CHAPTER 4

A STUDY OF THE COMPLEX SUNSPOT GROUPS OF 20 NOVEMBER - 1 DECEMBER 1967

SUMMARY

The development of two nearby sunspot groups of 20 November - 1 December 1967 are studied in the light of Babcock's theory on the formation of sunspot groups. Both groups seemed to be produced by a single flux rope of the same turn. Analysis of the data, however, indicates that they did not occur from the same flux rope of the same turn.

4.1 INTRODUCTION

Since January 1966 a programme of solar observations has been in progress at the Observatory of the Bangkok Planetarium, Sukhumwit Road, Bangkok, and, as part of this programme, interesting sunspot groups have been selected on occasions for extended high resolution studied of their development. The sunspot groups which appear near the east limb of the solar disk on 20 November 1967 were studied during their transit across the disk which is shown on Plate 4.1. Photospheric photograps were taken every day from 20 November to 1 December 1967 with the 150 mm-Zeiss-coude' refractor of the Sukhumwit Observatory. This chapter describes the development of these complex sunspot groups.

Sunspots appear on the surface of the sun by the emergence of

Plate 4.1.-The apparent transit of sunspot groups across the solar disk caused by the rotation of the sun. Photographs taken at the Sukhumvit Observatory, Bangkok.

solar magnetic flux ropes in the photosphere. According to BABCOCK (1961), the weak poloidal field of the sun of strength 1 - 2 gauss, has shallow submerged lines of force which, are distorted by the solar differential rotation. These lines are drawn out in longitude to form rather tight spirals or toroidal fields on opposite sides of the solar equator. This continues until the magnetic energy of the submerged toroidal fields locally attains a critical limit, and instabilities occur. Magnetic bouyancy will lift the concentrated flux ropes to the surface. The lines of force cut the solar surface at two adjacent equal areas of opposite polarities which are referred to as the preceding part and the following part in relation to the rotation of the sun. These two regions which are produced by each loop are called bipolar magnetic regions, and bipolar magnetic regions in the two hemispheres have inverse polarities. Sunspots occur within bipolar magnetic regions wherever the lines of force are sufficiently concentrated to inhibit convection on the solar surface.

As a consequence of differential rotation, the spiral winding of the toroidal field is tighter in moderate latitudes than near the equator, so sunspots first appear at moderate latitudes at the beginning of the sunspot cycle and then progress to lower latitudes at the end of the cycle.

4.2 GENERAL CHARACTERISTICS OF A SUNSPOT GROUP

A sunspot group first appears as one or more sunspot pores.

Most groups do not develop beyond this stage, and they usually disappear by the following day. Groups that have survived continue to develop rapidly to maximum area and then slowly decline. According to Waldmeier (1955) (quoted from BRAY and LOUGHHEAD (1964)), the lifetime of a sunspot group is related to its maximum area by the rule

$$T = 0.1 A_{max}$$

where T is the lifetime in days and A_{max} is the maximum area in millionths of the visible hemisphere. The area of a sunspot is related to its magnetic field strength. The lifetime of a sunspot group ranges from 1 day to more than 100 days. The frequency of occurrence decreases rapidly with increasing lifetime. The Zürich classification of sunspot groups is used to describe their development. Large sunspot groups pass through all classes during their lifetime, whilst medium sunspot groups and small sunspot groups only pass through some classes.

The presence of a sunspot generally has no effect on the surrounding granulation except in the case of new and developing spots, which have occasionally caused disturbances in the granulation pattern. Dark lanes have been observed developing between two groups of pores of opposite polarities. BRAY and LOUGHHEAD (1964) interpreted this phonomenon as evidence of the existence of a rising loop of magnetic flux. The development of a sunspot pore during the first day is rapid because of the increase of magnetic flux in that region. Most pores with diameter exceeding 5 sec of arc will develop into small spots having a penumbral structure surrounding them. Both the umbra and the penumbra develop with increasing area. The structure of a well developed penumbra depends on the size and the stage of its evolution. Most penumbral structures are filamentary, tending to run radially outward from the umbra to the photosphere. In most spots there are various kinds of bright features which are classified into three distinct morphological types by BRAY and LOUGHHEAD (1964). Bright regions are also found in the umbra of most spots and these are called light bridges. They show great diversity in shape, size, and brightness. They may be in the form of large masses of bright material or of thin streamers of about 1 sec of arc in width. Some bridges are brighter than the photosphere and some are so faint as to be seen only on overexposures. Light bridges are often stable and longlived. Most of them have a lifetime of at least several days. They often occur at one side of the umbra and then extend to the other side of the umbra, and the appearance of light bridges in the umbra of a spot during the later part of its life is frequently a sign of final dissolution.

