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# The Cancellation of Magnetic Flux. II In a Decaying Active Region*

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*Abstract*

An active region was studied in detail during its period of decay from 3 to 8 August 1984 using H$\alpha$ filtergrams and videomagnetograms acquired at the Big Bear Solar Observatory. The decay was initiated by a process of fragmentation in which very small knots of magnetic flux separated from larger concentrations of flux. The fragmentation was observed at discrete locations around the periphery of both the dominant areas of negative and positive field, but possibly occurred more frequently in the main polarity inversion zone. The fragmentation and migration of knots of magnetic flux were common predecessors to the disappearance of flux.

The disappearance of magnetic flux was always observed when the small fragments of flux encountered other small fragments or concentrations of flux of opposite polarity. This type of disappearance of magnetic flux, called 'cancellation', is shared by both polarities of magnetic field. It was deduced that the disappearance of flux occurred either at or within 5 arcsec of the apparent dividing line between the opposite polarities. Cancellation was the only observed means of major loss of flux in the photospheric magnetic fields of the active region. Approaching fragments of opposite polarity flux always collided and, after apparent collision, permanent loss of magnetic flux was subsequently and invariably observed. Thus, cancellation is a highly predictable phenomenon.

All of the 22 flares observed during the decay of this region were initiated around the sites where magnetic flux was cancelling or was deduced to be cancelling during the flares. The intervals of time during which magnetic flux was decreasing at the flare sites was very much longer than the duration of the flares. Abrupt changes in magnetic flux on the time scales of the H$\alpha$ flares were not observed. Several flares started at a site of disappearing flux but spread to other locations of plage where no loss of flux was observed during the flares. We hypothesize that cancellation was a necessary condition, but not the only necessary condition, for flares to occur in this active region.

## 1. Introduction

When large active regions decay, it is well known that some of their magnetic flux gradually spreads over increasingly large areas of the Sun. In contrast to this picture, Zirin (1984) has recently shown an example of a decaying active region in which the areas of opposite polarity flux, as a whole, come back together and disappear. In addition, Wallenhorst and Howard (1982), Wallenhorst and Topka (1982), Wilson

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and Simon (1983), and Topka and Tarbell (1984) have shown that some flux of only one polarity seems to mysteriously disappear *in situ*.

During August 1984 at the Big Bear Solar Observatory, we recorded videomagnetograms and H$\alpha$ filtergrams of the growth and decay of an active region of modest size (number 19425, Solar Geophysical Data). Remarkably, this active region displayed all three of the modes of decay cited above with the exception that the disappearance *in situ* always consisted of flux of both polarities. The most dramatic part of the decay was the opposite polarity flux reconverging and disappearing around the primary polarity inversion line in the active region. However, we also found during our analyses of the data that some of the magnetic flux of the active region dispersed around the periphery of the region.

At the Colloquium we illustrated the evolution of this active region from 31 July to 8 August and its dramatic disappearance of magnetic flux in a time-lapse film of videomagnetograms taken on 2, 3, 4 and 5 August. Then, we further illustrated the details of the magnetic flux disappearance using selected magnetograms and H$\alpha$ filtergrams from 3 to 8 August as illustrated in the present paper. The significant changes in the magnetic field of the active region take place on a relatively small scale. Following the details of the small-scale changes in the active region in the figures, however, is much more laborious than viewing the same changes in the time-lapse film. We also recognize that various readers will have differing degrees of interest in the fine observational detail. Therefore, we have organized the paper so that the following sections can be read independently as follows: Section 2 discusses the general evolution of the active region, while Section 3 presents a chronological description of the details of the disappearance of magnetic flux. Section 4 summarizes and discusses the primary results, including changes preceding the disappearance of flux, the disappearance of magnetic flux, and the association of H$\alpha$ features and events with disappearing magnetic flux. The conclusions are presented in Section 5.

## 2. General Evolution of the Active Region

The general pattern of evolution of the active region as a whole is illustrated in Figs 1 and 2. The region was born near the east limb on or before 30 July 1984 at a latitude of S17. Its apparent transit of the Sun's central meridian was early on 5 August. The sunspots in the region reached their maximum area on 2 August; the positive polarity sunspots began their decay by 3 August; the negative polarity sunspots declined in area throughout 4 August and all of the sunspots had disappeared by 5 August.

Fig. 1 shows the active region during its maximum development and throughout its decay in sections taken from the daily full-disc Kitt Peak magnetograms from 2 to 8 August 1984. The magnetograms are shown in the form of contour maps made by us at Caltech using the digital data from Kitt Peak supplied on magnetic tape by staff members of the National Solar Observatory in Tucson. The contours given are the 20, 40, 80, 160 and 320 G levels (1 G $\equiv 10^{-4}$ T). In all illustrations here solar north is at the bottom and east is to the right. The leading negative polarity field is to the west (left) of the trailing positive polarity field in the most common orientation for southern hemisphere active regions during the current solar cycle.

The active region stopped growing by 3 August. On 4 August, the opposite polarities ceased expansion and, in fact, are seen in Fig. 1 to have partially reconverged towards the centre of the region. There is also a notable elongation of the region in the north–south direction. The apparent general decline of the magnetic flux

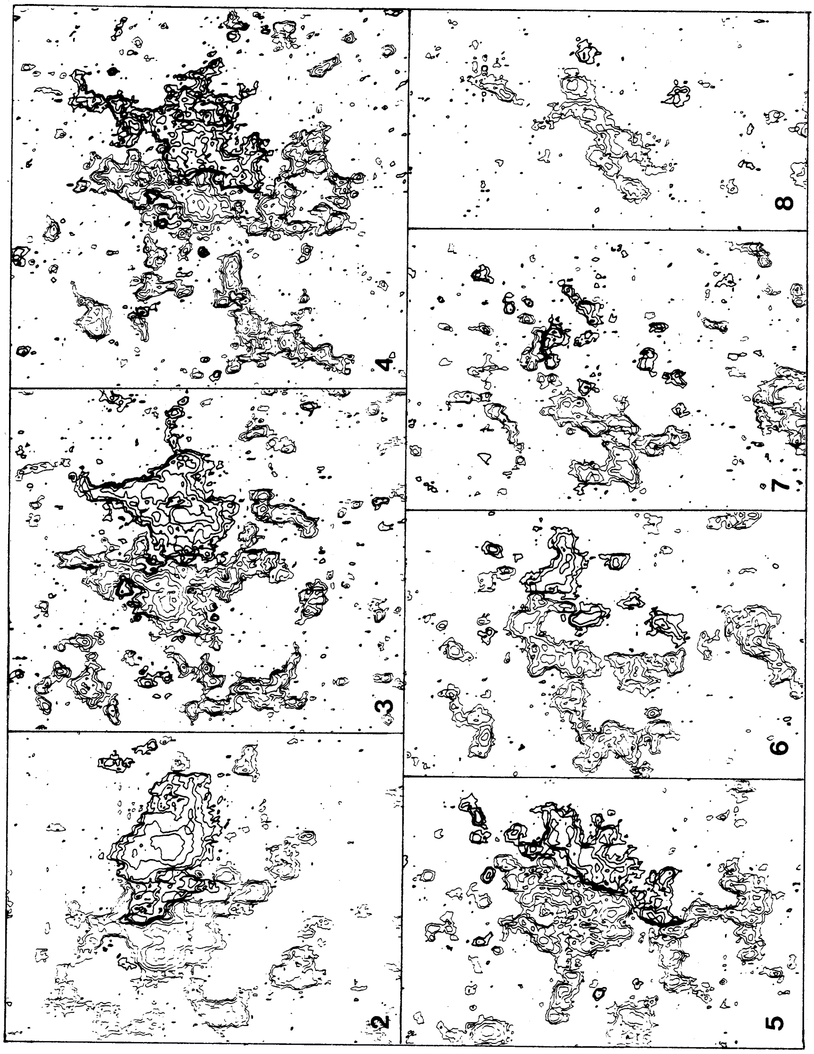


**Fig. 1.** General pattern of decay of an active region is illustrated in sections from Kitt Peak daily, full-disc, digital magnetograms over the period 2–8 August 1984. Positive polarity flux is shown by lines thicker than the negative polarity. The rapid disappearance of the magnetic flux of the region occurs from 3 to 8 August.

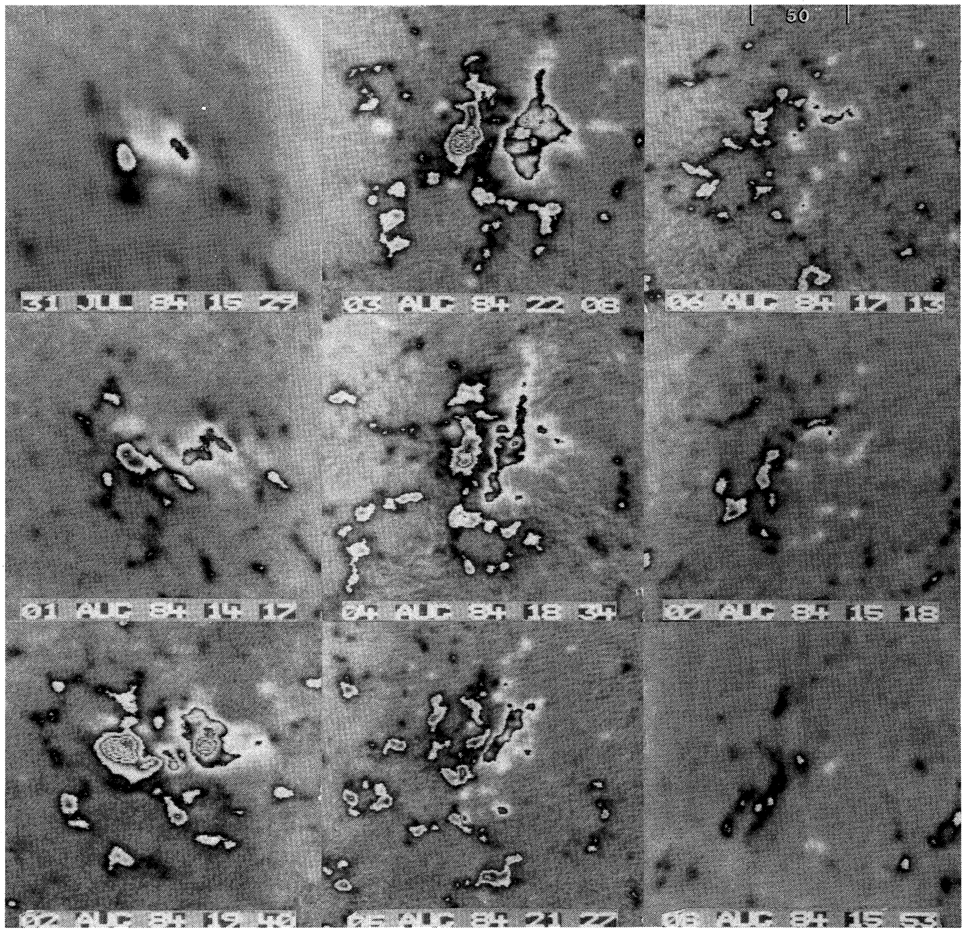


**Fig. 2.** Videomagnetograms from the Big Bear Solar Observatory show the evolution of an active region from its early stage of growth on 31 July 1984 until its very late stages of decay on 8 August. The order of the sequence is shown from top to bottom in columns. Negative polarity is black and positive is white. The contours within each polarity begin at approximately 50 G, with each successive contour representing a doubling of the field strength. The contouring system breaks down in the strongest fields containing sunspots.

of the region continues until 8 August. Each day a large fraction of flux is lost until, on 8 August, only two small isolated fragments of positive polarity remain among the scattered network of negative polarity. Cloudy weather terminated our obtaining any further information on the fate of the last two fragments of positive polarity flux both at Big Bear or from Kitt Peak. From each daily Kitt Peak magnetogram, we measured the total flux in the concentrated fields in the central part of the region where the fields appeared to change markedly in total flux from day to day. The total magnetic flux consistently declined after 3 August. During the phase of decay from 4–8 August, the average rate of magnetic flux lost from the Kitt Peak magnetograms is $1 \cdot 3 \times 10^{20}$ Mx per day or $5 \times 10^{18}$ Mx hr$^{-1}$.

In Fig. 2 we show a series of photographic magnetograms from the Big Bear Solar Observatory depicting the general evolution of the active region beginning on

31 July and continuing to 8 August. In this illustration and the remaining illustrations in this paper, the time sequences are given in order first from top to bottom and secondly from left to right. The universal time (UT) given on or adjacent to each photograph is ending time of the magnetogram. Negative polarity is black and positive polarity is white, except within the contours. The polarity of any contoured feature is distinguished by whether the feature is black or white around the periphery of the lowest contour. In this data set, the first contour represents approximately 50 G. Each successive inner contour represents a doubling of the field strength with each change from black to white or white to black. The method of generating the contours is described more completely in the paper by Zirin (1985, present issue 961).

