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The Manifold Structure of the Chromosphere and Corona

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The manifold structure of the chromosphere and corona

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[Plates 8 and 9]

Although the photosphere is a uniform region for scales greater than the granulation, the fact that the magnetic field strength falls off less sharply than the gas pressure leads to strong magnetic influence at greater heights in the solar atmosphere. This magnetic influence leads to non-uniformity and fine structure in the chromosphere and corona. The existence of such structure has been deduced mostly from measurements of photospheric phenomena; in particular, from measurements of photospheric velocity fields (Leighton, Noyes & Simon 1962) and of photospheric magnetic fields (Bumba & Howard 1965). The determining factor would thus appear to be in the photosphere; but visible effects only are produced in the chromosphere and corona.

In recent years, high resolution filter photography has enabled us to recognize different regions of the chromosphere, where qualitatively different structure is associated with distinct magnetic field patterns. This progress has been possible because of better Lyot filters, better films and better observing sites; the spectroheliograph has always been limited for high resolution work by the finite slit width and the difficulty of accurate guiding during the long exposures.

Figures 1 to 3, plates 8 and 9, show, respectively, pictures of the chromosphere in the centre of Hα, $H\alpha^{+}0.05$ nm, and the Zeeman field. The last is a cancelled Zeeman spectroheliogram made by Leighton's method (Leighton *et al.* 1962) at the Aerospace Corporation Observatory; the first two are made with the $12\frac{1}{2}$ cm Caltech Photoheliograph in Pasadena. The frame covers one solar radius horizontally (15′), north top, west right. We have marked on figure 2 numbers corresponding to the following regions of chromospheric structure (Veeder & Zirin 1970):

(1) The quiet chromospheric network, with average field strength less than 0.5 mT*, characterized by an irregular network marked by spicules, and vigorous oscillatory motion. The magnetic fields are clumped in limited areas of high field (~ 10 mT) marked by K-line emission and spicules (dark in Hα wing).

(2) High field regions, with average field over 10 mT. The network is here filled with vertical field, and the cells appear as bright plages, if the field is predominantly vertical and of following polarity. The field may be strong and horizontal, in which case it is marked by dark fibrils parallel to the magnetic field. The bright plages are made up of thousands of bright points about 1″ across, which oscillate in brightness and position.

(3) Enhanced network, regions of average magnetic field > 0.5 mT made up of a regular network of fields of more than 5 mT. These are the unipolar regions of Bumba & Howard. The network of lines of greater field strength are the origin of spike-like structures which are probably well-developed examples of the spicules of the quiet chromosphere. Inside the network the field

* 1 mT = 10 gauss.

is either zero or horizontal, probably the latter. The network is dark in the wing of Hα, bright in the centre of Hα and K 3.

(4) Horizontal field regions, marked by long fibril structures, with no apparent network or cellular structure. The magnetic field strength is unknown, but it probably exceeds 0.5 mT and is not clumped.

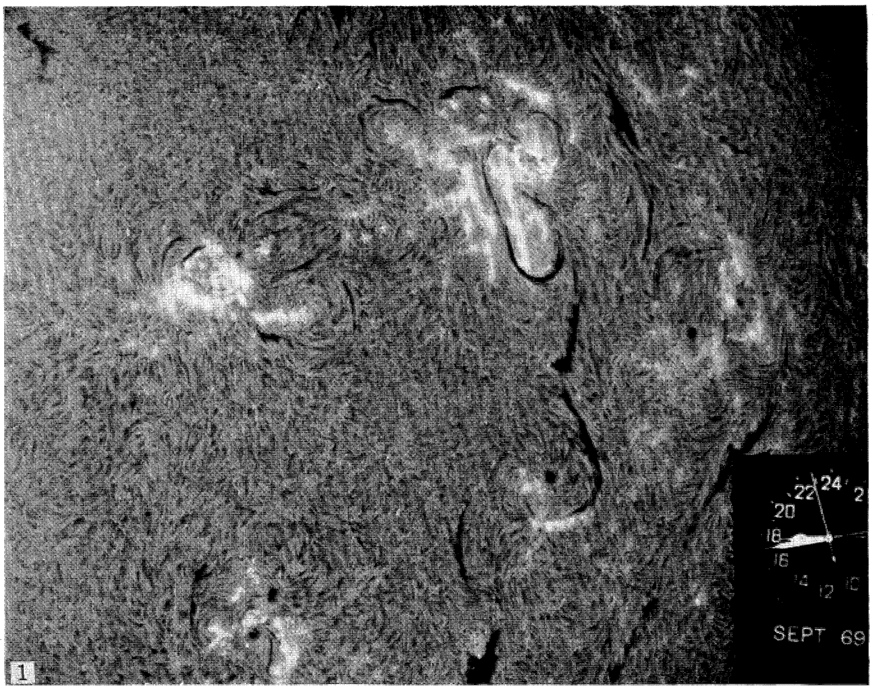
We see that there is a great regularity in the chromospheric structure. Whenever the field is weak, we *invariably* see the quiet network pattern (1). The same is true of the other field levels; they invariably produce the structures indicated. For peculiar reasons, the magnetic fields themselves only appear in the stable forms noted; typically the fields are either vertical or horizontal, with almost nothing between them. The horizontal field regions show no clumping, while the weak and intermediate field regions always do. Apparently vertical fields below 3 mT or so are not stable. It is further interesting that the transition between one polarity and the opposite is marked by arched field structure in intense field regions, but by horizontal fields running parallel to the boundary in extended moderate field regions. In the latter, filaments occur.

