CONCERNING THE FORMATION OF GIANT REGULAR STRUCTURES IN THE SOLAR ATMOSPHERE

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Abstract. Using the Mt. Wilson magnetic synoptic charts from the recent solar activity cycles the dynamics of the formation of giant regular structures formed in the plus (leading) polarity of older more extended magnetic fields are studied. Although their diameters are about one order greater than those of supergranules, the processes of their development go analogously to those of supergranulation and granulation.

The close relation of the minus (following) polarity distribution to the new formed active regions is demonstrated and the possible different mode of distribution and different role of both opposite polarities on activity processes is discussed.

1. Introduction

Some time ago (Bumba *et al.*, 1964; Bumba, 1967a, b) we called attention to the existence of very large regular structures in the solar photosphere with mean diameters of the order of 400 000 km which are best seen in the large-scale distribution of background magnetic fields. These structures seem to represent a third type of convective element in the solar atmosphere – the giant cell. Together with the granules and supergranules the giant cells belong evidently to a hierarchical scheme of solar plasma and magnetic field convective motions in which the individual cell of some dimension transforms slowly (from the point of view of its own time-scale) into another cell of practically the same dimension through the gradual redistribution of elements of smaller dimension. (For example supergranules change shape through changes in position and the development of new bright grains of facular granular structure (Bumba, 1967a).) The theoretical background for the existence of such a hierarchy of three sizes of convective cells on the Sun was discussed recently, by Simon and Weiss (1968a, 1968b).

In 1965 we discussed the behavior of so-called 'Complexes of Activity' – the concentration of activity in separate impulses over a certain heliographic longitude range (Bumba and Howard, 1965). In complexes the activity behaves as in other solar phenomena – it rises rapidly to its maximum which is followed by a slow decline of activity. The area occupied by fields expands in both latitude and longitude. The expansion in the North–South direction is limited by a certain value of the heliographic latitude. The shift of the magnetic field boundary in longitude has different velocities for the leading and following part but each value of the velocity is practically the same for all the complexes studied.

More recently the existence of long-lived regularities in the longitudinal large-scale distribution of solar background magnetic fields, elongated parallel to the Bartels'

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heliographic longitudes, was demonstrated (Bumba *et al.*, 1969; Bumba and Howard, 1969). The characteristic behavior of the most pronounced regularities coincides very well with that of so-called 'active longitudes' – preferred intervals of heliographic longitude in which continuously developing new active regions may be observed for many rotations.

Because only in such a region of the solar surface where the activity and therefore the supply of new magnetic flux appears over at least several rotations (this means only in active longitudes in which new complexes of activity develop) may the above-mentioned system of three sizes of dynamical elements be seen. The study of the process of development of such a situation promises to bring some new results. Of course, during the time of higher activity we see definite regularities in the longitudinal distribution of magnetic field over the whole disk (Bumba *et al.*, 1969) in very complicated interrelations. But during the period of moderate activity, time-intervals may be found when only one or two 'active longitudes' are in operation and therefore they are so widely separated that the redistribution of magnetic fields in the convective elements may be followed uninfluenced by other activity in the neighborhood. At the same time, of course, the level of the background magnetic field intensity must reach just the value necessary for best visibility of the giant regular structure. These are the best conditions for a systematic investigation of the process and in our observational material they seem to be present during the second half of the year 1963 on the magnetic synoptic charts of our Atlas (Howard *et al.*, 1967).