4.3 OBSERVATION AND REDUCTION

Photographic observations were made everyday from 20 November to 1 December 1967 with the 150 mm- Zeiss-Coude' refractor. On each day the observations were usually taken between local time 09 h 00 min to 16 h 00 min. The good solar seeing moments occur between 11 h 00 min to 13 h 00 min. The first images were taken through the OG2 filter, and the enlarged images through the OG2 and the RG5 filters using Gaveart

Duplo pan rapid roll film. The response curves of the emulsion and the transmission curves of various filters are shown in Figure 4.1. Development was undertaken in a tank using Kodak D76 developer at 20° C for 9 minutes.

Enlarged prints have been made from good quality negatives with an enlargement of 10 times original size on high contrast Agfa BS1 paper. The print scale is 10.8 mm to 10 sec of arc.

4.4 DESCRIPTION OF THE COMPLEX GROUP OF 20 NOVEMBER - 1 DECEMBER 1967

Two medium sunspot groups appeared on the east limb of the solar disk on 20 November 1967. At first they appeared to be a single group of class D, but from the later observations it is evident that they were two separate groups. For convenience, the larger group is called the W group, and the smaller one, the E group. Between these two sunspot groups, several pores appeared, as shown on Plate 4.2.The faintest pores at the left near the W group developed further and extended to the W group as the following part of the group. Other pores occuring between the two groups and which had persisted for 5 days appeared very faintly on 24 November and then disappeared on the following day. The pores above the E group developed on 21 November like a class B sunspot group and disappeared by the following day. Unfortunately the resolution of the photographs

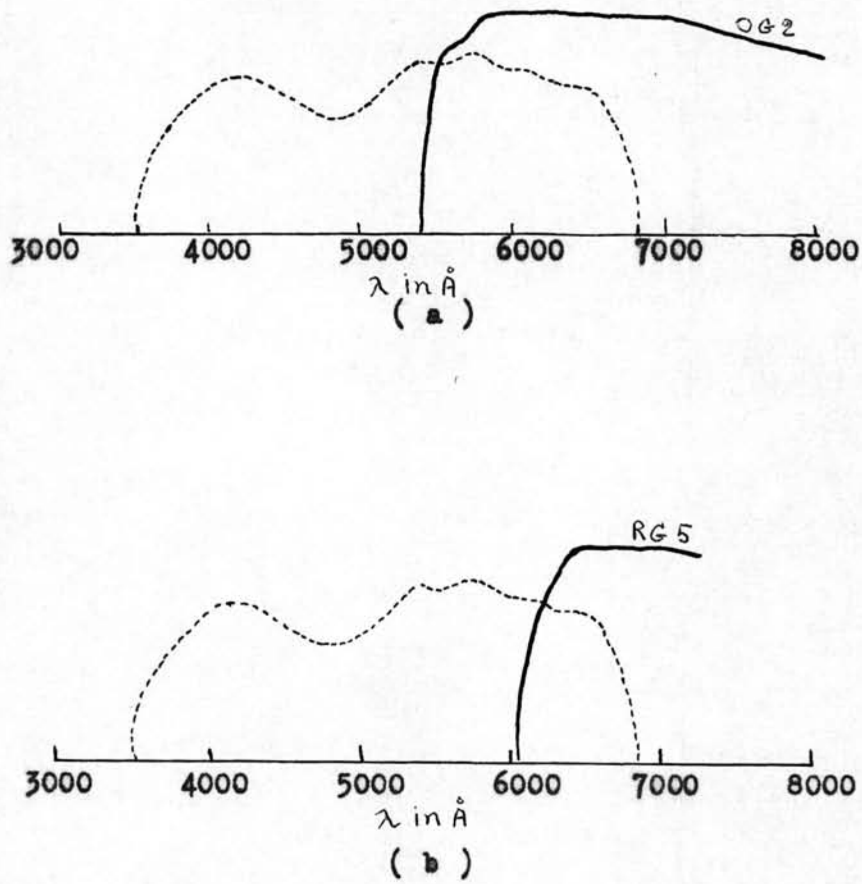


Figure 4.1 The response curve of Duplo Pan Rapid emulsion and transmission curves of filters (a) OG2 and (b) RG5.