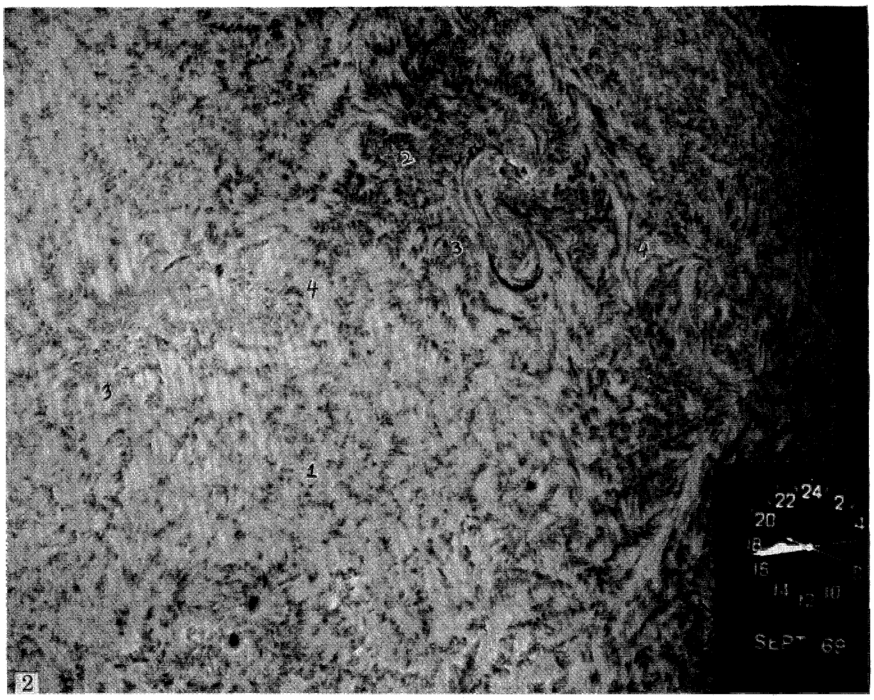
Figures 1 to 3 incidentally show other special types of solar activity of interest. The bright region at top centre is an emergent spot group of the type we have called bright regions with loops (b.r.l). But the polarity is perfectly inverted; the preceding spots are of following polarity for that hemisphere. This situation usually leads to great solar activity, as it did in this case. A similar case, much less spectacular, may be seen in the spot at left centre; the small bright region preceding the spot is included following polarity, and gave rise to small flares.

We see that the chromosphere is indeed a varied region of the Sun. Since most of the past research has not differentiated these regions, there is little known about the height structure. Perhaps some of the contradictions in present observations would be removed if observations pertaining to the different chromospheric regions were sorted out. There is, of course, some evidence that the coronal density and temperature increase with the intensity of the vertical field in the chromosphere. We do not know, however, if the field must indeed be vertical, or if coronal condensation will also occur over regions of strong horizontal field. It is necessary to make radio or extreme u.v. observations with better than 1′ resolution, and have high-quality Hα pictures for comparison so that we can identify the chromospheric regions.

