PHENOMENA ACCOMPANYING THE BIRTH OF SUNSPOT PORES

By R. E. LOUGHHEAD* and R. J. BRAY*

[*Manuscript received April* 4, 1961]

Summary

Disturbances in the photospheric granulation accompanying the birth and development of some sunspot pores are illustrated (Plate 1) and described. The disturbances last for about 3 hr and take the form of a number of dark lanes lying between two groups of pores whose location with respect to the rest of the spot group suggests that they are of opposite magnetic polarities.

The detailed process of the birth and development of one of the pores is also illustrated (Plate 2). The pore starts as a dark area no larger than a single photospheric granule; subsequently it becomes darker and larger and coalesces with a pre-existing pore. Significant changes in shape and area take place within periods of half an hour.

The phenomena described are interpreted as evidence of the existence of a rising loop of magnetic flux. The nature of the interaction between the rising field and the solar material is discussed with reference both to the present observations and to observations of the umbral granulation.

I. INTRODUCTION

It is now generally accepted that the many diverse and often spectacular phenomena associated with active regions on the Sun owe their origin to the presence of magnetic fields which have risen from the solar interior and pushed their way through the photospheric layers into the chromosphere and corona above. Little is known about the three-dimensional configuration of the field in an active region; however, it can be pictured in an idealized way as a system of gigantic loops of magnetic flux whose ends are "anchored" to sunspot umbrae of opposite polarities (see, for example, Babcock and Babcock 1958).

The actual penetration of the visible layers by the loop of magnetic flux joining two sunspots of opposite polarities presumably takes place during the birth and initial development of the spots. At the ends of the loop, where the field is large and predominantly vertical, the photosphere is radically altered by the field—as is shown by the appearance of spots at these points. Between the spots, on the other hand, the field in the rising flux loop must be predominantly horizontal. Does the field in this region produce any effect on the photospheric granulation?

The observations described below show that disturbances in the neighbouring granulation do indeed accompany the birth and development of new sunspot pores. The disturbances take the form of dark lanes lying between two groups of pores whose location with respect to the rest of the spot group indicates that they are of opposite magnetic polarities (Section II). The detailed process of

* Division of Physics, C.S.I.R.O., University Grounds, Chippendale, N.S.W.

the birth and development of one of the pores is described in Section III. Finally, in Section IV the nature of the interaction between the rising field and the solar material is discussed with reference both to the present observations and to observations of the granulation in sunspot umbrae.