The active region did not appear to be unusual until it began to partially reverse its pattern of growth on 4 August. We note again the elongation of the region in the north–south direction after the decay phase has become apparent on 4 August. However, the decay phase begins on 3 August with disappearance of the positive polarity sunspots; this is indirectly indicated in Fig. 2 by the reduction in the peak flux and the spreading of the positive polarity (white). In addition to the north–south elongation of both polarities, the decay phase differs from the growth phase in another respect; the flux does not become as compact and does not reconverge to a single central site as it disappears.

## 3. Chronological Description of Details of the Disappearance of Magnetic Flux

### *(a) Detailed Description of the Early Phase of Decay*

In Fig. 3, we illustrate examples of the fragmentation of large concentrations of magnetic flux and examples of the migration and disappearance of small knots of flux. The six images in Fig. 3 were selected from the original film at intervals of about 1 to 2 hr throughout the observing day on 3 August. We first call attention to the deviations from the overall simple bipolar character of the active region as a whole. The polarity inversion zone in the middle of the region shows some mixing of opposite polarity fragments of magnetic field. Around the main concentration of negative field, other small fragments of both polarities can be seen. Magnetic flux loss takes place at nearly every site where small positive or negative fragments move into apparent contact with opposite polarity field. Most of the flux loss appears to happen exactly in the same way as on the quiet Sun (Livi *et al.* 1985; Part I, present issue p. 855).

Positive fragment P1 in the first frame of Fig. 3 is a clear example of the disappearance of magnetic flux in a fragment for which we have no previous history. It was already losing flux when the daily observations began. In the first frame of Fig. 3, it is nearly surrounded by negative flux. It is seen to gradually lose flux throughout the day and, by 0021, it has almost disappeared completely.

This sequence in Fig. 3 is especially effective in showing the reality of the flux loss because the general sensitivity of the magnetograms is seen to be increasing throughout this day. Under this condition, we can be certain that any consistent reduction in magnetic flux observed in many frames of the original film is not due to variations in the quality of the data throughout the day. The slow sensitivity increase is apparent from the increasing area within the contours. It is important to examine isolated fragments of flux of either polarity, especially around the periphery of the region in Fig. 3 and the subsequent illustrations. In all areas where there is no contact

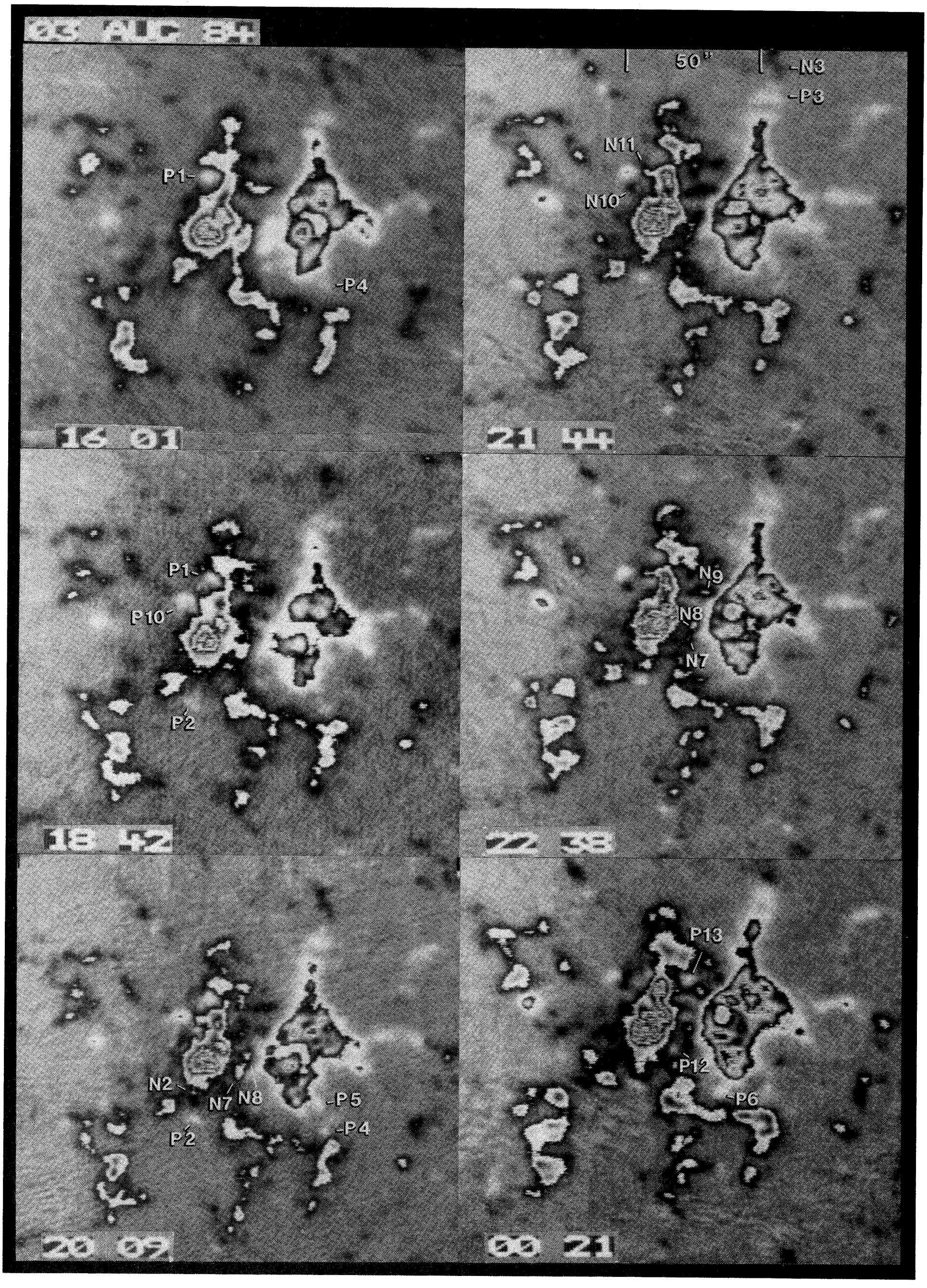


**Fig. 3.** Early changes in the decay of the magnetic fields take place in very small fragments denoted by P and N respectively for positive and negative. Positive fields are white and negative are black. P1 is a disappearing fragment; P2, N2 and P3, N3 are approaching fragments of opposite polarity; P4, P5 and P6 are knots breaking away from the main concentration of positive flux; N7, N8, N9, N10 and N11 are knots breaking away from the main concentration of negative flux; P10, P12 and P13 (also possibly negative knots N10–N11) are moving magnetic features emanating from the main concentration of negative polarity containing the sunspot.

between positive and negative fields, no major flux loss can be seen although minor changes in the shape of the isolated single polarity fragments do occur; the changes in shape are due partially to real migration of the flux and partially to changes in image quality from frame to frame. The examples of changes in the magnetic flux illustrated and discussed in this paper can be observed on many successive frames of the original film as well as in the digital magnetograms recorded on magnetic tape. The illustrated changes in magnetic flux, consistently observed over the course of many successive frames, are greater in magnitude than both the instrumental and background variations.

An example of fragmentation and pre-disappearance motion is illustrated by fragments N2 and P2 (2009) respectively. P2 exists as a very faint positive fragment (or unresolved collection of fragments) below the main concentration of negative flux, while N2 is a negative fragment that is beginning to break away from the main concentration of negative flux at 2009. In the remainder of the series, N2 is seen as a successively elongated appendage of the main concentration of negative flux. As N2 moves towards P2, P2 is also slowly migrating towards N2. By the last frame, 0021, the two opposite polarity features are in contact. Flux loss is expected to begin at this stage. The images in Fig. 4, from the next day's observations, verify the disappearance of P2.

In Fig. 3, above the main concentration of positive polarity is another site where one or more knots of flux, designated as P3 at 2144, moves away from the main concentration and towards an opposite polarity fragment N3. P3 and N3 are somewhat diffuse in appearance and may be a collection of unresolved fragments which coalesce as the opposite polarities migrate towards each other. The two fragments come into contact by the end of the observing day (0021 in Fig. 3).

In Fig. 3, P4, P5 (2009) and P6 (0021) are other examples of the fragmentation of flux located just below the main concentration of positive field. In the first frame (1601), P4 is still an appendage to the main concentration. It separates from the main concentration before the time of the second frame at 1842 and, by 2009, it is in contact with the negative flux toward which it was moving. It is disappearing by 2144, but its demise is not clear because it is followed by additional weak fragments of positive flux, notably P5, moving in its wake. Since there is no build-up of positive flux at the junction with the negative flux, we infer that flux is being lost when it comes into contact with the negative flux. At 0021, to the left of P4 and P5, is yet another example, P6, of a fragment of flux beginning to separate from the main concentration of positive polarity.

Fragmentation seems to occur with the highest frequency from the main concentrations of flux near the main polarity inversion zone. At 2009, N7 and N8 are representative examples of fragments that have separated from the main concentration of negative flux and are in contact with less distinct fragments of positive flux. They slowly lose flux during the remainder of the observing day as they also migrate closer to the positive flux. Note that the inner contour of N7 disappeared altogether by 0021. While N7 and N8 are losing flux, just above them, N9 in frame 2238 is seen to have migrated into contact with the positive flux.

Where the magnetic field is highly concentrated, especially in the middle of the region, the fragmentation and the disappearance is more difficult to see than around the periphery of the region. Sometimes, in the middle of the region, the fragmentation appears only as slowly changing appendages of both polarities. The fragmentation

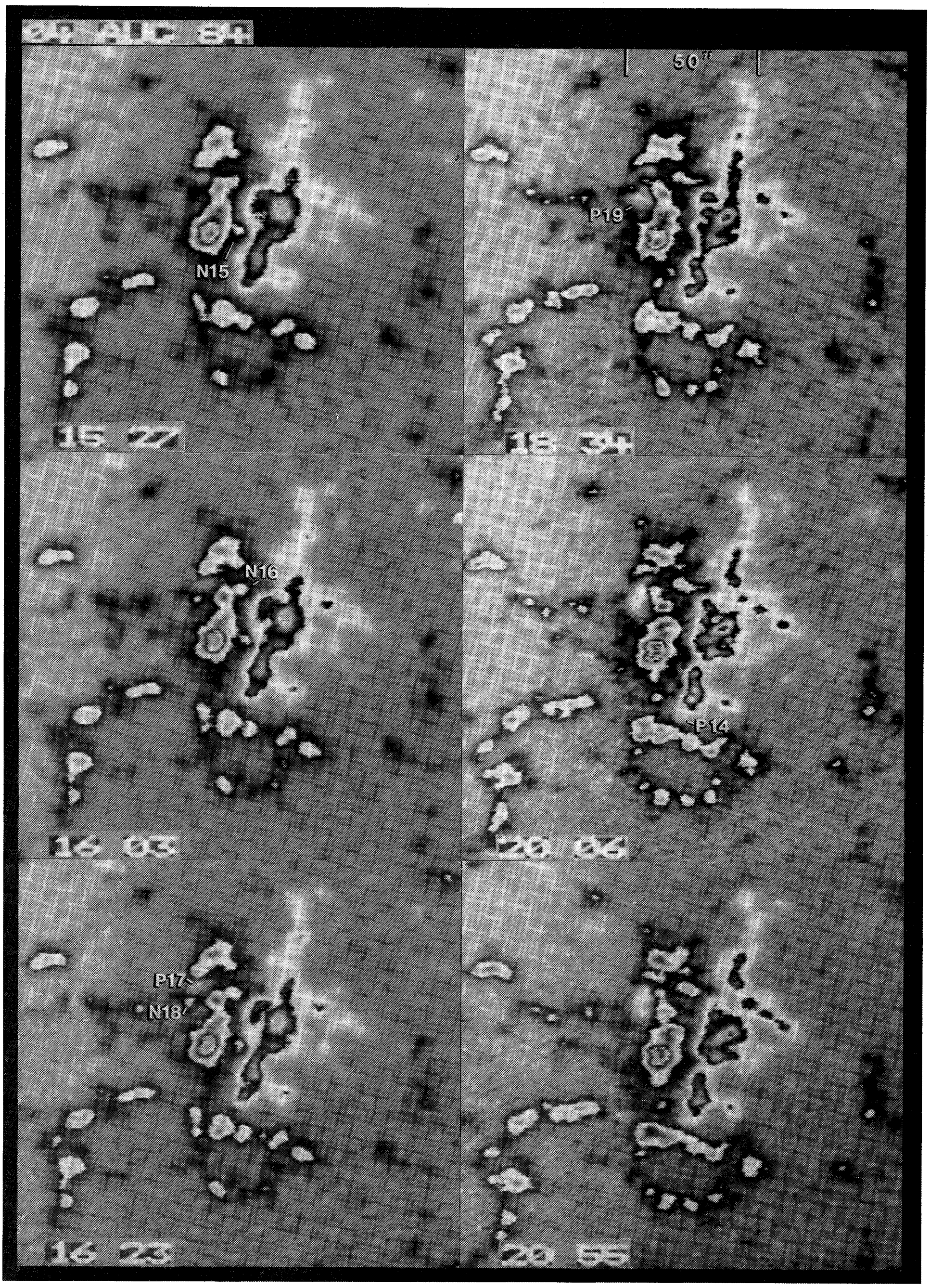


**Fig. 4.** P14 (2006) and N15 (1527) are knots of flux that follow in the same paths as P6 and N8 on the previous day in Fig. 3. Part of N16 (1603) intrudes into the adjacent area of positive polarity. P17 (1623) disappears as it moves into negative polarity flux. N18 (1623) is also cancelled completely by P19 (1834). Both N18 and P19 are part of a collection of the final 'moving magnetic features' emanating from the negative concentration of magnetic flux containing the final dying sunspot.

