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BIG BEAR SOLAR OBSERVATORY

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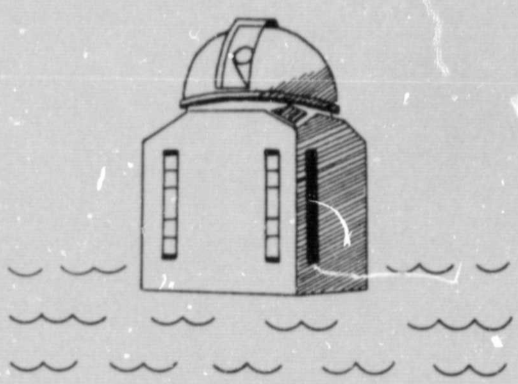

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REVERSED-POLARITY REGIONS

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ABSTRACT

We present results of a statistical study of reversed-polarity regions, RPRs, collected over the past 11 years, 1969-1979.

The 58 RPRs we studied have a lifespan comparable to normal active regions and have no tendency to rotate toward a more normal alignment. They seem to have stable configurations with no apparent evidence suggesting stress due to their anomalous magnetic alignment. Magnetic complexity in RPRs is the key to flare productivity just as it is in normal regions ——— our weak field RPRs produce no flares and regions with complex spots produce more flares than regions with non-complex spots by a factor of 5.

The RPRs however, differ from normal regions in the frequency of having complex spots, particularly the long-lived complex spots, in them. Less than 17% of normal ARs have complex spots; less than 1.8% have long-lived complex spots. In contrast, 41% of RPRs have complex spots and 24% have long-lived complex spots.

1. INTRODUCTION

Bipolar magnetic regions (active regions) on the sun have an east-west orientation with positive or negative polarity in the lead (west) that varies with solar cycle and hemisphere according to Hale's law (Hale and Nicholson, 1938). Yet a small number of the active regions (ARs) do not obey this rule. Some have the bipolar fields oriented north-south, others have an east-west orientation but inverted from the proper order for that hemisphere. The latter are commonly known as reversed-polarity regions. For simplicity we will call both kinds of anomalous regions reversed-polarity regions, RPRs.

Rust (1973) found that the likelihood of occurrence of a flare in a large bipolar region increases if, in the vicinity of the magnetic neutral line, there is a rapid development of small reversed-polarity magnetic feature. Tanaka (1979) found a high probability (90%) of coincidence between regions with reversed-polarity δ spot group and the occurrence of great flares.

Little is known however, about the statistical properties of RPRs and their flare productivity. We decided to study the RPRs as a group to find out their frequency of occurrence, life-span, tendency to rotate toward normalcy, if any, and flare production ——— properties that might shed light on the effect of their anomalous orientation.

Bipolar magnetic regions are formed when flux ropes of the subsurface toroidal field rise to the surface (Parker 1955, Babcock 1961). Since the RPRs have their field lines at 90° and 180°

to the toroidal field of that hemisphere, one suspects that the flux ropes of the RPRs experience different stress in the subsurface level than do normal regions. If so, one would be interested to know (1) what effect would this have on the stability of RPRs, (2) if there is a tendency to rotate toward a more normal alignment and thus reduce the stress and (3) if this subsurface stress makes the region more flare productive.

2. DATA

The 11 years covered by this study are 1969-1979, the second half of cycle 20 through the first half of cycle 21, the present cycle.

Full disk solar magnetograms from Mount Wilson Observatory in the form of isogauss contour drawings published in Solar Geophysical Data are used for identification and selection of the RPRs. The Mt. Wilson instrument measures the longitudinal component of the magnetic field in the range $\pm$ 5 gauss to $\pm$ 80 gauss. Sunspots where field strengths are hundreds to thousands of gauss are invisible but the diffuse fields of the active region in tens of gauss are evident on the drawings. Because of the small scale of the reproduction the lower limit of reverse bipolar regions can be confidently identified is about 75 arc seconds across and $\pm$ 10 gauss in field strength. This limits us from collecting RPRs from the small end of the spectrum of ARs. Beginning in 1974 our data source is supplemented by the black and white full disk magnetograms taken at Kitt Peak National Observatory also published in Solar Geophysical Data.

Detailed Mount Wilson sunspot drawings with polarity information are used for study of the sunspots in identified RPRs. Regions are identified by their McMath numbers based on calcium plage. (Occasionally a region contains more than one magnetic region.)

