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OBSERVATIONS ON THE MACULA LUTEA.

By GEORGE LINDSAY JOHNSON, M.D. (CANTAB.), F.R.C.S.
(LONDON).

HISTOLOGY OF THE HUMAN MACULA (*Continued*).

(*With eight microphotographs and two diagrams in the text.*)

B.—THE BACILLARY LAYER.

OF all the layers of the retina the bacillary layer is by far the most delicate, and the most susceptible to post-mortem changes, and that is no doubt why in so large a number of cases I have obtained specimens perfect throughout the retina with the sole exception of this layer, which can evidently only be preserved by instantaneous fixation and most careful subsequent preparation. It is moreover essential that the eyes should not only be healthy but should be obtained from the living subject. In no case have I been able to preserve the bacillary layer in eyes in any way diseased, or enucleated after death. The eyes of new-born children are likewise unsuitable, the retina being insufficiently developed.

The bacillary layer, when perfectly preserved, presents an appearance which differs so fundamentally from all the descriptions hitherto given that I hesitated to publish my results, until I found the appearance usually described to correspond to those of my own specimens in which the bacillary layer was obliquely cut, degenerated or disturbed, and until I had confirmed my observations by the microscopical examination of the eyes of several of the monkeys.

I have used various methods of preparation and staining in order to eliminate as far as possible any errors due to the

action of the reagents employed, and I systematically rejected all specimens in which I could not confirm the details of structure by more than one method of treatment.

I may here remark that the results I have been able to obtain by the Golgi and Ramon y Cajal methods have not been sufficiently uniform to justify my drawing conclusions from them. Moreover, specimens prepared according to these methods will not bear high magnification, and, therefore, cannot reveal the extremely minute structure of the retinal elements.

When treating of the hexagonal layer and describing the network which I termed the crystal-pigment plexus, I already stated that the bacillary layer was directly continuous with and organically bound to that plexus. In other words, I find that the established doctrine of rods and cones terminating by free ends is not only erroneous, but that on the contrary the rods and cones are in direct continuity with the hexagonal layer, through the above-mentioned plexus. Borysiekiewicz¹ seems to be the only author who has stated that the cones are of equal length with the rods. I not only find this confirmed, but I have been able to preserve the outer half of the bacillary layer intact, and this outer half varies materially in structure in different parts of the retina. This outer part of the bacillary layer breaks up in various ways in imperfectly preserved specimens, and it is probably this which has led observers to differ in opinion as to the shape of the ends of the rods and cones.

The bacillary layer—by which I understand that portion of the retina which extends from the membrana limitans externa to the pigment layer—can be described as consisting of two parts of nearly equal length, an inner or basal half and an outer or filamentous half, the latter being united to the crystal pigment plexus, which, as shown in my previous paper,² penetrates the hexagonal layer to terminate at or in the spherules.

¹ "Weitere Untersuchungen über den feineren Bau der Netzhaut"—Denticke, Leipzig, u. Wien, 1894.

² ARCH. OF OPHTHALMOLOGY, vol. xxiv., p. 310.

Omitting the modifications which occur near the ora serrata, I find that the retina can be mapped out into five areas, each characterized by a distinct modification of the bacillary layer.

Before describing these five modifications or systems, and indicating the areas they occupy, I think it will be conducive to a clearer understanding of the bacillary layer as a whole, if I state that the more I examine microscopic sections of the retina and investigate its structure, the more I become convinced that the ultimate fibrils of the optic nerve run from the disc to the spherules in the pigment layer without interruption. One of the leading purposes of the retinal structure seems to be to support and insulate these fibrils throughout their course. The basal portion of the rods and cones are, as Borysiekiewicz has pointed out, sheaths, in the centre of which we find a nerve fibril; but, in addition to what he describes, I notice these fibrils to be sustained in the centre of the sheaths by very minute radiating fibrillæ. In the cones the nerve fibril is not only sustained by radiating fibrillæ, but is moreover surrounded by a protoplasmic substance which fills out the sheath. This renders it difficult to distinguish the nerve fibril and the fine radiating supporting fibrillæ in the cones.

Obliquity, which is practically unavoidable in transverse sections, frequently causes the nerve fibril to appear decentred. The protoplasmic substance in the cones easily coagulates during the preparation of the specimen and thus becomes opaque, and the sheaths themselves vary considerably in transparency according to the hardening reagents employed. The following figure shows the basal portion of the rods and cones as seen transversely under a high power, and shows the fine fibrillæ sustaining the nerve fibrils.

The interstices between the rods and cones are filled out with a substance which stains somewhat darker than the rest, but I have not yet been able to ascertain its nature. This, however, shows that the rods and cones in their basal portions are held together, and are not separated from each other by a free space, as generally described and figured.