II. Disturbances in the Granulation between Growing Pores

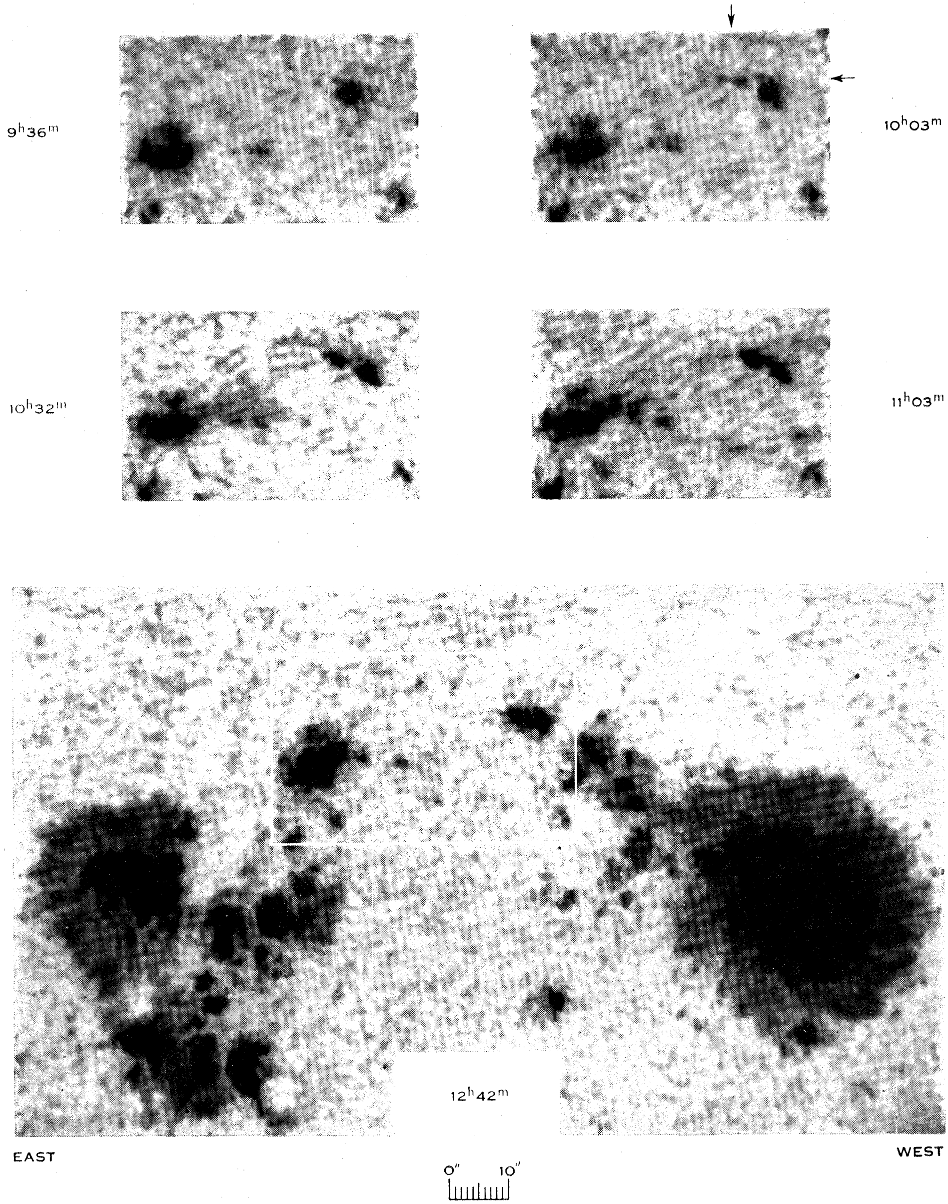
In general the presence of a sunspot has no marked effect on the appearance of the surrounding photospheric granulation, although sometimes a slight increase in brightness is observed, particularly at shorter wavelengths (Waldmeier 1939; Das and Ramanathan 1953). Rösch (1959) and Miller (1960*b*) investigated the packing of the granules near and away from sunspots, but found no significant difference in the number per unit area. (Macris (1953) found a small difference in their mean diameters, but his result does not appear to be statistically significant.) In films of some 50 different spot groups obtained by the authors with the Sydney photoheliograph, a difference in the appearance of the granulation around a spot has been noticed on only one occasion: in this case the larger ($\sim 2''$ of arc) granules of the normal pattern were noticeably absent around portion of the periphery of the spot.

These results have been derived mainly from observations of the granulation in the neighbourhood of quiescent spots. In this paper, on the other hand, observations are described of the granulation in the neighbourhood of new and developing sunspot pores. In this case a marked disturbance in the granulation is found to occur.

The region of interest is indicated by the white rectangle in the lowest photograph of Plate 1; it lies between the leader and follower components of a typical bipolar sunspot group, which was photographed with the Sydney 5-in. photoheliograph (cf. Loughhead and Burgess 1958) for a period of 6 hr on February 4, 1958. During the period covered by the sequence of photographs shown in Plate 1, a pore is born on the upper right-hand side of the region and subsequently coalesces with a pre-existing pore; this event is described in detail in Section III. At the same time, similar events occur near the left-hand side of the region. The location of the region strongly suggests that the left- and right-hand pores are areas of opposite magnetic polarities (magnetic data are not available).

