

CHAPTER 3

The Dark Fine Mottles¹ at the Chromospheric Limb

3 - 1

Introduction.

The dark fine mottles in the chromosphere were previously studied in spectroheliograms taken in different parts of the H_{α} -line and in wide band pass filtergrams. The characteristics obtained by many observers (d'Azambuja 1930, de Jager 1957, Klepenheuer 1957, 1960, Bruzek 1959) are in general agreement but there are still other characteristics yet to be studied. The motion and lifetime of the dark fine mottles were recently studied by Beckers (1963) who used time sequence high resolution filtergrams taken with the C.S.I.R.O. $\frac{3}{8}$ Å tunable filter. From filtergrams obtained with the C.S.I.R.O. $\frac{1}{8}$ Å filter the author of the present thesis has studied the general characteristics and time variations of the dark fine mottles at the extreme limb

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Data

Dr. Ravi Bhavilai's time lapse cinematographic filtergrams of 3.4.64 are used for reduction. They were obtained through the C.S.I.R.O. 5 inch-chromospheric telescope coupled to the $\frac{1}{8}$ Å birefringent filter tuned at $H_{\alpha} + 0.75$ Å. With the objective of 1776 m.m. and an enlarging system, the solar image produced is about 100 m.m. in diameter at the final image plane. The scale is such that 0.1 m.m. on the filtergrams corresponds to 2 sec. of arc on the sun. These filtergrams reveal the general characteristics and time variations of the limb chromospheric structures near the pole at the level of about 1500 km. above the photospheric limb.

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Reduction

Initially slow scanning of the movie was made, to classify the filtergram quality. Eye estimates on a scale of 0 to 4 were used with 0 representing the best quality. The 98 negatives of qualities 0-2 were then selected such that the spacing between filtergrams was about 1 minute. However the spacings were, in general, not uniform. Because of the fluctuating in seeing conditions combined with the use of an automatic exposure triggering mechanism actuated by a seeing monitor (Chapter 2), the spacings between some consecutive filtergrams are as high as 6 minutes. The 98 selected filtergrams were printed with ten times enlargement and two sets of different exposure times of the prints were obtained. By this method, a set of prints of low density show the dark and bright features at the extreme limb clearly while the other set of higher density show the features on the disk. Studies of the chromospheric dark fine mottles were made both on the two sets of the prints and also on the movie projector to clarify their changes.

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Results and Discussion

In the $H_{\alpha} + 0.75$ filtergrams, the dark fine mottles near the limb show elongated structures such that their lengths and widths can be distinguished. The two ends of each dark mottle are quite different in shape. Generally the ends pointing to the limb are narrower and more diffuse than the other ends. By using prints of lesser exposure, one finds that the dark mottles at the extreme limb are in clusters of average length 4.0×10^4 km. along the limb. At positions away from the limb the clusters of mottles form elliptical networks. The eccentricity of the elliptical networks depends on the distances from the limb