Want of material has rendered it impossible for me, up to the present, to obtain transverse sections through the five different modifications or systems of the bacillary layer. I have, so far, only obtained sections through what I shall hereinafter term the first or peripheral system.

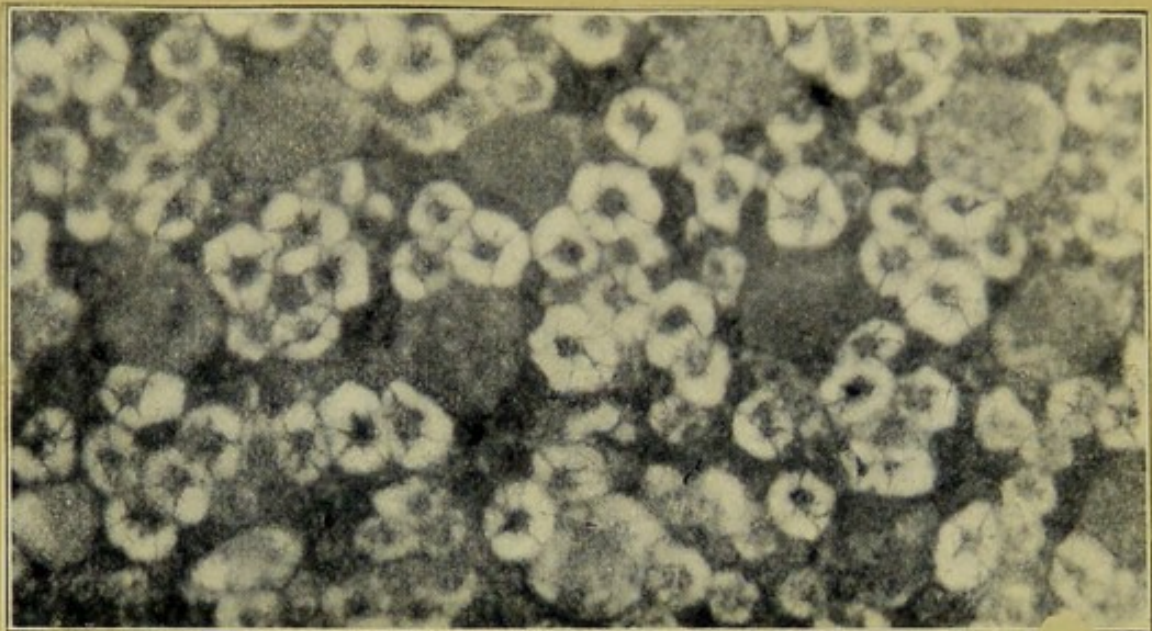


FIG. 11.

Transverse section through the basal portion of the bacillary layer, showing the rods as clear spaces, in the centre of which the section of the fibre is shown supported by radiating fibrillæ. The cones, much fewer in number, appear as large, dark, granular patches in which the fibres and supporting fibrillæ can be indistinctly seen. $\times 1000$ diameters.

In transverse sections of this peripheral system the outer, or distal, portion of the rods and cones presents the appearance of very minute separate sheaths. In the centre of these sheaths we find, just as in the basal portion, a nerve fibril supported by radiating fibrillæ. The cones are slightly larger than the rods and contain the protoplasmic mass above mentioned. The following figure is a photograph of such a section.

It will be seen by comparing these two figures that the nerve fibrils, probably through diminution of their perifibrillar substance, become thinner and thinner as they approach the crystal-pigment plexus, hence it is not surprising that it should be so difficult to trace their course through the plexus to the spherules.

It is only when the sheaths are very transparent that the nerve fibril can be traced through the rods and cones in vertical sections. Swelling of the cone sheaths and coagulation of the protoplasmic mass, produced by certain reagents, frequently cause the cones to stand out like swollen flask-shaped bulbs, whilst in reality the contrast between the rods and cones is much less marked than shown in the text-books.

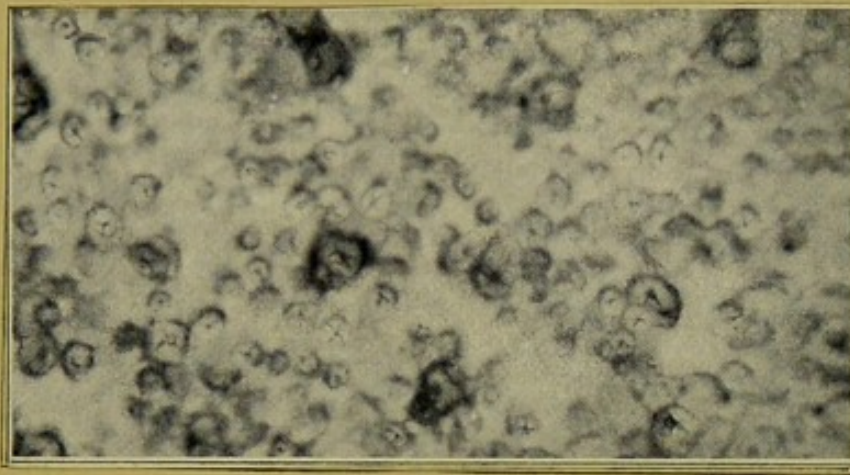


FIG. 12.