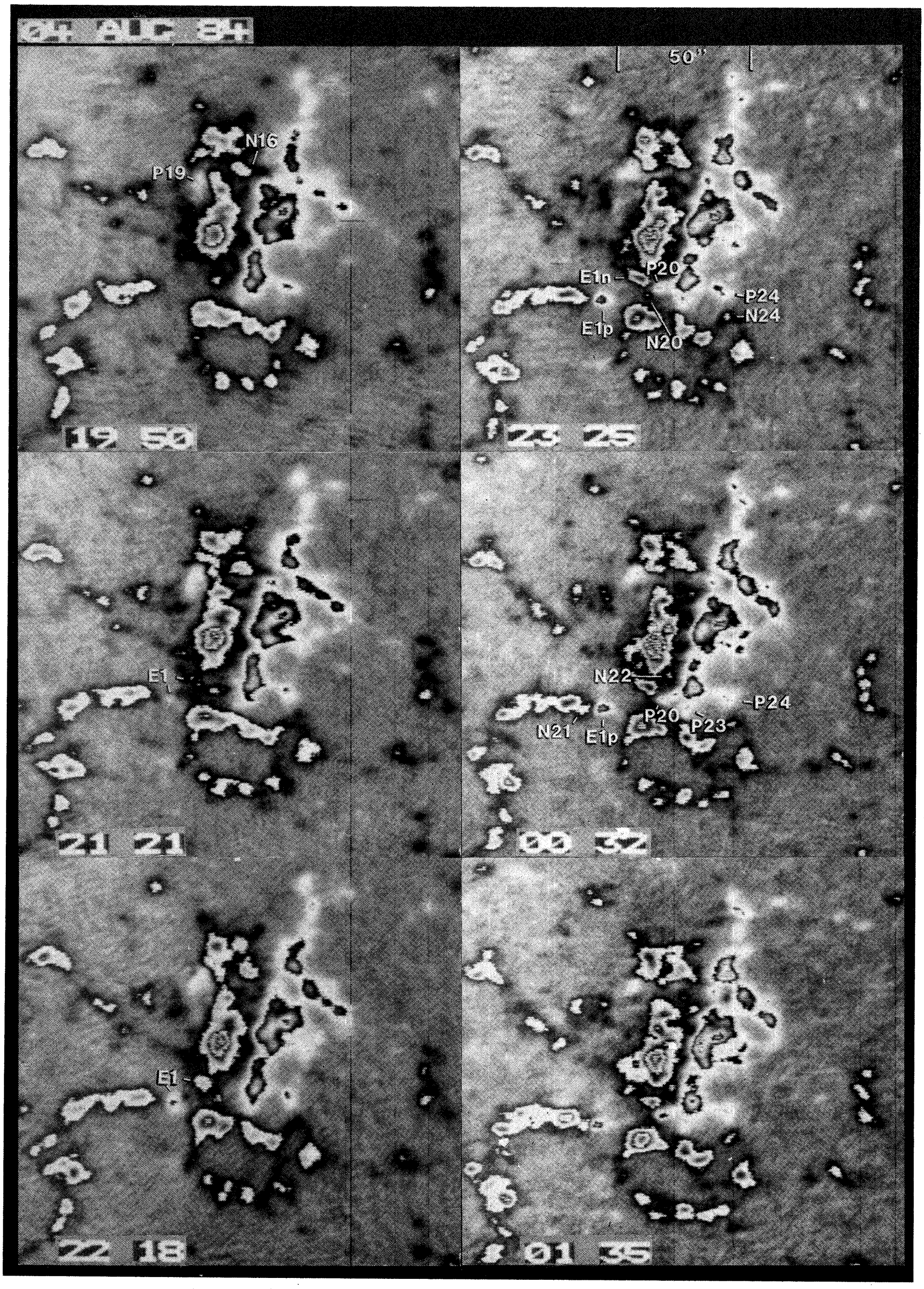


**Fig. 5.** E1 is a new growing ephemeral region first seen at 2121 in this series continuing from Fig. 4. P20 (2325) cancels with N20 and moves into contact with E1n at 0135. N21 (0032) breaks away from a concentration of network and collides with E1p. N22, P23, P24 and N24 are knots that break away from larger concentrations of flux and move towards opposite polarity field.

often results in the temporary interleaving of the positive and negative fragments or appendages in the middle of the region. This is very noticeable in the last frame of Fig. 3. In some circumstances, we cannot immediately see evidence of the loss of flux because the percentage change of flux can be too small to be detected. However, in most circumstances, the disappearance of flux can be inferred because of two observed conditions: (1) there is no long-term progressive build-up of flux in the polarity inversion zones and (2) the separated fragments typically do not reverse direction.

There is one striking difference between the fragmentation of the positive flux which contains only tiny sunspots and the negative polarity field which contains a larger decaying sunspot on 3 August (Fig. 3). The fragmentation from the negative concentration containing the sunspot consists of features of both polarities. These fragments are the 'moving magnetic features' described by Harvey and Harvey (1973). P10 (1842), P12 and P13 (0021) are examples of positive polarity moving magnetic features which spontaneously appear and emanate from the perimeter of the dying sunspot within the concentration of negative flux. Fragments N10 and N11 follow P10.*

Figs 4 and 5 show respectively further details of the changes in magnetic flux during the first and second halves of the observing day on 4 August. The most conspicuous overall change in the active region, since the previous observing day, is the reduction in distance between the main negative and positive concentrations of flux. By comparing frames of equivalent quality on 3 and 4 August, it is also obvious that there has been a substantial reduction in flux by 4 August. We can surmise that the fragmentation and loss of flux in the centre of the region has been substantially greater than the fragmentation and loss of flux around the periphery of the region. Additionally, there has been a general, slow migration of the opposite polarity fields towards each other. This general migration has followed in the same directions as illustrated for the individual moving knots of magnetic flux seen in the centre of the region on the previous day, 3 August.

In Figs 4 and 5, we point out many new examples of opposite polarity fragments moving together and disappearing. At the same site as P6 on the previous day (Fig. 3), another positive fragment P14 (2006) is seen to break away from the primary positive concentrations of flux and move into contact with the negative flux below. At approximately the site of N7 and N8 on the previous day, N15 (1527 in Fig. 4) is seen to be separating from the main negative concentration. Between 1834 and 2055, N15 gradually disappears. N16 (1603) which is at or close to the site of N9 on the previous day, breaks away from the main negative concentration of flux and follows the course of an obvious but weak protrusion of negative flux into the neighbouring positive flux. Continuing in Fig. 5, we see that flux is lost in the protrusion of N16 into the positive flux and that the protrusion disappears by 2218. These examples on 4 August are continuing the same pattern of fragmentation, motion, and flux loss as on the previous day. However, N16 reveals a different component of motion. It is slowly migrating towards the upper part of the field of view as well as toward the positive polarity. In Fig. 5, N16 is seen to merge with the negative field above it. Concurrently, it may be shedding very small fragments of its flux, at the threshold

* In this paper we label the moving magnetic features in the same way as other fragments with a P for positive, or N for negative, followed by a number. Opposite polarity features which come into contact are labelled with the same number. Otherwise, the number following the N or P only denotes the approximate order in which each fragment is mentioned.

of our detection in these images, in the direction of the adjacent positive field. We suspect that a lot of action may be taking place in the weaker magnetic flux below our sensitivity threshold and spatial resolution in this set of data.

Fragments P17, N18 (1623) and P19 (1834) on 4 August (Fig. 4) appear to be additional examples of moving magnetic features all following approximately the same path. The larger positive fragment P19 almost completely cancels the negative fragment N18 and continues its motion toward the negative field above it. P19 joins the remnant of P17; it may also be the composite of several smaller knots of flux. Continuing through frames 2121, 2218 and 2325 in Fig. 5, it appears that the rapidly moving P19 is able to force the displacement of the more stable negative flux in its direction of motion until about 2325. After this time, P19 is obviously losing flux and some of the adjacent negative flux reoccupies its original position as these features interact with each other.

Another interesting change in the vicinity of the positive fragment P19 is the opening of a lane of little or no magnetic flux between it and the main concentration of positive flux. The lane is first seen in Fig. 5 at 2325 and it becomes slightly wider thereafter.

In addition to flux migration and disappearance from the existing flux of the active region, Fig. 5 reveals the development of a new ephemeral region. The characteristics of ephemeral regions are reviewed in Livi *et al.* (1985). The evolution of E1 is shown in the second to the sixth frames of Fig. 5. The separation of its opposite polarities occurs rapidly between 2121 and 2218. By 2218 the negative half, E1n, has merged with the nearby negative field, but its location is still identifiable. As the two halves of the ephemeral region continue their initial motion, we observe interesting coincidental changes in the pre-existing opposite polarity flux at the extremities of the ephemeral region at 2325. To the right of E1n, a pronounced appendage of positive polarity flux P20 has moved towards an existing negative fragment N20 in the general direction, but a little below, the negative field of E1n. At 2325, loss of flux is apparent in N20. By 0032, N20 has almost completely disappeared but the flux that we assume was lost in P20 is being replaced by positive flux flowing along the appendage established first by P20. The magnetic field gradient increases as the appendage of positive polarity moves close to E1n. The stage is set for flux disappearance between E1n and renewed P20 by the last frame at 0135.

At the other end of the ephemeral region at 2325, the positive pole E1p has come close to the pre-existing negative field to its left. By 0032, the adjacent negative field has developed an appendage, N21, extending into contact with E1p. Again the stage is set for loss of flux. E1p has already lost flux by 0135, which is obvious from its reduced size, while E1p and N21 have completely disappeared by the beginning of the next observing day, as shown in the series of magnetograms in Fig. 6.

To the right of E1n in Fig. 5, there are several significant sites where other fragments move toward concentrations of opposite polarity flux. Fragment N22 (0032) has separated from the main concentration of negative polarity and moves towards the concentration of positive polarity to its right. The appendage of positive flux P20 that moved to meet the negative pole of E1 is the most rapidly moving and last of three appendages that develop from the concentration of positive flux just below the centre of the frames in Fig. 3. The adjacent appendage P23 to the right of P20 was initiated by P14 (Fig. 4) while the third appendage P24 further to the right follows the path established by P4 and P5 (2009, Fig. 3).

