

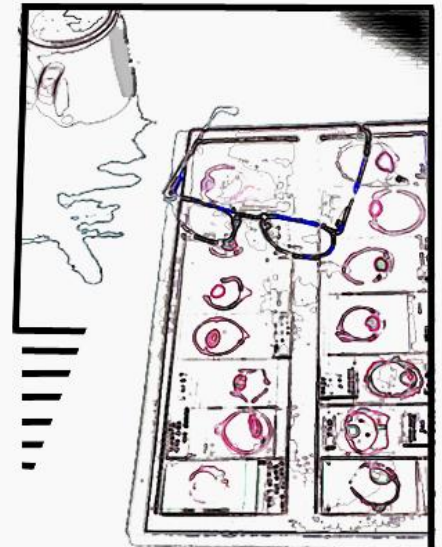


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*Advancing animal and human health with science and compassion*

# Comparative Anatomy of the Vertebrate Eye & Evolution

Dick Dubielzig

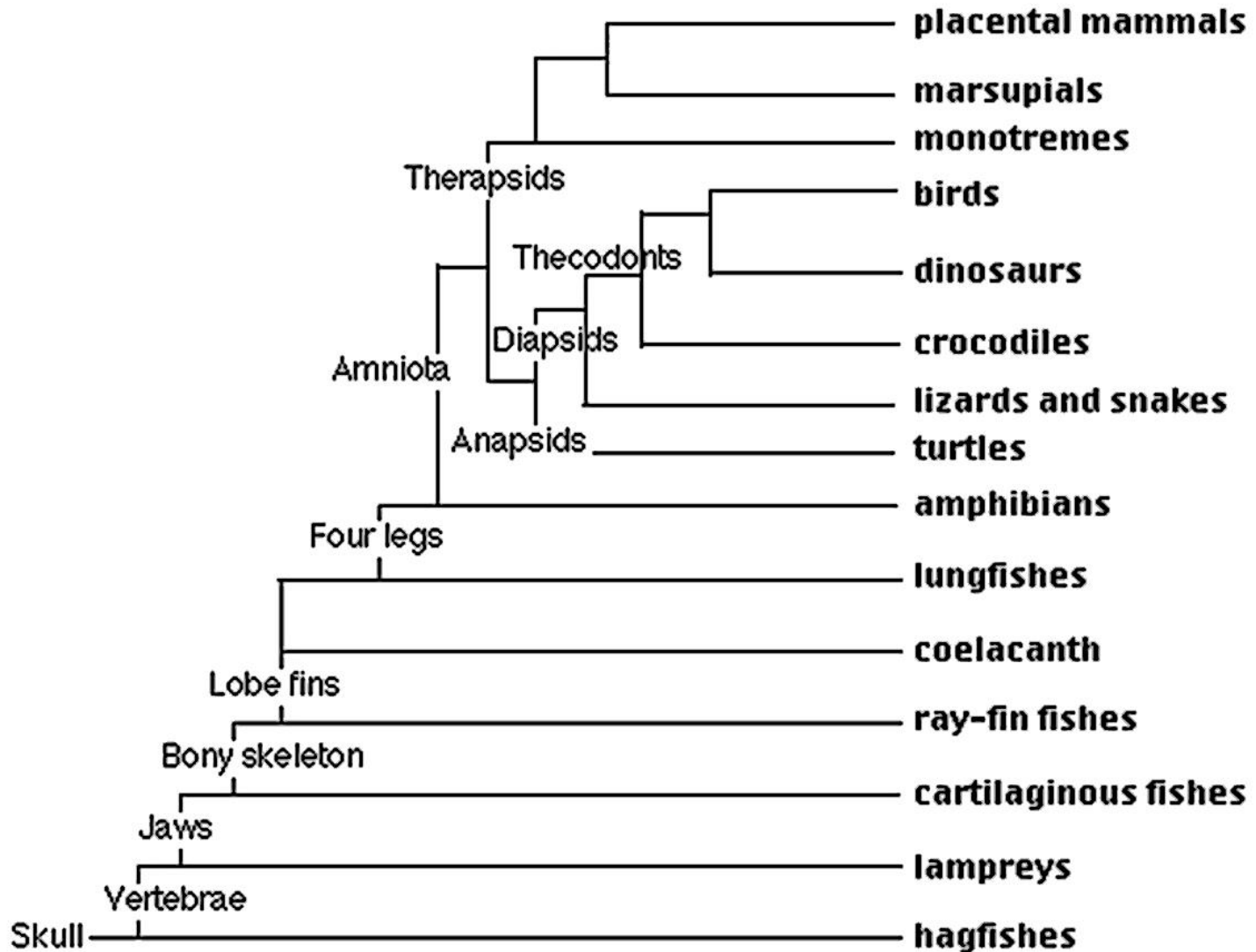


**COPLOW**

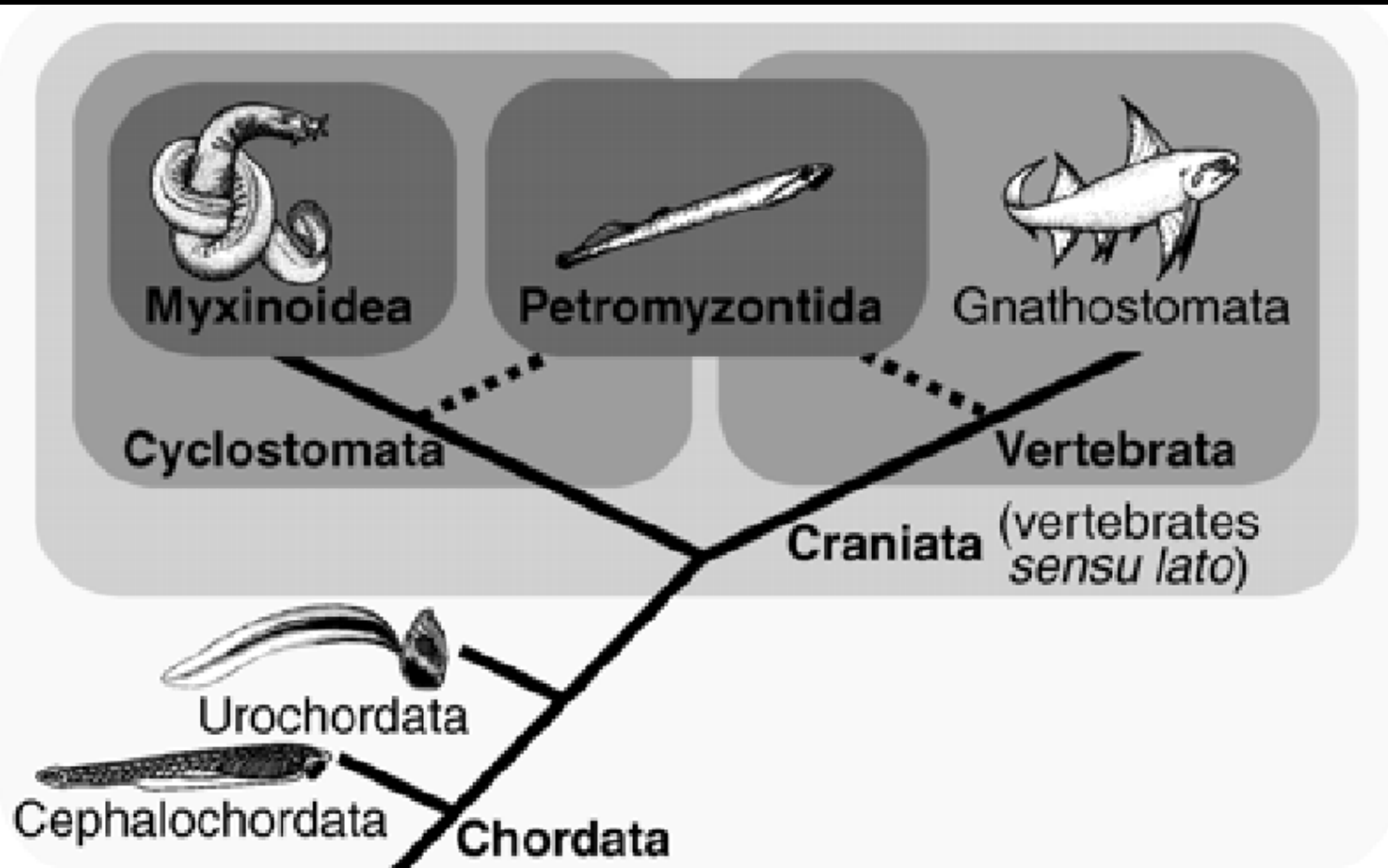


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# Vertebrate Evolution



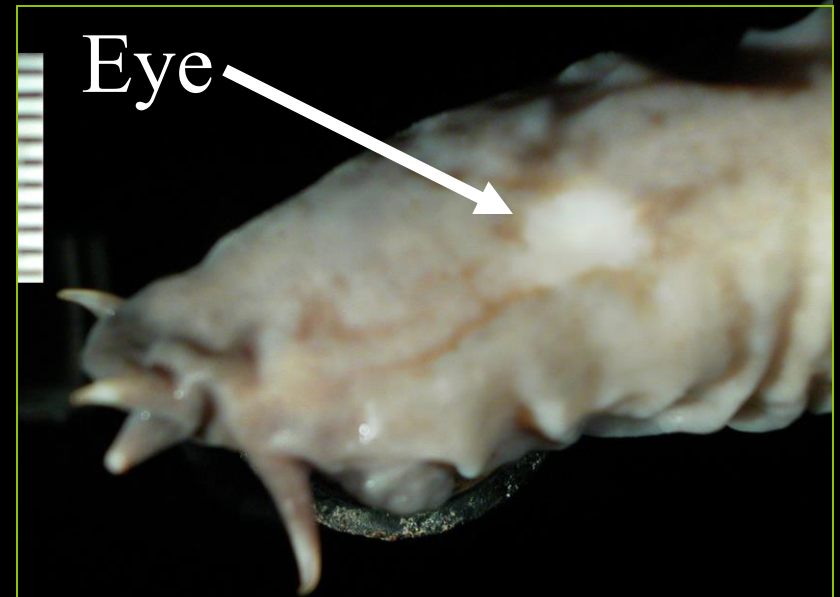
# Hagfish & Lampreys



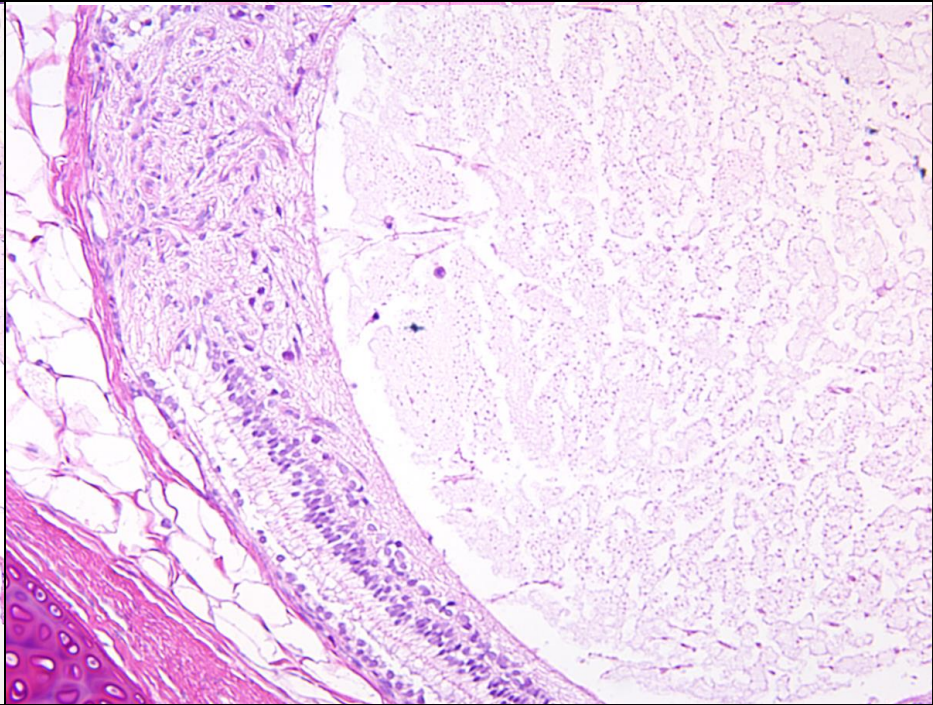
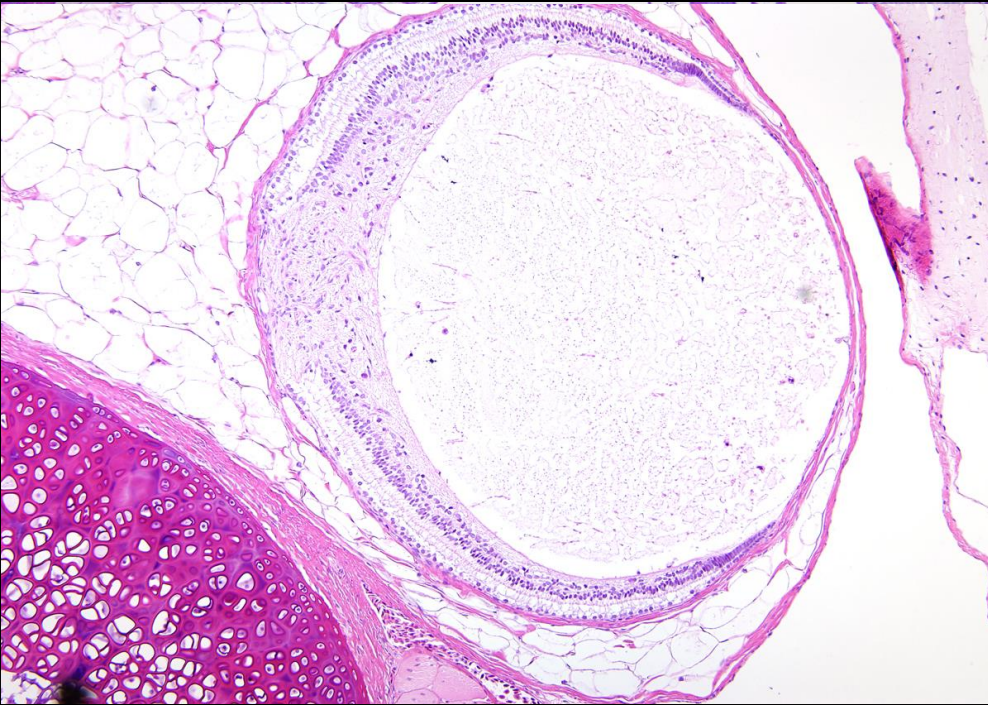
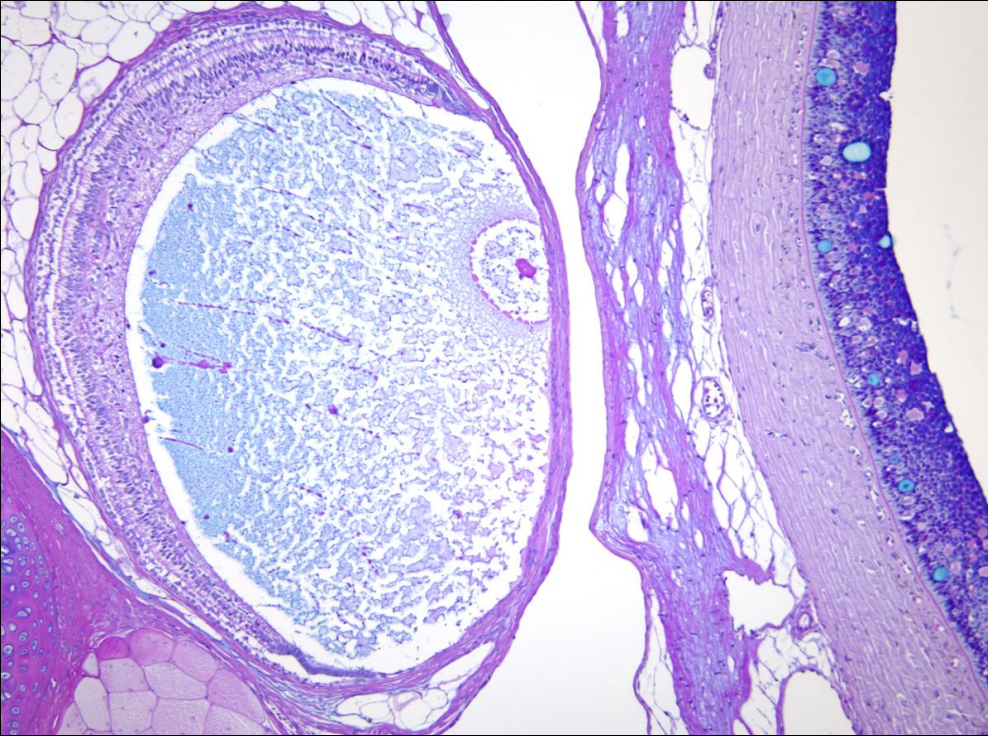
<http://rspb.royalsocietypublishing.org/>

# Hagfish Eyes

- No cornea
- No lens
- 2-layered retina
- No melanin
- Wired to the brain like a pineal gland



Recommendation: You-Tube: “Eddie and the Hagfish”



# Lamprey Eyes



Adult

- Larval form and adult form
- Cornea largely continuous with the skin
- No muscles of accommodation
- Has most of the structures of the vertebrate eye
  - Lens
  - 3-layered retina
  - 4 Cone types
  - Extraocular muscles no intraocular muscles
  - Wired to brain like a visual eye
  - Melanin in Choroid and RPE



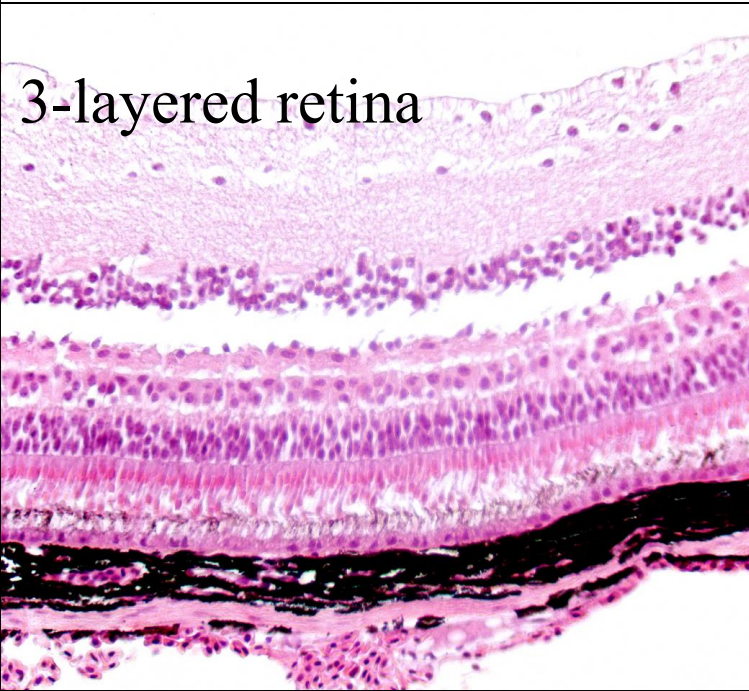
Larva



Larva



Adult

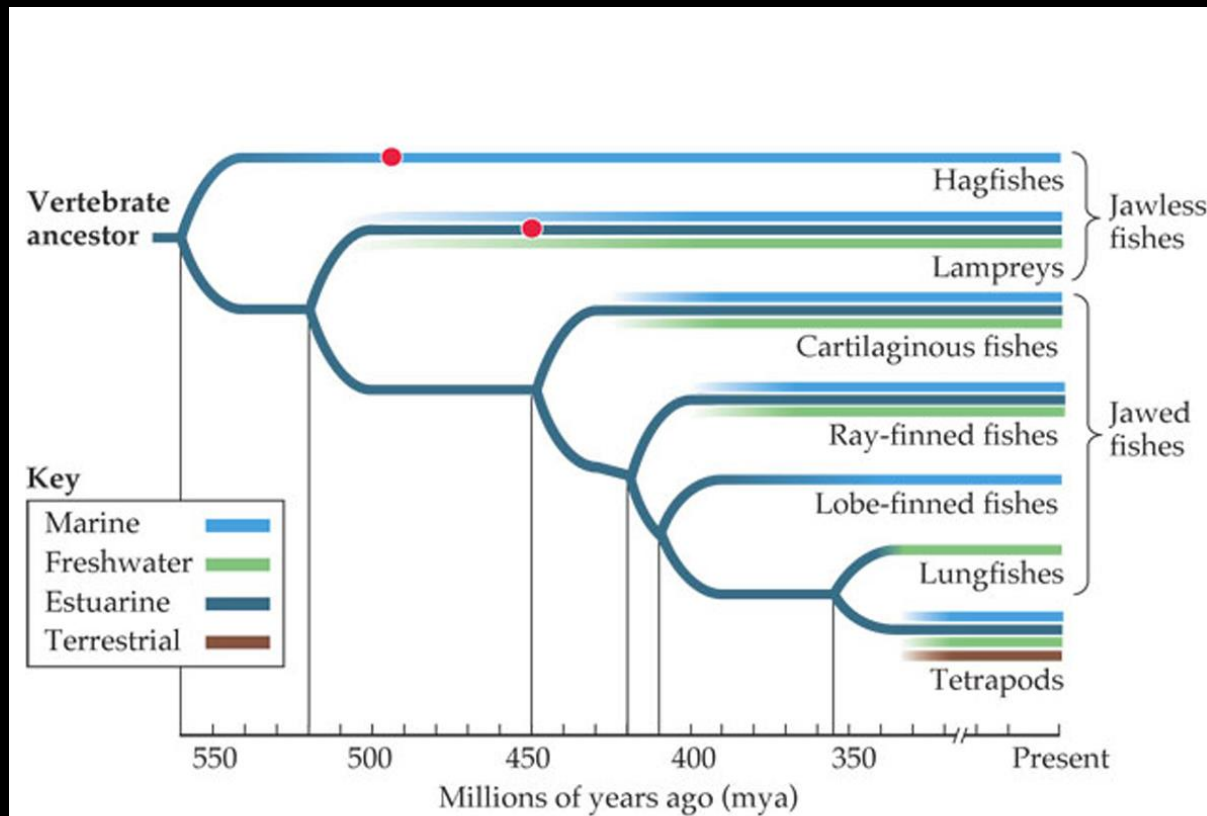


3-layered retina



Cornea continuous with skin

# Vertebrate Evolution



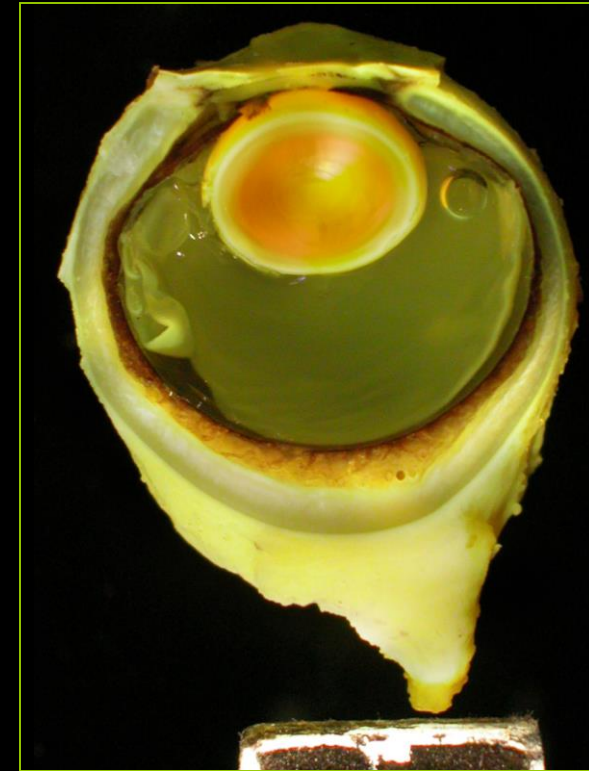
LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 34.8 A Current Phylogeny of the Vertebrates  
© 2004 Sinauer Associates, Inc. and W. H. Freeman & Co.

<http://www.blc.arizona.edu/courses/schaffer/>

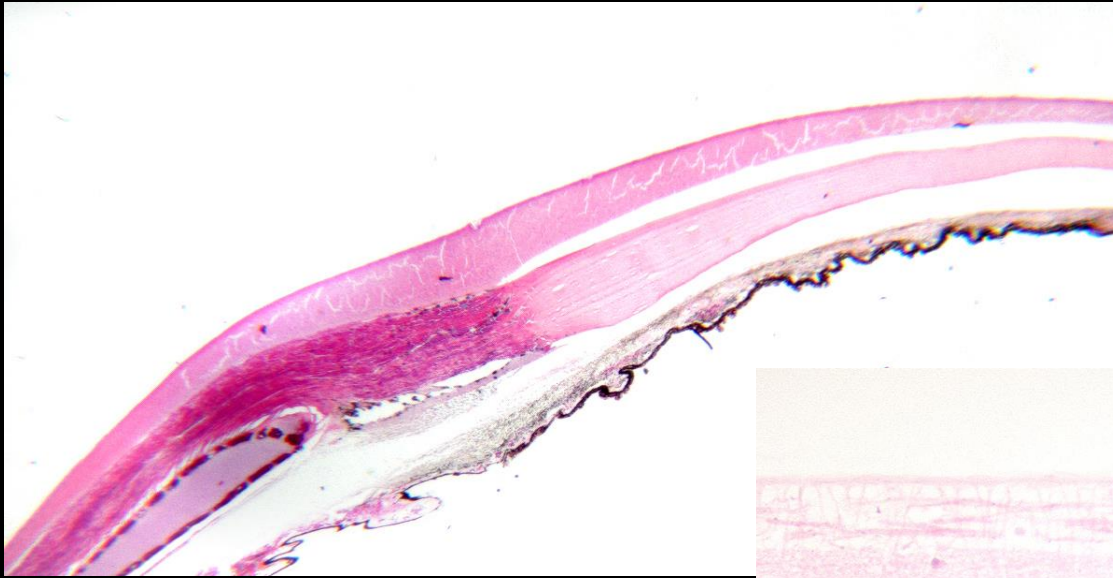


# Shark & Ray Eyes

- Cartilaginous sclera, but no bone
- No muscle in the ciliary body
- Smooth muscle attached to the ventral lens
- Double cornea (scleral and skin)
- No shading of outer segments by the retinal pigment epithelium (RPE)

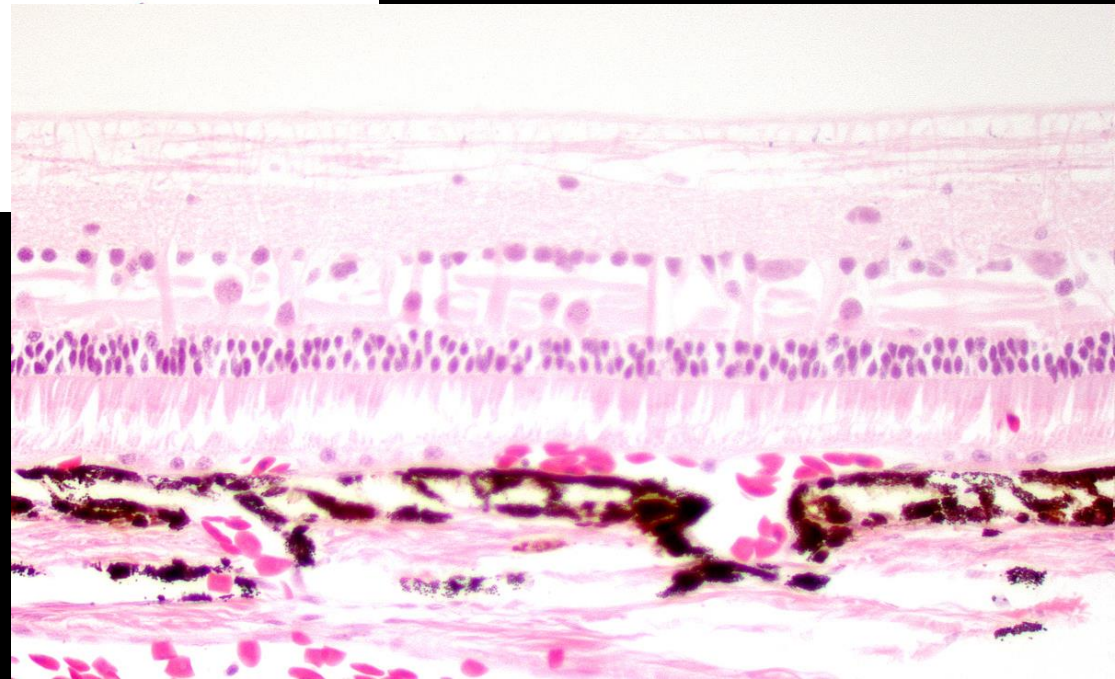


# Sharks and Rays

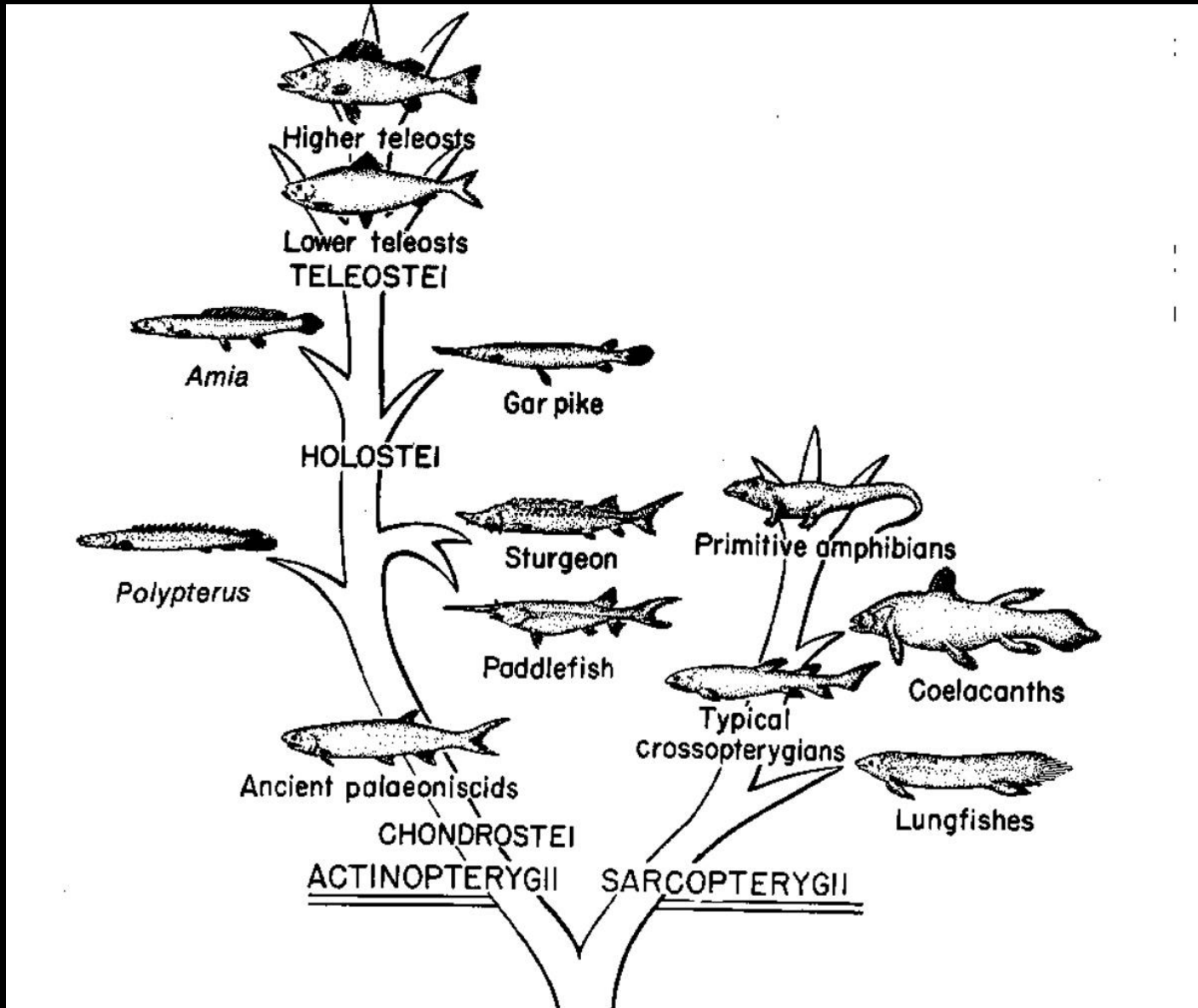


Double cornea

No shading of the  
photoreceptors  
by the RPE



# Evolution of the Fishes

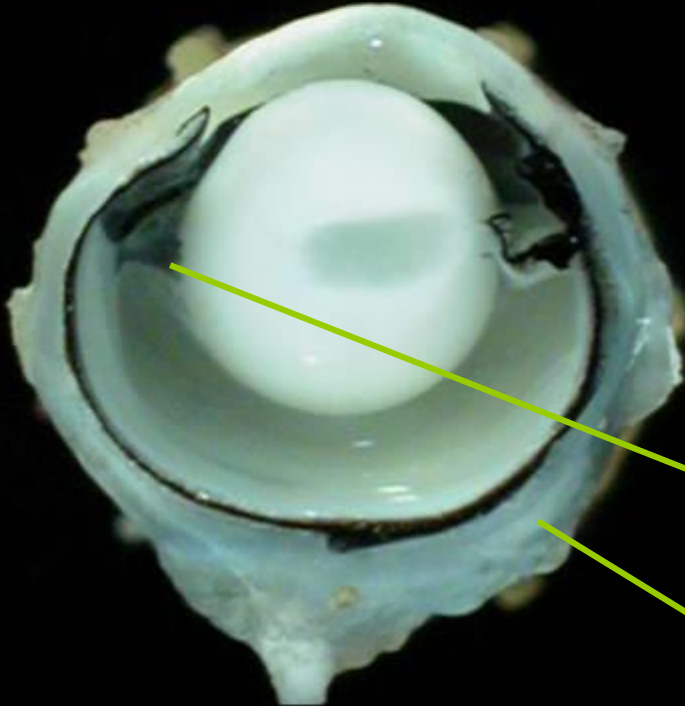


# Sturgeon Eyes



- Cartilaginous sclera, no bone
- No muscle in the ciliary body
- The lens is supported on a papilla, but no accommodation and no muscle are known
- Choroidal guanine tapetum lucidum
- Limited shading of the outer segments by the RPE