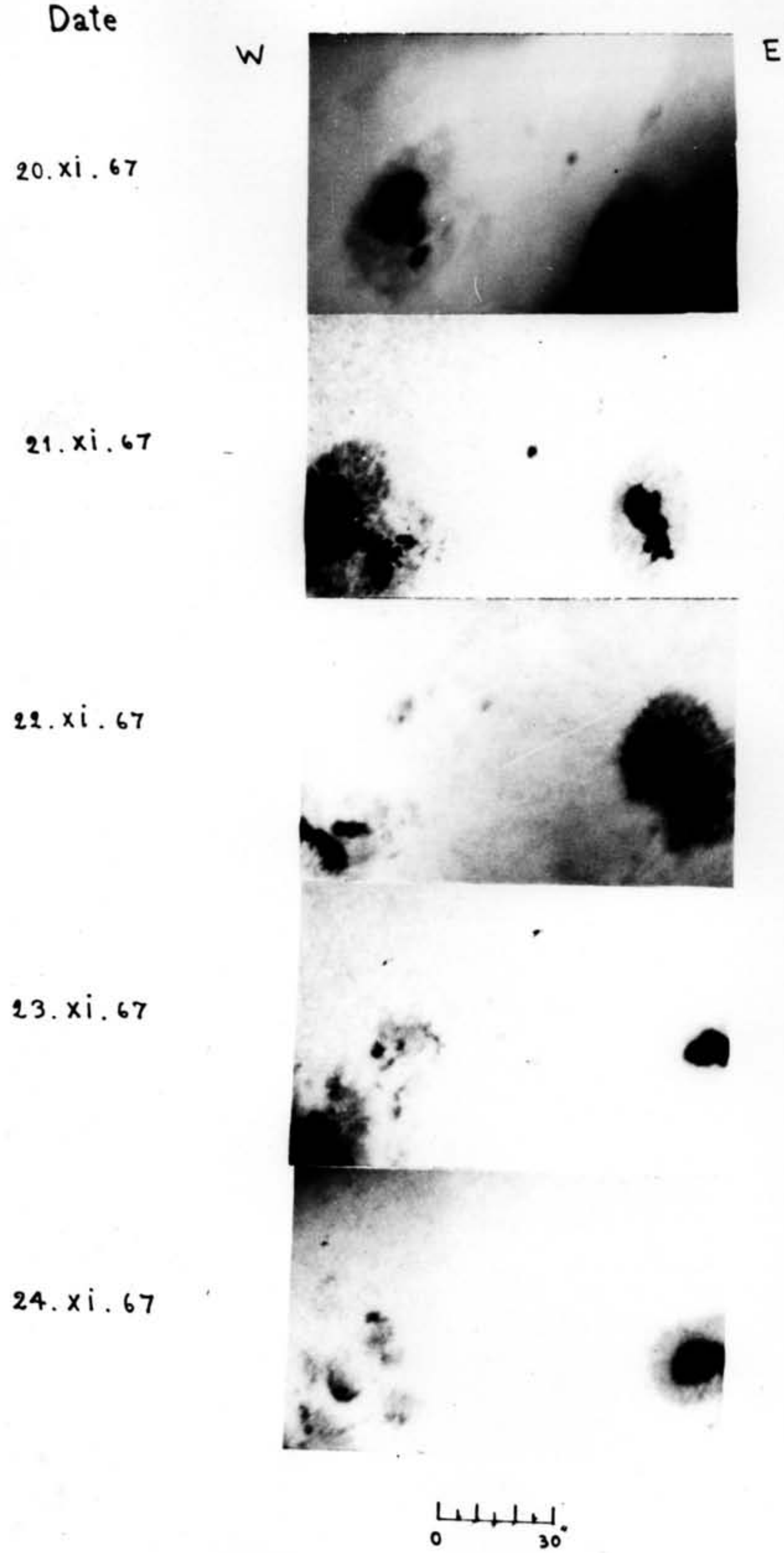


Plate 4.2.- The development of pores between two sunspot groups.

is not good enough to show the details in each spot. Bright regions were found between the two small umbrae in the large spot of the W group and at the lower part of the umbra of the E group.

The W group developed further as shown on Plates 4.3 and 4.4. It gradually moved to the centre of the solar disk with increasing area. A light bridge at the right of the largest umbra began to invade through the umbra on 21 November. The umbrae developed and became larger and larger, the lower part of the largest umbra extended and elongated. A light bridge at the lower edge of the largest umbra appeared on 22 November and invaded to the upper edge. These two light bridges divided the umbra into three parts on 23 November. Small umbrae at the right of the spot developed and combined into two elongated umbrae on 22 November. The left part of one elongated umbra near the largest umbra separated from the rest to combine with the right part of the largest umbra to form the third part. So there were five large umbrae in the main spot on 23 November. The faintest pore near the group began active and expanded into a large spot as several small sunspots following the main spot. The bright region at the upper right part of the penumbra of the main spot still persisted and seemed to invade through the penumbra to separate into two main spots on 23 November. On 24 November the two main spots began to move apart. The left, nearly roundish spot, was the preceding spot while the right (combined from 4 umbrae) elongated one, with the several small spots were the following spots. The group tended to a maximum on 24 November and then gradually declined. The small following spots began to disappear. The group slowly moved toward

