdol observatory still remained to be executed, and the transit-observations and the times of the Astronomer Royal's photographs had to be computed. The necessary triangulation consisted of one triangle only: Sahdol Eclipse Station was visible from two old trigonometrical points, fixed in 1862, Barjana and Ghúngúti. The horizontal and vertical angles were observed by Mr. Mc A'Fee, and the computed results are:—

Sahdol Eclipse Station ...	*Latitude*	23° 16′ 45″·3
	Longitude	81 21 33 ·0
	Height	1502·4 feet.

The calculation of the times of the contacts and of the Astronomer Royal's photographs occupied some days. I append a copy of the Tabular Statement, which I sent to the Astronomer Royal after his departure. This Statement merits a few words of explanation, as its contents are the only visible return for all the expenditure incurred in the carriage of the Astronomical and Electrical instruments to Sahdol.

January 21st and 22nd, 1898.	*Times as recorded by ear and hand.* Local Mean Times of Star observations for determination of Chronometer Error.	Times of the contacts observed by H. H. Turner recorded by C. H. McA'Fee from the Mean-Time Chronometer on hearing Turner's Signal.	Times of the Astronomer Royal's Photographs as recorded by C. H. McA'Fee from the Mean-Time Chronometer on hearing the Click of the Shutter.	Correction for Error of the Mean-Time Chronometer determined from Star observations by S. G. Burrard with a Transit instrument.	Correct Local Mean Times of the contacts and photographs as deduced from McA'Fee's record = **A.**	*Times as recorded by the Chronograph.* Sidereal Times of Star observations for determination of Clock Error.	Times of the contacts observed by S. G. Burrard with telescope of 2-inch aperture and recorded by him on an Electric Chronograph with a tappet, Sidereal Clock working the Chronograph.	Times of the photographs as recorded by the Astronomer Royal on the Electric Chronograph, Sidereal Clock working the Chronograph.	Corrections for Error of the Sidereal Clock determined from Star observations by S. G. Burrard with a Transit Instrument and Electric Chronograph.	Correct Local Sidereal Times of the contacts and photographs as deduced from the Chronograph record.	Corresponding Local Mean Times of the Sidereal Times in the last column = correct Mean Times of contacts and photographs = **B.**	Difference in Mean Time between the Chronographic and McA'Fee's record = **B − A.**
	h m s	h m s	h m s	m s	h m s	h m s	h m s	h m s	m s	h m s	h m s	s
Mean Epoch of Star-observations	18 30 58	...	...	+ 0 23·2	...	14 36 36	...	...	+ 0 12·83	...	...	...
Photograph No. 1 (Double Sun for orientation) ...	...	...	23 50 0	...	...	...	...	...	...	...	...	...
First Contact	...	*Not recorded*	...	...	...	...	20 19 43·50	...	+ 0 13·74	20 19 57·2	0 13 22·8	...
Photograph No. 2 ...	...	...	0 14 10	+ 0 23·1	0 14 33·1	...	...	*Not recorded*	...	...	...	...
" " 3 ...	...	...	21 12·5	23·1	21 35·6	...	...	20 27 57·71	+ 0 13·76	20 28 11·47	0 21 35·7	+ 0·1
" " 4 ...	...	...	31 1·5	23·1	31 24·6	...	...	37 49·15	13·79	38 2·94	31 25·5	+ 0·9
" " 5 ...	...	...	38 45·5	23·1	39 8·6	...	...	45 32·81	13·81	45 46·62	39 7·9	− 0·7
" " 6 ...	...	...	48 35·5	23·1	48 58·6	...	...	55 24·72	13·84	55 38·56	48 58·3	− 0·3
" " 7 ...	...	...	59 59·5	23·1	1 0 22·6	...	...	21 6 50·69	13·87	21 7 4·56	1 0 22·4	− 0·2
" " 8 ...	...	...	1 10 59·5	23·0	11 22·5	...	...	17 53·40	13·89	18 7·29	11 23·3	+ 0·8
" " 9 ...	...	...	17 22·5	23·0	17 45·5	...	...	24 17·30	13·91	24 31·21	17 46·2	+ 0·7
" " 10 ...	...	...	21 50·5	23·0	22 13·5	...	...	28 45·04	13·92	28 58·96	22 13·2	− 0·3
Second Contact ...	...	1 40 40	...	23·0	41 3·0	...	21 47 38·10	...	13·98	47 52·1	41 3·3	+ 0·3
Third Contact	...	42 25·5	...	23·0	42 48·5	...	49 23·00	...	13·98	49 37·0	42 47·9	− 0·6
Photograph No. 11 ...	...	...	1 59 2·5	23·0	59 25·5	...	...	22 6 4·00	14·02	22 6 18·02	59 26·2	+ 0·7
" " 12 ...	...	...	2 8 32·0	23·0	2 8 55·0	...	...	15 34·41	14·05	15 48·46	2 8 55·0	0·0
" " 13 ...	...	...	17 9·5	23·0	17 32·5	...	...	24 13·42	14·07	24 27·49	17 32·7	+ 0·2
" " 14 ...	...	...	27 8·5	23·0	27 31·5	...	...	34 13·43	14·08	34 27·51	27 31·0	− 0·5
" " 15 ...	...	...	35 11·0	23·0	35 34·0	...	...	42 17·00	14·12	42 31·12	35 33·3	− 0·7
" " 16 ...	...	...	41 33·0	23·0	41 56·0	...	...	48 40·61	14·14	48 54·75	41 55·9	− 0·1
" " 17 ...	...	...	47 41·5	23·0	48 4·5	...	...	54 50·29	14·15	55 4·44	48 4·6	+ 0·1
" " 18 ...	...	...	53 23·5	23·0	53 46·5	...	...	23 0 32·21	14·17	23 0 46·38	53 45·6	− 0·9
" " 19 ...	...	...	58 49·5	23·0	59 12·5	...	...	5 59·70	14·18	6 13·88	59 12·2	− 0·3
Fourth Contact ...	...	3 1 15·5	...	23·0	3 1 38·5	...	23 8 23·60	...	14·19	8 37·8	3 1 35·7	− 2·8
Photograph No. 20 (Double Sun for orientation) ...	...	...	3 10 0	...	...	...	...	...	...	...	...	...
Mean Epoch of Star-observations	7 21 13	...	...	+ 0 22·9	...	3 28 58	...	...	+ 0 14·88	...	...	...

26. It will be seen from the Table that two separate records were made of each timing, one by Mr. McA'Fee and one by electricity. The Astronomer Royal recorded the times of his photographs on the electric chronograph by means of a break-circuit tapper, the astronomical clock marking seconds of sidereal time on the chronograph also. As electricity is liable to fail at critical moments, the Astronomer Royal asked Mr. McA'Fee to listen to the click of the shutter, accompanying the exposure of each photograph,* and to note in writing the time of each click to the nearest half-second from a mean-time chronometer. If the electric record were successful, it would be adopted, but if it failed, Mr. McA'Fee's record would be in reserve to replace it.

On January 22nd, for a few hours in the early morning, and again in the evening, I took star-observations to determine the errors of the sidereal clock and mean-time chronometer. The Table shows that the mean-time chronometer was $23^s\cdot2$ fast in the morning and $22^s\cdot9$ fast in the evening: the clock was $12^s\cdot83$ fast in the morning and $14^s\cdot88$ fast in the evening. The Astronomer Royal took twenty photographs, and the four contacts were timed. For the *first* photograph, which was taken before the Eclipse had begun, the same plate was exposed twice to the Sun, and a double image of the Sun thus impressed on it; this was done to obtain a record of the Sun's direction of motion. I observed the first contact, and the Astronomer Royal then took nine photographs at intervals of about 10 minutes during the first partial phase. Mr. McA'Fee recorded their times by listening to the click, and the Astronomer Royal recorded them electrically with the exception of No. 2. Professor Turner and myself timed the 2nd and 3rd contacts independently as shown in the Table. At the third contact when totality was over the Astronomer Royal commenced again, and took nine more photos of the partial phase. We timed the last contact, and he then observed another double Sun for orientation, thus completing his programme.

27. I had with me in camp two break-circuit chronometers; they are excellent time-keepers, and have steady rates, but I used the clock in preference to them for the chronographic record, because their electric mechanism is apt to fail. As a check on the rate of the clock, hourly comparisons were taken between it and the chronometers, on the electric chronograph, from the time when the morning star-observations for clock-error ceased, to the time when the evening star-observations commenced.

From these comparisons the rate of the clock was found to be:—

At the	first	contact,	$0^s\cdot150$	losing	per hour
Do.	second	,,	$0\cdot159$	,,	,,
Do.	third	,,	$0\cdot159$	,,	,,
Do.	fourth	,,	$0\cdot165$	,,	,,

It was considered advisable to take these comparisons, because the clock was in a grass-hut and subjected to a range of 50° of temperature, and doubts were entertained as to whether its rate would remain constant from sunrise to sunset.

The last column in the Table exhibits the differences, that obtained between the electric record and Mr. McA'Fee's notes.

The camp at Sahdol was finally broken up on February 5th.

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* The exposures for the totality-photographs were of different lengths and made by hand: those for the partial phase were instantaneous and made by a shutter.

Part IV.

The Hindu Method of Eclipse Prediction.

28. The visitation of India by a Solar Eclipse recalls to our remembrance the early history of Astronomical Science. In no country have so many Eclipses been scientifically observed as in India, in no country have the series of observations been so long and continuous. Before Europe had emerged from barbarism, India was calculating the planetary motions, and when Greenwich was the home of savages, Benares was foretelling Eclipses. On January 22nd, 1898, the path of the lunar shadow was strewn with the astronomers of Europe and America, but where were the representatives of Brahminism, the trustees of Hindu Astronomy?

The jungles of Sahdol abound with stone-carvings, relics of an early civilisation, of a great extinct city, and the Eclipse observatories, which we erected, were surrounded by memorials of antiquity. The analogy between the stones and sciences was complete, and it was impossible to avoid comparing the extraordinary vitality of modern investigation with the dying condition of Hindu Astronomy. The unmerited ridicule, to which the latter is subjected in these last days of its life, is due partly to the enigmas and allegories, the fables and mysteries which enshroud its rules and data, and partly to the enormous antiquity assigned to the creation of the world. Because the Moon's nodes, the two points where her path cuts the plane of the Ecliptic,—because these nodes were called Rahu and Ketu, or the head and tail of a mighty dragon*, the essential fact is overlooked, that their positions on the celestial sphere were known with precision, and that the eighteen-yearly cycle of their revolution round the Ecliptic, obscured as it is to the casual observer by the rotatory and orbital motions of the Earth and the Moon, had been discovered. Because the Hindus gave millions of years to the age of the World, periods so vast when compared with our date of B.C. 4004, the mathematical basis underlying the millions is ignored.

29. The fundamental error in the Hindu system was their adoption of the Earth as the centre of the universe: this error however does not greatly affect the predicted places of the Sun or Moon or even of the more distant planets; the Moon of course does revolve round the Earth, and the theory, that the Sun does so, though opposed to fact, is an allowable mathematical hypothesis for working purposes. The prediction of Solar Eclipses is therefore not rendered impossible by the mistake in the original assumption.

30. The Hindus discovered that the Sun, Moon and Planets were at certain times nearer to the Earth than at others, and they explained these changes by a theory of eccentric circles: every orbit was taken to be a circle, but these circles were not taken concentric; all the orbits encircled the Earth, but the Earth was not located at any one of their centres.