Transverse section through the distal portion of the rods and cones of the peripheral system. The cones, twelve in number, appear larger and darker than the rods. $\times 1000$ diameters.

I have endeavored to determine the extent of each of the areas of the retina in which the five distinct systems of the bacillary layer occur, but up to the present I have only obtained reliable results in a line projected through the disc and fovea and in lines parallel to it. The limits of the systems are most clearly defined in the above-mentioned line, whilst the further we go from this line the more we find that the systems merge imperceptibly into each other. This renders it extremely difficult to determine where the one system begins and the other ends. I think that sections at right angles to those I have already obtained will be necessary in order to check my results before I can map out the whole extent of the areas with accuracy.

I will therefore, for the present, rest content with giving the following diagram of the distribution of the systems on a line projected through disc and fovea.

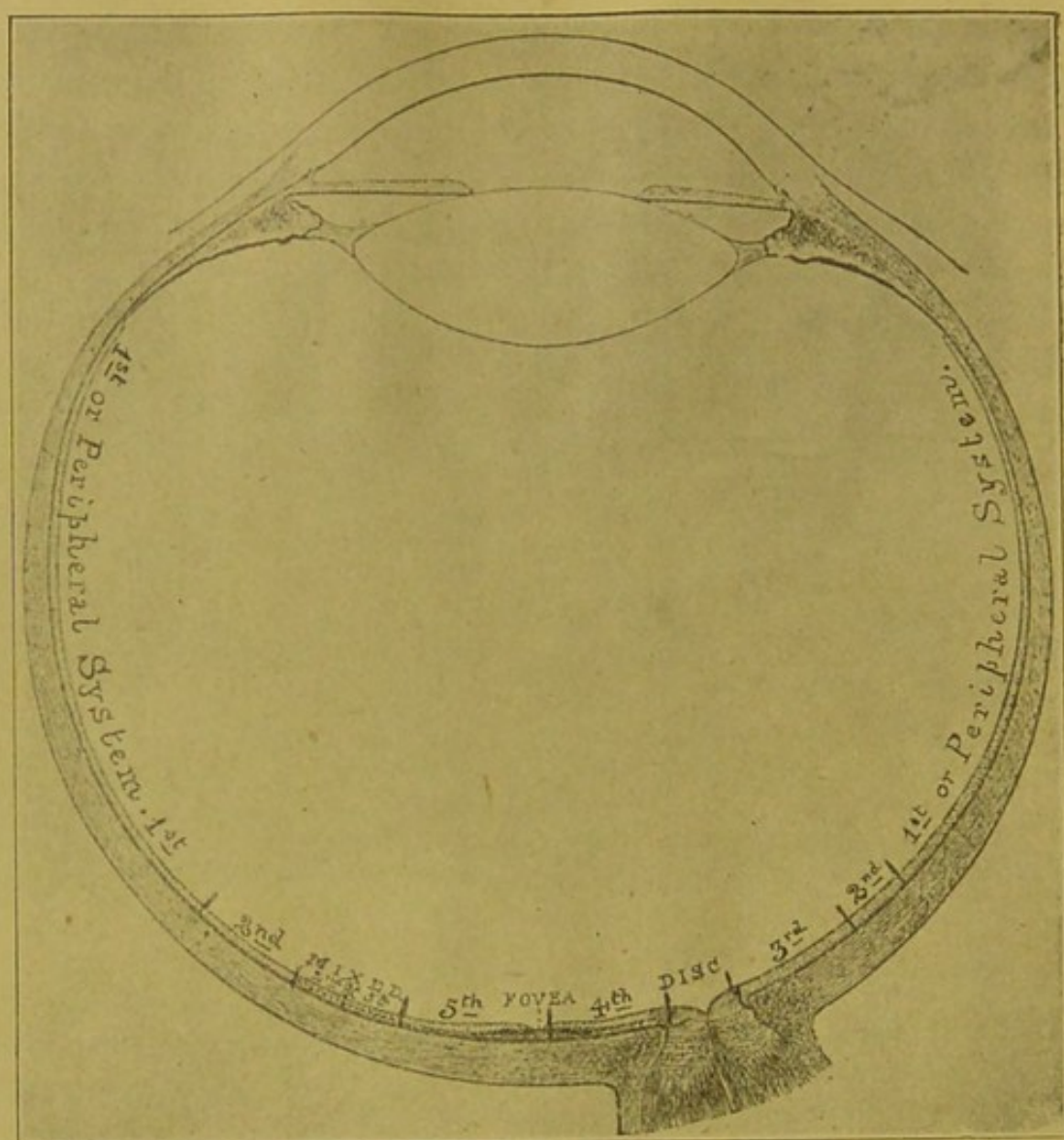


FIG. 13.