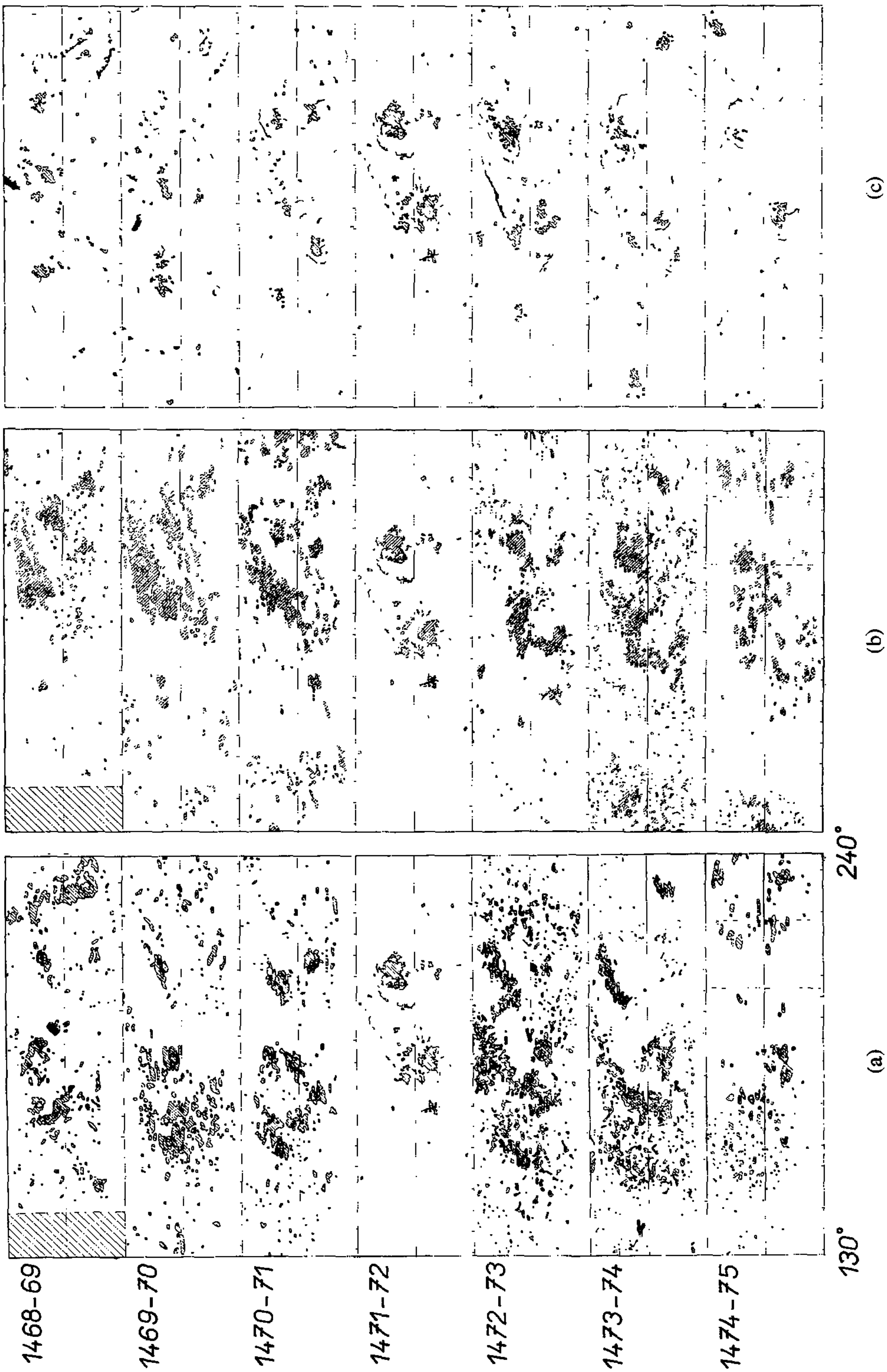
2. Method of Investigation

As several times before the magnetic synoptic charts drawn from the Mt. Wilson daily magnetic maps (Howard *et al.*, 1967) were used as basic observational material for the study. Because there were some indications about the different behavior of the leading and following polarities, the synoptic maps or their parts were copied separately for each from both polarities. To check the stage of activity in the time-intervals studied we used synoptic charts constructed from the Daily Maps of the Sun published by the Fraunhofer Institute.

As was already said, the most simple situation seems to occur during the second half of the year 1963. (It is a great pity that for the first half of that year no observations are available.) Eight charts demonstrating subsequent rotations (Nos. 1468–1475) were studied. To know how the dynamic development of giant regular structures found during the relatively simple conditions is modified in a more complicated situation through the interference with nearby activity, the charts from the years of higher level of solar activity (mostly the year 1960) and the charts from a time period close to the minimum of activity (1964–65) were investigated again for both polarities separately.

3. Dynamics of Development of Giant Structures in 1963

Before we start to study the chosen intervals of our synoptic charts of photospheric


1468-69
1469-70
1470-71
1471-72
1472-73
1473-74
1474-75
130°
240°
(a)
(b)
(c)

magnetic fields ($L = 130°–240°$) in sequential rotations, as they are presented in Figure 1, we must emphasize that the center of gravity of the solar activity during that time lay in the Northern hemisphere. This influences the patterns of the background fields so much that they are highly asymmetric about the equator. Consequently the rules we may find from the systematic repetition of regularities in subsequent maps concern mostly the plus polarity as the leading and minus polarity as the following one. Although toward the end of the studied time interval the minus polarity may be seen in the role of the leading one in the Southern hemisphere.