The Hindus determined the points of each orbit, that were nearest and furthest from the Earth, and calculated the long periods, in which the lines joining them, the lines of apsides, revolved through 360°. They also fixed for *each* heavenly body the two points, called the nodes, at which its inclined path cut the plane of the Ecliptic, and they measured the periods in which these nodes revolved respectively round the Ecliptic.

31. The periods of time, that the heavenly bodies themselves took to move round their orbits, were measured by the Hindus as follows:—

	Hindu period of revolution.	Modern period of revolution.
Moon	27·3 days	27·3 days
Sun	365·25 „	365·25 „
Mercury	88·0 „	87·4 „
Venus	281·6 „	224·25 „
Mars	687·0 „	686·0 „
Jupiter	4,332·3 „	4,333·0 „
Saturn	10,765·75 „	10,759·0 „

* In European Astrology the nodes are personified by a dragon, Caput Draconis being the name for the ascending node and Cauda Draconis for the descending. In Hindu mythology a dragon is always symbolical of darkness, and eclipse, and evil.

32. The point on the globe, to which all their data were reduced, was an imaginary place named Lanka, situated on the Equator near the meridian of 78°. The selection of a mythical point as an origin is not mathematically unsound, provided that its latitude, and longitude with reference to some known observatory are stated once for all. The advantage to the computer and the compiler of having the origin situated on the Equator is great, and there was probably a similar reason for the adoption of the chosen meridian. The exact longitude of Lanka in Greenwich terms may be said to be 78° 1′, because it was five degrees west of Benares observatory, which is in 83° 1′. In the *Surya Siddhanta* are given the old observations made for determining the Longitude of Benares from Lanka, and these rather refute the idea, that the latter was on the meridian of Ujjain: the time of a lunar Eclipse, which had been predicted for Lanka, was observed at Benares, and the resulting difference between the predicted and observed times was exactly 20 minutes, which is equivalent to 5° of longitude*. The fact, that the difference of longitude between Lanka and Benares was exactly five degrees, is significant: it may mean that Benares was selected for an observatory, *because* it was five degrees East of Lanka, and it may mean that the meridian of Lanka, the imaginary meridian of origin, was deliberately placed five degrees west of Benares. It is clear from other observations, that the Hindus were able to observe to a far greater accuracy than whole degrees, and a difference of longitude of exactly five degrees cannot be taken as a rough approximation. It is difficult to understand why the meridian of Benares was not made the prime meridian: it may possibly have been advantageous to the computers and observers of those days to have the meridian of prediction somewhat west of the meridian of observation; or the difference of longitude may have been regarded as an elastic quantity, as a reserve for correction, capable of being changed, if future errors of prediction proved large. It is worthy of note that the prime meridian of India, adopted in 1840 by Colonel Everest as the origin of modern Indian Geography, is within twenty miles of the prime meridian of the ancient civilisation. Even now the Hindu Astronomical day still begins at midnight of Lanka, a minute earlier than midnight of Kaliánpur, the modern origin of the Indian Survey.

The Hindus observed the latitude of Benares by measuring the lengths of shadows at noon on the days, when the Sun was in the Equator, and obtained the result 25° 26′, against the value 25° 19′ of the modern survey. They measured the diameters of the Sun and Moon by noting the time that elapsed between the first appearance of the limb on the horizon and the instant of the whole disc being risen, and they were able to do this with sufficient accuracy to learn, that both the Sun and Moon at times receded from the Earth and at times approached.

33. The anxiety of the Brahmins of old to assist a future posterity has left an impress on all their writings, and the great antiquity, which they assigned to the creation of the world, was probably due to a desire to record for us and for ever the results of their astronomical observations. Instead of registering the positions of the Sun, the Moon and the planets, as observed on different dates in different centuries of different eras, they calculated back to a time when all the bodies were together, and they gave one date to all. In deducing this date—the date of the Hindu creation—they imagined a straight line drawn from Lanka to a point in the constellation Aries, the equinoctial point of the Heavens, and they then computed the lapse of time that had occured since the centres of the Earth, of the Moon, of the Sun, of Mercury, of Venus, of Mars, of Jupiter and of Saturn, and also their several apogees, perigees and nodes had all been in this line together at the same instant. If they had remained content with merely making their line from Lanka to Aries pass through the centres of all the heavenly bodies, their date for the creation would have fallen short of B. C. 500000. But they had discovered the slow motions of the lines of apsides and nodes, and these they fearlessly determined to include in the Aries-Lanka alignment. It is therefore not surprising that their computations placed the creation so long ago as B. C. 1955883103†. The date of the creation is Sunday, March 22nd, at midnight, B. C. 1955883103.

This affords a convenient basis for computation, whilst the adoption of an ancient epoch as a starting point will introduce no error into results deduced from it: any error in

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* A Solar Eclipse occurs at different times at different places, but a lunar Eclipse, when the Moon enters the Earth's shadow, is independent of an observer's place, and is everywhere seen at the same instant. The instant of the Eclipse was predicted in Lanka time, and the Benares observer observed it in Benares time: the difference between the two times was the difference of longitude.

† This number has been obtained by converting the Manwanteras and Yugas into terms of the Christian era, and the sidereal years of the Hindus into solar years; it is perhaps not rigorous.

the calculation of this date, working back to it, will be cancelled out exactly in working forward again, when a modern celestial place has to be computed.

The above date was determined before the Surya Siddhanta was written, but was found to be not precise, when fresh measurements of the lengths of the several cycles had been made. The Surya Siddhanta applies a correction:—

Date of creation	B. C. 1955883103	
Deduct the period that Brahma took to make the world ...	17064000	years
Date from which to calculate	B. C. 1938819103	

34. The Surya Siddhanta gives strict rules for calculating Eclipses, but warns posterity not to trust blindly to its *data*, without occasional checks from direct observation of the places of the planets and Moon. "The science and its principles", it says, "are always the same but the motions of the Sun, Moon and planets vary in every age". The instruction is "always to adopt that place which agrees with observation".

The apsidal and nodal motions, as recorded in the Surya Siddhanta, may have served for computations in the remote past, but they do not give correct results now. Redeterminations have been made by Hindu Astronomers at frequent intervals, and corrections have been introduced, the periods of the apogees and nodes being generally decreased. The corrections cast no slur on the original observations: they are merely in the form, for example, of our leap-year, and they mean in so many words, that after a certain number of cycles have elapsed, a sensible error has accumulated and an allowance for it must be made.

In the Surya Siddhanta are given tables of sines, versed sines, and solar and lunar equations, compiled like modern auxiliary tables.

35. The first step in the prediction of an Eclipse by the Hindu method is to find the number of days, that have elapsed since the creation: this number counting to the first day of the present Hindu year is, I believe, 708,154,370,615.

Now for a Solar Eclipse to occur two conditions must be fulfilled, *viz.*, the Moon must be new, and she must be in the plane of the Ecliptic: in other words the Moon must be both new and at a node. The Hindus look for that date, on which the Sun, Moon and node are all in the same longitude, measured from the first point of Aries round the Ecliptic.

36. To find the longitude of the Moon, they divide the number of days elapsed since the creation, by the time, which the Moon takes to travel round the Earth: the total number of revolutions, which the Moon has made since the creation, they reject, and from the fraction left over they deduce the longitude of the Moon on the first day of the year.

Similarly they find the longitudes of the Sun and of the node by dividing the time elapsed since the creation by the respective periods of solar and of nodal revolution.

37. Having found the longitudes of the Moon, Sun and node for the first day of the year, they calculate them forward through the months of the year, until they find by trial that day on which the three longitudes nearly agree, and they then compute them exactly for the midnight preceding the Eclipse, allowing for the difference of longitude between Lanka and the place of observation.

38. They then deduce the exact instant when the centres of the Sun and Moon will be in the same longitude, and by comparing this instant with the time of the Moon's arrival at her node they can tell the portion of the Sun's disc that will be obscured and the points on her limb, where the first and last contacts will occur. From their knowledge of the positions of the two points of contact and of the relative lengths of the Sun and Moon's diameters, they can then calculate, how long before and how long after the exact instant of longitudinal coincidence the first and last contacts between the two discs take place. They are now in a position to predict the *time* of commencement of the first partial phase and the *time* of termination of the last.

39. From the known eccentricities of the orbits they can deduce the distances of the Sun and Moon from the Earth at the time of the Eclipse, and by comparing the ratio of these distances with the ratio of the Sun and Moon's diameters, they calculate the diameter of the Moon's shadow and penumbra at the surface of the Earth. From the diameter of this penumbra, they can tell the *size* of the terrestrial area, from which the partial Eclipse will be visible.

They compute whether, at the central moment of Eclipse, the Moon's centre is above or below the Sun's with regard to Lanka, and from the distance between the two centres they can predict the *region* of the Earth from which the Eclipse will be seen.

40. Detailed observations of the Heavens have been made by Hindu Astronomers at frequent intervals since the Surya Siddhanta was written, and their results compiled in other books. The Grahalaghava, which is only a few hundred years old, gives data and rules for predicting an Eclipse by a graphical method of diagrams. The data of the Grahalaghava being more recent than those of the Surya Siddhanta, its predictions might be expected to be more accurate, though they are said by the Hindus to be less so. The time of first contact of an Eclipse could not *now*, I think, be predicted from the Surya Siddhanta within two hours, and the diameter of the Moon's penumbra at the surface of the Earth could not now be calculated within a hundred miles*. Neither book can presume now to deal with the *total* phase of an Eclipse: though they can foretell still with perfect propriety the main facts of the *partial* phases, it is absolutely beyond their powers to prophesy even roughly either the duration of totality, or the terrestrial position of the central line.

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* The diameter of the penumbra in the recent Eclipse was sufficiently large to admit of the partial Eclipse being visible from Siberia to Ceylon: an error of a hundred miles does not therefore denote a serious blunder in prediction.

PART V.

FUTURE TOTAL ECLIPSES IN INDIA.

41. If we take very long periods of time extending over millions of years, we find that on the average every part of the globe is visited by a total Eclipse equally often, and that no region has an unfair advantage over another. On the average every town in the world witnesses a total Solar Eclipse once in five centuries.

Eclipses can be predicted by means of the Saros: the method was discovered by the ancient Chaldees, and was used by Thales of Miletus to foretell the Eclipse of May 28th, B.C. 585. It does not appear that the old Hindus ever employed the Saros for their forecasts: possibly in the days of Maya the method was regarded by the Brahmans as insufficiently exact, though it is an open question now, whether its results are not as accurate as Benares prophecies.

The Saros is a period of 18 years 11⅓ days, (or, if five leap-years chance to have intervened, of 18 years 10⅓ days) at the end of which the Earth, the Sun and the Moon are very nearly in the same relative positions as at the beginning; if there is an Eclipse at the commencement of the cycle, there will be another at the conclusion of it. The Sun and the Earth are always in the plane of the Ecliptic, and if the Moon remained in this plane also, she would eclipse the Sun every time that she was new. Unfortunately for students of the Corona, the path of the Moon is *inclined* to the plane of the Ecliptic, half her journey being performed above it and half below, and it is only twice a month that she is absolutely in it. The two points, where she dashes through the Ecliptic plane, are called her nodes, and unless she is at a node, no Solar Eclipse can take place. A Solar Eclipse can only occur, if the Moon on her arrival at a node happens to be new.