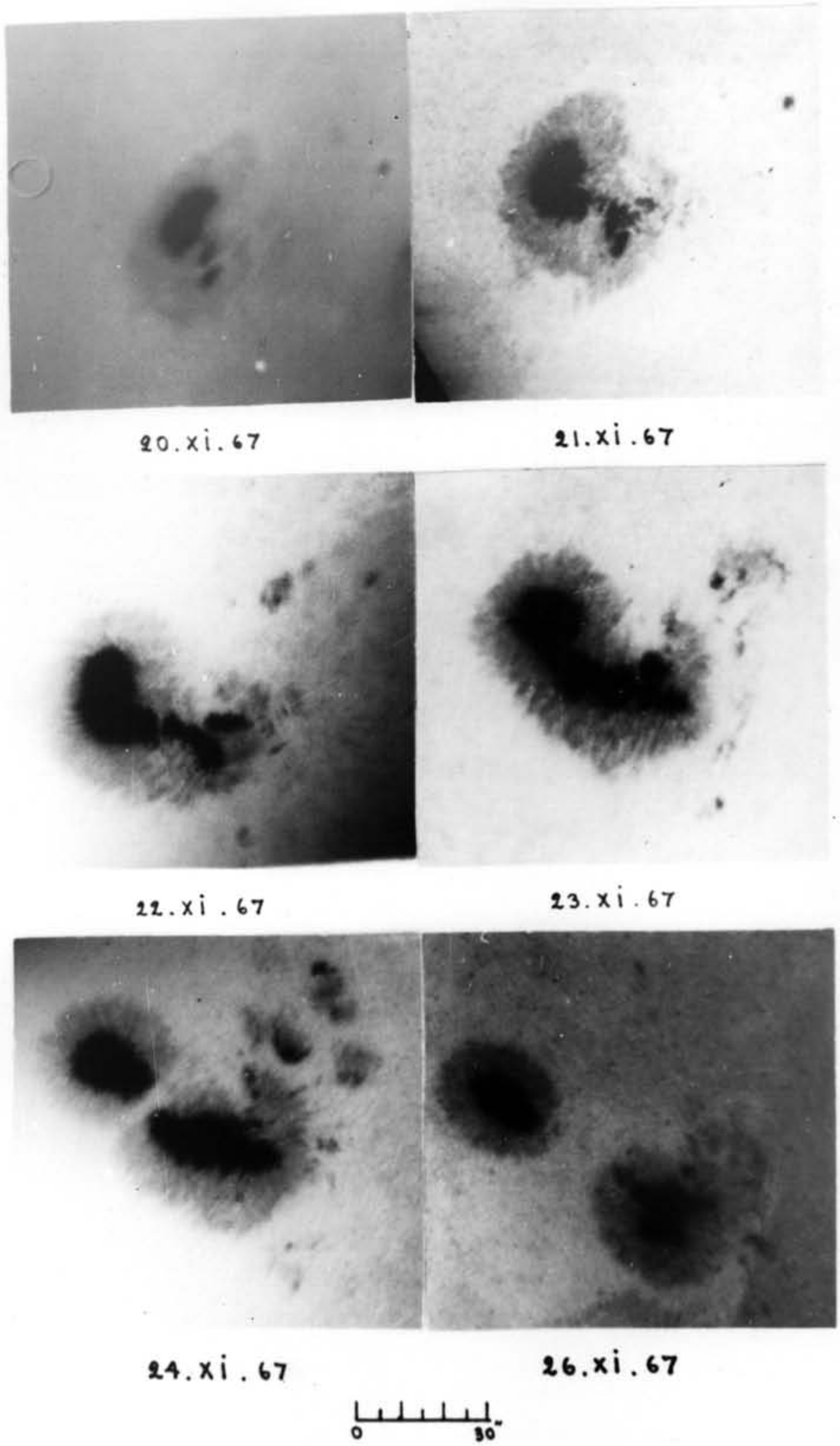
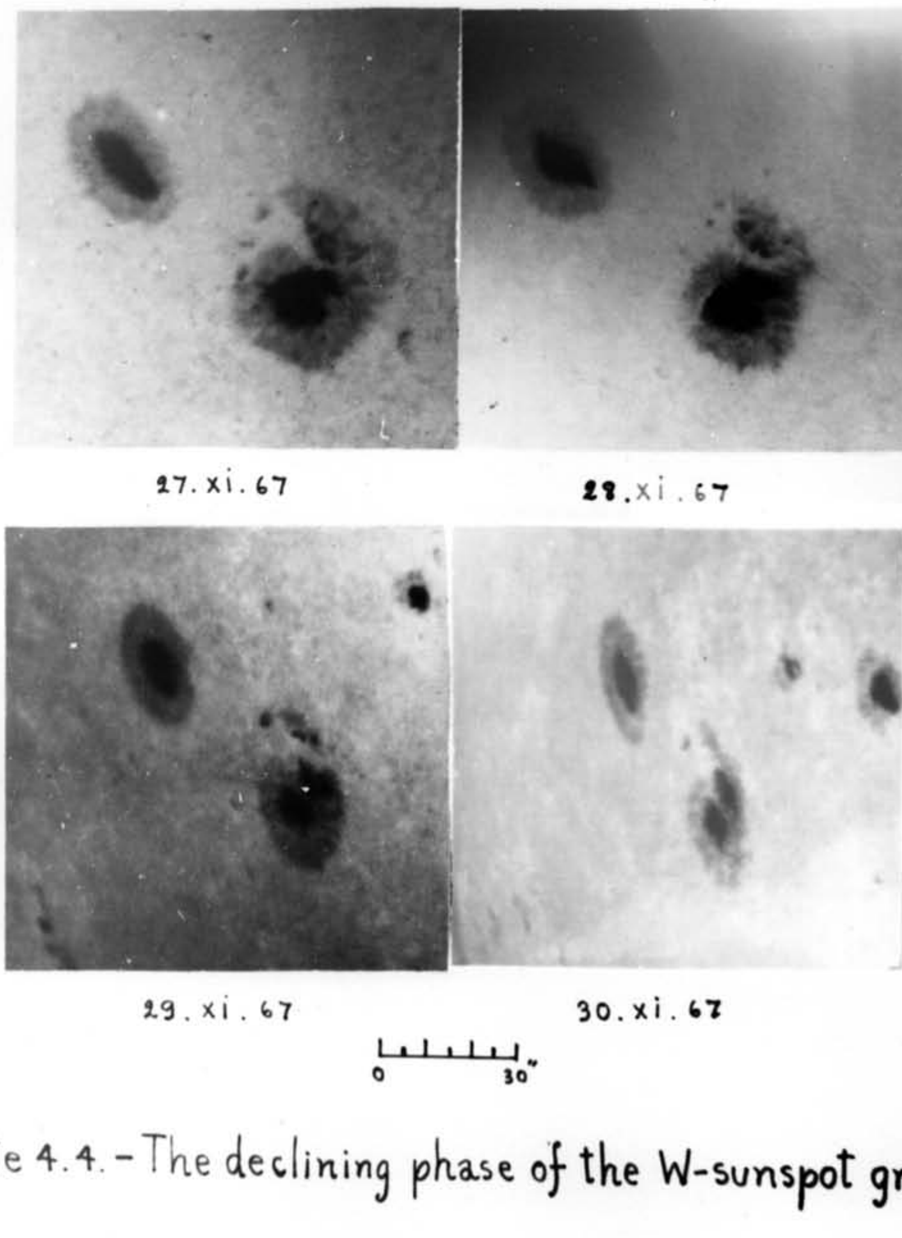