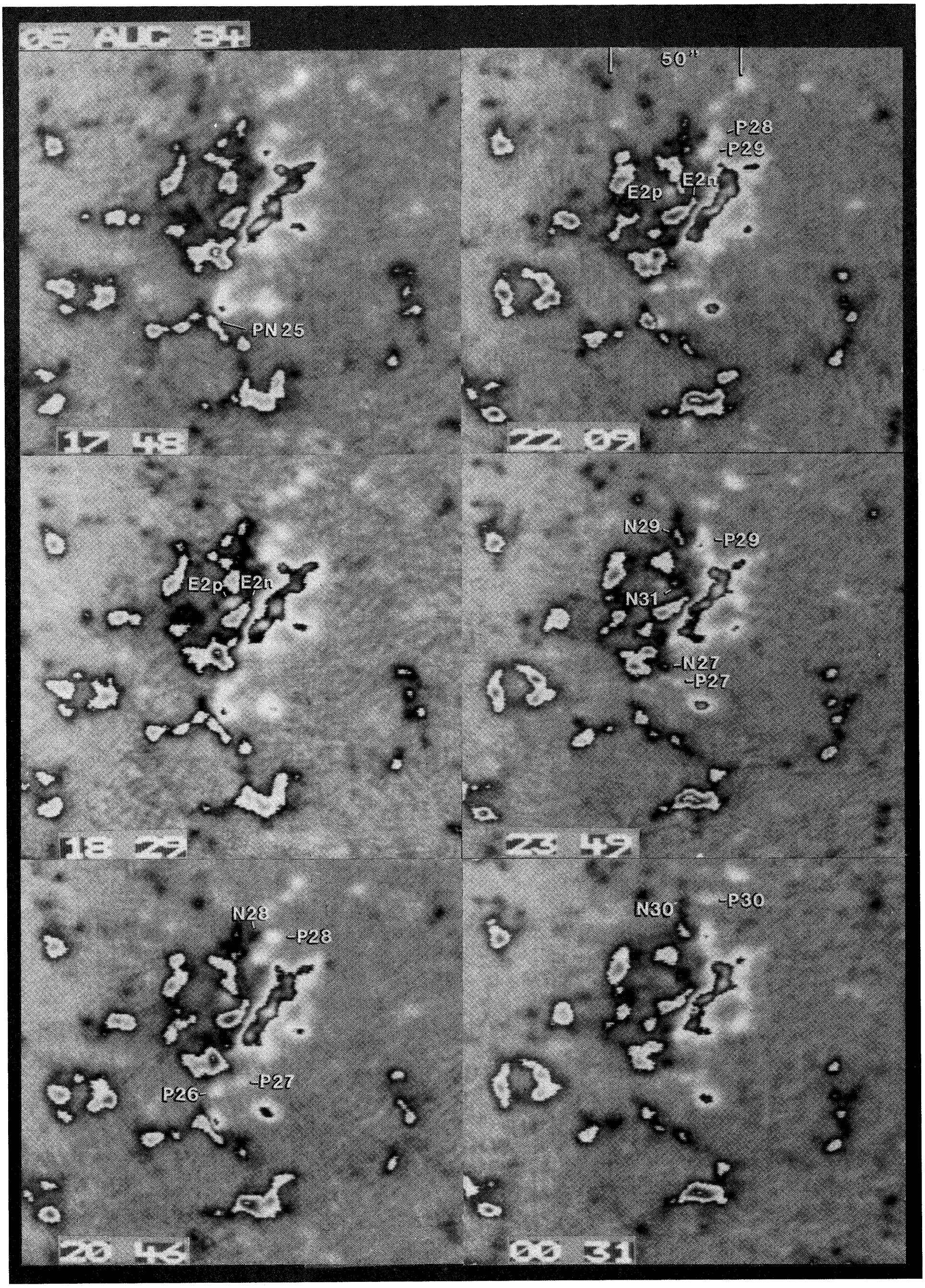


**Fig. 6.** PN25 (1748) is an example of very rapid cancellation in which both polarities are seen to lose flux. P26 (2046) moves up in the field and cancels with a concentration of negative flux. N27 (2349) breaks away from the same concentration of negative flux and moves toward P27. N28 cancels with P28 while P29 merges with P28. N29 begins to cancel with P29. P30 moves toward N30. E2p and E2n (1829) are the poles of an ephemeral region. Both poles cancel with adjacent fields of opposite polarity (2209).

By the beginning of the next observing day, 5 August, shown in Fig. 6, radical change has also taken place in this part of the active region. A large amount of both positive and negative flux has disappeared. Only two fragments of positive flux remain in the vicinity of the concentration of flux with its three appendages P20, P23 and P24 (see Fig. 5). The negative flux is clearly reduced and the remaining negative fragments have shifted in position. In this part of the region, there is only one site, PN25, where opposite polarity fields are in contact.

In Fig. 6 and in the subsequent text, we designate sites of cancellation as PN (positive–negative) followed by a consecutive number which continues to designate the order in which the features are described in this paper. If referring to either half of a cancelling feature, such as PN25, we use either P25 or N25 to denote whether we refer to the positive or negative half.

At all of the sites where we observe and can measure flux loss during our observing day, the loss takes place in exactly the way as illustrated by example PN25 in Fig. 6. PN25 is seen to lose flux very rapidly. By 2349, P25 has completely disappeared and the flux of N25 is obviously much reduced. Between 1748 and 1829, prior to the interval of obvious flux loss, P25 was a part of a slightly larger concentration of flux which separated into two fragments. The upper fragment is designated as P26 (2046). This splitting is already distinguishable at 1829. P26 moves up to meet a larger concentration of negative flux. Flux loss at PN26 is evident by 2349 and the fragment P26 has completely disappeared by 0031. At 2349, to the upper right of P26, fragment N27 is seen to be breaking away from the same concentration of flux with which P26 is cancelling. N27 begins to migrate towards P27.

In the case of PN25, flux loss is initiated about the time that the centre or peak of flux in the smaller fragment is 5 arcsec or less from the first contour (50 G) of the larger concentration. As the magnetic flux is disappearing, a relatively high magnetic field gradient is established and maintained between the two polarities until all of the flux of the smaller fragment is completely gone. This behaviour is consistent with the way that flux disappears in much smaller cancelling fragments. From this behaviour we conclude that the site of disappearance is at or within a few arcsec of the dividing line between the opposite polarities, and that the disappearance of the flux in this narrow zone is accompanied by continued migration of the opposite polarity fields together until the smaller fragment has completely disappeared.*

As a first step in estimating the rate of flux loss in the whole active region due to cancellation, we measured the rate of flux disappearance in P25 and P26 because these are relatively isolated and distinct examples of flux disappearance at different rates. The measurements were made from digital magnetograms from the Big Bear Solar Observatory which were recorded about once an hour throughout the observing

* For brevity and clarity in continuing our discussion of the observations, we call this type of observed loss in magnetic flux 'cancellation' and assign it the specific definition: 'the apparent mutual loss of magnetic flux in closely spaced features of opposite polarity'. We choose to use this term because the root word 'cancel' means to remove the effectiveness of something or alternatively that one factor offsets the effect of another. 'Cancel' does not mean 'destruct' and 'cancellation' is not synonomous with 'annihilation'. It is an appropriate observational term because it has a more precise meaning than 'disappear', yet it does not imply that we pretend to know exactly how the magnetic field is removed from the photosphere. Our intention is to leave the theoretical interpretation to be addressed subsequent to the presentation of the observations. The questions of whether the cancelling magnetic fields are really being submerged, expelled outward, annihilated, or some combination of these interpretations remain open.

day. P25 lost flux at the average rate of $5 \times 10^{18}$ Mx hr$^{-1}$, while P26 lost flux at the much slower and more typical rate of (1–2) Mx hr$^{-1}$. Assuming an equal rate of flux loss in the negative polarity concentrations with which P25 and P26 were cancelling, a conservatively estimated rate of cancellation for a small element exemplified by P26 and its unresolved negative conterpart is $2 \times 10^{18}$ Mx hr$^{-1}$. A high rate of flux loss is $10^{19}$ Mx hr$^{-1}$, as exemplified by P25, one of the fragments which in the time-lapse films appears to cancel rapidly. Assuming that the lower rate of $2 \times 10^{18}$ Mx hr$^{-1}$ is typical, only 2·5 sites of cancellation of this magnitude need to exist on average throughout the decay phase to account for all of the observed loss of flux during the decay phase of the active region, as measured from the Kitt Peak magnetograms ($5 \times 10^{18}$ Mx hr$^{-1}$). Since it has been shown in Figs 3–6 that several cancellation sites frequently can be observed at the same time, we conclude that the general phenomenon of cancellation is of the correct order of magnitude to account for the flux that has disappeared from the photosphere during the decay phase of this active region. To verify this estimate a detailed accounting of all the measurable cancelling features in this active region is planned for a subsequent paper.

In most of the examples cited thus far, the cancellation of flux was preceded by fragments breaking away from larger concentrations of flux. Sometimes, however, cancellation is preceded or accompanied by the merging of knots of flux of the same polarity. An example of the coalescence of fragments preceding and accompanying cancellation is shown in the upper part of the active region in Fig. 6. A cluster of fragments of negative polarity merges throughout the day. One of the fragments, labelled N28 at 2046, moves into contact with adjacent P28. N28 cancels completely with P28 by the end of the day and loss of flux is also apparent in P28. In addition, while N28 is cancelling with P28, P29 can be seen to merge with P28 between 2209 and 2349. Merging of the negative polarity fragments to the left of P29 also can be seen to slowly take place during the day. At 2349, we denote the merged cluster of negative fragments as simply N29 and the merged positive fragments as P29. By the last frame at 0031, N29 and P29 have almost moved sufficiently close for cancellation to begin. By the beginning of the next observing day (see Fig. 11 in the next subsection), all of P29 has completely disappeared along with most of N29.

Fig. 6 also reveals the dramatic effect of the fragmentation of the main concentration of negative flux. The main concentration has entirely dissipated at the site where the decaying sunspot was present on 3 August. In Fig. 6, the site of the previous concentration appears to be the centre of one or more newly forming network cells. The small concentrations of flux around the periphery of the cell are, on average, equivalent in magnitude and peak flux to the scattered negative flux in the rest of the field of view.

In the centre of the region and to the left of the polarity inversion line in Fig. 6, we observed the appearance of a new ephemeral region E2, whose poles are labelled E2p and E2n at 1829 in Fig. 6. The negative pole is growing in the upper end of a larger area of adjacent negative flux. The ensuing separation of the two poles, E2p and E2n (2209), is typical behaviour for ephemeral regions, as already shown for E1 in this paper and for other examples in the paper by Livi *et al.* (1985). E2p moves left and upward into adjacent negative flux, while E2n moves right into the main concentration of positive flux. Steady, obvious loss of flux occurs in E2p and the adjacent negative flux. The negative flux with which E2p is cancelling becomes identifiable as fragment N31 at 2349. By 0031, E2p has almost disappeared. In the other pole of the ephemeral region E2n, flux loss is not obvious. However, it can be seen in Fig. 6 that E2n forces a slight change in the shape of the interface with the positive flux. The polarity boundary appears to be locally shifted to the right as E2n moves right. In such cases where cancellation is expected along the main polarity inversion line, flux change cannot immediately be seen because it is a small percentage change in a large concentration of flux. In these cases, flux loss can only be verified after a sufficient length of time during which the percentage change increases enough to be recognized and measured. By the next observing day, it is seen that E2p and E2n are gone, as well as all of the concentrations of flux around E2p and E2n.

Before proceeding to the description of the magnetic field changes in the late stage of decay of the active region, we present in Figs 7–10 events seen in H$\alpha$ filtergrams that occurred at the sites of cancelling magnetic flux. In Fig. 7, we show a small flare at the site where N16 in Fig. 4 (2006) protrudes into neighbouring positive flux. The site of the flare in Fig. 7 is enclosed with a dashed oval on both the H$\alpha$ image and the magnetogram. The flare is seen to straddle N16, its protrusion into the neighbouring positive field, and the adjacent positive field below the protrusion. Fig. 5 shows the series of magnetograms for several hours after this flare and reveals the flux loss indicated by the absence of the protrusion of N16. By 2325, the positive flux at the flare site below the protrusion has moved to occupy the previous site of the protrusion. Although magnetograms were acquired continuously throughout the flare, we found no impulsive changes in the line-of-sight magnetic field either at or around the flare site during its lifetime. The loss of flux is a gradual change taking place in a period of several hours encompassing the interval of the flare, in agreement with the findings of Harvey *et al.* (1971).

In Fig. 8, the larger dashed oval encompasses a low intensity flare centred at the site where P20 meets N20. At the same time in Fig. 8, a microflare also coincides with E1p and a fibril or flare loop in absorption connects E1n and E1p. These features are enclosed within the smaller dashed oval.

A flare is seen in Fig. 9 around the site where the negative pole of the ephemeral region E2n (Fig. 6) pushes into the neighbouring positive flux. One of the flare elements appears to lie over the positive flux adjacent to E2n and the other over the negative flux just below E2n. Due to the high concentration of magnetic flux, the small percentage reduction in flux, expected where E2n pushes into the neighbouring positive field, is not seen in the magnetograms in Fig. 6. However, it is clear in the magnetograms that there is a slow build-up of magnetic field gradient, beginning before the flare and continuing after the flare and through the remainder of the observing day. By the next day, a large amount of both positive and negative field have disappeared. We infer that a slow loss of flux, which in other cases is distinct when observing small fragments, must be taking place as the gradient of the field increases on this day. The change in gradient and loss of flux occur in exactly the same way as illustrated for PN25 (Fig. 6, 1748–2209), where the field gradient also increases as the flux obviously disappears.