Selected are regions considered to be genuine reversed bipolar and not chance encounters of two unrelated opposite polarity fields that give the appearance of a RPR. Ambiguous cases without additional spot polarity information are also excluded from our collection.

Regions with the proper polarity in the lead and axial tilt $<|45^\circ|$ from the east-west direction are considered normal regions. Regions with axial tilt $\leq|45^\circ|$ from the local meridian are referred to as north-south (NS) aligned and regions with the wrong polarity in the lead and axial tilt $<|45^\circ|$ from the east-west are called EW inverted regions. The latter two polarity orientations are collectively called RPRs. Table I gives the list of the 58 RPRs selected.

Figure 1 shows two examples of the RPRs. MM12556, a simple inverted polarity region, was born on Oct. 9, 1973. It is identifiable as a RPR on the magnetogram when the region grew to half as large as the size shown in Figure 1a. Figure 1b shows a large NS oriented RPR MM16368 in its third rotation. Like many RPRs, small new bipolar flux had emerged within them. The new flux might conform with the existing polarities of the RPR, (indicated by the arrow); or the new flux might ignore the existing polarities thus creating mixed polarities in the negative (black) polarity field (indicated by the double arrows), but the predominant large scale NS field pattern persisted. The polarity makeup of some of the RPRs however, are more complicated (mixed) than the ones shownn.

3. RESULTS

3.1 Latitude Distribution

We found 58 reversed-polarity regions between 1969 and 1979. The distribution of the RPRs is shown in Figure 2. The cluster of RPRs during 1972 and 1973 resulted from regions returning multiple times. The latitude distribution has the general resemblance to the butterfly diagram for sunspots —— broad during maximum years, narrow and at low latitudes during solar minimum. This suggests that the mechanism that produced the RPRs is basically the same as that which produced all other spots and active regions.

3.2 Orientation

Dividing the RPRs into NS oriented and EW inverted, as defined in section 2, we found 32 regions oriented NS and 26 EW. However, many RPRs returned for 1 to 4 more rotations (see section 3.5) mostly with the same orientations. Excluding the returned ones, we found 18 regions oriented NS and 14 EW. If the orientation of the polarities is random, the number of NS versus EW should be 2/1. Since few of the RPRs, especially the large ones, could be traced to their births, we know little about the early evolution of these regions. The orientations discussed here are those which the developed RPRs settled into.

Weart (1970) studied the orientations of new arch filament systems (AFSs). He found the orientations of first day AFSs to be random. According to our definition 41% of his sample were NS aligned and the rest normal. In the 61 cases he studied P polarity spots were invariably in the lead, i.e. no inverted-polarity spots were observed.

3.3 Rotation

One region, MM11191, rotated 90° from a normal orientation to a NS aligned orientation, as shown in Figure 3. In this case the larger P polarity spot remained stationary. Rotation was accomplished by the emergence of small new F polarity spots at an increasingly slanted angle. This is similar to what Weart (1970) and Frazier (1972) found in new arch filament systems where rotation is achieved by the emergence of new spots at a different axial tilt.

A total of 14 RPRs were observed to rotate through an average angle of 35°. Six of these rotated toward a more normal alignment and eight toward a more anomalous orientation. No obvious rotation (< 20°) was observed in the other 44 regions. It is evident that a tendency to rotate toward normalcy is not there. The chance of rotating one way is just as probable as the other —— suggesting a mere random perturbation of mostly stable configurations.

3.4 Hemispheric Distribution

As Figure 2 shows, unlike the butterfly diagram the RPRs are unevenly distributed between the two hemispheres. 44 of the 58 RPRs are in the north, 14 in the south; a ratio of 3 to 1 compared to a typical value of 1.1 to 1 for normal active regions in the three years surveyed 1970, 1974 and 1979.

Asymmetry in favor of the northern hemisphere is not new. Roy (1977) found while the north to south ratio for the magnetically non-complex spots (Mt. Wilson classification α, β) is 1.20 from 1962 - 1974, the ratio for magnetically complex spots (Mt. Wilson classification δ and γ) is nearly 2.

3.5 Longevity

As we pointed out in section 2, because of the threshold effect in the selection of RPRs, regions smaller than 75 arc seconds and less than $\pm$ 10 gauss in field strength escaped our detection. Undetected are the young RPRs that died in their early stage. Weart (1970) found that most of the new AFSs he studied, and particularly the ones with large axial tilt (i.e. NS aligned), died within a few days.