Plate 4.3.- The development of the W-sunspot group.



27.xi.67 28.xi.67

29.xi.67 30.xi.67

0 30"

Plate 4.4. - The declining phase of the W-sunspot group.

the west limb. The umbra of the main following spot broke into three parts on 28 November. The preceding umbra did not break but the area decreased. A bright streak appeared in the penumbra near the upper left part of the main following umbra on 28 November at local time 10 h 43 min and brightened up at 11h09min as shown on Plate 4.5. It consisted of bright blobs connected together and persisted until the last observation on that day at 16h07min. The group was at the west limb on 1 December, the last day of observation for this group.

The E group slowly developed as shown on Plate 4.6. On 22 November, the umbra broke into two major parts and one small part at the lower end. There was a bright region in the penumbra at the lower left part of the upper umbra. The penumbra began to be divided by this bright region. The lower small umbra expand to combine with the large one. The two large umbrae moved apart with the penumbra surrounding them and bordered by the bright streak on 23 November. The upper "preceding" spot and the lower "following" spot slowly moved apart and entirely separated on 27 November and then began to decline. A bright bridge invaded the left of the following umbra on 24 November to separate the umbra which showed the beginning of the declining phase. On 29 November a sunspot group occurred near this group, having the main spot above the group and several pores at the east of the group. This new group still appeared and moved toward the west limb by the solar rotation with the old group. They were seen on the west limb on the last day of observation