These examples of flares around the sites where ephemeral regions meet a pre-existing magnetic field, confirm the finding of Marsh (1978) that 'ephemeral region flares' do not occur between the poles within the ephemeral regions, but rather are related to the sites where their poles encounter opposite polarity magnetic flux. However, some flare configurations that we have observed in relation to ephemeral regions obviously differ from the configuration suggested by Marsh (1978). In the

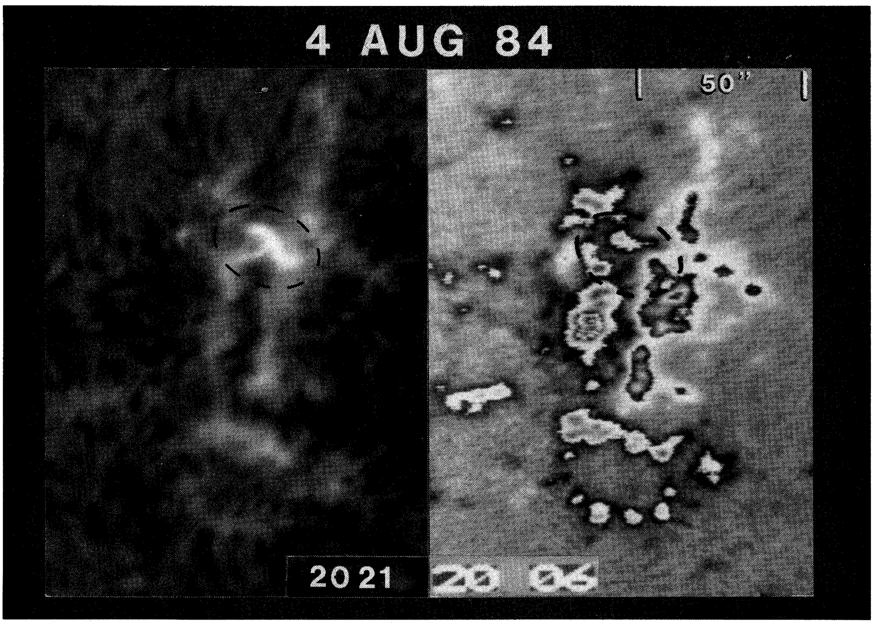


**Fig. 7.** A flare in Hα (left image) occurs where a negative fragment intrudes into a positive polarity field and loses flux. The Hα image is intentionally over-exposed to better show the flare in contrast to the Hα plage and background.

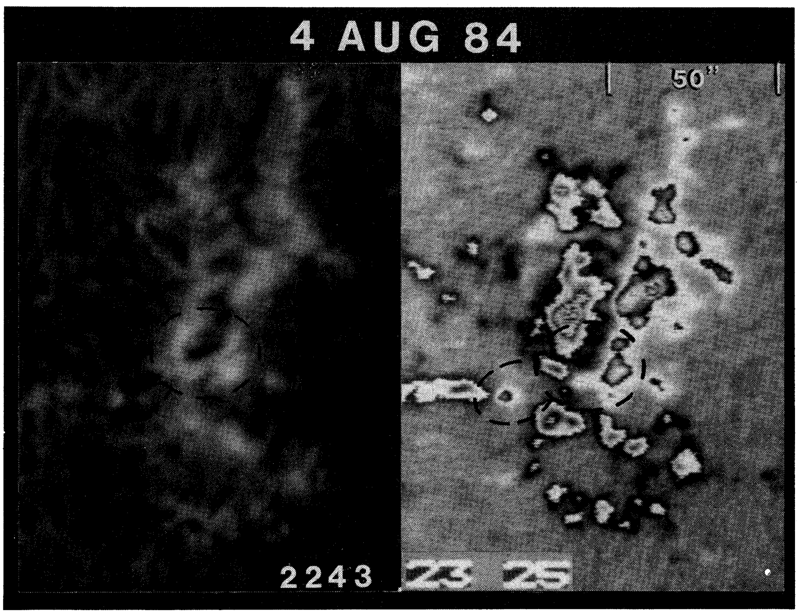


**Fig. 8.** A weak flare in Hα (left image) occurs around the site where positive flux, P20 (see Fig. 5), moves into negative fragments. The larger of the two closest negative fragments is the negative pole of ephemeral region E1 in Fig. 4. Concurrent with this flare in the larger dashed oval, a microflare is seen in the positive half of ephemeral region E1, shown in the smaller of the two dashed ovals.

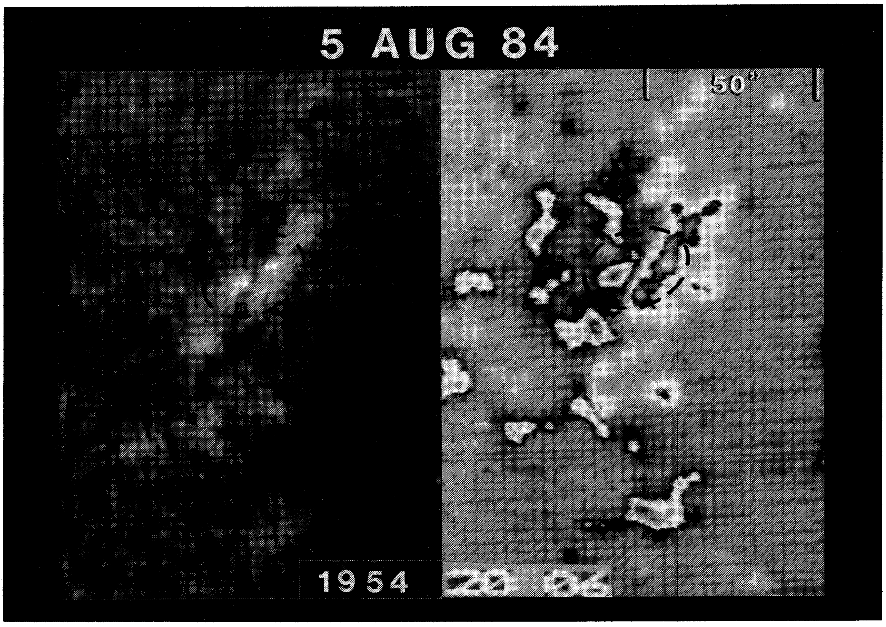


**Fig. 9.** A flare occurs where E2n in Fig. 6 moves into the main polarity inversion line.

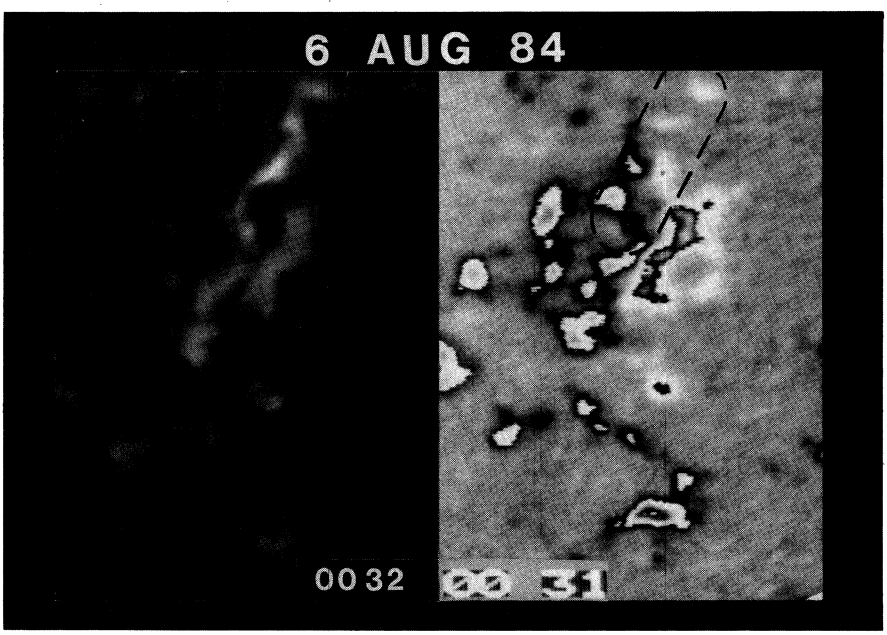


**Fig. 10.** This flare in H$\alpha$ occurs after P29 has moved into contact with N29 and also after the cancellation P28 and N28 in Fig. 6.

Marsh model, the chromospheric flare foot points would be connected by coronal flare loops extending from one pole of the ephemeral region to the closest adjacent opposite polarity field. It is clear in some of our magnetic field and H$\alpha$ images that one chromospheric foot point of the flare occurs near or on one pole of the ephemeral region, as suggested by Marsh, but that the other flare foot point is found in an opposite polarity field further from the site of collision of the ephemeral region pole with opposite polarity field. The flare in Fig. 9 is such an example.

In Figs 5 and 6 respectively, E1 and E2 are the only ephemeral regions identified during the decay phase of this active region. In both cases, the net effect, after the eventual complete cancellation of both poles of the ephemeral regions with neighbouring magnetic field, has been the removal of magnetic flux from the photosphere.

Another example of a flare at the site of approaching and cancelling fields of opposite polarity is shown in Fig. 10. The flare starts near the juncture of N29 and P29, where N28 previously cancelled with part of P28, while P28 was merging with P29 as shown in Fig. 6. The flare is brightest around the site of PN29. However, we note in this case, the outer extensions of the flare, near the ends of the encompassing oval in Fig. 10, are in adjacent areas. The lower end of the flare lies in negative flux including N31 (see Fig. 6). The upper part of the flare extends across two fragments of weak positive flux.

From these observations it appears that flares might represent a rapid readjustment of the magnetic field necessitated by cancellation.

### *(b) Detailed Description of the Late Phase of Decay*

Our designation of the days from 6–8 August as the late phase of decay is partially arbitrary, but we make this distinction because there are several general differences worth noting between this phase and the earlier phase of decay from 3–5 August. First, the active region has evolved entirely into a cellular structure. The effects of convection in contributing to the motion of the magnetic fields has become obvious in the 6 August magnetograms in Fig. 11. Secondly, major flux loss has unquestionably occurred. In the late phase, there is a smaller number of sites of fragmentation, merging, and cancellation. However, the processes of fragmentation, migration, and the disappearance of magnetic flux continue in the same way as observed during the early phase.

In Fig. 11, examples of merging fragments are P32 and P33. Cancellation takes place between P33 and N33. Another site of cancellation is between P34 and N34. An example of fragmentation can be seen at the right side of the remaining highest concentration of positive flux, where P35 has almost become a separate fragment by 1942. P36 and N36 (1942) are approaching fragments of opposite polarity where flux loss will predictably occur before the next observing day.

In H$\alpha$, large changes were also noted on 6 August, as shown in Fig. 12. Most notably, strands of a filament have formed concurrently with the opening of the region into a cellular network. The filament strands display mass motion and associated structural change throughout the day. At 2105, the filament appears very dense. This is a prelude to its eruption with the occurrence of a flare beginning at 2120 as seen in Fig. 13. Two additional images of the filament are shown in Fig. 13 to show its position relative to the flare and its degree of change before the flare. The flare importance rating should be only about 1N (normal) or 1F (faint) on the commonly

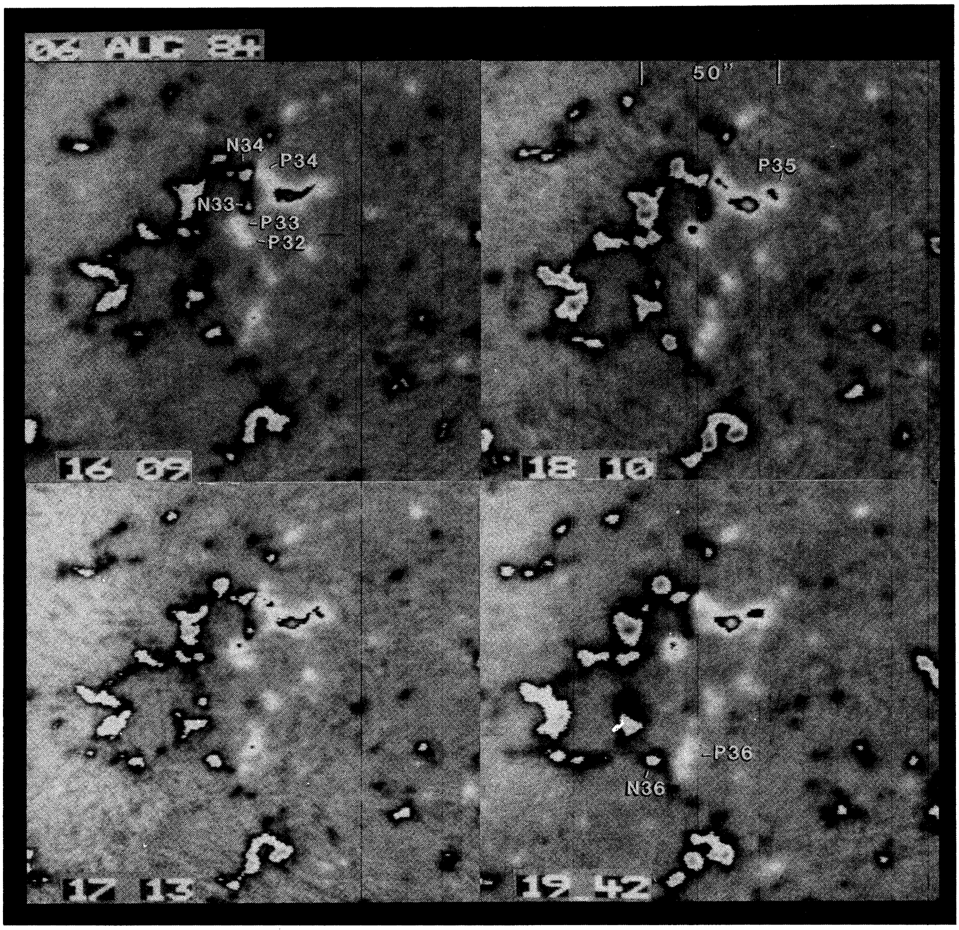


**Fig. 11.** P32 and P33 are merging fragments; N33 cancels with P33 and N34 cancels with P34. P35 (1810) establishes its identity as a separate fragment breaking away from a larger concentration of positive flux.

used relative scale of 1 to 4 in area. However, in relation to the previous flares in this active region, it is a major flare in the sense that it brightens almost every fragment of plage in the whole active region. Flare points are even seen over the network in the lower right of the image at 2139, an area of old network that was not a part of this active region.