# Juvenile Sturgeon Eye

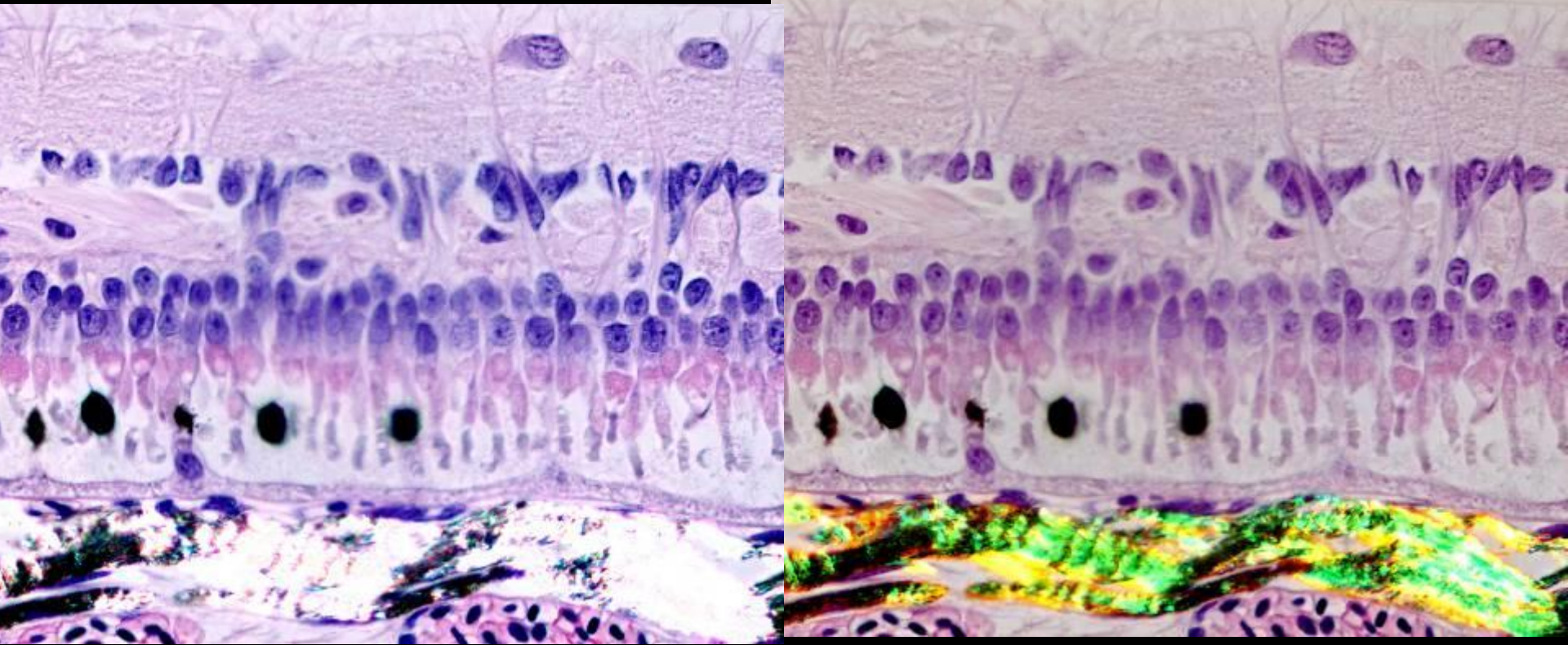


Papilla

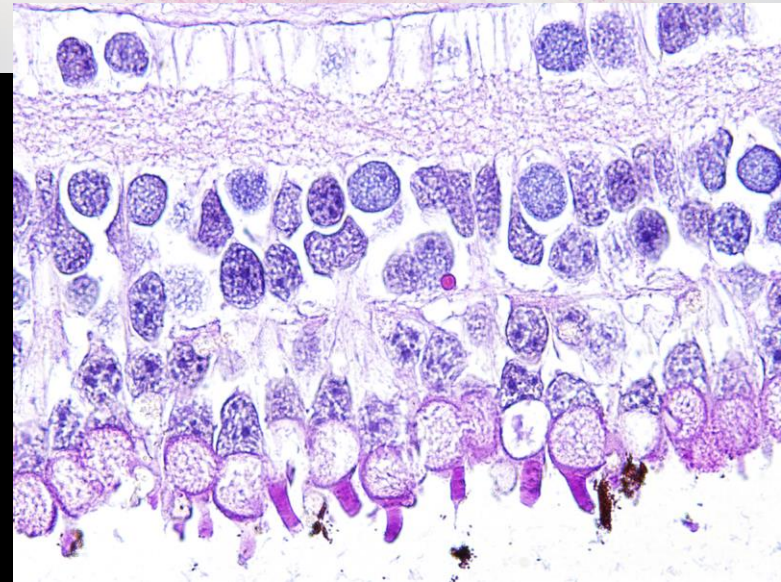
Cartilaginous sclera



# Sturgeon Eye Guanine Tapetum



# Lungfish



- No Choroidal Rete
- No retractor lentis muscle
- Limited shading of outer segments

# Higher Teleosts

- Cartilage and sometimes bone in sclera
- Retractor lentis muscle (smooth muscle) accommodation
- Vascular rete called “choroidal gland”
- RPE melanin has photomechanical movement
- Some fish have a retinal fovea
- Trichromatic vision
- Double cornea (skin and scleral)
- Papillary process supplies blood to the retina



# Higher Teleosts

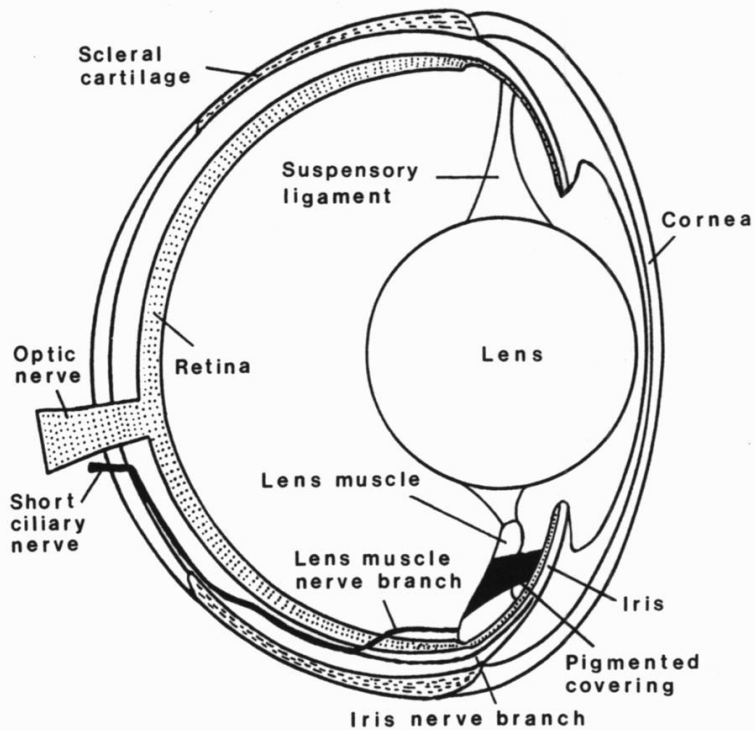
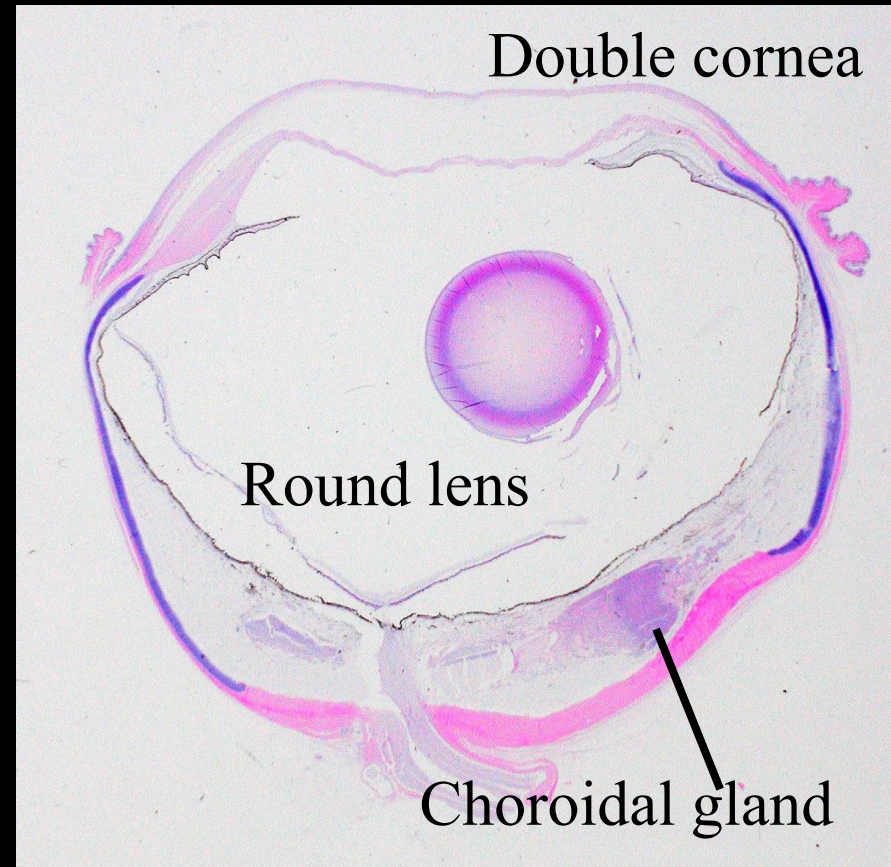


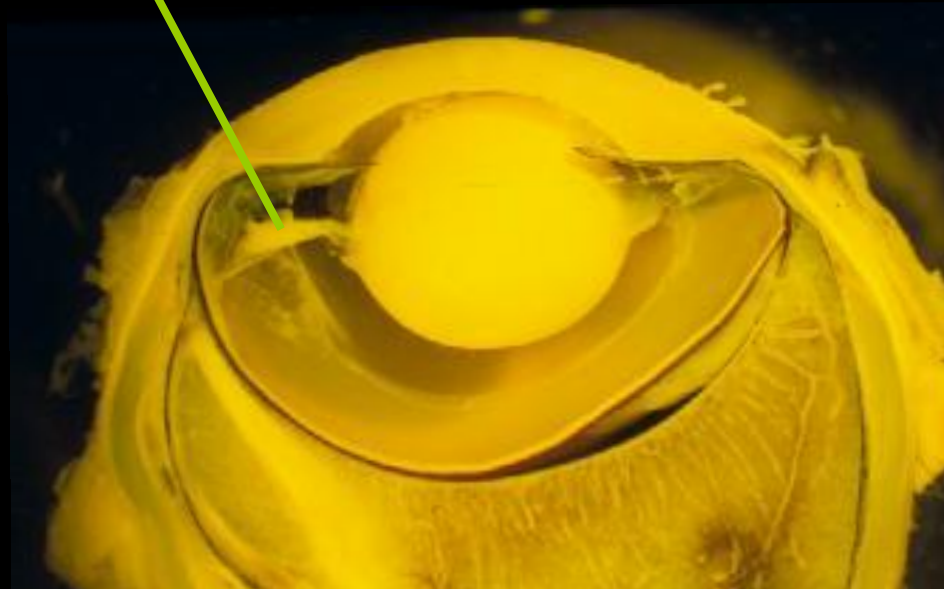
Fig. 7.7. Vertical section of the eye in a bass showing the lens muscle and its nerve supply (from Somiya 1987).



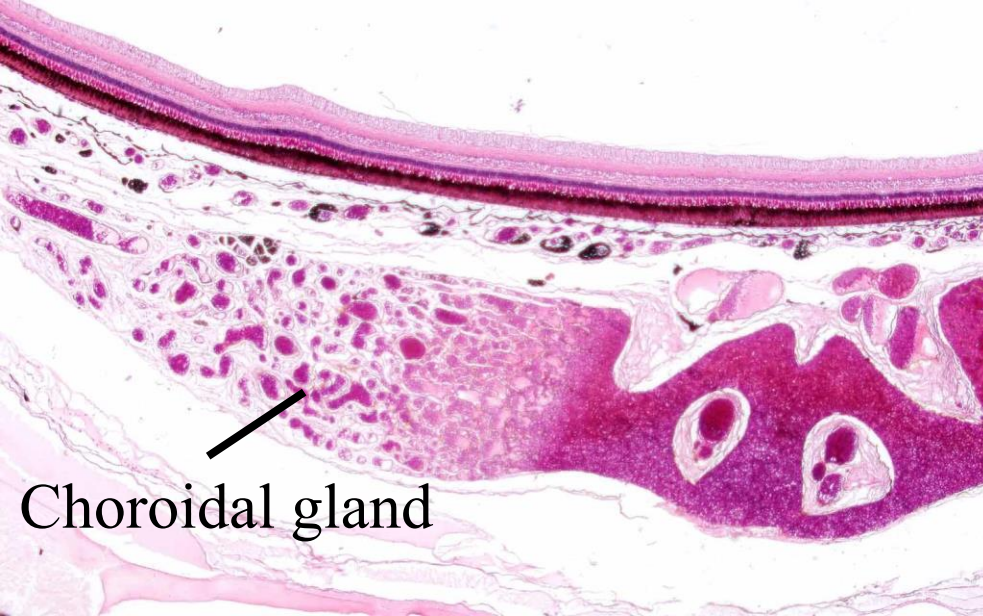
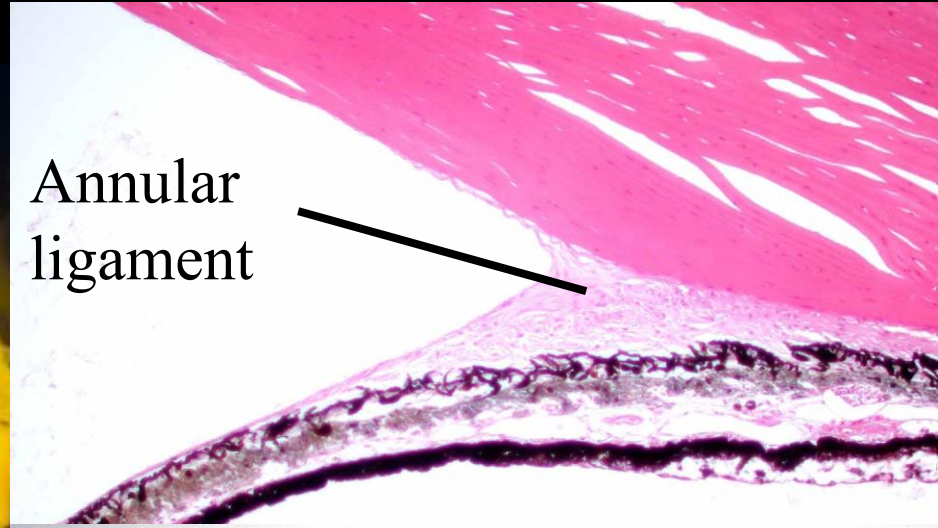
*Walls. The Vertebrate Eye  
and its Adaptive Radiation. 1942.*

# Higher Teleosts

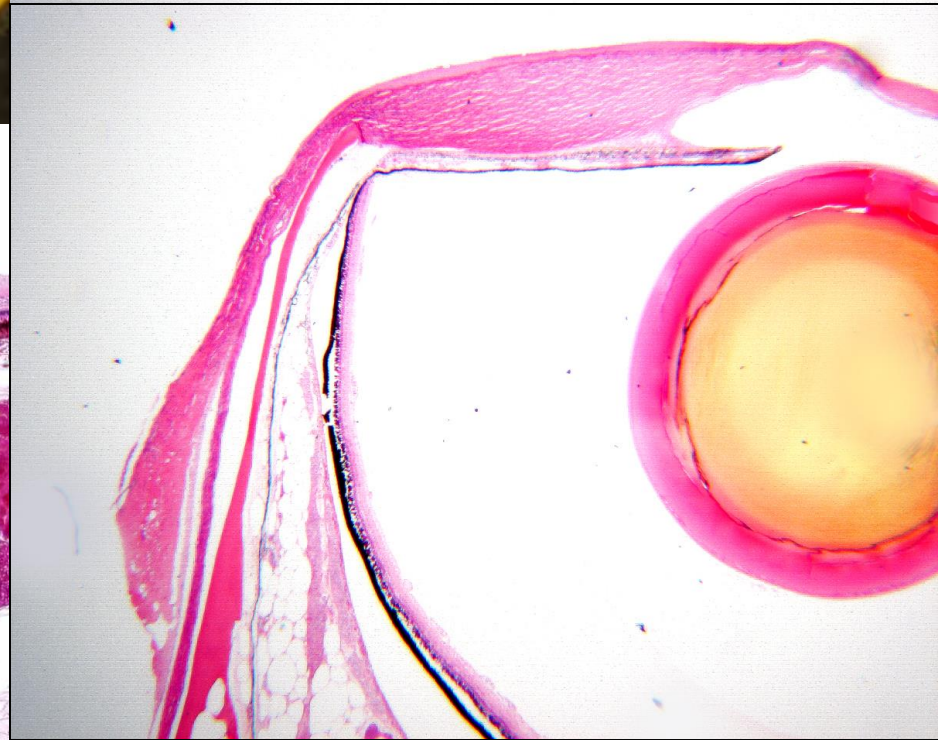
Retractor lentis



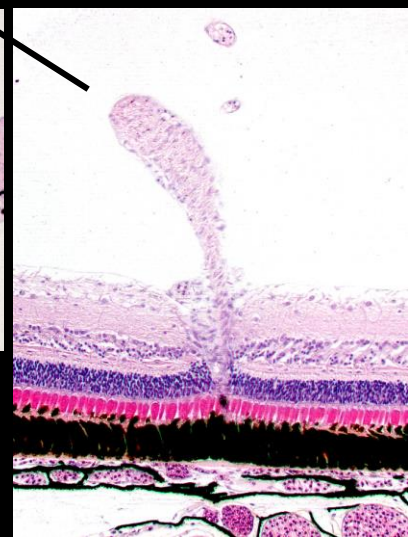
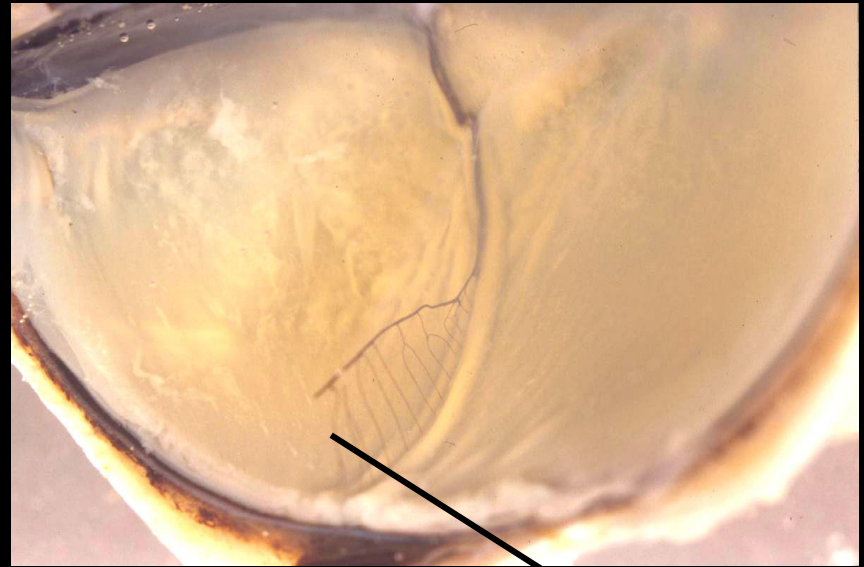
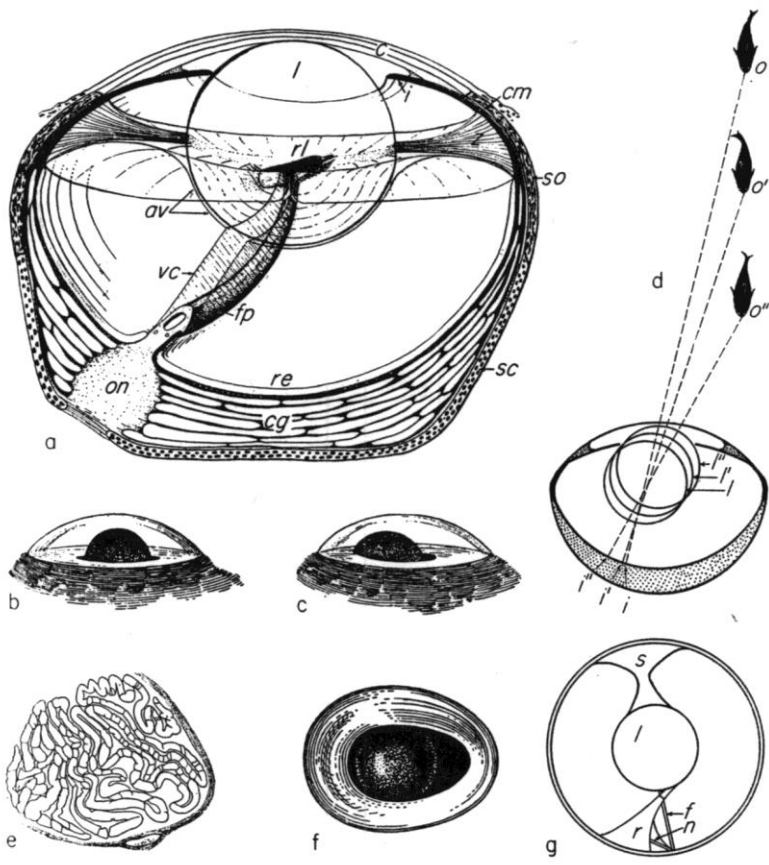
Annular ligament



Choroidal gland



# Higher Teleosts Falciform process & accommodation



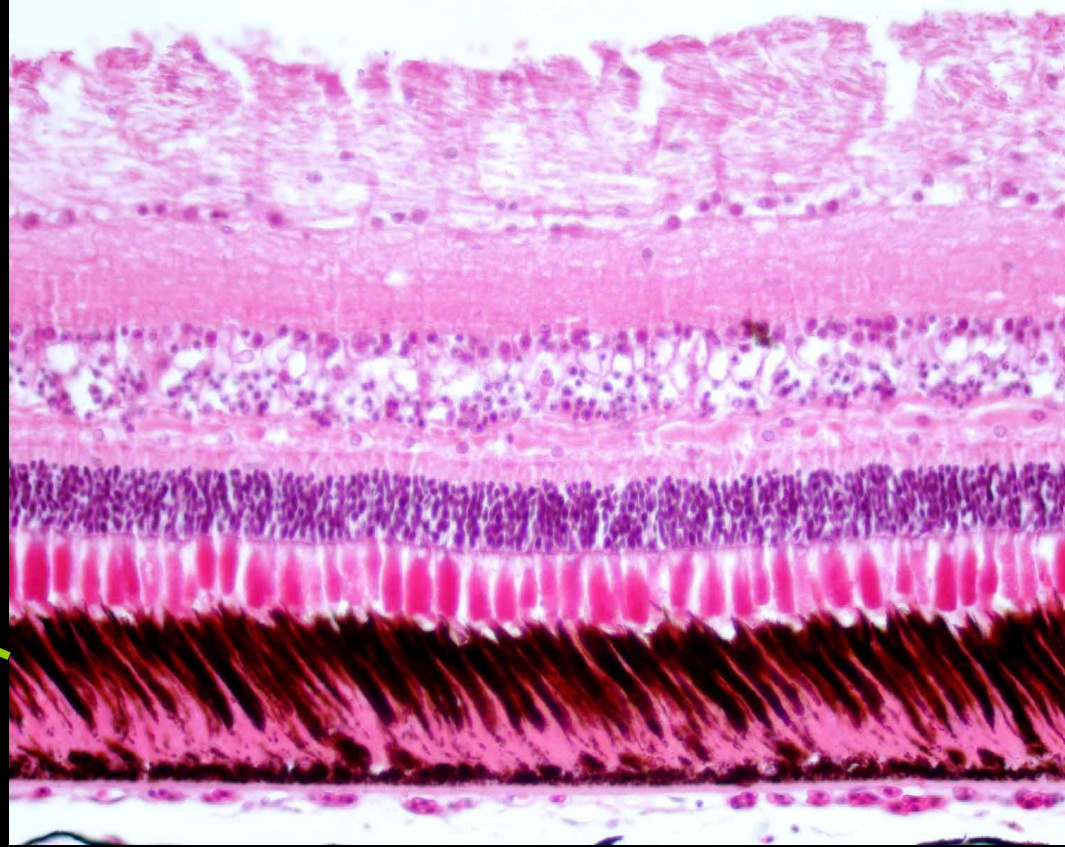
*Walls. The Vertebrate  
Eye and its Adaptive  
Radiation. 1942.*

Retractor lentis muscle

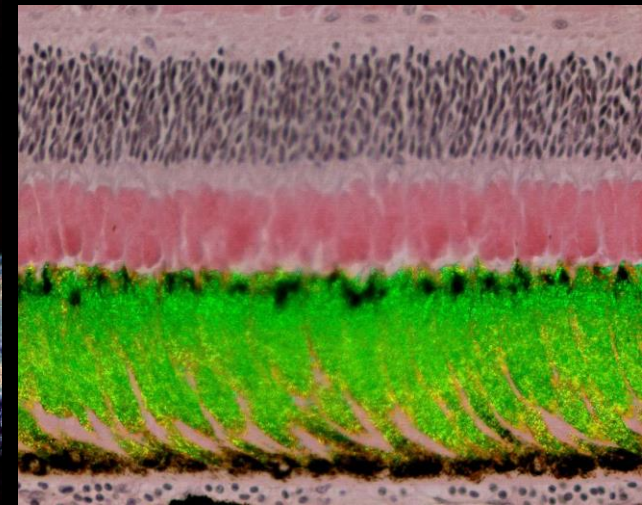
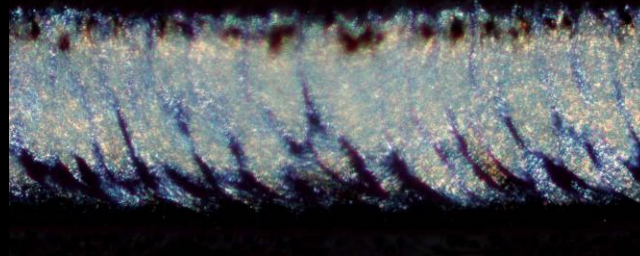
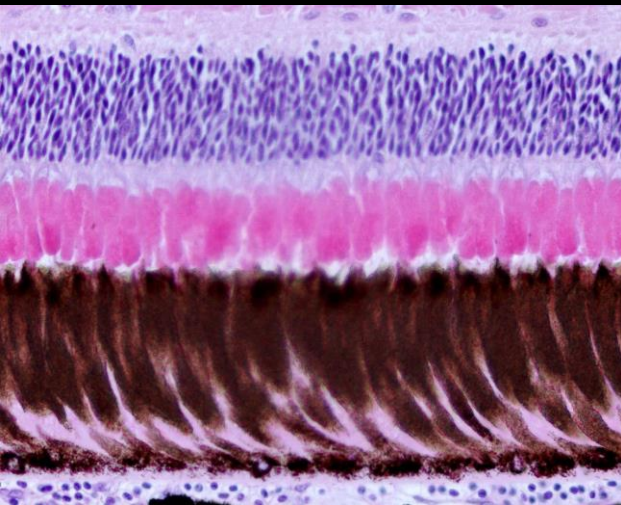
# Higher Teleosts

## Retinal Variations

Photomechanical  
Movement



Guanine in the Retinal Tapetum  
of the Walleye



# Amphibian Eyes

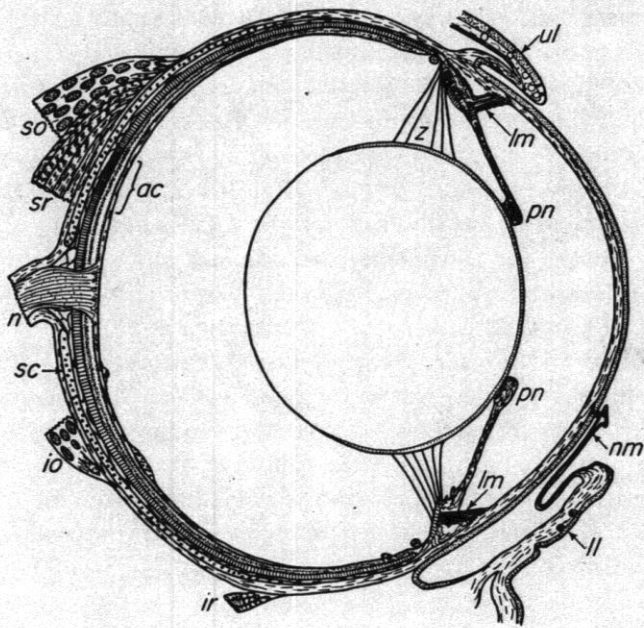
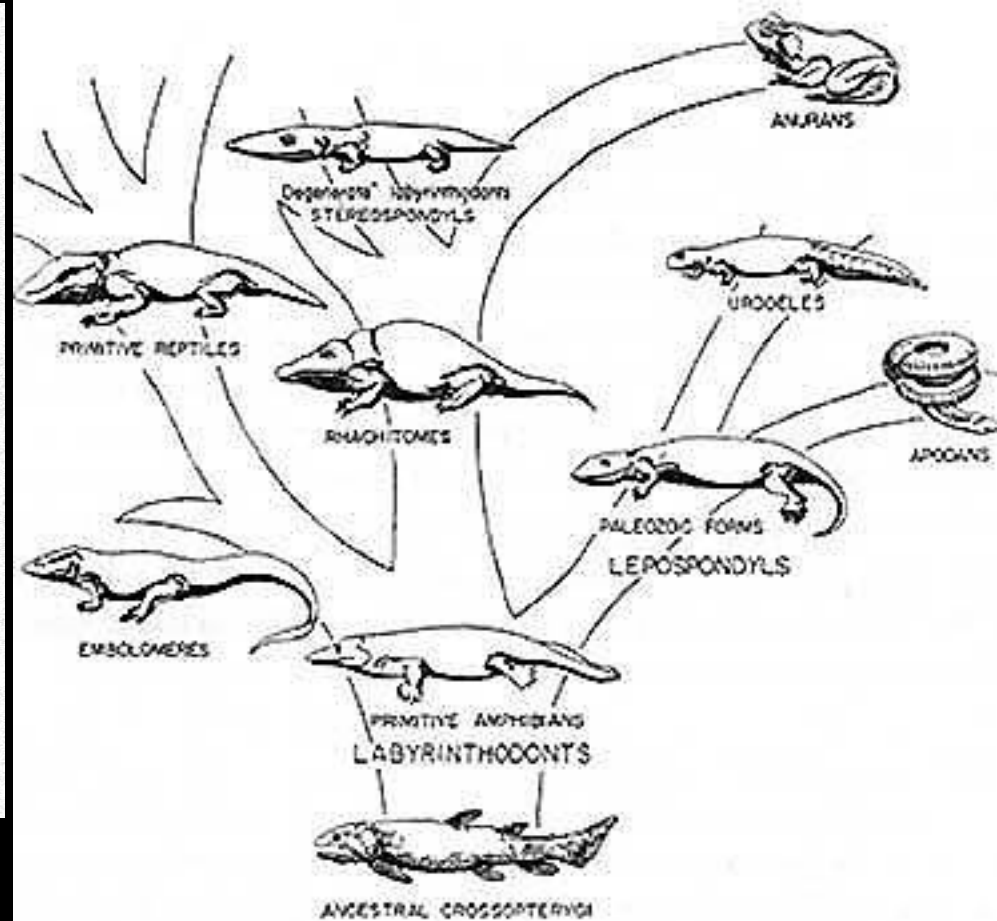


Fig. 172—The anuran eye in vertical section; semi-diagrammatic; based largely upon the leopard frog, *Rana pipiens*.  $\times 11\frac{1}{2}$ .