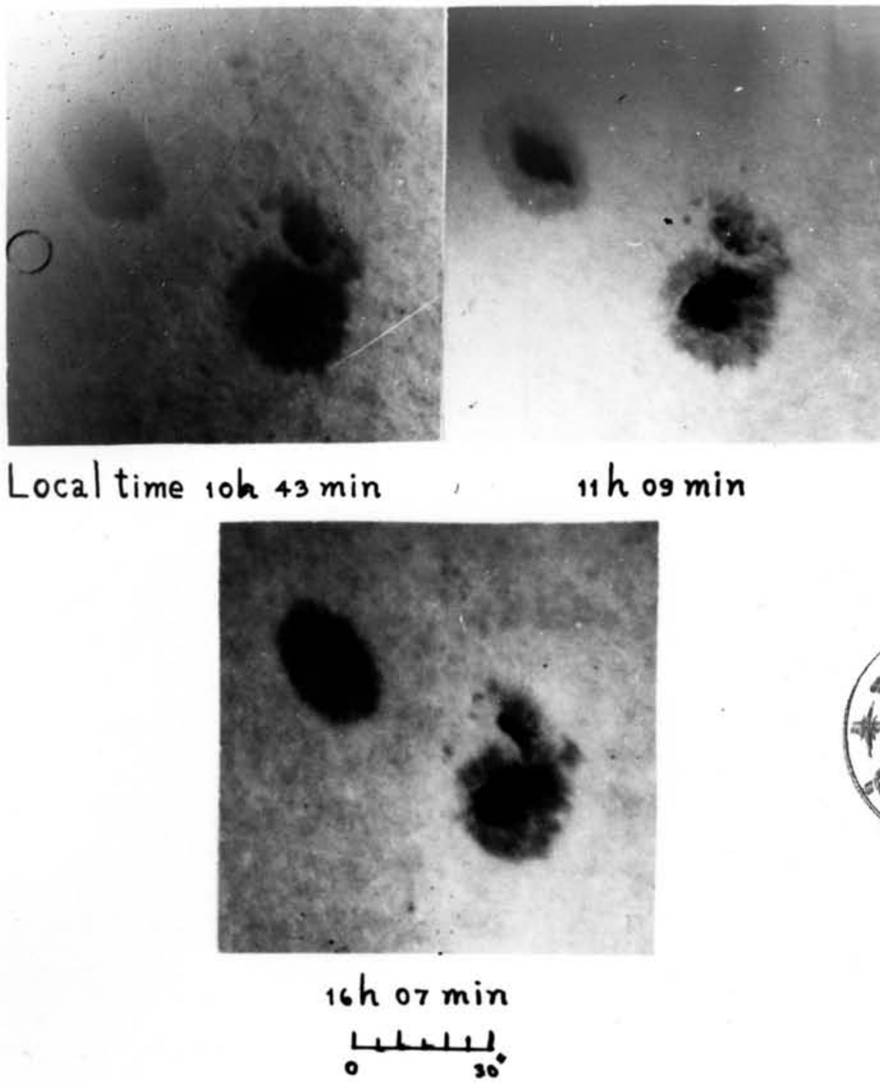


Plate 4.5. - A bright streak in the penumbra of the main following spot of the W-sunspot group shown on 28 November, 1967.