The significance of the flare in Fig. 13 is that it is not unusual. It is a common 'garden variety' two ribbon flare; the ribbons are discontinuous rather than continuous as should be expected when the underlying network and plage is also fragmented (Tang 1985). The filament eruption was also not unusual. It was continuously recorded on film at a 15 s interval through a 1/4 Å passband Hα filter. The filament was observed to erupt in the most common style. At the start of the eruption, the centre of the filament first expanded outward with the extreme ends retaining their footing. Then it developed the classic arch form as it disappeared from view against the solar disc.

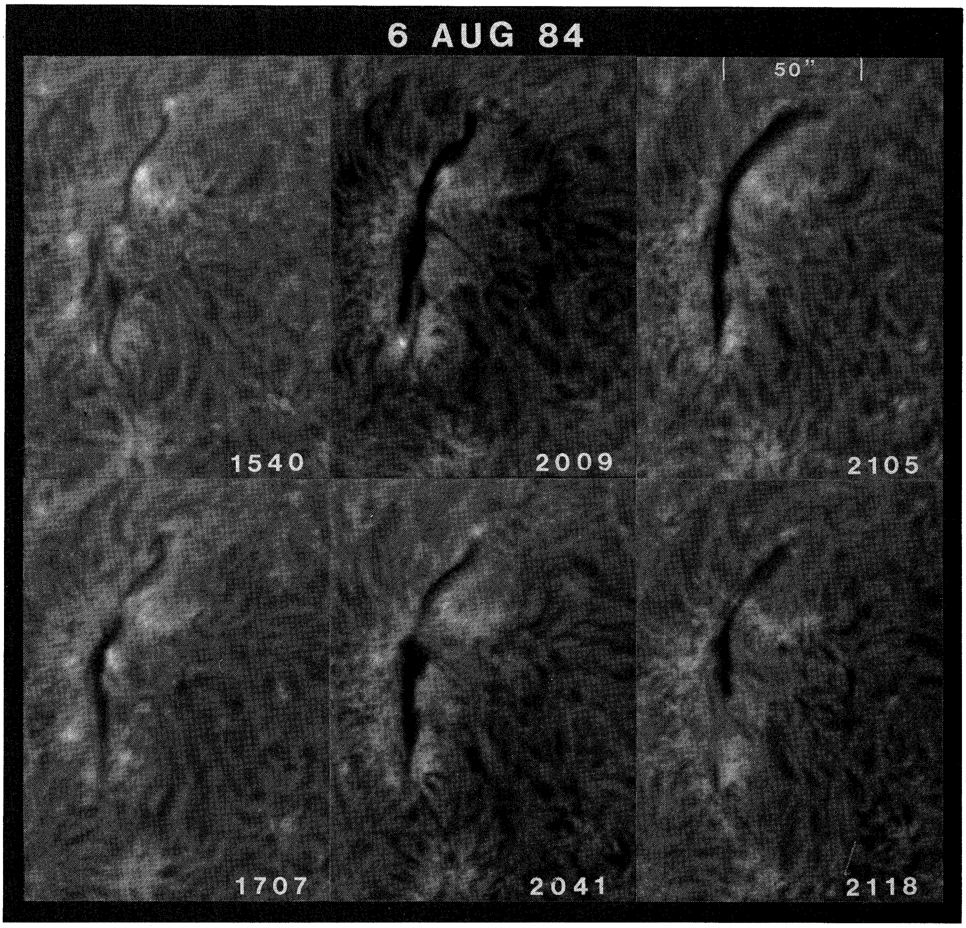


**Fig. 12.** A filament is able to form where gaps have developed between the fragments of flux of opposite polarity. Development of the filament accompanies the cancellation of magnetic flux.

Three important factors are seen in the association of this flare in Fig. 13 with the underlying pattern and changes in the photospheric magnetic field: (1) the flare starts at the main site where magnetic flux is disappearing, as seen in the line-of-sight fields in the photosphere; (2) the flare is brightest in the vicinity of the cancellation sites; and (3) the flare foot points develop throughout the active region where no magnetic flux is being lost at the time of the flare. The first two factors are important because they are common to all of the flares observed in this active region during its decay phase. Hence, we need to learn if these factors are common to flares in general. The third factor is significant because it offers possible evidence of the storage of energy in the active region as a whole, or alternatively of the possibility of the transport of flare energy from a localized site to the remainder of the active region.

The active region magnetic fields continue to decay in the established pattern on 7 and 8 August, as seen in Fig. 14. Only two distinct sites of flux loss are visible at the beginning of the observing day on 7 August. Flux is decreasing at PN37 and PN38 in Fig. 14. At 1739, PN38 is recognized to be two cancelling sites. The site to the right is identified as PN39. By 2224, PN39 ceases to be a cancelling site because the

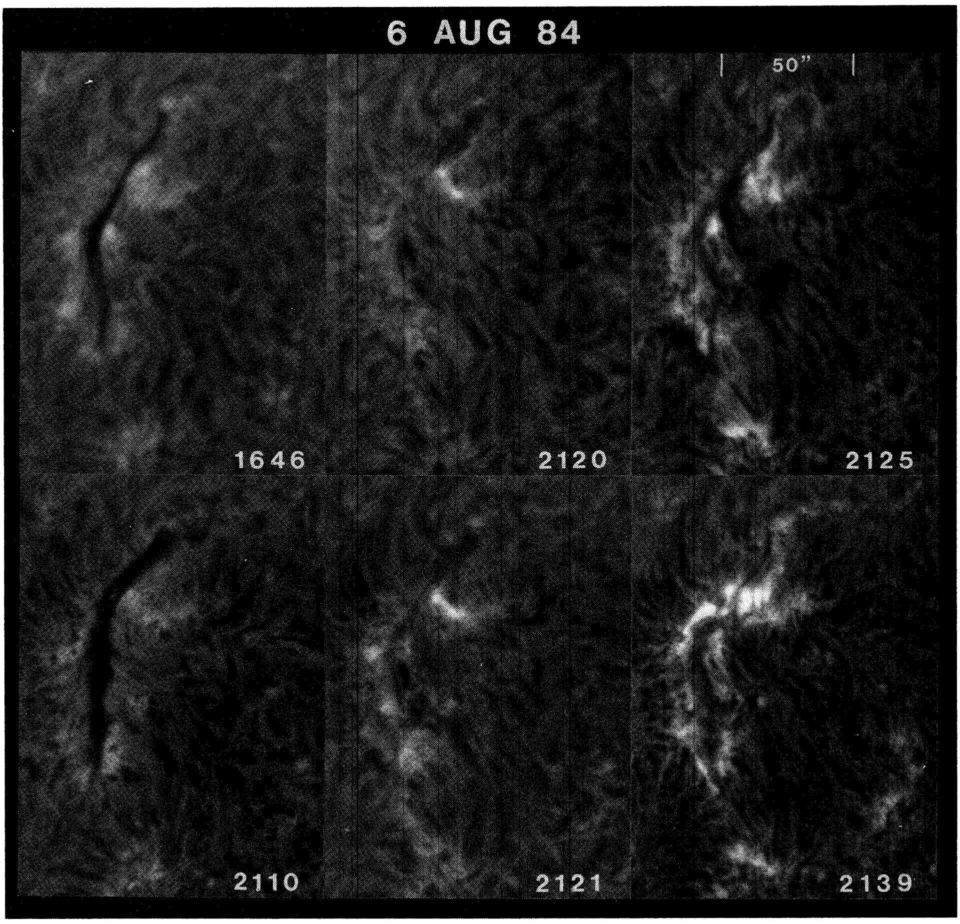


**Fig. 13.** The active and developing filament in Fig. 12 ends its short-lived existence by erupting in association with the flare beginning at 2120. The flare begins near cancelling fields N34 and P34 in Fig. 11 and spreads throughout the remainder of this decaying active region.

negative part of PN39 has completely disappeared. N40 approaches P39 to initiate a new site of cancellation designated as PN40 at 2356. Another very minor site of flux loss, PN41, also develops late in the day (2356).

In Fig. 15, we illustrate four successive flares at 1505, 1550, 1712 and 1902, which involve cancellation sites PN38 and PN39 in Fig. 14. Minor filament activity also is seen. We specifically note at 1902, the formation of a small active filament between PN38 and PN39 just as the cancellation is nearly complete. The filament remains active until the flare at 2156 involving the fields near PN40. In the final frame of Fig. 14, we observe a faint flare and surge at PN41.

The last frame in Fig. 14 is from 8 August, more than 17 hours after the preceding frame on 7 August. By 8 August, only two isolated fragments of positive flux remain. The site of this decayed active region was observed for a few hours on 8 August. During the relatively short interval that the site of this decayed active region was observed, no significant change was seen in the magnetograms and no further transient events were observed in H$\alpha$.