The lifespan of the RPRs discussed here refers only to that portion of the lifespan while the region remained an RPR; not necessarily the total life span of that region.

The shortest-lived regions of the 58 RPRs in our study are two regions that had a life span of 5 days. One region, MM11577, first appeared with bipolar spots nearly north-south aligned, but new spots came up at increasingly east-westerly direction and by the sixth day the axial tilt was only 30° from the east-west direction and by our definition no longer an RPR. The other region, MM12520, was born at W22° and therefore had a short disk passage. A total of 17 regions lived short of a full disk passage but had an average lifespan of 9 days. The remaining 41 regions lived from limb to limb.

45% (26) of the 58 RPRs are returned ones. A sample survey reveals that the fraction of region return among all ARs is 1/3 to 1/2 (1979), with more returned regions during solar maximum. Thus the percentage of RPRs that return for one or more rotations is in the range for all ARs. There are 7 regions that lived 2 rotations, 3 each lived 3 and 4 rotations, and 1 region lived 5 rotations.

The RPRs therefore not only have no tendency to rotate toward a more normal alignment (section 3.3), they live a healthy long life. This can only mean that their anomalous magnetic structure has no adverse effect on the regions' stability.

If we compare RPRs, which have an average lifespan of 9 days or longer, with other active regions having a lifetime $\geq$ 9 days, we find 2416 such ARs of which 58 are RPRs. The RPRs thus consists of no more than 2.4% of the total population of ARs with comparable lifespan.

3.6 Flare Productivity

The 58 RPRs we studied produced 1573 flares reported in Solar Geophysical Data. Table II is a comparison of flare productivity according to the type of spots in the RPRs. The third row shows the average number of flares produced by RPRs with no spots, non-complex spots and complex spots, respectively.

The last row in Table II shows the average number of flares produced by RPRs with the non-complex spots category subdivided according to the number of spot groups in the region and the complex spots category subdivided into short-lived (1-6 days) and long-lived (≥ 7 days). Note (1) the old and/or weak field RPRs with no spots in them produced no flares and the regions with a single group of bipolar spots produced only an insignificant number of flares ——— in spite of their anomalous magnetic orientation. (2) The increasing flare productivity with increasing magnetic complexity is apparent. (3) By far the most flare productive regions were the ones with long-lived complex spots. All this indicates that magnetic complexity is the key to flare productivity in RPRs just as it is in normal polarity regions.

Table II also shows that 24 of the 58 RPRs had complex spots in them and 14 had long-lived complex spots. To compare RPRs having complex spots with normal ARs having complex spots, we searched 11 years of data and found a total of 394 such ARs of which 42 had long-lived complex spots. Thus, less than 17% of the normal regions had complex spots; less than 1.8% had long-lived complex spots. In contrast, 41% of RPRs had complex spots and a phenomenal 24% had long-lived complex spots. The reason is that many of the large δ spots have reversed-polarity umbrae. Regions with these large δ spots often are also reversed in polarities accordingly in their large-scale fields. (The July 1974 region MM13043, however, is not a RPR, though the δ spot is).

To see if being RPR in addition to having long-lived complex spots is more flare productive than their normal region counterpart, we compared the number of flares in each group and found the normal polarity regions produced an average of 88 flares compared to 75 for RPRs. The two most productive regions (nearly 200 flares each) were actually normal regions. The result of this comparison and those of Table II all suggest that anomalous magnetic orientation of the large scale fields that make up the RPRs does not make the region more flare productive.

3.7 Production of Important Flares

Regions with complex spots are known to produce the most important flares (Svestka, 1976). Using Dodson and Hedeman's comprehensive flare index, CFI, data (1971, 1975) we found that during the 5 years (1969 - 1974) that our data overlapped, there were 49 major flares with CFI $\geq$ 10 produced by 36 ARs having complex spots for $\geq$ 7 days. 8 of the 36 ARs (22%) were RPRs and they produced 17 of the 49 (35%) major flares. Of the 4 most outstanding flares with CFI $\geq$ 15, 3 were from RPRs. The 5 years data seems to indicate that RPRs with long-lived complex spots are more productive in major flares, thought not in total number of flares, than there normal counterpart.

At least part of the time these RPRs with long-lived complex spots had reversed-polarity δ spots (γ spots the remainder of the time). It is reasonable to assume, based on Tanaka's (1979) finding, that those are the times the regions are most productive in major flares.