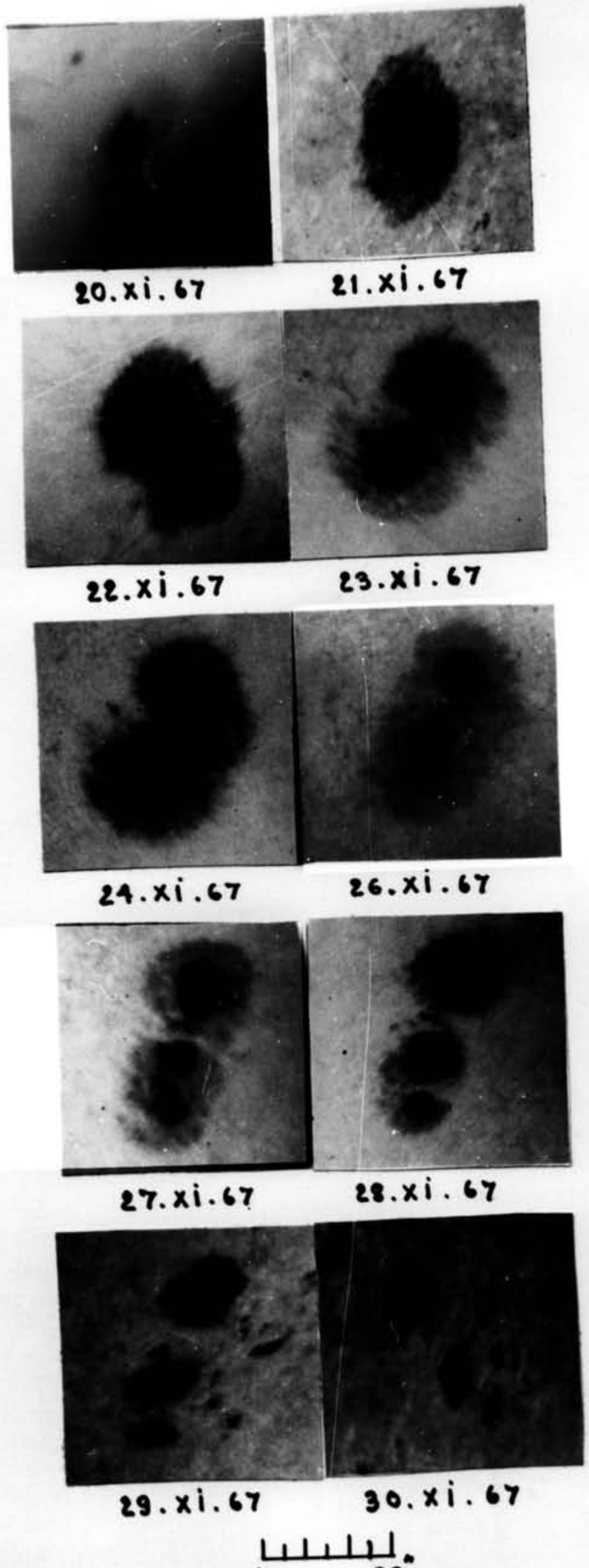


Plate 4.6.-The development of the E-sunspot group.

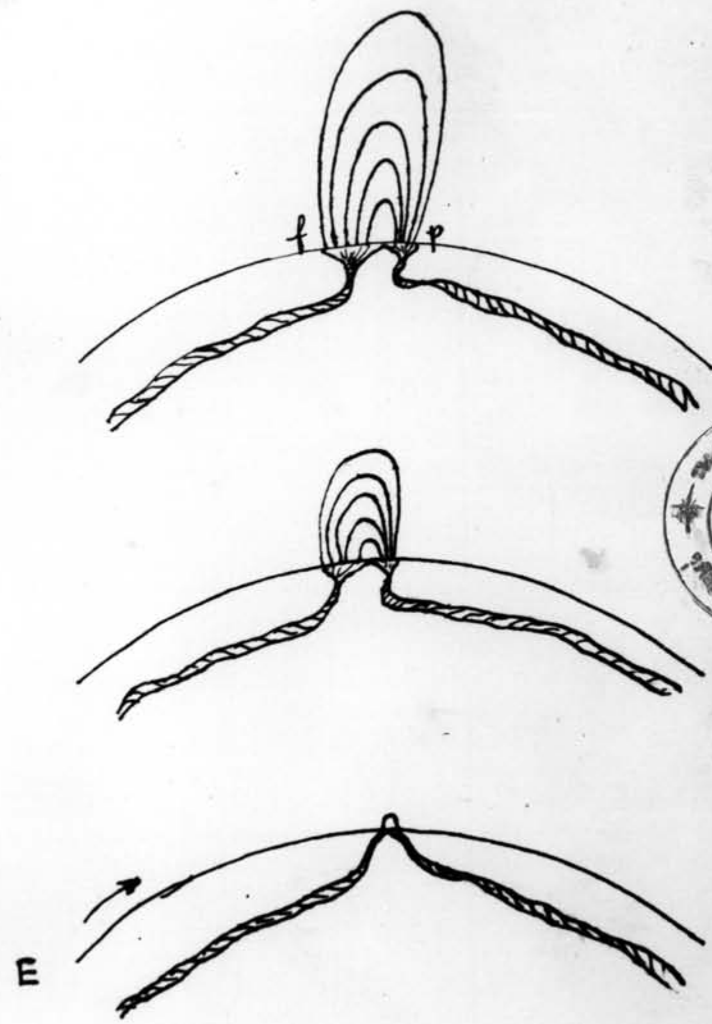


Figure 4.2.- The formation of a BMR according to Babcock (1961).

4.5 DISCUSSION AND CONCLUSION

The development of these two sunspot groups followed Babcock's theory (1961) on the formation of a BMRs. A submerged flux loop is brought to the surface by magnetic bouyancy and first breaks the surface at one region with condensed flux. This is the region where a small spot or pore starts to form. Then the flux loop continues to rise, and the disturbed region breaks into two contiguous regions as shown in Figure 4.2. These regions are compact and may quickly produce spots or other form of activity as shown in the observations on 21 - 24 November. The magnetic flux gradually arches into the atmosphere which causes the lines of force on the surface to spread out. The apparent spots will break. The preceding and the following parts continue to spread, the field intensity diminishes, the decline begins and finally the spots disappear. These phenomena are shown on photographs for 25 November to 1 December. Both groups disappeared from the solar disk by solar rotation but they were still on the surface of the non-visible hemisphere for several days before diminishing to become undisturbed region.

The present sunspot cycle is the 21st cycle and it began in 1966. Babcock postulated that the latitude at which the field is adequate to induce sunspot activity is given by

$$\sin \phi = \pm \frac{1.5}{n+3}$$

where n is the number of years elapsed since the beginning of the cycle and ϕ is the latitude. The activity zone in 1967 is between the latitudes ± 22° at the beginning of the year and ± 17° at the end of the year. From calculation we find that the W group was at latitude about + 20°.5 and longitude about 324°; and the E group was at latitude about + 19°.4 and longitude about 315° on 20 November. As WOLFER (1899), quoted from BABCOCK (1961), has stated, sunspots tend to recur in preferred zones where there has been prior activity and Babcock's theory can explain this phenomenon. When a submerged flux loop is first formed due to excess twisting, the plasma within the rope must be squeezed longitudinally away from the constriction. After the loop has risen to the surface, the BMRs begins to spread in area and the plasma required for the expanding BMRs can be supplied only by longitudinal movement of material along the flux rope. Therefore the adjacent section of the flux rope, not greatly displaced from the apparent BMRs, will become constricted with increase in field strength and is likely to produce a new BMR close to the old one, but predominantly on the following or easterly side.