If on the plane of the Ecliptic we draw a line joining the Moon's two nodes, this line is found to revolve in that plane through a complete circle, once in 18 years 219 days; if we then allow for the Earth's movement also, the conditions necessary for the Saros are fulfilled, and the period becomes 18 years 11⅓ days. The late Eclipse of January 22nd, 1898, was a return of the Eclipses of December 21st, 1843, December 31st, 1861 and January 11th, 1880, and there will be future repetitions of it on February 3rd, 1916 and February 14th, 1934.

42. It is not to be assumed that a total Solar Eclipse occurs only once every 18 years 11⅓ days. This is the period of nodal revolution, and during that period, the Moon, when she is both new and near enough to the Earth to have a disc larger than the Sun, will be in a node twelve times; there are thus twelve total Eclipses every 18 years 11⅓ days*. If the date of each of these twelve Eclipses be noted, there will be an Eclipse corresponding to each, 18 years 11⅓ days after. The Eclipse of any year is a repetition of a similar phenomenon, which took place 18 years previously, and there will be a recurrence 18 years later.

Total Eclipses can thus be classified into twelve families, successive Eclipses of *each* family being separated by 18 years 11⅓ days. Each of these families is progressing slowly across the Earth, some moving from north to south, some from south to north. Each family originally commenced as a partial Eclipse at either the north or south pole, and at each return it has moved slightly towards the opposite pole. After returning some twelve times as a partial Eclipse, a larger portion of the Sun's disc being covered at each return, each family has become total at that pole, where it first appeared; at every subsequent recurrence, it has crossed the Earth as a total Eclipse further and further from that pole. Six of the families are moving from north to south, and six from south to north. In those that originally commenced at the north pole, the lunar shadow impinges on the Earth 200 miles further south at every recurrence, and will eventually die out as a partial Eclipse at the south pole: in the six families that originally commenced at the south pole, every successive visitation now appears 200 miles further north than before, and will continue to do so, till the Eclipse passes out into space at the north pole.

The life of a family embraces 12 partial Eclipses at its commencement, 43 total Eclipses during its earthly progression, and 12 more partial Eclipses at its conclusion; these 67 Eclipses recur at intervals of 18 years 11⅓ days, and a family therefore endures for 1200 years.

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* If the new Moon, when at a node, is not near enough to the Earth to have a disc apparently larger than the Sun, the Eclipse will be not total but annular.

43. If the Saros-cycles were a whole number of days, such as 18 years 11 days, or 18 years 12 days, each successive Eclipse of any particular family would return at every visitation to the same terrestrial longitude; but as the cycle is not a multiple of a day, and the fraction of one-third of a day forms part of it, the meridians formerly visited are 8 hours too far ahead at the next return; the daily rotation of the Earth thus causes every successive recurrence to fall 120° in longitude further west, or one-third of the circumference of the Earth, and it is only after three complete cycles have passed, *viz.*, 54 years 34 days, that an Eclipse returns to the same terrestrial region.

44. There is one other fact of interest in the Saros, and that is that the duration of totality, though different in different families, always remains the same for any particular family. The duration of totality on January 22nd, 1898 was 2 minutes: at the former appearances of this Eclipse in 1843, 1861 and 1880 the duration was 2 minutes, and when it reappears in 1916 and 1934, the duration will be 2 minutes. This is speaking *generally*: if the *exact* duration of totality is required, the latitude of the shadow's path on the Earth would have to be taken into consideration. If as was pointed out on page 2 the path happens to be at the Equator, an observer is whirled round by the Earth's rotation in the same direction as the lunar shadow is moving, and the latter cannot pass him by in so short a time, as if he were near either pole, where the rotation is slower. Two of the Eclipse families possess durations of 6 minutes of totality; they are known as the Great Eclipses and appeared last in 1883 and 1886: they will recur again in 1901 and 1904. When these families visit the Equator, the rotation of the Earth extends their durations of totality to 7 minutes; when they appear at either pole, their totality is reduced to 5 minutes.

45. To predict by the Saros method we have to make use of the following data :—

(*a*) There are twelve families of Eclipses.
(*b*) In each family a recurrence takes place after 18 years 11⅓ days.
(*c*) The latitude of the path changes 200 miles at each recurrence.
(*d*) The longitude at each visitation is 120° further west.
(*e*) The duration of totality in each family remains constant.

To be able to predict from these data we require, *firstly*, to have noted the exact dates of the last twelve Eclipses and the terrestrial regions visited; and *secondly*, to have ascertained from earlier Nautical Almanacs, whether the progression of a family is northwards or southwards across the Earth.

46. The following table gives the twelve families, their respective durations of totality, their directions of progression, and the dates of their last and next visitations :—

Family.	Chart illustrating the family's appearances.	Duration of Totality.	Direction of Progression.	Date of Visitation.	
				Last.	Next.
I	I	2 Minutes	Northwards	May 17th, 1882	May 28th, 1900
II	II	6 Do.	Do.	„ 6th, 1883	„ 18th, 1901
III	III	2 Do.	Southwards	Sep. 9th, 1885	Sep. 21st, 1903
IV	IV	6 Do.	Do.	Aug. 29th, 1886	„ 9th, 1904
V	V	4 Do.	Do.	„ 19th, 1887	Aug. 30th, 1905
VI	VI	2 Do.	Northwards	Jan. 1st, 1889	Jan. 13th, 1907
VII	VII	4 Do.	Do.	Dec. 22nd, 1889	„ 3rd, 1908
VIII	VIII	4 Do.	Southwards	Apr. 28th, 1892	May 9th, 1910
IX	IX	5 Do.	Do.	„ 16th, 1893	Apr. 28th, 1911
X	X	1 Minute	Northwards	Sep. 29th, 1894	Oct. 10th, 1912
XI	XI	2 Minutes	Do.	Aug. 9th, 1896	Aug. 21st, 1914
XII	XII	2 Do.	Southwards	Jan. 22nd, 1898	Feb. 3rd, 1916

47. In the twelve charts that follow page 23, the progressions of the twelve families of Eclipses across the Earth are respectively illustrated, the red lines showing the tracks

of the central lines of totality. The tracks of *past* Eclipses have been laid down on the charts from old Nautical Almanacs, and those of *future* Eclipses have then been drawn symmetrically to the progression of the past. The charts being constructed on Mercator's projection, the distortion at the poles is great, and the symmetry lost. From these charts the total Eclipses, that will be visible in India in the future, may be roughly predicted as follows :—

Chart I. This family is progressing northwards, and has now reached a latitude of 40°. It will not be seen in India again, except as a partial Eclipse.

Chart II. An Eclipse of this family, one of the families of Great Eclipses, will next appear on May 18th, 1901, visible in totality from Sumatra and Borneo. In A.D. 1955 it will be seen as total from Ceylon, and in A.D. 2009 its central track will probably cross Upper India.

Chart III. This family is of no more interest to India. It is moving southwards, and will be only visible in future from southern seas.

Chart IV. The members of this family are known as Great Eclipses. One appeared in India in 1868, and was observed at Guntúr by General Tennant. On September 21st, 1922, it will be visible in India again, but only as a partial Eclipse, its central line being then south of Ceylon.

Chart V. An Eclipse of this family will probably be visible in totality in India in A.D. 1995.

Chart VI. No member of this family will ever be seen again as total in India; one will be visible in Central Asia in A.D. 1907.

Chart VII. This family is moving northwards, but its progression disobeys the laws of movement, and future tracks are difficult of even rough prediction. An Eclipse of this family cannot appear in India as total before A.D. 1980, but one may possibly show itself near Quetta in that year*. It was last seen in India in 1871, when it was observed by General Tennant in the Nílgiris.

Chart VIII. This family has long ceased to be of interest, totality in the future being only visible from the Antarctic Ocean. It will die at the south pole during the next century, and will be replaced by a new family, the first member of which is expected to be born at the north pole on June 17th, 1909, and to follow the track shown on Chart VIII. The second member of this new family will be the first Eclipse visible in England and will appear on June 29th, 1927†.

Chart IX. This family has passed India in its southern progression, and no member of it will be seen again in totality.

Chart X. This is a young family with a long life before it. One of its Eclipses will probably be visible as total in India in A.D. 2002, and another in A.D. 2056.

Chart XI. An Eclipse of this family was visible in India in A.D. 1734: its last appearance on the earth was in 1896, when many observers in Norway and Japan were disappointed by clouds. It will next appear in 1914, when it will cross Greenland, Europe, Persia, Makrán and Sind.

Chart XII. This family is moving southwards, and it was one of its members that appeared in India last January. Another Eclipse of this family was visible in India on December 21st, 1843, when Caldecott observed it on the Malabar Coast. Though the position of the track, that lay in India in 1898, was north of the line, which crossed India in 1843, the progression of the family is southwards, and the *general* position of the 1898 track on the globe was south of that of the 1843 track. Each recurrence is not exactly 120° west of the former position, and India fell in 1898 on a different part of the curve to what it did in 1843. Owing to this family's disobedience of the laws of progression future predictions are difficult: Eclipses will recur in 1916, 1934, 1952, 1970 and 1988, but their tracks will not cross India.

* Chart VII shows that a total Eclipse passes in 1962 near North-Eastern Burma.
† Mrs. Todd's "Total Eclipses of the Sun".

48. The Saros method of prediction enables us to say with confidence, that no total Eclipses will appear in India again from any of the seven following families:—I, III, IV, VI, VIII, IX and XII; and it also shows us, that no total Eclipse from family II can cross India before A.D. 2009, nor from family V before A.D. 1995, nor from family X before A.D. 2002. It leaves us in some doubt about family VII; the Eclipse of A.D. 1962 will probably appear not far beyond our North-Eastern Frontier, and that of A.D. 1980 not far from our North-Western Frontier. It might have been thought, that family XI had bidden us farewell for ever in the last century, but, in A.D. 1914, it will run across Greenland, Europe and Persia, and not stop, till it reaches the Indus between Sukkur and Kotri*.

49. The positive information gained from the Saros is, that the first total Eclipses, which will cross the Indian peninsula, will occur in A.D. 1995, 2002 and 2009, that an Eclipse with a duration of totality of 2 minutes will be visible in Sind on August 21st, 1914, and that total Eclipses will probably be witnessed in 1962 and 1980 *beyond* our North-Eastern and North-Western Frontiers respectively. One of the Great Eclipses of family II will occur, almost at our doors, in 1901, being visible from Sumatra on the 18th of May, and it will recur again in Ceylon on June 20th, 1955. The Eclipse of 1914 will not attract Astronomers to Sind, because its track crosses Europe first, and in August Europe will furnish more favorable sites for observation than Sind. It is not likely that the Astronomer Royal of England will have to visit India again before A.D. 1995.

50. Though the Saros method cannot be employed to predict details of totality, it is reliable for forecasts of *partial* Eclipses, and we were quite safe in prophesying to the villagers of Sahdol, that on February 25th, 1952 (or 54 years and 34 days after January 22nd, 1898) they will see a partial Eclipse of the Sun.

The Saros method shows us that India will not be so favored in the twentieth century as it has been in the nineteenth: since 1840 the track of a total Eclipse has crossed India four times. The tracks of 1843 and 1871 were almost identical, both running from Calicut to Palk Bay: many of the inhabitants of the Calicut, Coimbatore and Madura districts thus witnessed *two* total Eclipses in 28 years. Viziadurg has also been unduly favored, for it was the point on the Western Coast, where the central line of totality entered India, both in the total Eclipse of 1868 and in that of 1898: the villages of Karád and Masur witnessed totality both in 1868 and 1898. The good fortune of these places may be measured from the fact, that London has only seen one total Eclipse since the twelfth century, and that it will not see another till the twenty-fifth century.

