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THE FUNDUS AND FOVEA CENTRALIS OF THE
ALBATROSS (*DIOMEDEA CAUTA CAUTA*—GOULD)*

BY

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“And a good south wind sprang up behind;
The Albatross did follow,
And every day, for food or play,
Came to the mariners' hollo!”

COLERIDGE.

THE general fundus reflex of the eye of the Albatross is a dark grey merging into a delicate shade of pink at the lower periphery (Fig. 1). The grey surface is covered with innumerable, glistening, white spots. The only vessels to be seen are choroidal running up a little way from the lower periphery in indistinct parallel lines. The margin of the optic nerve entrance is visible as a white crescent around the upper part of the base of the pecten. The latter structure projects well forwards into the vitreous and it is with difficulty that one may catch glimpses of the fundus past its peripheral extremity. It consists of nine fan-like folds increasing in size from the centre to the periphery. The fringe of the smaller central folds has a translucent brown

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appearance and a distinct ridge is visible along the summit of the pecten. The site of the fovea cannot be definitely determined, although a small circular area of darker colour than the rest of the fundus, is to be seen to the nasal side of the upper part of the base of the pecten. The bird expresses its resentment at the ophthalmoscopic examination of this area by becoming restless and trumpeting loudly.

The fixed specimen (Fig. 3) reveals the presence of a well-marked, elevated, central strip with a single oval fovea to the nasal side of the pecten. The central strip is 1.75 mm. wide and the oval fovea approximately the same width, the central strip bulging to accommodate it. The angle between the central strip and the major axis of the optic nerve entrance—the *infundibular angle* (Casey Wood) is 75°. The base of the pecten overlaps the edges of the optic nerve entrance. Viewed from the lateral aspect it is quadrilateral in shape with a curved base of 10 mm., an apex of 5 mm., a central edge of 7 mm., and a peripheral of 6 mm. (Fig. 5).

The fundus reflex of the eye of the Giant Petrel (*Macromectes Giganteus Giganteus*—Gmelin) is a darker grey than that of the Albatross (Fig. 2). The margin of the base of the pecten is completely surrounded by a white border, which in its turn is almost completely separated from the rest of the fundus by what appears to be a choroidal blood sinus with vessels radiating from it. Other choroidal vessels run up from the lower periphery. The folds of the pecten are placed further apart than in the Albatross and terminate in a little tail. The fovea cannot be easily recognised. Examination of the fixed specimens shows a central strip and fovea as in the Albatross (Fig. 4). The base of the pecten does not extend to the edge of the optic nerve entrance, and the tail of the pecten is a continuation of the apical ridge.

The chief dimensions of the eye of the Albatross are as follows :

Antero-posterior diameter	...	...	21 mm.
Equatorial diameter	...	...	26 mm.
Limbal diameter	...	...	12 mm.
Depth of anterior chamber	...	...	2.3 mm.
Lens—Transverse diameter	...	...	10 mm.
Antero-posterior diameter	...	...	5 mm.
Pad	...	...	1.5 mm.

These measurements taken on the fixed eye are only approximate, as the cornea of the specimen examined was distorted by the contraction of the nictitating membrane during fixation. The bird is the size of a large goose.

FIG. 1.

Fundus of the right eye of the Albatross (*Diomedea cauta cauta*—Gould). Ophthalmoscopic view.

FIG. 2.

Fundus of the right eye of the Giant Petrel (*Macromectes giganteus giganteus*—Gmelin). Ophthalmoscopic view.

FIG. 3.

Fundus of the right eye of the Albatross (*Diomedea cauta cauta*—Gould). Fixed specimen.

FIG. 4.

Fundus of the left eye of the Giant Petrel (*Macromectes giganteus*—Gmelin). Fixed specimen.

FIG. 5.
Pecten of Albatross. $\times 6$.

FIG. 6.
Temporal edge of fovea of Albatross. $\times 150$.

FIG. 7.
Para-central section of fovea of Albatross. $\times 150$.