*ac*- area centralis; *io*- inferior oblique; *ir*- inferior rectus; *ll*- lower lid; *lm*, *lm*- lens muscles (cf. Fig. 173); *n*- optic nerve; *nm*- 'nictitating membrane'; *pn*, *pn*- pupillary nodules; *sc*- scleral cartilage; *so*- superior oblique; *sr*- superior rectus; *ul*- upper lid; *z*- zonule.



Walls

# Features of Amphibian Eyes

- Cartilaginous sclera, but no bone
- Trichromatic vision
- Photomechanical motion in the RPE
- Minimal amount of accommodation with smooth muscle
- Double cornea only in the tadpole
- No annular pad in lens
- Retractor bulbi muscle and eyelids

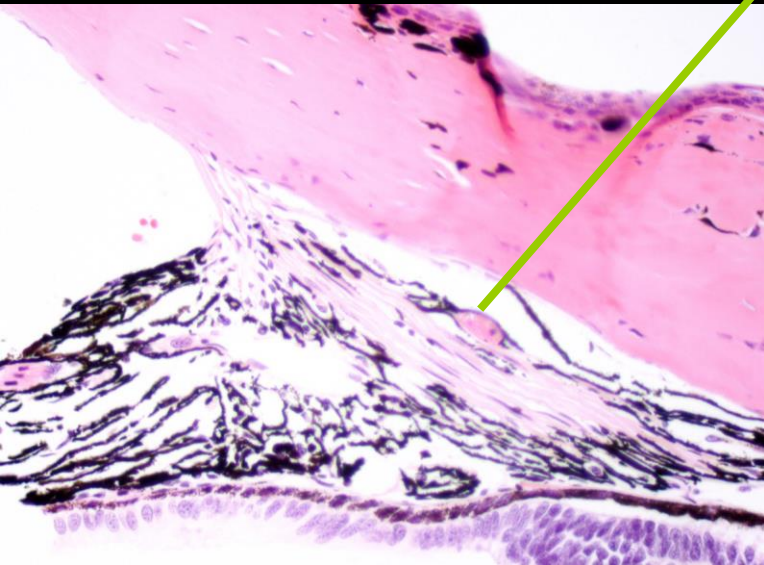
# Features of Amphibian Eyes

## Frogs and Toads



Bull  
Frog

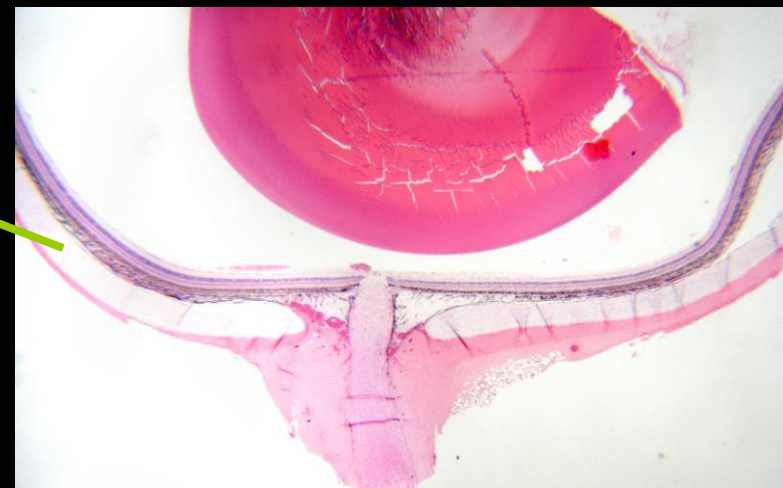
Smooth Muscle



Cartilage



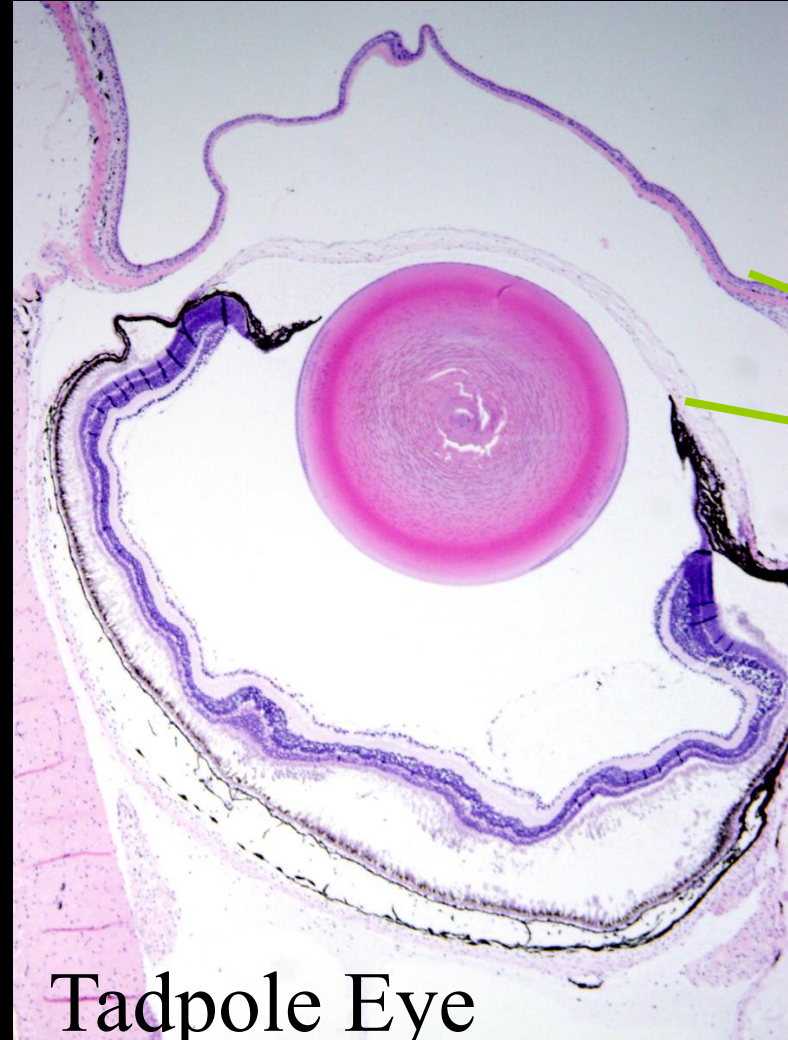
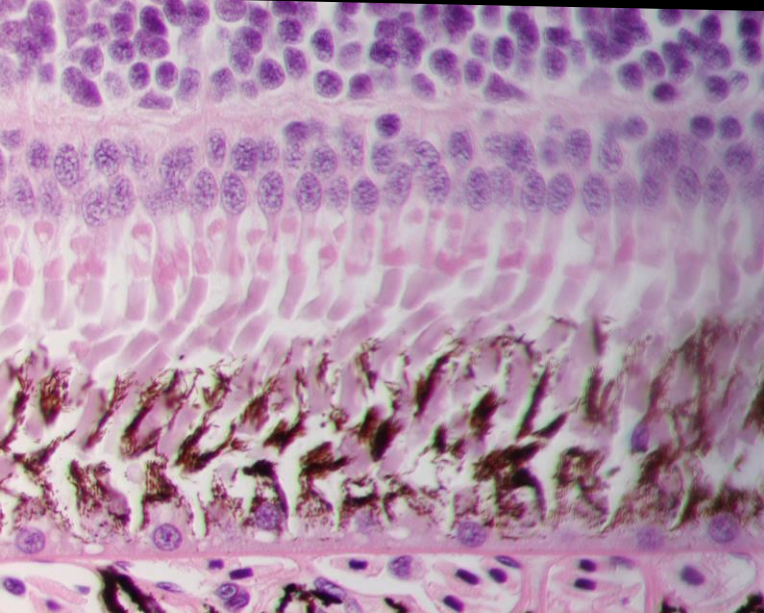
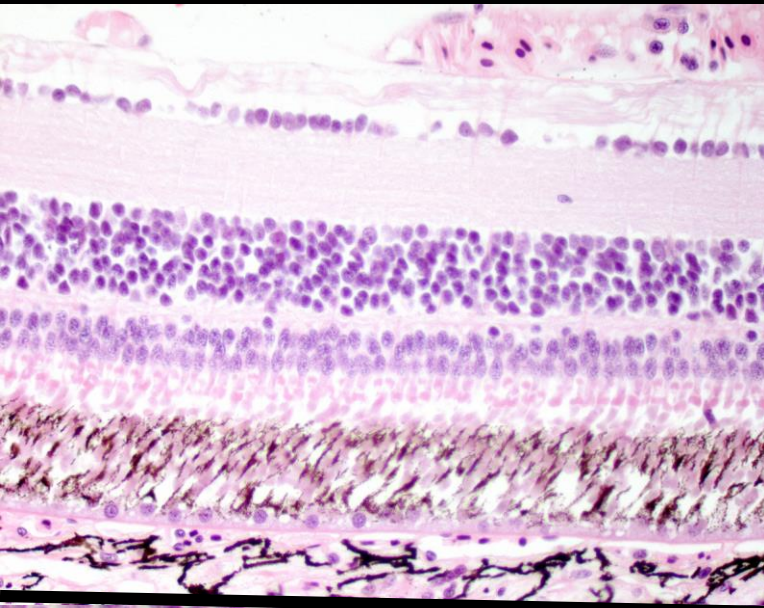
Cornea



# Features of Amphibian Eyes

Frogs and Toads

Retina

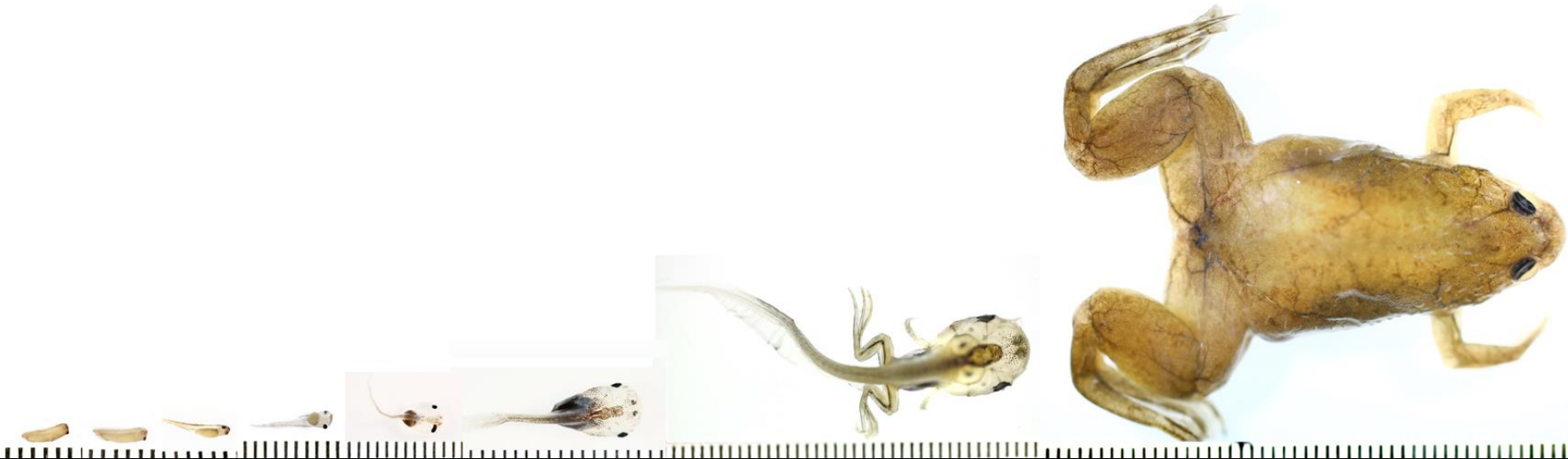


Cornea

Tadpole Eye



# Xenopus Tadpole



# Xenopus Tadpole

6 to 7 Weeks



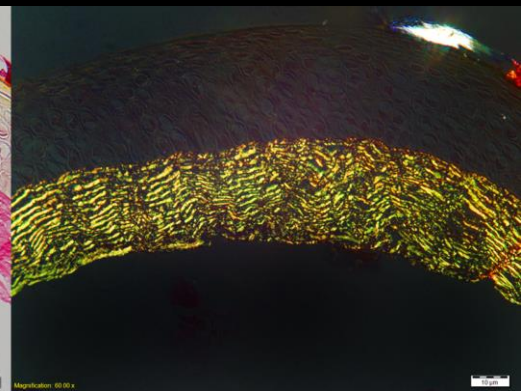
4 to 5 Months



6 to 7 Weeks



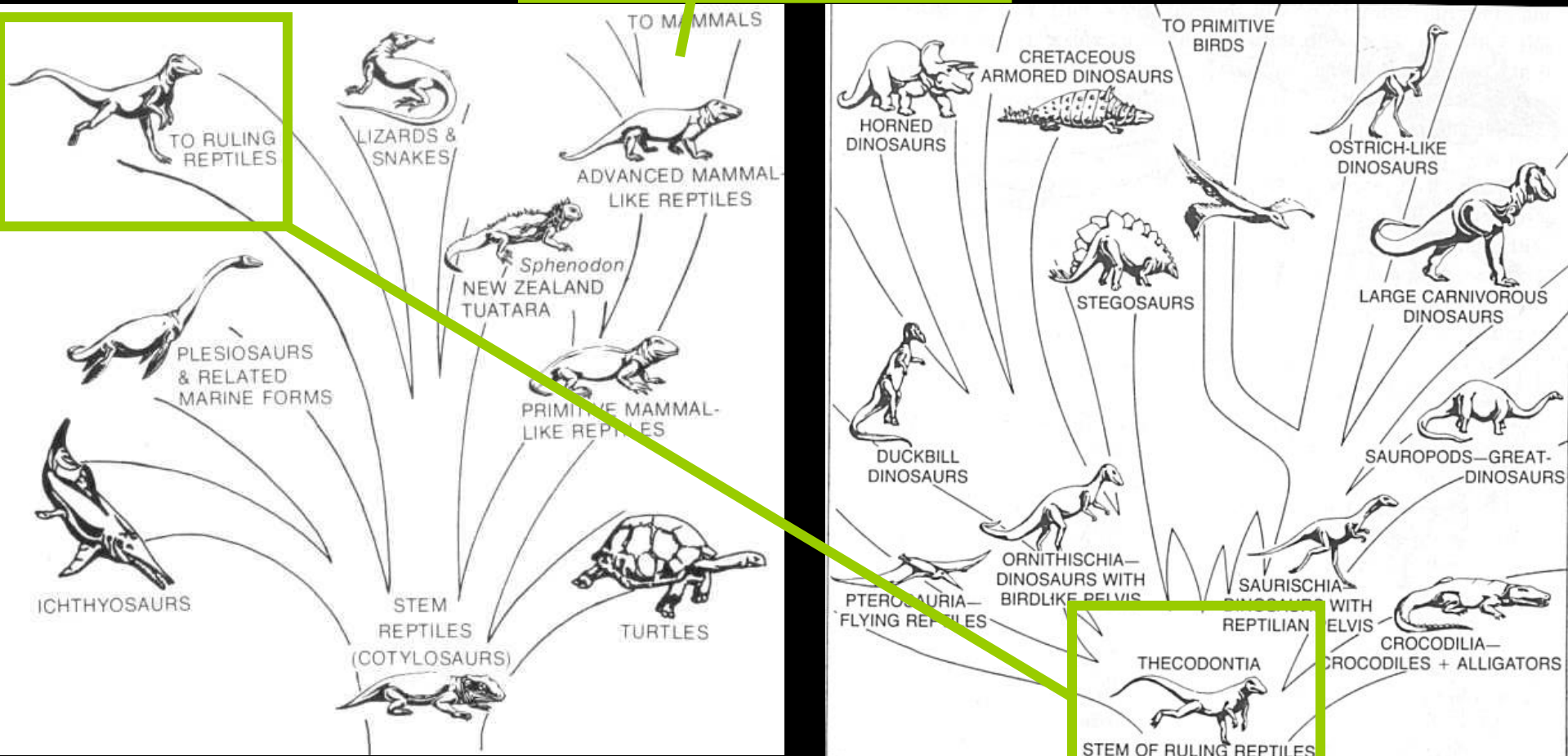
4 to 5 Months



# The Rise of Reptiles

Duck-billed Platypus  
Monotreme

Birds

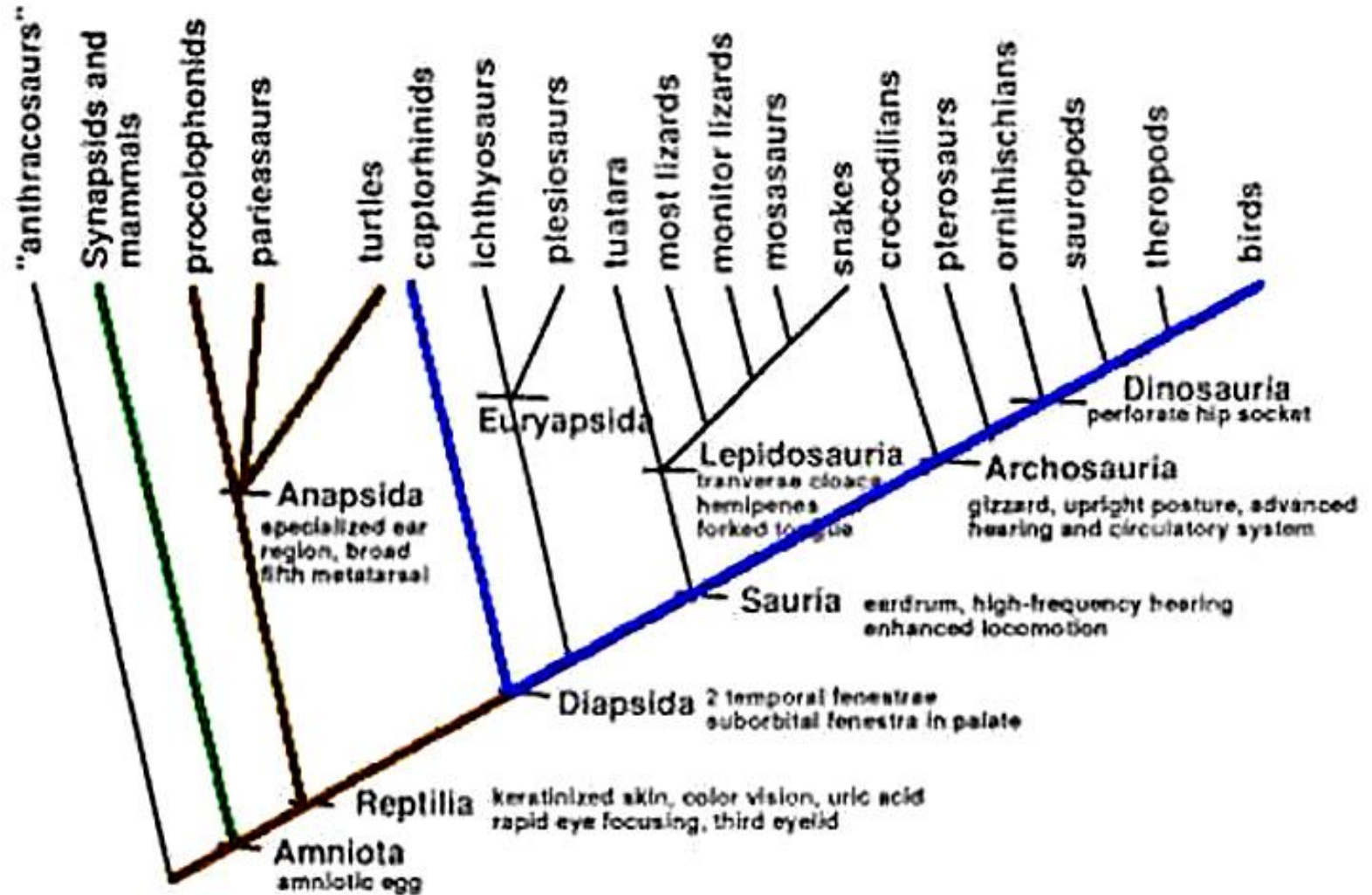


Amphibians

# Contrasting Features

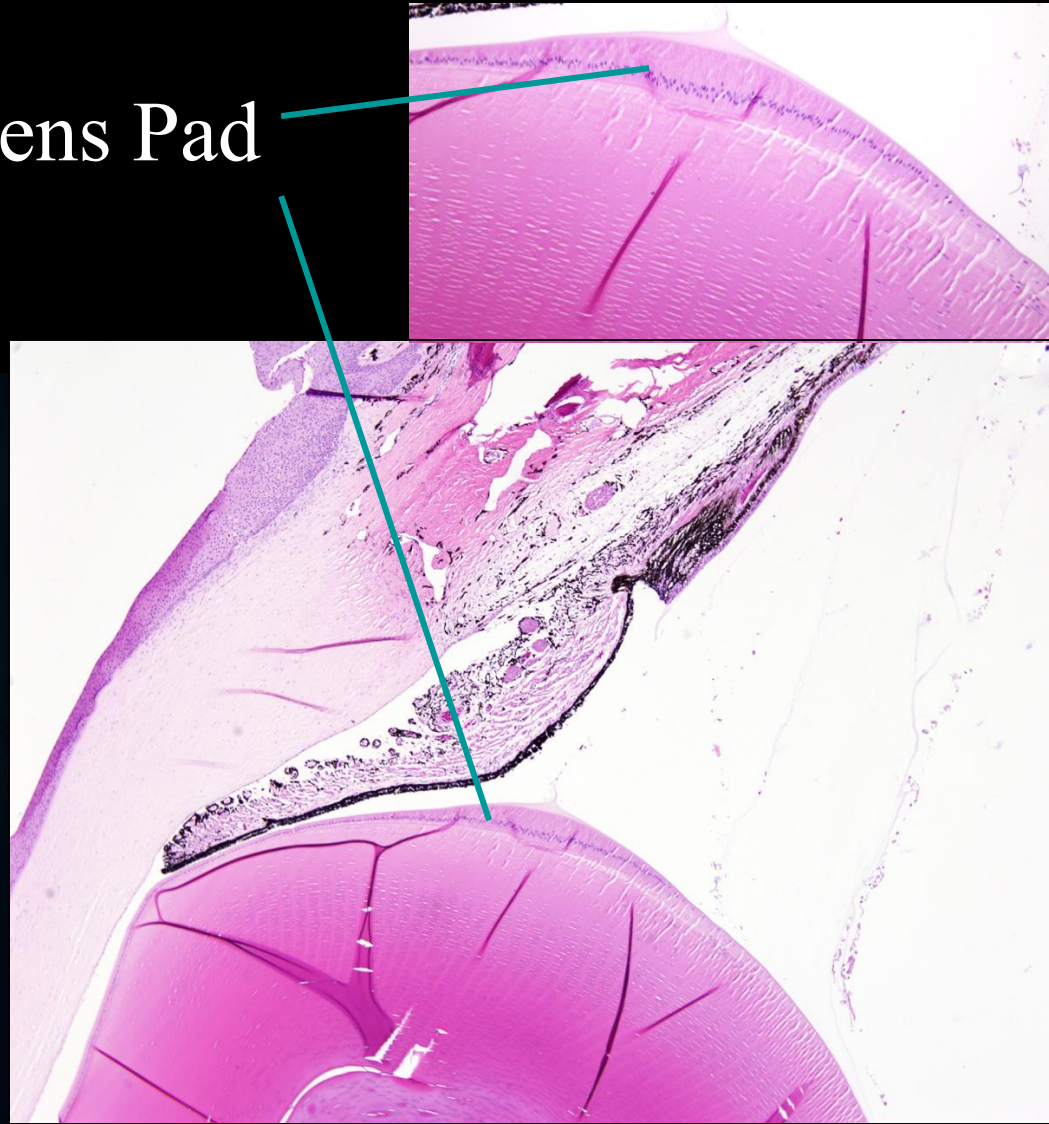
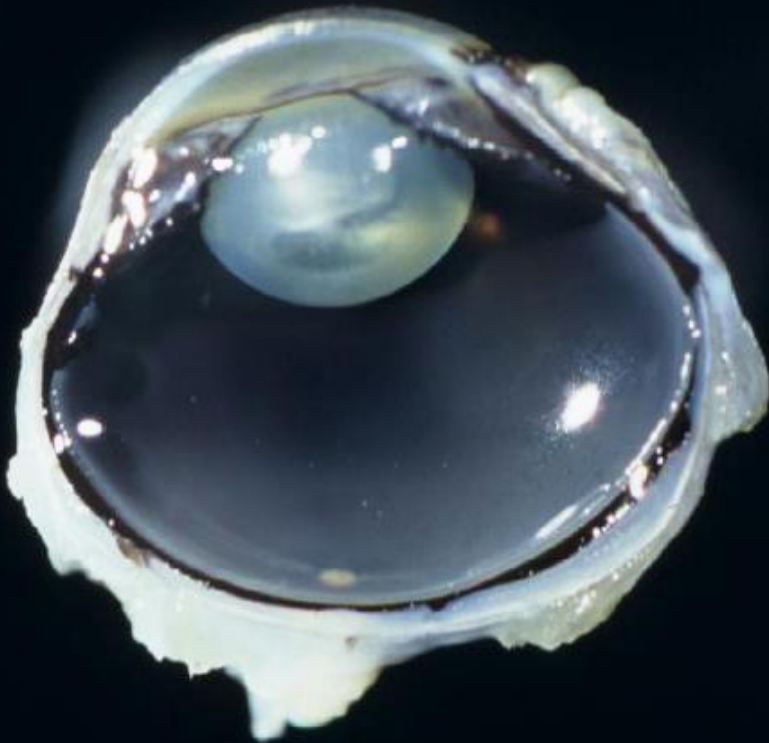
Amphibian	Platypus	Placental Mammal	Turtle
Cartilage, no bone	Cartilage, no bone	No bone or cartilage	Cartilage and bone
Uveal muscle is smooth muscle	No uveal muscle	Uveal muscle is smooth muscle	Uveal muscle is skeletal muscle
Photomechanical movement	Photomechanical movement	No photomechanical movement	Photomechanical movement
No annular lens pad	No annular lens pad	No annular lens pad	Small annular pad

# Reptiles

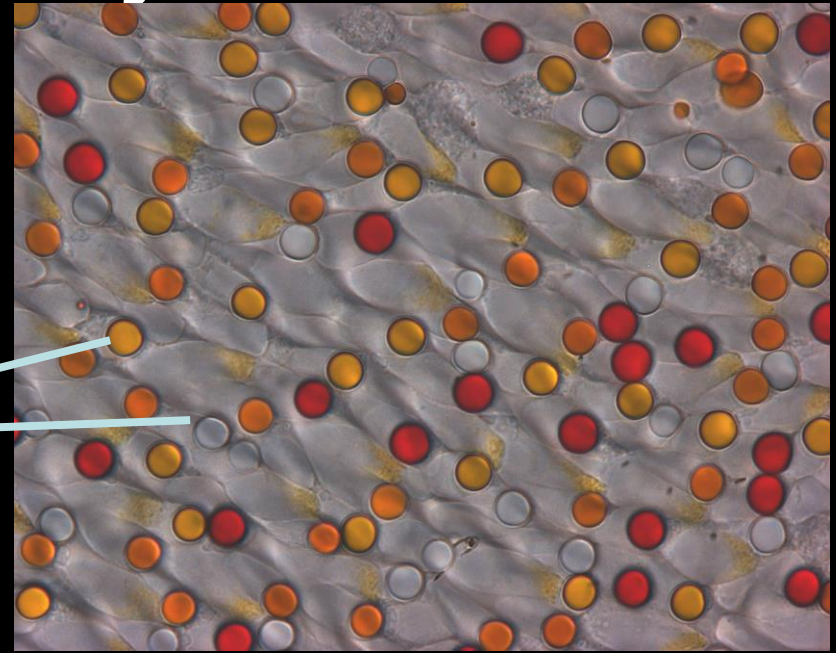
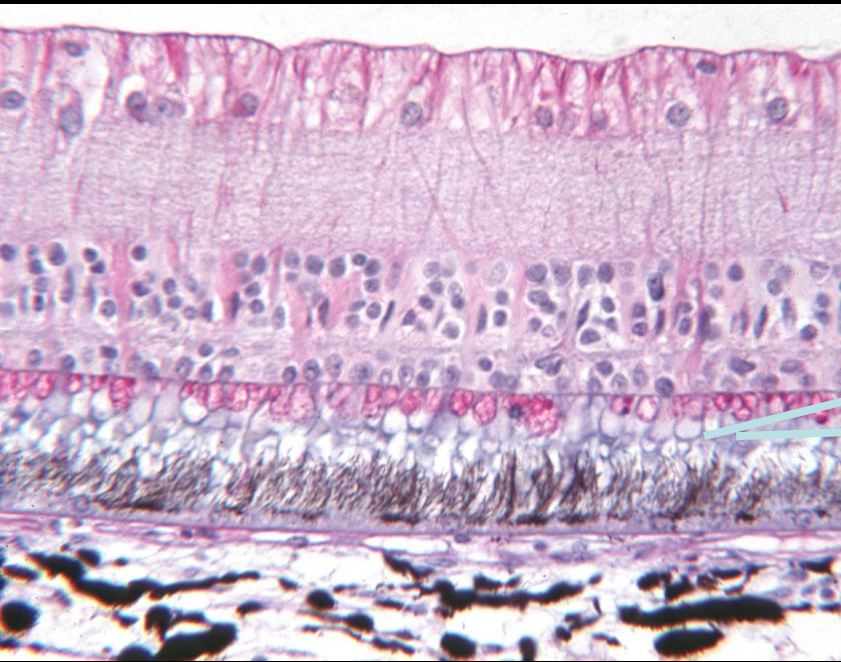