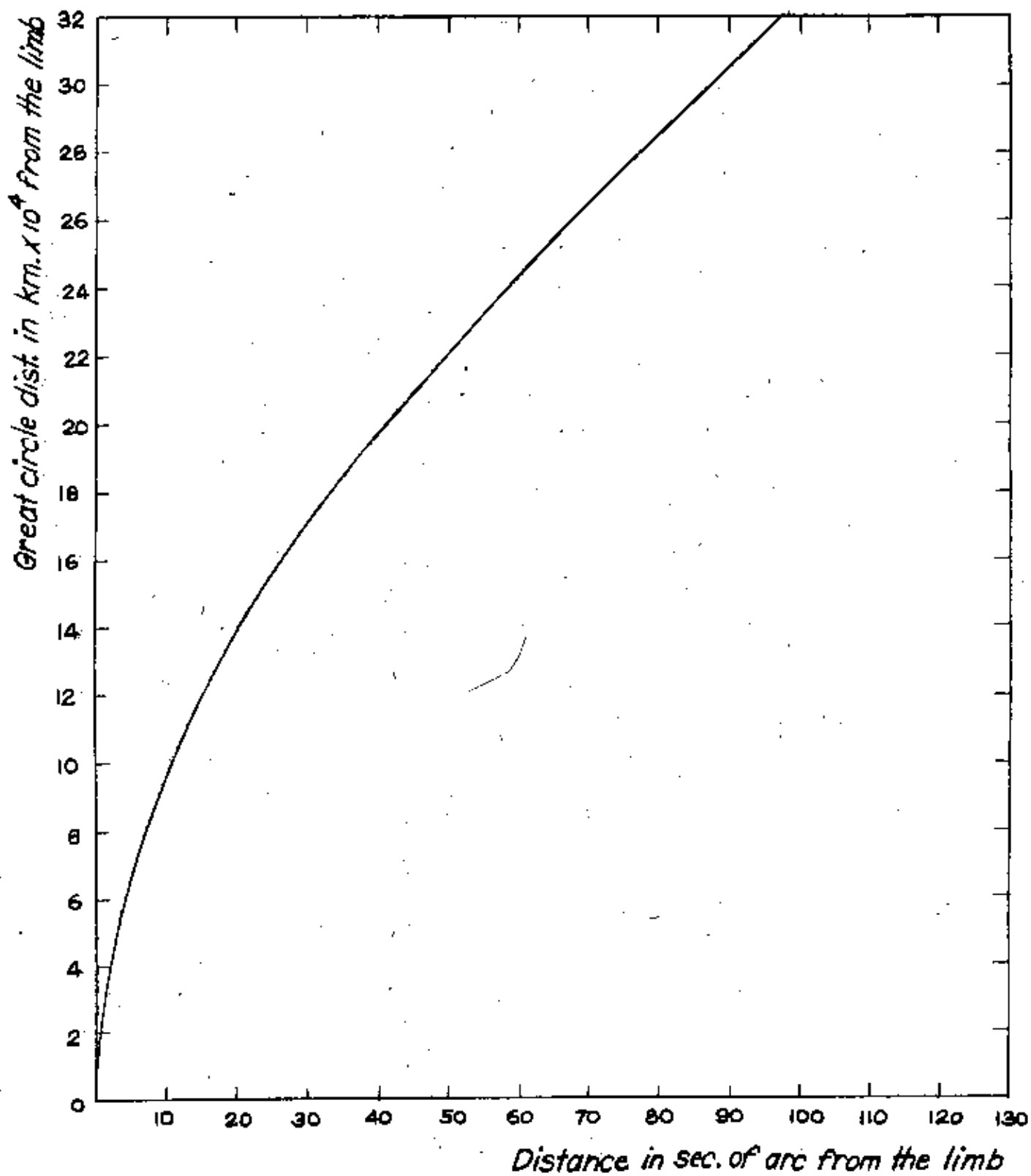


Figure 3-1

PLATE 3 - I

Clusters of the dark fine mottles are shown at the extreme limb in the print of less density. At the position away from the limb the clusters of the dark mottles form the elliptical networks. Inside these networks appear bright areas and, sometimes, bright streaks (near the extreme limb)

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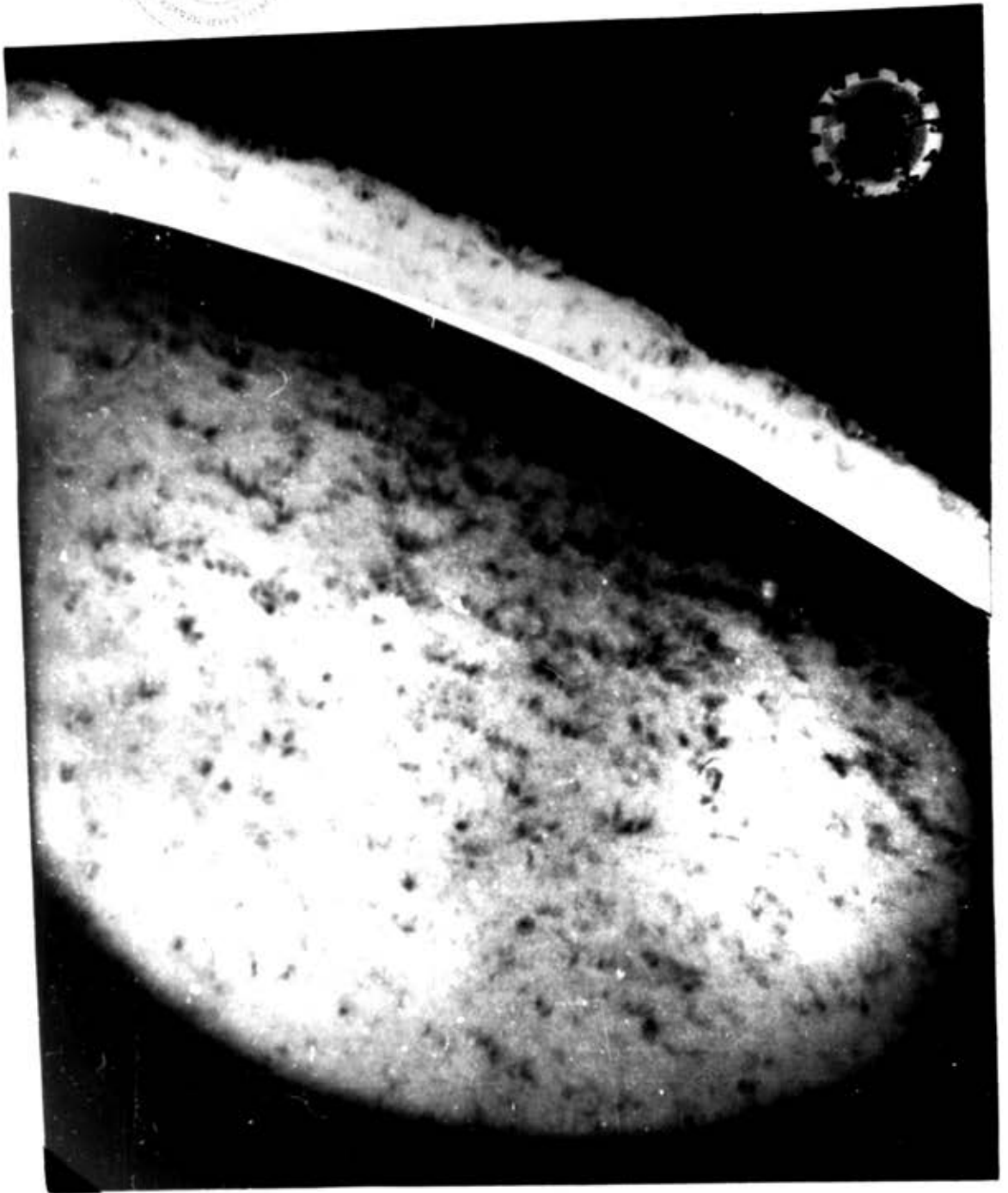


