FLARE RESEARCH WITH THE NASA/MSFC VECTOR MAGNETOGRAPH: OBSERVED CHARACTERISTICS OF SHEARED MAGNETIC FIELDS THAT PRODUCE FLARES

R. L. MOORE, M. J. HAGYARD, AND J. M. DAVIS
Space Science Laboratory, ES52, Marshall Space Flight Center, AL 35812, U.S.A.

ABSTRACT. The present MSFC Vector Magnetograph has sufficient spatial resolution (2.7 arcsec pixels) and sensitivity to the transverse field (the noise level is about 100 gauss) to map the transverse field in active regions accurately enough to reveal key aspects of the sheared magnetic fields commonly found at flare sites. From the measured shear angle along the polarity inversion line in sites that flared and in other shear sites that didn't flare, we find evidence that a sufficient condition for a flare to occur in 1000 gauss fields in and near sunspots is that both (1) the maximum shear angle exceed 85 degrees and (2) the extent of strong shear (shear angle > 80 degrees) exceed 10,000 km.

1. INTRODUCTION

One of the greatest flares of the last solar cycle occurred on 25 April 1984. The off-band H-alpha photograph in Figure 1 shows that this flare was seated in a complex group of impacted sunspots. This is a graphic reminder that a flare is very likely a sudden release of magnetic energy, energy built up in the preflare magnetic field by deformation of the field from its minimum-energy, potential configuration (Svestka, 1976; Sturrock, 1980; Hagyard et al., 1984; Moore and Rabin, 1985; Machado et al., 1988; Moore, 1988). If (as we believe) this view is correct, then to see how flares work and to tell when a flare is about to happen, the obvious thing to do is to look at the magnetic field; specifically, we need to observe the nonpotentiality of the field.

A direct measure of the nonpotentiality in active regions is provided by photospheric vector magnetograms such as those from the NASA Marshall Space Flight Center Vector Magnetograph. In addition to mapping the longitudinal (line-of-sight) component of the field vector (the only component measured by most magnetographs now in operation), a vector magnetograph also maps the strength and direction of the field component transverse (perpendicular) to the line of sight. The nonpotentiality of the observed field can be measured by comparing the observed transverse field with the photospheric transverse field computed for a potential field from the longitudinal magnetogram. The greater the difference between the observed and computed transverse fields, the greater the nonpotentiality of the observed field. The usefulness of this method for examining the nonpotential features of active regions has been demonstrated by Gary et al. (1987).

Any flare is seated in one or more magnetic bipoles and straddles the polarity inversion line of each bipole (Svestka, 1976). The usual

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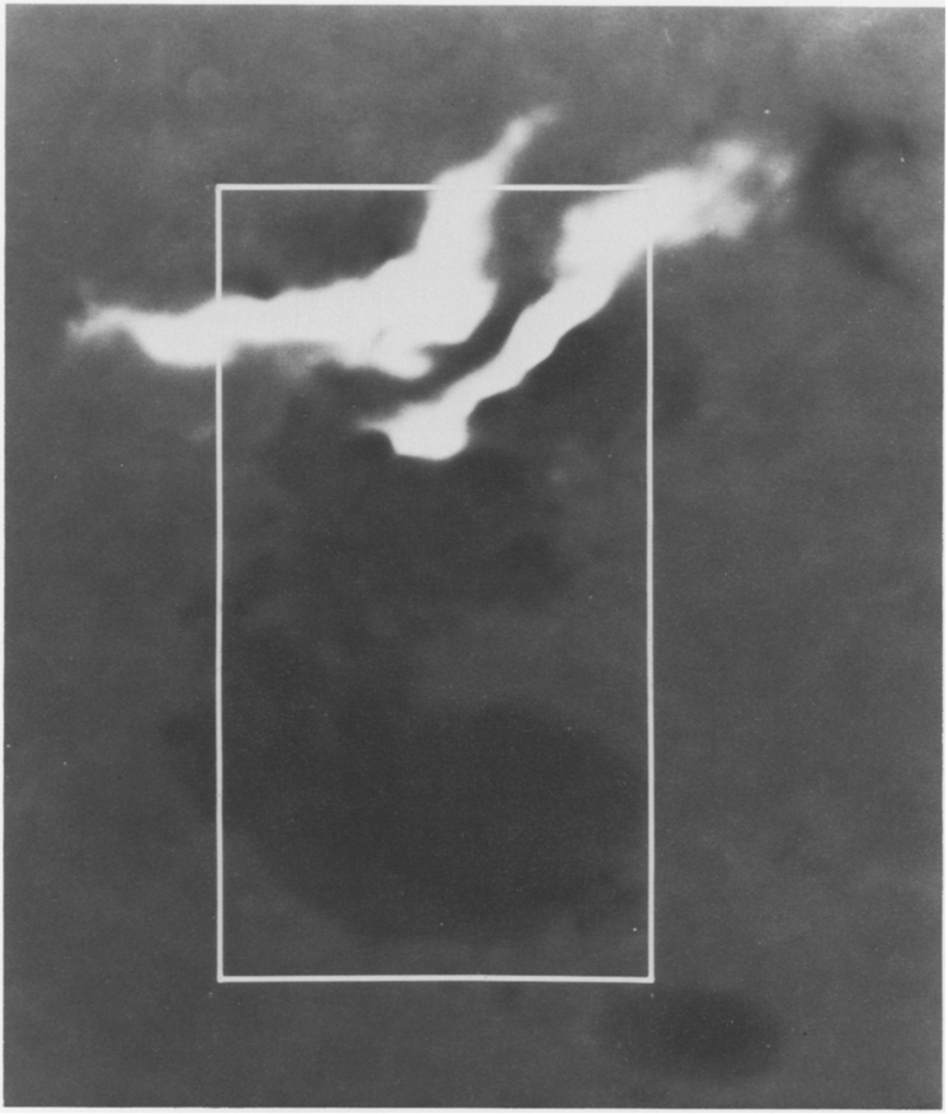