Figure 4 shows a good Hα photo made at Big Bear on 26 October 1969; this photo covers about 180″, and some of the features only dimly seen in figures 1 to 3 are more clear. At lower left is a preceding sunspot (west is left here), followed by plage of the same polarity (1). Directly right (2), is a transverse filament system marking the horizontal field transition to a plage of following polarity. All bright regions in the area marked (3) are vertical following polarity; in the dark surrounding region (4) we see dark fibrils marking the horizontal field; the transition between horizontal and vertical fields is beautifully abrupt. In the centre of the photo, a dark prominence (5) marks the transition to another region of preceding polarity. As we have noted, field transitions between spots and strong fields are marked by arches perpendicular to the boundary as (2), but field changes in weaker fields are marked by horizontal fields *parallel* to the boundary. The plage (6) just right of the prominence is preceding polarity, as are the large spots following it. Two emerging field regions (7) are seen at left centre and top right. Finally, at the upper left we see a portion of fairly quiet chromosphere, with clumps of field (8) here and there.

It is obvious that we have exhausted the potentialities of resolution like that of figures 1 to 3 and need more pictures like figure 4, plate 9 with extreme u.v. and X-ray observations to accompany them. With the high resolution, many things become very clear.





FIGURES 1 and 2

(*Facing p.* 78)

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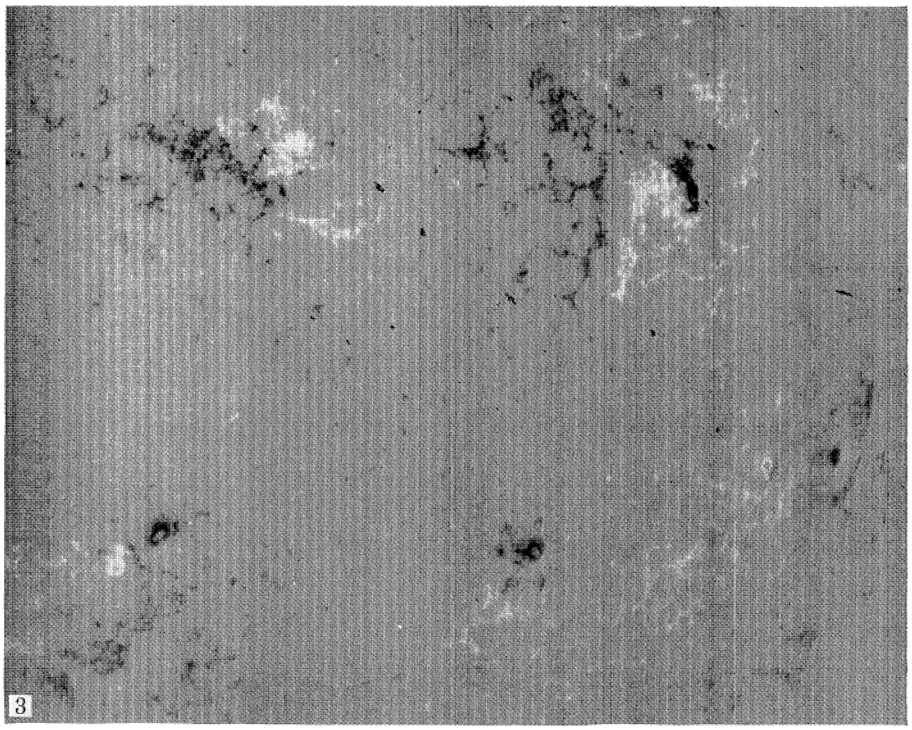