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0" 20" 40"

PLATE 3-1

to their centres. (Plate 3 - 1) With the aid of the curve (Fig. 3 - 1) which is the plot of the great circle distances from the limb against the distances in sec. of arc from the limb, the average dimension of the networks in the radial direction is about 4.6×10^4 km. compared with 4.3×10^4 km. in the direction parallel to the limb. Inside these networks of dark fine mottles, bright areas and, sometimes, bright streaks appear as seen in plate 3 - 1. The association between the bright features, called spicules (Bhavilai 1964) and the dark fine mottles recently suggested by Bhavilai (1964) seems to be confirmed and the networks mentioned above are certainly the same as the networks of coarse mottles of size about 5.0×10^4 km., found by de Jager (1957) near the centre of the disk in the spectroheliohram taken in the light of $H_{\alpha} + 0.5 \text{ \AA}$.

Dimensions of the Mottles

The widths of 53 dark fine mottles at the extreme limb were measured from three good quality prints: 18 mottles from 10 17 55, 20 mottles from 10 53 05, and the rest from 10 53 15 prints. The widths, defined as the broadest parts of the dark fine mottles are in the range 1.0 - 4.1 sec. of arc. with an average of 2.5 sec. of arc. Their lengths as measured from 140 mottles at the extreme limb have a distribution ranging from about 1.5 to 14 sec. of arc as shown in the Table 3 - 2. It is worth noting that the upper ends of all the dark fine mottles at the extreme limb merge with the background and show broad defined ends instead of sharp diffused ends as they do elsewhere. Comparing the result from the Table 3 - 2 to that of the Table 3 - 1 which show the correlations between the length of the dark fine mottles and the distances from the limb, it is found that

Table 3-INumber of dark fine mottles near the limb ($H_{\alpha}0.75$).

Distance from limb in sec. of arc length in sec. of arc	10-20	20-30	30-40	40-50
2 - 3				
3 - 4			2	
4 - 5		1	3	1
5 - 6		3	2	3
6 - 7	1	3	8	5
7 - 8	3	6	12	11
8 - 9	3	3	2	
9 - 10	3	13	1	1
10 - 11	12	4	6	1
11 - 12	11	2	4	1
12 - 13	7	1		
13 - 14	1			
14 - 15	2			

Table 3 - 2Number of dark fine mottles along extreme limb, ($H_{\alpha} + 0.75$)

Length (in sec. of arc)	IO 18 47	IO 49 20	IO 53 03	IO 53 15	Total
1.0 - 2.0	1	1	1	1	4
2.0 - 3.0	5	2		4	11
3.0 - 4.0	6	3	1	3	13
4.0 - 5.0	4	5	2	4	15
5.0 - 6.0	5	4	3	1	13
6.0 - 7.0	5	4	4	2	15
7.0 - 8.0	6	2	5	5	18
8.0 - 9.0	7	6		5	18
9.0 - 10.0	3		3	4	10
10.0-11.0	2	4	1	1	8
11.0-12.0	1	1	1		3
12.0-13.0	2		1	3	6
13.0-14.0	1	2	1	2	6

about 70% of the dark fine mottles at 10 - 20 sec. of arc from the limb are 10 - 13 sec. of arc long; 61% at 20 - 30 sec. of arc from the limb are 7 - 10 sec. of arc and at greater than 30 sec. of arc from the limb 73% of measured dark fine mottles are 6 - 8 sec. of arc in length. The decrease of length with the increase of distance from the limb is quite obvious.

Orientation

The orientations of the dark fine mottles are very interesting too. Generally most of them point limbward making angles to the radial direction. The orientations of fifty mottle at the extreme limb were measured and an average angle of about 8° to the radial direction was obtained. In the case of dark fine mottles belonging to the same cluster, their alignment are parallel to each other.

Time Changes of The Mottle

Twenty two prints from 10 17 55 to 10 59 19 were used for the study of the changes of the dark fine mottles with time. It is obvious that in the 40 min. 24 sec. interval the individual dark fine mottle in each network do change in dimension and contrast but the networks themselves can be traced through the interval without variations in size and form. Plate 3 - 2) To study the variations of contrast with time of the dark fine mottles a contrast scale in the range of 0 to 5 is selected in which 5 represents highest contrast as estimated by eye. The contrast of the dark fine mottles at the extreme limb, in general, shows only small variations throughout the interval while that of the mottles away from the extreme limb vary greatly. The five curves in fig. 3 - 2 show the variations of contrast against time of five dark fine mottles at distances greater than 20 sec.

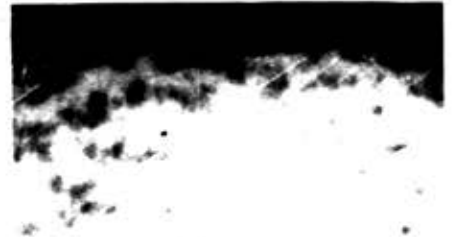
PLATE 3 -2 (a & b)

In the H - filtergrams, individual dark fine mottles in the network do change in dimension and contrast but the network itself show no variation in size and form in the 40 min. 24 sec. interval. Note that dark feature does not appear in the bright area inside the network throughout the interval.