DEHRA DÚN: }
June 18th, 1898. }

S. G. BURRARD.

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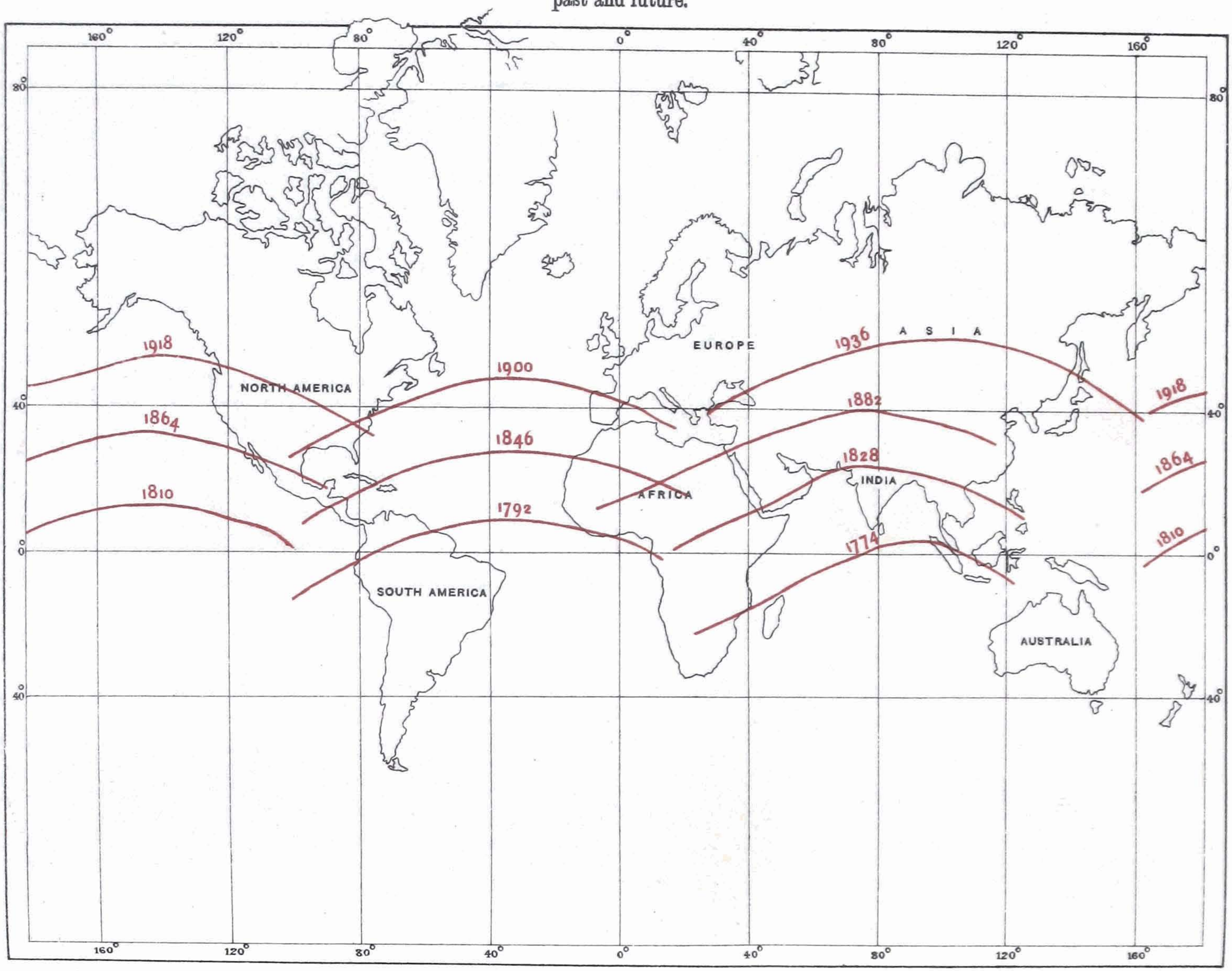
* In Volume I of the Columbian Knowledge Series, Mrs. Todd shows the track of the Eclipse of 1914, and takes it up to the Indus.

Chart No. 1.

TRACKS of SOLAR ECLIPSES
past and future.



Family No. 1. Duration 2 minutes. Moving Northwards.

Chart No 2

TRACKS of SOLAR ECLIPSES
past and future.

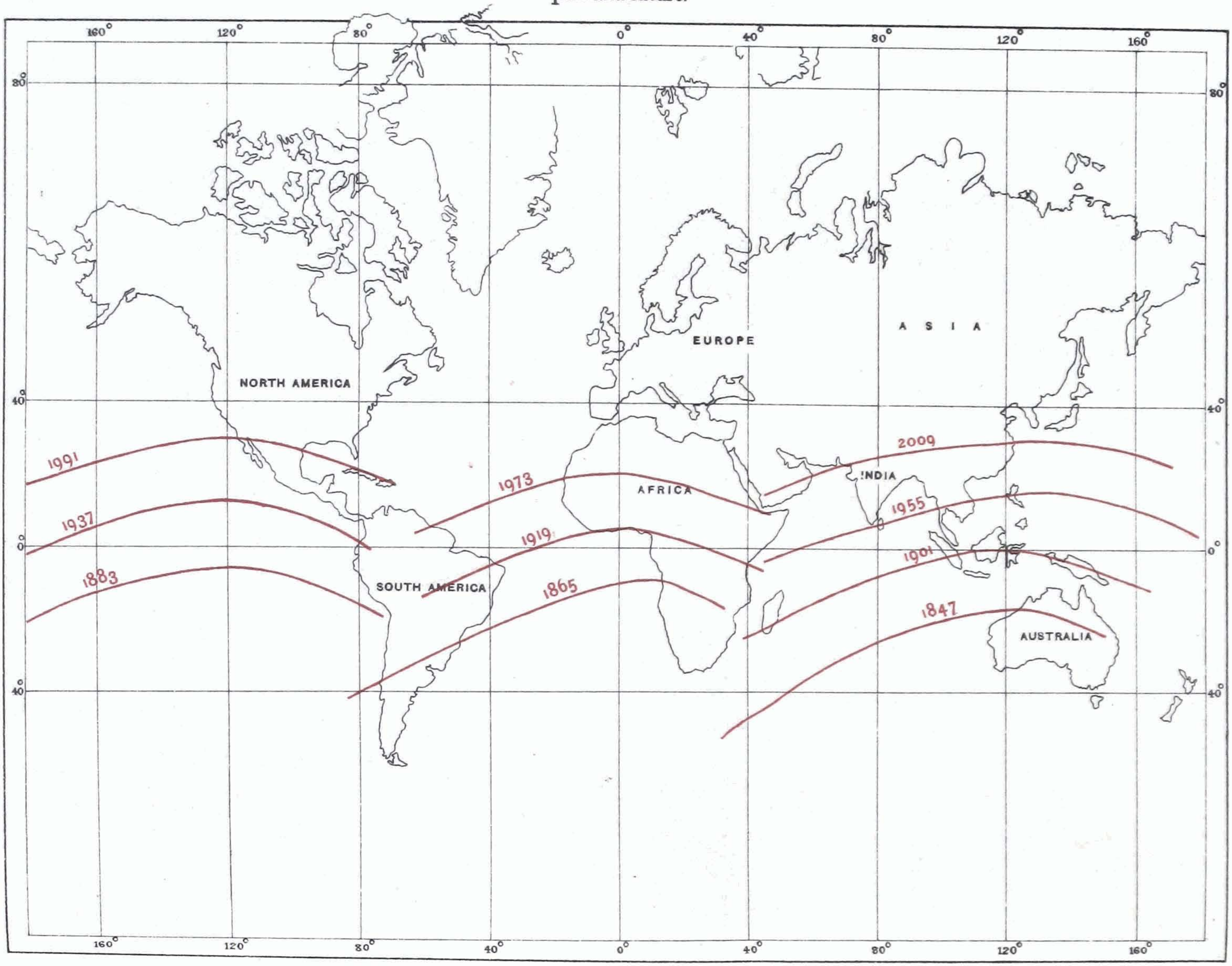
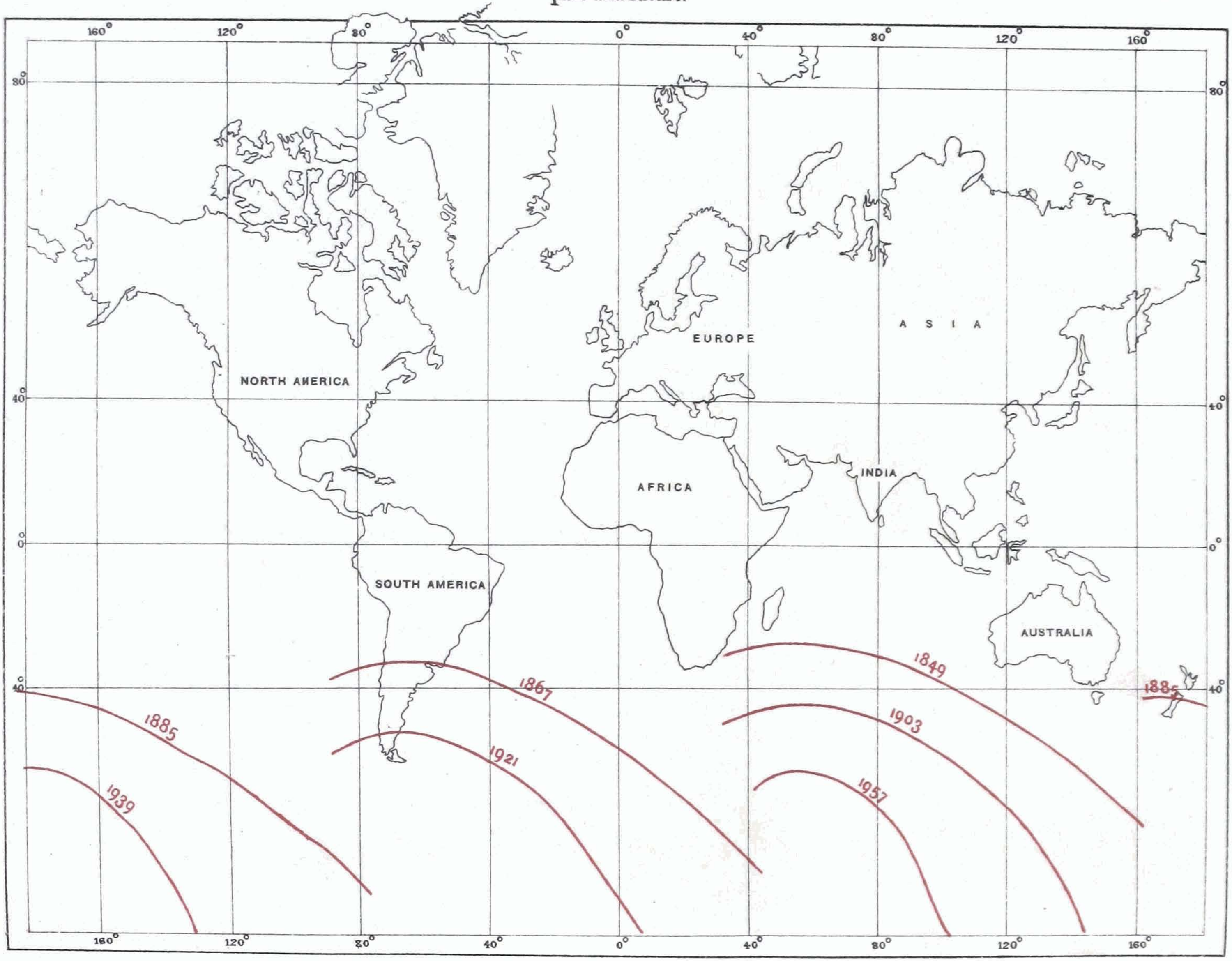


Chart No 3

TRACKS of SOLAR ECLIPSES
past and future.