# Turtle Eyes

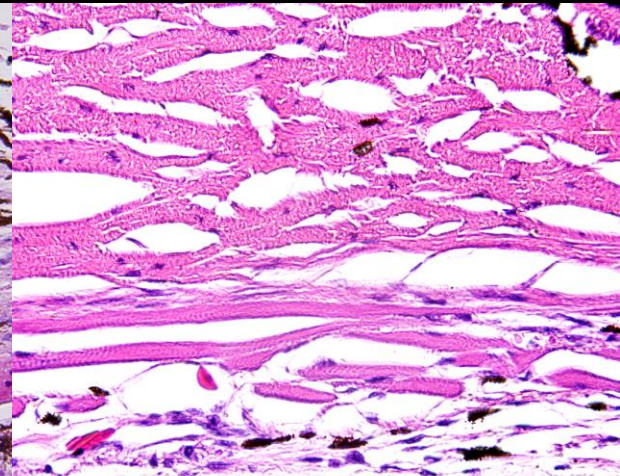
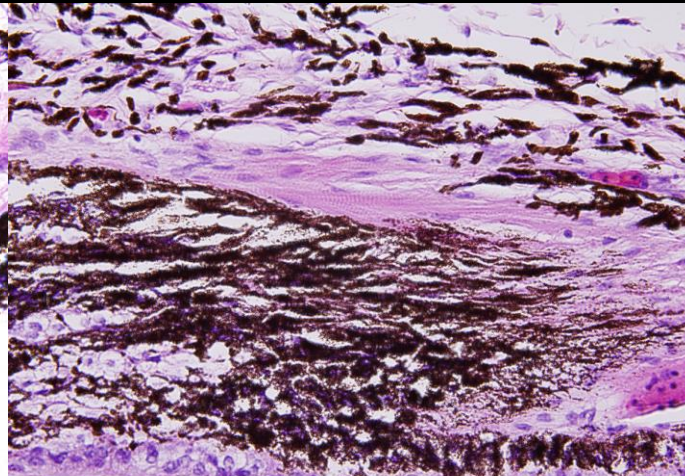
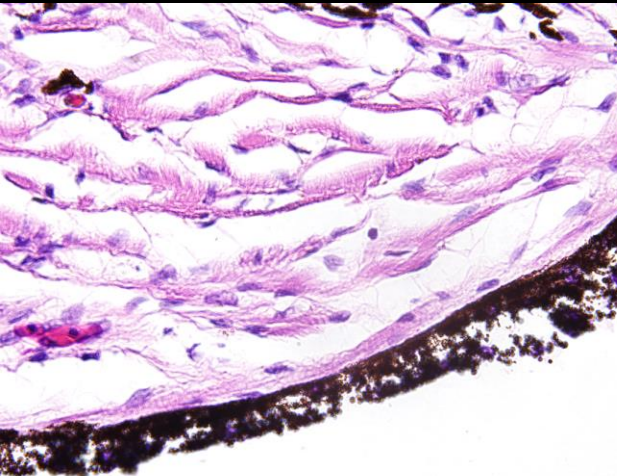
Annular Lens Pad



# Turtle Eye



## Skeletal Muscle



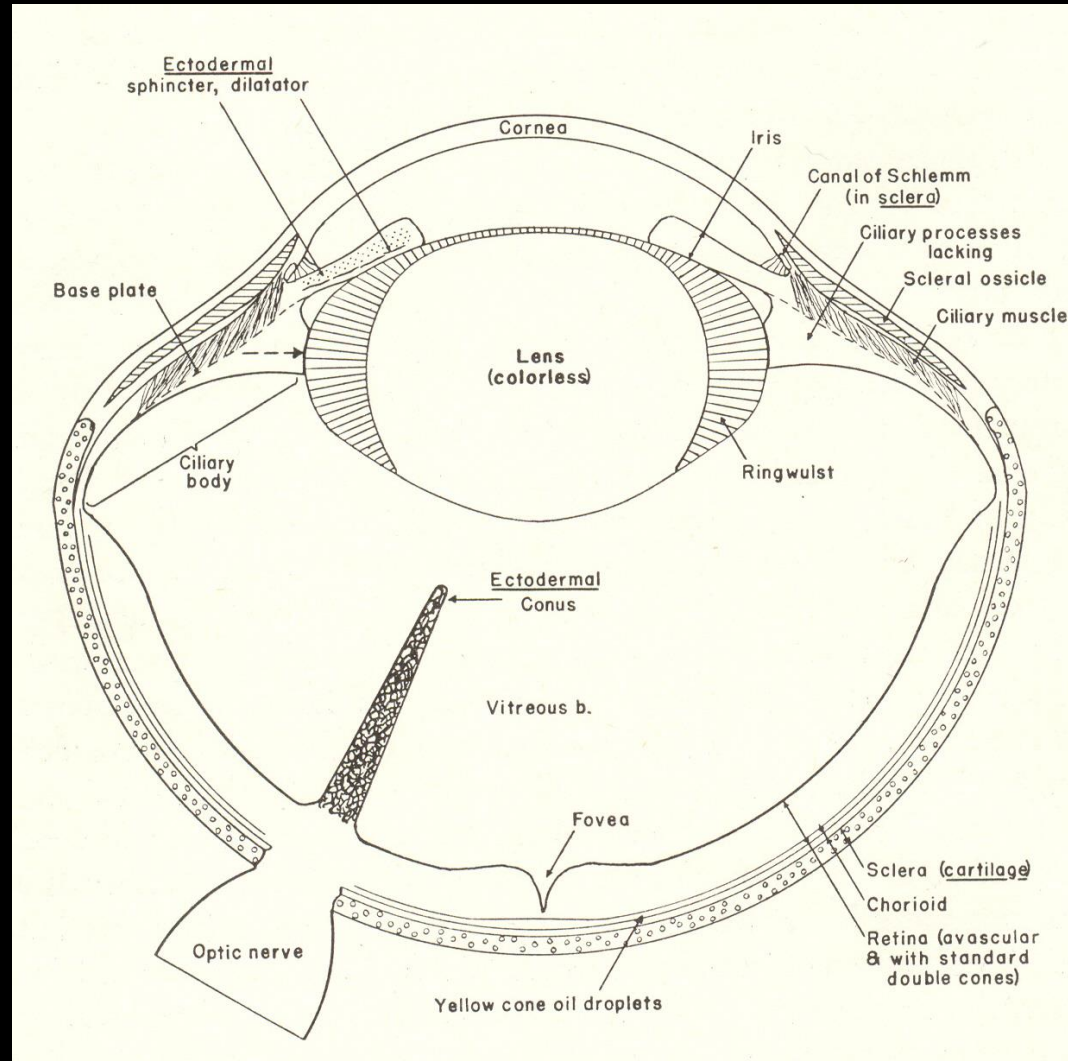
# Lizards

- General features of lizard eyes
  - Scleral bone and cartilage
  - Annular pad in lens
  - Skeletal muscles for accommodation
  - Trichromatic vision or more
  - Fovea
  - Avascular retina with special adaptations for blood supply
  - Special considerations by group
    - Tuatara, the most primitive of the extant lizards
      - Lacks a conus papillaris
    - Iguana, Chameleons, Monitors
    - Gecko
      - Ecdysis
      - Spectacle
    - Snakes are treated separately



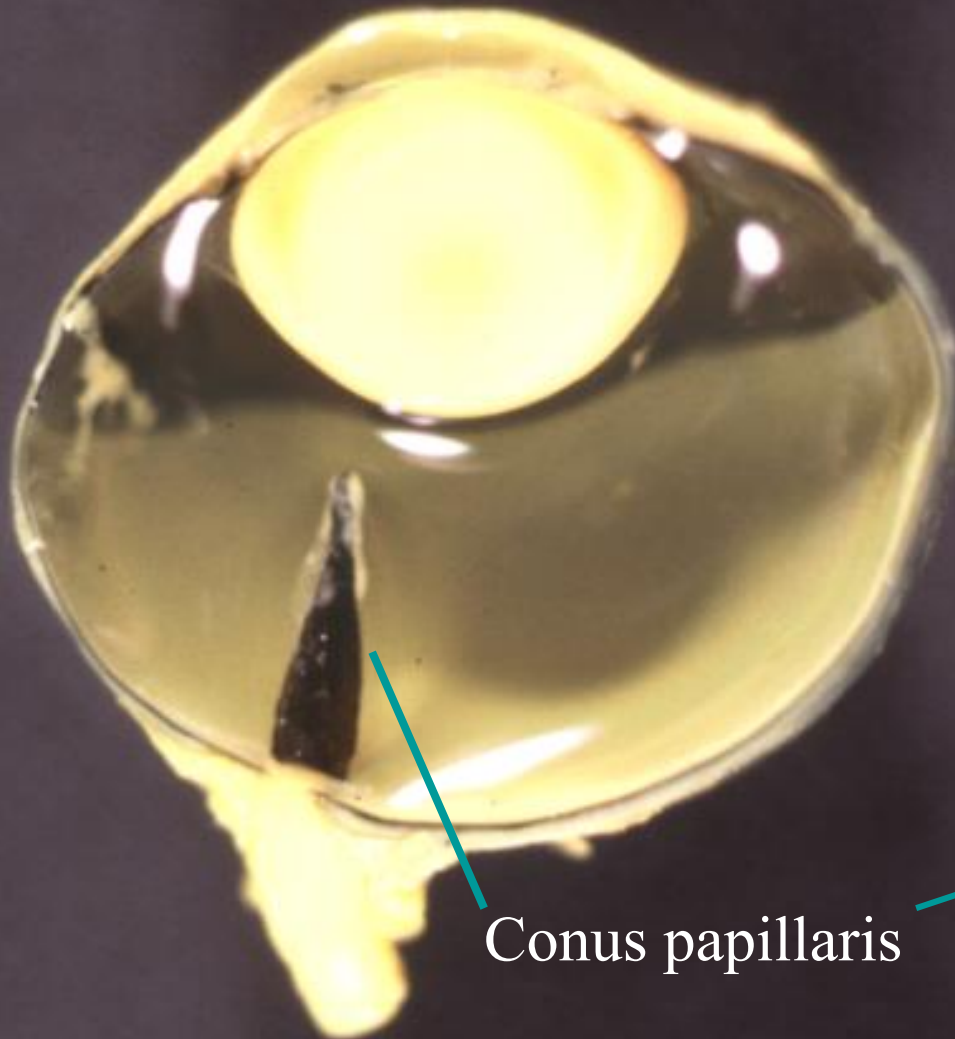


# General Features of Lizard Eyes

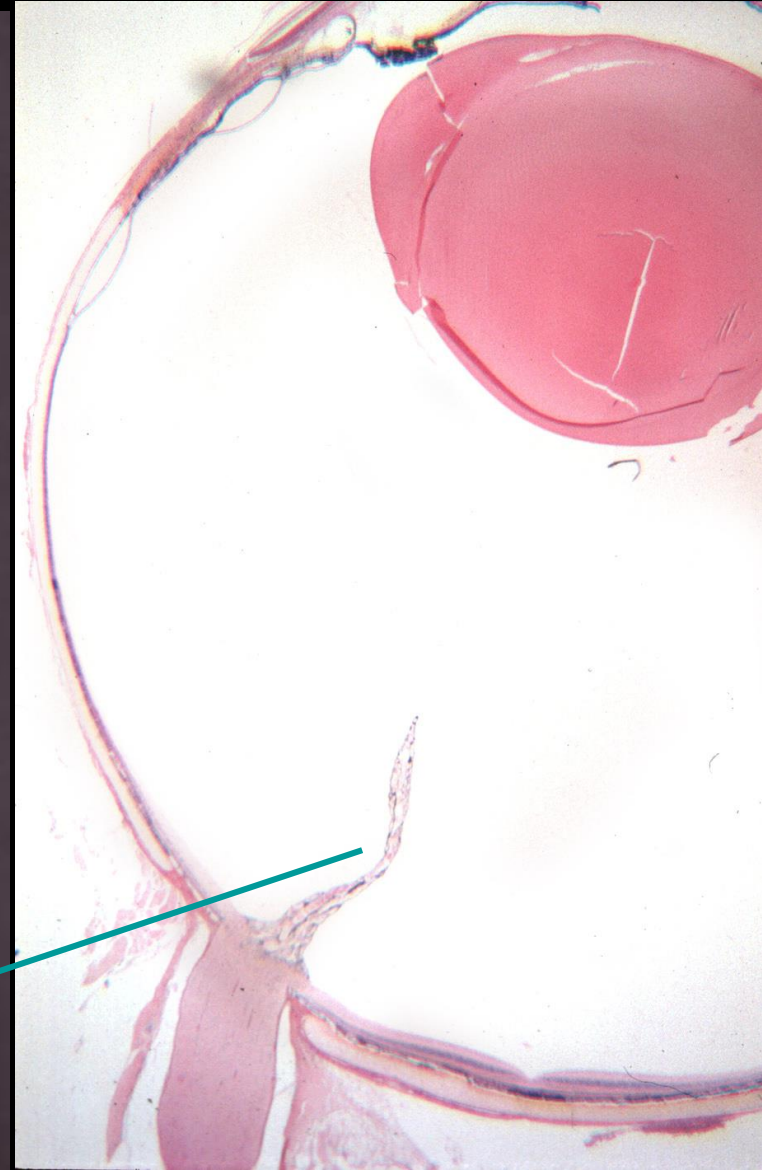


Walls

# Features of Lizard Eyes

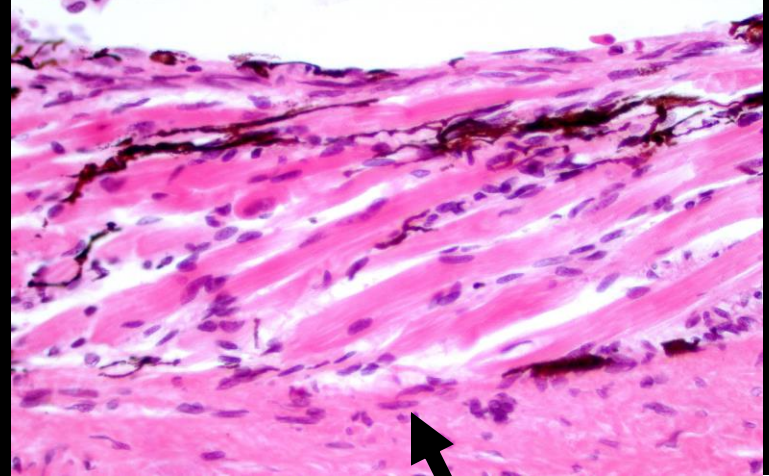
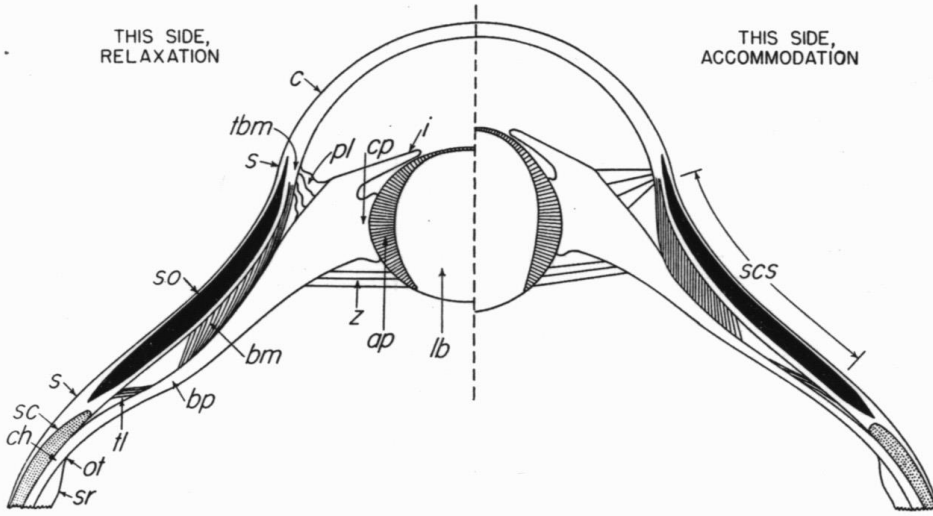


Conus papillaris



# Features of Lizard Eyes

## Accommodation



Chameleon Magnifying Lens

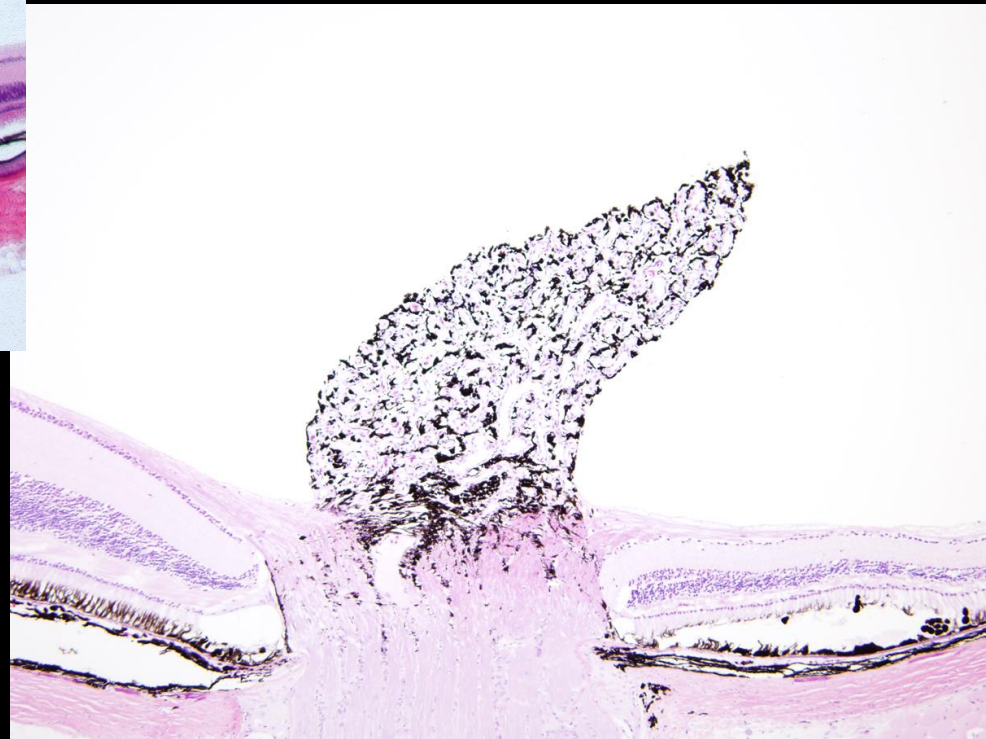


# Features of Lizard Eyes

## Conus Papillaris



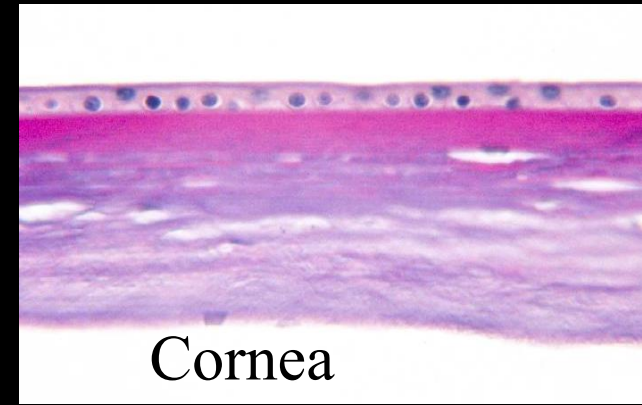
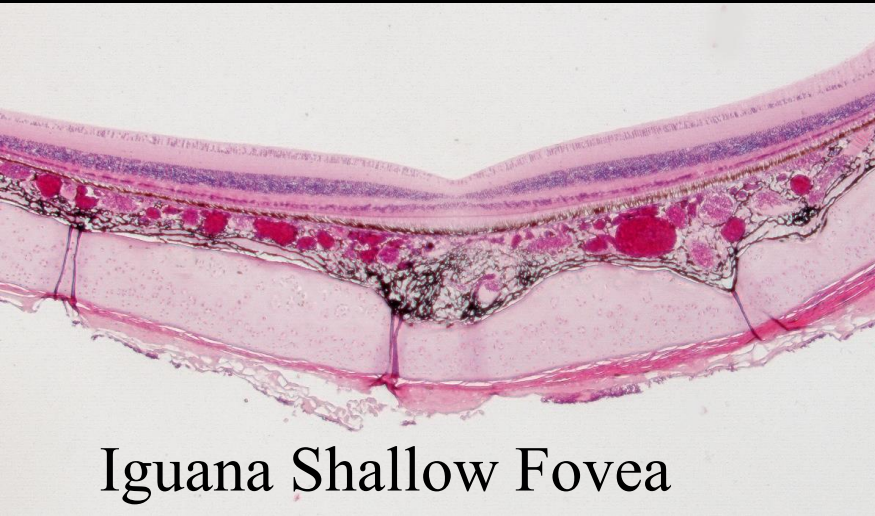
Gecko



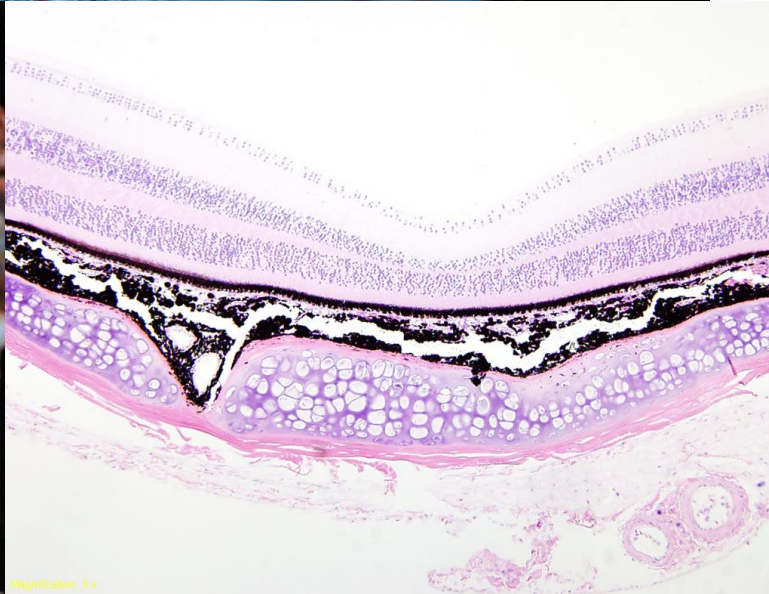
Chameleon

# Features of Lizard Eyes

## Retina & Cornea



# Chameleon Eyes



# Features of Snake Eyes

- Snakes are closely related to the lizards and are thought to have lost ocular features in a degenerative process
- No cartilage or bone
- No annular lens pad
- Smooth muscle in iris, none in ciliary body
- Vessels on the inner surface of the retina
- Some snakes have a conus papillaris
- Photomechanical movement in the RPE
- Spectacle in front of cornea



# Features of Snake Eyes

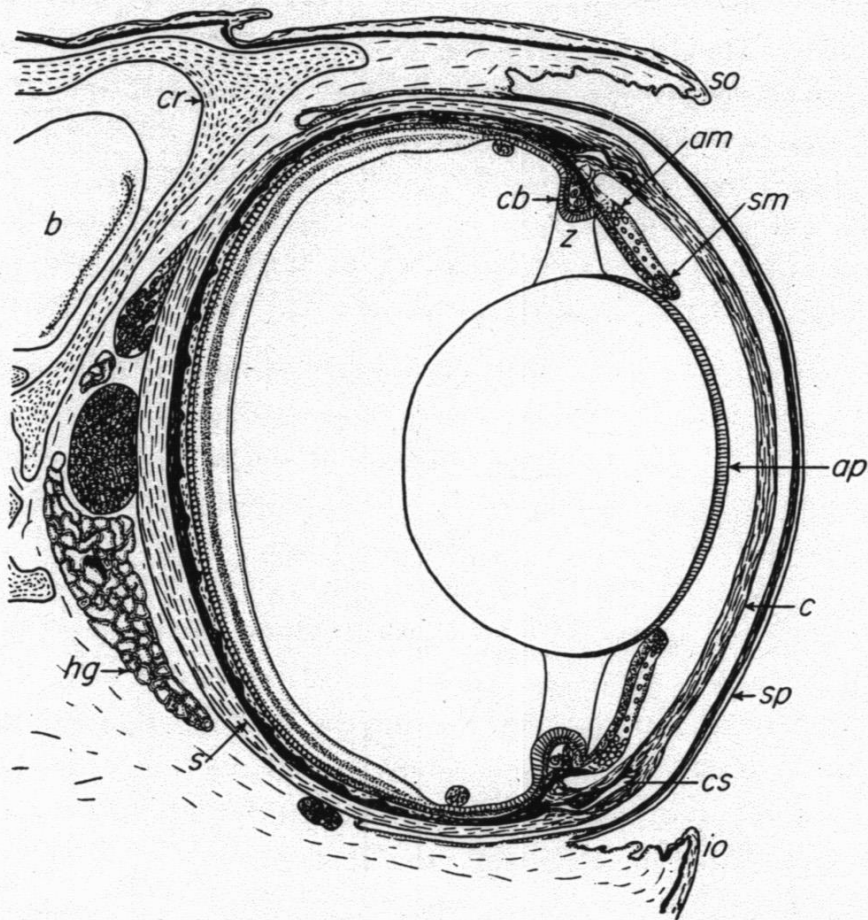


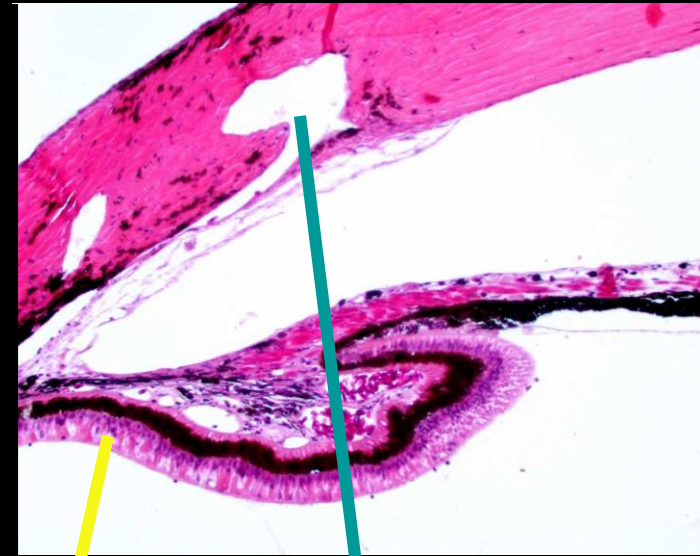
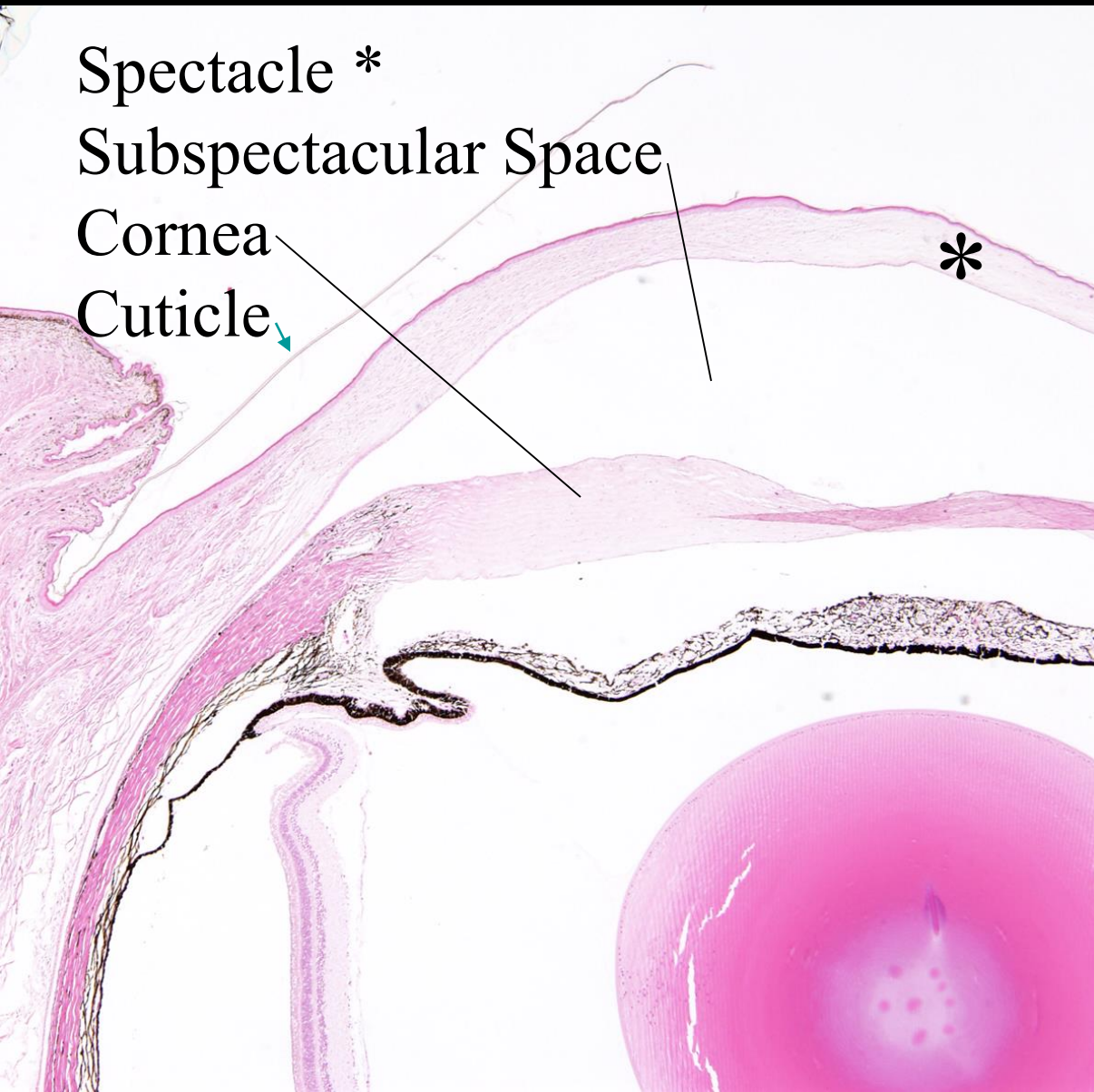
Fig. 181—The ophidian eye in vertical section: *Natrix natrix*.  $\times 22$ .  
Redrawn from Schwarz-Karsten, modified from original preparations.