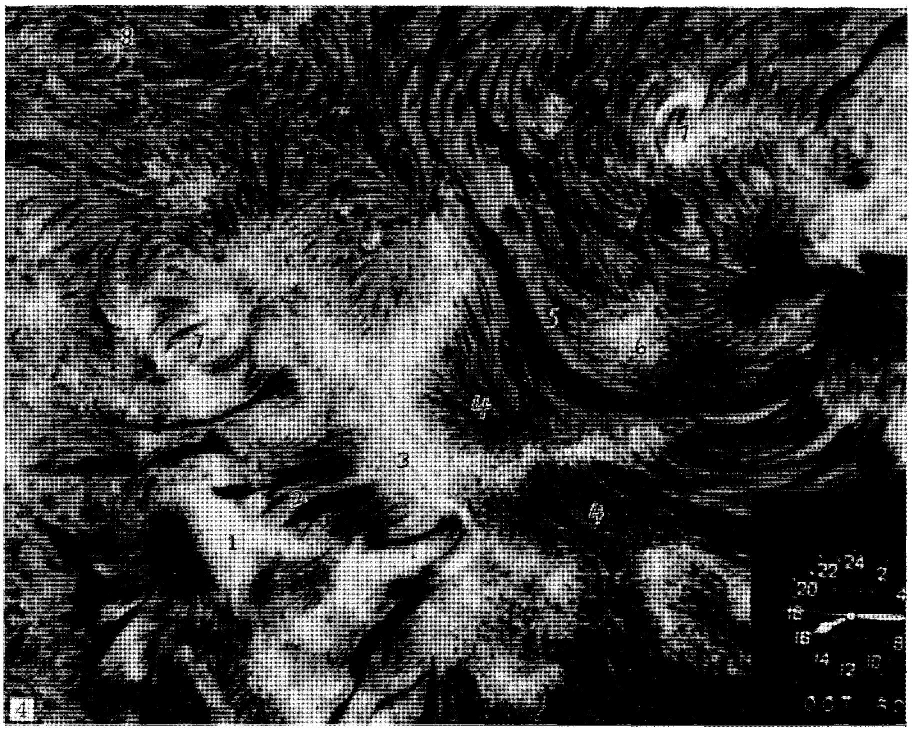

FIGURES 3 and 4

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The present evidence indicates that the vertical fields are a pathway for the flow of energy to the corona; every place that such regions exist—in the quiet chromosphere, enhanced network, plages—there are peaks in the coronal density and temperature. This may be judged, for example, from the A.S. & E. quiet Sun X-ray photos. The transition zone must be quite different in plages from the other chromospheric regions; the normal spicule forest seen near the limb always disappears over plages and is replaced by a homogeneous bright mound. The great input of energy must make for a sharp temperature rise a few thousand kilometres up. The fact that there are no spicules in plage areas, yet the corona is strongly heated, suggests that spicules do not play an important role in coronal heating.

Yet the spicules do play an important role in our concept of the chromosphere because their vertical extent makes them dominate the chromosphere as seen at the limb. Thus, most of the flash spectrum that we have studied over the years is the spectrum of spicules, and curiosities like the observation of He lines at low heights are merely due to spicules in front of the limb. It is conceivable that spicules play a role in the heating of the quiet corona, but there is no evidence one way or another. The spicule seems to be an accidental hydrodynamic phenomenon of the chromosphere at vertical fields between 5 and 10 mT, and its greatest importance is as a tracer of such fields.

The chromospheric regions here classified have a lifetime of weeks. Individual cells of the chromospheric network have lifetimes of a day or so, while individual spicules live 10 to 20 min. It is astonishing how stable the chromospheric structures are, and how limited and repeatable are the forms that occur. Clearly there are only certain patterns in which the force-free chromospheric fields will withstand the constant oscillation and pushing and pulling by the velocity field. The field appears more stable if it is bunched and vertical, or spread out and horizontal. It would be valuable if someone could produce a theoretical stability analysis of these forms.

We know much less about the structure of the corona, because we cannot observe it on the disk with any resolution to speak of. What we do know about the large-scale structure has been covered in great detail by Newkirk (1967), Bohlin (1970) and Newkirk & Altschuler (1970). These works are principally concerned with the large-scale coronal streamers observed at eclipse. The large streamers seem to be connected with large-scale magnetic features, in particular the unipolar regions which trail active regions. The intensity (i.e. density) in the streamers depends on the level of solar activity in the dominating active region. Just as the chromospheric structure corresponds to the magnetic fields, the coronal structures, too, follow the magnetic fields. Attempts have been made to predict the structure of the corona at total eclipse on the basis of disk magnetograms, but the success of these predictions is disagreed upon.

There is much less information on the small-scale structure of the inner corona. Filtergrams have been obtained for some years in the 530.3 nm line, but I do not know of any work tying them to the active regions beneath. There are great possibilities in the extreme u.v. observations when the resolution becomes high enough. Those observations which do show the corona on the disk such as the A.S. & E. X-ray photos, and the Harvard and N.R.L. extreme u.v. pictures, show predominantly active regions and the resolution is not quite good enough. The same is true of radio observations, with the possible exception of the Buhl & Tlamicha (1970) work. So all the data on the inner corona pertains to the corona in the active Sun. The substance of our knowledge of coronal structure in active regions is that the corona is strongly enhanced there, the temperature and density increasing with the degree of activity in the region. There are many beautiful observations of arches and looped structures in the corona over active regions, but it is conceivable that some of these are due to the continuum connected with loop prominences and the like. We should soon have extreme u.v. observations which resolve these questions, and it will be particularly instructive to tie these in with the magnetic structure of the underlying active regions.