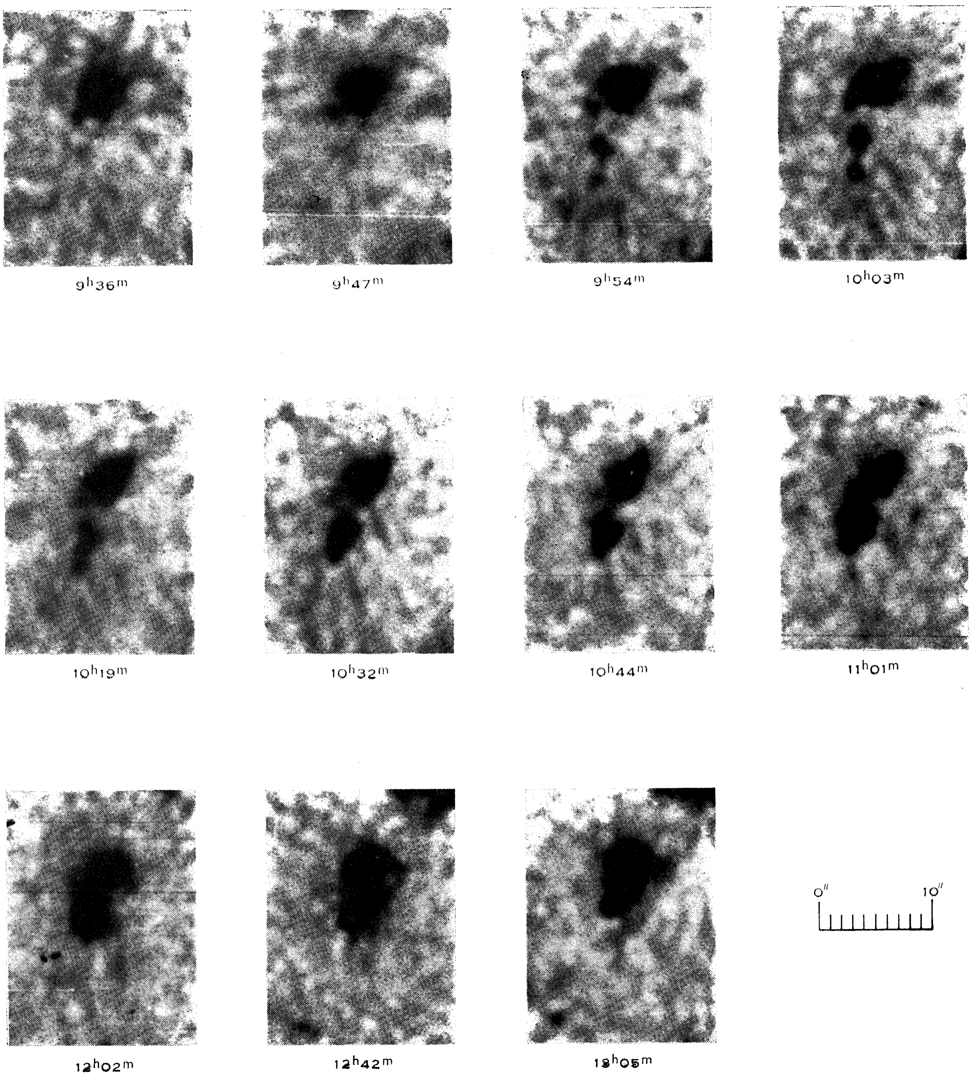
At $9^{\mathrm{h}}\,36^{\mathrm{m}}$ E.A.S.T. (Plate 1) the granulation between the two groups of pores appears to be more or less normal. However, a number of dark lanes are visible at $10^{\mathrm{h}}\,03^{\mathrm{m}}$, when the birth of the new pore on the right-hand side has already begun, at the point indicated by the arrows. The lanes appear to be somewhat darker than the ordinary intergranular material. Between the lanes individual photospheric granules can still be distinguished, but they now lie along lines parallel to the lanes. The direction of the lanes is roughly parallel to a line joining the two groups of pores. They are even more evident on the third photograph ($10^{\mathrm{h}}\,32^{\mathrm{m}}$); on this photograph they exhibit a decided curvature. They are most prominent at $11^{\mathrm{h}}\,03^{\mathrm{m}}$, by which time the two pores on the right-hand side have coalesced. By $12^{\mathrm{h}}\,42^{\mathrm{m}}$ the period of activity of the pores has come to an end; at the same time the disturbance in the granulation has died