Diagram of an adult eye in a horizontal plane through the optic nerve and fovea, showing the order and relative extent of the five areas of the retina corresponding to the five systems of the bacillary layer. Drawn to scale and magnified four diameters.

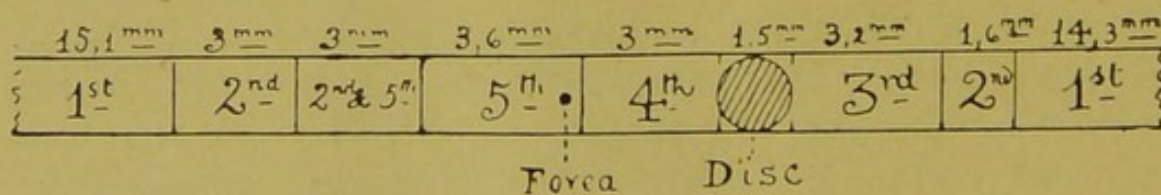


FIG. 14.

Diagram of the differentiated area showing the extent of the systems drawn to the same scale as above with the actual measurements indicated in millimetres. The first and the second system are identical in appearance on both sides.

By using the expression differentiated area I wish to draw a distinction between the large peripheral area in which the first system occurs, and the areas in which we find the layer differentiated and more highly organized.

It will be seen from the above diagram that the fovea is the centre of this differentiated area, and that the point at which the fourth and fifth systems meet is not far removed from the fovea.

In all sections through the differentiated area I find the transition from the first to the second system abrupt; the other systems merge gradually into each other everywhere except in the line represented in the diagram. In that line the limit between all the systems is clearly defined except between the second and fifth. Between these we find a considerable extent over which the bacillary layer partakes of the characteristics of both these systems, gradually losing the appearance of the one as we approach the other. I have therefore indicated this transition area in the above diagrams.

I now propose describing the five systems *seriatim*.

THE FIRST OR PERIPHERAL SYSTEM.—This system is to be found throughout the peripheral area, marked "1st" in the diagram, which is much the largest in extent and it presents the appearance shown in the following figure.

It will be seen from the following figure that the filamentary prolongations of the rods and cones are of equal length and are continuous with the crystal-pigment plexus.

The basal portion of this system somewhat resembles the description usually given. Near the ora serrata the difference between the bulbous cone-bases and the narrower bases of the rods can be distinctly seen, but the more we move away from the periphery the longer the rods and cones become, and the less apparent is the distinction between them, until ultimately they are so close together and present so little contrast that one can only distinguish between them with great difficulty.

The distinctive feature of the outer half of the bacillary layer in this system is that the distal portion of the sheaths

is unsupported, every one of them being separated from its neighbour. The rod sheaths present a fine strap-shaped appearance, whilst the cone sheaths appear slightly thicker and are marked with fine irregular transverse striations.