The most outstanding region of the last two decades is MM11976 which produced the great proton flares of August 1972: CFI=16 on Aug. 4 and CFI=15 on Aug. 7 (studied in detail by Zirin and Tanaka, 1973). The region is a simple inverted-polarity region with a large inverted δ spot lasting the entire disk transit.

4. DISCUSSION

The two outstanding properties of RPRs we found in this study are: (1) The stability of RPRs and their similarity to normal polarity regions. They are evidenced by the very healthy lifespan of RPRs, their lack of tendency to rotate toward a more normal alignment, and the lack of evidence suggesting anomalous "stress" in general. (2) The striking high incidence (24 out of 58) of complex spots, and long-lived complex spots (14 out of 58) in these RPRs.

A possible scenario for such a RPR to come about would be that there existed a small, tight kink in the subsurface toroidal flux rope sketched in Figure 4. The kink is localized so that the rest of the rope on either side of it is undisturbed. Buoyancy is strongest at the kink because the field strength is strongest there. The rope rises in the shape of a loop with the kink undisturbed and the rest of the loop intact. If turbulence in the convection layer destroys the kink, there would be no RPR. But if the loop with the kink in it survives the turbulence, a RPR is born. Since most of the loop is intact and untwisted, the region would be stable and similar to a normal polarity region, which presumably is born from an untwisted flux rope. The "forces" that work the kink into the rope probably somehow scramble the fibers of the rope in such a way that spots come up without the usual distance between them (δ type spot) and/or with polarities mixed up (γ type spots). In short, it paves the way for magnetically complex spots to evolve from the RPR.

Alternative to this scenario would be that the anomaly is caused by twisting of the flux rope by the convection either at the top of the loop or near the bottom of it as the flux rope is brought to the surface. Our argument against it is that twisting an already formed loop would put stress on the whole loop. The restoring force would then want to untwist and correct the anomaly ——— a trend we failed to detect from our study. It is possible that the NS aligned ones that died early, as observed by Weart (1970), are loops twisted by the convection as the flux ropes are brought up.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1. a) Mt. Wilson magnetogram on 10/13/73. MM12556 (arrow), an EW inverted-polarity region was born 10/9/73. It is identifiable as a RPR on the magnetogram when the region grew to half the size shown. Top is north, west is on the right in all figures.

b) Kitt Peak magnetogram on 10/18/79. The large NS aligned RPR in its third rotation, MM16368, is in the center of the disk. Although two new bipolar fields had emerged in it: one conforming with the existing polarities (arrow), the other not (double arrow), the large scale NS field pattern persisted.

Figure 2. Latitude distribution of RPRs in the years 1969 - 1979.

Figure 3. Rotation of a normal polarity region to a NS oriented RPR MM11191. Mt. Wilson sunspot drawings are in the top row. Magnetograms of the region (arrow) on the corresponding days, on a smaller scale, are at bottom. Rotation was achieved by the disappearance of old F polarity (indicated as V in the drawings) spot and the emergence of new F spots at an increasingle slanted angle.

Figure 4. An illustration of how a stable reversed-polarity region might be formed. The toroidal flux rope rises with a kink already in it but the rest of the rope is untwisted.

TABLE I

REVERSE-POLARITY REGIONS 1969-1979

No.	MCMATH	LAT.	CMP Date	No.	MCMATH	LAT.	CMP Date
1	10358	N13	10-12-69	30	12475	N15	8-10-73
2	10406	N14	11-7-69	31	12520	S11	9-7-73
3	10460	N14	12-4-69	32	12556	N12	10-12-73
4	10560	S10	2-6-70	33	12595	N15	11-8-73
5	10556	S30	2-4-70	34	12641	N13	12-6-73
6	10608	S11	3-5-70	35	12651	N5	12-13-73
7	11191	S16	3-13-71	36	13015	N11	6-23-74
8	11221	S17	3-31-71	37	13225	N7	9-15-74
9	11301	N5	5-13-71	38	13280	N10	10-11-74
10	11312	N4	5-15-71	39	13324	N9	11-7-74
11	11577	N13	10-27-71	40	13360	N8	12-4 -74
12	11578	N22	10-30-71	41	13926	N6	11-10-75
13	11621	N13	11-27-71	42	13965	N11	12-8-75
14	11657	S13	12-24-71	43	14143	S7	3-30-76
15	11659	N14	12-25-71	44	14943	N8	9-15-77
16	11693	S15	1-20-72	45	14979	N13	10-12-77
17	11734	S16	2-16-72	46	15021	N11	11-8-77
18	11895	N9	5-30-72	47	15047	N12	12-5-77
19	11933	N8	6-26-72	48	15162	N38	2-26-78
20	11963	N12	7-21-72	49	15203	N37	3-27-78
21	11976	N13	8-4 -72	50	15494	N10	8-29-78
22	11995	N13	8-19-72	51	15521	S15	9-10-78
23	12007	N13	8-31-72	52	15768	N12	1-18-79
24	12021	N17	9-10-72	53	16224	S26	8-20-79
25	12056	N11	10-2-72	54	16239	N6	8-26-79
26	12322	N12	4-24-73	55	16285	S25	9-16-79
27	12352	N12	5-21-73	56	16298	N6	9-22-79
28	12387	N15	6-17-73	57	16368	N5	10-19-79
29	12431	N12	7-14-73	58	16416	S30	11-11-79