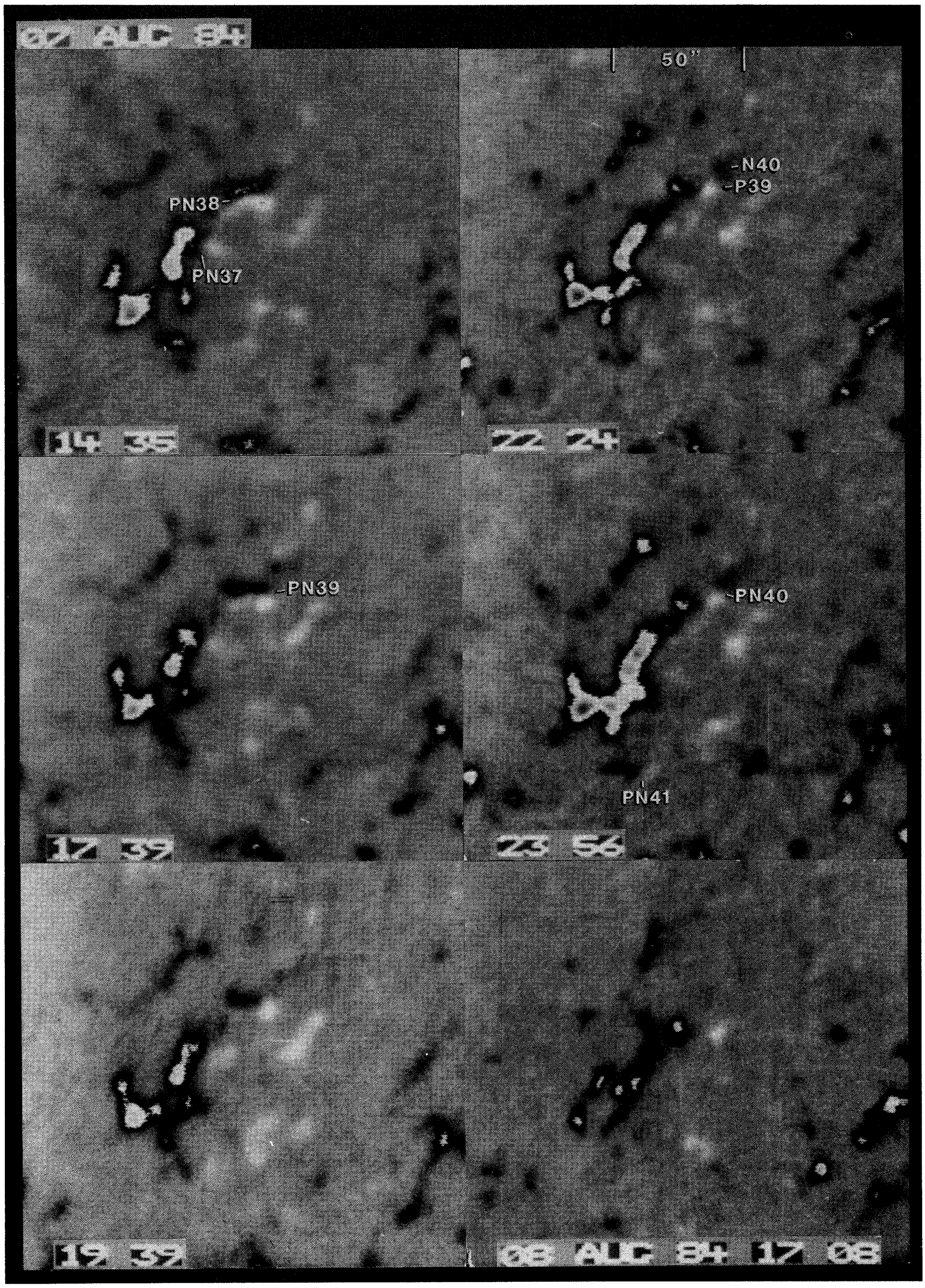


**Fig. 14.** Final sites of magnetic field cancellation observed are PN37, PN38, PN39, PN40 and PN41 on 7 August. The last frame is the following day 8 August. The remaining fragments of positive flux are at least temporarily isolated but probably eventually collide with surrounding negative flux to totally remove all flux of this active region from the Sun.

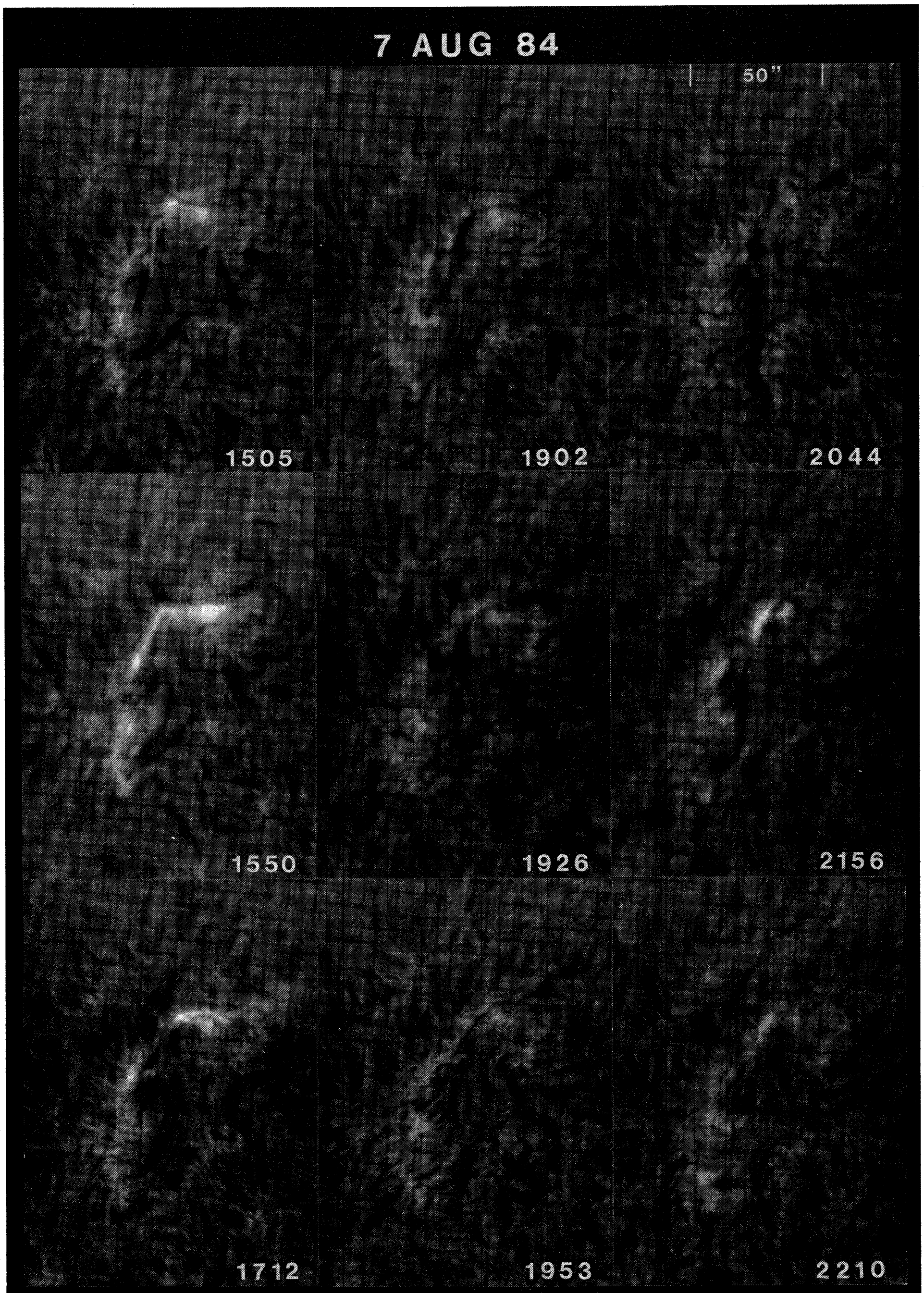


**Fig. 15.** Sequence showing that flares and minor filament activity continue in association with the cancellation sites in Fig. 14, even though very little magnetic flux remains. By 8 August, all H$\alpha$ activity ceased when the cancellation of flux also temporarily ceased.

Table 1 lists the approximate time of maximum of all of the flares observed during the decay of this region. The decay phase begins on 3 August. The primary cancelling fragments directly beneath or beside the brightest flare elements are listed in columns to the right of each column of flare times. It is seen that all of the flares are spatially related to one or more of the sites of cancelling magnetic flux.

**Table 1. Flare time and related cancellation sites during the decay of active region 19425**

| 3 August | | 4 August | | 5 August | | 6 August | | 7 August | |
|---|---|---|---|---|---|---|---|---|---|
| Time | Site | Time | Site | Time | Site | Time | Site | Time | Site |
| 2129 | N9 | 1813 | N16 | 1954 | E2n | 2012 | P/N36 | 1435 | PN38<br>PN39 |
| 2146 | N9 | 1830 | N16 | 2131 | PN25<br>P27 | 2140 | P/N34 | 1528 | PN37<br>PN38<br>PN39 |
| | | 2023 | N16 | 0032 | P/N29<br>N30<br>E2p | <0046 | P/N34<br>P/N33 | 1719 | PN38 |
| | | 2142 | E1n<br>P20 | | | 0107 | P/N33 | 1808 | PN37 |
| | | 2243<br>(2247) | E1n<br>P20<br>E1p | | | | | 2156 | PN37<br>PN40 |
| | | 2325<br>(2343) | E1n<br>P20<br>E1p | | | | | 2201 | PN41 |
| | | 0050 | N22 | | | | | | |
| Number of flares per observing day: | | | | | | | | | |
| 2 | | 7 | | 3 | | 4 | | 6 | |
| Total number of flares observed: 22 | | | | | | | | | |

We end our description of the details of the decay of this active region, having illustrated an inescapable association between the cancellation of magnetic flux and solar flares commonly observed in H$\alpha$. Since the time scales of flares and cancelling fragments of magnetic flux are different, we are left with fundamental puzzles. Is magnetic flux accumulating in the transverse component of the field when it is disappearing in the line-of-sight component? How much magnetic energy is converted to flare energy?

Where all of the cancelled flux goes and exactly how it is lost remain open theoretical questions which need to be addressed. A more detailed quantitative analysis is being carried out as a follow-on to this presentation, which is primarily a qualitative description. Our following observational summary and discussion is just a beginning step in suggesting factors that need further investigation.

## 4. Summary and Discussion of the Primary Results

### *(a) Changes Preceding the Disappearance of Magnetic Flux*

*Fragmentation of magnetic flux.* The first significant process observed during the decay of the active region was the fragmentation of the two main concentrations of positive and negative magnetic flux. At discrete locations around the periphery of each pole of the region, small and initially unresolved fragments of magnetic flux were seen to separate from larger concentrations of flux and thereby reveal their identity as discrete knots of flux. The motion associated with the small knots was often, but not always, in the direction of a feature of opposite polarity. In the negative half of this active region, the fragmentation from the strongest concentration of magnetic flux containing a sunspot was seen to be synonomous with the generation of 'moving magnetic features' around sunspots as previously described by Harvey and Harvey (1973). The knots identified as moving magnetic features consisted of either polarity, but otherwise were not recognized to be different from other fragments that originated from concentrations of flux not containing a sunspot. The majority of the fragments were very small with low values of total flux, typical of the 'knots' described by Zwaan (1978) having a flux of $10^{19}$ Mx or less. Such knots might correspond to a cluster of several facular points.

Fragmentation appears to be a recurrent sporadic occurrence, rather than a continual streaming or uniform flow of magnetic flux from one site to another. At a given location it is highly directional. The fragmentation that occurs around the entire periphery of the active region was confined to the apparent boundaries of network cells.

In the early stages of the decay of the specific active region described here, fragmentation and subsequent losses of flux seemed to happen more frequently in the polarity inversion zone in the middle of the active region than within any equivalent area around the periphery of the region. The fragmentation around the periphery of the region is confined to the boundaries of network cells. However, in the polarity inversion zone between the main concentrations of negative and positive magnetic flux, the fragmentation and ensuing migration do not appear to be confined to a pattern resembling network boundaries, at least when decay of the region first begins. In the early stage of decay, there is no distinct polarity inversion line in the middle of the region. Rather, there is a zone of interleaving of opposite polarity fragments which is continuously changing (see Fig. 3, 0021 UT). However, in the late stages of decay, when cell structure is evident in the middle of the region, the fragmentation does appear to be confined to specific paths that probably coincide with the boundaries of network or supergranule cells. In addition to fragmenting, knots of magnetic flux of similar polarity are equally able to merge with other knots and lose their individual identity within the resolution of our magnetograms. In this paper, we restrict our use of the word 'merge' to the apparent joining of fragments of the same polarity. When fragments merge, there is no apparent loss in total flux. The fragmentation and merging of the knots of flux in the decaying active region is the same as the splitting and joining of fragments of magnetic network on the quiet Sun (Martin 1984). During the decay phase of the active region, we note that fragmentation is dominant while on the quiet Sun the occurrences of fragmentation and merging are more nearly equal in number.

The net result of the fragmentation and migration of the magnetic flux of this active region was that the centroids of the opposite polarity fields moved together during the decay of the region.

*Migration of fragments of magnetic flux.* All of the reasons for the migration of magnetic flux are not definitively revealed by our study, but the data allow us to identify some factors that could lead to the observed motions. Possibly the most important factor contributing to fragmentation and subsequent motion of knots of flux during the decay of the region is the action of convection around and beneath the active region. The sites of formation of new supergranule cells could make a significant difference in how much of the flux is able to flow into the polarity inversion zone. If supergranules develop exactly in the zone, they might inhibit the motion of opposite polarity fields towards each other, leaving the flux to be dispersed mostly outward around the periphery of an active region. However, if the new supergranules form within the concentrations of flux, they might push opposite polarity fields together and limit the amount of outward dispersal of magnetic flux. The latter is a conceivable circumstance for the region described in this paper, because this region is unusual in its rapidity of decay and in the minor role that outward dispersal plays in its general pattern of decay. The effect of supergranules on the migration of flux warrants further study in this and other decaying regions.

Another possible factor contributing to migration is induced motion related to the local cancellation of flux. When flux disappears, however it happens, we might expect a local drop in magnetic pressure at the site of flux loss. If a drop in magnetic pressure occurs, adjacent flux could be induced to move toward that site to re-establish magnetohydrodynamic equilibrium. The continued migration of additional knots of flux toward some sites of disappearing magnetic flux might be explained in this way.