*am*- accommodatory muscle; *ap*- anterior pad of lens; *b*- brain; *c*- cornea; *cb*- ciliary body (main portion, the ciliary roll; note cross-section of hyaloid vein lying on orbiculus behind it; the very small vessels of the hyaloid plexus, lying on the inner surface of the retina, are omitted from the drawing); *cr*- cranium; *cs*- canal of Schlemm; *hg*- Harderian gland; *io*- infraocular scale; *s*- sclera; *sm*- sphincter muscle; *so*- supraocular scale; *sp*- spectacle; *z*- zonule (collapsed; see text).





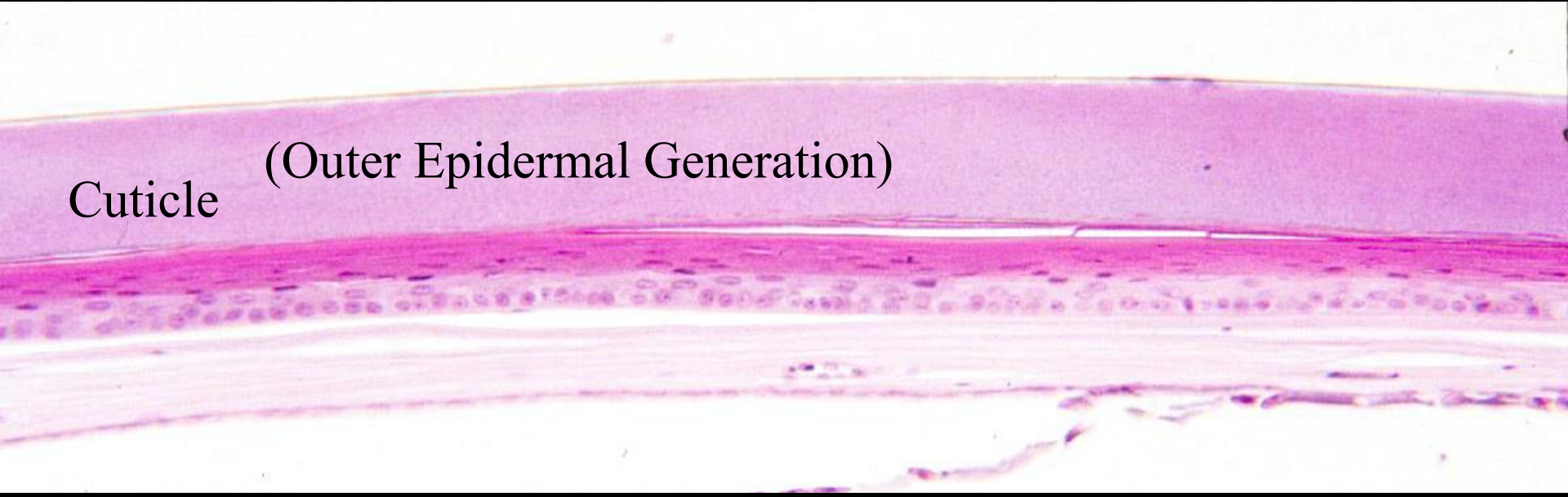
# Features of Snake Eyes



Schlemm's canal  
Ciliary roll

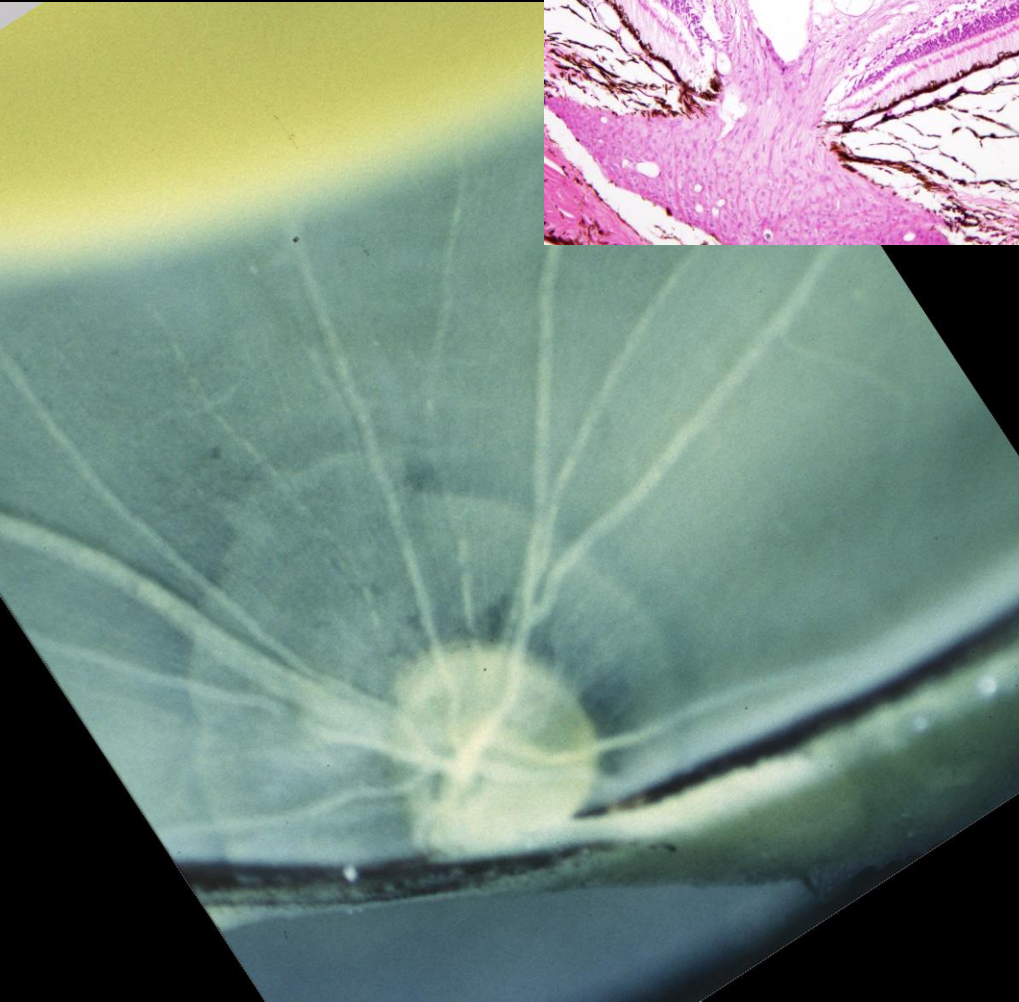
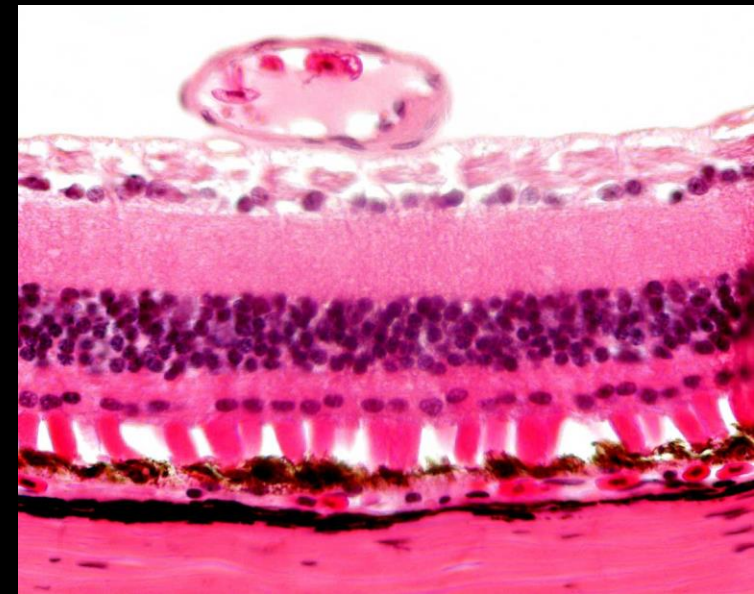
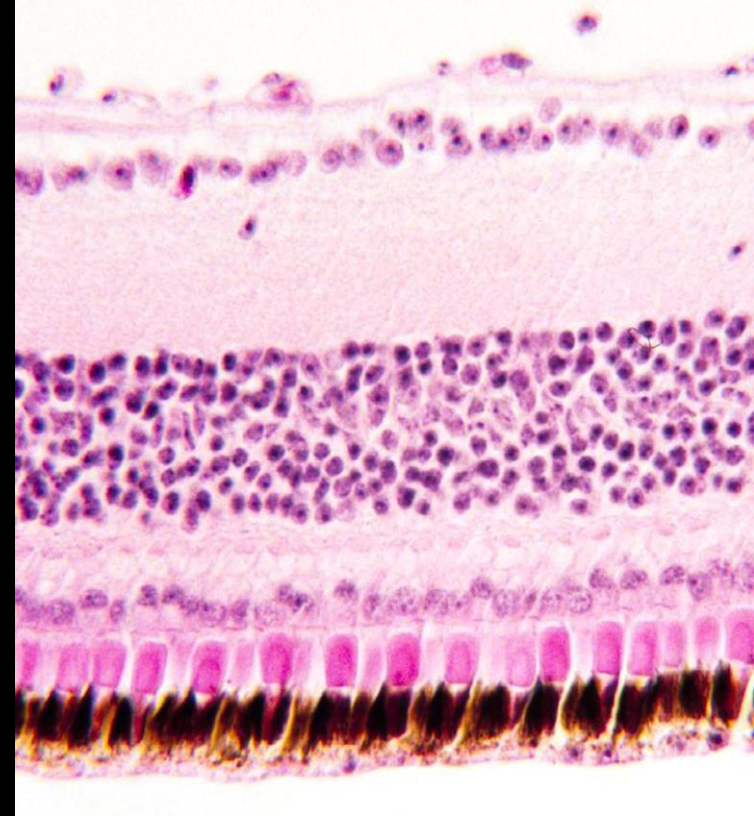
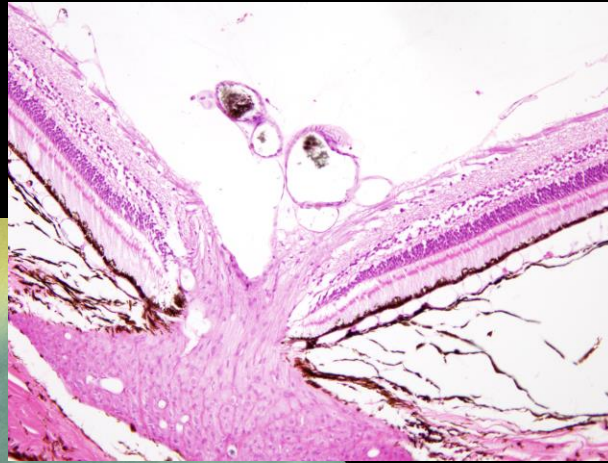
# Ecdysis

Cuticle (Outer Epidermal Generation)

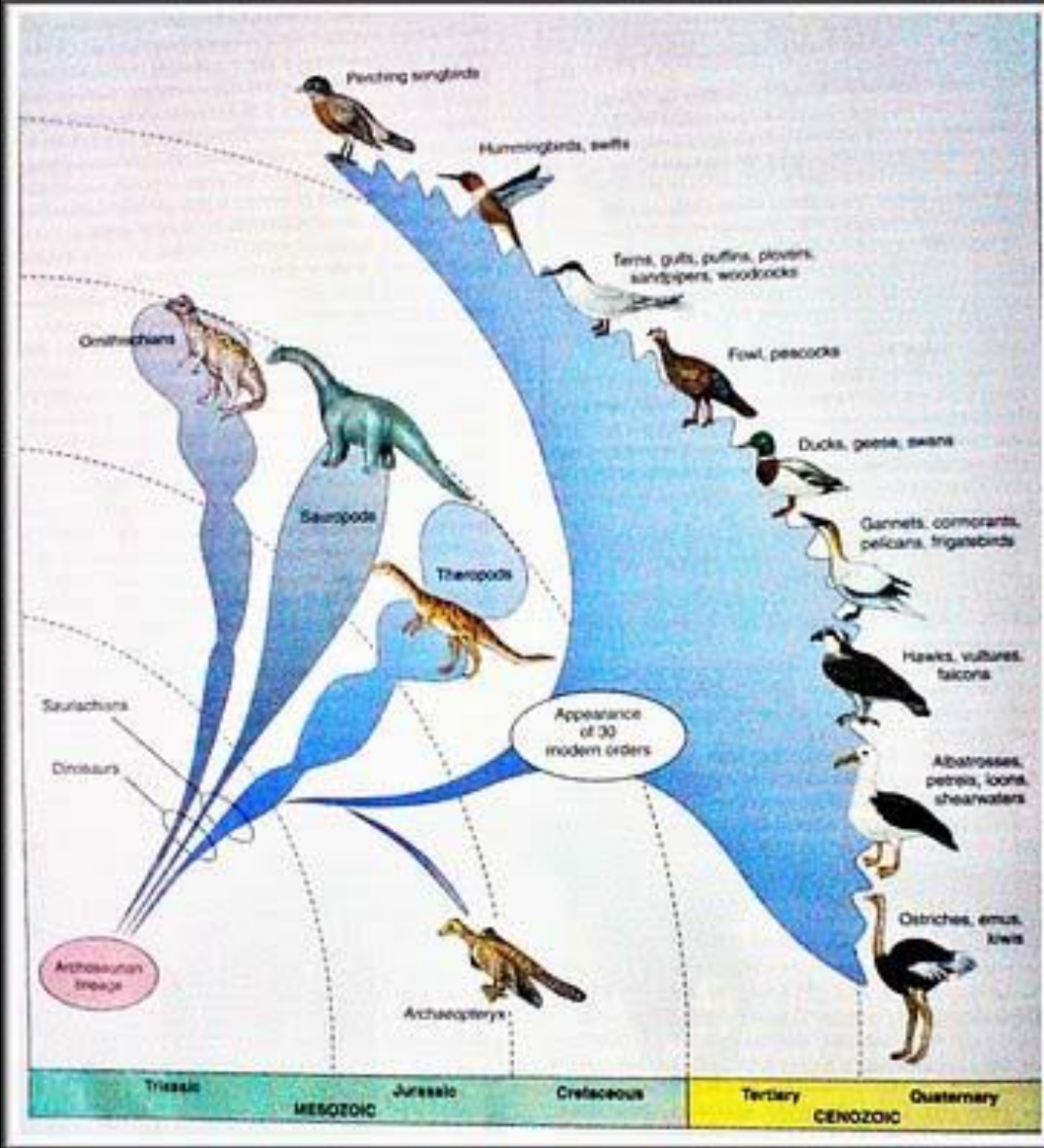


Transparent cuticle over the eye

# Snake Retina



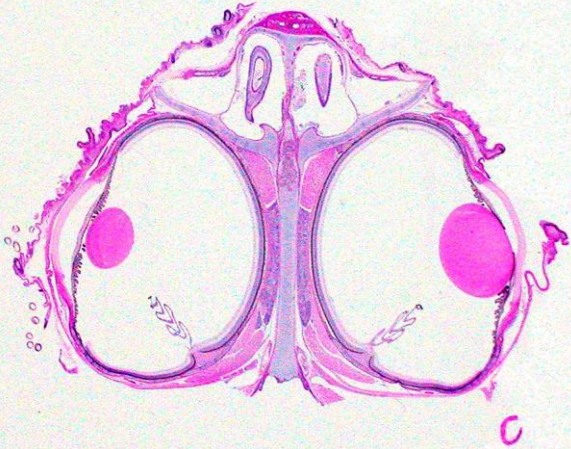
# Avian Eyes



# Features of Bird Eyes

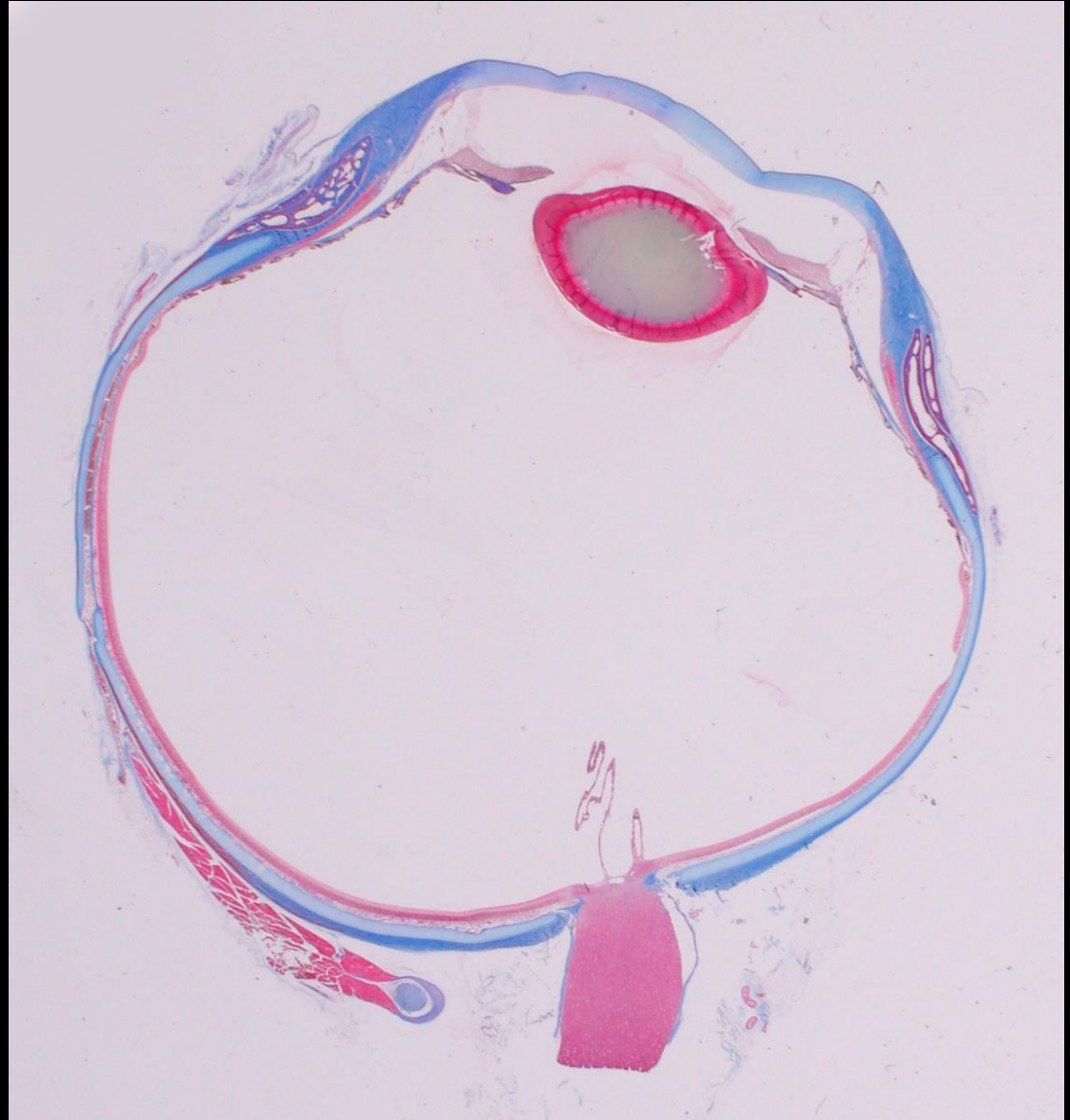
- Cartilage and well-developed ossicle
  - Some birds have a tubular eye shape
- Skeletal muscle in iris and ciliary body
- Annular lens pad
- Photomechanical movement in the RPE
- Pecten oculi
- Fovea common - some birds have two fovea
- Corneal accommodation
- Trichromatic vision or more

# Features of Bird Eyes

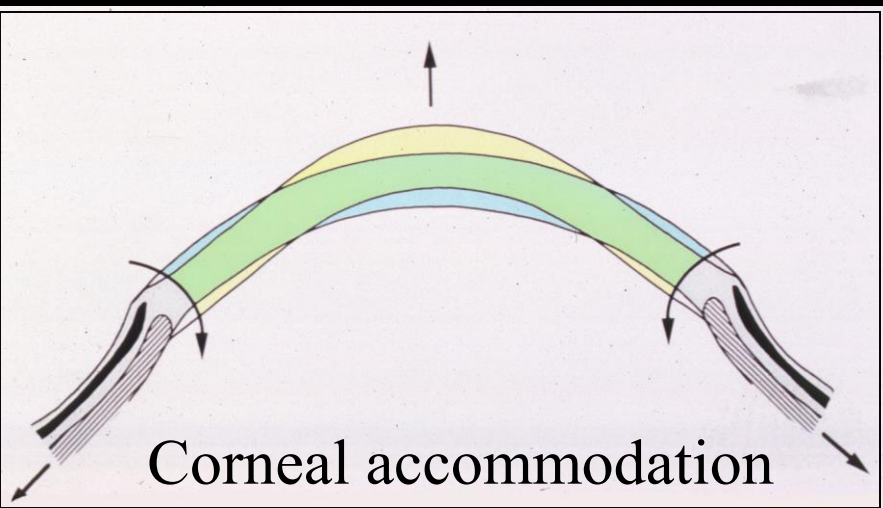
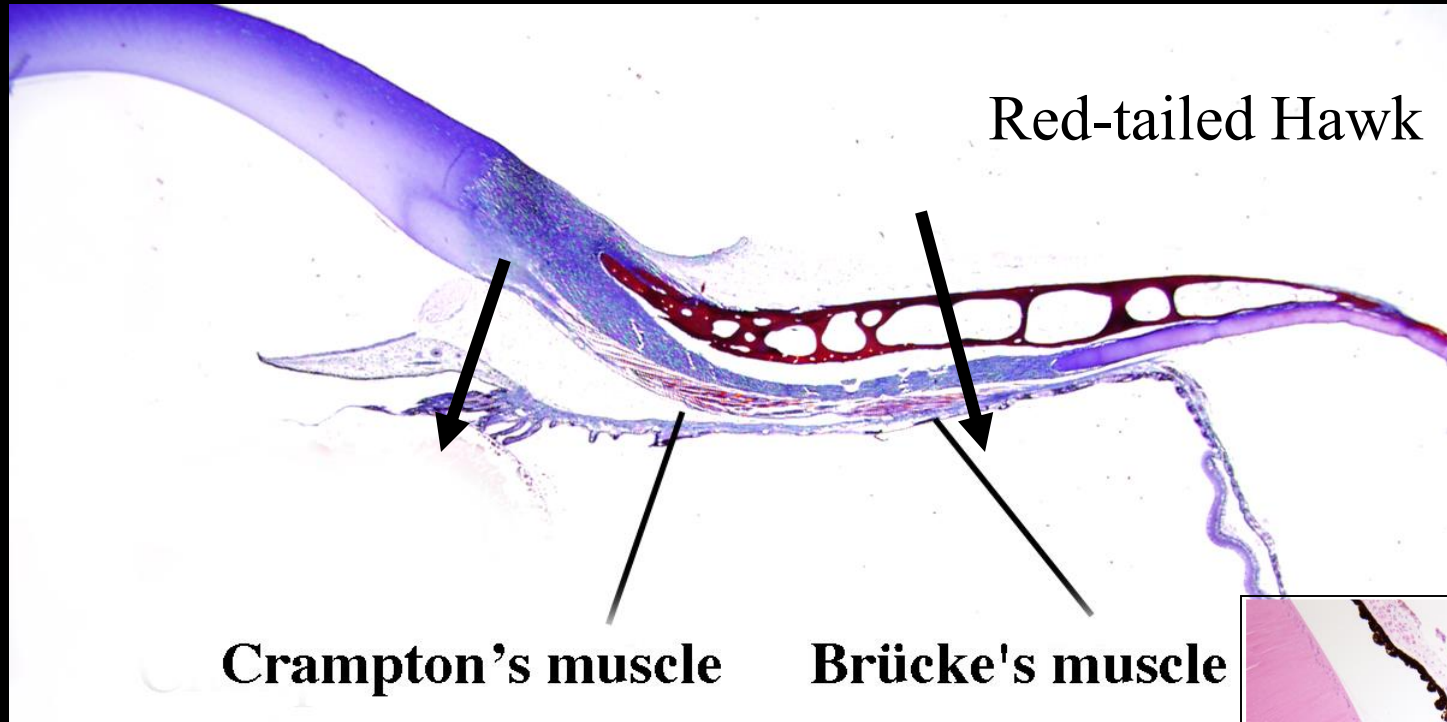


Ferry Bird

Loon Eye

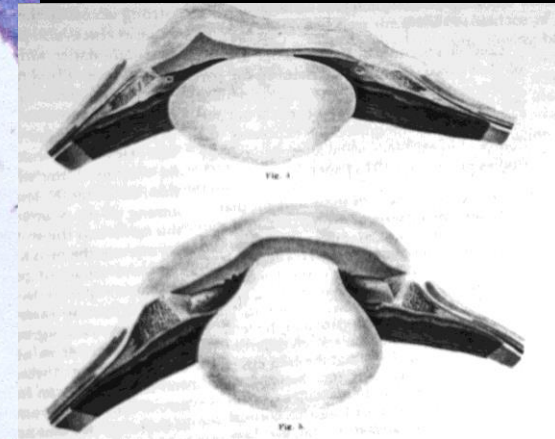
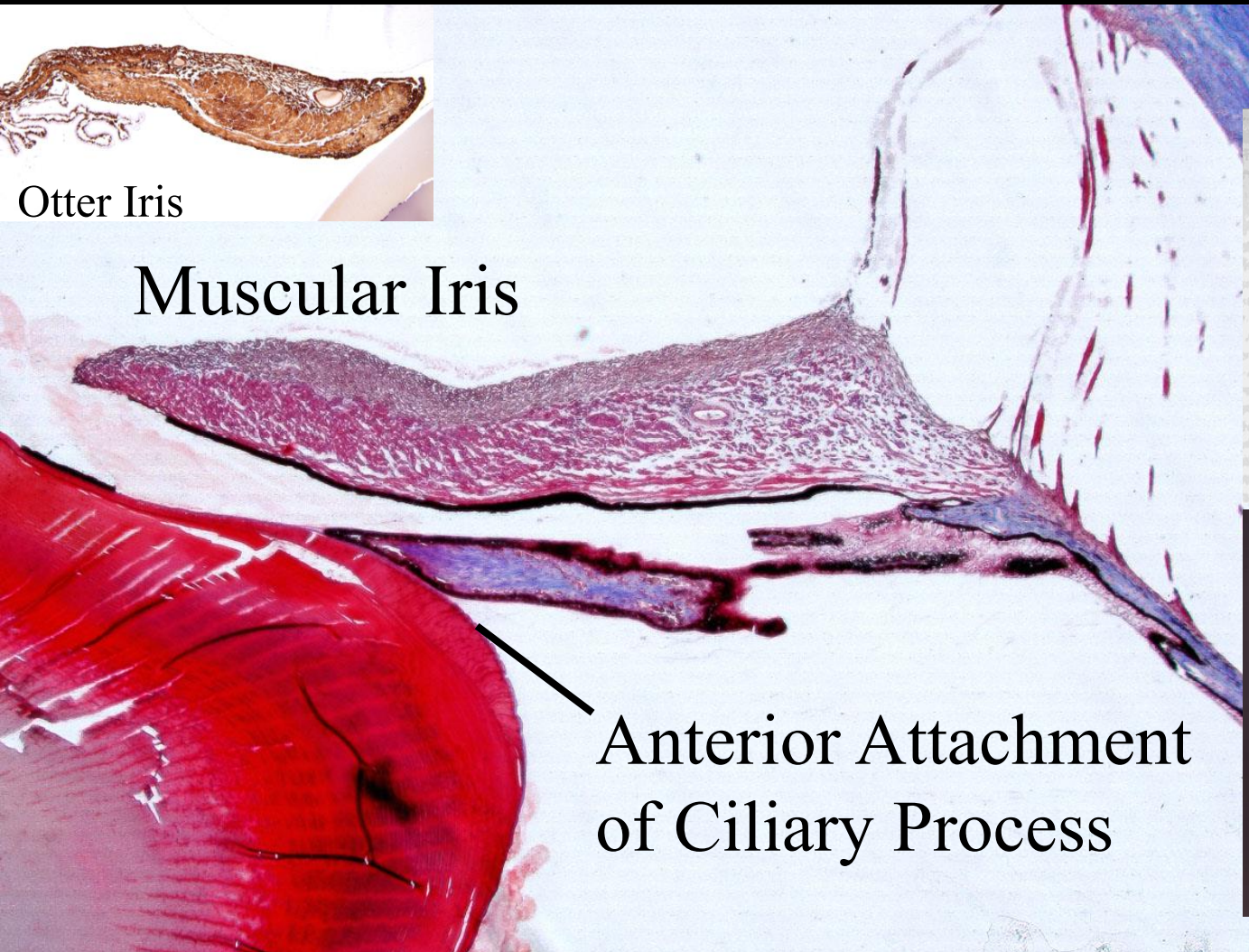