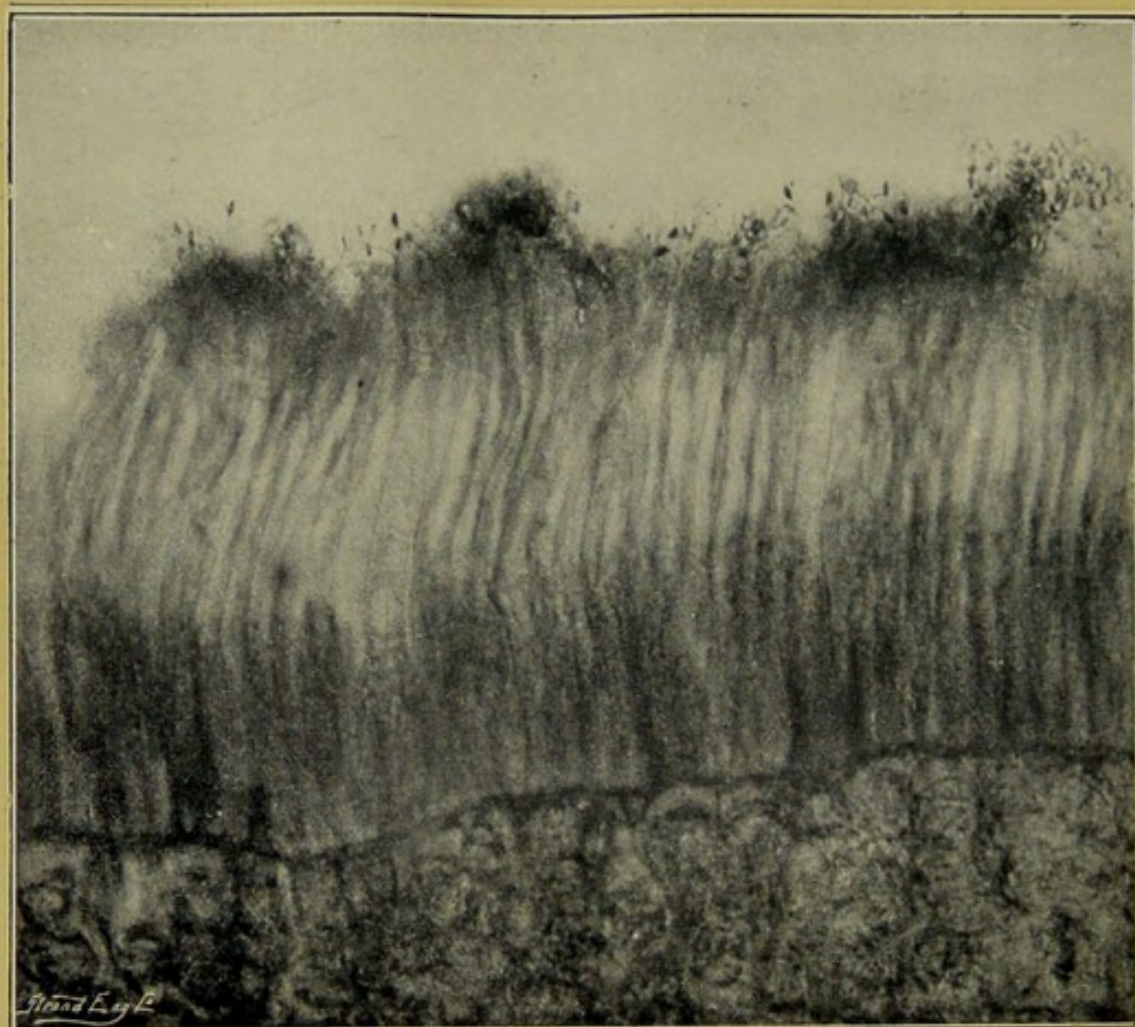


FIG. 15.

Vertical section through the bacillary layer of the first or peripheral system.
x 1000 diameters.

When carefully focussed with a high power these fine striæ seem to proceed from the central fibril towards the sides, and are therefore no doubt the sustaining fibrillæ as seen through the transparent cone-sheaths, since they correspond both in size and direction to the sustaining fibrillæ seen in the transverse sections (*vide* Figures 11 and 12). The outer extreme end of the cone sheath, however, shows some eight or ten transverse buttonhole-shaped apertures.

THE SECOND OR INTERMEDIATE SYSTEM.—This system occurs in the area marked "2nd" in the diagram, and presents the appearance shown in the following photograph.



FIG. 16.

Vertical section through the bacillary layer of the second system. x 1000 diameters.

In the basal portion of this system the rods and cones cannot be clearly distinguished. The striking feature is to be found in the distal portion which consists of a coarse plexus which joins on to, and is continuous with the finer crystal-pigment plexus. The striated cone-sheaths can be seen running through this coarse distal plexus, but the finer distal rod sheaths can nowhere be seen. The rod sheaths themselves seem to differentiate to form this plexus, whilst the nerve fibrils leave the basal rod-sheaths supported by this coarse plexus until they reach the finer crystal-pigment plexus.

Transverse sections, which I hope to obtain, seem necessary to confirm this interpretation.

THIRD OR "INNER PAPILLARY" SYSTEM.—This system is to be found in the area marked "3rd" in the diagram, situated on the inner side of the disc. It presents the appearance shown in the following photograph.