FIG. 11.
Visual cells and pigment epithelium of the Albatross. $\times 700$.
"Rods" and "cones" of Albatross. (Para-foveal).

The globes were fixed by injecting the vascular system of the bird with Kolmer's fixative immediately after asphyxiation with coal gas. One globe was embedded in celloidin and sections were prepared and stained with iron haematoxylin and phloxine as well as with Mallory's connective tissue stain. A few sections were bleached with "Diaphanol" to reveal the structure of the outer segments of the visual cells.

Examination of the retina with the low power reveals many local differences of structure to correspond with the macroscopic view of the fixed specimen. In general the architecture is typically avian, with a thick layer of bi-polar cells, glial masses in the outer reticular layer, a double layer of outer nuclei and a dense layer of pigment concealing the distal extremities of the outer segments of the visual cells. Along the central streak the retina is thicker than elsewhere, with a resulting ridge projecting into the vitreous. Here the single layer of ganglion cells is transformed into three, there is an enormous increase in the number of nuclei in the bi-polar layer, the horizontally arranged glial masses disappear from the outer reticular layer, the outer nuclei are increased in number as well as becoming attenuated, and there is a slimming and lengthening of the outer segments of the visual cells. To accommodate this increased lengthening, the external limiting membrane curves inwards, that is, with its convexity towards the vitreous.

The foveal sections were cut at right angles to the central streak. Approaching its edge, there is a sudden very great thickening of the bi-polar layer due to the lateral displacement of cells from the centre of the fovea which causes a ridge to appear around the edge (Figs. 6, 7). This layer dwindles away as quickly as it thickens but does not entirely disappear in the centre three or four cells still remaining. The nuclei of the optic-nerve fibres are arranged in palisade formation in groups of three (Figs. 8, 9). There is no appreciable diminution in the number of nuclei in the outer layer and the dendritic termination of their fibres may be made out. At the edge of the fovea there is a sudden thickening of the layer of synapses as those from the "rods" join in. There is no layer of Henle. The external limiting membrane bends outwards at the centre of the fovea, that is its convexity is towards the sclera. In the same area the outer segments of the cones, which elsewhere are well preserved, are badly distorted and buckled. Kolmer¹ from his own experience and from studying the photomicrographs of other observers comments on the difficulties met with in fixing this interesting area.

"Rods" and "cones" are present throughout the retina except at the centre of the fovea, where only the latter are to be found. The nuclei of both are finely granular, the background of

FIG. 8.

Fovea centralis of the Albatross. X135.

1. Internal limiting membrane.	4. Nuclei of "rods" and "cones."
2. Nuclei of optic nerve fibres.	5. External limiting membrane.
3. Bipolar cells.	6. Nuclei of pigment epithelium.

FIG. 9.

Fovea centralis of the Albatross.

1. Nuclei of optic nerve fibres.	5. External limiting membrane.
2. Bipolar cells.	6. Oil droplets.
3. Outer molecular layer,	7. Outer segments of cones.
4. "Cone" nuclei.	8. Nuclei of pigment epithelium.

the latter being a little more deeply staining (Figs. 10, 11). The nuclei of the "cones" are arranged next to the limiting membrane, whilst occasionally in the extreme periphery and in the region of the pecten they are to be found outside it in the accessory

member of the double "cones." Both single and double "cones" are present, the latter being found more easily at the periphery. The proximal part of the myoid of the single cones does not stain well with Mallory or phloxine although there is no definite evidence of the presence of a paraboloid. The distal

FIG. 10.

Visual cells of Albatross. $\times 1000$.