Fig. 1. The great flare of 25 April 1984. This photograph from Big Bear Solar Observatory was taken at 00:07 UT in the far red wing of H-alpha (1.5 Å from line center). West is up; north is left. The white box outlines the the 70 arcsec by 130 arcsec field of view of the magnetogram in Figure 2. Comparison of this photograph with the magnetogram shows that the flare straddled the magnetic inversion line between impacted sunspots of opposite polarity.

signature of nonpotentiality in bipoles that flare is strong magnetic shear across the inversion line (Hagyard et al., 1984; Machado et al., 1988). In this paper, we present results from our quantitative observations of the shear angle (the angular deviation of the observed transverse field from the potential transverse field) along the inversion lines in active regions that flared. We find evidence that for a flare to occur in a field having the typical form of observed shear, the degree of shear (shear angle) and the extent of shear along the inversion line (shear interval length) must both be sufficiently large.

2. MAGNETIC SHEAR AND THE GREAT FLARE OF 25 APRIL 1984

For the area within the box in Figure 1, the magnetic field observed two hours earlier with the MSFC Vector Magnetograph is shown in Figure 2. The computed potential field in Figure 2c demonstrates a general feature of potential fields: near inversion lines, the transverse direction is predominantly perpendicular to the inversion line. Comparison of the observed transverse field (Figure 2b) with the potential transverse field (Figure 2c) shows that there were three intervals along the inversion line where the field was markedly nonpotential, the three sites numbered in Figure 2a. At each of these sites, the observed field was so greatly sheared from its potential configuration that it was directed nearly parallel to the inversion line rather that nearly perpendicular.

In more quantitative terms, at each of the shear sites the shear angle exceeded 70 degrees in two or more consecutive pixels along the inversion line (each pixel was 2.7 arcsec or 2000 km square). The longest interval of such strong shear was at site 3, the site of the great flare two hours later. The first points to brighten in the chromospheric flare ribbons bracketed the inversion line at the point where the shear angle was maximum. The maximum shear angles at sites 1 and 2 were nearly as large as at site 3, but neither site 1 nor site 2 flared. These results suggest that a flare is triggered if the shear angle becomes large enough, but only if the interval of strong shear is long enough.

3. FURTHER COMPARISON OF STRONGLY SHEARED FIELDS THAT FLARED AND STRONGLY SHEARED FIELDS THAT DIDN'T FLARE

To begin to test the above suggestion, we have examined the shear angle along the inversion lines of two more active regions in which a flare occurred on a day for which we have vector magnetograms of good quality similar to that in Figure 2. For all three regions, the observed magnetic shear and its correspondence with flare incidence is summarized in Table 1. Measurement of the transverse field direction to an accuracy of about 1 degree with our present magnetograph requires a field strength no less that about 1000 gauss. We restricted our study to observations with this level of accuracy; hence, that the observed field strengths listed in Table 1 are all 1000 gauss or more simply reflects this selection. This selection criterion also resulted in all of the studied shear sites being in or near sunspots, in the manner seen in Figures 1 and 2.