I have examined carefully the A.S. & E. soft X-ray photo of the quiet Sun taken on 8 April 1969, as well as the high resolution scans of the Sun at 3 mm obtained by Buhl & Tlamicha (1970). The signal: noise ratio of these observations falls just short of showing the situation in the corona and high chromosphere above different features of the chromosphere, except for the expected enhancement above plages and small faculae. The X-ray pictures do not quite reveal the quiet chromospheric network, although there are a few features that might be identified with the enhanced network. The radio maps show some suggestive minima around prominences and horizontal field regions, but other horizontal field regions show no such structure.

There are some important indirect data on the quiet corona. Although radio telescopes cannot resolve the fine structure of the quiet corona, the total emission is easily measured. It appears (Simon & Zirin 1969) that there is no evidence of limb brightening at any radio frequency emitted by the corona or chromosphere. What has hitherto been noted as limb brightening has been the contribution of active regions. Since the temperature is known to increase upward, the only explanation is that the quiet corona has a very coarse structure, so that the radio telescope only senses the same amount of material at all position angles. This strong inhomogeneity is detected in radar observations as well as in analysing the problem of the escape of metre wave radiation from the corona.

Another important indirect datum is the comparison by Sheeley (1964) of the number of polar faculae and the sun-spot number. The faculae are most numerous near sunspot minimum; one might therefore expect them to be connected with the fine polar plumes, also seen most prominently near minimum. If this connexion is reasonable, one would then understand that the fine structure of the low chromosphere is mapped out in the corona without degradation, and that the corona inside the supergranulation cells is weak or absent.

Thus, we see that the chromosphere and corona have topographies no less well-marked than the hills and valleys of our homelands, and if we learn to recognize and understand them, we will feel as much at home with them.

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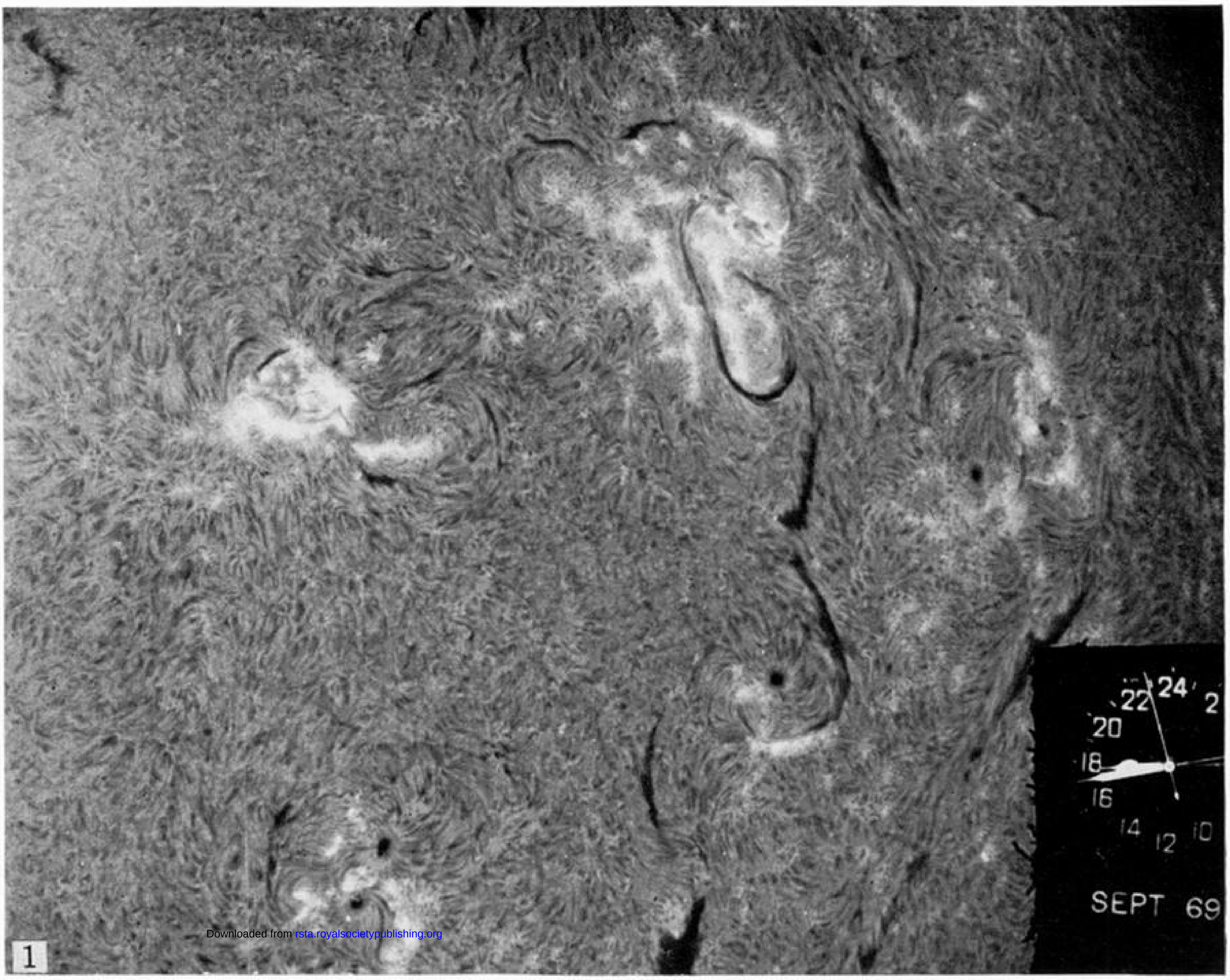