1. Outer molecular layer.	7. "Cone" Ellipsoid.
2. "Rod" nucleus.	8. Oil-droplet.
3. "Cone" nucleus.	9. "Rod" myoid.
4. Paraboloid.	10. "Rod" ellipsoid.
5. "Cone" myoid.	11. "Cone" outer segment.
6. Double "cone."	12. "Rod" outer segment.
	13. Nucleus of pigment epithelial cell.

third is traversed by a centrally situated cylindrical structure terminating abruptly at the deeply staining ellipsoid. The cylinder stains well with the acid fuchsin of Mallory's stain and with iron haematoxylin. The ellipsoid stains a mauve colour with Mallory and pink with phloxine. An oil-droplet is situated at its distal extremity which in its turn gives way to a thread-like outer segment. The chief member of the double "cone" resembles the single "cone" in structure with the exception that the

protoplasm of the myoid is definitely granular. The outer segment of the accessory member contains no oil-droplet. In the fixed condition it contains a greatly elongated, non-staining, oval, structure just outside the limitans—the paraboloid. This is surmounted at its distal extremity by a short cylinder, corresponding in its staining properties with the similar structure in the single cone. Apart from this, the outer segment does not stain well and thins down rather gradually to a thread-like distal extremity. In the fixed specimen, the oil-droplets are of different sizes and not all at the same level. They are still present in the fine cones at the centre of the fovea. Even in thin, bleached sections, it is not possible to determine accurately how far distally the thread-like distal extremities of the "cones" extend. The writer has the impression that they stop well short of the nuclei of the pigment epithelium. The "cones" are shortest and most plump at the periphery of the retina and near the pecten. In the central streak they are longer and more slender. In the centre of the fovea, even allowing for the distortion commented on above, whilst they are very slender, they are undoubtedly shorter than in the surrounding areas.

The myoid of the "rod" is very slender and it is not an easy matter to distinguish its structure amongst the outer myoids of the "cones." The sudden slimming of the "cone" distal to its oil-droplet allows the "rod" to swell just as suddenly before the myoid terminates in a short, thick, deeply staining ellipsoid. Just proximal to its termination the ellipsoid contains a small, seed-like body, highly refractile, and stained deeply with acid fuchsin and phloxine. The ellipsoid passes over into the sensitive distal extremity without any change in shape or volume. The latter structure does not stain and can be easily traced to the level of the nuclei of the pigment epithelium (Fig. 11). The rod myoids contain no oil-droplets and are arranged everywhere at a level distal to the oil-droplets of the cones. Because of the characteristic structure of the "rods," it is quite an easy matter to determine their absence from the centre of the fovea.

The pigment of the pigment epithelium, is dense everywhere, and takes the form of short, slender needles arranged in cylindrical masses which envelop the visual cells from the level of the inner edge of the nuclei of the pigment epithelium to the level of the oil droplets. It is the density of this layer which is probably responsible for the grey fundus reflex, as it would completely prevent any light from reaching the choroid.

The deep central fovea of the bird, as this example demonstrates, presents many remarkable differences from that of the deep central fovea of the lizard and the shallow, central one of man and the primates. In those diurnal lizards in which the eye is not too

small to allow of such a manoeuvre, all three nuclear layers of the retina are pushed away from the centre of the fovea so that no nuclear elements come into the path of these rays of light reaching the centre of the fovea. As a result of this, the cone fibres are elongated and there is a well-marked layer of Henle. In addition the outer segments of the foveal cones are greatly elongated, very slender and appear to lack oil-droplets. The elongation of the cones results in the inward curving of the external limitans, that is to say with its convexity towards the vitreous. The writer has seen this structure beautifully demonstrated in two Australian agamids—the bearded lizard (*Amphibolurus barbatus*) and the Gippsland water-dragon (*Physignathus lesuerii*). The more shallow fovea of man is constructed on the same principles—elongation and slimming of the visual cells to increase visual acuity without losing any sensitivity, and the removal of structures which might impede the light rays falling on the fovea. The bird has attained its high standard of visual acuity whilst neglecting to a large extent these two apparently essential factors. Kolmer¹ remarks that the retention of the oil-droplets in the fovea and the presence of a possibly more accurate accommodative apparatus renders the lengthening of the “cones” unnecessary. He quotes Rochon-Duvigneaud in support of his contention that the oil-droplets would tend to correct any aberration. The incomplete barring of the foveal area of the bird would seem to support the theory of Walls³ that the function of the foveal depression is not to remove obstacles from the path of the light falling on it, but to scatter it over a wider area.

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