# Avian Accommodation



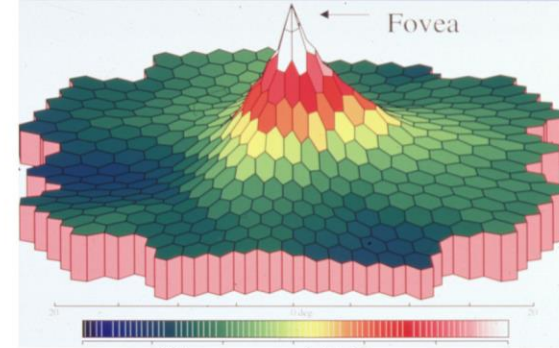
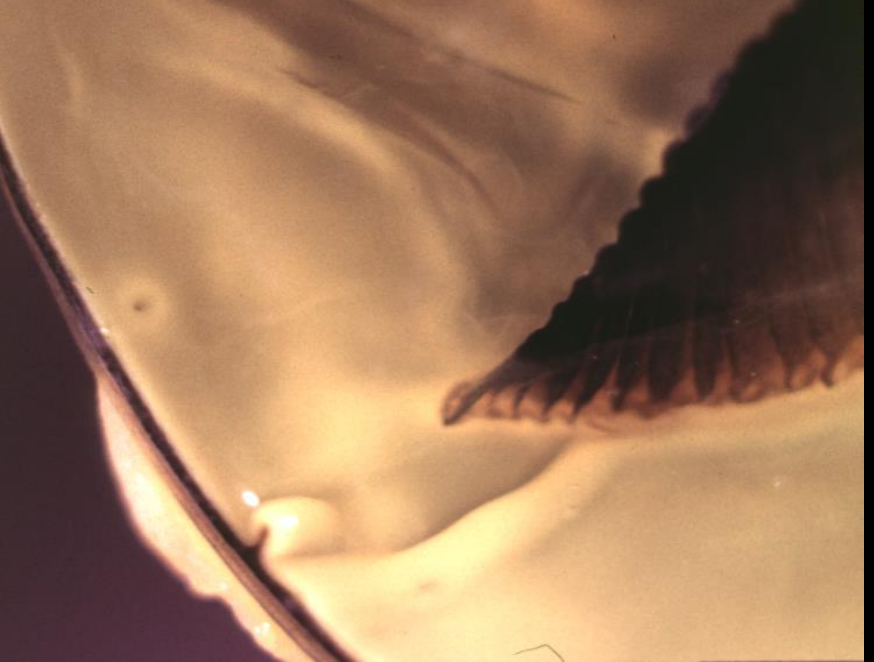
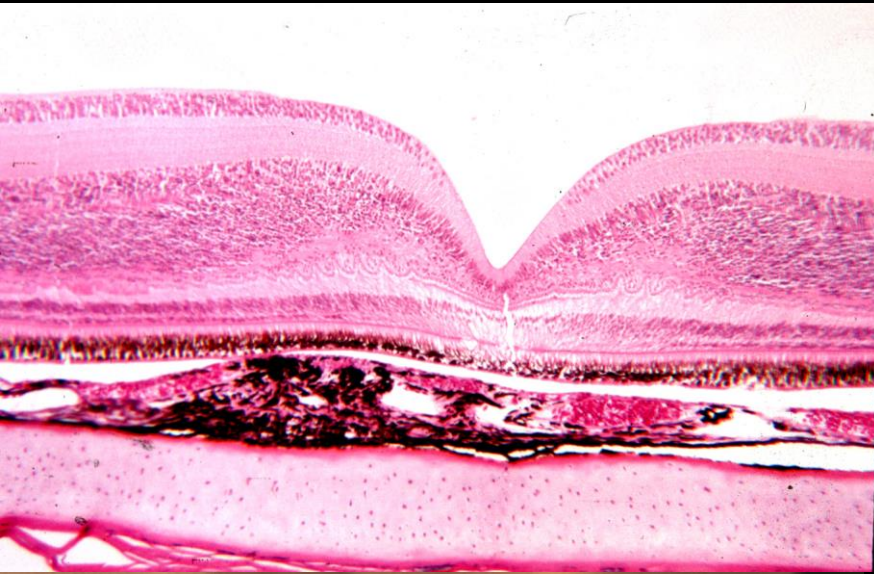
# Accommodation in Diving Birds

Loons, Puffins, Penguins, Cormorants

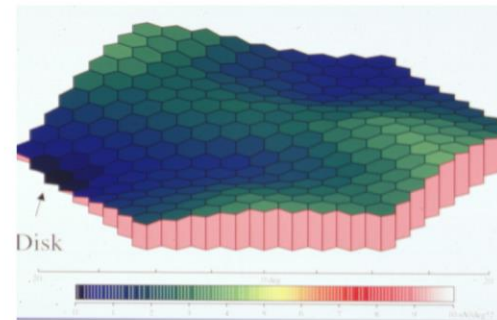




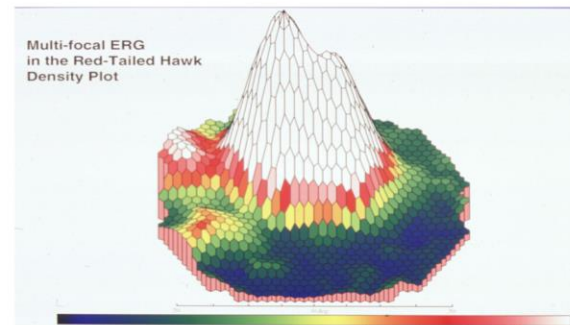
# The Double Fovea



Human mERG



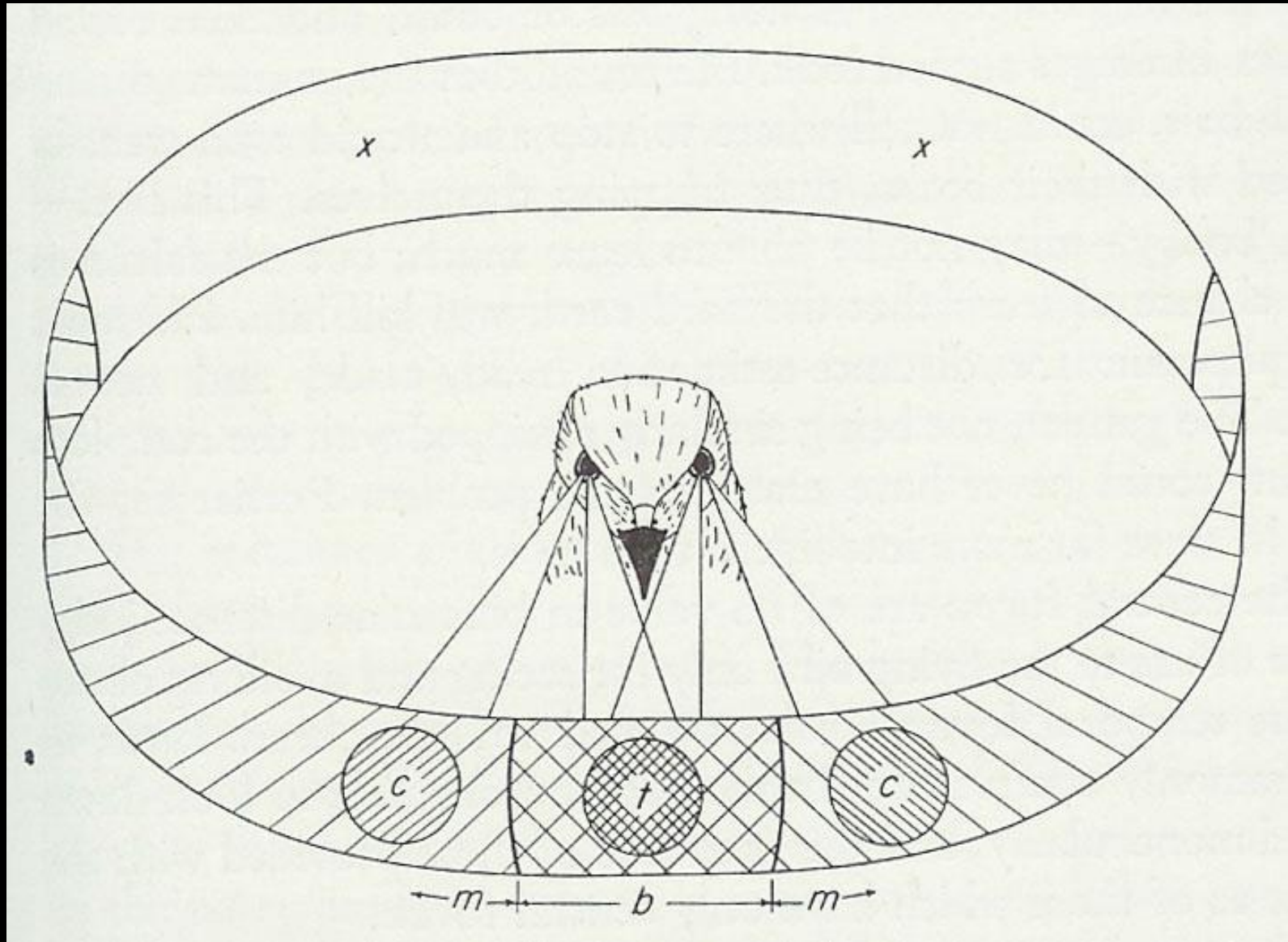
Equine mERG



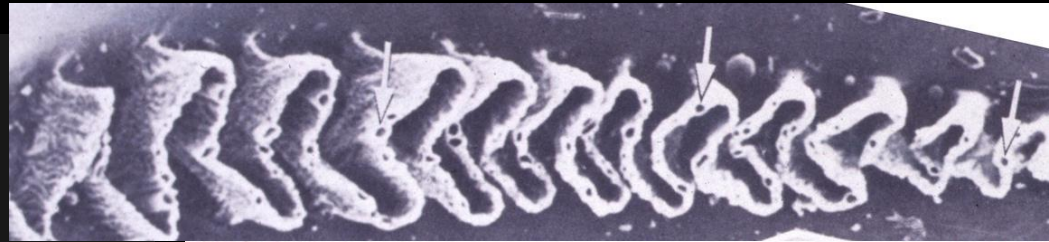
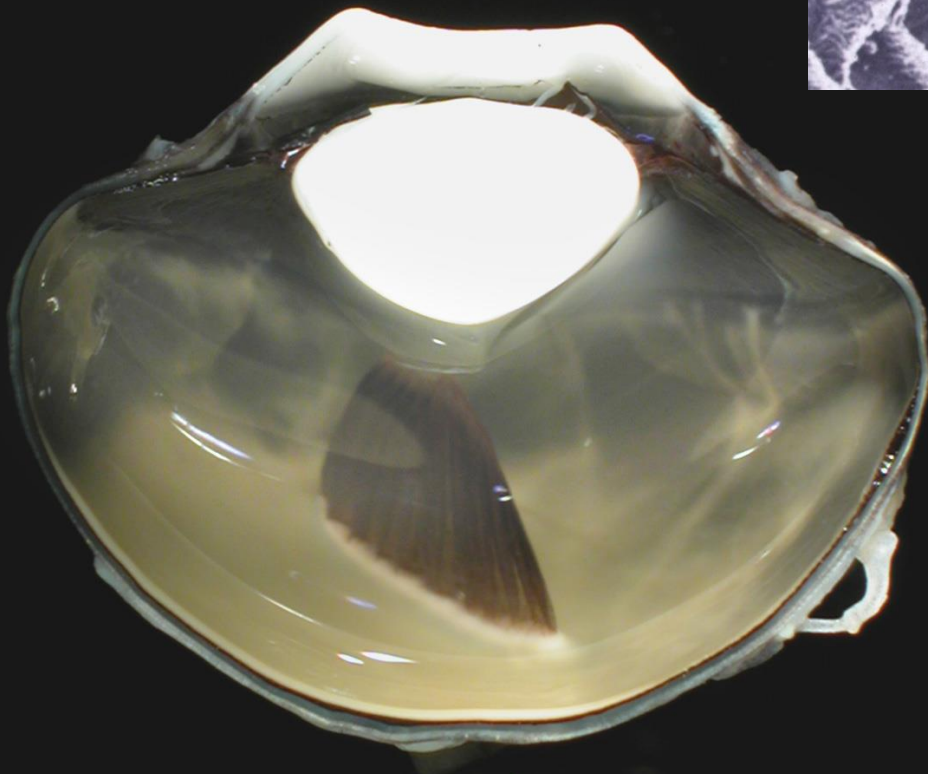
Red Tailed Hawk mERG

Dr Jim Ver Hoeve

The temporal fovea is bilateral vision  
The central fovea is used by just one eye



# Pecten Oculi



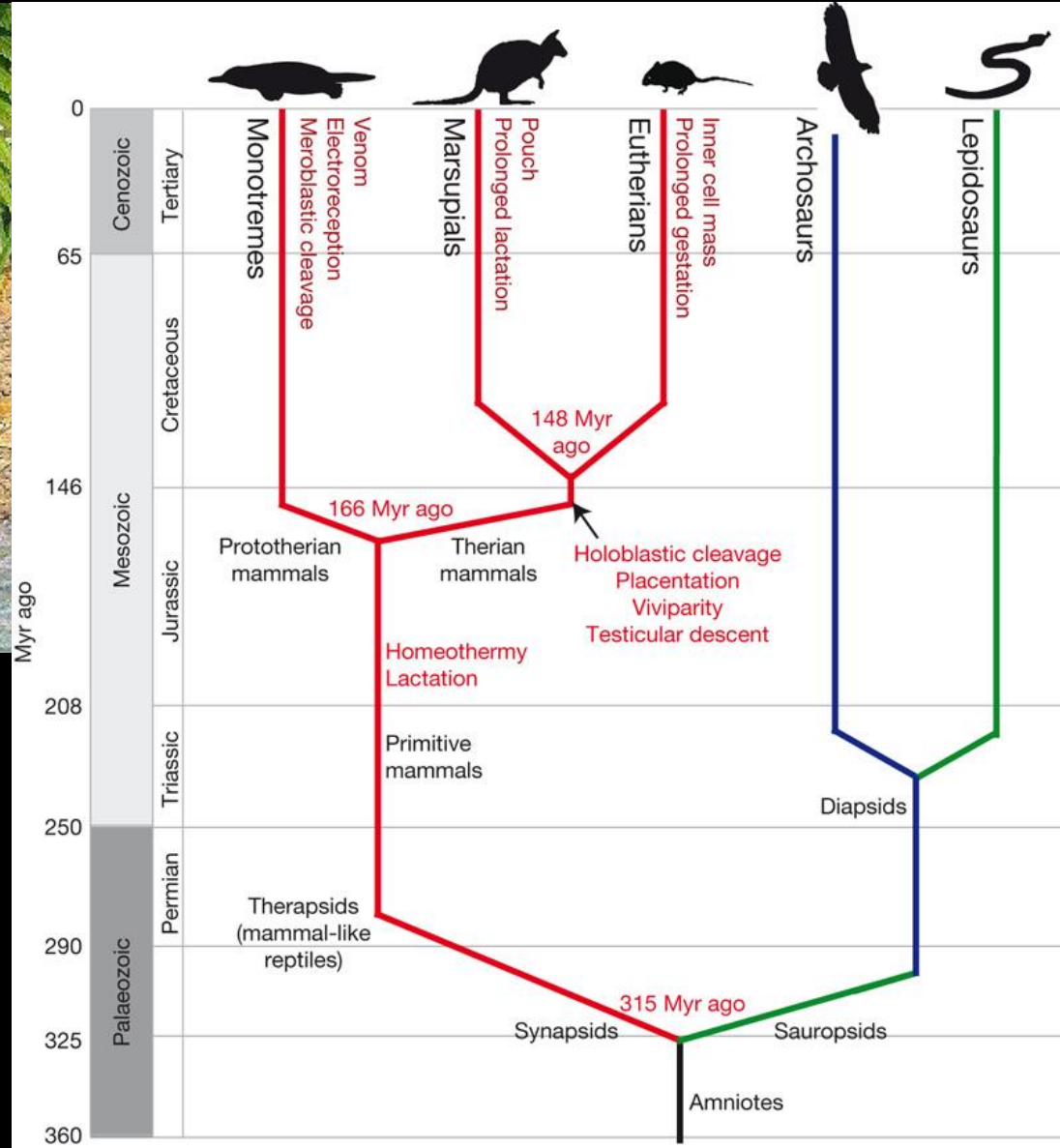
# The Monotreme Eye

## Duck-billed Platypus



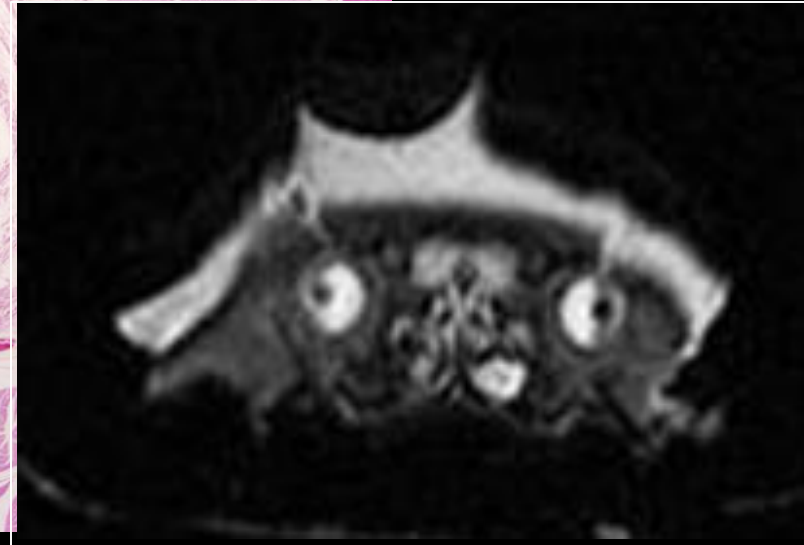
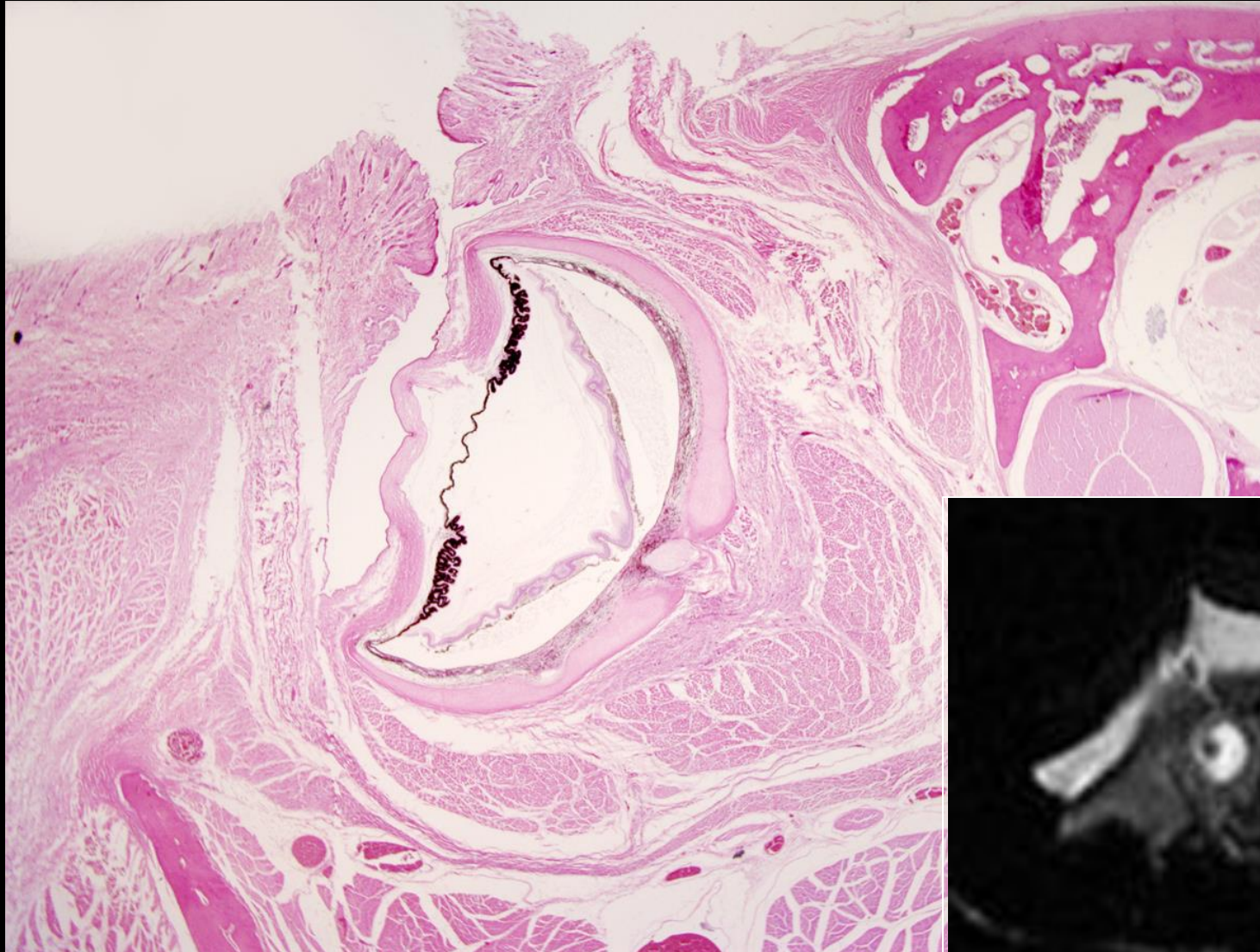
### Lost Features

- 4 cone types
- Double cones (Some Marsupials)
- Oil droplets (Some Marsupials)
- Shading or outer segments
- Cartilage



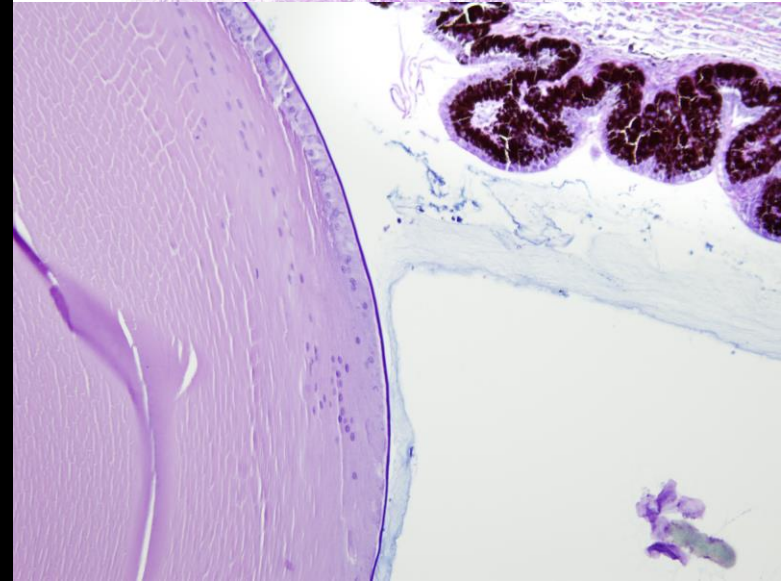
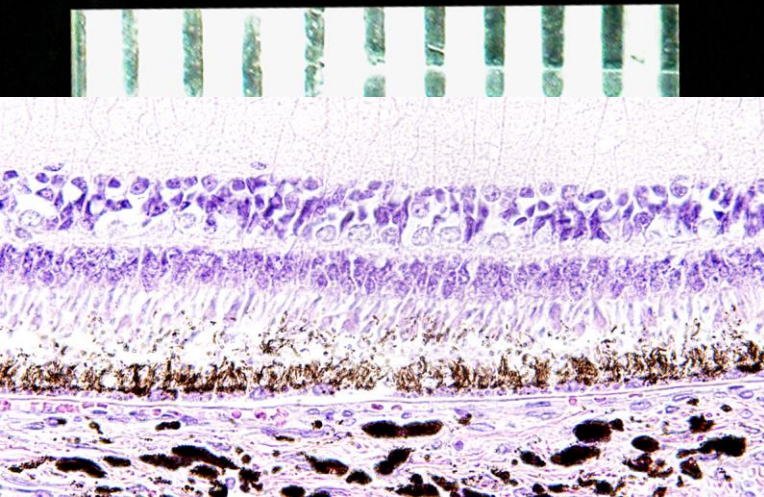
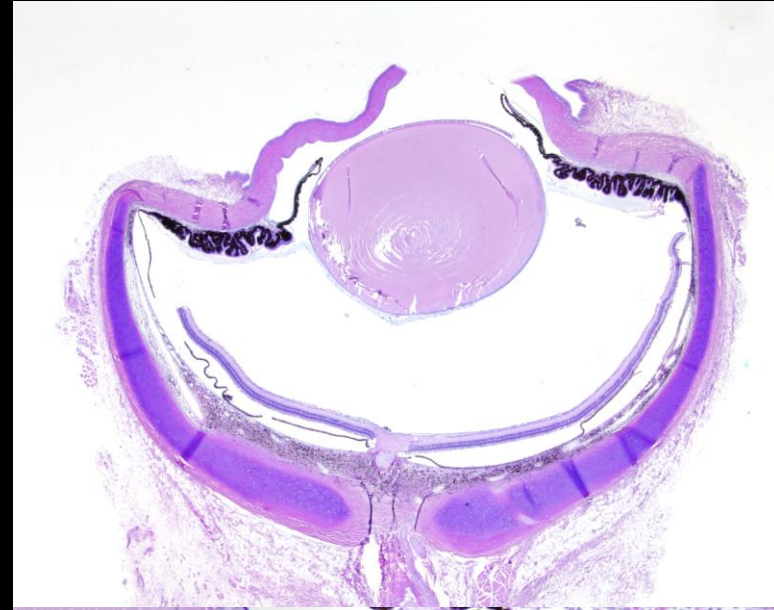
# The Monotreme Eye

## Duck-billed Platypus



# The Monotreme Eye

## Duck-billed Platypus



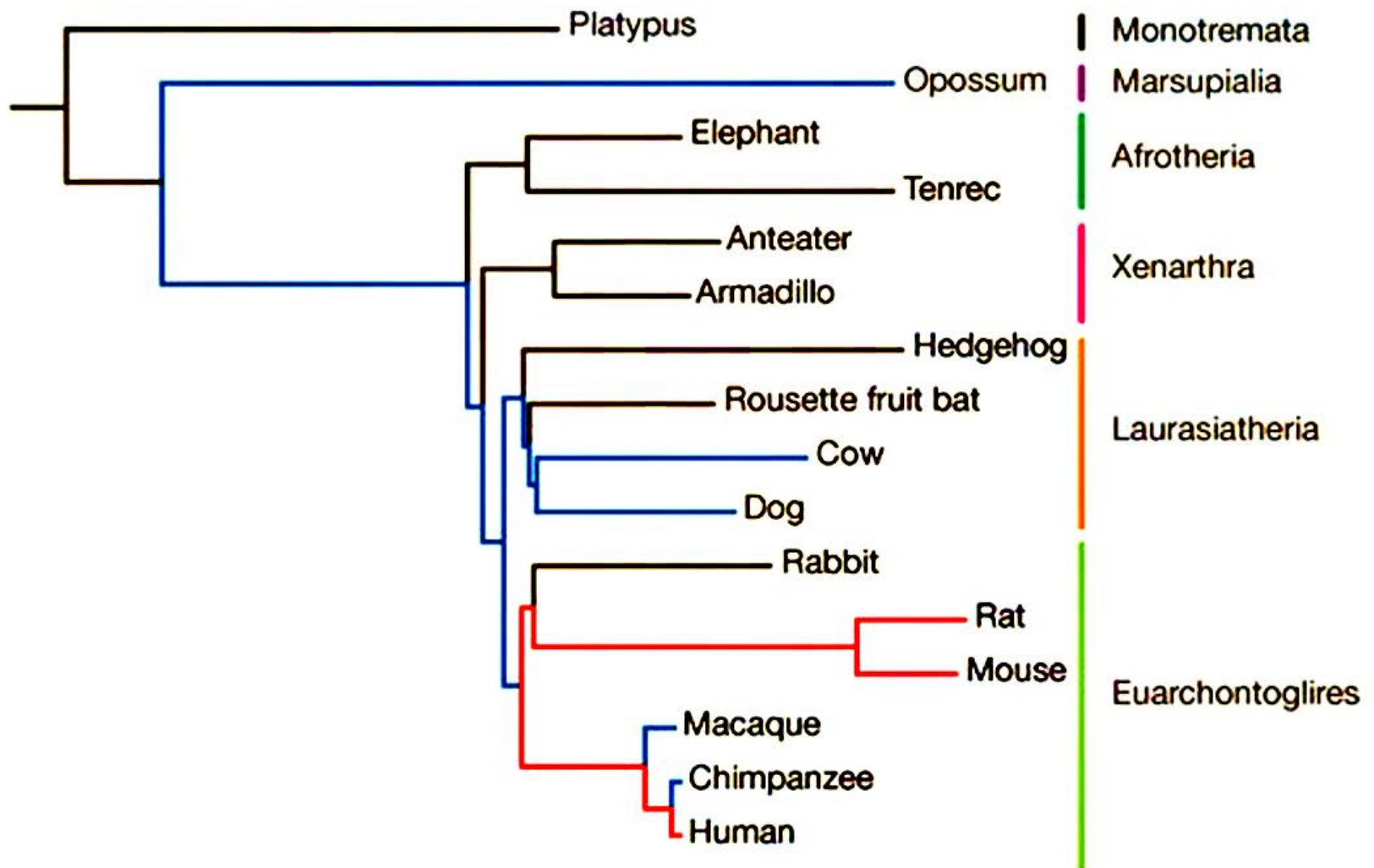
# Features of Mammalian Eyes

## Marsupials and Placental Mammals

- No bone or cartilage in sclera
- No skeletal muscle
- Iris dilator muscle
- No photomechanical movement in RPE
- Dichromatic vision (except Old World primates)
- No fovea (except Old World primates)
- Most have blood vessels within the retina
- Accommodation limited by passive action of lens capsule on lens

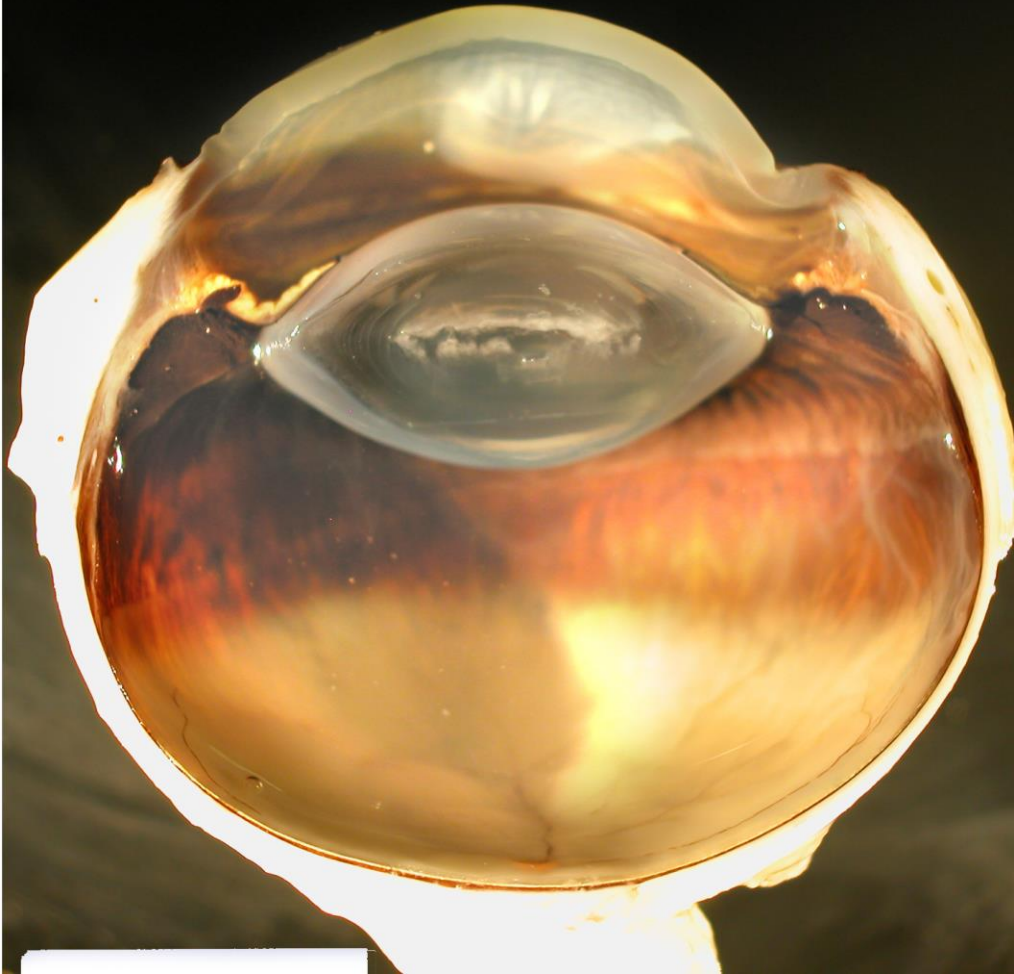
# Phylogeny of Mammalian Eyes

## Marsupials and Placental Mammals

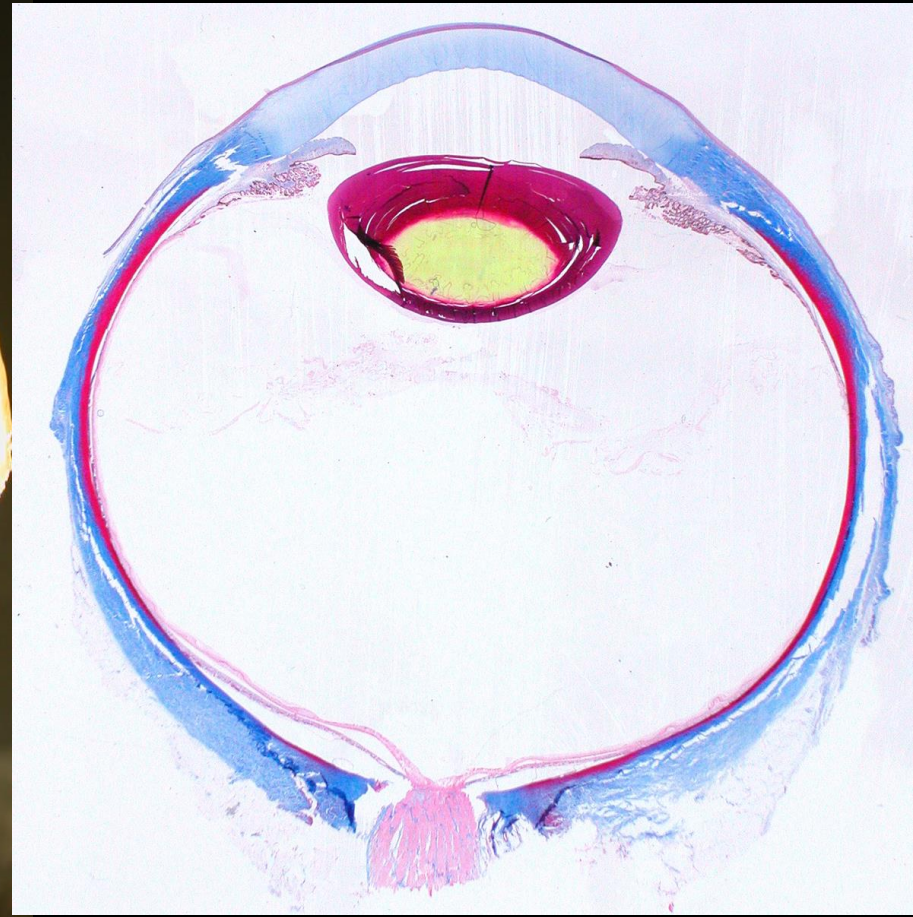




# Features of the Mammalian Eye



Lion Eye



Rhinoceros Eye

# The Nocturnal Eye from Walls

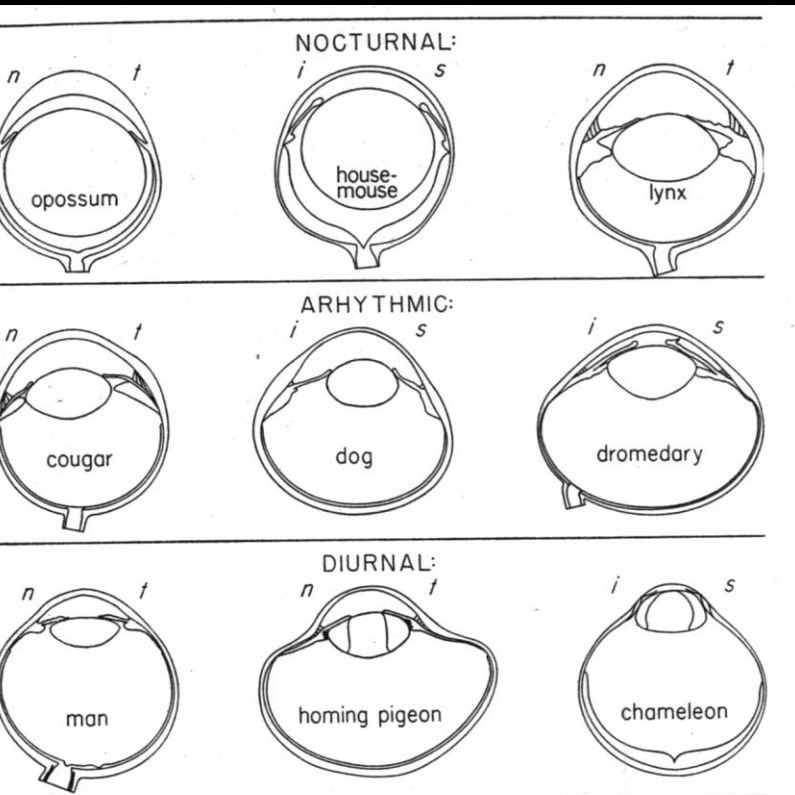


Fig. 71—Intra-ocular proportions in relation to intensity habits.  
Redrawn from various sources.