Under some conditions there is evidence of an attraction of opposite polarity fields, a situation anticipated by Gold and Hoyle (1960). If motion is induced by magnetic attraction, two necessary conditions are suspected: (1) that the opposite polarity fields first move within a critical distance of each other, a distance not yet observationally specified, but probably less than the approximate average diameter of a supergranule cell (30 000 km), and (2) that the opposite polarity fields are not magnetically connected, at least initially. An especially good example of apparent attraction presented here is the motion of pre-existing flux towards both poles of ephemeral region E1, as shown in Fig. 5.

In the case of newly emerging active regions or ephemeral regions there is an inherent motion associated with the growth of the regions. This motion can be just due to the pre-existing loops of the active region emerging through the photosphere. In the case of ephemeral regions, however, this motion often continues after the region stops growing and results in a widening space of intranetwork field between the poles of the ephemeral region. The inherent motion associated with the growth of newly emerging magnetic flux regions is not obviously inhibited by convective motion associated with supergranules. However, pre-existing network or any other fragments of relatively strong flux can block or inhibit this motion associated with the growth of new flux, as shown for ephemeral regions on the quiet Sun by Wang *et al.* (1985).

### *(b) Disappearance of Magnetic Flux*

Our observations confirm the speculation by Zwaan (1978) that 'apparently magnetic flux disappears from the photosphere whenever opposite polarities meet'. Throughout the decay phase of the active region studied in detail, the disappearance of magnetic flux was only seen or deduced to happen at or within a few arcsec of the junction of opposite polarity fields which had migrated together. The magnetic flux was seen to disappear within and around this active region in exactly the same way as we have already observed on the quiet Sun and in other active regions (Martin 1984; Wang *et al.* 1985). We conclude that Zwaan's deduction is true in general for all solar fields.

It is relevant to the interpretation of how the flux disappears to know the possible origin of the fields and the circumstances that bring opposite polarity fields into juxtaposition. For the active region studied, the opposite polarity fields originated from four possible sources: (1) fragments of network or older active region fields present before the development of the active region under study, (2) fragments of the active region, (3) new ephemeral active regions developing within the active region, and (4) 'moving magnetic features' (MMFs) from the decaying sunspot—some of which are opposite in polarity to the spot (Harvey and Harvey 1973). Sources (1), (2) and (3) are just active regions that have originated at different times in the same field of view. We regard them as independent sources of field which initially contribute to the total flux in the field of view. Source (4), the MMFs, are presumably not independent fields, but rather are thought to be part of the flux of the active region and represent some type of topological change in the geometry of the magnetic field as a sunspot decays (Harvey and Harvey 1973). We list them as a fourth source because they represent opposite polarity fields that we observe to disappear in the same way as the opposite polarity fields from any of the other three sources.

The disappearance of magnetic flux takes place in a specific way that we call 'cancellation'. The term 'cancel' implys no physical model of how the flux disappears. It is a descriptive term which we define as 'the mutual apparent loss of magnetic flux in closely-spaced features of opposite polarity' (in observations of only the line-of-sight component of magnetic fields). Cancellation is almost invariably preceded by prior motion of the opposite polarity fragments towards each other. When the pre-cancellation phase is observed, we often see that the fragments involved in cancellation were preceded by a period during which one or both features moved toward the other with no apparent loss of flux until the fragments were within a few arcsec of each other. From the pre-cancellation migration patterns of isolated fragments and their subsequent motion during cancellation, we deduce that the observed loss of flux occurs at or within a few arcsec of the interface between the opposite polarity fields.

Before opposite polarity features first move into apparent contact, the gradient of the magnetic field is seen to be about the same everywhere around their periphery. That gradient is presumably the decrease of field from a point source or cluster of point sources of magnetic field, whose real strength is unknown and depends on the true size of the magnetic elements. The measured flux from the source magnetic field is smeared by seeing and telescope guiding errors. Hence, the true gradient is reduced to an apparent gradient which we can observe and measure. In our magnetograms, having spatial resolution of 2–3 arcsec, cancellation begins when opposite polarity fragments appear to come into contact. At the same time we observe a steepening of the apparent magnetic field gradient between the opposite polarity fragments. As the cancellation proceeds, the gradient seems to increase to some limiting value which may depend on the speed of prior motion or the quantity of flux involved in the cancellation.

The half-rate of magnetic flux loss per cancelling feature is of the order of $10^{18}$ $\mathrm{Mx\,hr^{-1}}$. This amount of flux loss is easily seen and measured for small knots having a total flux less than $10^{19}$ Mx. This amount of flux loss is sufficiently small that it is difficult to detect at the boundaries of larger concentrations of flux under circumstances where there are no apparent resolved fragments of flux. Two factors inhibit our detection of flux loss under these circumstances: (1) variations in image quality make it difficult to detect small percentage changes in large features with high concentrations of flux, and (2) adjacent flux moves towards the cancellation sites thereby obscuring the local loss of flux. However, in many circumstances, we were still able to deduce that cancellation was taking place because of several observational factors: (1) after a critical magnetic field gradient was reached at a given polarity inversion zone, there was no further build-up of flux near the polarity inversion line or zone; (2) after a sufficient length of time, such as by the next observing day, and assuming that several successive cancellations of knots of magnetic flux took place, the percentage change in the large concentrations became high enough to easily detect the loss of flux; and (3) cancellation was the only type of major flux disappearance seen during the decay of the region—isolated features of single polarity remained relatively constant in flux magnitude in contrast to the flux at junctures of opposite polarity fields which showed substantial net loss of magnetic flux over intervals of a few hours to a day.

Cancellation often takes place simultaneously at several sites. It occurs sporadically on approximately the same time scales as the preceding fragmentation. The measured rate of disappearance can vary substantially depending on the quantity of flux in a fragment and the number of fragments that are cancelling at any given time. The rates of disappearance can also vary, possibly as a function of the nature of the source fields and their rate of motion or rate growth prior to cancellation. The largest measured rate of cancellation in the decaying region was $5 \times 10^{18}$ Mx hr$^{-1}$ for the positive half of a relatively large fragment that could have been composed of several knots of magnetic flux. The cancellation ended in 3–4 hr upon the complete disappearance of the positive field. Assuming that an equal amount of flux of both polarities disappeared, this cancellation alone was losing flux at a rate of $10^{19}$ Mx hr$^{-1}$, twice the average hourly rate measured from the Kitt Peak daily magnetograms and found to be $5 \times 10^{18}$ Mx hr$^{-1}$. At a more typical rate of cancellation of $2 \times 10^{18}$ Mx hr$^{-1}$, the steady loss of flux at a continuous average of 2·5 sites would account for the total flux loss during the main phase of decay of the region. Thus, the phenomenon of cancellation alone is estimated to be of the correct order of magnitude to account for all of the flux that disappeared during the decay of this active region. A detailed accounting of all of the measurable loss of flux in the many fragments within this active region is planned for a subsequent paper.

Cancellation can be interpreted as the removal of magnetic flux from the photosphere in several ways. Zwaan (1978) mentioned two possibilities. Both involve reconnection to create loops that would either be pulled out of the photosphere or below the photosphere depending on the height at which reconnection occurs. In Zwaan (1984), the case of simple submergence without reconnection was also outlined. Parker (1984) mentioned the possibility that magnetic fields can 'cancel' as a third means of removal of magnetic flux from the photosphere, in addition to submergence and outward expulsion. Parker's use of the term cancel was not explained; he argued only for the case of simple submergence.

In our view, there are at least two additional alternative interpretations of cancellation: (1) collapse of the magnetic fields due to local annihilation of the electric currents that are the source of the magnetic fields and (2) apparent loss of magnetic flux due to changes in the topology of the magnetic field, such that the observed line-of-sight component becomes a transverse component of the magnetic field.

The correct interpretation of cancellation is not yet known. The question at least partially hinges on knowing whether the components of cancelling fields are: (1) parts of the same magnetic field, i.e. parts of a true magnetic bipole; (2) parts of separate magnetic fields that collide without reconnection; or (3) parts of separate magnetic features that collide and undergo magnetic reconnection.

We have examined many H$\alpha$ images corresponding to our videomagnetograms in seeking the correct interpretation of cancellation. Unfortunately, in existing sets of data, we have only partial evidence of which fragments are magnetically connected to other fragments. Sometimes flare loops reveal the magnetic connections, although these may be temporary. H$\alpha$ fibrils also sometimes give us clues. We have found an apparent lack of fibrils connecting fragments of magnetic field that are cancelling. However, this does not constitute proof of the absence of direct magnetic connection, because of a possible local increases in temperature which would prohibit the existence of cool fibril structures at the cancellation sites. The possibility of slow reconnection further complicates the picture, because we cannot know even for ephemeral regions whether their poles remain magnetically connected parts of a bipole, or whether soon after birth each pole reconnects to other flux in its vicinity. Transverse magnetic field measures in the photosphere and chromosphere, as well as direct observations of coronal fields or structures, are needed to determine how the magnetic field is configured at any given point in time. Knowledge of the three-dimensional structuring of the field as a function of time is necessary to observationally verify exactly how the flux disappears. Simultaneous velocity and magnetic field observations should also be helpful in learning the correct interpretation of cancellation.

### *(c) Spatial and Temporal Association of Solar Flares and Disappearing Magnetic Flux*

All of the 22 flares observed during the decay phase of this active region were initiated around the sites where photospheric magnetic fields were cancelling or inferred to be cancelling. All of the flares were small, classed as subflares or microflares, except one flare of importance 1 which spread throughout the entire active region. There were also many other brightenings around the cancellation sites not sufficiently large or well defined in time to identify as specific events. Distinct flares were observed at most, but not all, of the sites of cancelling fields. Notably, during the late phase of decay, all of the cancellation sites were associated with one to three flares each (see Table 1 in Section 3). Additionally, when flares were observed, the brightest part of the flares were always close to the sites of cancelling fields. However, several flares extended to areas where no cancellation was taking place.

The time scales of cancellation and flares are notably different. Small-scale cancellation takes place over periods of several hours, whereas flares occur impulsively in periods of a few minutes. The time occurrence of flares relative to the cancellation is not obvious in viewing the time-lapse film of magnetograms, because there were no impulsive or short-lived changes in the magnetic field at the times of the flares.

Further study is required on the details of the spatial and temporal associations of flares and disappearing magnetic flux. From our knowledge of these associations to date, we hypothesize that cancellation was a necessary condition, but not the only necessary condition for flares to occur in this active region.

## 5. Conclusions

At least three processes were found to be significant contributors to the decay of the specific active region studied. The first observed process was fragmentation of concentrations of flux by the breaking away of very small knots at the periphery of the concentrations. Second was a preferential migration of opposite polarity fragments towards each other, although fragmentation was found to occur in all directions around the periphery of the primary concentrations of positive and negative magnetic flux. The third and most significant process was the observed disappearance of magnetic flux at or within a few arcsec of the interface between opposite polarity fragments of flux. This type of disappearance of magnetic flux, called cancellation, was the only kind of major and real loss of flux observed in the active region.

Cancellation most typically involves small knots of flux; the few large knots that cancel probably are clusters of small unresolved knots. The cancellation observed in this active region occurred in the same way as the cancellation of magnetic flux fragments on the quiet Sun (Livi *et al.* 1985). However, the rate of cancellation is sometimes greater than on the quiet Sun. The rate of flux loss at a single site can be as much as $10^{19}$ Mx hr$^{-1}$ and possibly greater. The frequency and rate of cancellation was estimated to be sufficient to account for all of the magnetic flux lost during the decay of the active region.

The consequence of cancellation for the active region illustrated in this paper was the effective removal of the equivalent of its entire flux from the photosphere. Thus, this active region made no net contribution to the long-lived network fields of the quiet Sun. However, it should have resulted in the redistribution and replacement of the pre-existing long-lived network.

The *in situ* disappearance of flux of one polarity in magnetograms of lower sensitivity than shown here can be due to two phenomena. First, it can be due to the lack of detection of the many small knots of flux that cancel with larger, more easily detected concentrations of flux. Secondly, it can be due to small knots of flux breaking away from larger knots. If a magnetograph does not detect these small fragments due to inadequate spatial resolution and magnetic sensitivity, one could conclude that the disappearance of flux is inexplicable.

The mechanism of the observed cancellation of flux needs to be ascertained through additional observational and theoretical investigations. Observationally, an important question is whether the cancelling flux can be a consequence of the line-of-sight component of the magnetic field temporarily changing into the transverse component.

The formation of several short-lived filaments was observed upon the cessation of cancellation at some sites. All of the flares observed during the decay of the active region were initiated at the sites of cancelling fields. However, the time scale of flares differs radically from that of cancellation. Cancellation is a slow and long enduring change, in contrast to the impulsiveness of flares. This spatial and temporal association may be significant to the interpretation of cancellation and to flare theory.

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