The plus polarity which was usually concentrated closer to the equator during the declining part of the last solar cycle of activity forms on Figures 1 relatively well observable regular structures connected with the main 'Bartels' active longitude' (Bumba and Howard, 1969). The shape of a single regular structure resembles a rhombus with the longer side parallel to the equator. The length of this side is about 30°–35°. This value is a little greater than that of the side perpendicular to the equator which makes an angle of about 25°–30°. The individual structures compose together a regular network best visible during rotation No. 1472/3. As for the life-time of the individual giant structure, it is very difficult to estimate its precise value because of the lack of several magnetic charts in the first half of the year 1963; but something like five rotations may be estimated. It requires about two of three rotations to be formed and about three or four rotations to be lost or transformed into another structure in the near neighborhood.

The visibility of the network of these giant cells of plus polarity seems to be related to the age of the magnetic fields. If we compare the longitudinal distribution of both polarities with the longitudinal distribution of actual activity (Figure 1) we may see at once the shift between the centers of gravity of the longitudinal distribution of both polarities which amounts to about 50° and also the close connection of the following polarity with the position of active regions. Therefore we may conclude that the regular cells in the leading polarity fields developed only when the fields became sufficiently old and extended in heliographic longitude and strong enough to form the structures. For example, the formation of the September active region in $L \approx 310°$ influenced the visibility of the giant network in subsequent rotations and the greater activity in the Southern hemisphere during rotation No. 1471/2 led to the formation of weak giant structure in the minus polarity (again the leading one) South of the equator in the three last rotations investigated.

The process of formation of giant regular structures in the background plus (leading) fields seems to go analogously to that of the formation of supergranules or granules, which means through continuous changes in the position of smaller elements. In this case the elements are supergranules belonging to the background fields and the old

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Fig. 1. Portions of magnetic and activity synoptic charts for the most interesting intervals, demonstrating the development of giant regular structures in the leading (plus) polarity regions (a), different behavior of the minus (following) polarity fields (b) and their correlation with activity (c) taken from the Fraunhofer Institute maps. In rotation No. 1471/72 the unavailable measurements of magnetic fields were replaced by activity maps.

active regions concentrated in the edges of the rhombus forming the giant structure. We believe it is very interesting that the individual giant cell once formed seems to keep constant its heliographic position in the Carrington system of coordinates (not only the longitude of its center but also the position of the overall periphery with the concentrated field). This constant position of giant cells in Carrington longitude takes part through the whole time-interval investigated. Nevertheless the longitudinal boundary of the photospheric magnetic fields is shifted throughout the same time-interval, both to the West and to the East with a constant velocity which means that these shifts form in a Carrington system inclined lines with different values of inclination for the leading and following parts. The shift to the West may be represented by a rotational velocity close to 27.0 days and the shift eastwards by a velocity of about 28–29 days (Bumba and Howard, 1969). This fact may be seen in Figure 1 in the plus polarity fields where the development of giant cells proceeds in both directions, and on the minus polarity fields where the features themselves are shifted in both directions. In the case of the minus polarity the shift eastwards seems to be strongly influenced by differential rotation, although for the plus polarity fields the influence of differential rotation is practically not observable. The values obtained for the westward and eastward shift coincide with those found by the expansion of the West and East boundaries of the complexes of activity (Bumba and Howard, 1965a; Sýkora, 1969).