10 17 55



10 18 58



10 20 29



10 21 32



10 23 54



10 26 28



10 32 57



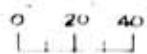
10 33 26

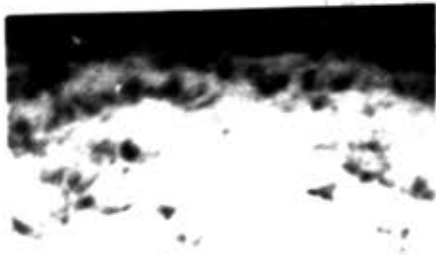


10 35 52

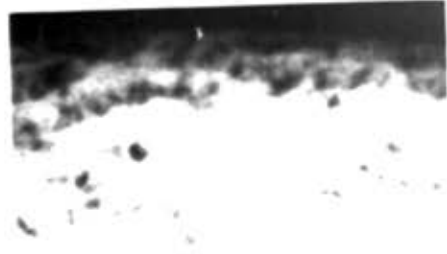


10 35 11





10 35 36



10 36 03



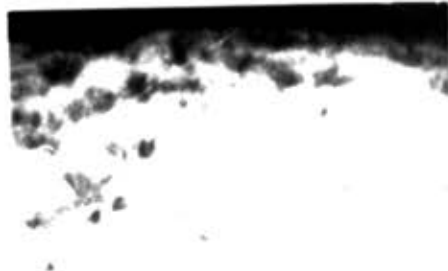
10 42 42



10 47 00



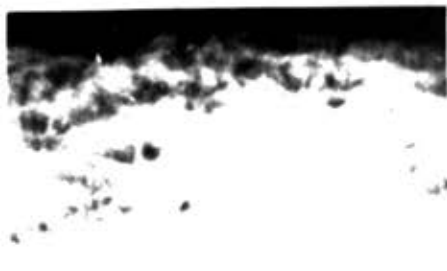
10 47 45



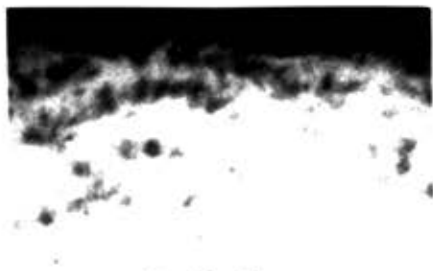
10 50 32



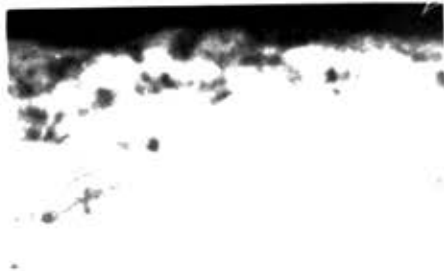
10 51 28



10 53 15



10 56 12



10 58 19

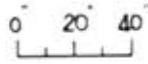


PLATE 3-2 (b)

PLATE 3 - 3 (a & b)

A comparison of the two filtergrams, taken in $H + 0.75 A$ shows that in the interval of about 3 hours, the overall structures in the two filtergrams remain similar, only the length and contrast of individual dark fine mottle are different.