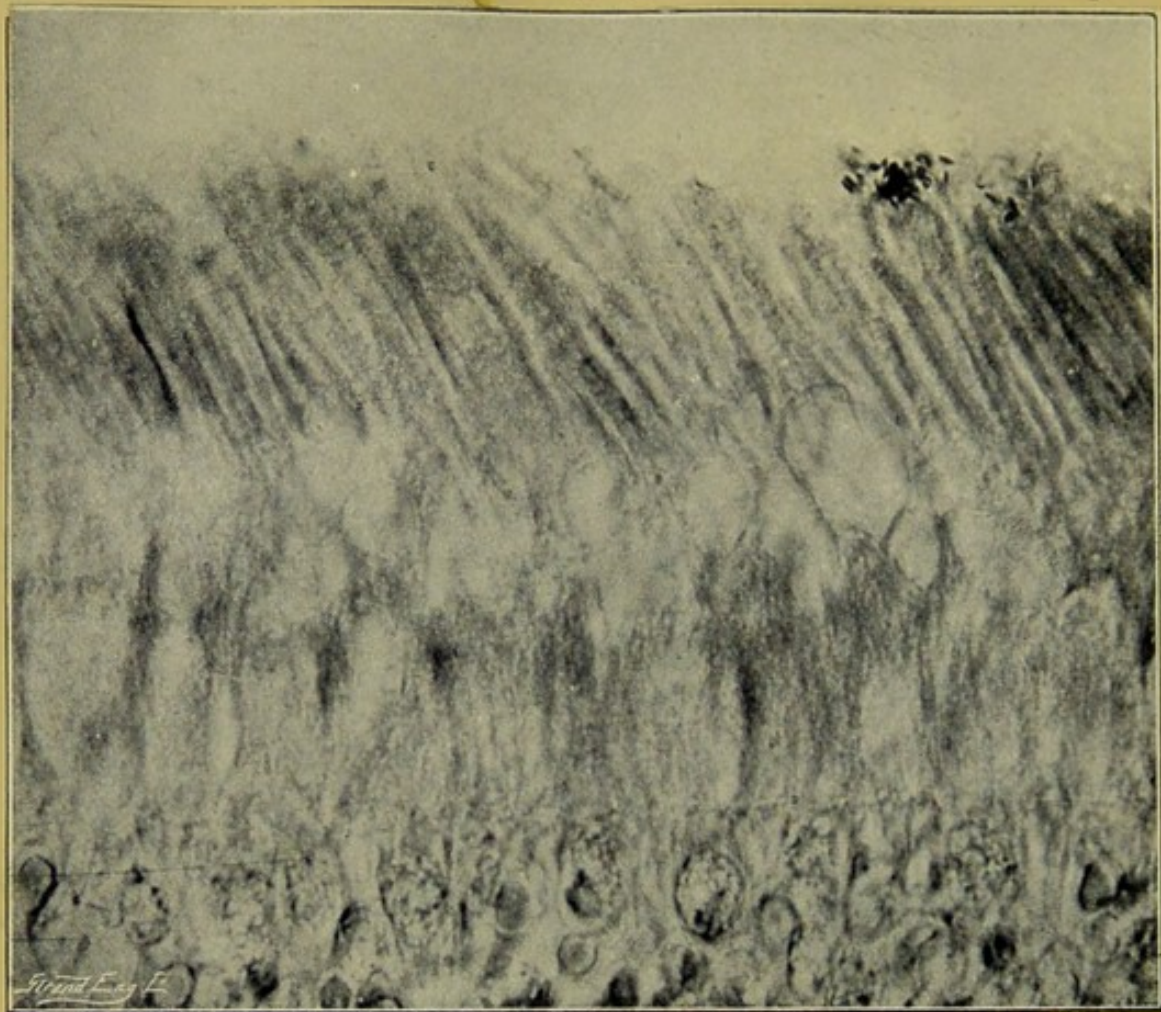


FIG. 17.

Vertical section through the bacillary layer of the third system. x 1000 diameters.

In this system the distance from the membrana limitans externa to the crystal-pigment plexus is nearly half as great again as in the other systems. It is widest near the disc, narrowing as it approaches the second system.

The basal portion of the layer in this system is very ill-defined, but the rods and cones can be distinguished. The outer portion can be divided into two parts, the inner being more like the coarse plexus which we meet with in the second system, the outer being composed of striated sheath-prolongations, similar but coarser than those we have met with as the distal cone-sheaths in the first system.

It is these striated sheaths which join on to the crystal-pigment plexus.

FOURTH OR OUTER PAPILLARY SYSTEM.—This system occurs in the area marked "4th" in the diagram, which extends from the outer edge of the disc to near the fovea. The basal part consists of rods and cones, whilst the outer portion shows striated cone-sheaths finer than in the other systems, intermingled with a fine plexus through which nerve fibrils run as they leave the rod sheaths.

The following photograph shows this system :