PHENOMENA ACCOMPANYING THE BIRTH OF SUNSPOT PORES



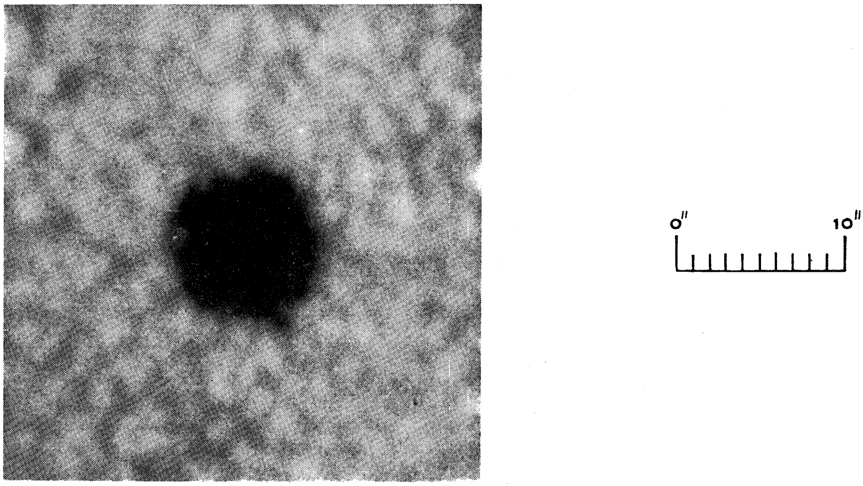
Dark lanes in the photospheric granulation between two groups of developing sunspot pores photographed on February 4, 1958. The lanes are prominent between $10^{h}\ 03^{m}$ and $11^{h}\ 03^{m}$ but have disappeared by $12^{h}\ 42^{m}$. Note the curvature of the lanes at $10^{h}\ 32^{m}$. The location of the two groups of pores with respect to the rest of the spot group (cf. $12^{h}\ 42^{m}$) indicates that they have opposite magnetic polarities. The arrows at $10^{h}\ 03^{m}$ point to a new pore which grows during the course of the sequence, ultimately coalescing with a pre-existing pore just to the right of it; this event is shown in more detail in Plate 2.

PHENOMENA ACCOMPANYING THE BIRTH OF SUNSPOT PORES

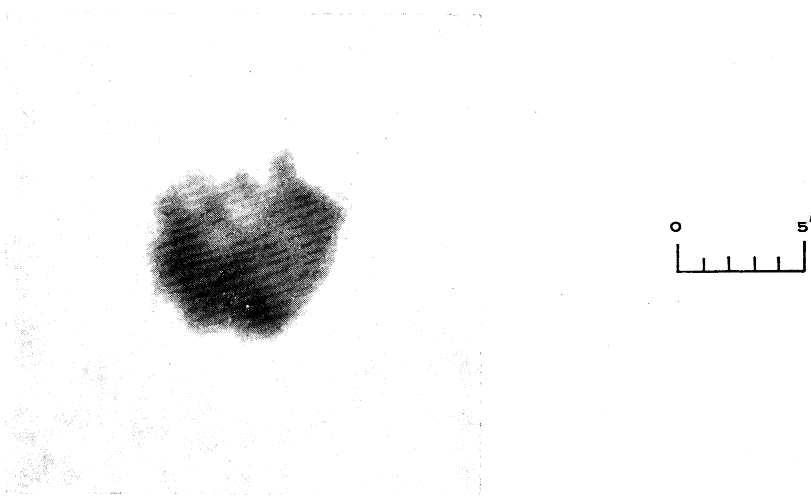


Birth and development of a sunspot pore photographed on February 4, 1958. The new pore starts as a small dark area, only about 1″ of arc in diameter, in the photosphere a few seconds below a pre-existing pore (9^{h} 36^{m}). For a detailed description of its subsequent growth and development, see text. The photographs in Plate 2 are orientated at right angles with respect to those in Plate 1.