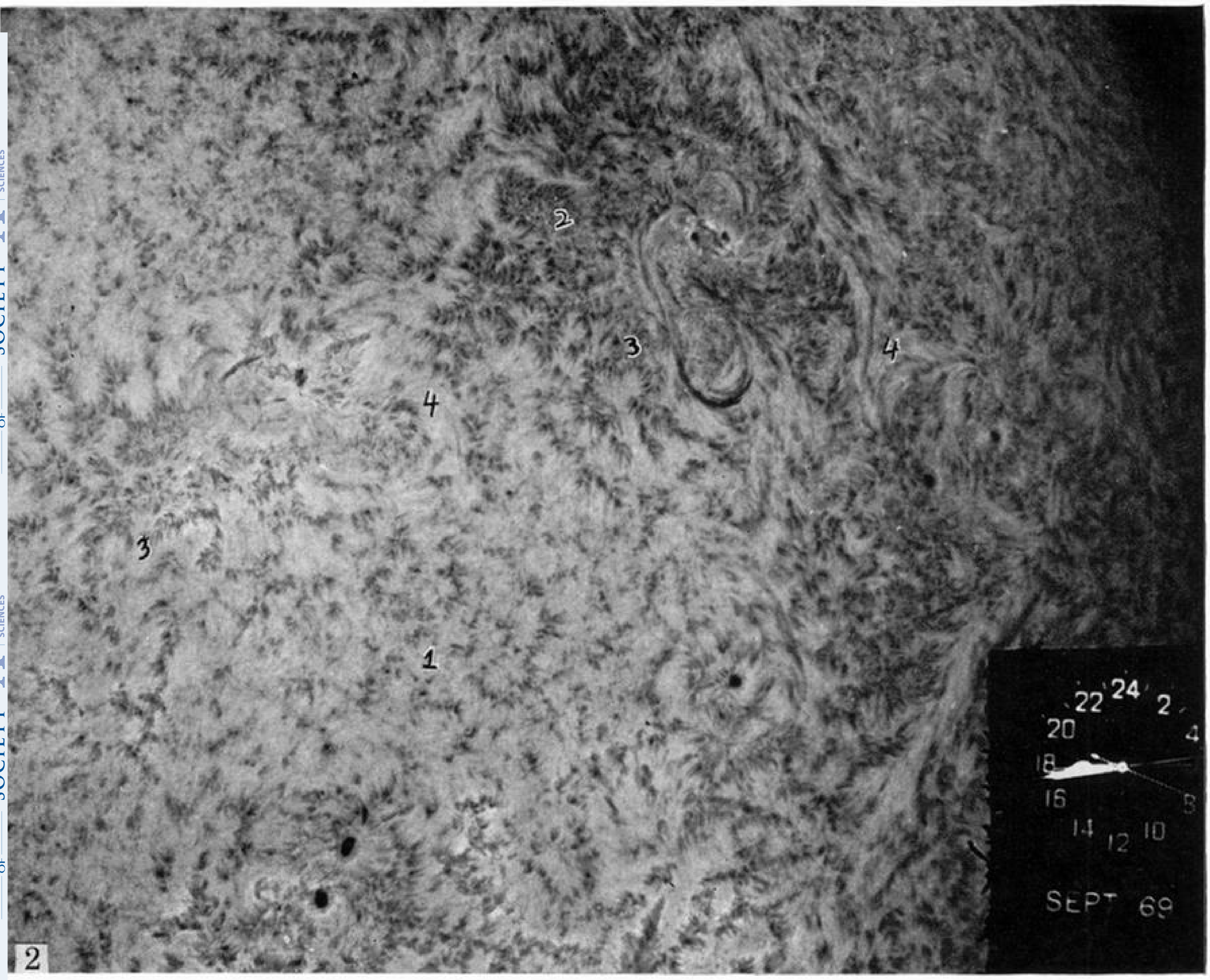

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