TRACKS of SOLAR ECLIPSES

past and future.

Chart No 4

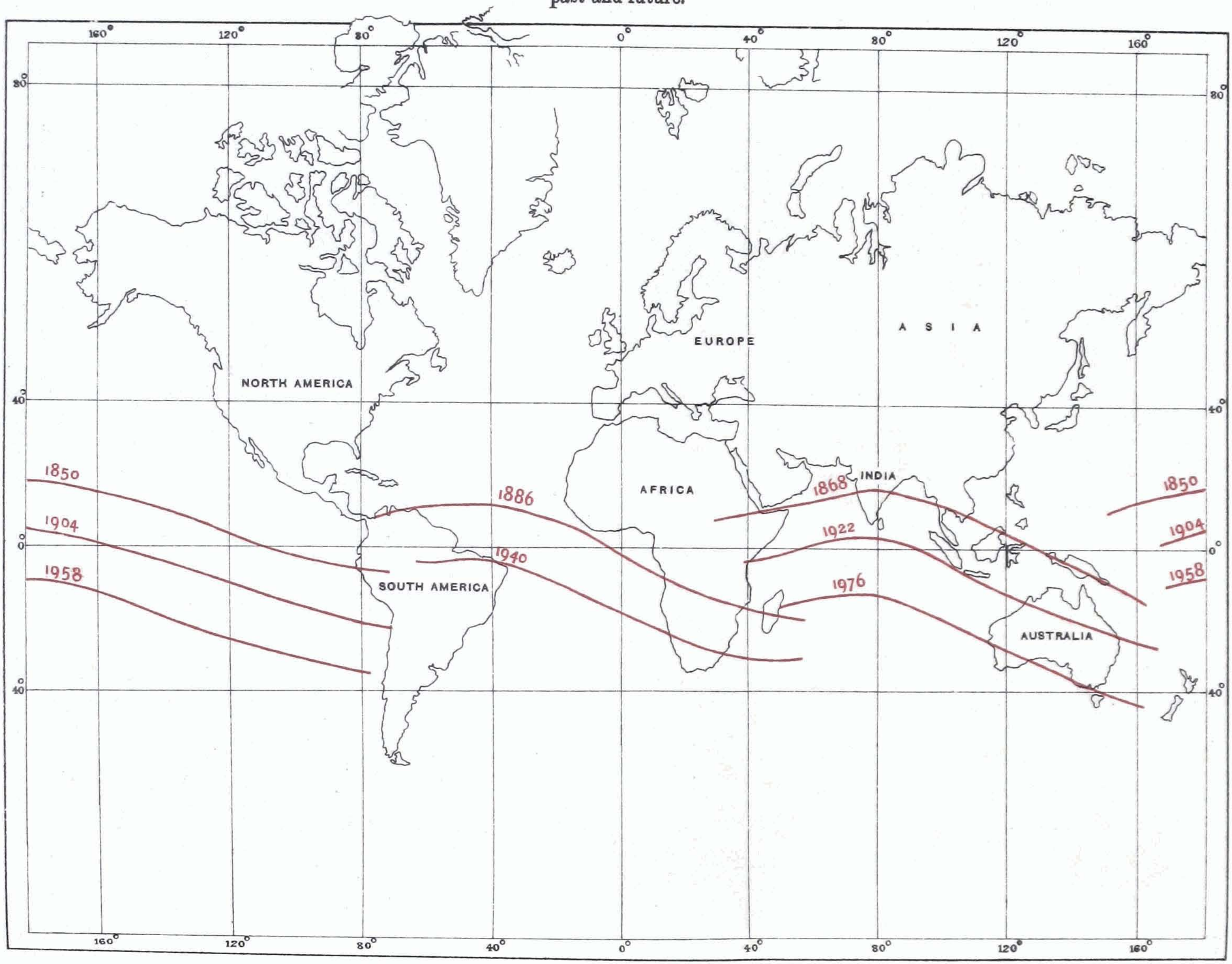
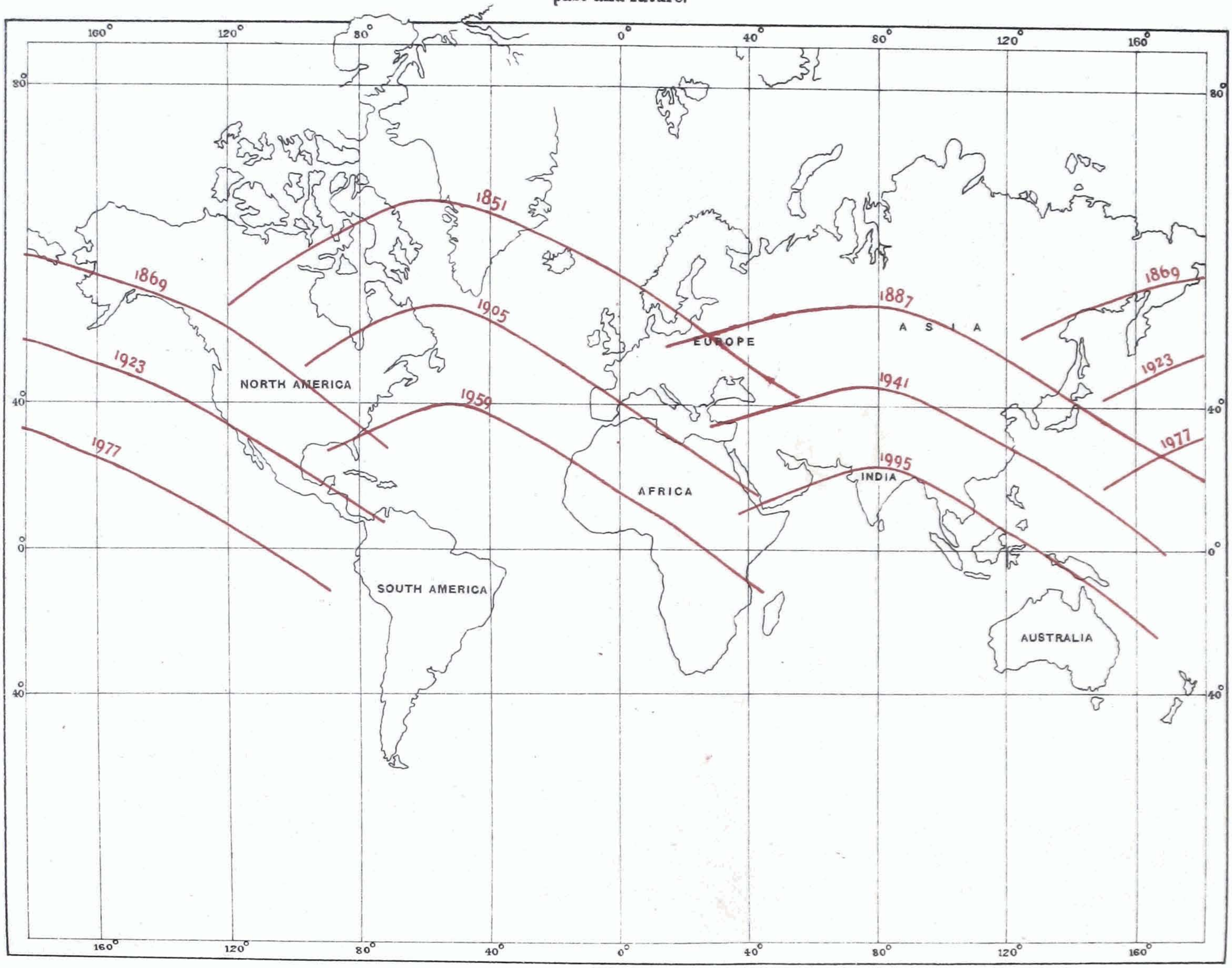
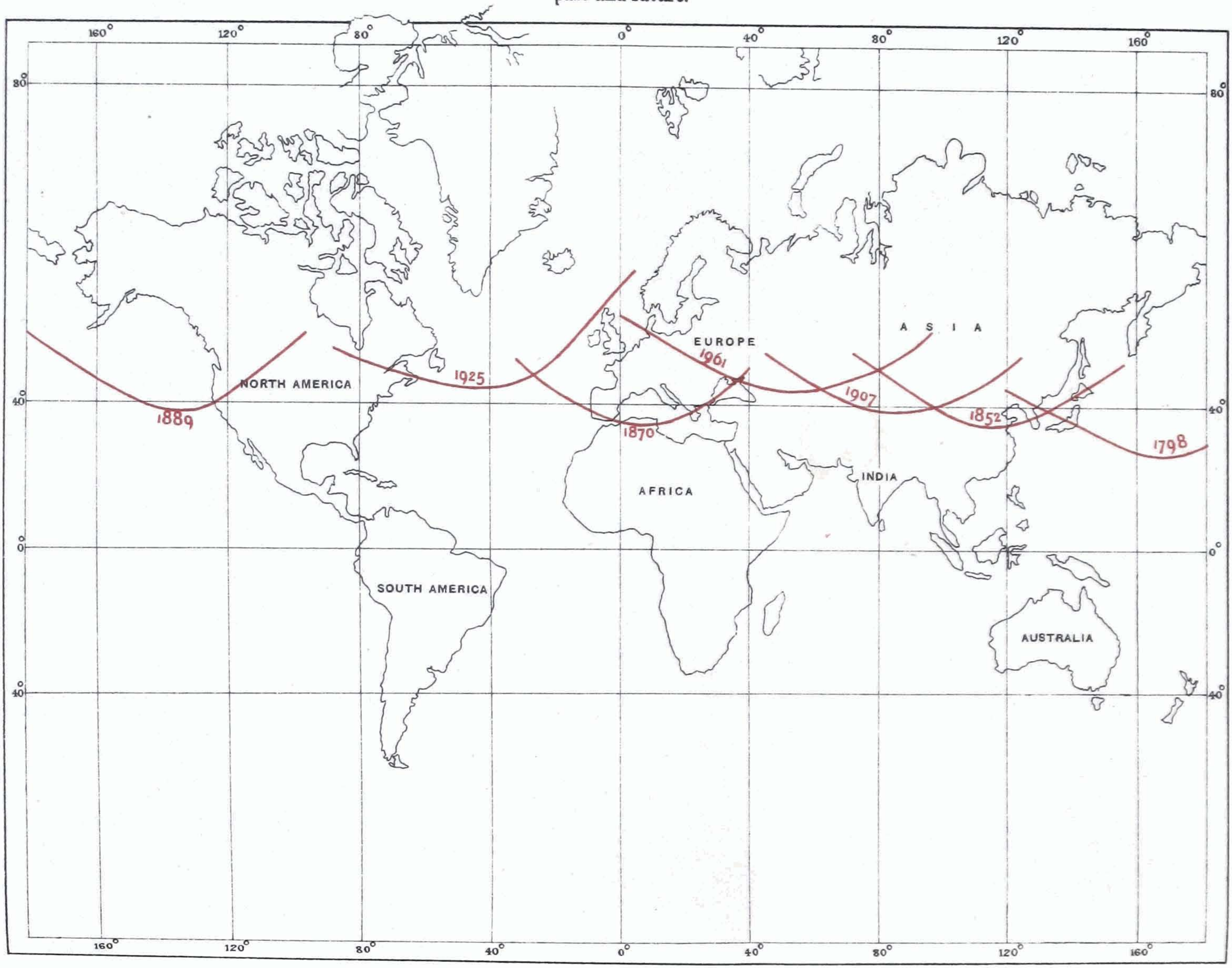


Chart No 5

TRACKS of SOLAR ECLIPSES
past and future.