*i*: inferior side of eyeball; *n*: nasal side; *s*: superior side; *t*: temporal side.

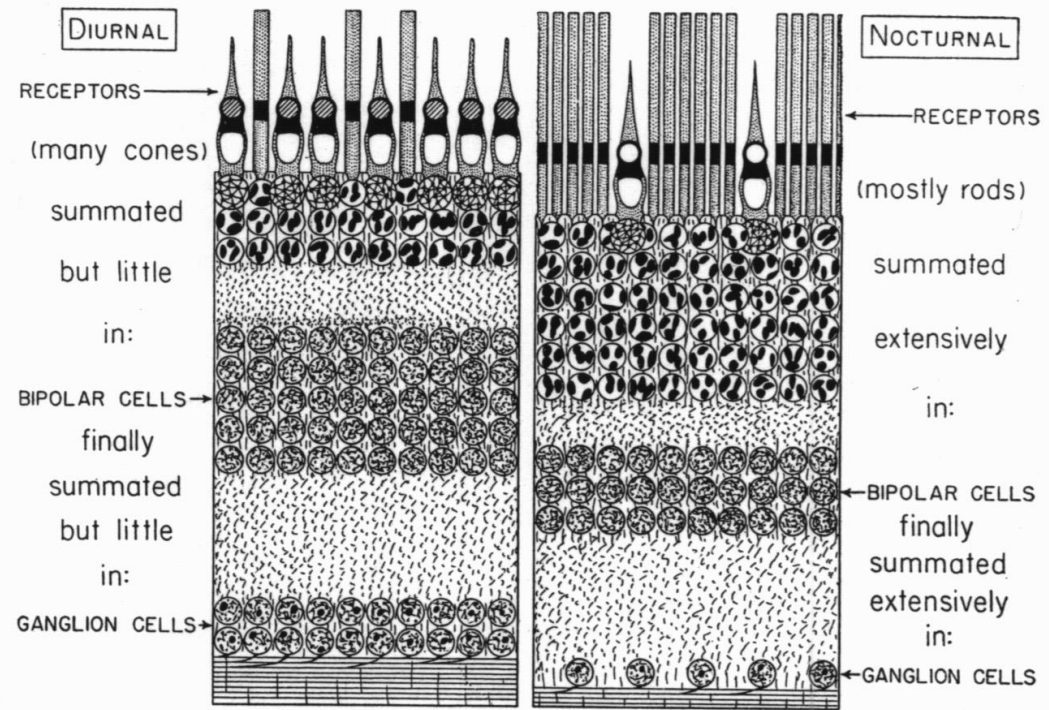
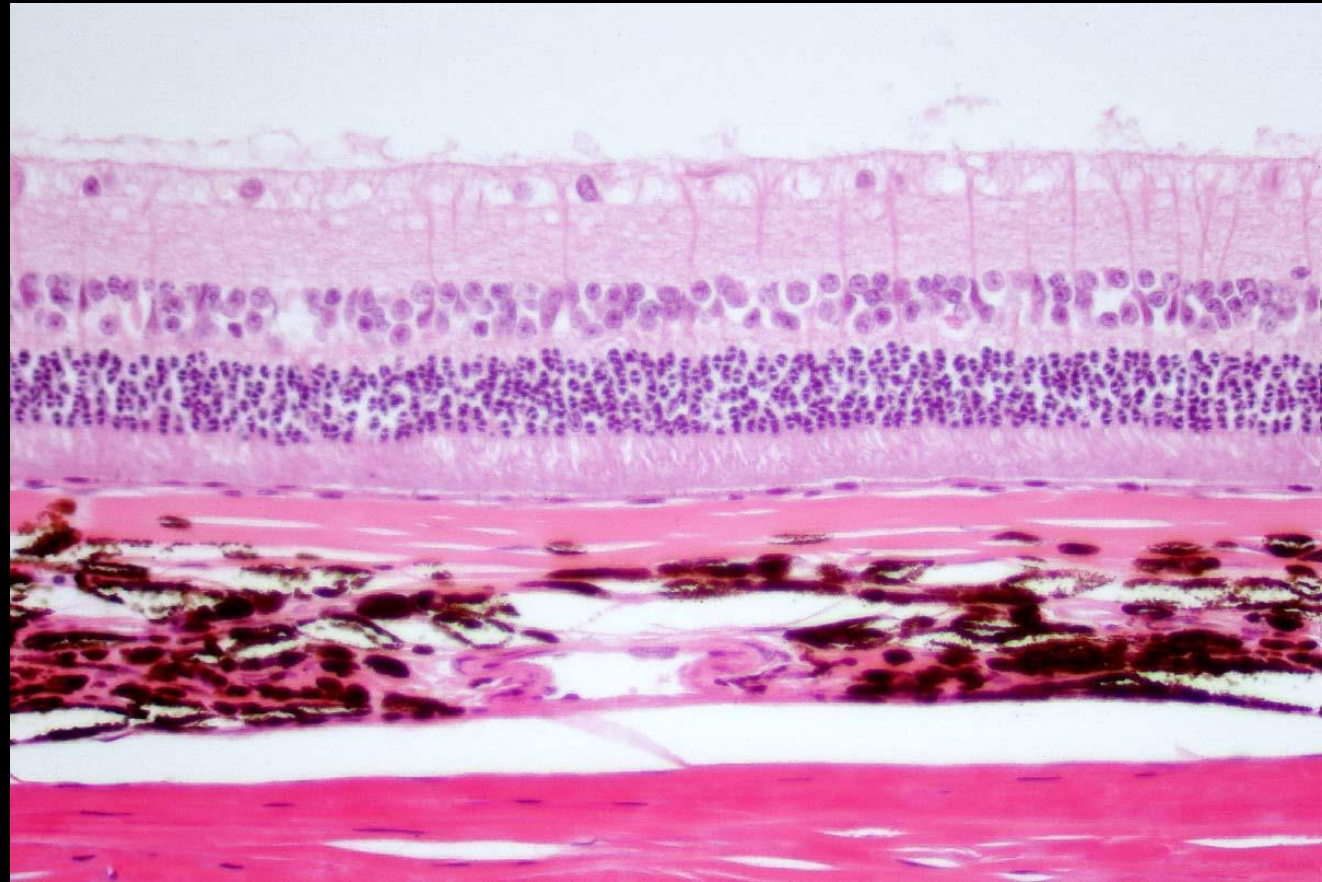
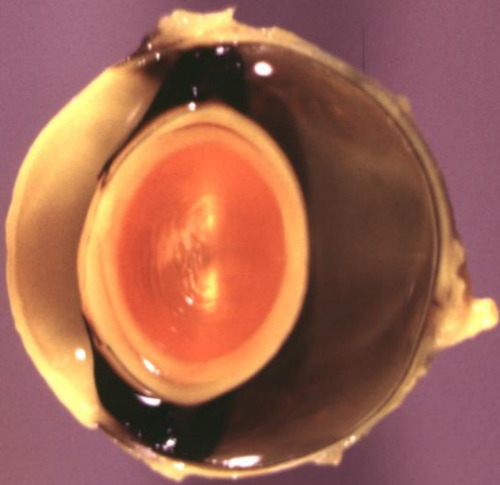
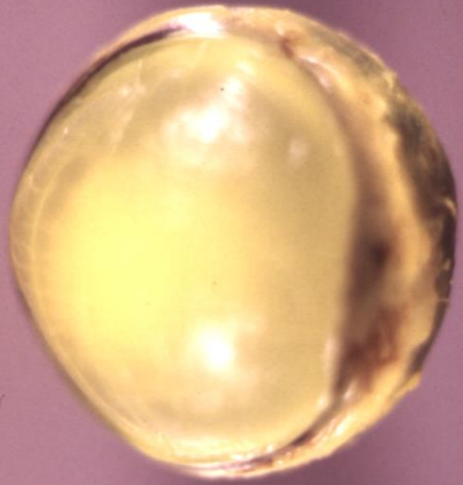


Fig. 72—Diurnal and nocturnal retinae contrasted.

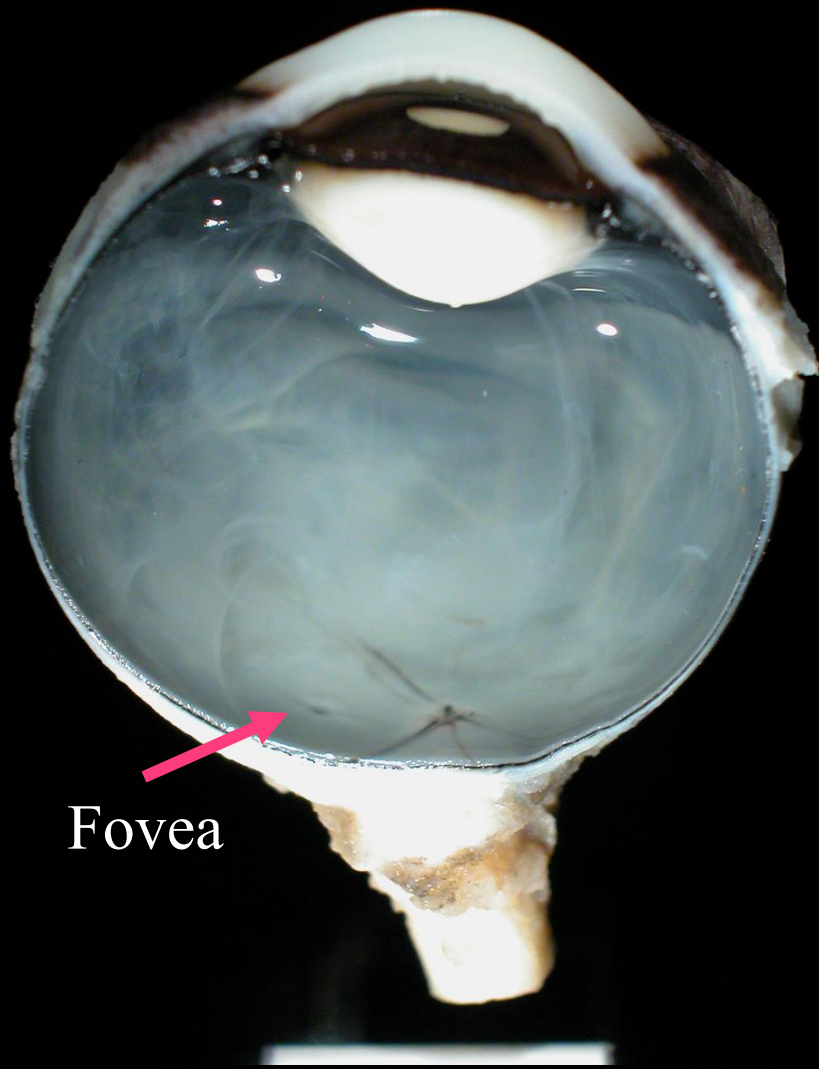
The diagrams represent two related species, one of which is diurnal and the other nocturnal. The characteristic differences in the relative thickness of the nuclear layers are the result of the visual-cell patterns and the differing extents of summation in optic nerve fibers.

# The Nocturnal Mammal



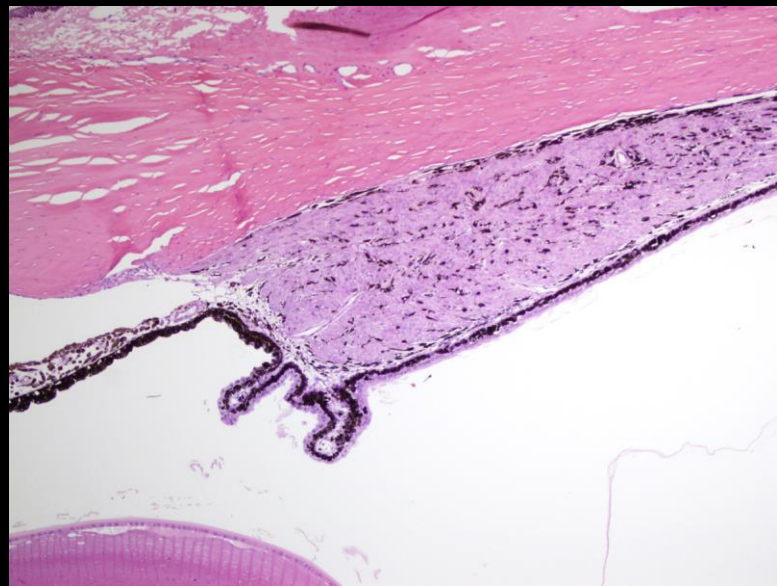
Springhaas

# The Diurnal Eye

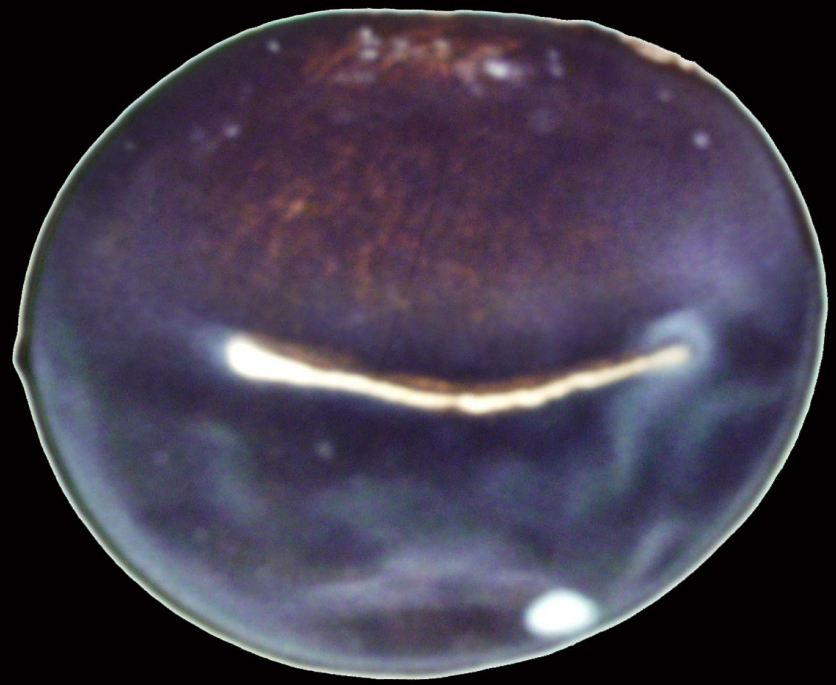
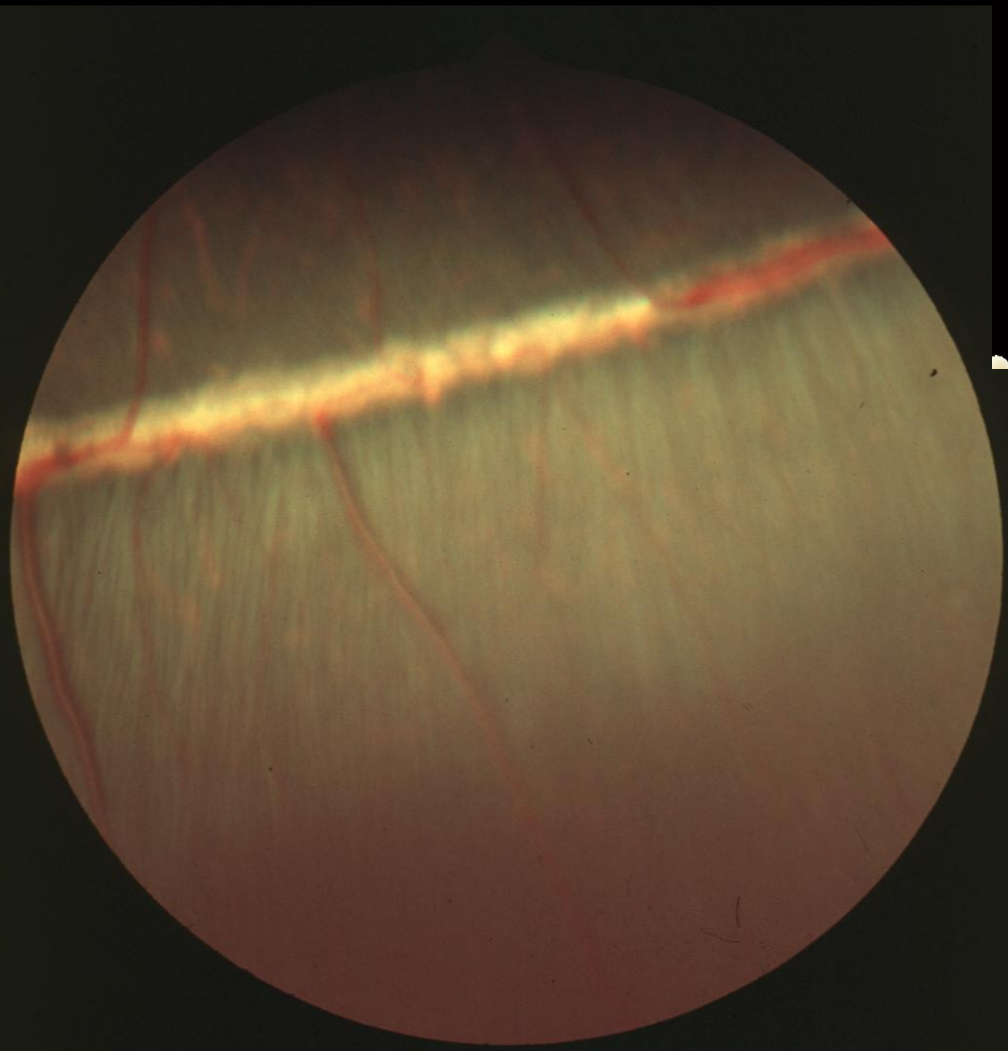