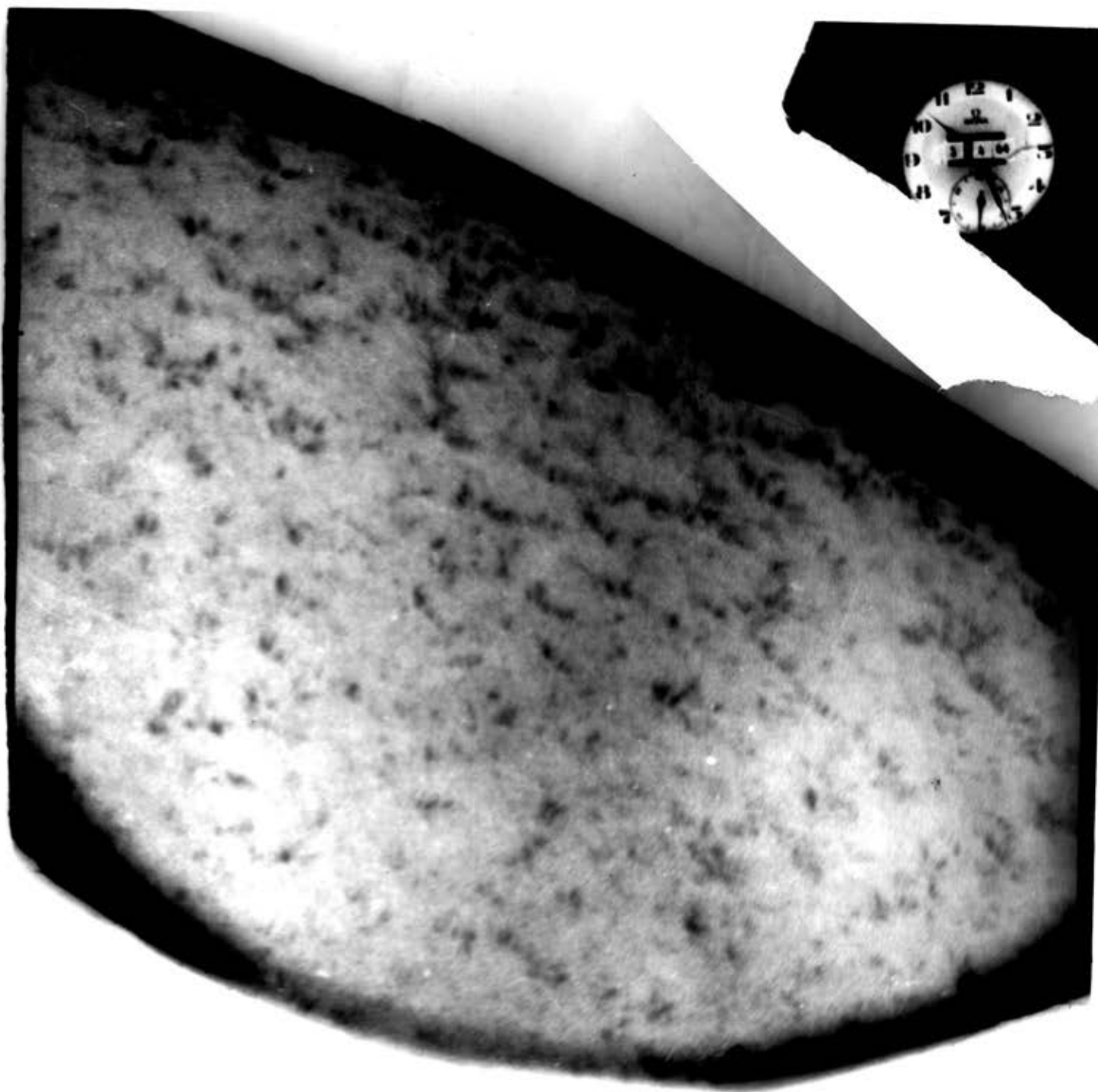


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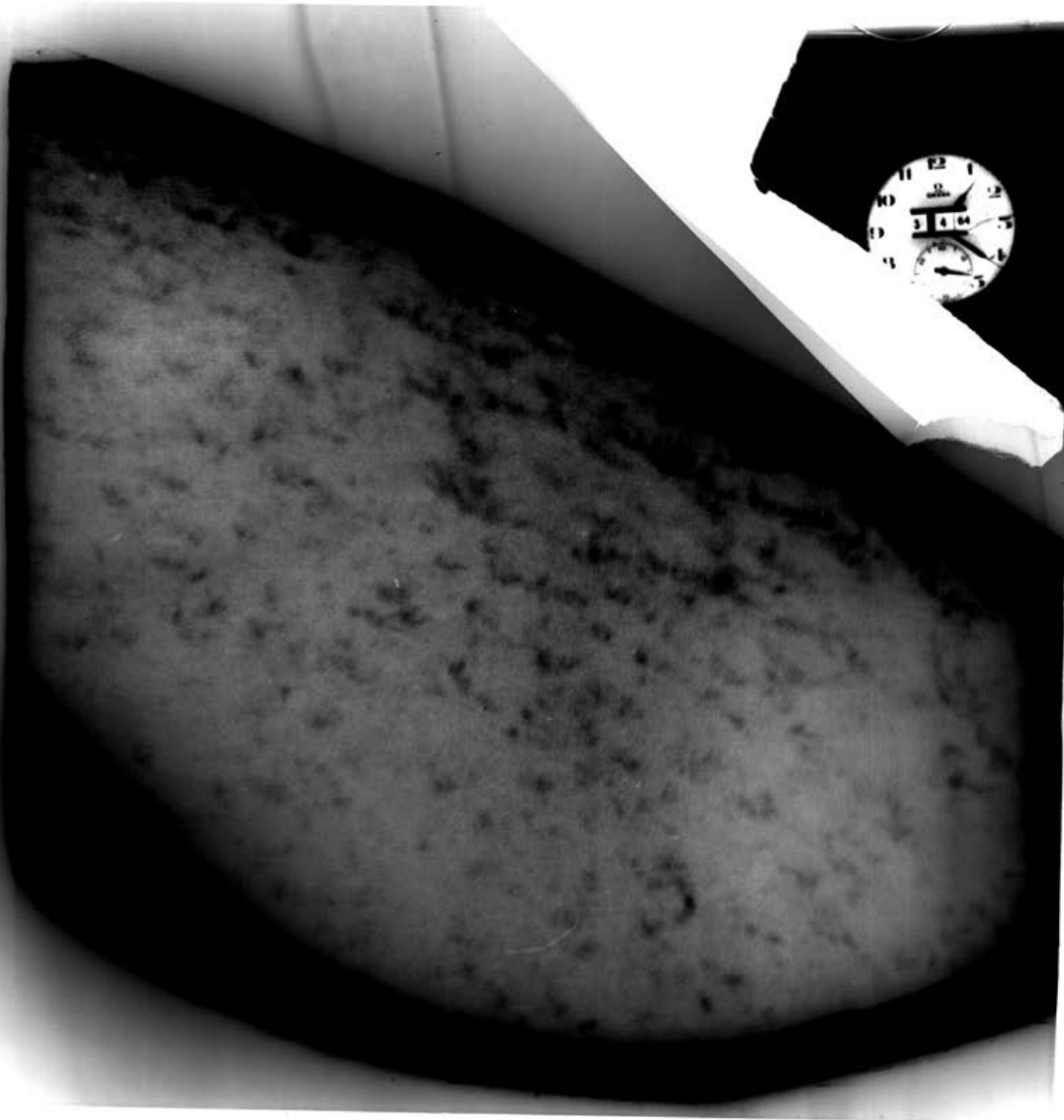
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0" 20" 40"

PLATE 3-3 (a)



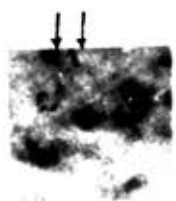
0" 20" 40"

PLATE 3-3 (b)

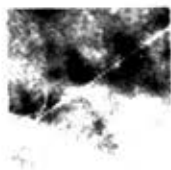
PLATE 3 - 4 (a)

Lengthening of two dark fine mottles (indicated by two arrows in the IO I7 55 print) are shown clearly in the IO I7 55 - IO 26 28 prints. When they disappear (IO 32 57 - IO 51 28) the position which they previously occupied still appear darker than the surrounding.