TABLE II

FLARE PRODUCTIVITY OF RPRs ACCORDING TO SPOT TYPES

Spot Types	No Spot	Non-Complex Spots				Complex Spots	
No. of Regions	7	27				24	
Total Flares	0	265				1307	
Flares/Region	0	10				54	
Subdivision of Spot Types		1 group	2 groups	3 groups	≥ 4 groups	lasting 1 - 6 days	lasting ≥ 7 days
No. of Regions		23	1	1	2	10	14
Total Flares		146	8	18	94	256	1051
Flares/Region		6	8	18	47	26	75

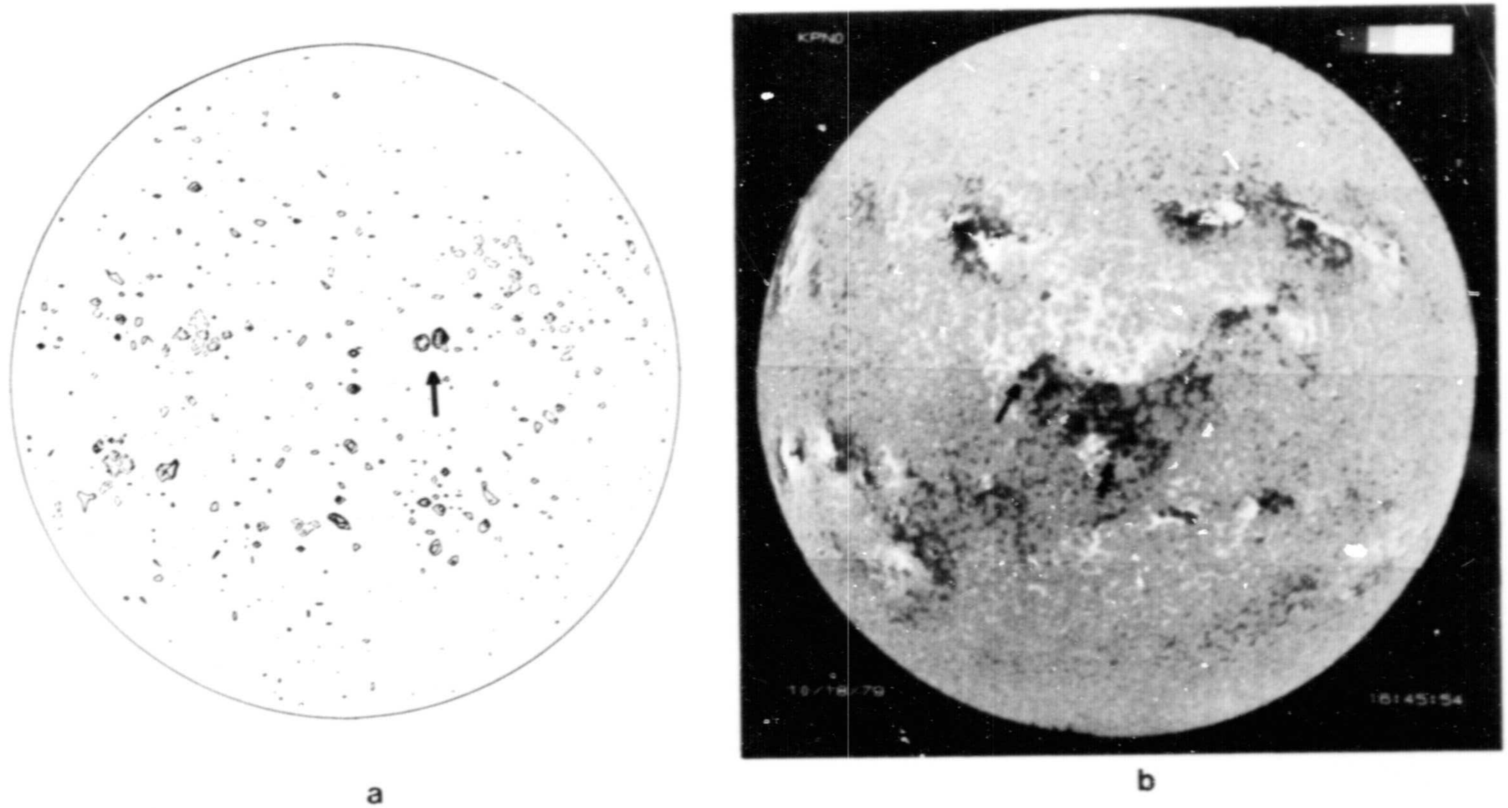

Figure 1

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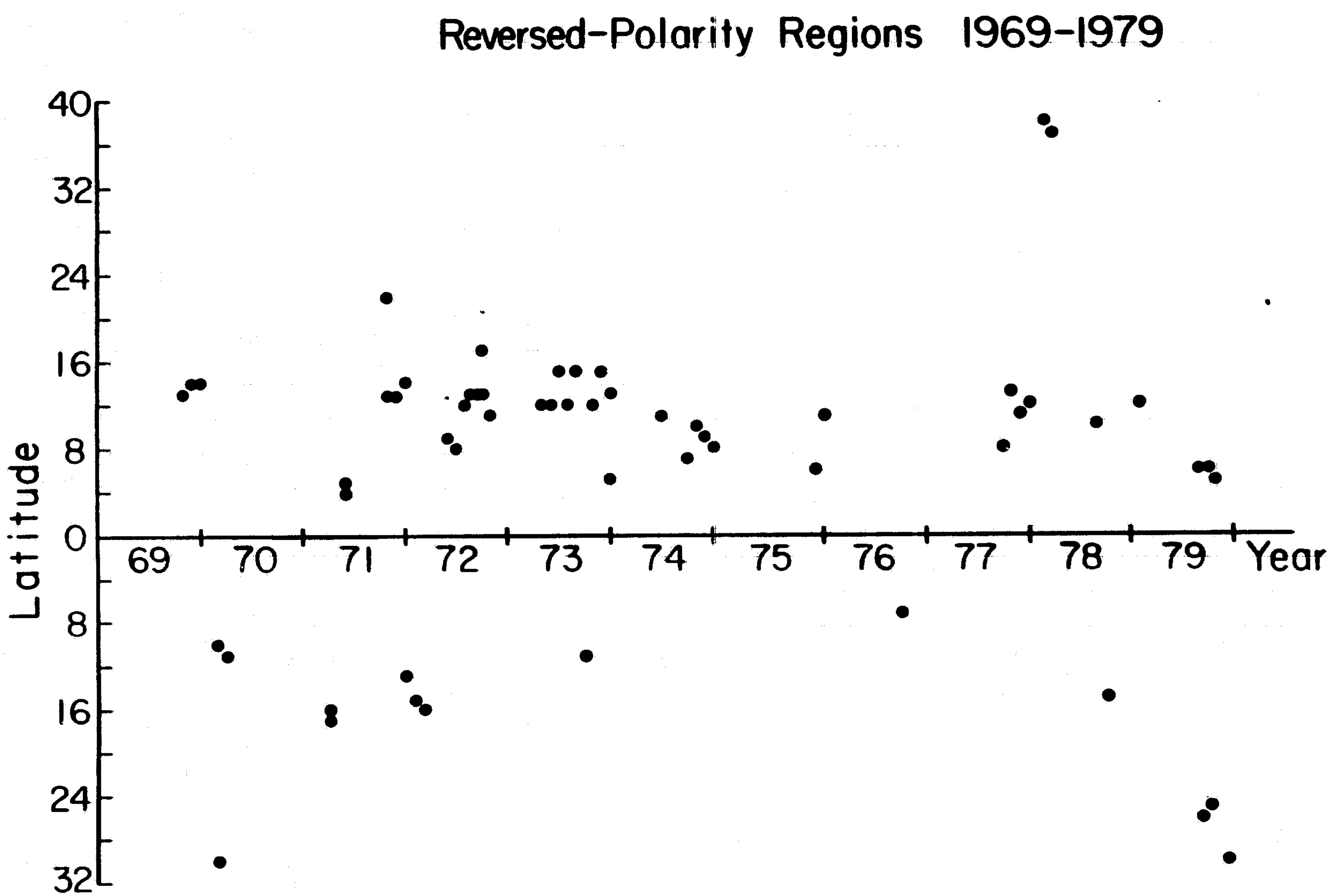
Reversed-Polarity Regions 1969-1979
Latitude
40
32
24
16
8
0
8
16
24
32
69
70
71
72
73
74
75
76
77
78
79
Year