PHENOMENA ACCOMPANYING THE BIRTH OF SUNSPOT PORES



(a)



(b)

(*a*) Sunspot pore photographed at $13^{h}\,59^{m}$ on August 27, 1958. Note the sharpness of the boundary and the normal appearance of the photospheric granules just outside.

(*b*) The same pore some 42 min later, shown with enhanced exposure and greater magnification. Although the right-hand side is somewhat smeared by mediocre seeing, several umbral granules are clearly visible. On the original negative one faint umbral granule can be seen in the lower left-hand side, which is darker than the rest; however, it fails to appear in the reproduction. Umbral granulation is a characteristic feature of sunspot pores and the umbrae of fully developed sunspots (see text).

away, the pattern reverting to normal. No further disturbance was observed between $12^h\ 42^m$ and the close of observations at $15^h\ 28^m$. The total time interval between the appearance and disappearance of the dark lanes is about 3 hr.

The possibility that the disturbances illustrated in Plate 1 might be due to poor seeing has been excluded by an examination of many other good-quality photographs taken during the same period. The persistence of the dark lanes from photograph to photograph leaves no doubt that the phenomenon is real.

III. Birth and Development of a Sunspot Pore

The birth and development of a new pore near the right-hand side of the region illustrated in Plate 1 are shown in more detail in Plate 2. (Note: the photographs in Plate 2 are orientated at right angles with respect to those in Plate 1.)

The first sign of the advent of the new pore is the appearance of a small dark region, only about 1″ of arc in diameter, in the photosphere a few seconds below the pre-existing pore. At first ($9^h\ 36^m$) this dark region is not distinguished in any way from normal intergranular material. However, it soon becomes darker and larger and, by $9^h\ 54^m$, a second such region has appeared, about 3″ below the first. At $9^h\ 54^m$ and $10^h\ 03^m$ the two small dark regions are seen to be joined together by a narrow lane of dark material. By $10^h\ 19^m$, the two regions have completely merged to form a typical sunspot pore of irregular shape, some 5″ long and 2″ wide at its narrowest point. The whole process of formation of the new pore from a region of hitherto normal photosphere is completed in a period of some 45 min.

The new pore now enters into the second phase of its development. Initially ($10^h\ 03^m$) it is separated from the upper pre-existing pore by a narrow strip of photospheric granulation. However, the granules in this region gradually disappear until, finally, only a single chain of granules separates the two pores ($10^h\ 32^m$). This chain is soon broken ($10^h\ 44^m$) and the pores merge into a single pore with a narrow waist; the amalgamation of the two pores takes place in about 25 min. Finally ($11^h\ 01^m$–$13^h\ 05^m$), the granules in the neighbourhood of the waist gradually disappear and the composite pore loses its dumbbell appearance.*

These observations show that significant changes in the shape and area of pores during their birth and development take place within periods of half an hour or so. A similar time scale was derived by Secchi (1875) from visual observations of changes during the *dissolution* of a pore. (Secchi recorded no observations of the birth of a pore.) This time scale is short compared with the total lifetime: even the smallest pores persist for at least several hours and, in fact, in most cases a single day's observations are not adequate to determine their lifetimes.

* The dark material visible in the top right-hand corners of the last two photographs of Plate 2 is portion of an elongated region of spot debris trailing the leader spot of the group (cf. Plate 1: $12^h\ 42^m$). During the day the distance between this debris and the pore illustrated in Plate 2 steadily decreased.

IV. Discussion

In our opinion the phenomena described in Sections II and III are to be interpreted as evidence of the existence of a rising loop of magnetic flux. This raises the question of the nature of the interaction between the rising field and the solar material.

Let us first consider the interaction in regions where the field is strong and predominantly vertical, i.e. sunspot pores or the umbrae of fully developed sunspots. Umbral granulation is invariably present in these regions (Bray and Loughhead 1959 ; Loughhead and Bray 1960). The umbral granules (apart from their smaller brightness) resemble the ordinary photospheric granules outside sunspots in appearance, but have substantially longer lifetimes and are more closely packed. If the umbral granules, like the photospheric granules, represent convection currents, then it is evident that even the strong magnetic fields present in the umbrae of large spots fail to suppress the convective motions. However, the interaction between the field and the convection currents is presumably responsible for the difference in properties between the umbral and photospheric granules. The observed sharpness of the boundaries of sunspot pores (cf. Plate 3 (*a*)) shows that the field can affect one granule but leave a neighbouring granule unaltered.