TRACKS of SOLAR ECLIPSES
past and future.



TRACKS of SOLAR ECLIPSES
past and future.

Chart No 7

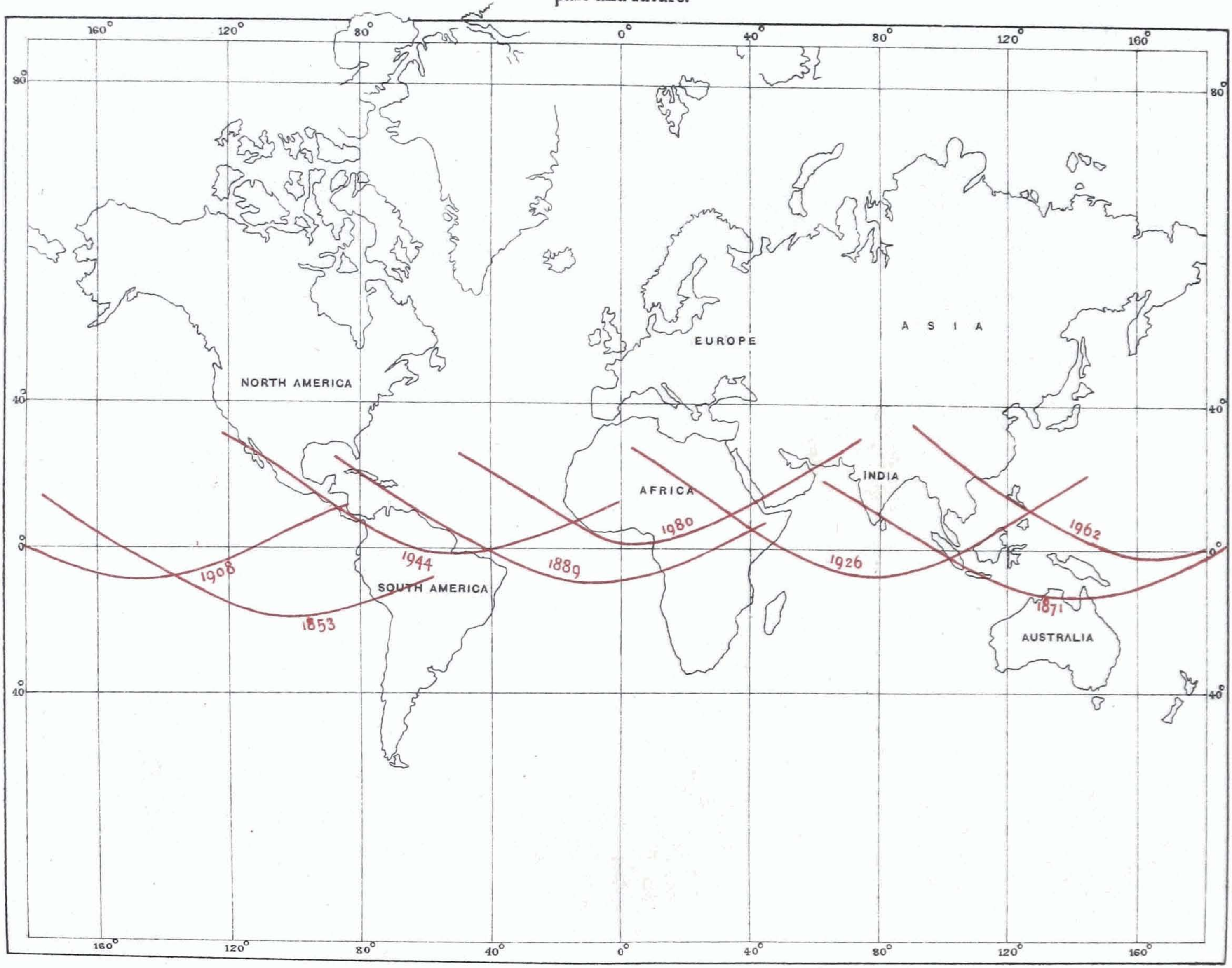


Chart No 8

TRACKS of SOLAR ECLIPSES
past and future.

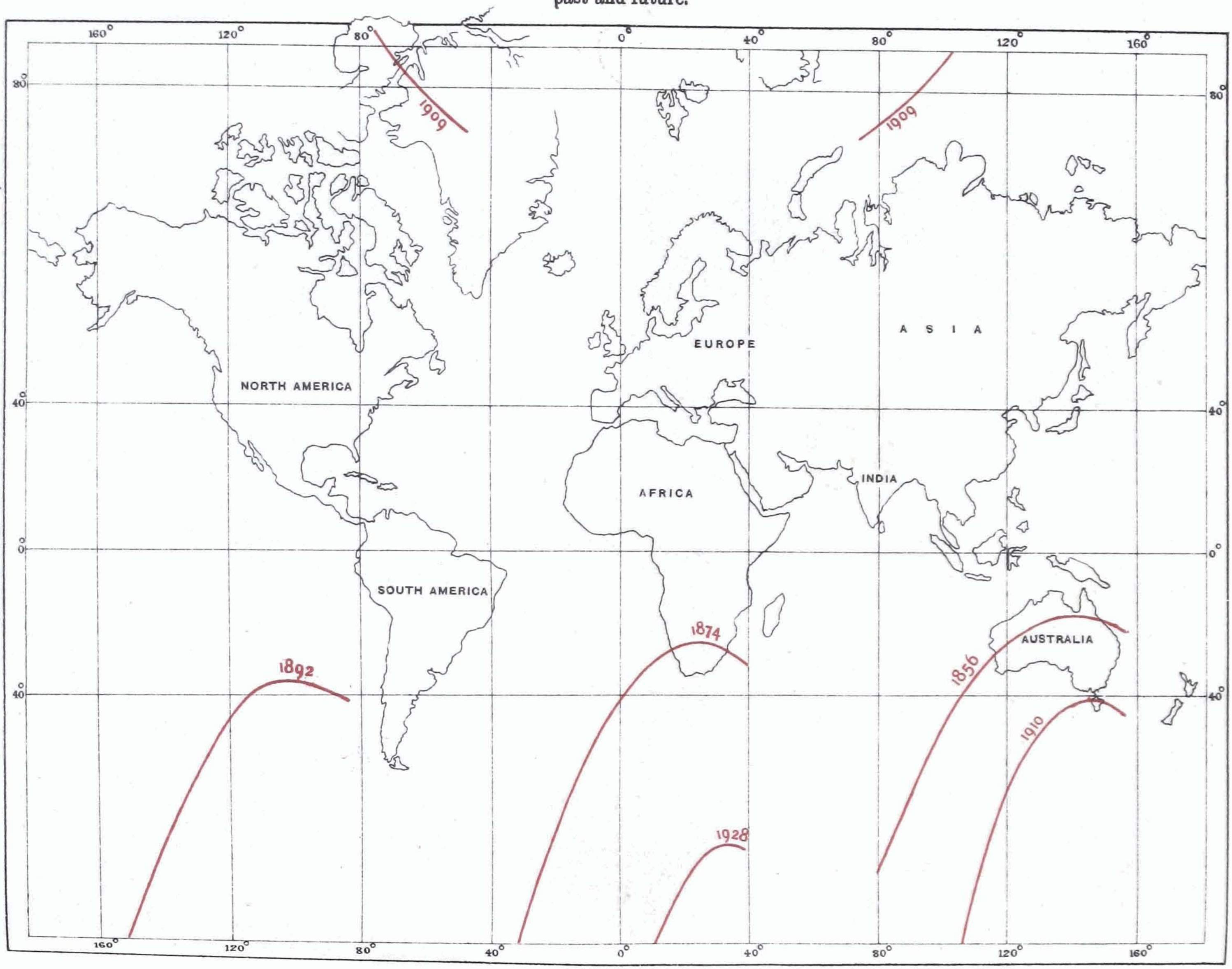
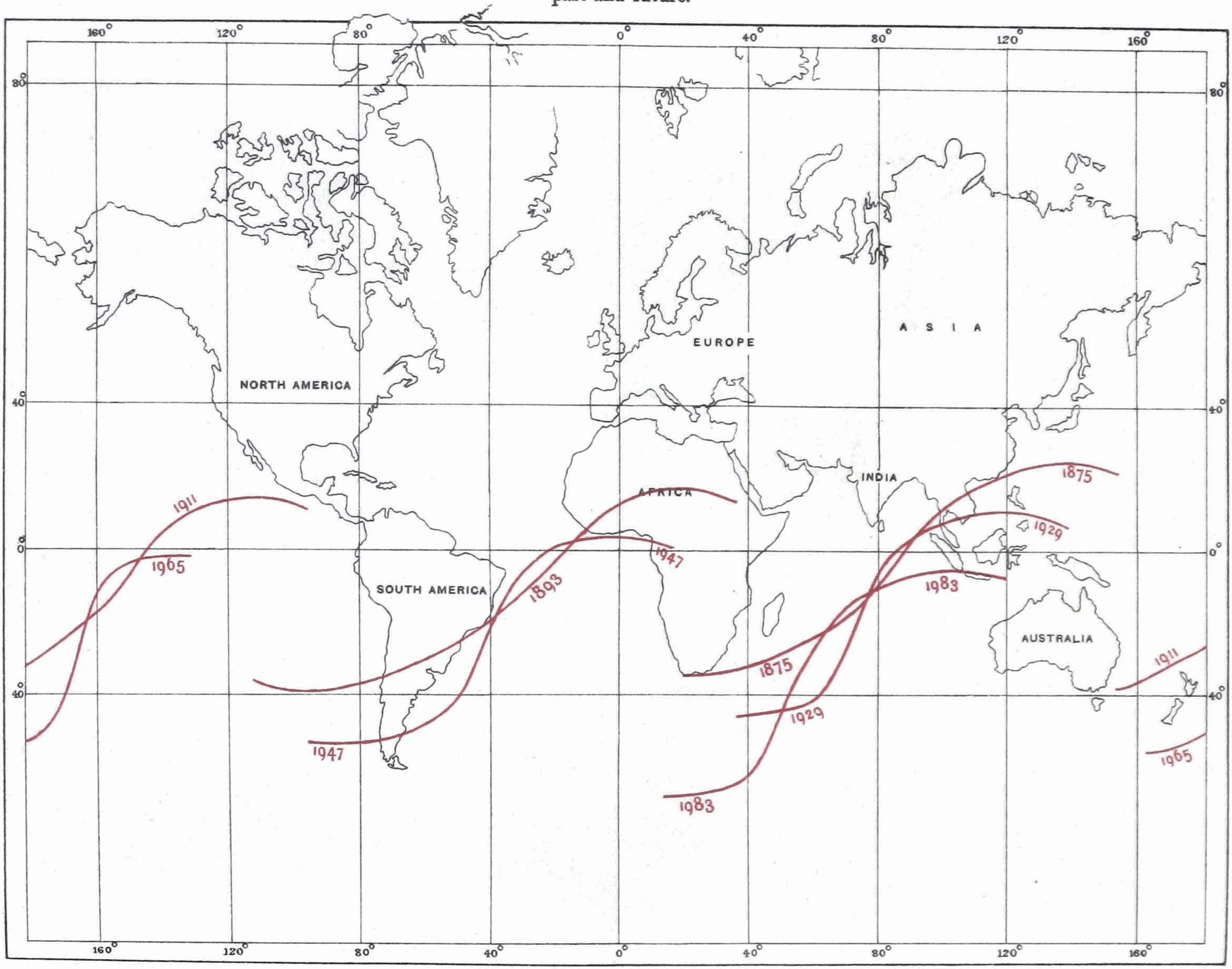


Chart No 9

TRACKS of SOLAR ECLIPSES
past and future.