Fovea

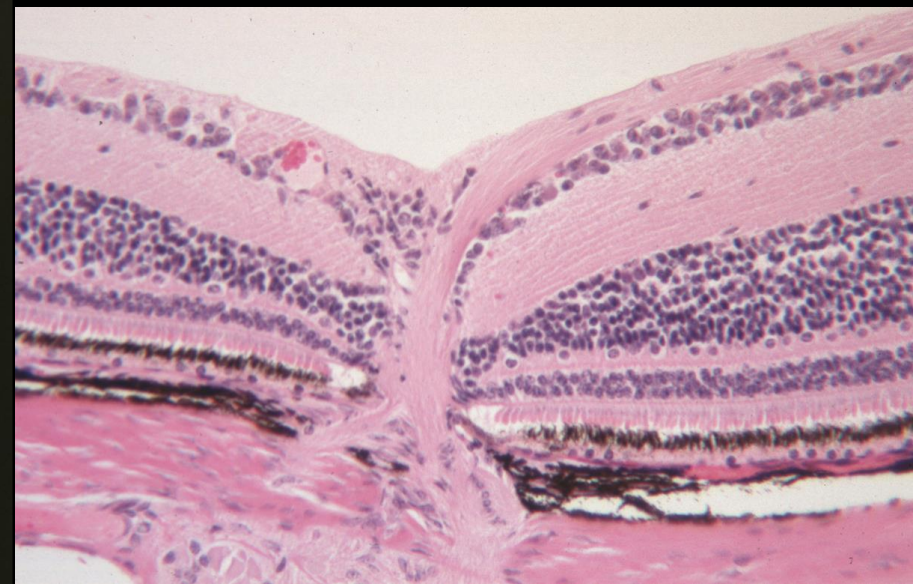
Orangutan



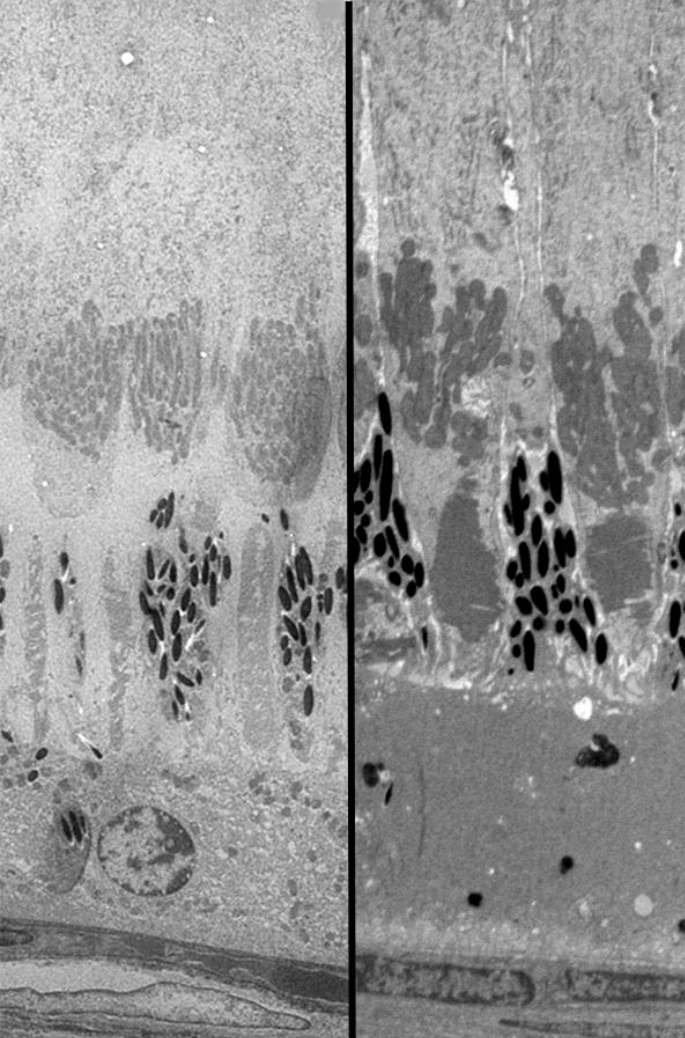
# Diurnal Eye Ground Squirrel



Woodchuck

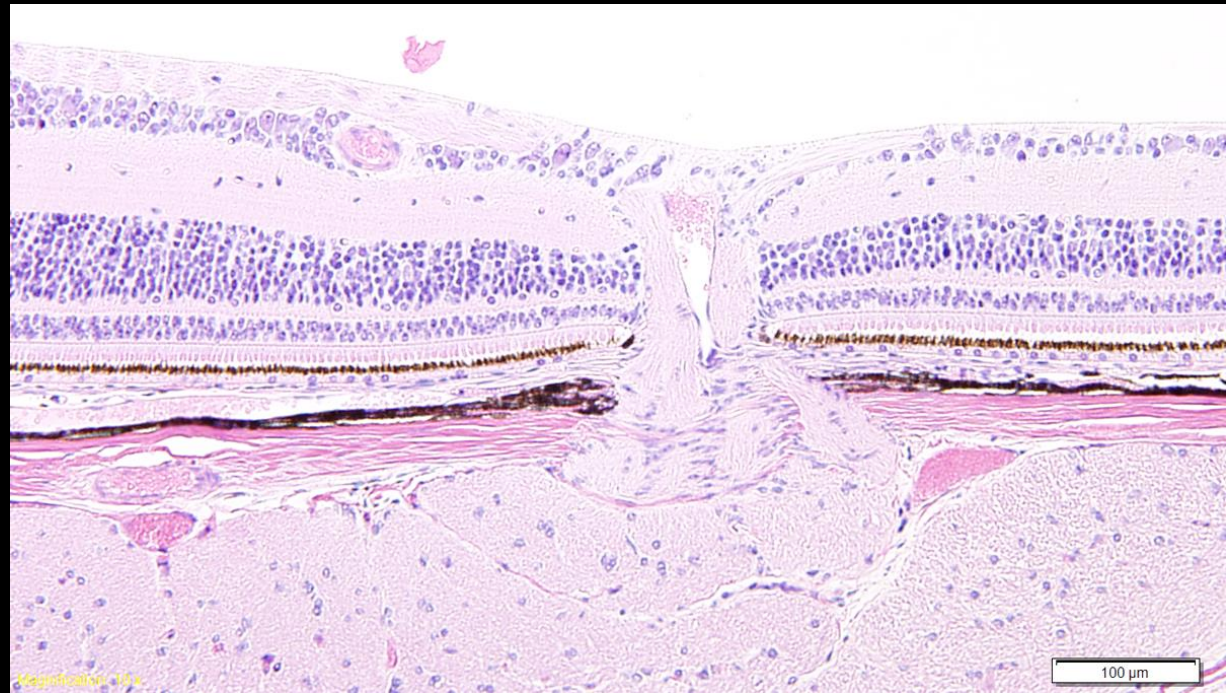


# Diurnal Eye Ground Squirrel



Summer

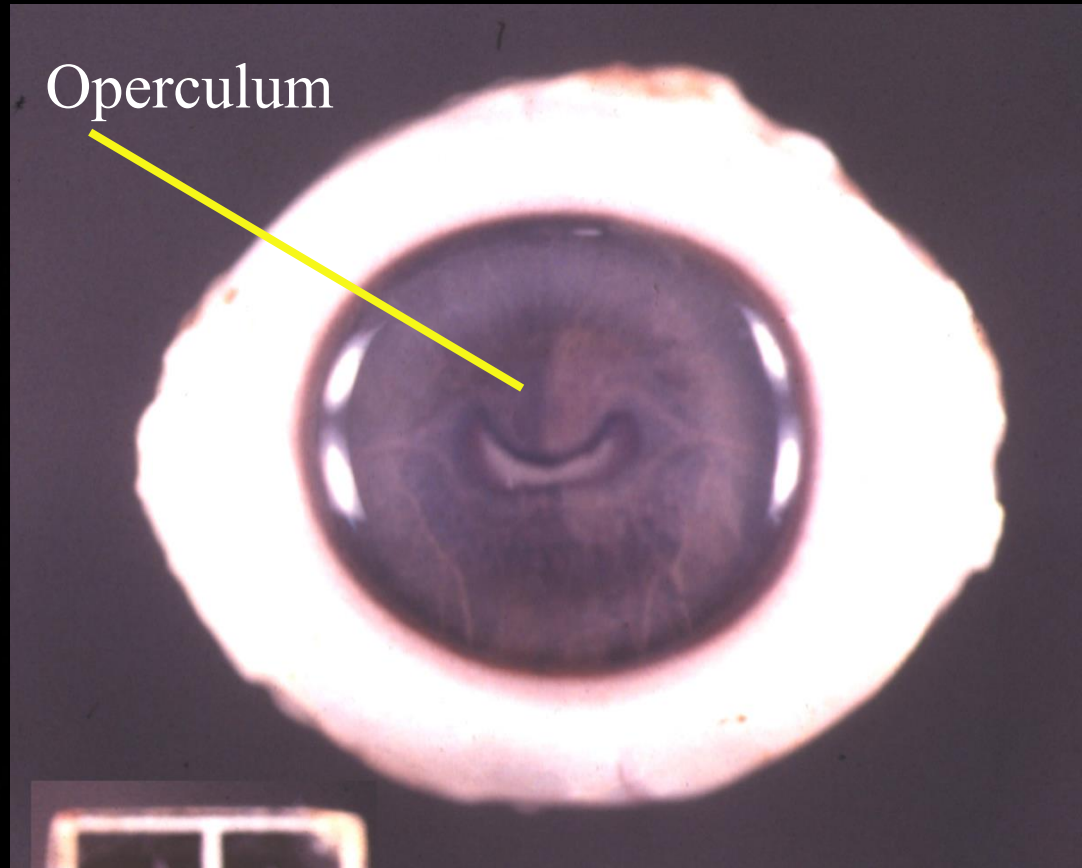
Winter



100 μm

# Underwater Eye

## Cetacean

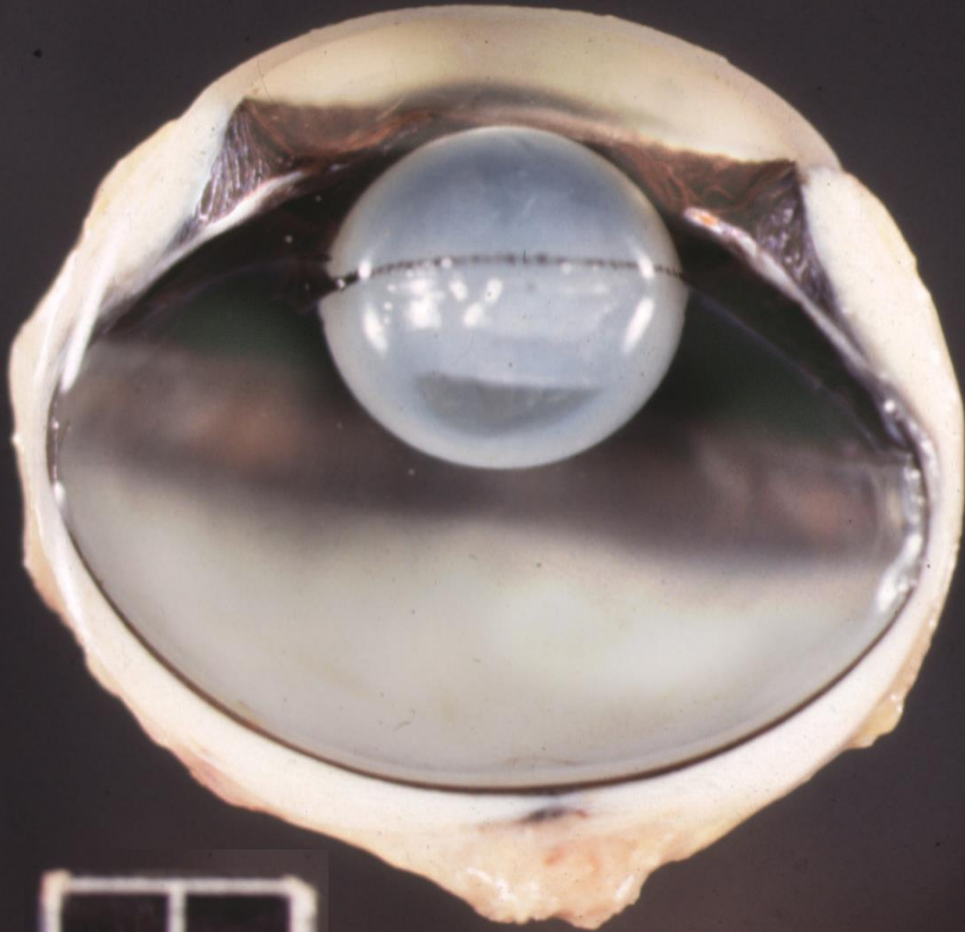


Operculum

Dolphin

# Underwater Eye

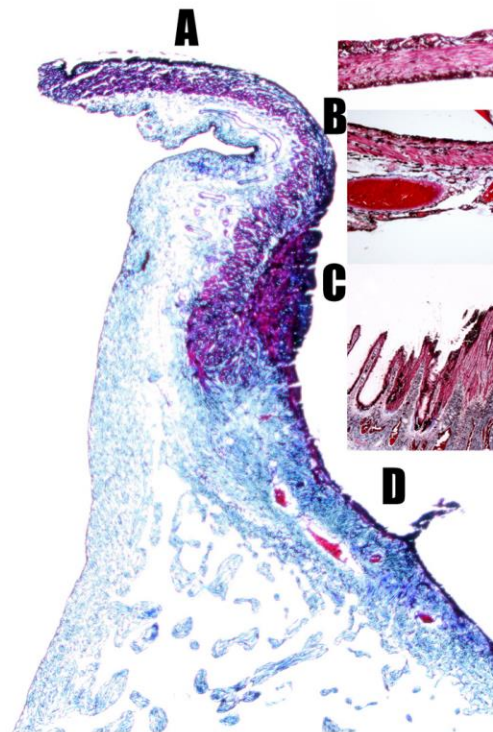
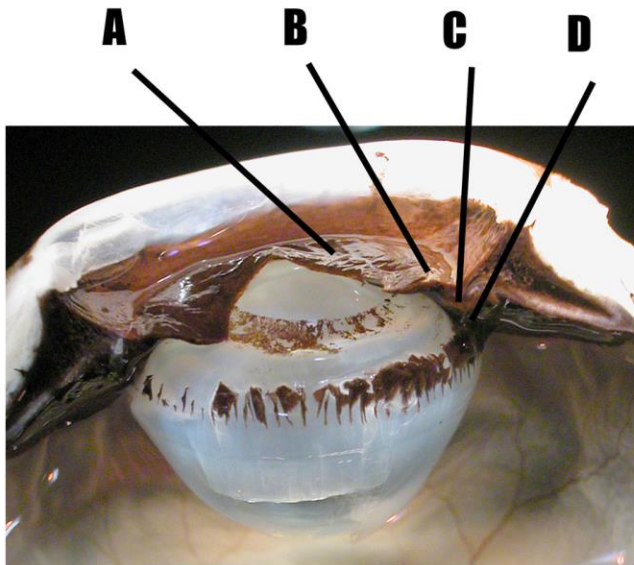
## Pinniped



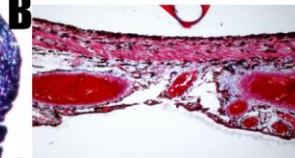


# Underwater Eye

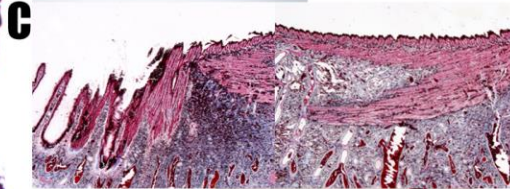
## Pinniped



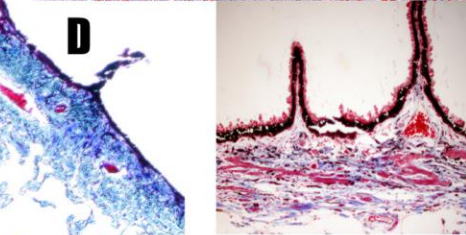
**A** Iris: Almost no dilator muscle



**B** Iris: Large sphinctor  
small dilator



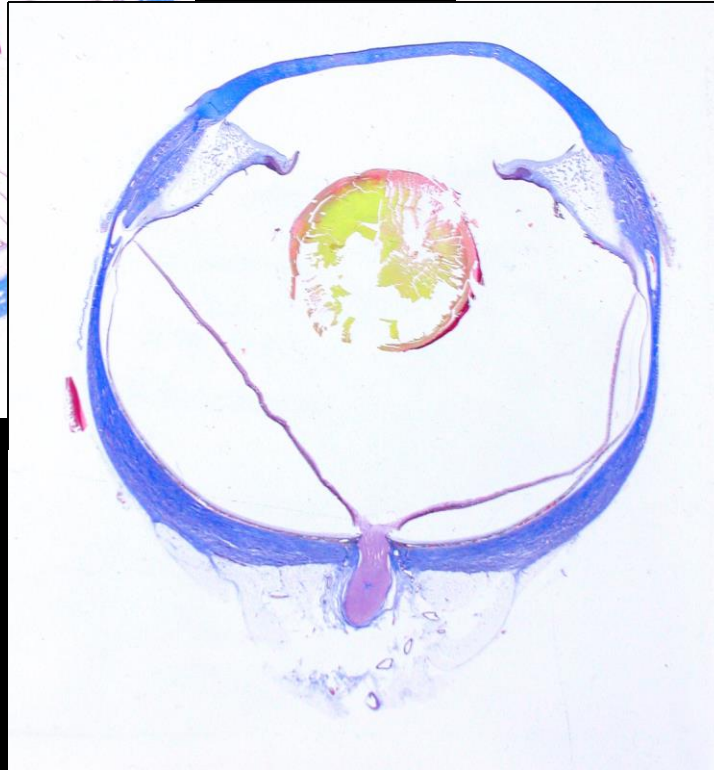
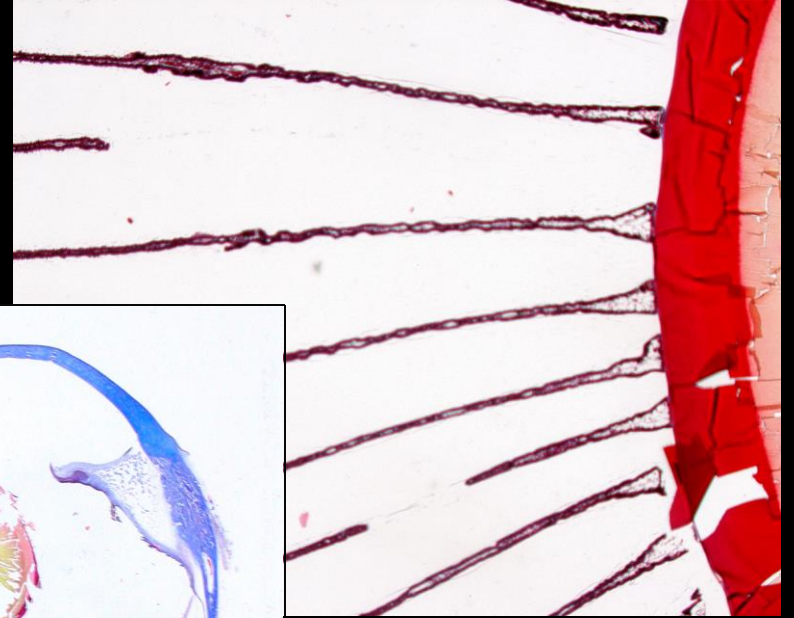
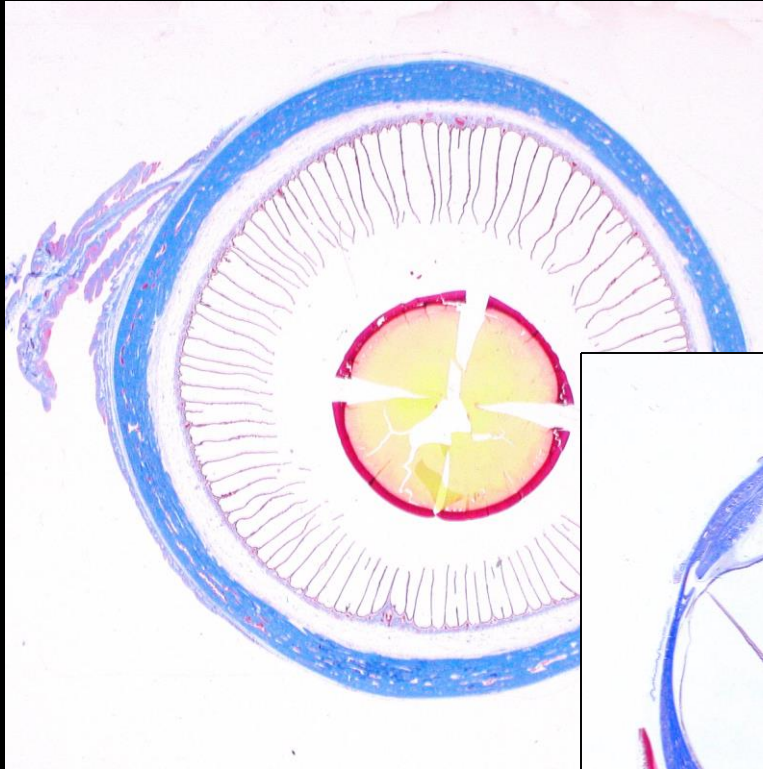
**C** Fusion  
of  
dilator  
&  
sphinctor



**D** Circumferential  
muscle at  
the base  
of  
pars plicata

# Underwater Eye

## Pinniped



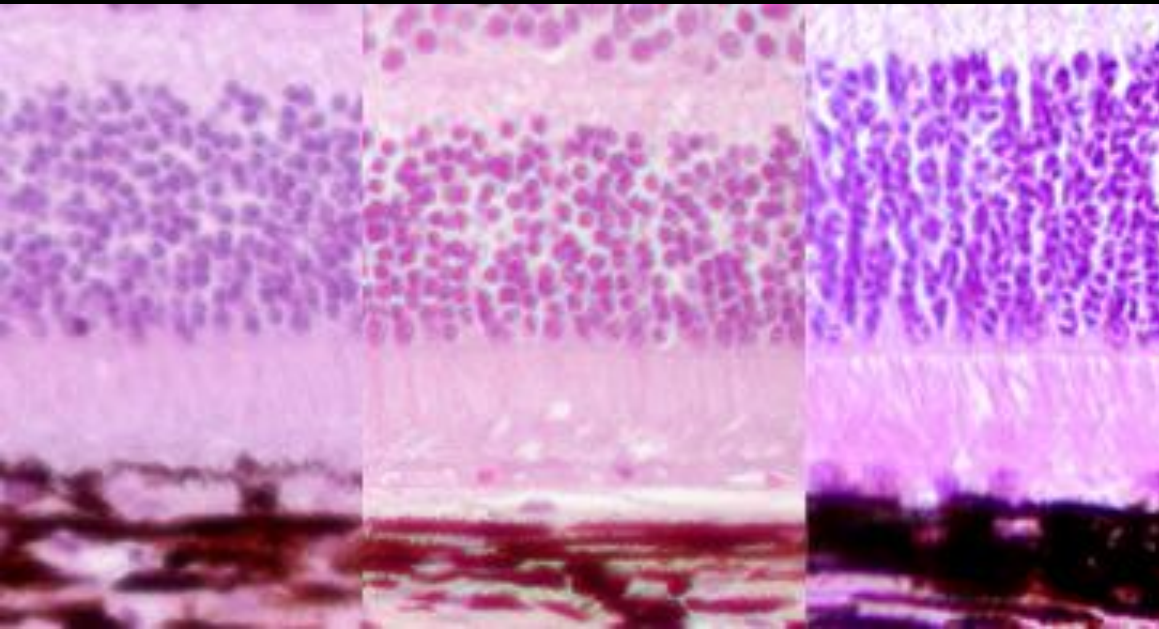
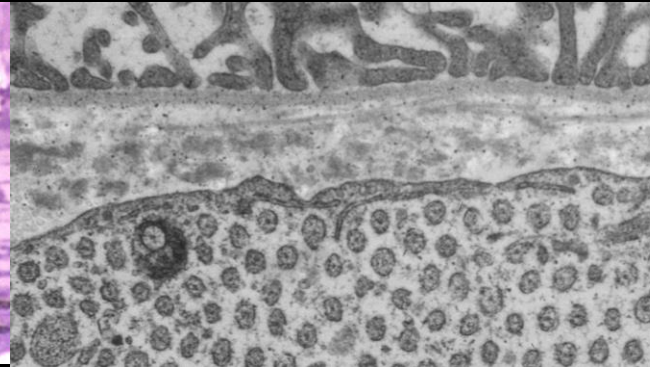
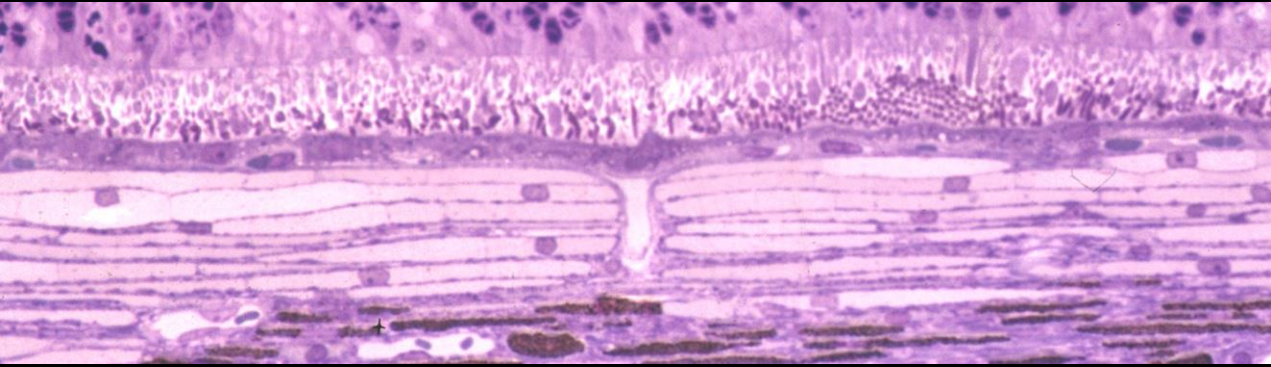
# The Tapetum Lucidum

- Fibrous Tapetum: Herbivore
  - Equine/Tapir/Hippo
  - Ruminant: not Camelid
  - Cetacean
- Cellular Tapetum: Carnivore
  - Canine type
    - Mustelids
    - Pinniped
    - Bears
  - Feline type
    - Hyena
- Fibrous Tapetum in other groups
  - Springhaas: Rodent
- Cellular Tapetum in other groups
  - Fat-tailed Lemur: Primate
- Retinal Tapetum: American Opossum



Dolphin Fibrous  
Tapetum

# Cellular Tapetum Lucidum Carnivore



Nontapetal

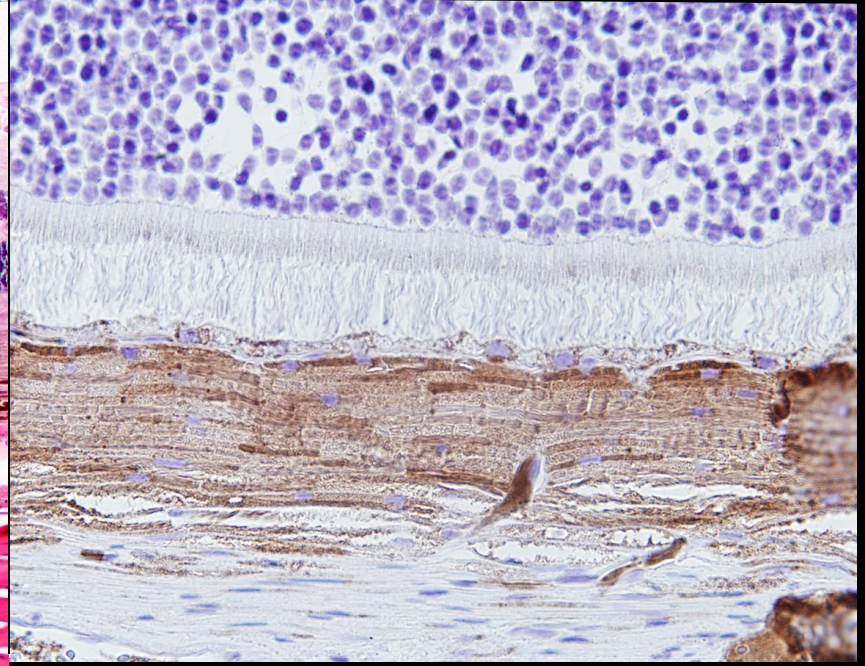
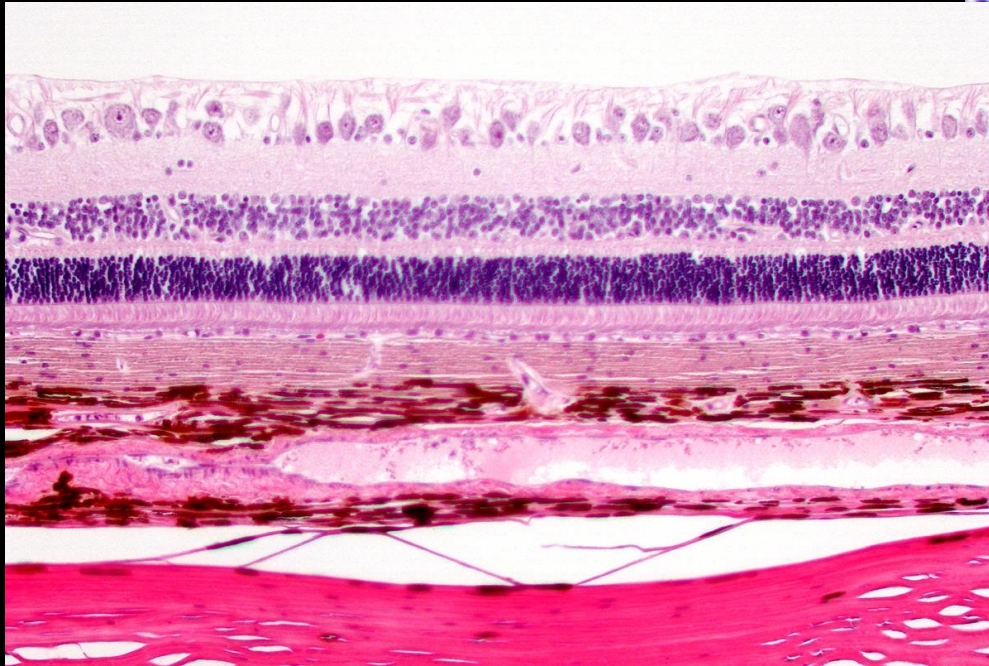
Tapetal

Tapetal

Eye Shine - Canine



# Cellular Tapetum Lucidum Feline



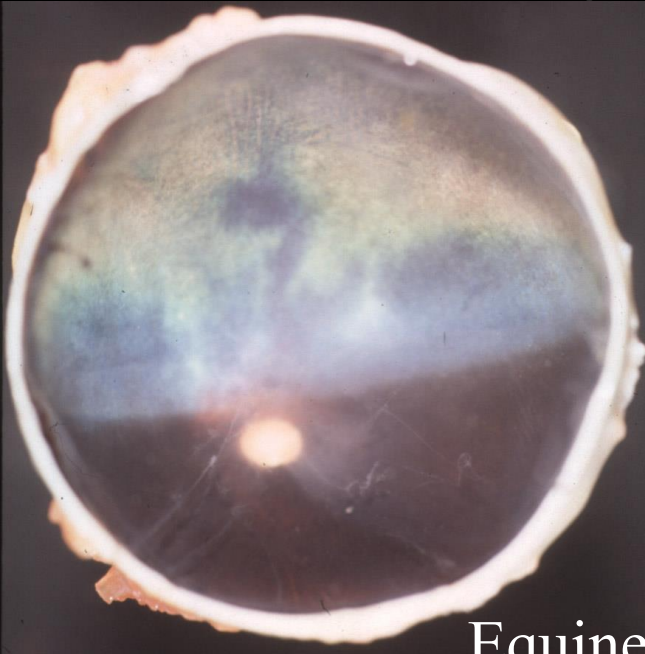
Melan-A



Autofluorescent

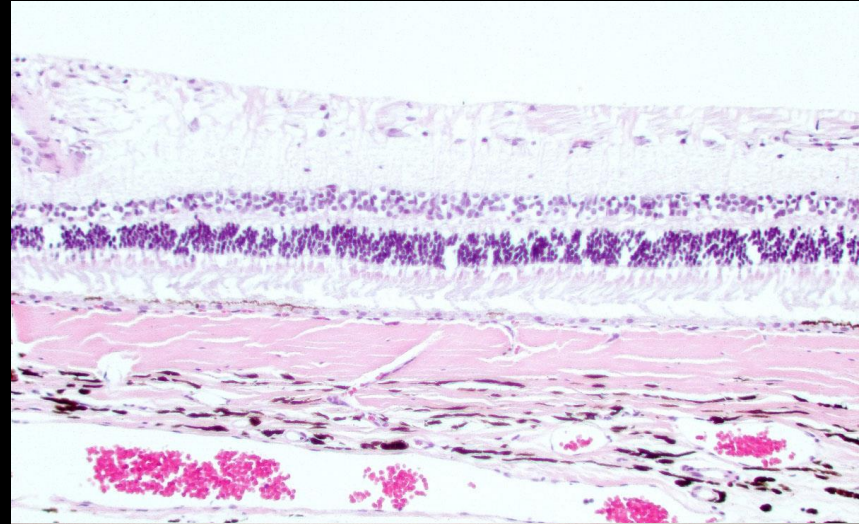
# Fibrous Tapetum Lucidum

Ungulates & Cetaceans

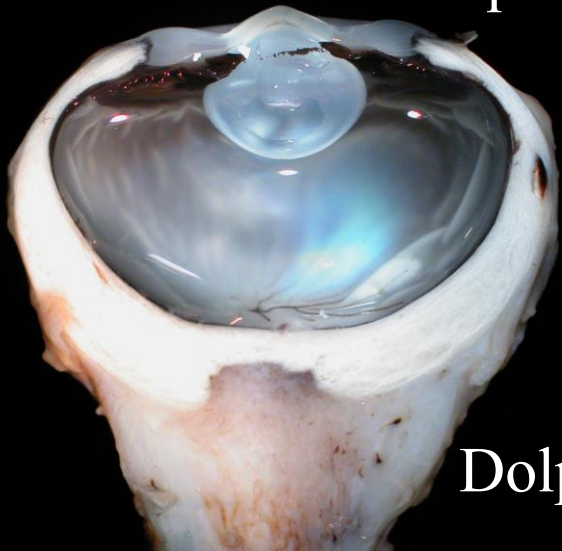
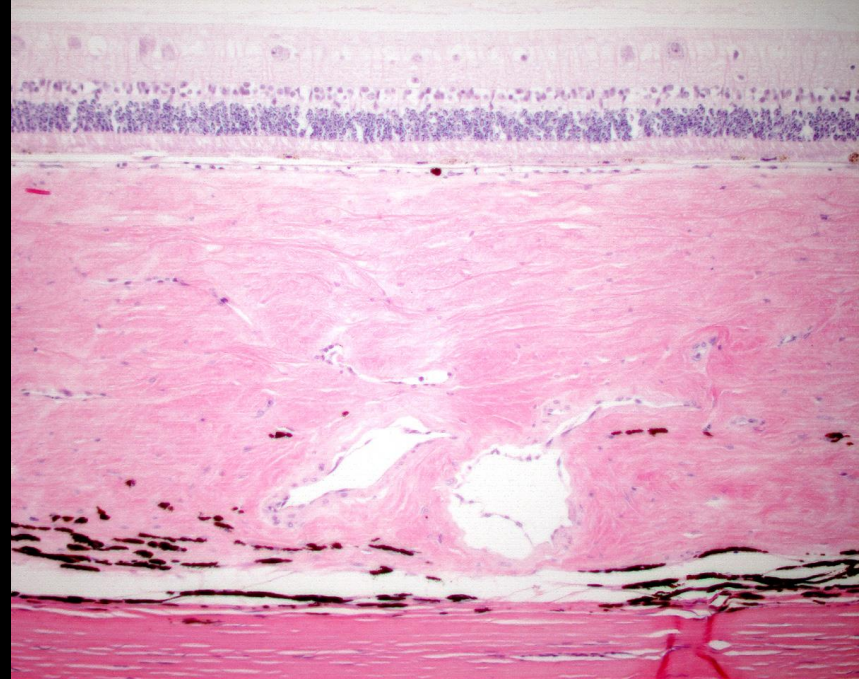


Equine

Impala

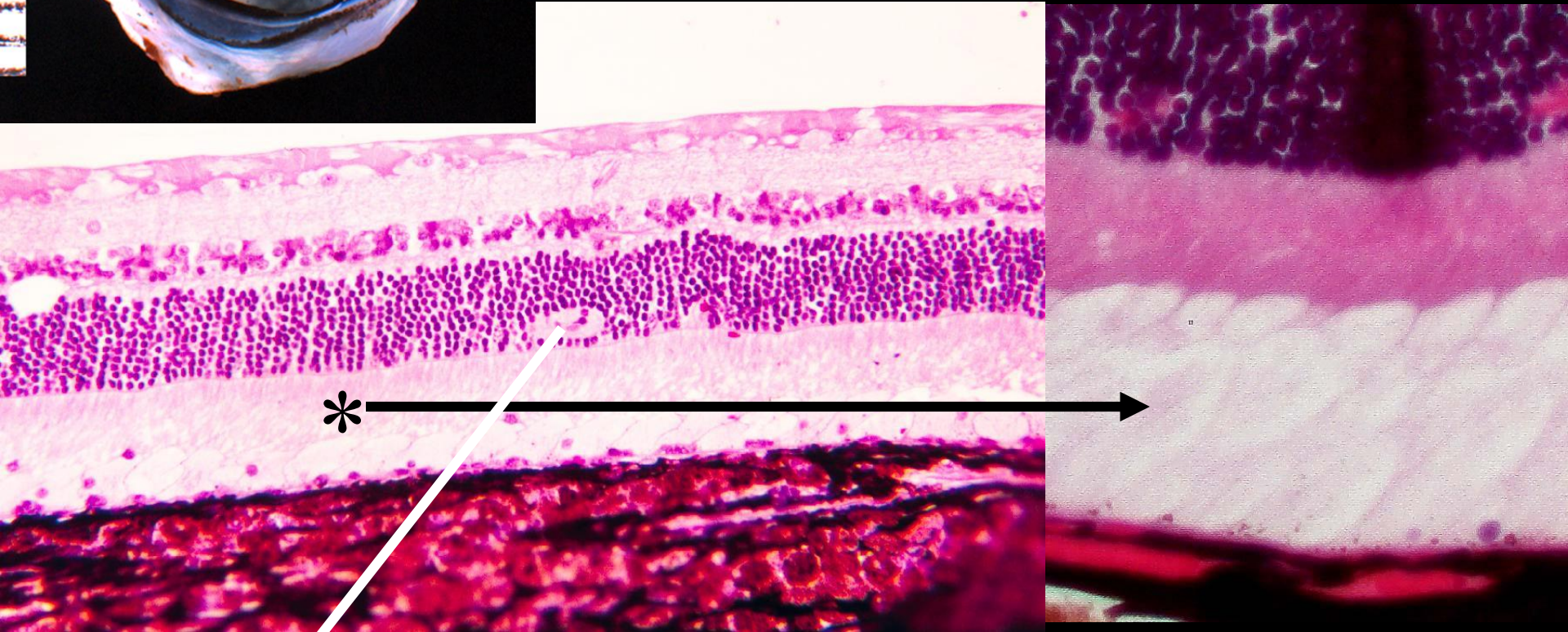
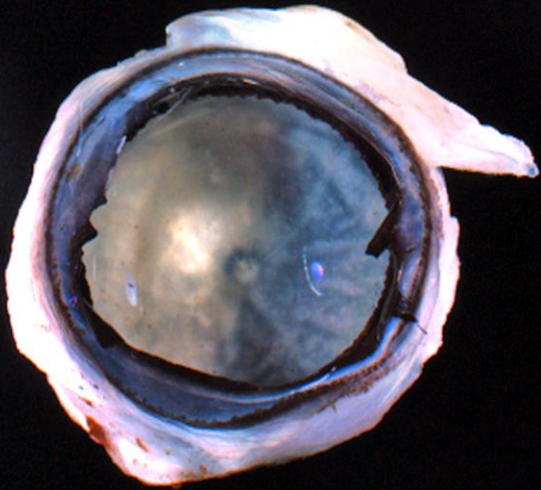


Tapir  
or  
Hippo



Dolphin

# Retinal Tapetum North American Opossum



Capillary blood vessels in the outer nuclear layer