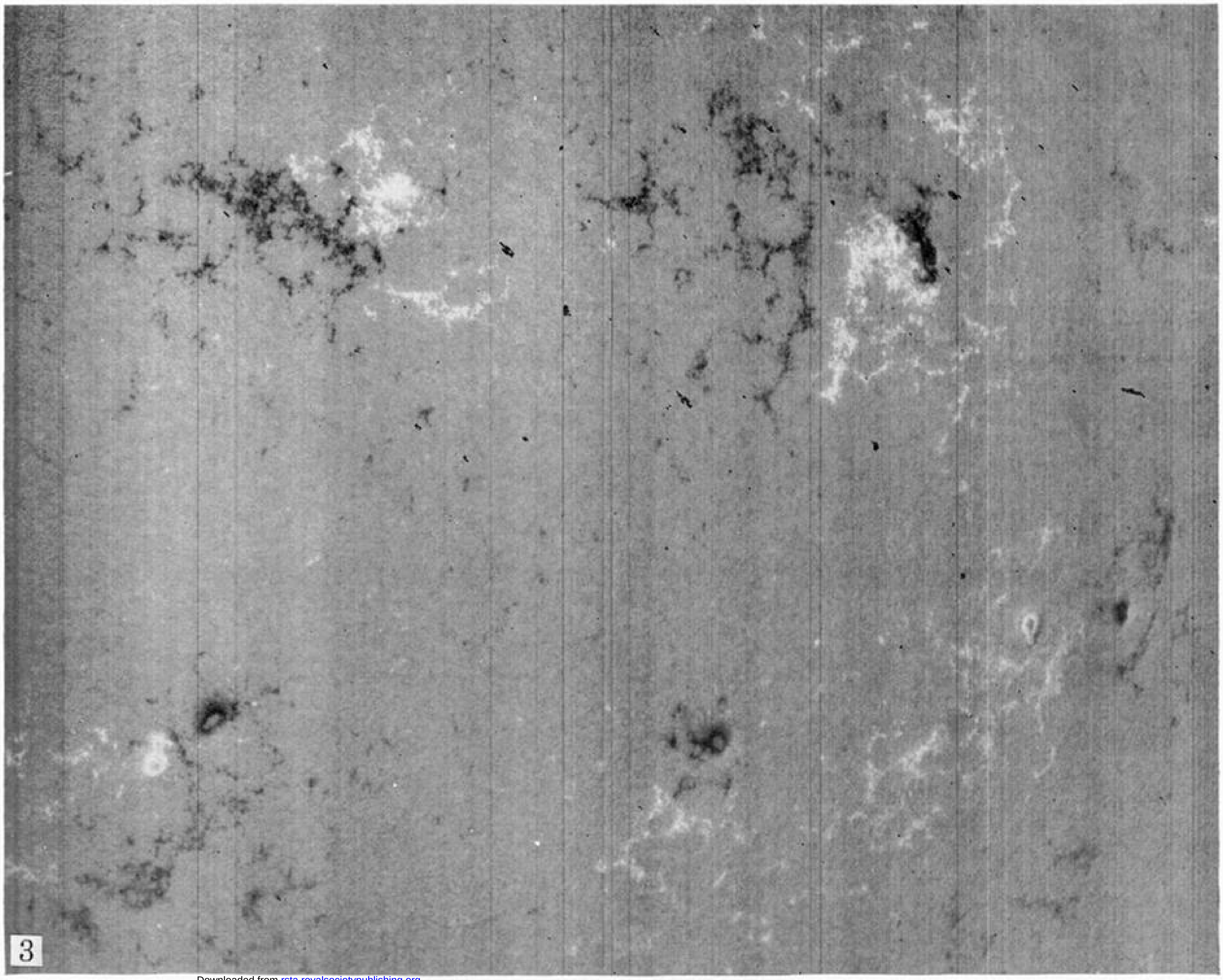