TRACKS of SOLAR ECLIPSES
past and future.

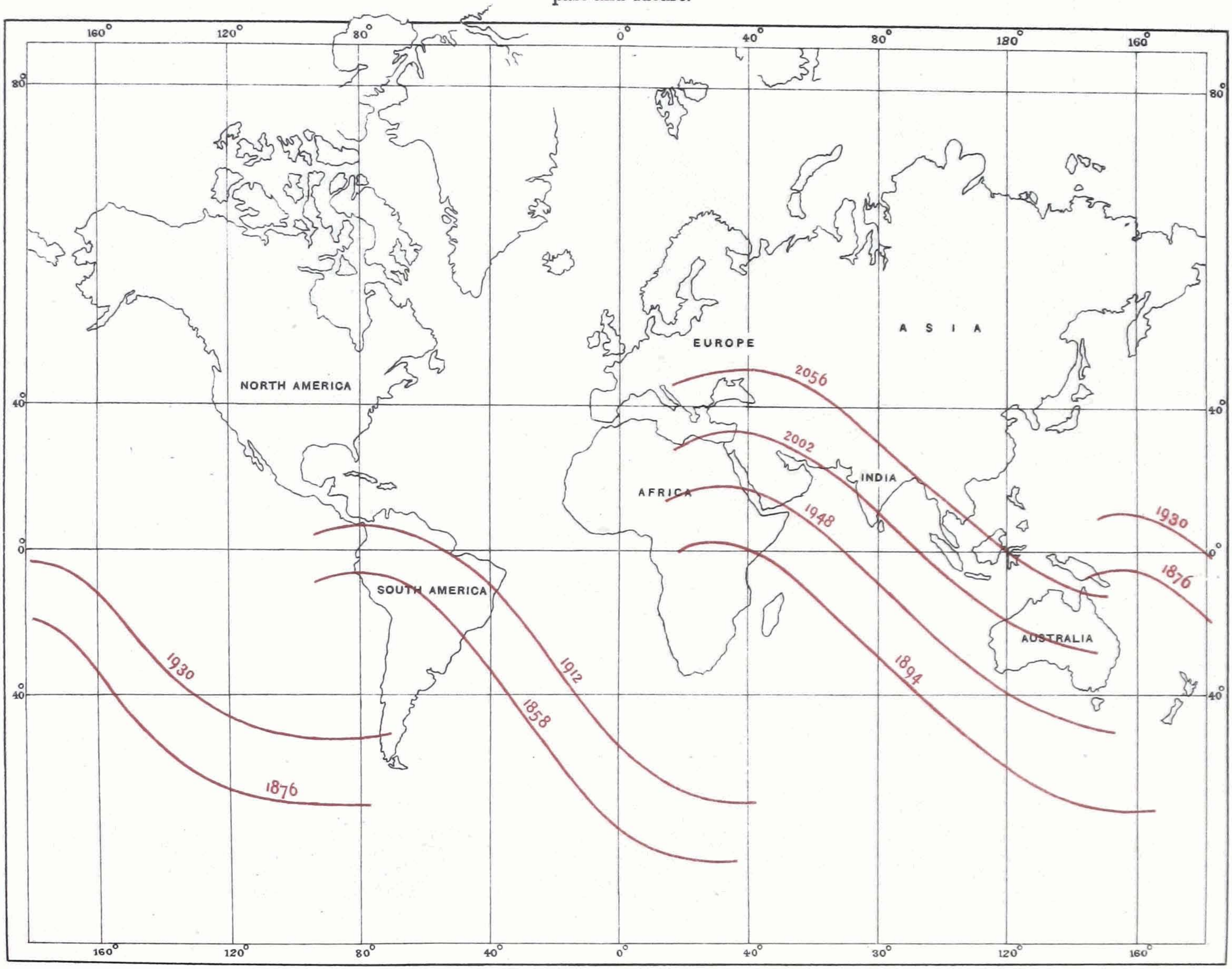


Chart No 11

TRACKS of SOLAR ECLIPSES
past and future.

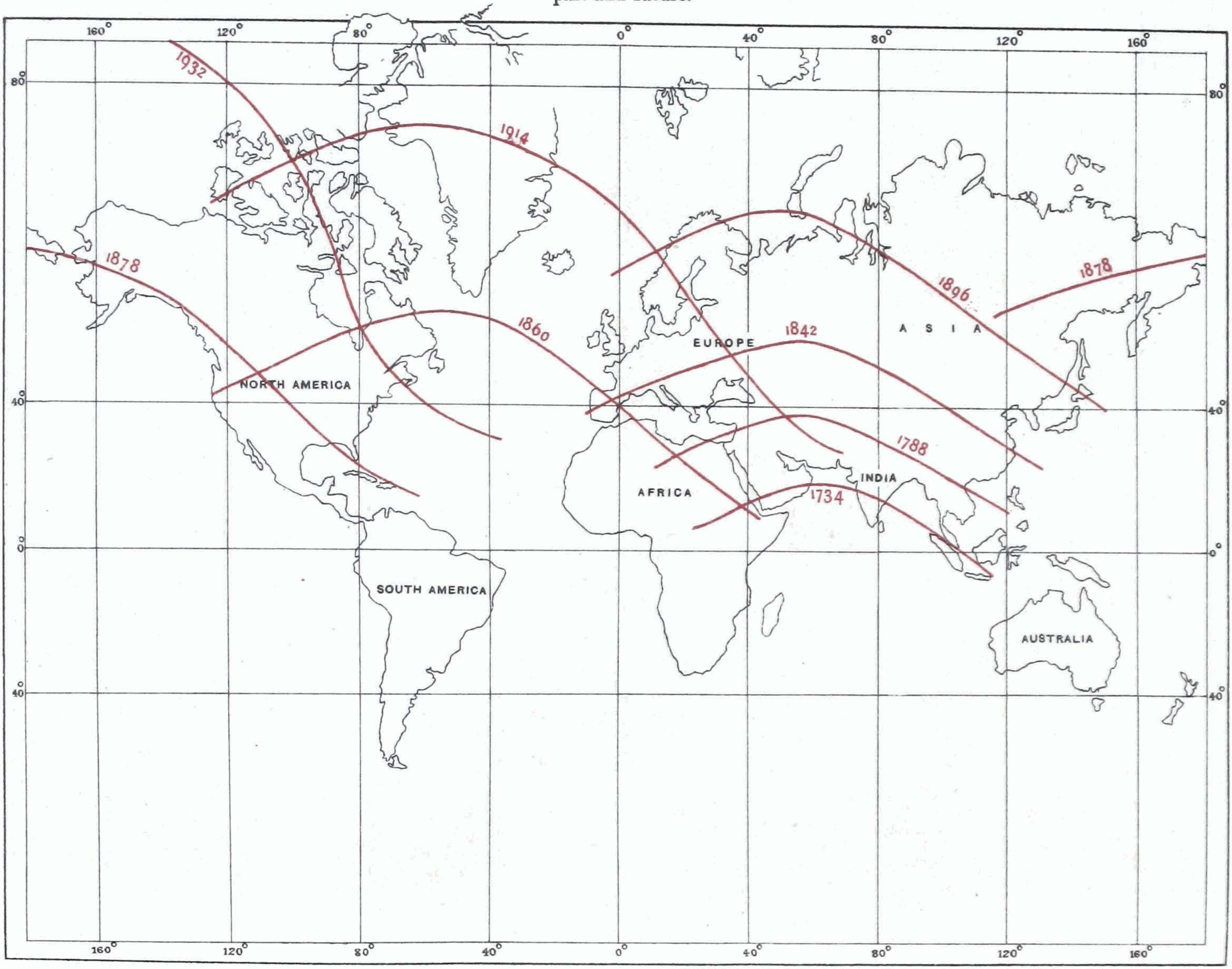
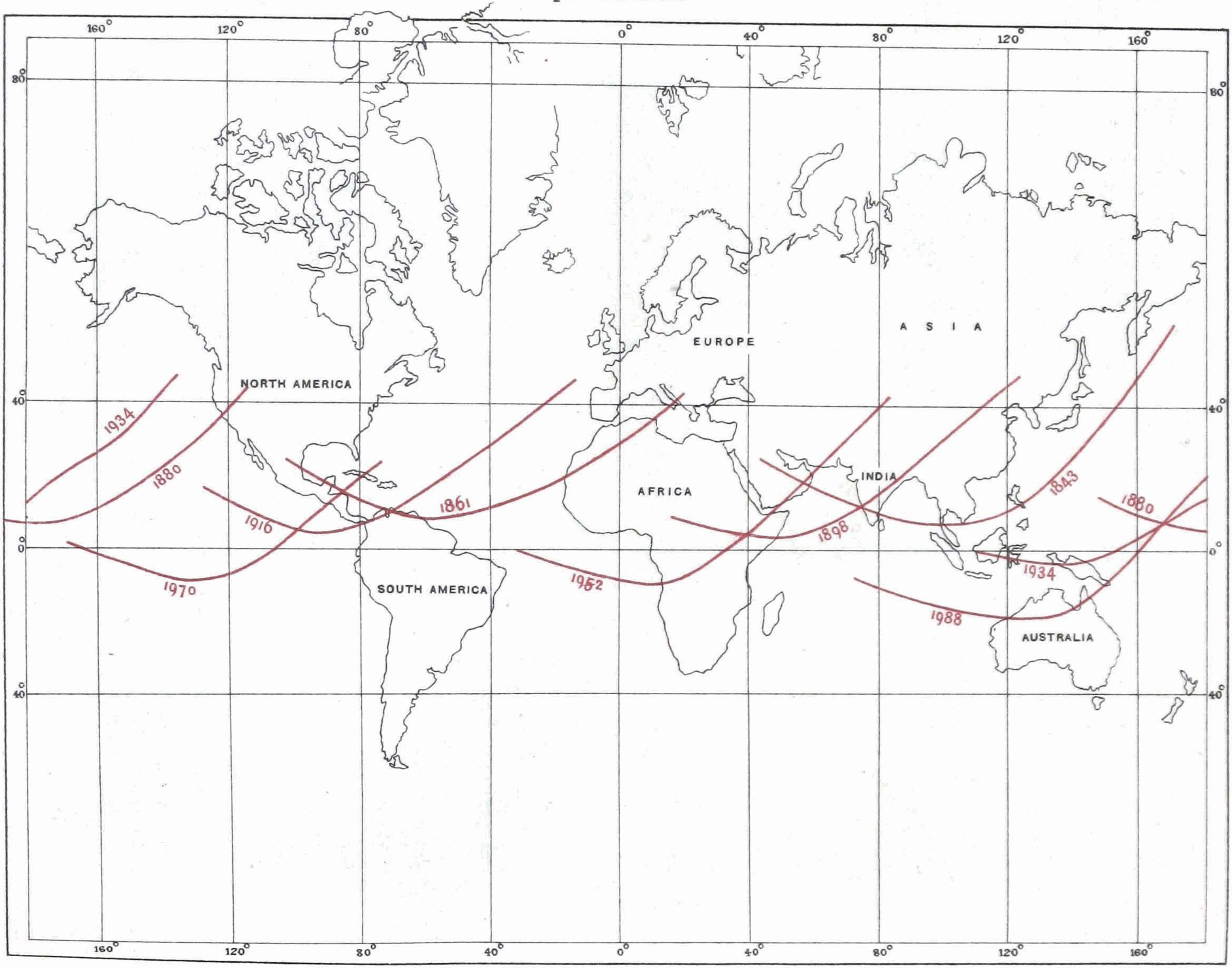


Chart No 12

TRACKS of SOLAR ECLIPSES
past and future.