10 17 55



10 18 58



10 20 29



10 21 32



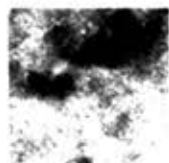
10 23 54



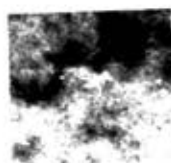
10 26 28



10 32 57



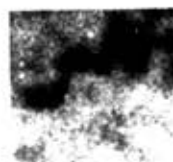
10 33 26



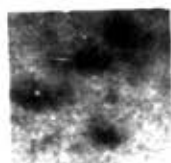
10 33 59



10 35 11



10 35 36



10 36 03



10 42 43



10 47 00



10 47 45



10 51 28

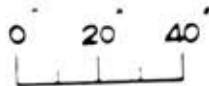


PLATE 3-4(a)

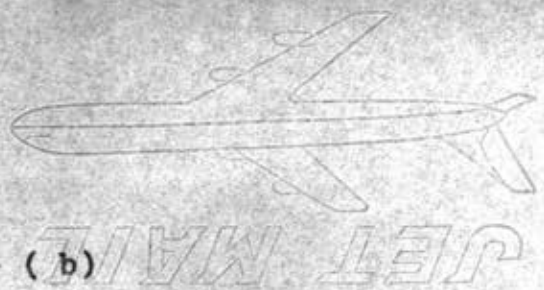


PLATE 3 -4 (b)

Lengthening and shortening of a dark fine mottle (indicated by short vertical lines) are shown. Notice the bright streak appearing near the extreme limb (for example, at the right of the plate)



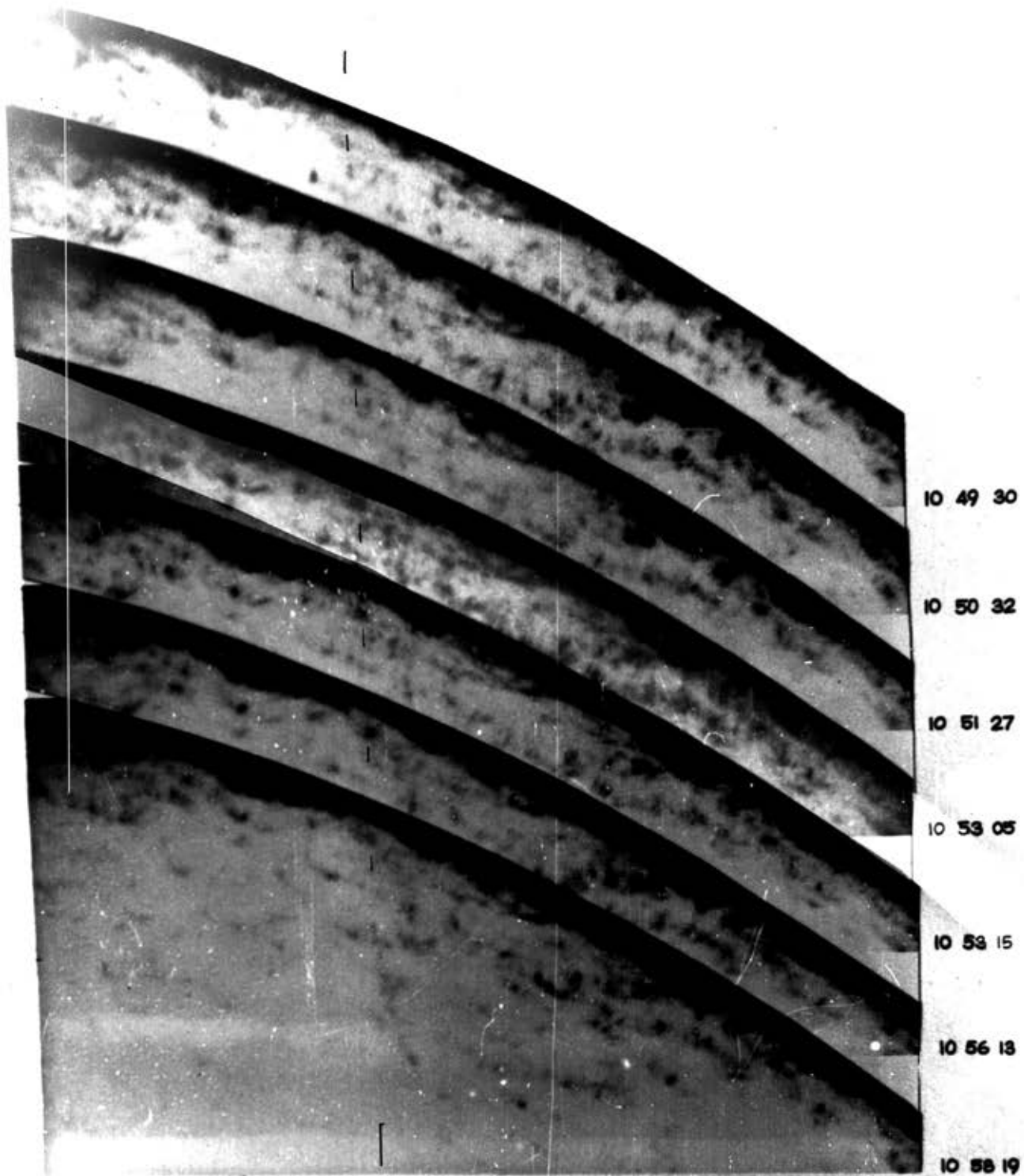


PLATE 3-4(b)