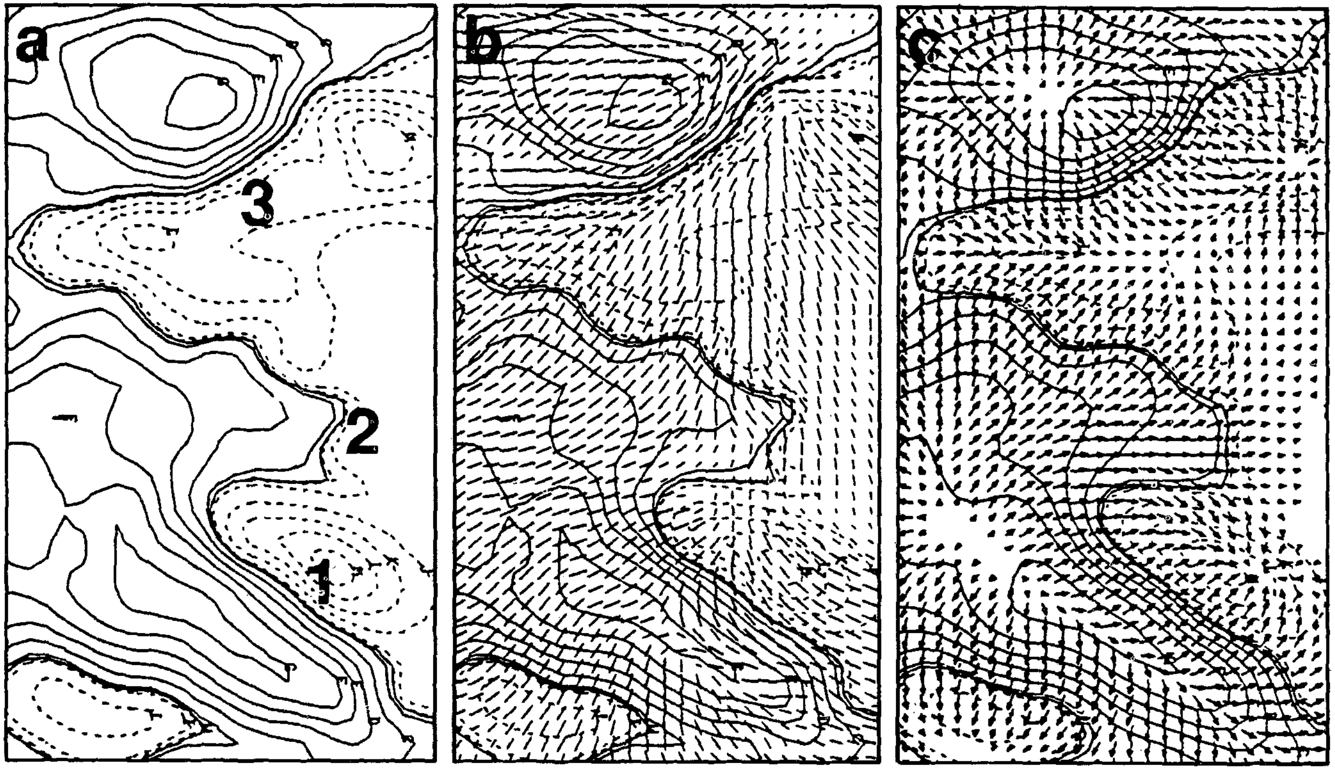


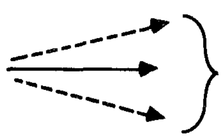
Fig. 2. MSFC vector magnetogram of region in Figure 1. a) longitudinal magnetogram; contours of positive (negative) field are solid (dashed); contour levels: 10, 100, 500, 1000, 1500, 2000, and 2500 gauss. b) transverse field vectors superposed on longitudinal map; vector length proportional to transverse field strength; the longest vectors represent 2000 gauss. c) potential vector field map. Each number in panel a) marks a site of strong magnetic shear across the inversion line.

TABLE I. OBSERVED* MAGNETIC SHEAR AND FLARE INCIDENCE

AR	DATE	SHEAR SITE	MAX. FIELD (GAUSS)	MAX. SHEAR ANGLE (DEG)	LENGTH OF STRONG SHEAR [>80°; (>70°)] (km)	FLARE?	FLARE CLASS (Hα /SXR)
2372	6 Apr 80	1	1300	85	15,000	YES	1B/X2
2776	3 Nov 80	1	1100	70-80	(5,000)	NO	
	4 Nov 80	2	1200	70-80	(2,000)	NO	
		3	1300	70-80	(4,000)	NO	
		4	1100	70-80	(5,000)	NO	
	5 Nov 80	5	1500	88	14,000	YES	1B/M4
4474	24/25 Apr 84	1	1700	89	4,000	NO	
		2	2000	85	(6,000)	NO	
		3	1700	90	20,000	YES	3B/X13

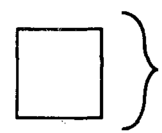
*OBSERVED WITH MSFC VECTOR MAGNETOGRAPH

ACCURACY:



~2°

PIXEL SIZE:



~2000 km

For each site of observed strong shear, the maximum field strength, the maximum shear angle, the length of the interval of strong shear, whether a flare occurred on the same day, and the H-alpha and soft X-ray magnitudes of the flare are listed in Table I. For each of the three sites that flared, the maximum shear angle was 85 degrees or greater and the length of the inversion line interval along which the shear angle exceeded 80 degrees was more than 10,000 km. At two of the sites that did not flare, the maximum shear angle was also 85 degrees or more, but the length of strong shear was less than 10,000 km. In the other four sites that didn't flare, both the maximum shear angle and the length of the interval of strong shear were less than in the sites that flared. Thus, these results for our small sample suggest that for typical sheared field configurations in and around impacted sunspots, a sufficient condition for a flare to happen within several hours is that both (1) somewhere along the inversion line the shear angle exceed 85 degrees and (2) this point be in a strong shear interval in which the shear angle remains greater that 80 degrees for at least 10,000 km.

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