APPENDIX.

Opinions of the Eye-observers.

All persons, who kindly undertook to make hand-sketches of the Corona, were asked to answer six questions in writing immediately after the Eclipse. The following are the questions and answers :—

1. What changes occurred in the colors of the sky, and landscape?

Sahdol.

COLONEL D. W. K. BARR ...	The sky and landscape were a leaden grey: there were no clouds observable during the Eclipse.
MRS. BARR	The sky was light grey: during totality a dark cloud appeared to the south.
MISS E. C. BARR	The sky and landscape looked as when seen by electric light. Sky over head deep blue, and the horizon lemon yellow.
CAPTAIN A. F. PINHEY ...	Wind died completely: blue haze: like full-moon light: clouds appeared over the hills.
MRS. A. F. PINHEY	Sky dark blue with yellowish glow on horizon: before totality no clouds were visible, but during totality a large bank of purple clouds appeared in the south-west: after totality there was a pinkish color visible for a few seconds on the east of the Moon.
LIEUTENANT E. BARNES ...	Landscape neutral tint: sky deep blue, except round the horizon.
MRS. WEIR	General greyness.
MAJOR-GENERAL C. STRAHAN ...	Ten minutes before totality the general color of the landscape was the same as through smoked glass: the sky became leaden: a haze on the horizon below the Sun.
SIR THOMAS HOLDICH ...	Yellow on the horizon, deep purple sky: cries of "Rám Rám" from the village, a flickering dancing series of shadows in bands across my Plane-table and then totality. The shadows, that danced in waves across the white expanse of paper pinned down to my Plane-table, took my attention off the stop-watch, so that I forgot to time the interval between first appearance of the Corona and totality: I was quite unprepared for the waves. During totality there was ample light to make sketches by. When the Eclipse began, there was no cloud in the sky, but when totality supervened, a horizontal band of clouds appeared to the south. I had the opportunity of comparing the relative value of the dark Moon with that of the shadows on near trees, and the latter were the darker and stronger.
MAJOR S. G. BURRARD ...	Colors at totality were those of ordinary evening darkness: the Corona was the lightest object visible, and after that the horizon.
CAPTAIN W. EWBANK ...	Sky and landscape dull purple.
CAPTAIN J. A. DEALY ...	Nil.
MRS. A. COOKE	The sky was of a lead color to the south, and purple to the north.
MR. J. B. LEVENTHORPE ...	General moon-light effect: long clouds appeared over the hills to the south.
MR. F. MARSH	I saw no coloring during totality.
MR. A. T. GOODFELLOW ...	Grey sky with pale yellow horizon. White filmy clouds appeared five minutes before totality: one and a half minutes before totality a darker cloud appeared half-way between the white cloud and horizon.
MR. G. D. OSWELL	Every thing near of a yellowish tinge, distant hills indigo.

Dumraon.

MR. J. ECCLES	None.

Buxar.

COLONEL HANBURY WHITE ...	Azure deepened into a silver grey and then into a leaden hue: during totality layers of deep orange gradually changing into lead noticeable on horizon facing south.
MRS. E. SCOTT	Color of sky changed gradually from deep azure to leaden grey before totality. During totality sky at horizon was deep orange, fading upwards through yellow into deep leaden color.

2. Specify any changes that you saw occur in the appearance of the Corona.

Sahdol.

COLONEL D. W. K. BARR	... I noticed no change.
MISS E. C. BARR ...	... The Corona did not change.
CAPTAIN A. F PINHEY	... Saw no changes.
LIEUTENANT E. BARNES	... A small streamer appeared to issue from the Corona towards the south later than the other streamers.
MRS. WEIR	... Saw no change.
SIR THOMAS HOLDICH	... The only change which I noticed was the appearance of a fringe of minor rays which seemed to shoot out suddenly low down to the west. They *may* have been there all through, but I do not think so.
CAPTAIN W. EWBANK	... No change noticed.
CAPTAIN J. A. DEALY	... Dividing the Eclipse into three equal periods—during the middle period the streamers were best defined and more in number, and the rifts extended almost to the Moon's disc: during the first and third periods there were only the four *main streamers*: during the middle period minor streamers appeared to the north-west. Rifts appeared and disappeared, and new ones appeared.
MRS. A. COOKE ...	... Saw no change.
MR. J. B. LEVENTHORPE	... The streamer to the north-west flickered, becoming more or less distinct and varying in length and breadth.
MR. F. MARSH ...	... A large streamer to the west of the Moon's disc was visible at first, but afterwards disappeared during totality.
MR. BIJAYNATH SIRKAR	... The two large streamers on the north-east of the Moon kept flickering and changing in length and breadth.
MR. A. T. GOODFELLOW	... The streamer to the west of the Moon appeared after the others.
MR. G. D. OSWELL ...	... After totality had begun, beautiful violet radial lines appeared to the south-west of the Corona.
MANOHAR KRISHNA ...	... The two streamers to the north-east varied in brightness.

Dumraon.

MR. J. ECCLES ...	... Saw none.

Buxar.

COLONEL HANBURY WHITE	... I did not notice any changes.

3. What colors did you observe outside the red prominences?

Sahdol.

COLONEL D. W. K. BARR	... I observed no colors.
MRS. BARR	... No colors were observed.
MISS E. C. BARR ...	... One yellow ring: the streamers were white.
CAPTAIN A. F. PINHEY	... The streamers were a dull yellow.
MRS. A. F. PINHEY ...	... The halo was of bright silver and shone like silver.
LIEUTENANT E. BARNES	... Colors observed were electric white.
MRS. WEIR	... Saw no colors.
SIR THOMAS HOLDICH	... There was a total absence of any color whatsoever in the Corona or Halo.
MAJOR S. G. BURRARD	... The streamers were bright white.
CAPTAIN W. EWBANK	... The streamers were a luminous yellow.
CAPTAIN J. A. DEALY	... Brilliant white silver.
MRS. A. COOKE ...	... Only white.
MR. J. B. LEVENTHORPE	... None of my party could see any colors, except a few who noticed red round the Moon and red prominences.
MR. F. MARSH ...	... No coloring.
MR. A. T. GOODFELLOW	... Silvery white.
MR. G. D. OSWELL ...	... A slightly diminished red.

Dumraon.

MR. J. ECCLES ...	... None.

Buxar.

COLONEL HANBURY WHITE	... The streamers were white but of different degrees of brightness. The streamer to the north-west was least bright: the long streamer to the south-west was the brightest of all, and was composed of white rays like electric light.
MRS. E. SCOTT ...	... No red prominence seen with naked eye: with binoculars I saw a yellow light on the west side, extending to a distance of a third of the Moon's diameter: beyond that the light was purple. The outer edges of the streamers were white like electric light.

4. Were the colors anywhere arranged in layers round the Moon?

Sahdol.

MISS E. C. BARR ...	... Saw one bright yellow ring immediately round the black disc of the Moon, otherwise no layers.
MRS. A. F. PINHEY ...	... The silver halo was arranged in layers round the Moon, as if she had a cloth of silver wrapped round her.
LIEUTENANT E. BARNES	... No.
SIR THOMAS HOLDICH	... The instant totality was over, the sky colors became arranged in layers—pink, purple, yellow—and the colors were precisely the same as I have been in the habit of applying to the ordinary effects of sunset on the *eastern* horizon on a clear day.
MAJOR S. G. BURRARD	... A white layer surrounded the Moon.
CAPTAIN W. EWBANK	... No colors in layers.
CAPTAIN J. A. DEALY	... A layer of silver all round the Moon.
MRS. A. COOKE ...	... No.
MR. J. B. LEVENTHORPE	... A few of my party noticed red round the Moon.
MR. F. MARSH ...	... An extra bright halo encircled the Moon, of greater brightness than the streamers.
MR. G. D. OSWELL ...	... Violet to the south-west.

Dumraon.

MR. J. ECCLES ...	... No.

Buxar.

COLONEL HANBURY WHITE	... Could not see.
MRS. E. SCOTT ...	... Yes, in layers, only visible with binoculars.

5. Were the colors anywhere arranged radially?

Sahdol.

MRS. BARR	... Five electric rays were seen radially.
MISS E. C. BARR ...	... Saw no colors arranged radially, only the white streamers from the halo.
MRS. A. F. PINHEY ...	... The colors were nowhere radial.
LIEUTENANT E. BARNES	... No.
SIR THOMAS HOLDICH	... The streamers that formed the Corona were all radial: they were like the phenomena of the Aurora. A multitude of shafts of white light appeared to me to be separated by thin lines of shadow.
MAJOR S. G. BURRARD	... The streamers were radial.
CAPTAIN W. EWBANK	... No radial colors.
CAPTAIN J. A. DEALY	... Silver rays radiating.
MRS. A. COOKE ...	... No.
MR. J. B. LEVENTHORPE	... No.
MR. G. D. OSWELL ...	... Violet radial lines to the south-west, and red colors in ridges to the north-east.

Dumraon.

MR. J. ECCLES ...	... Some slanting lines, but none radial.

Buxar.

COLONEL HANBURY WHITE	... Could not see.
MRS. E. SCOTT ...	... Could not say.

6. Did the dark rifts extend down to the Moon, or did they stop short before reaching it?

Sahdol.

COLONEL D. W. K. BARR ...	... The dark rifts did not reach the disc of the Moon.
MISS E. C. BARR ...	... The dark rifts stopped short at the Corona and did not reach the Moon.
MRS. A. F. PINHEY ...	... The dark rifts did not extend to the Moon.
LIEUTENANT E. BARNES ...	... The dark rifts did not extend down to the Moon.
SURGEON-LIEUT-COLONEL WEIR	One dark rift on the south-east extended to the Moon's disc.
MAJOR S. G. BURRARD ...	... No rifts extended to the Moon.
CAPTAIN W. EWBANK ...	... No rifts extended to the Moon.
CAPTAIN J. A. DEALY ...	... The rifts varied: near the centre of totality they nearly reached the Moon.
MRS. A. COOKE ...	... No rifts seen.
MR. J. B. LEVENTHORPE ...	... Rifts stopped short and did not reach the Moon.
MR. G. D. OSWELL ...	... One dark rift appeared within the immediate neighbourhood of the Moon.

Dumraon.

MR. J ECCLES ...	... No.

Buxar.

COLONEL HANBURY WHITE ...	... I only used the naked eye and could not answer this.
MRS. E. SCOTT ...	... Couldn't say.

S. G. B.