4. Correlation of Solar Activity with the Regions of Minus (Following) Polarity in 1963 in the Interval Studied

The different behavior of the plus (leading) and minus (following) polarities during the first stages of development of an active region has already been demonstrated (Bumba and Howard, 1965b). The prevailing activity of the minus (following) polarity during these processes seems to have a special meaning, although we do not yet understand its physical reason. In the previous paragraph not only has a phase difference in heliographic longitude of about 50° between the center of gravity of the plus and minus polarities been shown, but again the close relation of the nonrandom distribution of the minus (following) polarity with that of new formed active regions was demonstrated (Figure 1). At the same time the westward shift of the west boundary of minus polarity regions is of a different character than that of the plus polarity: it is more continuous in comparison with the step-wise shift of the characteristic formation of features of the plus polarity. The eastward shift better seen on minus polarity fields shown in Figure 1 two distinct branches: one starting in rotation number 1468/69 and the second one in rotation number 1472/73. The influence of the differential rotation which is much less observable on the plus polarity structures and the very small influence of convectional motions on large regular structures of the minus polarity seem to be very important for the understanding of the role of both polarities in the large-scale field and activity distribution. It looks as if the plus polarity fields have been redistributed by the motions forming large regular features or as if the plus polarity has been more involved in this process interfering with deeper layers of the solar atmosphere. On the other side the fast changes of the minus polarity, especially in higher latitudes caused primarily by the differential rotation, and the pushing out of this polarity from the equatorial belts speak in favor of the notion that the fields of this polarity are more shallow in the solar atmosphere, at least around the equator. At the same time the continuous westward shift (in Carrington's coordinate system) of the west boundary of the region of formation of this polarity (the following (minus) polarity is usually the first one which starts to develop or increase in the case of the appearance of an active center (Bumba and Howard, 1965b) (seems to interconnect this process with the source of activity rotating with a practically constant rotational velocity in about 27.0 days (Bumba and Howard, 1969).

5. The Giant Structures during a Period of Higher Activity

During the time intervals of high solar activity the background magnetic field forms one body with regular or semiregular patterns. The old and young fields are mixed up and the mutual influence of leading polarities from both hemispheres is very large, therefore it is difficult to follow the shapes of the giant regular structures. The pattern is too rich and confused.

But if we accept the giant regular structures we found during the period of 1963 as physically meaningful features then we may be able to see the same structures in the confused situation of these complicated background field patterns (Figure 2). However, it is much more difficult, and as yet we do not have any objective method to check their reality. The only help we have is the analogous morphology, development and behavior of these cells with those seen much better during 1963. Again the leading polarity seems to be more suitable for the formation of giant structures. The structures have the same elliptical or rhombus form with the same dimensions (length 25°–35°, width $\sim$25°), and same lifetimes. They tend to be clustered – usually three or five of them form a large body extended for about 60° in heliographic longitude. These long-lived large bodies which are as a rule parts of Bartels' active longitude streams (Bumba and Howard, 1969) and the formation of which is closely related to the complexes of activity (Bumba and Howard, 1965a) display often a continuous transition of individual cells into other cells keeping constant the positions of their centers in the Carrington system of heliographic longitudes. But they are influenced at the same time by the westward and eastward shifts of background magnetic field structures due to different types of active longitudes (Bumba and Letfus, 1970).

As for the following polarity, it is again connected with the longitudinal zones of greater and newer activity. It has less pronounced regularities and it seems to be less concentrated especially in the equatorial regions.

6. The Situation during Weak Activity

For the study of regularities in magnetic field distribution during a period of lower activity, we used the maps from 1966. The Bartels' main active longitude is already clearly visible. It is again better demonstrated by the following fields, although they changed their polarity with the new cycle from minus to plus. And these following fields are related to the stream of stronger activity. The leading field as well as the following one is not yet strong enough to form larger patterns. This means that we