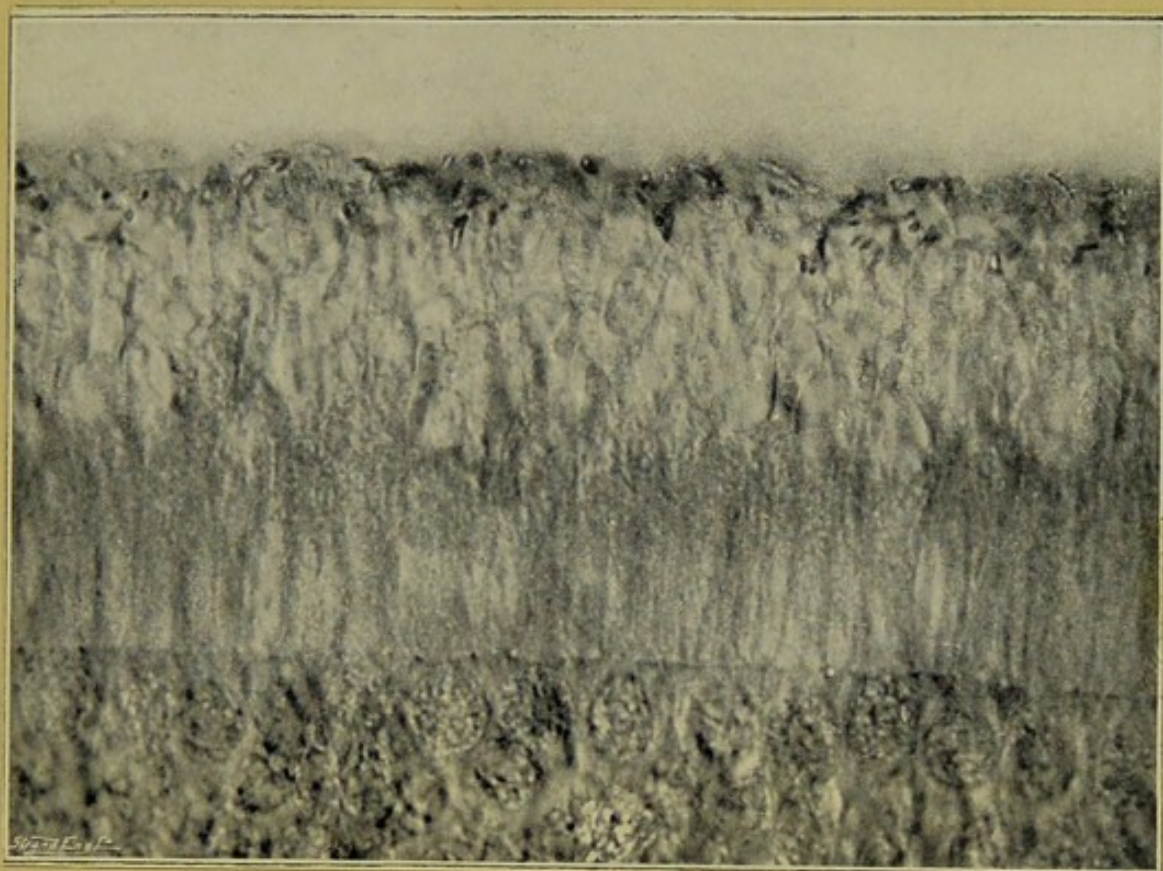


FIG. 18.

Vertical section through the bacillary layer of the fourth system. x 1000 diameters.

THE FIFTH OR MACULA SYSTEM.—This system which occurs throughout the area marked "5th" in the diagram presents the appearance shown in the following photograph.

It will be seen from this photograph that the basal portion of this layer does not differ materially from that of the other systems. This basal portion alone therefore would not warrant the statement that there are only cones at the macula.

The distal portion however shows nothing but striated sheaths so that we are no doubt in the presence of cones only. The distal sheaths of the fifth system differ considerably from those in the other systems, being of uniform thickness throughout their course, and having from the basal sheaths until they reach the crystal-pigment plexus very regular and equidistant transverse striæ, which, when greatly magnified, all appear as buttonhole-shaped apertures.