Figure 2

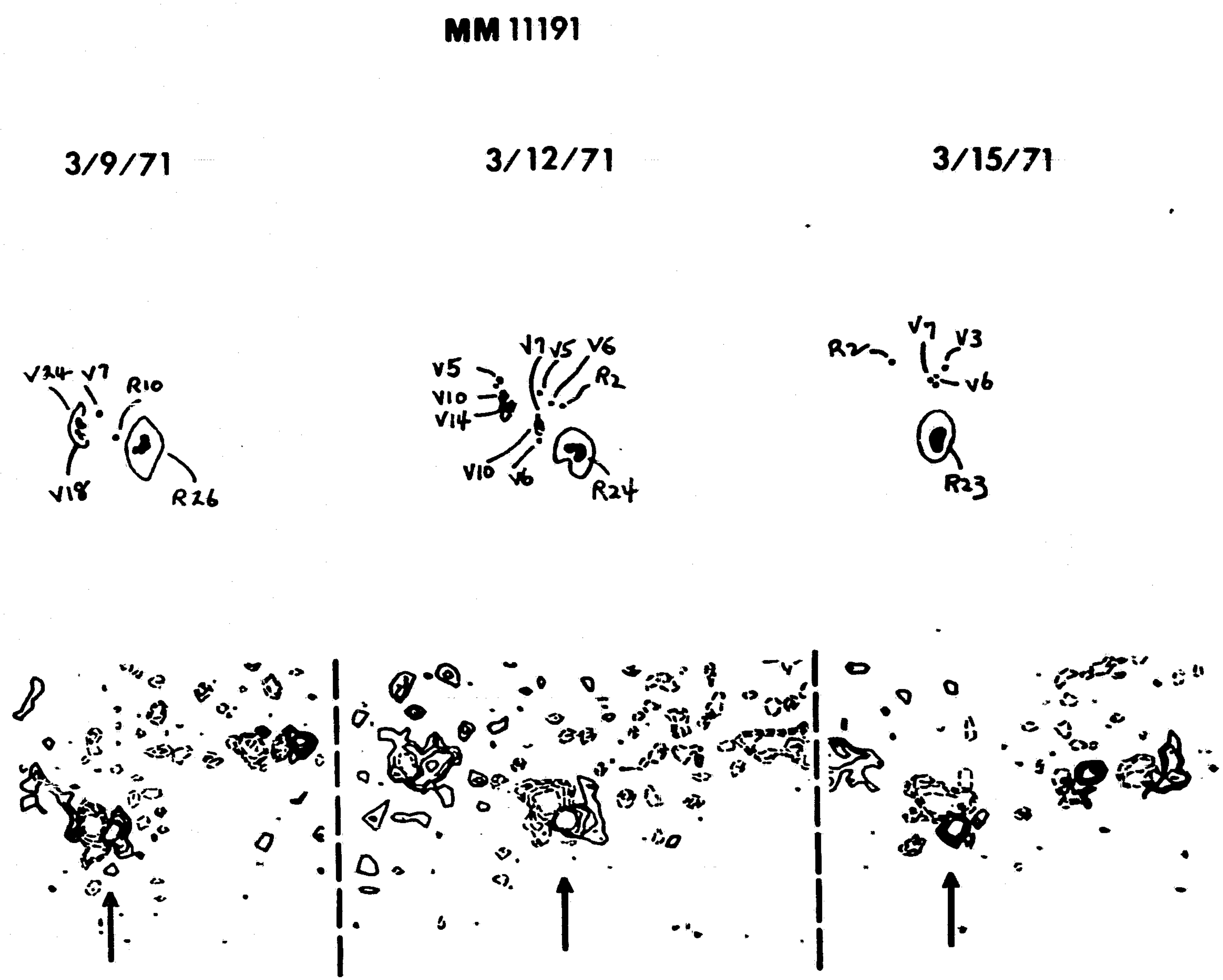
MM 11191
3/9/71
3/12/71
3/15/71
V34
V7
R10
V18
R26
V5
V10
V14
V7
V5
V6
R2
V10
V6
R24
R2
V7
V3
V6
R23