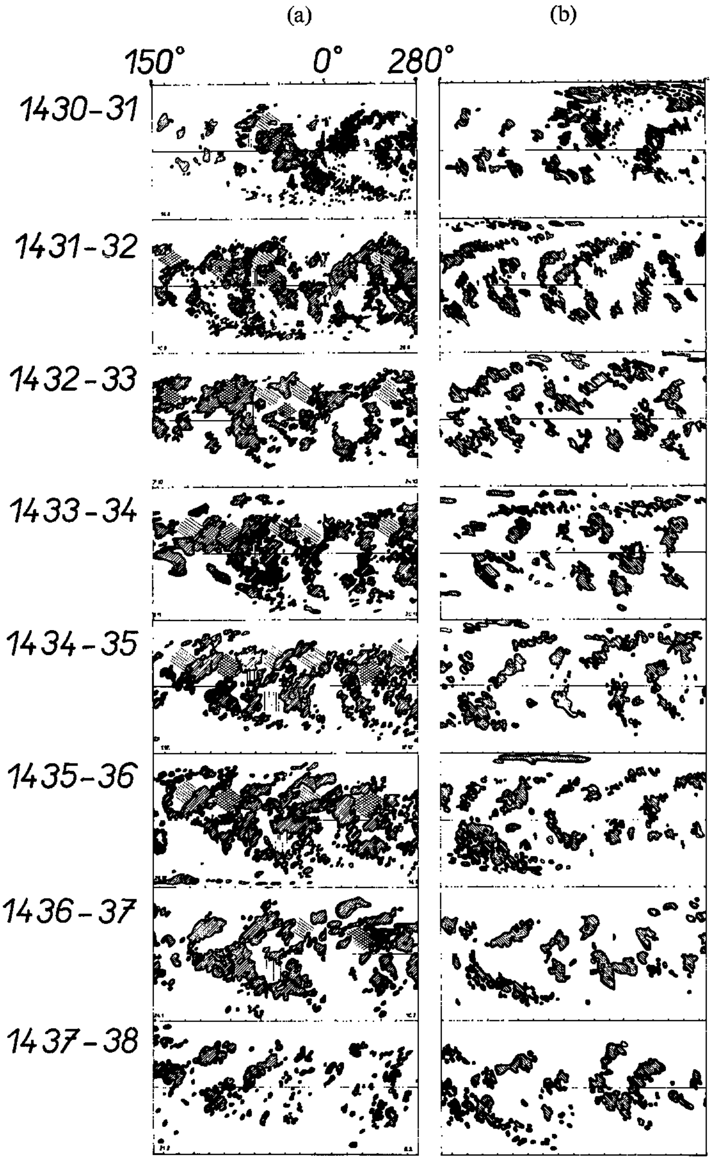

Fig. 2. Portions of magnetic synoptic charts for the period of higher activity showing again the development of opposite polarity regions separately – (a) plus (leading in the northern hemisphere) polarity; (b) minus (following in the northern hemisphere) polarity. – The giant regular structures in process of formation are emphasized by hatching.

cannot see the regularity of leading polarity distribution in a formation of large cells, but there are still clear indications of such structures in the regularly spaced islands of leading fields in eventual corners or crossings of cells which would be formed if there were a greater supply of magnetic fields. The distances of these islands are the same as the diameter of giant structures.

7. Discussion – Consequences for the Large-Scale Distribution of Magnetic Fields

The observational facts demonstrated above may be summarized in the following manner. It seems that there are several important factors influencing the morphology of magnetic field and activity distribution in the solar atmosphere:

(a) Existence of a hierarchical system of convective motions (granulation, supergranulation and giant cells), so to say the basic influence of a 'quiet Sun'.

(b) Existence of 'active longitudes' with different values of shifts in heliographic longitude per rotation in a given system of coordinates and with variable activity (development of complexes of activity of different importance) which temporarily changes as do all solar processes having a fast increase and a much slower decrease – a sort of 'modulation' of quiet Sun energetic release.

(c) Dependence of activity on heliographic latitude, not only Spörer's law but the probable existence of a more general law influencing the whole range of heliographic latitudes (Bumba and Růžičková-Topolová 1969).

(d) Possibly a different role and maybe different depth of magnetic fields with opposite polarities during the activity development, their probably different interference with old fields and motions during an active region formation.

In this phase of our studies it seems to be unreal to seek some theoretical interpretation of observed facts because much more information may be obtained from additional detailed investigation of available data which is already being undertaken. But the need for a new conception of solar activity appears to be obvious from the above arguments.

8. Conclusions

The main results may be formulated as follows:

(1) Only in a region of the solar surface where the activity and therefore the supply of new magnetic flux appears over at least several rotations, this means only in active longitudes in which new complexes of activity develop may the giant regular structures be seen.

(2) The giant regular structures are much better seen in the plus (leading) polarity fields which are concentrated in lower heliographic latitude in the form of a rhombus with the longer side parallel to the equator. The individual structures compose together a regular network which seems to develop only when the field becomes sufficiently old and extended but is still fairly strong. The process of formation goes analogous to that of supergranulation and granulation development. The evidence of the redistribution of plus (leading) polarity fields by the large-scale convectional motions

seems to show the involvement of these fields in processes affecting deeper layers in the Sun.

(3) The correlation of the regularly distributed minus (following) polarity fields with the position of newly formed active regions speaks for the important role of this polarity for the development of activity.

(4) Although during periods of higher activity the situation in the field distribution is much more complicated still, the giant regular structure formation (better seen in the plus (leading) polarity fields) may be followed, as well as larger features extending about 60° in heliographic longitude. The close relation of minus (following) polarity to new activity is also observed.

(5) The mutual influence of existence of a system of convective motions, of active longitudes with periodically changing activity, of heliographic latitude distribution and the different roles of opposite polarities on solar activity and large-scale distribution of magnetic fields suggests the need for a new conception of large-scale solar activity processes.

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