Consider these two sunspot groups which occurred close together. They probably resulted from the same flux rope as mentioned above with the W group as the old activity region and the E group as the new one. If this were so :

1) the E group should develop after the decline of the W group, and

2) the angles that the axis of sunspot groups make with the meridian should be the same or nearly the same.

We could not observe the beginning of the appearance of both groups and did not know which group appeared first. But from the observations

TABLE 4.1

Heliographic Coordinates of Sunspots

Date			B	L
23. xI.67	W group	preceding spot	$20^{\circ}.59$	$325^{\circ}.50$
		following spot	$21^{\circ}.56$	$324^{\circ}.03$
	E group	preceding spot	$19^{\circ}.13$	$315^{\circ}.60$
		following spot	$19^{\circ}.74$	$314^{\circ}.21$
27. xI.67	W group	preceding spot	$18^{\circ}.42$	$325^{\circ}.87$
		following spot	$20^{\circ}.78$	$323^{\circ}.42$
	E group	preceding spot	$18^{\circ}.66$	$316^{\circ}.49$
		following spot	$19^{\circ}.46$	$315^{\circ}.22$

of their development it can be estimated that they appeared nearly at the same time. For reduction of data of 25 November and 27 November as the method described in chapter 3, the results are given in Table 4.1 and the calculations are given in Appendix II. The inclination of the axis of the W group is 0.66 while of the E group is 0.45 on 23 November, and on 27 November the inclination of the axis of the W group is 0.96 while of the E group is 0.63. Neither before nor after the separation of the two main spots of these two sunspot groups, the inclination of the axis of these groups are not equal. So these two groups did not result from the same flux rope of the same turn. They may have resulted from the same flux rope but belonged to different turns or resulted from separate ropes. Babcock estimated that the submerged flux consists of eight ropes because he found that the total magnetic flux in the polar caps is 8×10^{21} maxwells

8×10^{21} maxwells which is eight times that of a typical sunspot group or BMR, 10^{21} maxwells. We still do not know how these eight ropes are arranged before and after amplification. It needs more observations and computation to find out their arrangement.

REFERENCES

BABCOCK, H.W. (1961) "The topology of the Sun's magnetic field and the 22-year cycle", Ap. J. 133, 572.

BRAY, R.J., and LOUGHHEAD, R.E. (1964) "Sunspots", ed. Sir Bernard Lovell and Zdenek Kopal, (Pitman Press, London).

WALDMEIER, M. (1955) Ergebnisse und Probleme der Sonnenforschung, 2nd ed. Leipzig, Geest u. Portig.

WOLFER, A. (1899) Pub. Zürich Obs., Vol. 2.

APPENDIX II

As the method used in chapter 3, the heliocentric coordinates of sunspots on 23 November and 27 November 1967 are found. Then the inclination of the axis of the sunspot groups are determined.

	23 Nov.	27 Nov.
The position angle of the axis of rotation of the sun (P)	$19^\circ.19$	$17^\circ.81$
The heliocentric latitude of the centre of the sun (B_o)	$1^\circ.90$	$1^\circ.39$
The heliocentric longitude of the centre of the sun (L_o)	$347^\circ.74$	$294^\circ.82$
The position angle of the preceding spot of the W group	$67^\circ.00$	$-41^\circ.00$
The position angle of the following spot of the W group	$67^\circ.00$	$-35^\circ.40$
The position angle of the preceding spot of the E group	$78^\circ.50$	$-31^\circ.70$
The position angle of the following spot of the E group	$78^\circ.50$	$-28^\circ.70$

The ratio of the distance of the spots from the centre of the disk and the radius of the disk are :

	23 Nov.	27 Nov.
The preceding spot of the W group	0.4800	0.5743
The following spot of the W group	0.5067	0.5609
The preceding spot of the E group	0.5867	0.4618
The following spot of the E group	0.6067	0

The heliocentric coordinates of the sunspots are found as given in Table 4.1. Then the inclination of the axis of sunspot groups are :

The W group on 23 November $= \frac{0.97}{1.47} = 0.66$

The W group on 27 November $= \frac{2.36}{2.45} = 0.96$

The E group on 23 November $= \frac{0.63}{1.39} = 0.45$

The E group on 27 November $= \frac{0.80}{1.27} = 0.63$