Secondly, in the region between the growing pores the magnetic field in the rising flux loop must be predominantly horizontal. In this case, as shown by the observations described in Section II, the field merely tends to align the granules in a preferred direction without affecting their brightness, although the material between the granules becomes somewhat darker than normal. The alignment lasts only while the magnetic loop is presumably pushing through the photospheric layers—a period of about 3 hr in the case of the present observations.

The difference in properties between the umbral and photospheric granules supplies direct evidence of an interaction between the field and the convection currents. This raises the question of the way in which the convection currents themselves influence the field. For example, do they assist the internal field to penetrate the visible surface layers? The answer to this question must await the development of an adequate theory of convection in the presence of a magnetic field under solar conditions.*

Miller (1960*a*) has published a photograph showing a number of curved dark lanes lying between regions of spot debris whose location with respect to the associated spot group is very similar to that of the pores illustrated in Plate 1. According to magnetic observations made at Mt. Wilson these areas of spot debris were probably of opposite polarities. The resolution of Miller's photograph is insufficient to show the granulation, and other supporting photographs are not available. Nevertheless, the similarity of the dark lanes photographed by Miller to those illustrated in Plate 1 (in particular the photograph at $10^{\rm h}\,32^{\rm m}$)

* The question of explaining theoretically some of the more general properties of sunspots and sunspot groups by means of a rising magnetic flux loop has been considered by Parker (1955). According to Parker, the field of a sunspot group is derived from an internal toroidal field, part of which is raised to the surface by " magnetic buoyancy ".

leaves little doubt that the phenomenon described by Miller is identical to that described in Section II. Miller suggests that the dark lanes follow lines of magnetic force.

Finally, Kiepenheuer (1960) has published good quality photographs of sunspots showing some of the small bright regions typical of the various types of bright structures commonly found in sunspot penumbrae (cf. Bray and Loughhead 1957). Although Kiepenheuer identifies these features with flux tubes of a deep-seated field which have penetrated the visible layers, they appear to be unrelated to the phenomenon described in Section II.

V. Acknowledgments

The authors wish to thank Mr. H. Gillett for processing the film and making the enlargements.

VI. References

Babcock, H. W., and Babcock, H. D. (1958).—"Electromagnetic Phenomena in Cosmical Physics." (Ed. B. Lehnert.) p. 239. (Cambridge Univ. Press.)

Bray, R. J., and Loughhead, R. E. (1957).—*Observatory* **77**: 201.

Bray, R. J., and Loughhead, R. E. (1959).—*Aust. J. Phys.* **12**: 320.

Das, A. K., and Ramanathan, A. S. (1953).—*Z. Astrophys.* **32**: 91.

Kiepenheuer, K. O. (1960).—*Z. Astrophys.* **49**: 73.

Loughhead, R. E., and Bray, R. J. (1960).—*Aust. J. Phys.* **13**: 139.

Loughhead, R. E., and Burgess, V. R. (1958).—*Aust. J. Phys.* **11**: 35.

Macris, C. (1953).—*Ann. Astrophys.* **16**: 19.

Miller, R. A. (1960*a*).—*J. Brit. Astr. Ass.* **70**: 100.

Miller, R. A. (1960*b*).—*J. Brit. Astr. Ass.* **70**: 146.

Parker, E. N. (1955).—*Astrophys. J.* **121**: 491.

Rösch, J. (1959).—*Ann. Astrophys.* **22**: 584.

Secchi, A. (1875).—"Le Soleil." 2nd Ed. Vol. I, p. 56. (Gauthier-Villars: Paris.)

Waldmeier, M. (1939).—*Astr. Mitt., Zürich* **1939** (138): 439.