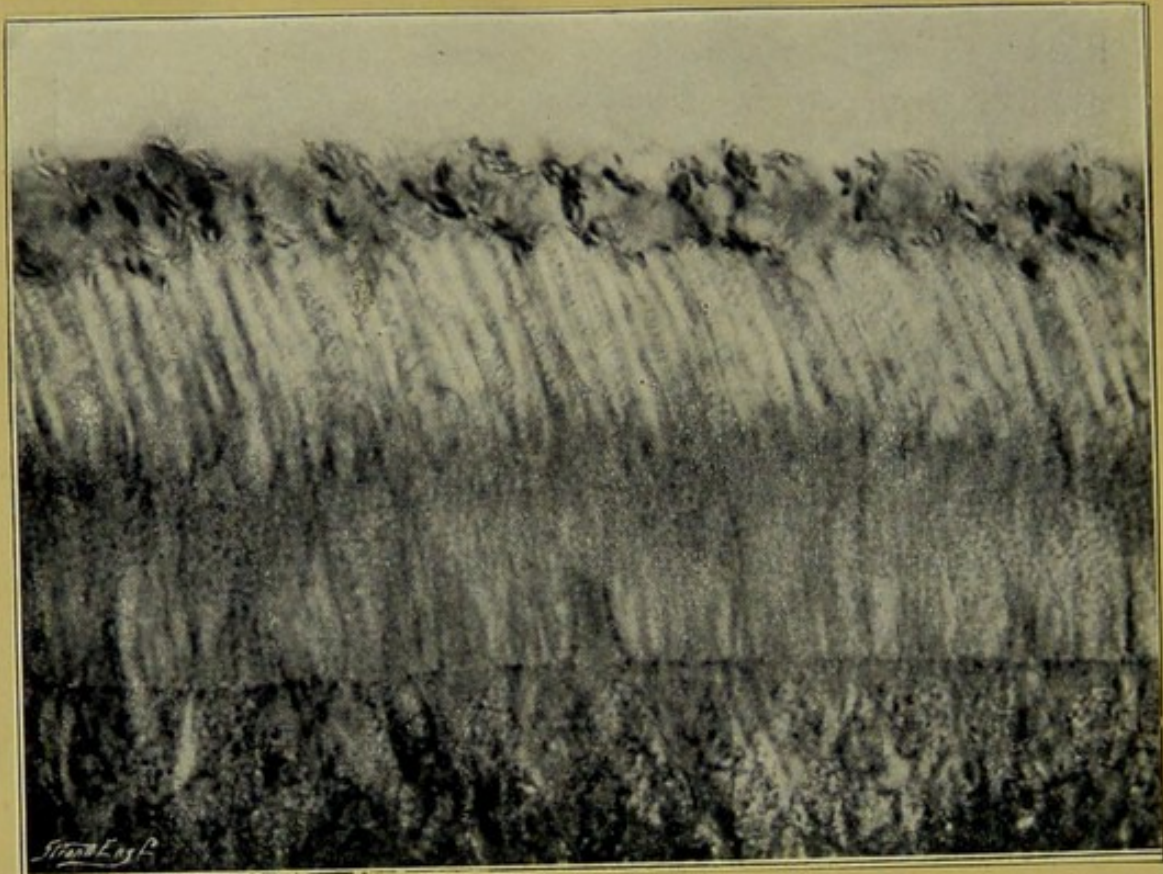


FIG. 19.

Vertical section through the bacillary layer of the fifth system. $\times 1000$ diameters. The crystal-pigment plexus is exceedingly well shown at the end of the cone sheaths in this photograph.

In the diagram showing the areas I have, as above explained, had to mark an area between the second and fifth which partakes of the characteristics of both systems. I have thought that it might prove useful to the understanding of this paper to give an illustration of this transition form in the following photograph.

I have throughout selected specimens for photography in which the crystal-pigment plexus had been torn away

from the pigment layer, carrying some pigment crystals with it. When the crystal-pigment plexus is in situ it is so obscured by crystal-pigment that it is difficult, if not impossible, to see how the bacillary layer joins on to it; the appearance being such as to lead one to suppose that the distal portion of the rods and cones penetrates directly into the hexagonal layer.



FIG. 20.

Vertical section showing the transition from the second to the fifth system.
x 1000 diameters.

To recapitulate them.—The bacillary layer—by which I understand that portion of the retina which extends from the membrana limitans externa to the crystal-pigment plexus—presents different appearances in different portions of the retina. The largest area is that comprising the entire peripheral portion of the retina, whilst surrounding the disc and the macula there is a differentiated region which can be divided into four areas each distinguished by a different form of the bacillary layer. The fovea is the centre of this differentiated region. The optic-nerve fibrils in their course from

the disc to the spherules run through the centre of the rods, and cones supported by fine fibrillæ. The rods and cones are merely sheaths for the purpose of protecting, supporting, and insulating these extremely delicate optic-nerve fibrils. In the first system the basal sheaths are continued as thinner distal sheaths which similarly support and insulate the nerve fibrils. In the rod sheaths the nerve fibrils run free whilst in the cone sheaths they are surrounded by a protoplasmic granular substance. In the second system, which borders the differentiated region, the cone sheaths are supported in their distal portion by a coarse-meshed plexus, the nerve fibrils emanating from the basal sheaths of the rods, being supported by the meshes of this plexus. A small area on the inner side of the disc shows a special differentiation of rods and cones which I have termed the third system. From the outer side of the disc until near the edge of the fovea, the fourth system occurs, which consists of fine cone-sheaths intermixed with a fine plexus in which the nerve fibrils which emanate from the rod sheaths are supported. From the fovea to the second system on the outer side, we find the fifth system which consists of cone sheaths alone, of a more definite and regular shape than the cone sheaths of the other systems. The cone sheaths of this system have transverse buttonhole-shaped apertures which under a low power appear as striæ. The nerve fibrils which run through the cones are protected by sheaths containing a protoplasmic substance. On the other hand, the fibrils which run through the rods are only entirely protected by sheaths in the first system whilst in the other systems they are partly protected by sheaths and partly supported by a plexus. In all cases the cones are of equal length with the rods and the entire bacillary layer joins on and is organically bound to the crystal-pigment plexus.

(To be continued.)