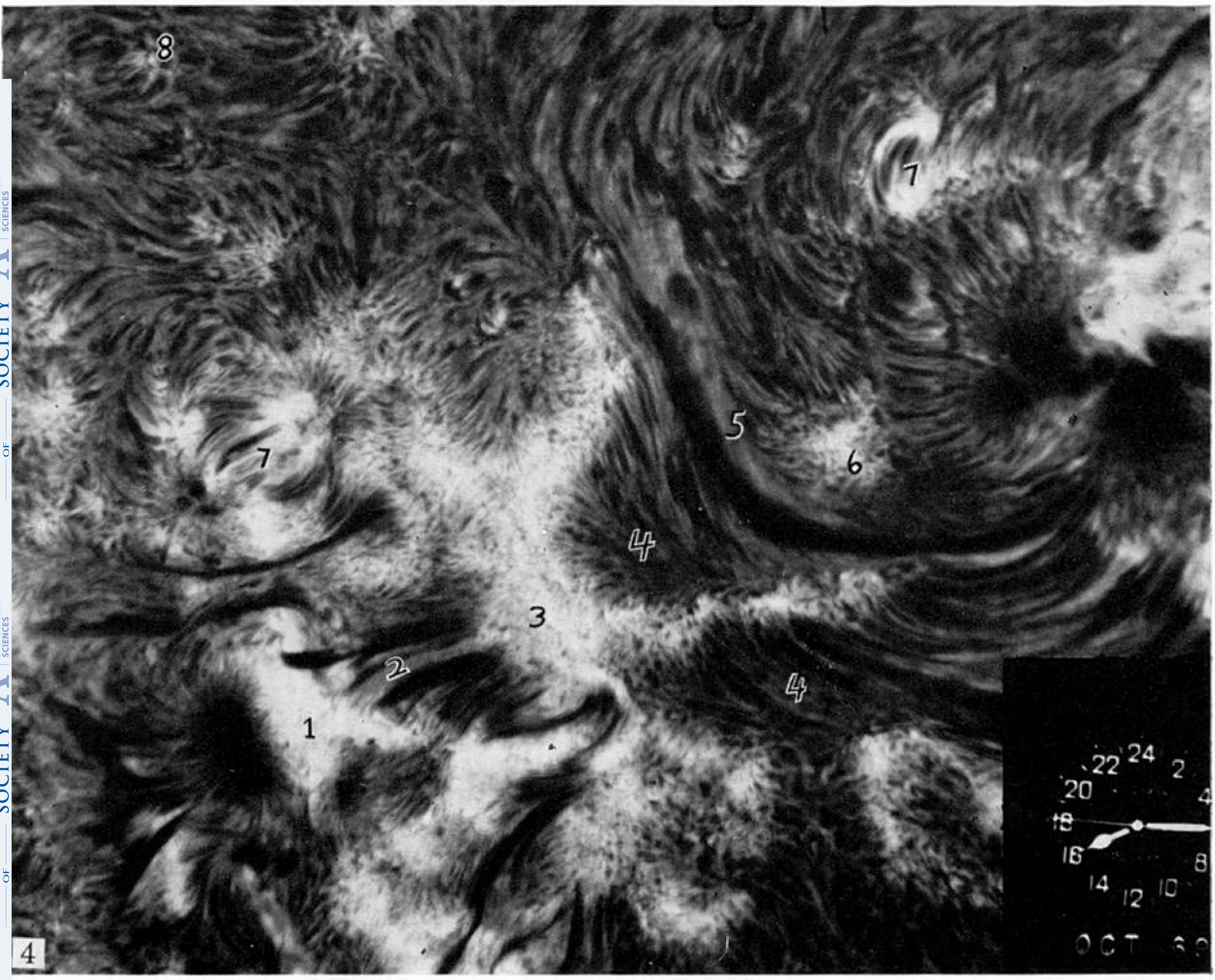
Figures 1 and 2





FIGURES 3 and 4