of arc from the limb. From these curves, it is found that the dark fine mottles, after decreasing in contrast, always reappear at the same positions. It should also be noted that regions not occupied by dark fine mottles initially, especially in the centre of the networks, are bright throughout the 40 min. 26 sec. interval. Furthermore, a comparison of the two filtergrams in Plate 3 - 3 shows that in the interval of about 3 hours the overall structures in the two filtergrams remain similar, only the length and contrast of individual dark fine mottles are different.

The variation in length of dark fine mottles is the same for both those at the extreme limb and those away from the limb as shown in Plate 3 - 4 (a). A shortening of the elongated dark mottles is also found in Plate 3 - 4(b). The extensions are at the rate of about 20.8 km./sec. , which is not far from the rate of about 23.0 km./sec. for the shortening of the elongated mottles, see Table 3 - 3. Although these values are approximate estimates, they reveal that the lengthening and the shortening of dark fine mottles do exist in the range of about $9 - 35 \text{ km./sec.}$

From the facts that the lengths of the dark fine mottles, as seen projected on the disk, depend on the distances from the limb and from the tendency of the elongated fine mottles to point limbward, the view that the mottles are vertical structure seems to be confirmed. However, the existence of fine dark mottles which are longer than $7''$ of arc, (Table 3 - 1) & 3 - 2) the height of chromosphere raise the question why the average unresolved chromospheric height is around that figure. Besides, there are some mottles, at positions very far from the limb (about $150''$ of arc) showing elongated structures of about $7 - 10 \text{ sec.}$ of arc (see Plate 3 - 3). The combination of these results with simple

Table 3 - 3

Variation in length of dark fine mottles.

From	L_1	To	L_2	Elongation	Shortening	Period of time	V in km/sec.
10 17 55	5.5	10 20 29	9.5	4.0		154	18.6
10 21 32		10 26 29	8.0	8.0		305	18.9
10 49 21		10 53 15	8.0	8.0		235	24.0
10 33 59	8.0	10 36 03	5.0		3.0	124	17.4
10 26 28	5.0	10 32 57	12.0	7.0		389	13.0
10 20 29	6.0	10 23 54	11.0	5.0		205	16.8
10 49 20	9.0	10 50 32	11.0	2.0		68	21.1
10 49 20	9.0	10 50 32	6.5		2.5	68	26.4
10 49 20	6.0	10 50 32	8.0	2.0		68	21.1
10 50 32	11.0	10 53 15	7.0		4.0	163	17.7
10 53 15	6.0	10 56 12	10.0	4.0		177	16.3
10 53 15	8.0	10 56 12			8.0	177	32.6
10 53 15	3.0	10 56 12	8.0	5.0		177	20.3
12 11 32	9.5	12 14 20	11.0	1.5		48	22.5
12 10 43	4.5	12 14 20	11.0	6.5		217	21.5
12 11 43		12 13 32	4.5	4.5		109	29.7
01 20 15	8.5	01 21 16	10.0	1.5		61	17.7
01 19 53	8.5	01 21 16	11.0	2.5		83	21.6
10 33 59		10 35 36	4.0	4.0		97	29.7
10 33 59	5.0	10 35 11	4.0		1.0	82	8.8
10 33 59	4.0	10 35 11			4.0	82	35.0

 L_1 and L_2 are in sec of arc.