Figure 3

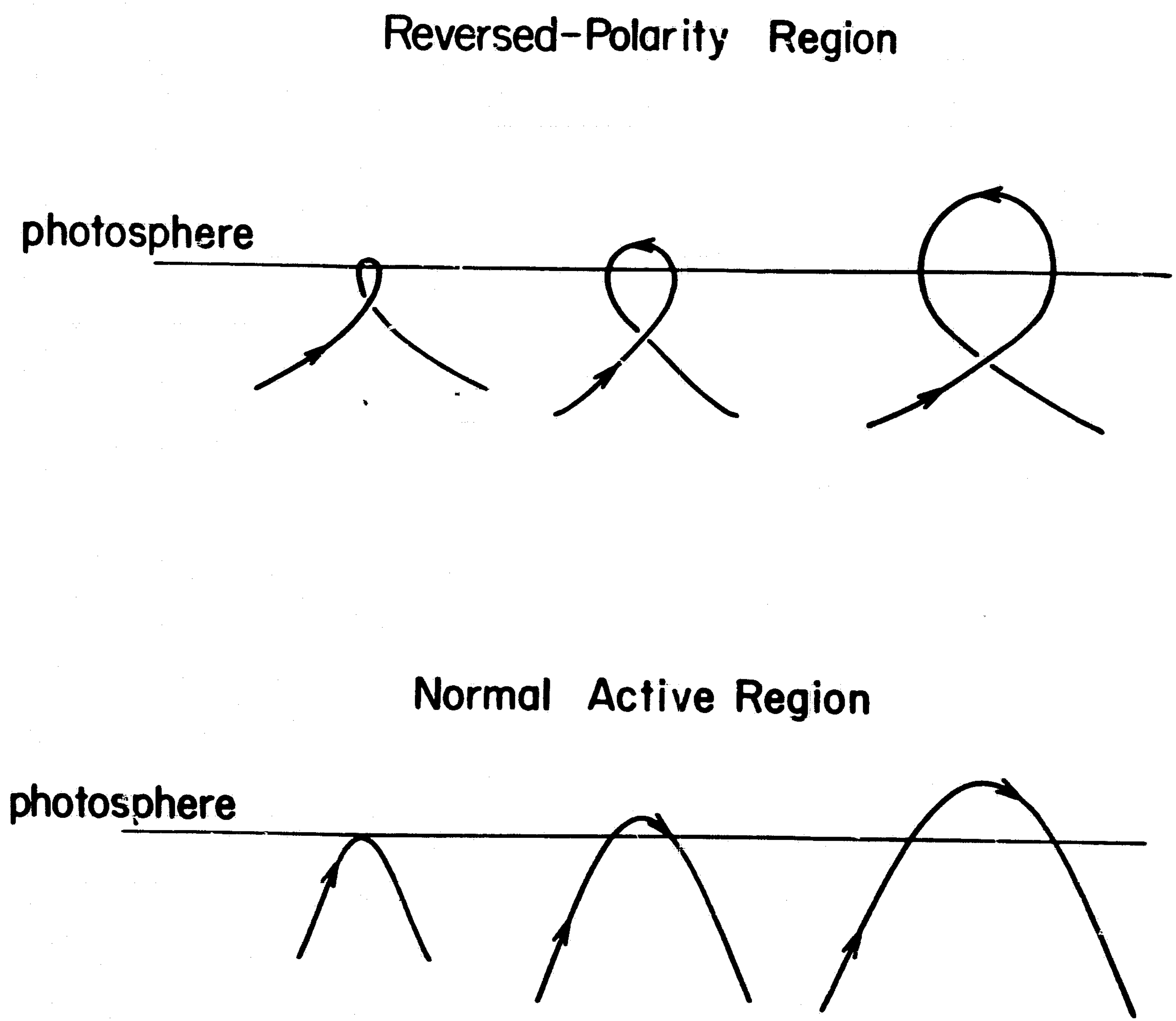
Reversed-Polarity Region
photosphere
Normal Active Region
photosphere

Figure 4