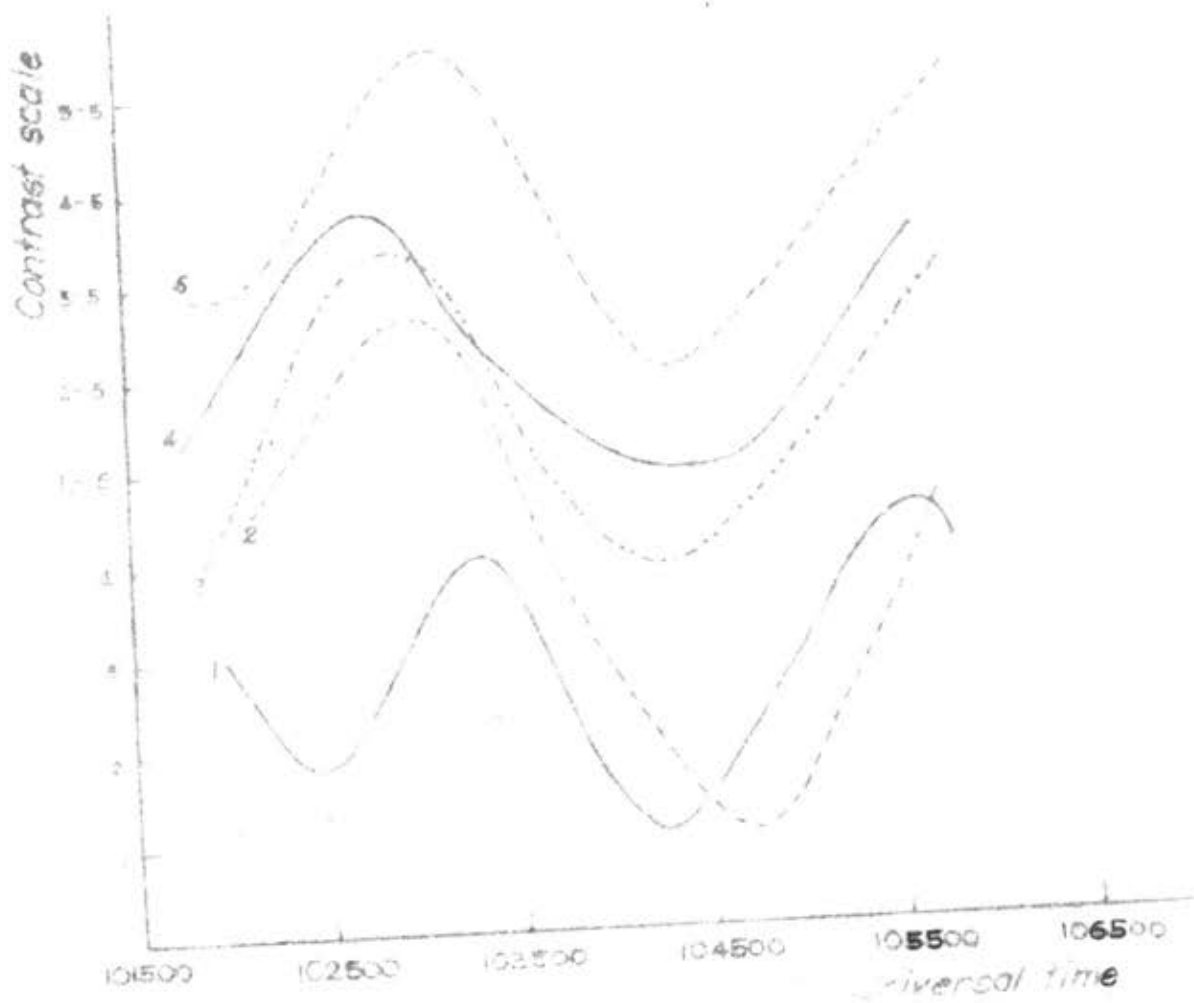
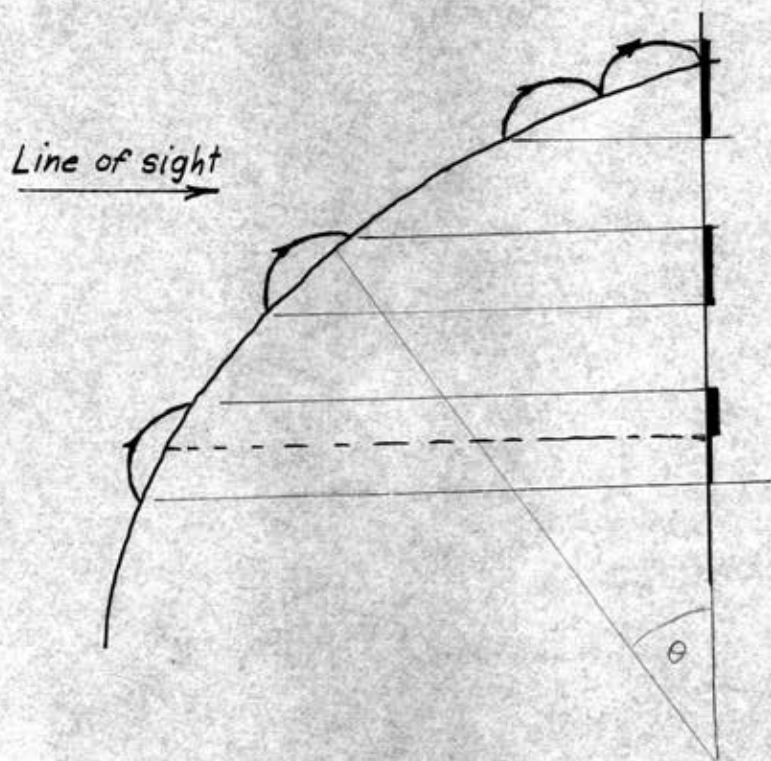


Figure 3-2

geometrical ideas (fig. 3 - 3) seems to suggest the loop model of the dark fine mottles (Bhavilai 1964).

The elongated mottles away from the limb can be interpreted as the loops as seen along the line of sight projected on the disk. The portions of loops at right angles to the line of sight are seen projected on the disk as elongated dark mottles, not longer than $7''$ of arc and so the elongated dark mottles may sometimes lead to the interpretation that dark fine mottles are vertical structures. The problem now arises as to how the very long dark mottles at the extreme limb (Table 3 - 2) are to be interpreted. Consider for example the mottles about $10''$ of arc long. From the curve in fig. 3 - 1, the roots of such dark mottles have a great wide distance of about 10^5 km. from the extreme limb. The distance is about twice the diameter of the networks, namely about $2 \times 4.6 \times 10^4$ km. It may be that these long dark mottles are due to the overlapping of dark fine mottles belonging to different networks.

This paper suggests that the dark fine mottles are not the same thing as the bright spicules, seen along the limb. The identification of spicules as the bright features on the disk will be discussed in the next Chapter.



One of the representation of loop model of dark engine mottles (not in scale)

Figure 3-3